Yuri Salamatov

TRIZ: THE RIGHT SOLUTION AT THE RIGHT TIME: A Guide to Innovative Problem Solving

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2-nd edition

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IID 2005

ISBN 90-804680-1-0

To my wife Lydia, with appreciation of her great patience.

Acknowledgements

This book would not be possible without help and support from:

> Genrich Altshuller, my teacher and the originator of the Theory of Inventive Problem Solving, whose sudden death broke off our close and fruitful collaboration;

Dear readers, I would be very pleased if you could make comments that can lead to making the book better. Please, send your comments to the publisher.

Yuri Salamatov,
January, 2005

Foreword

Life states new problems daily and hourly. Its aim is reaching you deadlock and pushing into corner. Therefore rapidly changing world requires from the person non-standard, flexible thinking. How to learn it?

Whether it is possible to create the system of simple, step by step becoming complicated trainings for the solution of real problems, for example, in technical invention and then effectively to use these methods for the solution of any other problems?

This book is about creativity: about the theory, principals, about ways of creation of new ideas and about problem solving.

The way of progress lies through generation of new ideas. Throughout the history they saved us more than once. New ideas are 'produced' by inventors. In the broad sense, inventors are people who bring something new to every area of social life. If they have rules and methods to generate new, fresh ideas, these rules and methods should be made familiar to everyone.

How does the 'invention industry' work? How effective is it? Quite surprisingly, this is the only industry in our well-organized world that still practices amateurish and hardly controllable 'mode of production'. The society is still at the mercy of the elements that govern the inventive mind. A novel idea appears only when somebody decides to find it. But the real problem with inventions is even worse: despite an ardent desire to invent, one may spend months, years, or a whole life falling short of solving the chosen problem. Getting into difficult situations, heroes of books and movies often talk to themselves in the following manner: "What if I do it this way? No, this does not work, let's try to do it differently.... What if I start from the other side? No, this is all wrong again", and so on. In this way, the search of variants continues, until the right solution flashes into the hero's mind. But in reality a solution may take dozens, hundreds or thousands of alternatives. Life may be too short to give the right answer.

Nowadays, the era of random collecting of ideas is coming to an end. It is high time we started using a different inventive technology.

SUCH TECHNOLOGY REALLY EXISTS. YOU ARE INVITED TO EXPLORE THIS NEW, PARADOXICAL SCIENCE BORN IN OUR DAYS.

The book aims to give a systematic overview of the main principles of TRIZ (the Russian acronym for the "Theory of Inventive Problem Solving"). The basic facts, ideas and recommendations of TRIZ are based on extensive analysis of patents and practical work. Through many years of teaching TRIZ, it has served as an effective tool in achieving a rapid increase in the creative potential of specialists. This goal turned out to be quite realistic, despite the skeptical claims of those who still believe in the 'flash of understanding'. Moreover, the TRIZ target audience consists not only of technical workers (engineers, researchers and students) but also of those who specialize in arts and humanities.

CONTRARY TO WHAT WE USUALLY HEAR, IT TURNED OUT THAT INBORN ABILITIES DO NOT MATTER MUCH. RATHER, THEY DO NOT MATTER AT ALL. ANYONE WITH A STRONG DESIRE TO LEARN CAN BECOME AN INVENTOR AND LEARN TO THINK CREATIVELY.

In our understanding, creative thinking is a powerful, well-managed thinking that has a set of special techniques, rules and programs at its disposal. Creative thinking has nothing to do with spontaneous, unpredictable, disordered judgments. Neither does it rely on intuition, 'insight' and the popular fallacy about 'geniuses' ('the chosen ones'!) and the 'mob', a fallacy based on the assumption that people have unequal abilities for making inventions. Instead, this book gives you a fully 'democratic' chance to use your creativity.

HOW CAN YOU BENEFIT FROM THIS BOOK?

There can be different levels of studying the material presented in the book. In the simplest case, you might treat it as a collection of interesting facts, examples and techniques and later put them to personal use. Admittedly, this is not the best kind of reading: our database of examples will be exhausted very soon but you will not acquire the desired skill that helps in finding and solving problems. A more promising way is to study carefully the main ideas of this creative theory, master the problem solving method and subsequently learn how to pose creative problems.

AND IN THE END YOU WILL BECOME A POWERFUL CREATIVE PERSONALITY

Hence is the structure of the book: it gives a brief and comprehensive revision of TRIZ, supplemented by numerous examples and problems. The brevity of style is justified by the fact that even the basic scope of TRIZ theory cannot be fully described within one book. That is why it is essential that the reader is a keen and active participant in the learning process. In addition, it is advisable to extend your knowledge by reading other literature and borrowing information from other resources on inventions.

HOW TO USE THIS BOOK

Above all, the book aims at people who have decided to acquire profound knowledge about creative inventions. For them it will serve as a valuable and informative point of reference. The first chapter demands a minimal effort from the reader. However, each new chapter brings more and more information; which to some people may seem an information overload. Such is the purposeful strategy of the author: effective learning can only be acquired through difficult tasks. Carefree problems are good as a warming-up but their effect is minimal for boosting your creative imagination. In-depth analysis should accompany your reading in each section of the book and in each problem. Ideally, the reader should solve one third of the problems; for about the same number of problems there is a general clue to solution. After your first reading, you may not be able to see all of them solved. But the most important result at this stage is your honest endeavor to come to a solution employing the full potential of your imagination and subsequently analyzing the possible deviations from the target answer descriptions. Indeed, an inventive problem may have more than one solution. In the end, your most valuable gain will be the skill to evaluate and give priority to solutions.

Upon the second reading, problems will not be in the focus of attention. Here you are advised to write down step-by-step solutions, your notes and thoughts about certain elements of theory and their application. This is the most effective way to master this creative methodology.

In addition to his own experience, the author has used research materials of Genrich Altshuller: inventor, engineer, science fiction writer and the Father of TRIZ theory who, throughout many years, published a series of books in the Soviet Union and abroad.

Every up-and-coming science calls for enthusiasts. That is why the author invites you to discuss various scientific, methodological and organizational issues that will stimulate the development of TRIZ. Any notes and suggestions concerning new ways of TRIZ application are welcome.

About the author:

Yuri Petrovich Salamatov, Ph.D., author of over 50 inventions and many publications, including books on TRIZ, to which the author has effectively contributed for over 30 years. In 1980 he joined the Public Laboratory of the Theory of Invention, headed by Genrich Altshuller. In 1982-1991 he trained engineers and scientists at Krasnoyarsk University of Creative Research and Development under the auspices of the local Research and Development Council. In 1989 Salamatov became the director of Krasnoyarsk branch of Invention Machine Laboratories. In 1998 he established and became the director of the Institute of Innovative Design.

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1. A MILLION ATTEMPTS VERSUS ONE LIFE

Each new machine or technology originates from a novel idea. The world around us was invented by man, as each item surrounding us – food, clothes, buildings, books, eyeglasses, tables, paper, means of transportation, communications and medicines – was brought about by human effort and entered our life due to the human ability to invent. There was a time when human creations did not exist, simply because they were unknown. Indeed, the transformation of the unknown into the familiar is a creative process.

We run into creative problems throughout our lives, but do not always solve them, or at least, we do not always solve them *creatively*. What does this mean? In short, the *creative* solution is a simple solution to a problem that, from the standpoint of common sense, would seem utterly complex. Such solutions are often called ingenious, or innovative. The paradox of the creative innovation is that although it is relatively easy to come up with a complex innovation, a simple innovation is by no means an easy task. In other words, not every innovation is a product of creative efforts.

Let us look at engineering, the most material of all creative activities. Nowadays the progress in engineering is dominated by automation and microelectronics. Below are a couple of problems taken from these areas.

> **Problem 1.** A robot was brought to a plant to operate a machine. After it was rigged up and switched on, the elderly worker who had operated the machine for years was amazed at seeing the nimble 'iron man' performing all the necessary steps.
>
> A half an hour later, however, the robot came to a standstill, to the bewilderment of the service team of electronic engineers. What happened? As it turned out, some chips had fallen from the workpiece into the moving element of the machine. This situation where a human worker would simply flip the chips away with a broom and continue working brought a robot to a deadlock. The engineers cleaned the machine with a broom, switched on the robot... only to see the robot stop again. How could this problem be solved? Obviously, one cannot attach a human worker with a broom to the robot...

As a rule, the more complicated solutions are the first to come: installing a system that washes away or blows off the chips, attaching a third broom–arm to the robot, etc. Why can't the chips just fall down from the workpiece **all by themselves**, without getting into the machine? How can this be done? It is only possible if there's no machine in the space between the workpiece and the floor. Indeed, it took some time to find an ingenious solution: to turn both the machine and the robot upside down. This solution illustrates the inventive mind that succeeds in rejecting a stereotype (since the robot, unlike human worker, might as well be turned upside down).

> **Problem 2.** A production line with robots installed at a clothing mill was unable to perform the cutting and stitching of the pieces of clothes properly. The pieces of fabric are not stiff, so the robots creased them with their grippers, stitched them Z-fold and made many other slips. Using clamps and servo-systems equipped with optical sensors and cameras did not help. Then it was suggested to wet the fabric so that it could stick firmly to the conveyer. And this, in turn, was useless, because the pieces were sticking together, crumpled up and got deformed. What could be done?

Here again, traditional thinking prompts complication: devising robots that possess human faculties. But why? Instead of changing the robots, it is more advantageous and timesaving to change the fabric used. However, clothes cannot be sewn from fabric as stiff as tin plate. It should only be as stiff as a tin plate under treatment, and should turn into ordinary fabric afterwards.

An inventive solution was to freeze the wet fabric. Keeping the temperature below 0° C is particularly easy in winter, because robots will not feel cold.

> **Problem 3**. A wafer with IC and other electronic components is usually given a coat of varnish that protects the wafer from exposure to negative interference. The varnish coating is then dried under elevated temperature. At this stage microscopic bubbles of gas evolve at some points of the wafer from the flux left after soldering, penetrating the varnish coating before it dries up. The bubbles damage the integrity of the protective coating. What can be done?

Clearly, vacuum drying (with the purpose of rapid suction of gas from the varnish layer while it is in liquid state) or the use of other sophisticated but bulky devices does not constitute an innovative solution. An utterly simple and witty idea was put forth: covering the wafer with a varnish foam so that the bubbles of gas become a part of foam during drying and do not break the air-tightness of the coating.

And again about robots.

> **Problem 4.** The introduction of robots *en masse* led to frequent cases of 'robotic revolts'. In England, a robot was transporting nuclear waste to a storehouse at an atomic power station when suddenly it went whirlgigging at a dangerously small distance to a concrete wall. Luckily, the technician managed to cut the power cable quickly. In Bulgaria, a manipulator first hit its creator on the back and then began to operate smoothly. In the USA, a robot that performed as a loader inside a reactor suddenly started knocking at its own frame with a steel arm and tumbled down in a few minutes. At a radio works in England, the press photographer's electronic flash triggered the infrared 'eyes' of the fire-detecting robot that discharged its whole load of foam at the guests invited to a ceremony... Malfunction of censors, unexpected faults in the 'brains' of robots are the source of danger for humans.
>
> Suppose a man notices that an accident is imminent. How can one, at a safe passing distance, down the unmanageable robot by stopping it, re-programming it or switching it off?

Here again, a solution is needed. Of course, an inventive solution is ideal.

In the recent past, such problems were unheard of. But the future comes so quickly: today our future is robotics, microelectronics, biotechnology, and space technology. Tomorrow we shall deal with the issues of artificial intelligence, bio-electronics, and nano-technology to name a few.

Undoubtedly, the introduction of fully automated systems powered by artificial intelligence is a revolutionary process. However, similar technological breakthroughs have happened earlier: 70 years ago the tractor took over after the horse, relieving the toil of millions of agricultural workers. Earlier, the introduction of electricity, a no less impressive process, had brought about a complete change in the industry. Yet earlier generations had witnessed another major technological breakthrough resulting from the invention of the steam engine, etc. Generally speaking, all the history of humankind is a history of inventions. Technology has always exerted active influence on humans.

The genesis of technology went hand-in-hand with the establishment of human society. Technology was created by man and has served man as a tool reducing the extent of human vassalage to nature, helping to satisfy the biological and social needs. At the same time, technological progress created the preconditions for other emergent needs and demands. Such is the essence of the dialectic, inseparable, unity between technology and human society.

Invention never was a play of fiat, but a prerequisite for the survival of man in a rapidly changing world. In order to remain in this world, man had to invent. Man is the only living creature in the nature that, overcoming formidable competition for survival, succeeded in acquiring a new property: *the ability to think rationally*.

Indeed, even the monkey has a predisposition to reasoning but it is man who started using it as a tool in the struggle for survival. For primitive people (e.g. the australopithecine, 2 mya) the struggle for existence meant procuring food. Vegetable food was procured manually, sometimes with the help of rocks and sticks used as the extension of human hand. The growth of population led to a shortage of vegetable food. Therefore, men began to hunt for animals and dissect their carcasses. The natural strength of human limbs did not suffice to perform such tasks. The arising need for the instruments that expanded human abilities led man to borrow them from the environment. Thus man came to use yamsticks, knife-edged flakes of stones and etc. Yet, these natural tools would often turn or get lost. It was necessary to find, store and repair them. In this way the production of tools started and technology came into being.

As the human needs grew, man acquired new tools, devised numerous and ever more sophisticated technical systems. The evolution of technology was accompanied by recurrent problems and incongruities. All of them were solved exclusively **by trial and error**. This method, familiar as it was to mankind throughout its history, was only postulated in 1898.

E. Thorndike, U.S. psychologist, described the trial and error method and applied it in his research into learning. According to him, the key to problem-solving lies in the acquisition of rational skills through a multiple repetition of random attempts. Thus, a cat put into a 'problem cage' that contains no food starts running about the cage and finally finds the door by accident, and gets some food outside. Repeated many times, this experience teaches the animal to open the door instantly. In other words, the cat acquires a rational skill, or learns.

What will happen if we change the cage or the way to open the door? The previous experience will appear to be useless: again, the cat will be beating around the cage trying to solve a totally new task.

What about inventors? Do they acquire the 'inventive skill' through dozens of problem-solving sessions? Below is a typical example which illustrates the use of the trial and error method: the story of how Charles Goodyear invented raw rubber vulcanization. One day Goodyear bought a lifebelt made of raw rubber. He managed to improve the air-valve which serves for pumping air into the belt. Goodyear then came to the company that produced lifebelts to show his invention. There he was advised to seek the way of improving the properties of raw rubber if he wanted to get rich. At that time, raw rubber was only used for rubberizing cloth, in particular, for manufacturing the popular waterproof raincoats invented by Charles Mackintosh and patented in 1823. Raw rubber was imperfect in many ways: it got detached from the cloth, items that were made entirely of raw rubber melted under the sun but stiffened at low temperatures. Goodyear caught on the idea of improving raw rubber. He started arbitrary experiments, mixing raw rubber with any substance that came at hand: salt, pepper, sugar, sand, castor oil and even soup. He was hoping that, by trying every possible substance, he would finally get a lucky combination. As a result, Goodyear ran into debt, his family was getting by on potatoes and edible roots. He managed to open a shop where one saw dozens of rubber overshoes on every shelf. On the first hot day, however, they all melted and turned into a stinky squash. Reportedly, when asked "Where can I find Mr. Goodyear?", his neighbors would say: "If you see a man in rubber coat, rubber boots and rubber top hat, carrying a rubber purse without a single cent in it, you can be sure he is Mr. Goodyear.". Solid citizens considered him to be insane. Yet he persisted in his search and once, treating raw rubber with acidic vapor, noticed a considerable improvement of its properties. After this first successful attempt, it took a long series of failures until Goodyear happened to discover the second condition of complete vulcanization, heating. This was in 1839, the year when rubber was invented. However, it was only in 1841 that Goodyear managed to work out an optimal treatment technique. There followed a flood of proposals to sell the patent. Inexperienced in commerce, Goodyear agreed to sell it at a very low interest profit. He died in 1860, his debts amounting to $200,000. By that time, more than 60.000 people were employed at big factories around the world, producing 500 varieties of rubber items with the total cost of production over $8 mln each year...

Goodyear only solved a single problem; he simply did not have lifetime enough to grasp the 'inventive skill'. In fact, he was remarkably lucky, because many other inventors never lived up to see their problems solved and passed away unknown.

The end of the 19th century saw the establishing of a widespread type of the self-made inventor who was unfamiliar with the basics of science (and often even despised science, like Edison). Using the only weapon they had – the trial and error method – they started out on a long and perilous quest. Their ambitions, their unabated perseverance and self-encouragement finally rewarded them, if lucky, with the glamorous reputation of a genius. But their research was guided exclusively by the trial and error method.

Even so, some inventors employed, however unwittingly, certain primitive inventive strategies, such as:

- *imitation of natural prototypes* (viz, flying vehicles with flapping wings, lineman's climbers, pendant bridges that represented the pattern of a cobweb),
- *increasing the size and number of simultaneously operating objects* (the gigantic Tzar Bell and Tzar Cannon in Russia, the complex cordage of a vessel),

- *joining objects into a system* (steam boat: a vessel and a steam engine, the Russian tachanka military wagon of 1918, that combined a vehicle and a heavy machine gun).

And still, these strategies were neither classified nor made familiar to inventors.

At the same time, another “type of inventor” evolved and finally became prevalent in the 20th century: the inventor relying on science.

For centuries, natural science did not back the development of technology, for natural science as such did not exist. The slow-moving scientific research lagged behind technology and was unable to offer new solutions or show the paths of progress. In the middle of the 19th century, natural science began to keep pace with technology sharing with the latter its recent discoveries: the study of steam engines efficiency, electricity, chemistry, etc. Finally, in the 20th century natural science left technology far behind and accumulated knowledge about a multitude of effects and phenomena many of which have not been incorporated into inventions yet.

One popular fallacy of our days is that technical invention results from direct application of scientific knowledge. If only it was that simple! But this topic will be discussed further.

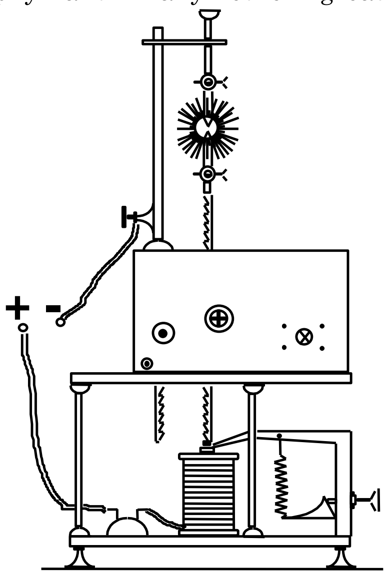
We only want to mention that science did help the inventors with reducing the number of those attempts that were doomed to failure and contradicted the main laws of nature. Therefore, science helps filter out absurd ideas.

The 19th century also saw the first scientific attempts to puzzle out the mystery of creation (although as early as in the Ancient world there appeared the concept of *heuristics*, created by the Greek mathematician Pappilus Alexander, the teaching about how discoveries are made). Before man worked out a clear vision of the mechanisms of creation, these mechanisms had been explained in the same way as all other natural phenomena: by Providence. The first explorations in the nature of creative work borrowed this assumption, particularly in explaining the genesis of the invention: “*This heavenly fire dawns upon the chosen one, irrespective of his efforts and sometimes undeservingly. Quite often, the best of thoughts occur to us in an idle talk, during everyday work, even when we sleep*.” This was said by Peter Engelmeyer, one of the first theoreticians of creative work, in his book entitled "Inventions and Privileges: A Guidebook for Inventors”, with a foreword by Leo Tolstoy and published in Moscow in 1897.

However, even in this early book Engelmeyer pointed out that “only sober attitude to work, the clear vision of the conditions of one’s task may lead to a ‘sensible invention’. In his later books, he emphasized the necessity to create a universal scientific theory of creation “that spans all creative phenomena, such as: the artistic creation, technical invention, scientific discovery as well as the practical activity that pursues benefit, or good, or any other ends” (“Theory of Creativity”, St. Petersburg, 1910). Further he added, “apparently, genius is not a gift from above... rather, it falls to everybody’s share”.

The accomplishments made using the trial and error method by the end of the 19th century were impressive. Among them are: electric motor, electric lamp, transformer, tunneling machine, centrifugal pump, internal combustion engine, drilling rig, open-hearth furnace, reinforced concrete, automobile, metro, the test flights of the first airplanes as well as the telegraph, telephone, radio, cinematography and many other great inventions.

What accounts for such rapid progress? Despite the low effectiveness of the trial and error method, it was successful for a number of reasons. The emerging union of science and technology; the increasing inflow of researchers and engineers into the area of technological creativity; the on-going studies of apparent natural phenomena that did not require much insight; direct application of these phenomena in technology; relative simplicity of technical systems helped very much. Nevertheless, other inventive problems cropped up, that required decades to solve. These problems were not always complex, but the trial and error method would stumble at simple problems too! Below is one of such problems:



> **Problem 5.** Attempting to use the electric arc as an illuminant, inventors of Europe, America and Russia spent 30 years developing a reliable technique to control the distance between the burning carbon electrodes in the arc lamp. It was necessary to maintain a permanent gap between the electrodes until they burnt out. Many subtle devices were designed, but to no effect: they were bulky and unreliable. P. Yablochkov, Russian inventor, realized the futility of these attempts. His solution was extremely elegant and as simple as ABC. And how would *you* solve this problem?

As a conclusion, the trial and error method does not seem to be the right solution in the age of technological revolution. Indeed, the waste of time and effort involved might appear to be even more hazardous than the damage caused by natural disasters.

TRY IT YOURSELF

This is how Plutarch characterized the inventions of Archimedes: “If anyone tried to solve these problems, he would fail, but once one becomes familiar with Archimedes solutions, he gets the impression that he would have found this solution himself – so straight and short is the path shown by Archimedes”.

Archimedes came up with numerous inventions: the method of determining the center of gravity of bodies, the law of lever, the Archimedes’ principle, the block, the winch, the gear transmission, the catapult, the Archimedean screw, the jack.

Offer your friends the Problems we presented above and watch them finding solutions to each of them. Keep track of their line of reasoning.

Below are two problems for you:

HOW DO YOU MEASURE THE HEIGHT OF A CAVE that has an arch so high that the light of a flashlight does not reach it and it's impossible to climb up the wall? The method should be very simple, and the device should preferably weight nothing.

A PROBLEM ON THE PYRAMID OF PHARAOH CHEOPS

Specialists were surprised to find out that the surface of the base of the famous pyramid, occupying 4,5 hectares, is perfectly flat.

What helped the builders of Ancient Egypt to perform this work properly without precision instruments or techniques of flattening such surfaces?

EXAMPLE OF A WITTY SOLUTION

The method to measure the height of a pyramid discovered by Thales of Miletus (625 – 547 B.C.) is one of the most remarkable creative solutions of those days: "when the shadow cast by the stick becomes equal to its length, the length of the shadow cast by the pyramid will equal the height of the pyramid".

AMATEURS AND PROFESSIONALS: A DIALECTIC RELATIONSHIP

The fact that an amateur does not posses a document certifying professional training does not mean that the amateur lacks knowledge. Paradoxically, amateurs contributed to the basics of many sciences. For instance: thermotechnics (brewer James Joule, physician Hermann Helmholtz), mathematics (lawyers Pierre de Fermat and Gottfried Leibnitz, biologist Leonhard Euler, physician Jean d'Alembert, barber Siméon Poisson, military officer René Descartes), astronomy (lawyer Edwin Hubble, the author of the theory of recession of galaxies), physics (linguist Charles Townes, one of the inventors of the laser), cybernetics (physician R. Ashby) and etc.

"There is one good thing and one bad thing about amateurism. On the one hand, the strong point is that the thoughts of the amateur are open to new combinations – they haven't been paralyzed by the traditional school. On the other hand, the weak point is the amateur's default to defend the new ideas, for the amateur lacks the expertise necessary to establish these ideas firmly." (P. Engelmeyer. *Theory of Creativity*, St. Petersburg, 1910).

"So, in order to make sure that Dostoyevsky is a writer, do you really need to ask him to show his certificate? Just take any five pages from any of his novels and you will be convinced without any certificate that you see a writer. I don't even think he had any certificate at all!" (M. Boulgakov. *Master and Margarita*. Moscow, 1986).

2. MONOPOLY OVER CREATIVITY DOESN'T EXIST

2.1 COMPETING WITH EDISON

The method used by most inventors of the 19th century can be characterized as ***the blind trial and error method***: possible solutions were chosen randomly. No rules of idea generating were used and, in principle, any idea could be accepted. No criteria were applied either, which forced the inventor into multiple experiments in order to evaluate each possibility. The inventive process was a *quid pro quo*, reciprocal exchange, where **ignorance was being exchanged for time** ("the less we know, the longer we search"). Thus Paul Ehrlich, originator of modern chemotherapy, was striving to "aim a chemical gun at the disease-causing microbe". His optimism kept him going after 300, 400, 500 failed attempts. He scored a triumph with a 606th medicine, the famous *Salvarsan*, and the 914th substance, *Neoarsphenamine*, turned out even more effective.

Thomas A. Edison took a similar path. In 1873 A.N. Lodygin invented a vacuum lamp that used carbon electrodes. Edison followed Lodygin in the endeavor to create the incandescent electric lamp. In his first experiments, a filament made of charred paper only lasted for 8 minutes and a platinum filament – 10 minutes. Subsequently, filaments from titanium-iridium alloy, boron, chromium, molybdenum, osmium and nickel were tried, but with poor results. The next series of tests using 1600 different materials led Edison nowhere. And finally, charred cotton filament was found that shone for 13,5 hours. Fourteen months later, filament from charred board shone for 170 hours, and filament of charred bamboo (constructed from a Japanese fan-case which Edison borrowed from a lady at a ball) shone as long as 1200 hours! This was in 1879, after more than 6,000 experiments. In 1880 Edison elaborated the entire electric lighting system that consisted of current generators, wires, switches, safety devices, lamp-holders, etc.

Many of Edison's 1093 inventions emerged as a result of an *exhaustive search for multiple variants* which is **the major disadvantage of trial and error method**. Such was the case with the alkaline cell, when Edison achieved positive results after 50 thousand experiments. And all this tremendous work was accomplished in a surprisingly short time! How did Edison manage to benefit from the exchange of knowledge for time? Because, most importantly, he invented *the research institute*. The total of 50 thousand tests were divided among 1000 employees. This idea, simple as it was, led to amazing efficiency; which gave the impression that the main drawback of trial and error method was done away with...

But in the 20th century, a vast number of ever more complex problems came into view. Because they could not be ignored, a mushroom expansion of research laboratories began both in the US (300 in 1920, 1600 in 1930, 2200 in 1940 and toward 15,000 in 1967) and worldwide. The *more-people-more-ideas* approach sounded reasonable as long as human resources were available and the economy could cope with the unprecedented increase of money being spent on the development of science and technology. In 1970–80s, however, all industrialized countries faced the depletion of human and material resources. So, the rate of increase in expenditure for science and engineering began to slow down and finally stopped at its ceiling. i.e. the rate of national income growth.

As a conclusion, the only promising way to optimize engineering and scientific development can only be achieved by intensifying the process of creative problem solving.

Long ago the deficiencies of trial and error method became a source of constant concern to scientists and engineers: sometimes even large-scale research institutes would fail to solve 'million-test' problems. Therefore the **intensification of the trial and error method** developed in two directions: *acceleration of idea generation* (the more ideas are worked out prior to experimenting, the greater the probability that an idea will emerge by fiat) and *intensification of idea filtering* (the more ideas are dismissed at preliminary discussions, the fewer experiments are needed). It seemed at first that both ways combined successfully in *mental experiments*, because, due to the enormous volume of knowledge accumulated by man, the majority of variants would have predictable results, and notably, mental experimenting required considerably less time and practically no costs. Yet, these ways turned out to have two major shortcomings which canceled out all their strong points: *subjective selection of variants* (the risk of errors) and *the lack of unexpected side discoveries* (no "Columbus effect": sailing to India Columbus discovered America).

There exists ample evidence suggesting that many major discoveries in science and technology were side-products of material experiments. Edison discovered the phonograph principle while experimenting with automatic telegraph machine. But on another occasion he made a serious mistake discarding the 'trifle' effect of motion of electrical charges in vacuum space and not patenting it (later studies of the effect led to the discovery of the electron, invention of the electron tube and explorations in radio engineering).

Below is another example. We offered the following problem to numerous teams of engineers and scientists for mental experimenting.

> **Problem 6.** While drilling deep boreholes in the earth it is essential to monitor the condition of the teeth of the instrument that digs into the rock, for the teeth will break off sometimes. Unaware of the condition of teeth, a technician has to work blindly, regularly replacing the working instrument with a new one (just in case). To do this, the entire column of pipes is pulled out of the borehole which is often a few miles deep. However, replacing consumes too much time and labor. It is necessary to find a simple way to control the condition of the working instrument.

Together with the problem, a number of possible search directions were suggested. They included a dozen stereotyped solutions (making teeth unbreakable or self-replaceable, creating a device to dismantle the pipes quickly, installing electronic sensors, etc.) and a few 'bizarre' ones (consult a perfumer, study the system of household gas supply, refer to the branch of chemistry that studies esters). Mental experiments would always go along the same path: the 'bizarre', absurd ideas were discarded offhand and gave way to dispute on microprocessors and micro-robots shuttling inside the pipes.

Meanwhile, only the 'bizzare' ideas could furnish the clue (see Soviet patent # 163 559). They suggest supplying the teeth with micro-capsules containing fragrance (hence perfumery, ester) or some stinky substance (e.g. Methylmercaptan a substance with foul smell at concentration as low as 1 mg in 10,000 m^3, which is admixed with town gas).

Therefore, *inventive problems can be of two kinds: simple and complex*. The former can be solved by everyone. Let us make sure they do:

> **Problem 7.** Everyone knows how the incubator works. But can incubation be carried out in space? Space station provides all the necessary conditions for incubation (atmosphere, heat), except one: gravity. That is why chickens simply won't hatch! An idea for the space incubator is wanted. What would you recommend for creating artificial gravity?

Most likely, the solution occurred to you before you finished reading the problem. Yes, one should make the incubator revolve around its axis. Isn't that too simple? Maybe, it is not an invention at all? Yes, it is. It is a *genuine invention* and it was granted Soviet patent 1 020 098 in 1983.

Let us try to solve another problem: Edison's problem.

> **Problem 8.** Edison used to offer 'tricky' technical problems to his would-be employees, especially theoreticians. Once he invited a mathematician into his lab, and asked him to calculate the volume of a bulb. For more than an hour the mathematician was busy doing measurements and intricate calculations. He dealt with the task successfully and proudly handed Edison a sheet of paper with the answer. To mathematician's bewilderment, in a few seconds Edison demonstrated an easier (and more reliable) way to measure the bulb.

Will you pass Edison's test? Incidentally, it only requires elementary knowledge of physics from an elementary school syllabus.

Middle school students tackled the problem in no time, high school students fared worse, and college students failed. A tendency was observed: the further the respondents were from the age at which Archimedes' principle was studied at school, the more difficulties they had. Nevertheless, in each team of engineers there were a couple of those who found the solution immediately. For some reason the principle lingered on in their memory from school physics.

To make sure this tendency really exists, try to solve another problem.

> **Problem 9.** The Dutch company advertises a device that provides rectilinear micro-displacements (measuring hundredths of micrometers) in microscopes. The device is very complex and contains an electric motor, a worm gear, a two-stage friction gear, all components being made of special hard steel with exceptional, precision, accuracy. The company emphasizes the advantages: no backlash, no lost motion, no lubricants used.
>
> Design a primitive device that uses a principle known from elementary school physics, has no lost motion but greater accuracy.

The reader might ask: where is the border that separates between simple and complex problems, if school knowledge is sufficient to solve both problems?

ZEBRA OR WAVES?

A town square was turned into a playground for children. At the same time it was impossible to bar the traffic in an adjoining street. This gave rise to a problem: is it possible to make motorists slow down while driving past the playground? Two proposals were put forth: covering a part of the street with a zebra crossing or giving this section of the road a waved profile. The first way was cheap but had a restricted effect, the second was safe but expensive. The desired solution should combine the advantages but be devoid of the disadvantages. What would you suggest?

FIRE OR ABASEMENT?

Lucas Cranach Junior, famous artist, was commissioned to paint a portrait of Cardinal Albrecht of Brandenburg, a notoriously cruel figure of those days. Cardinal was to be depicted in his own study, a Bible and a Crucifix in his hands. Showing the true character of Cardinal was out of question, but compromising would be immoral. What could be done?

TRIAL AND ERROR IN ARTS

"The seeker gropes in the dark, like a nightly air-raid in times of war" (E. Vinokurov, poet)

"Our cause demands a period of painstaking search; discovering, checking and rejecting hypotheses. You go to extremes, get into a dead end, run you head against a brick wall, feeling desperate about your stupidity and inaptitude... And suddenly, after a thousand failures, the thread of creative thought begins to weave" (G. Kozintsev, film director)

2.2. FORTUNE MAY NOT SPARK OFF A BRIGHT IDEA

The simple answer given by advocates of trial and error method to the question above (*i.e. the dividing line between simple and complex problems*) was: *the number of tests*. If so, then the process of solving complex problems can be accelerated by speeding up sequential search for variants. This principle was used in the computers of the first generation. Very soon, however, it became clear that the exhaustive search for variants wasn't effective enough even at enormous speeds.

G. Ivanitski, Russian scientist, points to the fact that this method is useless even in studying systems that are, from his viewpoint, relatively simple (chemical synthesis, development of new varieties of plants, machine-building, creating works of art). In biology, the difficulty to examine an enormous number of variants to accomplish a single task (e.g. modeling collagen (simple protein) requires 10^{120} attempts, a bacterial cell – $10^{20\,000}$ attempts) precludes us from using this method today or even in the near future.

In the 1960s, the idea of *heuristic programming* was proposed. Instead of examining all the possibilities, the computer uses certain rules to select as many of them as is sufficient to come up with a solution. Such programs were given pretentious names (e.g. General Problem Solver), but behind the new terminology there was the old formula: to use non-dialectic, i.e. rigid, logic as a basis for creating a problem solving tool.

According to Professor Yuri Shreider, the testing of such programs in the former USSR demonstrated their inapplicability even for solving problems that contained enough data to build a model. For instance, even when the structure and all necessary data on a chemical compound were given, it was impossible to predict the pharmaceutical properties of the compound.

Later, the exhaustive search as a main problem solving approach was used in the third and the fourth generations of computers. At this stage, the main ideas were: *mathematical modeling* and subdividing the 'ocean' of tests into separate 'rivers' and 'creeks' that are subsequently put under *parallel processing*. Mathematical models do not exclude, only complement, material experiments: computers calculate intermediate results or, given experimental data, process those variants that do not allow material experimenting (e.g. emergency operation of nuclear reactors, climatic and ecological change).

Thus, in 1967, a new phenomenon in plasma physics, the so-called T-layer, was first calculated and later verified experimentally. This discovery demonstrated computer-based acquisition of new knowledge. However, is it correct to speak of *computer-based creative problem solving*? Says G. Pospelov, Chairman of Artificial Intelligence Scientific Committee, Russia: "It appears as if the computer worked creatively... in fact, it only follows the program imposed by man and is fully dependent on the program.

The following is an example of a problem solved through a computational experiment:

> **Problem 10.** Theoretically, metals can be hardened in nitrogen using a laser beam. Due to high temperature, nitrogen penetrates into the surface layer of metal, forming nitrid, a high-tensile compound. Experiments have shown, however, that high temperature causes the metal to evaporate and 'fly away' from the hardening area before it enters a compound. The process starts at low evaporation rate, then the evaporation rate increases steadily and reaches peak values by the end of the hardening process. In other experiments, a pressure of 100 Bars has been created. Yet, such pressure is unacceptable for industrial hardening, so the application of this method is delayed. What is to be done?

Think of an inventive solution to this problem. The above-mentioned examples hint that there should be *a trick*: providing a normal hardening process at no extra pressure. That's right, this would be a creative solution. From later sections you will learn about specific evaluation criteria and the rules used to derive them. Let us now consider the solution given by a computer.

Two institutes within the framework of the USSR Academy of Sciences were busy solving the problem. The work was divided in two stages and involved complex mathematical modeling (with a system of 15 equations being solved at the first stage). Reportedly, "the work on this utterly complex task employed to the full the potential of contemporary computational mathematics". Despite the difficulties, the solution was obtained: the pressure should be kept at 30 Bars, the power of the laser beam should be at peak value at the very first moment and should be decreasing gradually towards one tenth of its initial value by the end of the process... Notably, it was concluded that technological tasks, usually involving multiple parameters, often turn out to be more complex than the tasks of nuclear physics, plasma physics and astronautics.

What makes computer-based solving of difficult problems so difficult? Is it only the tremendous number of variants? Not only that. The main problem is that computers are perfectly logical, whereas in many situations creative tasks demand either non-logical thinking or extra knowledge from a different area, that is not pre-programmed in the computer. In other words, dialectic logic should be at work, instead of traditional formal logic used now in the computers.

Dialectic logic possesses the power to expose and resolve contradictions: 100 Bars is good for hardening but impossible for industrial application, while 1 Bar (absence of excessive pressure) meets the industrial standards but makes hardening not possible. The computer chooses an intermediate value of 30 Bars, whereas the contradiction should be resolved in such a way that hardening may be performed at 1 Bar. Where traditional logic is used, there it is useless to bring on board a group of experts to model the task.

"Bringing the opinions of geniuses to an average, we get a mediocre opinion at best. Rejecting contradictory opinions we sap the strength of expert knowledge. There is only one road left: to seek the logic of tackling contradictions, which is, of course, far from easy." (Yu.A. Shreider, "Computers as a tool for knowledge representation", in: *Priroda*, Vol. 10, 1986, p. 20, in Russian).

In the USA the boom of computer creativity is now over, and 'new' ways are being sought of to galvanize the trial and error method. For example, IBM has hired 45 'free of duty agents': 'day-dreamers, heretics, rioters, oddballs and geniuses'. "We are fewer in number than there are vice-presidents in the corporation," says one of them. "A free of duty agent is free to do whatever he wants to do in the course of five years. His role is simple: to shatter the system. And that's precisely what we're doing."

The chance of catching a good idea is very low, so the main commandment of the inventor reads: "You should be prepared to failures... If you are not prepared to put up with mistakes, you cannot be an innovator." *True, trial and error method implies 99,99% mistakes and no one knows when the bright idea sparks off.* The wheel has gone full circle: 'free agents' are the 19th century 'free inventors' now being employed by large companies.

Trial and error method means tremendous material damage to society. The efficiency of research and development work is very low. Up to 50 percent of all launched projects are closed down as having no future, one half of the other 50 percent does not meet production requirements. Only one fifth of the projects brings profit to companies.

Not only the waste of time and effort is entailed by trial and error method. *Trial and error method is detrimental in that it rules out the possibility of anticipating new objectives*. In this respect, entire decades and even centuries may be lost. For example, the meniscus telescope, admits D. D. Maksutov, its inventor, could have been invented in the days of Descartes and Newton. There was a need and every possibility to invent it. The task was simply overlooked until the mid-20th century. In the opinion of Charles H. Townes, lasers could have appeared in late 1920s, all the theoretical premises having been developed for this. V.A. Fabrikant, Soviet scientist, described the concept of a laser in 1939. In 1951, he was refused a Soviet patent because the commission of experts considered the idea impracticable. Their decision was reconsidered as late as in 1964. Though it may be argued whether or not the society really needs this or that technical system, there is no question about the acute demand for new medicines, such as penicillin, that help to save millions of human lives. The fact that penicillin, discovered by Sir Alexander Fleming in 1929, only started being widely put to use during WWII is even less shocking in the light of the entire history of penicillin, dramatic and full of absurdities. Penicillin had been studied and used long before Fleming: research results on penicillin were published first by Russian scientists V.A. Manasein and A.G. Polotebnov in 1871, then by S. Grigorov, Bulgarian scientist in 1906. More than that, the healing properties of molds had been known as early as in Ancient Greece.

Also, trial and error method is responsible for the lack of criteria of evaluating new ideas: almost every important invention was once given the verdict: "Impossible". It took years, even decades, until some major inventions of our time were recognized: *vacuum diffusion welding* (I.F. Kazakov, 1951), *the memory shape effect of alloys* (G. Kourdiumov, L.G. Khandros, 1948), *the electro-hydraulic effect* (L.A. Yutkin, L.I. Goltsova, 1950), *the hydro-extrusion processing of metals* (1958), etc.

A YEAR BEFORE THE TELEPHONE

In 1875 American newspaper reported: "A man was arrested yesterday while trying to get a bank loan under false pretext. He claims he can make a device that consists of two small apparatuses and a long wire. Using this device one person can speak to another person a few miles away. No doubt, the man is a charlatan and unashamed ramper who needs a lesson that Americans are clever enough not to be fooled by a trick. Even if this mad idea can be realized, it will be of no practical use, except for performing conjuring tricks in a circus".

SOFT WATER NEEDED

High diving is getting more and more complicated and demands virtuoso performance.

Accidents happen very often during drilling. What precautions can be taken against injuries occurring when the diver hits against the water surface?

Imagine that the diver is midway from the diving board to the water surface when the coach realizes that the dive is not successful...

What should be done?

EMBODYING FINNISH SOUL

Designing the Government House in Kuwait, Finnish architect Pietile was striving to "express the Finnish soul in this land". However, Finnish architecture uses straight lines, sharp angles that do not combine with the streamlined, well-rounded style of Arabian buildings. What could be done?

2.3. DREAMS THAT DIDN'T COME TRUE

When mere accumulation of knowledge was no longer viewed as valuable, primary importance was attached to renewing ideas and generating new ideas (in science, engineering, humanities and society). **New ideas are considered to be the main source of national wealth determining nation's economic, cultural and military potential**. This became the reason for active search started towards finding ways to intensify the flow of new ideas. The idea to coordinate the inventive process thus easing the deadlock and creating a method of creative problem solving became dominant.

Gradually, creative processes became the object of keen inspection; the evolving scientific research gave inspiration to find universal rules of creative problem solving. Here, the previous progress of science was a source of encouragement: man had learnt to control the forces of nature, unveiled the secrets of matter, and reached out to far ends of the Universe. Why can't man clear the mystery of creativity and learn to control it?

At first, the researchers did not encounter many problems: there appeared a lot of works in psychology (*"On Early-Developing Intelligence of 300 Geniuses", "A Study of Genius", "The Psychology of Invention"*, etc.). Historians reconstructed in detail the situations in which geniuses gained insight into great discoveries, studied their personal accounts of such situations, their dreams of the eve of such great days. But no universal recipes of creative work were found and inventors continued to work in the old-fashion way.

Psychologists then proceeded to studying the finest mechanisms of human brain hoping to reveal the secrets of invention in the head of the inventor. Historians continued to collect meticulously the facts from the history of science and engineering, placing them on the time scale, analyzing epochs and technological revolutions in conjunction with social changes.

Undoubtedly, all these studies were not in vain. But their isolation caused by separation of these highly-specialized areas did not allow researchers to suggest valid practical recommendations. Psychologists ignored the tendencies from the history of technology, as well as of any other, social or creative, systems. At the same time, historians were unaware of the psychological peculiarities of the creative process. Meanwhile, a technological revolution brought on board millions of people: invention became a movement. The question "**how does one invent?"** became urgent. That is why, technology was the first to break through to the mystery of creative work: ***brainstorming*** became a pioneering technique of creative problem solving. As the term suggests, the emphasis was laid on the psychological side of invention. Despite its weak points and theoretical shortcomings (i.e. ignoring the objective character of systems development) the technique has played an important role in revealing some of the origins of creativity and also attracted attention to the problem of creative work theory.

As a technique, brainstorming is based on the assumption that the generation of ideas should be separated from evaluation. During discussions of a problem, people usually shun expressing bold, unexpected ideas for fear of ridicule, mistakes, or disapproval on the part of higher-ranking colleagues, etc. Once expressed, such ideas will often be castigated by other participants and will perish without further development.

In 1940s Alex Osborn suggested that ideas could be generated in a setting where criticism is banned and any idea, however odd or funny, is encouraged. Six-eight idea-generators, analysts, and neutral with possibly diverse backgrounds, form a group without a leader. The group generates ideas in an informal setting. The ideas expressed are recorded or stenographed. Then the ideas are submitted to a group of experts for evaluation and selection based on promise or potential.

A favorable setting allows a group of 'day-dreamers' to collect as many as 50-100 ideas in half an hour. The totality of ideas is boiled down to a few that "sound reasonable". Peak experiences of the group give rise to agitation, hectic outburst of ideas, intuitive suppositions. It is these ideas that constitute the most valuable product of brainstorming work.

"Thoughts are pelting down like rain. The group is gaining a 'creative insight'... The task is to find a fast, simple and effective way of connecting two ends of a wire. "Just clutch them together with your teeth, that's it!" somebody shouts. However absurd, this suggestion gave the idea of the clamp for cold-welding of wires.[1]

Freudianism is a philosophical basis of brainstorming. According to Freud, absurd, irrational ideas break out of the restless domain of the unconscious penetrating the thin and weak layer of consciousness. Consciousness controls ordinary thinking, restraining illogical actions, imposing a multitude of taboos. But an invention is always an overcoming of conventional views on what is possible and what is impossible. Unhitched, freed from the power of consciousness, the brain is able to produce ingenious ideas.

Brainstorming originated in the US where its way had been paved by Freudianism. For the first 10-20 years it was viewed as very promising and seemed to have unlimited power. In the course of time, the brainstorming proved a very powerful aid in solving problems in the field of management, advertising, etc, but turned out hardly appropriate for present-day inventive problems.

Compare the following three problems:

> **Problem 11.** Below is a patent formula (Soviet patent 1 011 460) which describes "an innovative device for packaging rubber nipples. In order to improve the vendibility of products by securing the alignment of rubber nipples in a package, the device is equipped with a guiding mechanism. The mechanism consists of a conveyer with sockets, a 180°-steerable positioner fixed over the conveyer and having open-bottom sockets and grips for holding misaligned rubber nipples straight, and a pusher located under the conveyer coaxially with the sockets of the positioner, allowing vertical reciprocating motion.

[1] B, Pekelis. Your Capabilities, Men! – Znanie, Moscow 1984. p.245

Never mind if the formula seems long-winded and you do not understand the principle of the mechanism: in this case you do not need to go into detail. Briefly, here is an expensive and bulky robot used for putting children's dummies into boxes in regular rows (to provide accurate packaging). How can one simplify the system, increasing productivity and quickly aligning the dummies? A novel idea is needed.

So, what are your suggestions?

> **Problem 12.** A company producing potato-peeling knives ran into marketing difficulties. At first their knives became very popular: they were made of hard steel, had a convenient plastic handle and were of elegant design. But in a few years the sales fell: the knives didn't break and it took long time till they got blunt. Housewives did not need a second knife at home. In order to stay afloat in the market, the company commissioned specialists in creative problem-solving. What should be done to increase the demand for knives without reducing the quality or spending money on a new advertising campaign? Any solution will do, but it should preferably be free of cost...

> **Problem 13.** In a new company building, the employees began to complain about improper functioning of the lifts: it took long to wait for a lift to arrive, which was very irritating... The administration was faced with a problem, whether to install new lifts, replace the old ones with high-speed lifts, or create a computer center to monitor the lifts. Each solution seemed too expensive and a creative problem-solving adviser was commissioned to tackle the issue. Is there a simple way to work it out?

More or less original answers to problems like 12 and 13 are found in groups that have at least a short record of brainstorming work. Quite often, these solutions surpass in clarity those that were put into effect by companies. With respect to problem 12, it was suggested to make handles resembling potato peels in color (so that the knives are more likely to be thrown into waste bins). For problem 13, it was suggested to hang big mirrors near the lift entrances (because the actual reason behind complaints was not the waiting itself but to the *boredom* of waiting, so while standing by the lift doors people should be busy doing something enjoyable).

Problem 11 caused more difficulties. As a rule, no less complex and equally unreliable solutions were put forth: orienting the nipples by placing them on a vibrating conveyer, into water, or a stream of air, using vacuum pump, rolling them down an inclined plane, etc. At times it looked as if the group were getting close to a simple and effective solution: introducing a ferromagnetic (a tiny piece of magnet) into the nipple or its ring and thus orienting the nipple in the magnetic field, but at this moment another idea would crop up, and the discussion took another direction or started anew.

Offer this problem to a group of respondents and watch their pointless, irrational search which constitutes the core of this method.

2.4. INVENTIVE ADVERTISING

There are many ways to beat brand names into customers' heads. A German tobacco company published an ad: "Remember the name: *PILO*". The caption beneath the picture read: *POLO*.

A flood of letters to the editor followed pointing to the slip. The papers replied with an announcement: “We apologize for the mistype that occurred. Indeed, *PILO* was an error, the correct name is *POLI*”. Consequently, other mistypes followed *PRZO*, *PAOLO* and so on. At last the papers reported that “the responsible typesetter has been fired, the new product’s real name is *POLO*“. All mistakes corrected, the tobacco company paid a good commission to the advertising agency.

THE MAN WHO INVENTED BRAINSTORMING

Alex Osborn was born in New York. He worked successively as a builder, office boy, clerk to pay for his education. At the age of 21 Osborn became a police reporter in a newspaper, then worked as a shop assistant and at the same time as a teacher at an evening school. After that he was an assistant manager of a small plant and finally entered an advertising agency. Brainstorming was developed in 1937, but the first publications only came out in 1957, when Batten, Barton, Durstine & Osborn has been using the method effectively for 20 years. By the end of WWII the company was running 14 branches with 1800 employees.

At present, there is a score of varieties of brainstorming: individual, paired, multi-stage, stage methods, idea conferencing, cybersession, “pirate briefing” and etc. Each of them has a weaker effect than pure brainstorming, because the attempts to manage a spontaneous process invalidate the most valuable mechanism of brainstorming – providing a setting for free expression of irrational ideas.

2.5. UNVEILING THE MYSTERY

It seems strange now that in those days, some 50-100 years ago, students of the origins of creativity disregarded the most obvious circumstance: **the objective character of technological development.** Ample evidence such as archeological findings (e.g. similar, often identical, tools discovered all over the world), historical explorations, numerous instances of independent ’parallel’ discoveries and inventions made in different epochs and different countries lead to an obvious conclusion that ***the development of technical systems, in the same way as of social, scientific, artistic and other systems, follows inherent rules that are independent of human will.*** But the overwhelming authority of old views on the nature of creativity, the domination of single possible problem-solving technique (trial and error method) were too powerful and it took decades to come to this basic postulate of the theory of creativity.

Due to the fact that around the world patenting offices registering technical inventions prescribe similar rules on how to report on new ideas, we have a unique opportunity to trace the history of any technical system from the moment of its conception. Usually, many inventors become equally concerned about the need to solve the task, but the patent is granted to the first-comer. Thus Alexander Bell, teacher at an oral school, filed an application to United States Patent Office on 14 February, 1876, and had the patent for the telephone issued in three weeks. Meanwhile, much the same application filed by Elisha Gray an hour later was rejected. Afterwards, A. Bell won about 600 cases against claimants to priority of invention.

Patent experts are the first to receive identical ideas coming from different parts of the country. Says N. Patrakhaltsev, "My experience of working as an expert (and I have examined over 400 applications) shows that quite often, identical solutions come in from several authors within a relatively short time. Inventive thought appears to be inspired by life itself, by science, industry and by product demand. In fact, it would be strange if no identical solutions were found in a long chain of applications".

State borders, differing social systems have little or no influence on the objective character of technological development. Academician V.V. Struminsky tells the story of a coincidence which seems amazing to an inexperienced person. When the US triggered the war in Korea, the USSR aided China with air fighters. The first missions of new Soviet MIG15 fighter was a shock to the American military. "After the MIGs started to be used successfully in the Korean air, Americans came up with F-86 Sabre, an innovative jet-fighter with swept-back wings. The two models came from two different countries; they were developed with absolute secrecy. But when missions began, the two models proved to have so much in common, their specifications being surprisingly similar... That's science! Scientists and engineers worked independently in the two countries only to achieve very similar results."[2]

This is to say, technology should be treated as material, and its development as dialectic. There seems to be no question about that. Clearly, technical systems are of material nature and therefore evolve, as any other systems, according to dialectic laws. What follows is the leading principle of inventive methodology: ***there exist objective evolution laws for technical systems. These laws can be studied and purposefully applied to inventive problem solving without resorting to a search for variants.***

Nevertheless, for the entire 20th century, ever since regular explorations into creativity started, research has focused on the psychological side of invention. Up to the present day it has been assumed that essential processes occur in the head of the inventor. To a certain extent, this approach was endorsed by inventors and scientists themselves, who all too often alluded to 'intuition', 'insight', 'revelation', 'instant flash amidst the darkness of thought' (Edison), 'free creation of mind' (Einstein),

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[2] M. Arlazarov. *A Propeller and a Wing*. Znanie, Moscow, 1980.

etc. in their biographical accounts. The wealth of annoyingly unconvincing statements has amounted to a "heap of rubbish, wherein we dump the mechanisms of intelligence we are unable to analyze or simply give name to, or don't care to name or analyze'.[3] Therefore, most present-day researchers into creativity agree that 'intuition', 'insight' stem from idealistic thinking. On the other hand, derisive remarks about intuition as "the vain ambition of idlers... the credulous offspring of knowledge, whose prattle is senseless..." [4] are equally unconvincing.

A question arises: how did the numerous inventions appear, both in the past and the present, if they required searching through an enormous range (hundreds of thousands, millions) of variants? This paradox becomes clear when we consider the fact that each invention results from joint efforts: partly due to cooperation of contemporaries and partly due to borrowing from the heritage of past generations. Despite the illusion that they are perceived by geniuses, lucky solutions are, in reality, a product of *cooperation of contemporaries* and *the relay-race of generations.* The 90% or even 99% of tests appear to have been performed by others and the lucky one has to complete that job. The 'inventive marathon' suggests a competition of gold-miners: the field is divided among thousands of prospectors, each one mining a plot. Some, despite the difficulties, continue to dig laboriously, while others, tired of excavating barren rock, walk away and look for another spare plot. Finally, there are no spare plots left. At this moment somebody comes to occupy a lucky plot, either accidentally (simply because there aren't any more plots left) or purposefully, bearing in mind the previous attempts (which may have shown that gold grains are more likely to be found up (or down) the river). It still takes some effort and good luck to strike a vein of gold. And then journalists and psychologists come to the site shouting: "Extraordinary! How did you do it? What method did you use?"

Therefore, the role of individual in science and technology is proportional to individual's awareness of the social demand to solve a problem, and to individual's conscious/unconscious conformity with objective development of the scientific or technical system.

Here is a unique acknowledgment made by one of the inventors of maglev (high-speed magnetic levitation rail): "You often hear a question: how does a new idea come into being? One might imagine a fascinating scenario in which the idea to reject the use of the wheel occurs to the author while he is somersaulting in his car that has had a wheel gone loose. But no. The decision to reject the wheel came as a result of long speculations about the ways to increase the vehicle speed". [5]

Does this mean that, in order to make a great discovery or invention it is enough to trace an objective tendency in the development of a system? Of course not. If you tell an inventor: "Look at the tendency and take one step forward", it won't work. It is not only the difficulty to project the

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3 M. Bunge. *Intuition and Science.* Nauka, Moscow, 1967.

4 A.C.Karmin. *Origins of Scientific Discovery*. Nauka, Moscow, 1986

5 G. Zelenkin. *Flying Expresses.* Vysheishaya Shkola, Minsk, 1984.

development of a system, but also the difficulty to find a way to overcome an obstacle that stands in the way of its development (for otherwise there would be no problem at all). Therefore, alongside with **the strategy**, or the main tendencies of development, the theory of creativity should teach **the tactics,** *or* the methods and techniques to deal with obstacles. Additionally, it is necessary to take into account the peculiarities of using inventor's main tool: the human brain. *Traditional thinking is extremely conservative*, it is biased towards the only method used for millennia, the trial and error method. Only a small part of us is inclined to *dialectic thinking* that is always looking for new ideas. Dialectic thinking should be made available to everyone, hence there is the need to incorporate the *rules of using dialectics* into the theory of creativity. To avoid errors, proper organization of creative work should employ the best of human thinking (*imagination, fantasy*) and take heed of its weaknesses (*psychological inertia*). Finally, for solving present-day inventive problems there is a need for knowledge, i.e. inventor should have an *information database* at his fingertips.

It is hard? It is not harder than learning to drive. One may head off towards the destination on foot, hoping that some 'heavenly fire' will at last show the way to the weary traveler. But wouldn't it be more practical (and more up to date!) to whiz down the newly-discovered road at a breath-taking speed!

HAD THEY NOT BEEN BORN:

Sir Isaac Newton, James C. Maxwell, Max Planck, Dmitri Mendeleev… These questions could start an interesting discussion on the role of individuals in science (there are many interesting materials devoted to this topic). The following quotation from Albert Einstein can be used to open the discussion: "I don't understand all these eulogies to myself as the creator of the theory of relativity. Had it not been for me, Poincare would have done the same a year later, or, Minkovsky would have done it in two years. After all, Lorentz did half of the job. My services are exaggerated." (K. Seling. *Albert Einstein*, Moscow, Nauka, 1964). A no less thought-provoking discussion could be organized that focuses on the originators of great inventions: the laser, the nuclear reactor, holography, spacecrafts, etc.

What about artistic inventions? What would have happened, if the originators of science fiction (Jules Verne), symphony (Joseph Haydn), landscape painting (Brueghel), air perspective (da Vinci), artistic documentary, the opera, the comedy, the musical comedy and etc., had never been born?

2.6. A TABOO ON POOR SOLUTIONS

There is always an abundance of inventive problems to be solved, since the development and practical application of technology is accompanied by continuous problem solving in every area of study. As a rule, problem solving begins with using familiar technical knowledge and technical means. It happens too often, however, that this knowledge and these means appear non-applicable.

Problem 14. When tanks appeared at the start of our century, there was an acute need to counteract them. What could be used against tanks? Aircraft? But in a duel between a tank and an aircraft the latter was obviously weaker, for it could easily be destroyed by the tank's machine-guns. What could be done? Designers in many countries attempted to construct armor-plated aircraft (such as German U-1 designed by Junkers) but these were heavy and slow and might be easily shot down from below. Many pilots during the World War I put cast-iron pans under their seats! After the war Americans tried to solve this problem. Many variants were examined: using powerful engines, avoiding extra weight, bearing fewer weapons on board. Similar research was carried in Russia by development laboratories of Tupolev and Polyakov, but with poor results.

The problem contained a paradox: the armature is vitally important only at certain short moments during the fight; and for the rest of time it is dead weight. In other words, the armature should be present to shield the aircraft and its crew from being shot down, but at the same time it should not be present, because it adds extra weight to the aircraft.

The problem acquired primary importance when the Great Patriotic War started: the situation did not allow poor solutions. What could be done?

In summary, in the 'aircraft-armature' system, better defense results in lower speed of the aircraft. And *vice versa*, higher speed requires thinner armature and consequently weaker defense. Such conflicts found between parts or properties of a system are called **technical contradictions.**

A problem containing technical contradictions can be solved either by seeking a compromise between the conflicting properties (*to what extent is it appropriate to lose in certain properties in order to gain in other properties?*), or by trying to resolve the contradiction (obtaining the desired result without much sacrifice). The first way is typical of ***engineering solutions***, the second way characterizes ***inventive solutions.***

Soviet aircraft designer Iliushin came to a brilliant solution to the 'aircraft – armature' system: he realized that armature should at the same time serve as a load-carrying structure of the aircraft, not only defending it, but also bearing the forces that occur when the plane is air-borne. Armature should strengthen the aircraft and thus there will be no 'dead weight'. The famous IL-2 attack plane (IL-10 since 1944), known as 'the flying tank' is recognized as the best in its class. The benefit of Iliushin's invention was great (the advantage of these planes over enemy's planes, more chances of victory) whereas the sacrifice was incommensurably small (alterations in the construction of the plane and in the production technology).

The essence of inventive creativity is to find a technical solution where the sacrifice for the result is either zero or nil as compared to the benefit achieved.

This proportion should be borne in mind while solving inventive problems. Let us compare two solutions to the problem described below.

> **Problem 15.** When shells and bullets penetrate the gasoline tank of the aircraft, it looks as if explosion is imminent. But combustion can only occur in the mix of fuel and air, when part of the fuel has been discharged and the fuel vapor is present in the empty part of the tank. Can formation of gasoline-air mix be avoided, and the chance of explosion reduced?

Obviously, one should prevent air from getting into the tank when fuel is being discharged. However, gasoline will not flow out of the tank without air input. Hence the technical contradiction: *the air should be present in the tank to make gasoline flow out, and it should not be in the tank to avoid the formation of gasoline-air mix*. Solution: in 1942 it was suggested to fill the empty space in the tank with inert gas nitrogen (which constitutes the four fifths of the earth atmosphere). Thus, the air *is* and *is not* present in the tank at the same time. The price paid for this solution was enormous: the weight of the cylinders with nitrogen, the valves, pipes, the operating system that weighted dozens of kilograms. But in those days this was the only possible way out (by 1942 another solution had been found: filling the tank with exhaust fumes of the engine). And below is a present-day solution, where the technical contradiction is viewed from the other side: *there should be gasoline in the tank to supply the engine with fuel, but at the same time it shouldn't be in the tank to avoid the formation of air-gasoline mix.* Yes, gasoline *is* in the tank (to secure the useful function of the system) but it is in gel-like form. The process of transforming fuel (in modern aircraft – kerosene) into a safe substance is called 'fuel stabilization'. It is enough to admix a small amount (0,3-3%) of certain polymer for the fuel to stop evaporating. Other properties of the fuel (such as fluidity) will be retained. Stable fuel will not combust during a clumsy landing and in racing cars a light bag may be used instead of a tank. A handful of polymer powder replaced the bulky system of nitrogen supply. In this case it was the working substance of the system (the fuel) that acquired the necessary property without using additional devices. Of course, the effect was first discovered scientifically and only later put into practice. Once discovered, each effect can be used endlessly and finally the wide use of the effect is a part of everyday reality. But the first application of the effect is always an invention, it empowers technology with a new idea. For example, the effect of the demagnetization of substances in heating above the Curie temperature was discovered long ago, but it is still actively used in inventive practice.

> **Problem 16.** Cereal often contains germs and eggs of pests that should be killed before packing. The best way to do it is by heating the cereal accurately up to 65^0 C, for cereals cannot be heated above $68\text{-}70^0$ C. During experiments, it was impossible to provide accurate temperature regime and high production rate at the same time: a thick layer of cereal did not get heated all through, and the lower layer burned. Using a

thinner layer of cereal led to lower production rate. Other ways to heat cereal were tried: placing the cereal on a sieve and blowing it through with a stream of hot air coming from below. But due to excessive heating the cereal would deteriorate all the same. An utterly safe method is needed to secure high production rate.

Absolute accuracy of temperature regime was conditioned with the help to ferromagnetic pellets, admixed in cereals. The pellets have Curie temperature at 65^0C. Getting into alternating magnetic field, pellets, as ferromagnetics, get heated; but when the temperature exceeds the Curie point the pellets get lost their magnetic properties and stopped heating. When the temperature of ferromagnetic dropped under 65 0C, the pellets 'switched on' again. Pellets could be easily separated from cereal afterwards, for they are magnetic. How can the technical contradiction be formulated for this problem? *Cereal should be processed in big quantities for high production rate, and in low quantities for temperature accuracy.*

Therefore, an inventive problem is a problem that contains a technical contradiction, which cannot be solved using familiar knowledge and common technical means. The conditions of the problem do not allow a compromising solution.

Once technical contradiction overcome, the inventive problem is solved and an invention is obtained.

The technical contradictions are sometimes on the surface of the problem. Such are the problems presented in this chapter. However, sometimes the contradiction is hidden, or dissolved in the formulation of the problem. Nevertheless, the inventor should bear in mind the technical contradiction that needs to be resolved. It is relatively easy to reveal the contradiction in problems that read: “Improve object X obtaining result Y....”. If only one part of this formula is presented in the task, i.e. “improve object X”, or “obtain results Y and Z...”, the problem is more difficult to solve.

YABLOCHKOV'S INVENTION

The technical contradiction underlying problem 5 can be formulated as follows: the gap between the carbon electrodes should be adjustable so that the electrodes are burning out at a constant distance between one another, and it shouldn't be adjustable to avoid using complex mechanisms. P. Yablochkov found an ingenious solution: he placed the electrodes vertically, one running parallel to another, and filled the gap with kaolin (or China clay). The electrodes burned out, but the gap remained did not change during the burning process.

LUCAS CRANACH JUNIOR faced a very complex contradiction, but managed to resolve it. Cardinal's face is normal. He is looking at the Cross. But the figure of Christ on the Cross looks so scared, intimidated, so miserable that it becomes clear that the man looking at Him is very cruel.

ZEBRA OR WAVE? BOTH.

Such was the solution to the problem about the road profile. A zebra crossing is painted on the flat road in the way it would look on a wavy road. Before realizing that it is an optical illusion, the driver will slow down almost instinctively.

IN ORDER TO EXPRESS HIS FINNISH SOUL the architect refused to compromise (giving the building neither streamlined form, nor straight lines and sharp angles), for this would have been a defeat. He used straight lines and sharp angles (the 'Finnish' way to build) that are arranged in a zigzag pattern, making the silhouette of the building look streamlined and very 'Arabian'.

FORMULATE A CONTRADICTION TO GET AN INVENTIVE PROBLEM.

For example, what contradiction was resolved in designing Chameleon sunglasses (sunglasses that change transparency when exposed to light)? Any item that comes at hand can be improved. Formulate technical contradictions for the pencil, the needle, the scissors, etc.

EGG SORTING

An egg-sorting machine has been installed at a poultry plant. The eggs move in a dotted line down the conveyer. Each egg passes between a source of light and a screen.

Depending on the shadow of each egg, its size and rating are determined. The screen serves as an electronic photosensor; it consists of multiple dots that contain photosensitive transducers. The bigger the shadow of the egg, the more dots are shadowed from the light. The signal from the screen is then transferred to a microprocessor that calculates the volume of the egg.

Eggs are to be separated into five categories:

Category	Volume, cm^3	Mass, g
1	over 59,33	over 64
2	52,67-59,33	57-64
3	46,02-52,67	50-57
4	38,41-46,02	42-50
5	under 38,41	under 42

The pilot model of the device appeared unreliable: it made numerous mistakes, especially if the screen was smeared, the sensors required constant maintenance service.

Therefore, the poultry plant announced a contest to find the best way of simplifying the system and making it reliable.

Do you remember how Edison taught a lesson to the mathematician? It took him just a few seconds to measure the volume of a bulb without going into sophisticated calculations...

Here, dipping each egg into water will obviously complicate the process. What can be done?

3. SUBSTANCE AND FIELD ANALYSIS: S-FIELDS.

3.1 PROBLEMS WITHOUT CONTRADICTIONS?

Overcoming contradictions helps with solving both simple and complex problems. But why do contradictions occur? Because, striving to improve the world around us, the inventor demands a lot from technical objects. And this is logical, for, in order to meet the ever-increasing demand, technical systems should be constantly gaining in efficiency (or reduced in harmful, or redundant properties).

This means that one group of inventive problems focuses on improving the existing technical systems. Once involved in evolution process, they start facing contradictions.

Not always can the increasing demand be met by improving the existing technical system. This gives rise to a question: are there problems where no contradiction can be defined?

> **Problem 17.** In the course of reconstruction, a match factory was equipped with high-performance machines to double the factory's production rate. Yet, there was an operation that slowed down the whole process: packing the ready matches into boxes. The old machines could not cope with twice as much production; the lack of space made it impossible to install two packing lines. Finally a decision was made to remove the out-of-date packing equipment. And that old equipment had some deficiencies too: it was 'blind' and would often pack reject matches without heads or pack wrong number of matches. Therefore, it became urgent to find an accurate method for packing matches into millions of boxes.

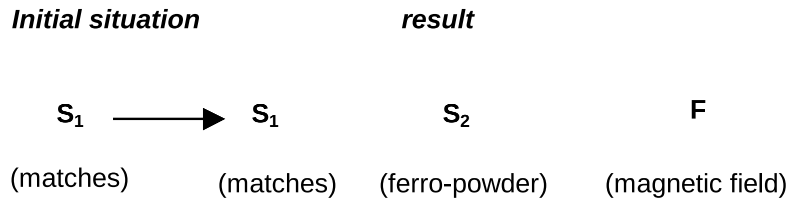
There is no visible contradiction in this problem, but still there is the need to find a solution. As you probably guess, we should follow the steps of Problem 11. By introducing a small amount of ferromagnetic powder to the ignition compound we give slight magnetic properties to each match. This is enough to orient the matches in the magnetic field and pack them much faster and with much higher accuracy (for a magnet of certain surface square attracts a fixed number of matches).

Let us analyze the problem and its solution in detail.

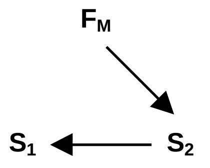
First, as the conditions of the problem suggest, there is nothing to improve: the old technical system was dismantled. Therefore, a new system should be created.

The matches are there, but what are we supposed to do with them? Should we count, orient, or package matches? Later we solved the problem using a familiar method: introducing ferromagnetic powder into the ignition compound of match head and using the magnetic field to create a system easy to control.

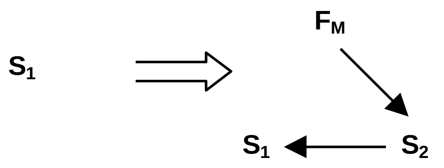
In the beginning, there was one substance (matches), in the end there were two substances (matches and ferromagnetic powder) and one (magnetic) field. We use the following symbols to represent the operation:



Let us now look at how the system works. Magnetic field (F) acts on ferromagnetic powder S_2 which, in turn, acts on matches (S_1). Graphically the operation can be represented as follows:



In other words, we worked from a single element (S_1) towards a system of interacting elements (S_1, S_2, F). This transition is indicated by double arrow (to avoid confusion with arrows that indicate the interaction between elements). The entire process of transition can be displayed as follows:



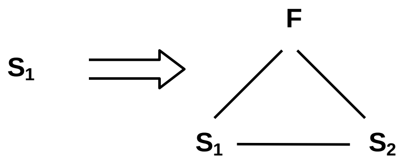
All this resembles symbolic representation of chemical reactions, doesn't it? Two elements (e.g. oxygen and hydrogen) are heated (i.e. an external thermal field is introduced). As a result of interaction, they form a molecule of water. But if a single atom is withdrawn from the molecule, the water will disappear...

Can we treat the right-hand triangle of this 'technical reaction' formula as a 'molecule' of technical system? Let us validate this idea: will the system work if we withdraw any of the substances? No, the system will fall apart and cease to be a system. The same holds true for the situation in which the field is withdrawn. Does this mean that system's operation is secured by the presence of all of its three elements? Yes. This follows from the main principle of materialism: substances can only be modified by material factors, i.e. by matter or energy (field). With respect to technical systems, this principle sounds as follows: substance can only be modified as a result of direct action performed by another substance (for example, impact – mechanical field) or by field action of another substance (for example, magnet) or by an external field.

As a consequence, the minimal number of elements any technical system consists of is three: two substances and a field. The concept of minimal technical system was named ***Substance-Field System***, or ***S-Field*** (from ‘Substance’ and ‘Field’).

S-Field is a model of minimal, functioning and controllable technical system.

The S-Field concept furnishes a clue to the direction of problem solving. As an example we shall take the problem on measuring the height of a cave (see page 9). Here S_1 is the height of the cave: the only element of the system should be developed into an S-Field model (SFM). Below is a formula of such transformation:



This formula is identical to that in Problem 17, but the S-Field model is presented in its general form (no arrows are used). Thus, we know nothing about the nature of the interaction(s) between the three elements. What we do know, however, is what the system lacks: the second element and the field. This pair (S_2, F) stands for the desired measuring instrument. However, the conditions of the problem strictly limit the scope of possible solutions: the weight of the device should tend to zero.

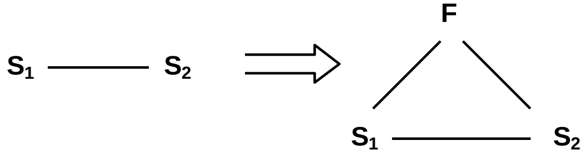
Let us intensify the contradiction: the device is there, but has zero weight! Incidentally, engrossment of contradiction is very often helpful in that it boosts the problem solving process, because, paradoxically, the more sharp and irreconcilable the contradiction might seem to us, the sooner we can resolve it. Let us intensify it further: the device exists, but has minus-weight (which seems an altogether impossible technical contradiction, for it implies anti-gravitation!). But let us bear in mind the law of energy conservation: the weight of the body can only become equal to zero if it is compensated. For a case in point, lift can make up for the body’s weight. And here the idea of solution occurs to us: why not using a balloon and a thread? That being so, the ‘minus-weight’ assumption does not seem so perplexing – for the lifting power of the balloon exceeds the weight of the thread and the reel.

Obviously, the problem above presents a sharp technical contradiction, whereas the preceding problem contained no contradiction at all. So, what is to be done with technical contradictions: should they be defined for each technical problem? In fact, technical contradiction may not emerge when we are synthesizing a technical system (completion of S-Field model), for nothing prevents the inventor from introducing the missing elements into the system. *This is the only case when inventive problems are solved without* *technical contradictions*. As for the rest of cases of technical system synthesis (when conditions of the problem contain restrictions), technical contradiction will always be there. This is not to mention improvement of technical systems, – the next step of technical evolution, – because *any development overcomes emergence of, intensification and resolution of contradictions.*

There is a wide class of problems which may be solved through SFM completion. Additionally, the left part of S-Field formula ("given") may not consist of just one element (S or F), but may have two elements (S_1 –S_2; S – F).

> **Problem 18.** The existing methods of determining water content in machine oil require too much time and special measuring instruments. How can one quickly determine the presence of water in the machine oil taken from the car's engine case, for example when the car has been pulled over to the side of the road for a short time. A quick method is needed. What would you suggest?

The conditions of the problem contain: S_1 (oil) and S_2 (water):

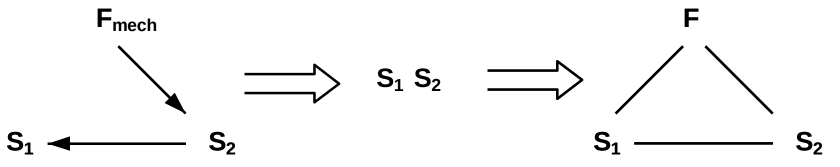


The field is missing. Which field, – mechanical, thermal, electric, or any other field should be used? At any rate, the field has to be simple and accessible. It should separate the substances to show whether there is water or not. Naturally, this separation should be based on disparity of the two substances' properties. Which properties should be used? Among the variety of differing properties the most obvious one is the boiling point. Japanese Patent 52 - 46837 states it clearly: a drop of oil should be placed on a metal plate and heated up to 100^0C (e.g. using a lighter). Boiling water will become visible.

Left-hand part of the formula is often deliberately simplified: a full, but ineffective S-Field model is deprived of one or two elements. What is left? The criterion for selecting dropouts is simple: the remaining one should be practical, easily controllable and cheap (they'd better cost nothing at all).

> **Problem 19.** The clamp of an industrial robot slides along a long hollow guiding boom. The sliding element of the clamp is a sleeve of fluoroplastic (polytetrafluoroethylene, teflone) and brass, because fluoroplastic has a low friction coefficient with steel. To diminish friction, it is recommended to lubricate the friction surface with liquid (i.e. water). Engineers have developed a lubrication feeder that consists of spray-guns connected with water-pipes. The feeder does not operate smoothly because the pressure in the pipes varies, drops of water go in wrong directions and the system requires continuous re-adjustment. The system should be reliable, independent of water pressure and the tiny droplets of water should cover the surface of the boom uniformly.

Because the problem contains an ineffective S-Field model, the whole system should be rejected. Let us set aside the unstable and uncontrollable mechanical field that feeds water to the boom. Thus we get new conditions: the boom (S_1) and the water (S_2) that have no interaction:



Therefore, the field is unknown. However, it is the field that should bring droplets of water from somewhere and put them onto the boom. Where from do these droplets come if they cannot be obtained from the water pipe? For example, one could use air moisture. Thus we need a physical effect to entrap moisture. UK Patent 1477784 suggests that the hollow boom has to be cooled below the dew point of the room to condense water.

FLAUNTING FLAG WANTED

'The flagpole is ready,' said the assistant director. 'We welded it from steel poles and gave it a coat of paint... Shall we install it? Or, maybe, let it lay here for a while. The forecast says we won't have any wind in the next three days'.

'But we need a flaunting flag tomorrow, six in the morning. Is that clear?' the film director pointed his speaking trumpet at the assistant's face.

'But the wind... How do you make the wind? Three days...'

This time the director increased the volume of his trumpet: 'I need that picture.'

'What if we hide air-blowers somewhere here?'

'Are you mad? There should be no technical things or camouflage within 200 feet around the location!'

'Two hundred feet? But even a wind tunnel they use for testing planes won't do here...'

'An idea!' shouted the key grip who had kept silence all this time. 'Think of S-Field analysis. We have two substances: the flag (S_1) and the air (S_2) blowing over it.. You only need a field which will make the air blow at the flag. The flagpole is a ready-made pipe...What was the key grip's idea? In order to make the SFM complete one needs a slightest blow, but there's no wind.

3.2. RULES FOR THE INVENTOR: S-FIELD ANALYSIS AND SYNTHESIS

Discarding redundancies, S-Field models shed light on the essence of transformations (synthesis, evolution) of technical systems and allow to use universal technical language to represent the process of solving any inventive problem. That is why analysis of substance-field structures in those parts of technical systems where contradictions occur is called **S-Field analysis.**

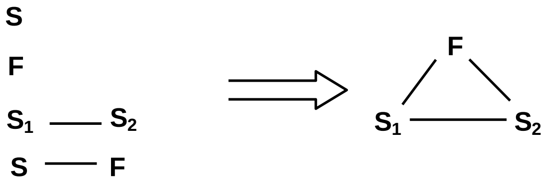
S-Field analysis presents a general formula that shows the direction of solving the problem. This direction depends heavily on the initial conditions of the problem. Consider any of the problems above: any slightest alteration of conditions will profoundly change the process of solving the problem. For example, no materials may be introduced into the match head, no cooling medium can be poured into the hollow boom of the robot, etc. How can you decide then, which step to take?

There are several rules of S-Field synthesis. For simplicity, futher in the text we will use abbreviation "SFM", which stands for *Substance-Field Model*[6]. These rules are called in TRIZ *Inventive Standards*. This means, that if two problems result in identical problem models, they have identical, or *standard*, patterns of solutions. In this book we only explain most frequently used inventive standards. Our goal is to help you with understanding basic principles behind problem solving based on the S-Field approach. Full list of 76 inventive standards can be found in Appendix B.

One of the rules was already mentioned above:

Non-S-Field systems (containing one element), or incomplete S-Field systems (with 2 elements), should be developed into a full S-Field Model according to the following rule:

<u>STANDARD 1-1-1.</u> If there is an object which is not easy to change as required, and the conditions do not contain any limitations on the introduction of substances and fields, the problem is to be solved by synthesizing a *SFM*: the object is subjected to the action of a physical field which produces the necessary change in the object.

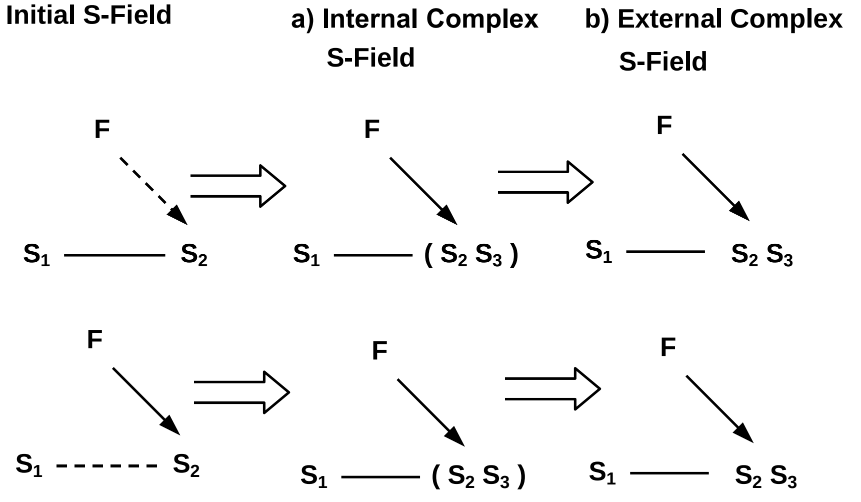


Quite often, conditions contain two substances and a field that have insufficient interaction and cannot be replaced with other substances or field. That is, the SFM is there (all the three elements are present) and, at the same time, it is not there: it simply won't work. The same may happen after completing a SFM. That means that the SFM needs to be improved: the substances should become controllable, the field should have a desired

[6] Sometimes, the word "model" can be omitted, and the term "S-Field" instead of "S-Field Model" is used. In other TRIZ literature, you can find alternative translations of this term, for instance, "Su-Field" or "Su-Fi".

effect, the character of interaction of elements should go as required. There is a set of transformation rules for substances and fields in S-Field models.

Formation of complex S-Field by introducing easily controllable admixtures possessing desirable properties into the substance. The admixture can be introduced into the substance (internal complex S-Field, Standard 1-1-2) or, where internal introduction is inadmissible, placed outside the substance (external complex S-Field, Standard 1-1-3).



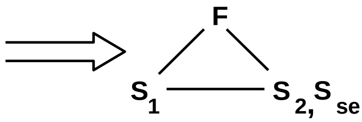
Non-existent interaction is shown by dotted lines, brackets indicate internal complex link. External complex link has not brackets.

Examples:

a) *internal complex S-Field:* wetting of fabric (Problem 2); foaming of varnish (Problem 3); emergence of multi-colored inserts impressed at certain distance to the cutting edge indicates the wear of the cutting tool (Soviet Patent no. 905 417);

b) *external complex S-Field*: admixing ferromagnetic powder to cereal (Problem 16), production of hollow metal porous balls: polystyrene balls are given a metal coat and subsequently dissolved in organic solvent (US Patent 3 371 405). To avoid rumpling, the corrugations of the thin surface are filled with low-melting-point metal which is withdrawn after treatment (Soviet Patent no. 776 719).

STANDARD 1-1-4. If the conditions contain limitations on the introduction or attachment of substances, the problem has to be solved by synthesizing an S-Field using external environment as the substance:



S_{se} **is the substance from the surrounding environment**

The left part of the formula coincides with that in the previous formulas.

Examples:

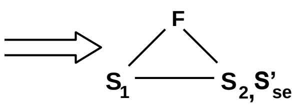
In order to secure permanent contact between ice and vibrator while measuring the depth of the river through ice, the ultrasonic vibrator is buried in well-tamped snow (Soviet Patent no. 900 233).

The flow of air that streams against a moving locomotive is used for clearing rail tracks. The shields and openings of the locomotive direct the flow at a required angle (Soviet Patent no. 1054483).

In particular, if it is necessary to change the weight of a moving body, but the weight cannot be changed, the body should be given a winged shape. Thus, changing the inclination of the wing towards the direction of motion, it is possible to get additional upward or downward force.

"Racing improves the nature of cars" is the motto of all car-racing competitions. But, unlike ordinary cars, racing cars travel at breakneck speeds. How can one make their wheels safely engage with the road? Such cars have planes in the form of the "anti-wing". Besides, the air outlets that abstract heat from the radiator, the car surface and the edges are located so as to create a considerable air rarefaction under the floorpan of the car.

STANDARD 1-1-5. If external environment does not contain ready substances required to synthesize S-Field, these substances can be obtained by replacing the external environment with another one, or by decomposing the environment, or by introducing additives in it.



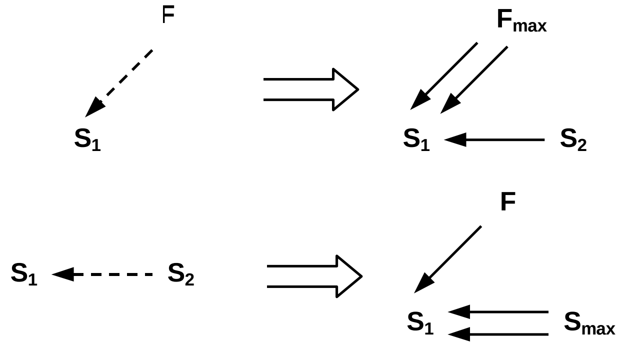
where S'_{se} **modified external environment**

Examples:

In recycling plastic wastes, the wastes are first sorted by size on a vibrosieve. But small particles rub against one another, get electrified, and lump together. Trying to break big lumps with a rod, the operator gets an shock coming from static electricity. It was suggested to blow ionized air through the vibrosieve to neutralize the electric charges.

Before they begin to fatten, pigs are inoculated to avoid epidemics in the herd. Can you imagine what happens if somebody attempts to inoculate each swine with a syringe? An alternative method is used in Germany: pigs are hustled into a chamber filled with hot air that contains tiny droplets of vaccine.

STANDARD 1-1-6. **If a minimum (measured, optimal) effect of action is required, but it is difficult or impossible to provide it under the conditions of the problem, use a maximum action, while the excess of the action is then removed. Excess of a substance is removed by a field, while excess of a field is removed by a substance.**



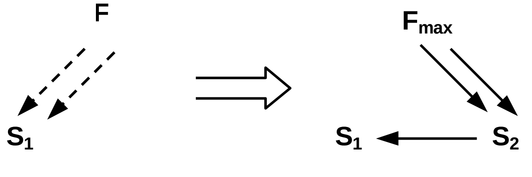
Two arrows indicate excessive action.

Examples:

If a high-rise building is on fire, its steel frame may become unstable due to overheating. To avoid this, the hollow columns of the building and other elements are filled with water that circulates within the frame. When water begins to boil, the vapor exits into the air.

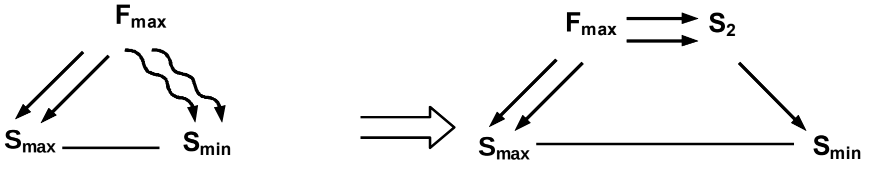
To obtain a thin coat of paint, the article is first submerged into a tank with paint (thus acquiring excessive paint) and then rotated. The occurring centrifugal force throws away excessive paint (Soviet Patent no. 242 714).

STANDARD 1-1-7. **If a maximum effect of action upon a substance is required and this is not allowed, the maximum action has to be preserved but directed to another substance attached to the first one.**



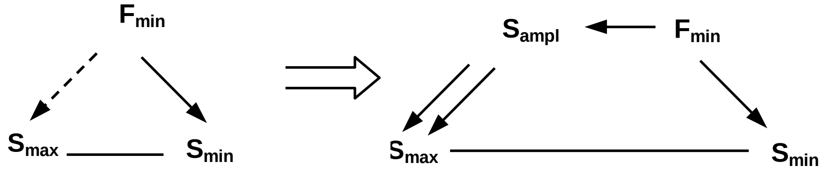
For example, production of pre-stressed reinforced concrete begins with stretching of wire. Heated wire gets longer and is fixed at this length. The extended length of the wire is proportional to temperature increase. However, at temperatures above 400 ^{0}C the wire loses its standard quality. It was suggested (Soviet Patent no. 120 909) to heat a non-consumable high-temperature bar. When heated, the bar becomes longer. At this moment it is fixed to the wire. When the bar cools, it shortens and stretches the wire which remains cold.

STANDARD 1-1-8-1. If a selective effect of action is required (maximum in certain zones, while the minimum is maintained in other zones), the field has to be maximal; then a protective substance is introduced in places where a minimum effect is required.



For example, a porous plate protects the flammable parts of the workpiece from fire but lets the fire heat the entire workpiece (Soviet Patent no. 1 000 033)

STANDARD 1-1-8-2. If a selective-maximum effect is required (maximum in certain zones, and minimum in other zones), the field should be minimal; then a substance that produces a local effect interacting with a field (e.g. termite compounds for thermal action or explosive ones for mechanical action) is introduced in places where a maximum effect is required.



S_{max} - substance of the area where maximum action is requied;

S_{min} - substance of the area where minimal action is required

For example, thermite compounds are used for creating additional thermal action (in the clearance between welded parts, see Soviet Patent no. 743 810), explosive compounds are used for mechanical action (e.g. an embossing technique where the artist draws the picture with soft-tip pen on a copper plate and then places explosive substance in necessary spots using a sprayer. The plate is then put on a rubber ‘anvil’ and the charge is blown up).

THE STORY OF A HAPLESS GAS-EXPANSION MACHINE

The inventor was shown a helium liquefaction machine.

'This is the gas expansion machine I promised to show you,' said the laboratory worker pointing at a tall metal cylinder. 'It is 3 m tall, 25 cm in diameter. We examine it every three months. Each time we need to remove this lid and each time something goes wrong. You are an inventor, I hear. Why don't you solve our problem then? Once, during an examination, a tennis ball fell into the machine. How were we to take it out of the tank? First we didn't know what to do, because you know, even a most skinny guy would not get through: the head will go, but not the ears... And the hand simply won't reach the bottom, even if you use a hoop-net for butterflies... Somebody said we should use grips such as those they use in the subway to retrieve things that fell down on the rails. But the handle

is too short. We were at a loss'

The inventor thought and said: 'Complete the S-Field.'

'Sorry, complete what?' said the laboratory worker, puzzled.

'Well, to make the system work you have another substance and a field added to the substance that is there (S_1)... The field will push the ball out. Or, rather, the second substance will create a field that will push the ball out of the h-mm what's-it-called?'

'Gas expansion machine. But how? Could you be more specific?'

'The easiest way is to fill the cylinder with water, if possible. Or you can take a hose-pipe, get it down to reach the bottom and use compressed air...'

'That's right, we used water. But another time a steel screwdriver (made of ferrosubstance) fell through. What are you going to complete this time? S-Field, or whatever you call it...'

'Now you use magnetic field: the screwdriver and a magnet on a cord. '

'Okay, done. But, when we did another examination, in spite of all precautions a brass ball fell into it. What were we supposed to do? The ball would not float or get attracted by a magnet.'

'Again you need to complete the S-Field model. But now the second substance will be...'

So, what will serve as the second substance?

3.3. FORMULAS THAT GIVE INSIGHT: NO MORE HARMFUL EFFECTS

Researchers into technical creativity have always been puzzled by the endless diversity of inventive problems. What is the point in talking about basic tools if each problem is unique? Attempts were made to classify problems using their field of application or functions. But such classification was always misleading and made the task even more complicated: an agricultural problem would suddenly resemble a problem on aircraft engineering, whereas two seemingly identical problems on cargo-lifting required totally different solutions.

S-Field analysis produced specific principles of problem classification that take into account the number of elements (substances, fields) involved in the problem model, the nature of elements (substances, fields), and the possibility of introducing extra elements.

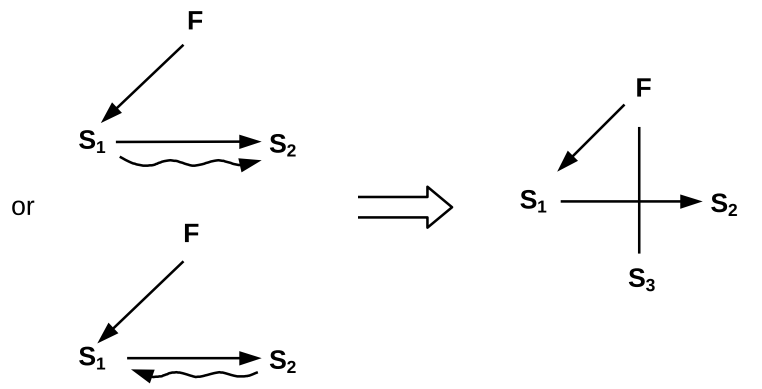
Another common variety of inventive problems are problems on ***destruction of harmful S-Field.***

> **Problem 20.** Copper smelteries that use centuries-long technology are usually surrounded by a 'dead zone', polluted with sulphur dioxide. Pollution leads to deforestation and draining of lakes. Sulphur dioxide is a product of sulphur oxidation. Sulphur evolves from ore in the course of its pre-heating up to 500 - 600^{0}C before the ore is loaded into the furnace.
>
> Fluid bath smelting developed by Russian engineer scientist A. Vaniukov in 1949 does not cause environmental pollution and allows to put the harmful side-effect to use: for oxidation of sulphur is an exothermic reaction, i.e. it is accompanied by heat generation. Melt does not require external heating at the stage when ore is thrown into it. Thus, the melting process becomes continuous. The melting point of ore is 1200 ^{0}C, and a slightly higher temperature of 1300 ^{0}C is maintained in the bath. But the air-tight walls of the bed are made of copper, that has a melting point at 1083 ^{0}C. How can the walls be protected from thermal destruction and abrasion caused by solid pieces of ore? It was impossible to use the old protective method, i.e. lining the walls with 1-meter thick refractory, since this would cause numerous stops for repairs. What could be done?

Conditions of this problem indicate clearly that there is an effective SFM present. $F_{thermal}$ heats S_1 (the ore) whereas S_2 (the wall) maintains the melt within the bath. One harmful effect is that the melt negatively influences the wall. Eliminating or neutralizing this harmful relation would solve the problem.

Destruction of SFMs is also subject to certain rules. All in all, there are four such rules:

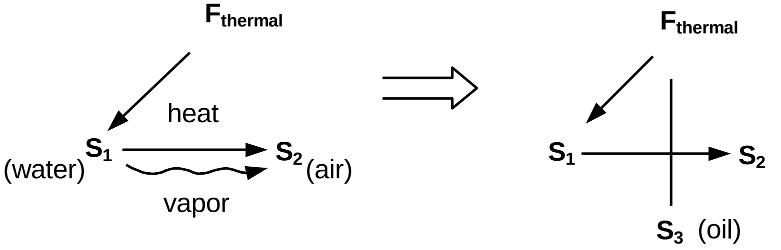
> **STANDARD 1-2-1. If useful and harmful effects appear between two substances in a SFM and there is no need to maintain a direct contact between the substances, the problem is solvedby eliminating the harmful effects by introducing a third substance between them.**



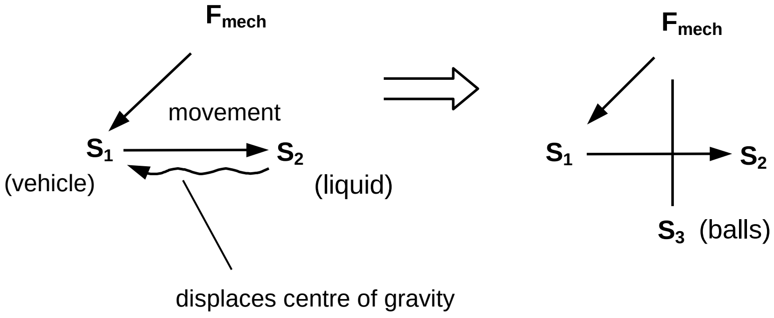
where a wave-shaped line indicates harmful (needless) action.

Examples:

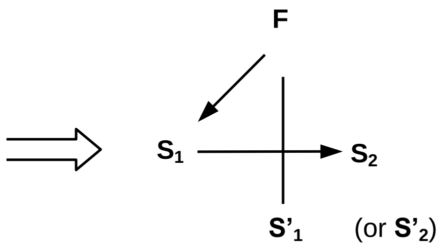
In cold winter of 1919, the students of Moscow Aviation College installed an oven aiming to warm the room where N. E. Zhukovsky was lecturing. But because the frost was so sharp, the oven did not suffice to warm up the entire room. So they put a tank of water on the oven that served as a heat accumulator. This worked, but the vapor from the tank was frustrating. Dampness turned out worse than cold. N. E. Zhukovsky suggested that the students pour some machine oil over the water surface. This primitive trick was helpful, for water did not evaporate and stored warmth for a long time.



In a new method of liquid transportation in tanks, light floating balls are used to protect the liquid from flowing out. The liquid surface remains stable under the floats even at a speed of 60 km/h (Soviet Patent no. 833 462).



STANDARD 1-2-2. **If there are a useful and a harmful effects between two substances, and there is no need to maintain direct contact between the substances, and it is forbidden or inconvenient to use foreign substances, the problem can be solved by introducing a third substance between the two, which is a modification of the first or the second substance.**



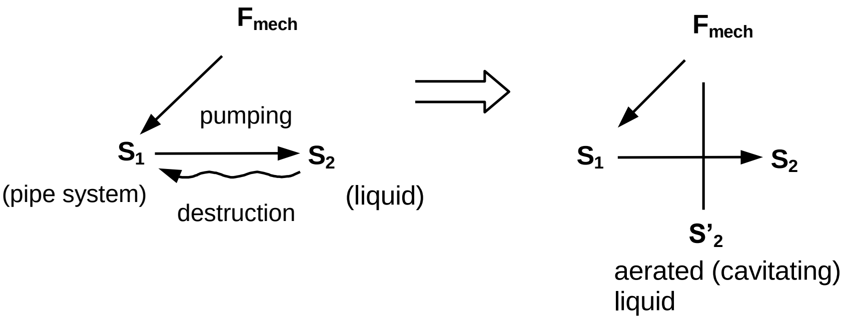
The symbols with strokes (') indicate transformed substance.

Essentially, this effective method of SFM destruction allows to get rid of a sharp contradiction: a third substance should be introduced to neutralize the harmful bond and at the same time should not be introduced because the system should not contain extra substances.

Examples:

Pumping water through pipe systems (e.g. in cryogenic systems) often causes emergency situations. When water is stopped on its way (e.g. as a result of turning off a tap) the pressure in the pipe increases abruptly and the hydraulic impact (wave of excessive pressure) starts expanding throughout the pipe at a huge speed, destroying all that stands in its way. Safety valves and security devices are of no help. It is observed that aerated liquid consumes the power of the impact immediately. However it takes some time to aerate liquid whereas the impact should be dampened instantly. Gas may not be introduced into liquid in advance. What could be done?

Invention granted Soviet patent 1 078 178 uses a well-known physical effect: cavitation. Liquid exudes dissolved gas present in all liquids in absolutely dissolved form. Cavitation is caused by ultrasonic waves (a process similar to boiling water) and thus no third substance (aerated liquid) is introduced but is formed as a result of cavitation. When ultrasonic waves are stopped, liquid returns to its original state (gas is consumed by water). The solution formula can be schematically represented as follows:

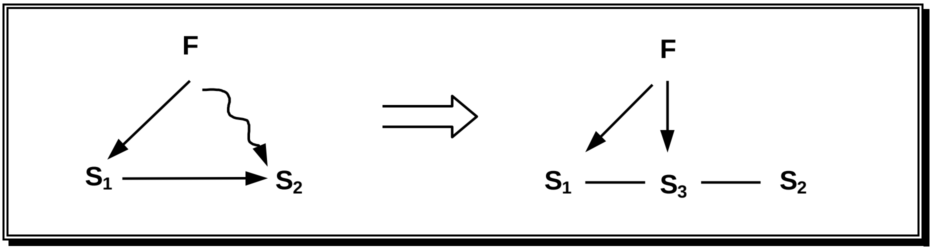


Much the same formula is used in the above-described problem “Soft Water Needed” (see page 18). In that problem, gravitational field (F_{grav}) acts on the diver (S_1) performing an exercise (in other words, the diver ‘works on’ water (S_2)). If the diver does not perform a dive properly, water (S_2) exerts negative influence on him/her, for he/she may hit his/her back or stomach against water surface. A third substance is formed by aerating water: pressing on the pedal the coach lets compressed air from a cylinder rush towards the diver through perforated pipes located at the bottom of the pool. This invention was granted Soviet Patents no. 1 127 604 and 1 229 293.

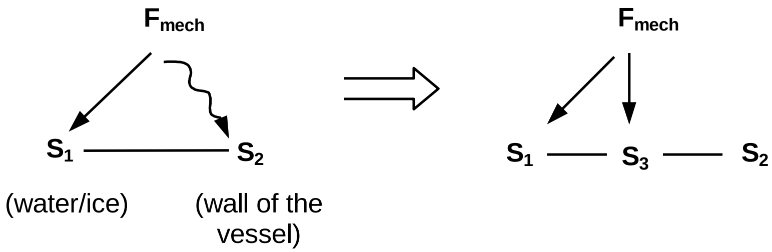
Solution formula for Problem 20 is slightly different from this problem in that the arrows between substances are reverted: thermal field ($F_{thermal.}$) melts ore (S_1), the walls (S_2) withhold the melt which, in turn, exerts negative influence on the walls. A third substance is formed out of the melt by cooling the walls with water. The solid layer of slag-lining protects the walls and is continuously renewed as it rubs away.

Problem 21. How can an ice cube be pulled out of a mould? It is relatively easy to pull ice cubes out of plastic moulds used in home refrigerators, but ordinary home ice-moulds are not so solid and have low thermal conductivity. For pulling ice cubes out of metal moulds in an industrial fridge, leverages are used. Alternatively, one waits until ice begins to melt and may be pulled out easily. However, these traditional methods are labor-consuming and ineffective. What can be done?

STANDARD 1-2-3. If it is required to eliminate the harmful effect of a field upon a substance, the problem can be solved by introducing a second substance that draws off upon itself the harmful effect of the field.

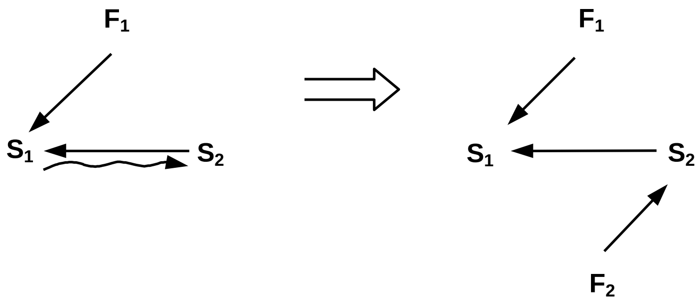


To protect water-filled vessels from rupture as a result of freezing, elastic inserts (chambers) are introduced. These can be a rubber hose, a ball and etc. (Soviet Patents no. 641 967 and no. 668 634).



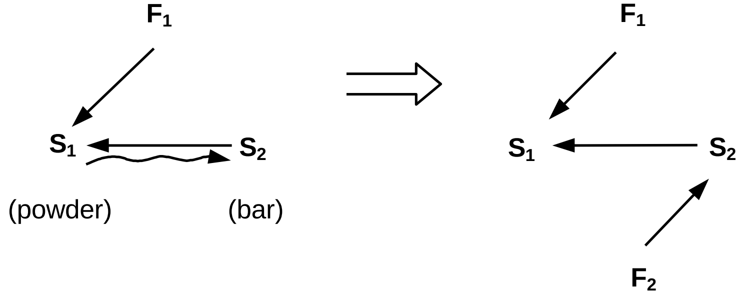
Here, a third substance (elastic insert) receives the pressure of expanding water. The insert shrinks and gets deformed but the vessel remains intact.

<u>STANDARD 1-2-4.</u> If a useful and a harmful effects appear between two substances in a SFM, and a direct contact between the substances must be maintained, the problem can be solved by transition to a *dual SFM,* in which the useful effect is provided by the existing field while a new field neutralizes the harmful effect (or transforms the harmful effect into a useful effect).



Example:

When steel powder sleeves are produced, an electric discharge goes through steel powder making particles weld together. But the electric discharge causes strong magnetic field which presses the particles to the central bar. Afterwards, it is difficult to withdraw the bar out of the sleeve. That is why the bar has a conductor inside. At the moment of discharge the conductor receives an impulse of reverse current.



Using inventive standards 1-2-3 and 1-2-4, solve Problem 21.

A WORD ABOUT WORDS ('SUBSTANCES' AND 'FIELDS')

In S-Field analysis the notion of ‘substance’ has a wider meaning than in ordinary language: it means not only a variety of matter, but also technical systems or their parts, the external environment and even living organisms. Eventually, S-Field analysis symbolically represents the problem solving process allowing to temporarily discard redundant properties of objects and focus on the contradicting properties. Substituting the name of the object for the neutral word ‘substance’ frees us from domination of prior knowledge about the object. Thus the contradiction becomes salient. Any object is a system (including the common ‘substance’ from the standpoint of its micro-structure). Therefore, using substances in S-Field formulas we are, in fact, dealing with systems.

The notion of ‘field’ in S-Field analysis is also distinct from its definition in physics. Four fields (or ways of interaction) are known to physics: gravitational, electromagnetic, strong (nuclear) field and weak field (that of elementary particles). Manifestations of these fields account for all natural phenomena. This four-fold classification is not enough for technology, however. Technical systems are very ‘sensitive’ to quantitative and qualitative parameters of fields. That is why S-Field analysis uses more detailed classification that differentiates mechanical field (pressure, impact, impulse), sonic (ultrasonic, infrasonic) field, thermal field, electric field (electrostatic field, electric current), magnetic field, electromagnetic field, optical field (ultraviolet, infrared, visible rays), ionic radiation, radioactive radiation, chemical fields (oxidizing, reducing, acidic and alcaline atmospheres), odor, etc.

3.4. CHAIN REACTION OF TECHNICAL SOLUTIONS: EVOLUTION OF SUBSTANCE-FIELD SYSTEMS

Once Charles Darwin was addressed by a group of farmers: the crops of red clover had dwindled drastically. Darwin suggested that they have more cats. Why cats? Darwin explained that clover could only be pollinated by bumblebees whose nests were devastated by numerous mice. Mice had proliferated because there were not enough cats in the neighborhood, for ever since soldiers had come back from war, there were not enough spinsters... All natural phenomena are linked and before intruding into the life of natural systems one should know tendencies of their development.

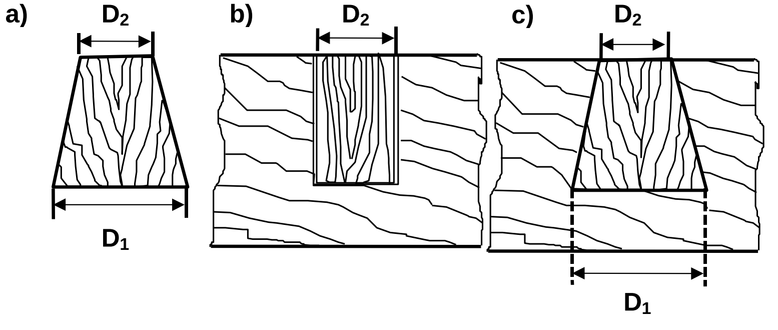
Technical systems, in the same way as other systems, display numerous internal and external connections, both with subsystems (components of each technical system), systems of a higher rank (to which they are subordinated) and the environment. Each technical system can be represented as a sum of S-Fields. Technical systems range from the most primitive one-SFM systems, e.g. the nail, hammer, mechanical field of human hand, to the most complex systems made up of thousands of SFMs, such as the automobile, space-launch complex, nuclear power station. Therefore, intrusion into the 'life' of 'technical beings' requires knowledge of their laws and tendencies of evolution.

One of such tendencies is ***the ever increasing number of S-Fields in a technical system (evolution of S-Fields).*** How do technical systems originate? The emergent need is first satisfied by a simple S-Field that includes an article, a tool and human power. But the functioning of this primary S-Field reveals drawbacks. New needs originate: higher efficiency, automation, additional useful functions, elimination of harmful side effects, and etc. All these needs are embodied in the additional subsystems of the technical system which, in turn, begins to reveal drawbacks. In this way all present-day complex technical systems have developed; all of them date back to the stone, the primeval yamstick, the wheel. Naturally, complexity cannot increase endlessly. At a certain stage of development, the system becomes subject to physical, economic, ecological and other constraints, which indicates the period of 'convolution' of technical system into an 'intelligent' substance. This tendency will be discussed later and this section of the book is devoted to the former tendency: ***development of simple SFMs into complex SFMs.***

Problem 22. At length, the holes in sleepers of railway tracks are destroyed by bolts. The bolts wave and do not keep the rails in fixed position. Waving rails endanger railway traffic. All traffic has to be stopped until the sleepers are replaced. Usually restoration of sleepers is performed. A plug of solid wood (oak, beech) is put into the widened hole and a new bolt-hole is made in it. Replacing and repairing of sleepers costs enormous money which amounts to one third of all the technical maintenance expenses of railways. Discontinuance of trains also causes great losses. Railway companies across the world are facing this problem.

An Austrian company developed a repair method that does not involve replacing sleepers. This method was patented in 28 countries and is performed straight on the railway track. The holes are widened, cleaned by rotating brooms and washed in acetone. Wooden plugs are fixed tightly in the sleepers with epoxy resin. When epoxy resin sets, new bolt-holes are drilled. It takes half an hour to fix each sleeper. And yet, half an hour means delaying a few trains and consequently bearing losses.

How can this method be improved so that the repair works are performed within a minimal interval between trains (approximately 5 minutes)? Adhesive materials cannot be used because the plug should be drilled right after it is inserted and by the end of the operation the plug should stand to the load of several tons. What could be done?



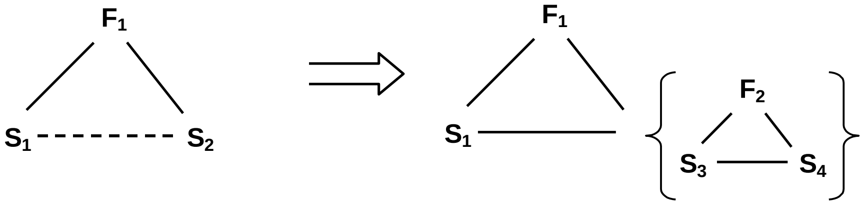
Repairing a sleeper without pulling it from under the rails: a) cone-shaped timber blank; b) cylinder-shaped timber blank inserted into the sleeper hole with a 1-2 mm clearance; c) wetted plug has acquired its original shape. The sleeper is ready, the plug cannot be pulled out.

"The easiest way to complicate an S-Field is to duplicate it, as proposed in Standard 2-1-1:"

STANDARD 2-1-1. **Efficiency of SFM can be improved by transforming one of the parts of the SFM into an independently controllable SFM, thus forming a *chain SFM*.**

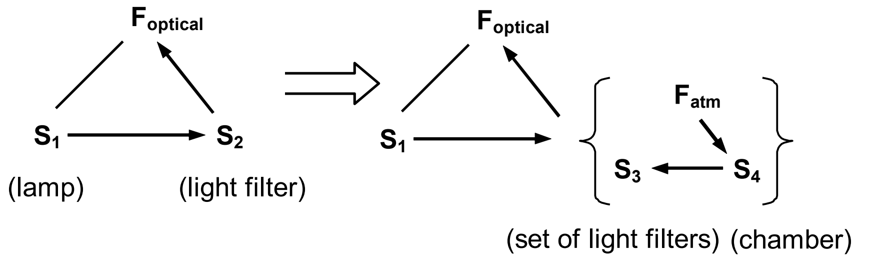
Chain S-Field can be formed in three possible ways:

a) Development of a substance within the SFM:

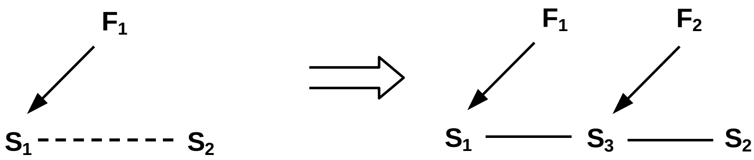


Substances S_3 or S_4, in turn, can be further developed into an SFM.

For example, a decorative lamp is invented that changes its color depending on the atmospheric pressure. An ordinary lamp contains one light filter in a fixed position. In the new lamp, there are several filters fixed on a corrugated vacuum chamber that changes its volume depending on the atmospheric pressure. The chamber moves multi-colored filters as it changes its volume (Soviet Patent no. 779726).



b) Development of bonds in a SFM:



In the case, the S_1 - S_2 bond is built up into F_2 - S_3 component of the SFM.

For example, UK patent 824 047 describes a device for transmitting rotation from one shaft to another: the shafts are inserted into two ends of a cylinder-shaped sleeve. The clearance between the shafts inside the sleeve is filled with magnetic liquid that stiffens under magnetic field. The sleeve works as an electromagnet. When the electromagnet is in off mode, the shafts (S_1, S_2) are driven by F_1 and rotate freely relative to one another.

When the electromagnet F_2 is in on mode, the liquid (S_3) stiffens fixing the two shafts tightly and thus allowing to transmit the torque.

c) Relocation of the center of gravity: Very often a mobile system can be made more effective by displacing its center of gravity.

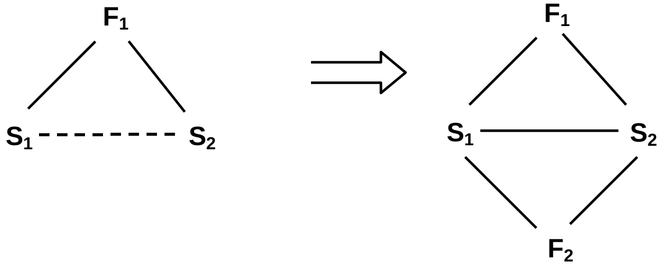
Examples:

The tractor that works on steep hill slopes has a shifting center of gravity (Soviet Patent no. 508 427).

The Russian rolling Van'ka-vstan'ka toy has an inside column with freely moving weight, which increases the playing options of the toy (Soviet Patent no. 645 661).

The hollow hammer that contains mercury rolling freely inside effectively resolves the following contradiction: *heavy hammer provides a good stroke, but a light hammer saves the worker's effort*. When the worker raises the hammer, mercury flows into the handle, and during the stroke mercury is in the hammer set.

STANDARD 2-1-2. If it is necessary to improve the efficiency of SFM, and replacement of SFM elements is not allowed, the problem can be solved by the synthesis of a dual SFM through introducing a second SFM which is easy to control.



Examples:

Soiled ampoules are filled with liquid and shaken (F_1). Rarefaction (F_2) is created around the ampoule that causes the washing liquid to boil (Soviet Patent no. 295 299).

Engagement between the car tire and the road surface is created not only due to the weight of the car (F_1) but also due to a special tread design. Air is pushed out of the recesses in the tire, the resultant vacuum (F_2) causes the tire to stick to the road.

Problem 22 is solved by building a chain SFM based on the fact that moisture causes wood to swell. The plugs are prepared beforehand; cone-shaped timber blanks are pressed to give them cylindrical shape and are dried afterwards. Each plug is then inserted into the sleeper hole, the former cone-base down. The water poured on the plug causes timber to swell and get jammed in the sleeper with a force amounting to several tons (Soviet Patent no. 765 529).

Give the S-Field formula of this solution.

AN ORDER FROM AGRICULTURAL DEPARTMENT

'We've got an urgent order from Agricultural Department,' said the lab chief to a group of trainees. 'When aerial spraying of plants is done, the wind blows chemicals to a wrong place, where they are not wanted and even harmful. And with all these environmental regulations, fines, you know... So, guys, you are to go into this problem, our top specialists are now busy completing this machine that makes plastic balls.' He gently touched a pile of balls that looked like soap bubbles. 'Any ideas?'

'Why can't they wait for windless weather to set in?' asked one of the trainees.

'They cannot wait. Look, you are given three days for spraying. Thousands of acres in just three days. The planes fly over fields in daylight,' the chief rubbed his forehead. 'Besides, waiting is not our method. In a month we have to catch on to this. We need a new idea.'

'Okay, let's charge drops with electricity and give the earth a charge of an opposite sign,' the youngest trainee in the group gave a free rein to his imagination. 'Or, put a powerful ventilator on the plane which blows the drops down to earth like a helicopter rotor.'

'No, no. This won't do,' the chief frowned. 'Obviously, the drops should be large and heavy not to be blown away by wind. But when they reach the earth they should get small for better spraying. Can we do that?'

'Let us use S-Field analysis,' said a girl. 'Freeze them and that's it! They will melt on their way to earth.'

'No dice. They will not let us turn a plane into a fridge. They are going to laugh at us. You see, your analysis does not help.'

'No, that was just hit-or-miss...' And she drew something on a sheet of paper. 'Well, here is S_1, large drops. S_2 is the air, and F is heat that comes from rubbing of drops against the air. Do we have any limitations on introducing substances? Okay, then we take....'

Okay, can you "catch on to it"?

3.5. A FIELD OF BATTLE: USING MAGNETIC FIELD

Depending on the field, SFMs are differentiated into T-S-Field (*thermal field*), F-S-Field (*ferromagnetic substance and magnetic field*), E-S-Field (*electric field*). These three classes of SFMs are now widely applied in present day technology and will retain their leading position over a long time, because thermal processes are the most common both in natural life and technology, magnetic field works at a distance and can easily control magnetic materials, while electric field is a universal kind of energy that is more controllable than others. There is no special term for S-Fields that use mechanical field, although S-Fields of this variety are no less frequently found than all of those mentioned above. The lack of a special term is not due to the occurrence of mechanical field but because of poor chances of this SFM in inventive problem solving.

Mechanical systems are now becoming history, mechanical actions being replaced by physical actions: technical systems become more light, user-friendly and effective. *It is physical, chemical and, later on, biological 'machines' that will dominate our life in future. In this respect, technology is reproducing, though at a faster pace, the natural evolution of matter.* This means the evolutional appearance of new forms of materials in the nature, from the origin of the universe to today on our Earth, including various elements, innorganic and organic compounds, and biological materials, even the life itself.

Let us consider F-S-Fields. Everyone knows about magnetic fields, and that is why problem solving processes that use it are easily understood. But one should always remember one simple but helpful rule: *if a conflicting part of technical system contains a substance with magnetic properties, the latter should be always put to use.*

And remember the next step: *if such substances are absent, but nothing precludes us from introducing them, we should do just this.* In other words, the battle with an inventive problem should be fought on a familiar territory, for example in the F-S-Field domain. Your martial art in such duels should comply with the main provisions of S-Field analysis described above (for F-S-Field is a particular case of S-Field). Yet, there are a few individual rules too.

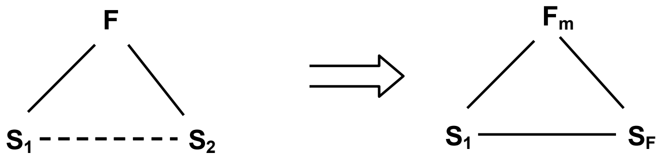
> **Problem 23.** An experiment was conducted at a hothouse farm. Air was blown over carnations through air nozzles. The air was fed from different directions at varying speed and impulse frequency. Carnations grew faster and gave large and beautiful blossoms. Isn't this a curious method of 'training' flowers? Question: are there any drawbacks in this system that can be improved?

If you offer this problem to your colleagues who are not familiar with TRIZ theory, they are likely to say: "You cannot put question this way. You did not specify what is wrong and what needs improvement."

But to a TRIZ expert, the problem is on the surface: the system is bulky (air-compressor, pipes, nozzles, etc.) and lacks easily controllable elements. Therefore, one is to introduce controllable elements and simplify the system. The same effect can be achieved the other way round: instead of pumping air to make flowers swing, it is advisable to make them swing in still air under the influence of a magnetic field. Attach small pieces of adhesive tape containing ferromagnetic powder to flowers' stalks and regulate magnetic field, making it permanent, then variable, then pulsating, rotating and etc.

Let us review the main S-Field analysis rules for F-S-Fields:

STANDARD 2-4-1. Efficiency of a S-Field can be enhanced by a transition to Ferromagnetic S-Field by using a ferromagnetic substance and a magnetic field:

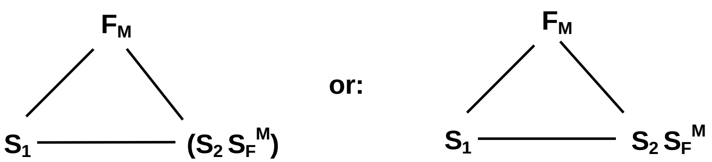


S_F - ferromagnetic substance, F_M - magnetic field.

Surprisingly, the first person to use this solution was, guess who? Tsin Shi-Guandi, Chinese Emperor, who thrived twenty-two centuries ago. After one assassination attempt, he ordered to erect a gate of solid magnetite at the entrance to his palace. When an assassin went through the gate hiding a dagger, the dagger would hop out all by itself. The royal guard knew the system very well, and was around in no time... Remember about Tsin Shi-Guandi when you go through a metal detector gate at the airport.

Many inventions have been made using this rule. Below are some of them: a trap for iron used in recycling food wastes into animal feed (Soviet Patent no. 682 217); method of soil-ripping that does not damage youth growth and does the same work that earthworms do. Ripping is performed when pieces of steel wire buried in the soil are pulled out by a magnet (Soviet Patent 986 309). Another example is a method of stuffing cracks in concrete. Magnetic mortar does not flow out of the crack due to metal pins installed into concrete and connected with an electromagnet (Soviet Patent no, 1 074 079).

STANDARD 2-4-2. Efficiency of S-Field can be improved by replacing one of the substances with ferromagnetic particles (or adding ferromagnetic fluid) and using a magnetic or electromagnetic field.



S_F^M is a finely fragmented ferromagnetic. Controllability of F-S-Field is proportional to reduction ratio of ferroparticles (i.e. their mobility). As to reduction ratio, ferromagnetic can be placed at a scale: *granules – fine grains – powder – liquid.* Magnetic liquid is a suspension of magnetic micro-particles in kerosene, silicone or water.

Examples:

When seeds are separated from weeds, the corn is mixed with ferromagnetic powder and passed through an electromagnetic drum. Fragments of iron entrapped by fleeces of weeds withdraw the weeds into a magnetic trap (Soviet Patent no. 831 185).

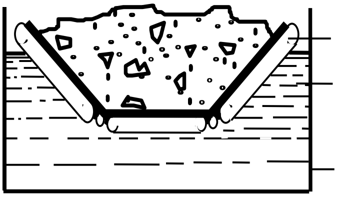
The pile of the roller used for painting spherical or waved steel surfaces is made of polymeric material containing barium ferrite (Soviet Patent no. 766 905).

In order to prevent blood losses when surgery is performed on major blood veins, magnetic liquid is introduced into the blood canal so as to stop blood where necessary with the help of a magnet. The same idea is implemented in the method of temporary blocking of pipelines (Soviet Patent no. 708 108).

When viscous liquids are pumped through pipelines (e.g. feeding viscous fuel oil into a tanker), the inner surface of pipes is covered with a layer of magnetic liquid that remains pressed to the walls by external magnets, which allows to double the pipe capacity (Soviet Patent no. 1 124 152).

Using elastic shroud filled with magnetic liquid and inside conductors it is possible to make formworks for concrete of any shape (Soviet Patent no. 883 524) and dams of variable geometry (Soviet Patent no. 1 068 574).

Problem 24. Conveyers that are used for fast transportation of loose materials are sometimes conveyers several kilometers long. To make the conveyer lightweight, it was suggested to reject the traditional conveyer design that consists of a massive steel frame with guides and a load-carrying belt. Instead, a new construction was invented where the belt is equipped with floats and placed into a water-filled chute. But water



will only be there if the chute is in strictly horizontal position. Improve the system.

STANDARD 2-4-6. If it is required to raise the efficiency of system control while replacement of substances with ferromagnetic particles is not allowed, the ferromagnetic particles should be introduced in the external environment and, using the magnetic field, the environment parameters should be changed and the system therefore can be controlled.

For example, in order to stop a vibrating non-magnetic element, it is necessary to place the element in a magnetic liquid and control its apparent specific gravity[7] using magnetic field (Soviet Patent no. 469 059).

[7]As the magnetic field strength changes, liquid gets harder or softer, but its actual density does not change.

By changing apparent specific gravity of liquid it is possible to accurately separate objects by density and regulate their buoyancy over a wide range (e.g. the light object floats up and the heavy object sinks).

Standard 1-2-5:

Destruction of F-S-Field: it is necessary to use physical effects that switch off either the magnetic properties of substance (demagnetization under impact, heating over Curie point) or the magnetic field itself (screening, shorting of magnetic lines by a shunt, a dam between the poles).

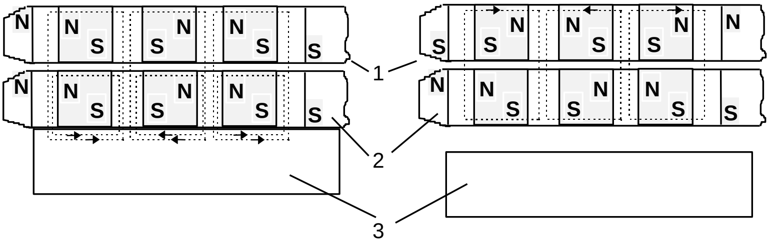
How can one scrape bright the inside surface of a 50 m long steel tube that is 100 mm in diameter?

If it were any material other than steel, it would be sufficient to get rotating magnetic field push some abrasive ferro-powder through the tube. But a steel tube is a ferromagnetic itself and therefore screens the field action on the powder, creating a harmful interaction in F-S-Field.

To destroy the harmful interaction, a circular coil is put before the electromagnet. It heats the tube to a temperature above the Curie point for steel, but below the Curie point for the powder (Soviet Patents no. 312 746, 955 911).

Permanent magnets can be used for lifting big weights (for the attracting force of present-day magnets exceeds their weight by 1000 times). Unlike electromagnets, permanent magnets do not require electricity. But how can the weight be detached from the magnet afterwards?

Soviet Patent no. 304 811 suggests an innovative design: a multi-segment magnet is divided into two parts along the height, the upper part being able to move relative to the lower part. When the two magnets are aligned their common magnetic field closes up on the weight and holds it, but if the upper part is moved aside, the magnetic field will close up within the magnets thus releasing the weight.



Functioning of load handling device: 1 – shifting magnetic component; 2 - stationary magnetic component; 3 - weight.

And now problem that you are now able to solve in one step with mathematical accuracy.

Problem 25. In Soviet Patent no. 305 445 it was suggested to film unrealistic scenes of fantastic films in a saucer containing a mixture of various liquids (glycerin, inks, iodine, alcohol, glue, etc.). Later the most successful footage can be selected. What would you suggest to do next?

UNSOLVABLE PROBLEM?

'Look, this is a cutting machine,' said the engineer to a group of visitors. 'The manipulator places a pile of plastic leaves onto the table. When the whole pile is pushed as far as it goes, the limit switch goes off, and the sharp knife cuts it off. No sawdust, chips, no wastes...'

'And what are these planks for? Do you also cut them with this thing?' asked a visitor pointing at an accurate pile of planks lying next to the manipulator. 'And look, there are some chips here too...'

'Oh, it's not the plastic. This is a big problem for us. A year has passed ever since the machine was installed and we still cannot solve it. The Chief engineer himself was supposed to help us, but it didn't work. You see, the table is made of steel. And if the knife hits against the table, it will turn or break. That is why there is a groove where the knife enters after cutting through the pile. Its blade goes 1-2 mm deeper than the pile. But the wooden planks underneath won't last long. We tried every possible variety of wood, it is best to use beech and oak. But it is expensive too, for each plank does not last longer than one shift.'

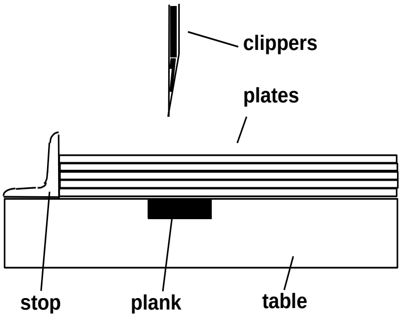
'What about using rubber, or plastic?' another visitor inquired.

'No, we tried so many things, rubber and plastic simply won't do. If you use solid material, you break the blades, and soft materials bend under impact which makes cutting inaccurate and causes cracks. It's a vicious cycle, you know. So, there is no point in...'

'No, no cycle here,' said another visitor. 'Here you have a contradiction. There should be something stiff under the pile, but when the blade touches it, it should soften in no time.'

'Well, let's move on. Soft, or solid, it makes no difference, it's impossible anyway.'

Was the engineer right in saying it is impossible? How would you solve the problem?



3.6. MASTER YOUR SKILLS

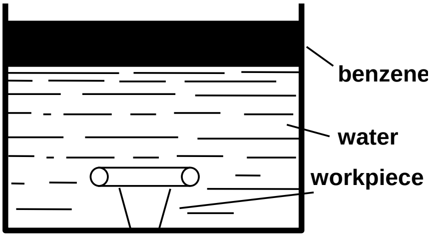
These problems are for you to exercise. They make available all data necessary to come up with a solution. You do not need any special knowledge or reference, though, frankly speaking, each task may be expanded into a research topic and supplied with a heap of extra materials. And since all this is just for drilling, you are only to give the basic solution idea.

Some of the problems were solved once. However, inventive problems, unlike mathematical problems, may have a number of solutions. Using all your strengths you may come to some fresh ideas.

Additionally, the idea is not to make a good guess (as the notorious trial and error method dictates). This way you will be wasting time, that's it. Even if you succeed in conjecturing a solution, your creative skills will not improve. Instead, you are to use the theoretical basics that you were made familiar with in this section. This is important in drilling your inventive skills.

Naturally, it is very hard to reject the habit that whispers: “What if I do this and that?”. This habit is so comfortable that you instantly get an overpowering desire to try a number of ‘evident’ ways. But these doors have been open to so many; you can rest assured that they have been knocked at. This is mainly the reason why the problem became an *inventive* problem: ‘evident’ solutions simply won’t do.

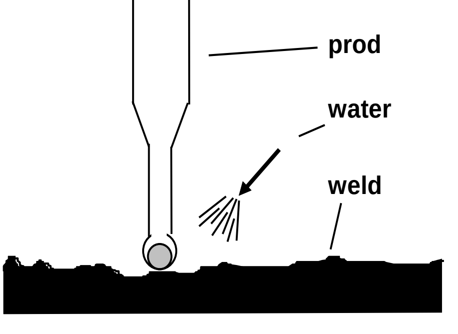
The problems have varying degree of complexity. Do not worry if you fail to solve some. The main idea of drilling is: ***the more work load, the stronger you get.***



Problem 26. After heat-painting, a metal workpiece is blown all over with cold air and sent to the assembly line. From time to time a workpiece is chosen to be tested for rust-resistance. The chosen workpiece is dipped into water (because if painted badly, the workpiece will develop surface spots of rust). The workpiece is given a coat of benzene-thinned paint and should be fully submerged into water without either damaging the coat of paint or bringing any extra substances into benzene and water. How can this be done?

Problem 27. Preserving ocean fish in good quality during its long transportation to the shore presents a big problem. Freezing leads to irreversible biological changes of fish and requires a lot of power for continuous refrigeration. If fish is transported alive, its quality will also deteriorate because on its way to the shore the fish does not move in the basins. The second method is more economical, but how can you prevent from ‘falling asleep’? Various ways were tried to keep fish active: mixing the water, pumping, blowing, vibration, electric impulses and other physical actions. All methods turned out useless: the fish would not move about. A novel idea is needed. The solution should be very simple; with hardly any elements introduced into the system. The fish should be kept active. So, what do you suggest?

Problem 28. When oil and gas pipe-lines are constructed, it is essential to determine the number of welds in the pipes as quickly as possible. Using the old (radiographic) method the builder can examine 36 m of pipe in 24 hours. But miles of pipe can be constructed in 24 hours! New highly-efficient portable ultrasonic machine is very handy: one only needs to trace the weld with the ball of its test prod as if one were writing with a ball-point pen. But accurate results can only be obtained if the ball remains in contact with the weld surface all the time, i.e. there is not air clearance between the surface and the ball. The weld surface is uneven.



In some foreign systems water is poured on the weld. It takes a few liters to examine each weld. But this will not work here: the machine will be too bulky to carry and water will freeze in winter. So, there should be liquid, to secure continuous contact and it should not be there so that the system is not over-complicated. What could be done?

Problem 29. A funny thing happened to a writer. After the war he journeyed around Germany and brought home a curious souvenir: hand-cuffs for prisoners made in the 13th century by a famous artisan. Demonstrating the handcuffs to his friends he put them on his hands and suddenly, click! – the handcuffs locked. The lock had a keyhole, but where was the key to be found? After numerous attempts to saw the hard steel they found a craftsman who managed to unlock the cuffs using self-made latchkeys.

Extraordinary situation, no doubt. But even in the case of less extraordinary locks, keys are often missing. We live in the world of locks: safes, apartments, various depositories... Think of a master key that will open all locks when necessary.

Problem 30. Painstaking attempts to mechanize a primitive manual operation – peeling pepper pods – brought no results. Traditionally, hundreds of women sit along a slowly moving conveyer peeling the pods. Even so, they do not have time enough to peel all the peppers that come in from the farms. The operation is simple: the worker cuts around the bottom where the pod is most fragile and then clears the insides out. A highly productive automated method is wanted. For example, pushing a button would cause the insides of thousands pods in a basket to tumble out.

Problem 31. The director of the company sent a request to the company's research-and-development division: "Our company produces quilts. Clearing wadding off the quilt is performed manually. We tried to mechanize this process, but in vain. We know that other companies do it manually too. Please help us to perform this process mechanically."

Think of what can be suggested. Imagine a quilt and a fluff of wadding on it. How can one make it fly away from the quilt?

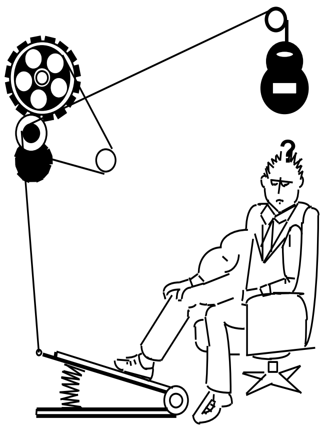
Problem 32. Quite often, exploration of virgin lands starts with underwater detonations. They are necessary for constructing underwater oil-pipelines, dams, seismic prospecting. Detonations damage the underwater world considerably creating a 'dead zone' that extends miles and miles around the point of detonation. Attempts were made to scare off fish with impulses of light, chemical substances, but the fish simply went down to the bottom and lies there paralyzed and dangerously close to the point of detonation.

What measures can be taken to protect the fish from the blast wave? It is hardly practical and much too expensive to pump the water out of the zone or cover it with heavy diving bell. And yet the National Game and Fishery Committee does not allow construction in such places without proper security measures. What is to be done?

Problem 33. A human psychic is full of mystery. We can adapt to anything... even if it is to our own detriment!

This is a summary of the continuous struggle of engineers for railway safety. Present day comfortable locomotives are equipped with automatic pilot systems. That is why engine drivers tend to fall asleep while going through long and desolate legs of the route. Engineers then installed alarm-buzzers. When the engine drivers feels drowsy, they simply turn the buzzer on. And so they did. But, while already half-asleep, the drivers would turn the buzzer off without thinking. Later came automatic buzzers that were programmed according to the train schedule. However, very soon engine drivers got used to sleeping to buzz. On the other hand, those who stayed awake were annoyed and fatigued by the buzz. Then it was suggested to shorten the legs of routes making intermediate stops for stopping the train required additional manipulations from the driver. Sleep was no longer a potential hazard to drivers but the general speed of travel decreased.

Different solutions were tried in other countries. Thus, in Poland, the engine-driver was to drive sucking a caffeine-containing lozenge with vitamins that brought down the harm effect of caffeine. In Germany, the driver was to keep a special pedal pressed. If the pedal went up or down, the emergency stop system was switched on. As it turned out, however, the drivers might as well perform all these things automatically in sleep.



Evidently, a technical system should wake up the driver or stop the train. The technical system should be activated only if the driver is definitely asleep. A problem arises: which signs of sleep should be used? Monitoring blood pressure did not help because it was inaccurate and inconvenient, for the driver had to wear a handcuff or a bracelet attached to a pressure meter. Doctors say, “a manifest symptom of sleep is the absence of swallowing reflex”. With this in mind, engineers developed a device granted Soviet Patent no. 196 238: an elastic pipe containing carbon powder (ohmic resistance transducer) is fastened on the larynx. If no swallowing is detected for a long time, the person is sleeping.

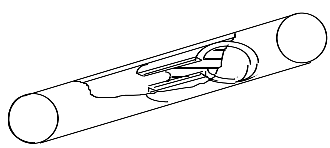
But imagine driving a locomotive with your head ‘in a noose’! Also inconvenient are German ‘safety glasses’. This electronic device monitors the blinking frequency of the eyes. It consists of wires and an electronic analyzer. A recently developed device monitors skin electric resistance to determine if the person is asleep (Soviet Patent no. 757 367). But this also means using wires, handcuffs, sensors, etc. A similar solution was patented in UK: a ring on a finger that stings the driver with its thorn if skin resistance changes to ‘sleep’ regime.

So, what is next? Is it possible to invent a more simple, safe and effective device?

Problem 34. Mechanical cotton-picking is performed with a spindle – a rotating long metal column that has teeth on it. The spindle touches upon the open cotton box of the plant and reels up the white fluffy cotton fiber. Then the spindle begins to rotate back reeling the fiber out so that it travels into a pipe and from there in into the storage tank. Because the spindle gets clogged with dust, juice, leaves, etc. quite often, it is necessary to stop the machine and clean the spindle, which takes half of the working time. This cotton picking method is so bad that there is hardly any point in improving it.

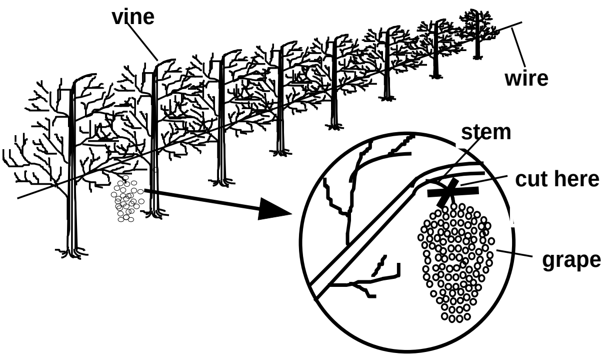
A novel idea is needed. Therefore, the initial model should better be an incomplete S-Field: there are cotton clots, they detach from the box and fly away. Where can they be directed and how?

Problem 35. A pipe contains a porous ceramic filter that clings to the walls of the pipe. Normal



filters (those that block the entire cross-section of the pipe) are washed by pumping water back through the pipe clearing the pores. But what can be done here?

Problem 36. Numerous methods have been devised by engineers to harvest grapes: mechanical blades, vacuum pumps, jets of compressed air, vibration. But these methods were applied at vineyards with similarly poor results: the machines worked blindly, i.e. cut and crushed ripe berries, leaves and branches. These machines are only good for harvesting non-edible varieties of grapes. But edible grapes should have high vendibility, i.e. be ripe and intact. Manual harvesting is good here, but it lasts for 30-40



days, and the perishable harvest cannot wait. An idea of new harvesting method is needed. Imagine a vehicle moving along a row of grapes and the grapes fall down on the conveyer and then go to the tank or into the boxes.

Think of a vineyard and the long rows of grapes, fastened to a wire (vineyards in Europe have rows of small grape plants just as shown in the figure, in contrast to ordinary Japanese vineyards where larger grape plants form a large area of roof from which grapes are hanging down). Some of these heavy ripe grapes are covered with foliage. The vehicle moves along in the inter-row spacing arbitrarily touching all the grapes (sometimes reaching out to a grape through foliage). The grapes break off from the vine and tumble down an inclined chute. How can one make the stem tear apart (or explode, or simply vanish) in a miraculous way without damaging the rest of the vine?

Problem 37. Many accidents occur during repairing power lines and machines that use very high voltage (up to thousands of volts). These accidents have serious consequences. For example, a maintenance worker, having fixed a fault, forgets to put rubber gloves on and turns on the current or worker turns on current not seeing that another worker is doing repairs nearby. It is necessary to work out an effective security method to prevent electric shocks, so that the worker cannot touch a charged wire even deliberately.

There is a science-fiction story by Stanislav Lem in which the main character gets on a planet where murder is totally impossible. The atmosphere is filled with molecule-sized computers that penetrate into your body, your skin, etc. The main program of these computers is “Do not kill”, so that when a person raises his/her hand intending to hit another person, the computers in his muscles paralyze the hand.

A similar principle is needed, which, of course, should not involve computers. If there is no current, the serviceman is working, but once the current is switched on, there will be a force that will throw human hands off the wire.

Please note, that the majority of high-voltage devices and power lines are AC-based, that is, the conductor with alternating current creates an alternating electromagnetic field.

Problem 38. According to one hypothesis, planets Uranus and Neptune are covered with diamond snow. A day will come when astronauts land on these planets. How can their cross-country vehicle be protected? Diamond is the most solid material and it will wear out any wheels. What do you suggest?

Problem 39. After years of research into industrial injuries, specialists came to the conclusion that the most dangerous working tool is ... the hammer. Apparently, this oldest tool needs some improvement too! The demand for safety has grown and brought about an inventive problem. The thimble was invented for safe work with a needle, but metal gloves cannot be used for the hammer. Some are trying to solve this problem teaching people to acquire the skills of safe work with hammer. For example, Soviet Patent no. 1 267 464 describes a complex electronic-mechanical training machine, but this training will hardly rule out any possibility of injury. What is to be done?

Problem 40. In winter, long-distance swimmer have many difficulties drilling in small swimming pools. Swimming a certain distance involves turning back each time you reach the wall of the pool. This requires concentration and takes time. How is it possible to provide uninterrupted race in a short pool? The pool should be long (for the swimmer) but you cannot stretch it! Sharp contradiction, isn’t it?

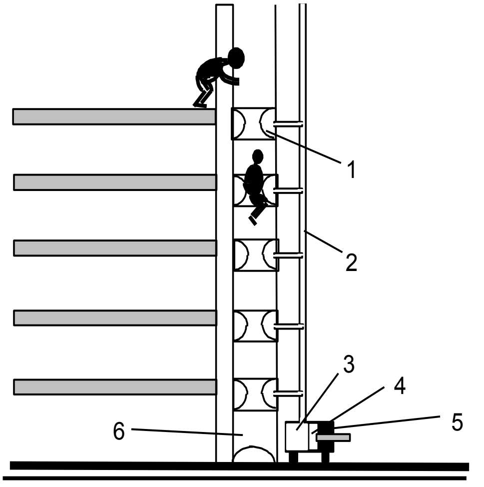
Problem 41. Tubes are made of round billets (cylinder-shaped steel pigs, each 1 meter long). A hole is made in the billet on a piercing rolling mill. The pierced billet is reeled on a hot mill, cut into parts and sent to cold mill where the billet is turned into a very long tube. Then the tube is again cut into parts of standard length. Thus many metal discards are formed that are re-melted later. This happens because the length of the tube (for instance, 37,5m) before cutting is not always divisible by the standard length of the tube (for instance, 8m). But the length of the tube depends on the length of the hot-rolled billet. The size of the billet differs from the standard size by many percent. Nothing can be done about it, for such is the technology of hot rolling.

This problem could be solved if somebody found a method of cutting hot-rolled billets into parts that, instead of equal size, have equal weight. This would allow to work without discards. But how can this be done? Even if we know the weight of the billet and the weight of each part, how are we to cut it? The walls of the billet have varying thickness, and the cross section also varies from round to oval in different places.

Engineers racked their brains over this problem for a long time. They tried using photoelectric cells, variable-induction pickups, machines with gamma- and X-rays aiming to find a method of quickly measuring several cross-sections of the billet and calculating the length to cut of each part on a computer. These methods have low accuracy, to say nothing of the unreasonable complexity, low reliability and expensiveness of such equipment.

It is necessary to develop a method to mark out the billets by parts of equal weight. What do you suggest?

Problem 42. Mooring lines are used to keep the ship moored to the wharf or to another ship. These are cords made of vegetable or synthesized fiber. One end of the line is thrown onto the wharf and then fixed around a iron or steel bollard. This seemingly simple operation that dates back to the times of sailing ships is a source of most accidents. Strained cords press the hands of negligent sailors, slip away or tear apart, hitting people on the wharf, etc. It is necessary to develop a new mooring technology that requires minimal participation of man.



Gravitational elevator, invented by G. Vilchinsky.
When a person gets on, elastic chambers (1) shrink, driving excessive pressure
through the pipeline (2) into the reservoir (3). The piston (4) moves, compressing the spring (5). When a person exits the receiving chamber (6), the spring brings the piston to its initial position, air enters the crushed chambers (1) expanding them.

Problem 43. New buildings are getting taller, 20-, 30-, 50-, 100-storied buildings appear. But survival craft remains practically with with practical no changes. The longest telescopic ladder available today only reaches the 12th floor. At the same time one can only rescue people through windows, because staircases and elevators turn into gigantic chimneys. Fire can spread very quickly turning a sky-scraper into a burning candle. You should not count on the rescue service with their ropes, ladders, automatic elevators and even the hi-tech ‘flying saucers’, or mini-helicopters manufactured now in Japan. There should be one simple and reliable method of urgent evacuation from a building on fire.

A ‘rescue hose’ was invented. It was made of elastic cloth and armored with glass fiber. When the hose is not used, its diameter is a bit smaller than the average thickness of man. One can regulate fall speed by expanding one’s elbows and moving one’s knees together. Unfortunately, not everyone can use this bright idea. The system cannot be recommended to elderly people and children even after long training. The system was improved by G. Vilchinsky (Soviet Patent no. 1 024 098).

We suggest that you improve it further: the process of technical system development is endless. What is bad about the system? Try to make it more effective, decrease it in size and mass, add new functions to it, for the fire may not happen at all the system will be out of use.

4. A STEP OVER THE BARRIER

4.1 BREAKING THE COMPROMISE: FROM TECHNICAL CONTRADICTION TO PHYSICAL CONTRADICTION

Dealing with problems and examples of S-Field analysis we often overlooked technical contradictions. Why? The reason is that the S-field formulas that we have been considering are ready-made solution models – they are part of a large class of standard solutions to inventive problems. They are standard because they are typical of common inventive problems.

These thousands of inventive problems were analyzed on the basis of technology evolution principles, and the essences of their solutions were presented as combinations of technical contradiction solving tools and physical effects, and formed a series of standard solution models (or Inventive Standards, we have so far analyzed only some of them). These "recipes" are formed in such a way that technical contradictions are automatically eliminated.

Of course, such ready-made solution models are very convenient. They allow us to solve inventive problems without pausing to formulate a technical contradiction. But it is impossible to give a definite solution to a bit more complicated problem if we don't understand how S-field formulas "work". What happens to a problem when we apply Inventive Standards?

Let us start by specifying the concept of contradiction. *Actions with contradictions (their identification, processing and solving) are underlying TRIZ*, so we shall gradually broaden this notion.

More precise definition of technical contradiction: if one part (or one parameter) of a technical system is improved by any known method, some other part (or some other parameter) will be inadmissibly impaired.

Let us illustrate this with the examples which are used above in the explanation of S-field analysis:

- if a tool depreciation is measured by common methods (such as using a gauge, callipers, etc.), which means frequent interruption of treatment, the productivity will decrease (see part 3, complex S-field Model);
- if an ultrasonic emitter is fixed to ice with common holders (a bracket with bolts, for example), their screwing and unscrewing would become time-consuming (SFM using external environment);
- if accumulated frictional electricity is discharged by common method (grounding), repeated interrupting of shaker work would be required so that the charge could leak not only from the surface but also from the core of polymeric powder lumps (SFM using external environment enriched with additives);
- if a hollow carcase of a high rise building is protected by common methods (heat insulation with ceramic or materials based on

mineral wadding), the weight and dimensions of the sections will greatly increase, which means that there is no weight benefit from using hollow elements but their assembly becomes more complex (SFM providing minimal action);

- if the elements of a detail, which can inflame from an open blowpipe, are heated with a separate covered heating element, the installation will become more complicated, more expensive and unsafe in exploitation (SFM providing selective-maximum action).

So you could formulate technical contradictions for all examples, if you knew not only the final solutions but also the initial details. In contrast to examples, problem conditions state technical contradictions more or less clearly (by the way, it could be helpful to you to exercise in formulating technical contradictions, no matter whether you know the solution to the problem or not.)

But what does it mean if formulation of technical contradiction doesn't prompt the solution? To find such prompts to solution, let us go on to analyse the mechanism of standard SFM transformations.

As mentioned above, a solution will be inventive *provided that the technical contradiction is eliminated without sacrificing the system's efficiency (benefit without loss)*. Thus the solution should always be as follows: with the improvement of one part (or parameter) of the system, any other part (or parameter) is not impaired. Let us formulate this for the same examples:

- tool depreciation is measured frequently (constantly), but the treatment is not interrupted;
- the emitter is firmly fixed but without any special holder;
- frictional electricity is continuously discharged but the work of the shaker is not interrupted;
- the hollow carcass is well protected from overheat but without heat-insulation;
- the component is heated with an open blow pipe but the flammable elements do not inflame.

Therefore, S-field "formulas" prompt us how to transform S-field system in order to eliminate technical contradiction: some internal additive could be introduced into the substance if possible. If not, then an external additive or the environment could be used. In such cases the solution is often based on some physical effect.

Naturally, to succeed in solving many technical problems it is necessary either to know a number of physical effects or to have a good reference book of physical effects at hand. In order to choose the right effect to solve the given problem, technical contradiction should undergo further transformation – it is deepened to the extreme, to the physical essence of the contradiction. Such contradiction is referred to as ***physical contradiction.*** A physical contradiction is found in the following way: an area in a technical system is selected which should satisfy the requirements of an eliminated technical contradiction, but it doesn't because it doesn't possess the necessary properties. *The properties should be physically antipodal: the area should be hot - cold, moving –fixed, short – long,* etc.

> **Formulation of <u>physical contradiction</u>: to be able to perform a specific function, given area should posses A property (e.g. electroconductivity). At the same time, to comply with problem requirements, it should posses non-A property (here, lack of conductivity).**

Let us take the problem about cutting machine (page 60) as an example.

Technical contradiction: if nothing is laid under the material where the guillotine blade hits the table, the blade gets damaged;

or: if some planks of hard wood are placed under the material where the blade hits it, the wooden planks get damaged, and their replacement makes the production process more complicated and more expensive;

or: if some soft material is used, the product (plastic sheets) gets damaged.

Eliminated technical contradiction: Cutting through a plastic pile, the blade hits against hard surface, but remains intact.

Physical Contradiction: The area of the table where the blade hits should be hard enough to ensure accurate cutting, but soft enough to keep the blade intact.

We have got an exceedingly keen contradiction: soft – hard area of the table. Thus, at the first glance, physical contradictions may seem absurd and their resolution doomed to failure. Is it possible to make a part of the table soft and hard at the same time? This brings the contradiction to the extreme where its "prompting" power manifests itself.

As one and the same segment of substance can't exist in two states at the same time, the only way out is to separate conflicting properties with **physical transformations** such as:

<u>to separate conflicting properties in space</u>
(to make an object of two parts with different properties);
<u>to separate conflicting properties in time</u>
(the object possesses alternate properties);
<u>to uses transitional states of substance</u>, something like co-existence of contradictory properties appears for some time, etc. TRIZ offers eleven typical physical transformations for solving physical contradictions – we will present them later.

And now let us solve a physical contradiction in the given problem: here the way we formulated physical contradiction prompts us that we should use separation of contradictory properties in time. What can be hard and momentarily become soft (liquid, viscous)? You are already aware of this physical effect – it is ferromagnetic fluid.

To formulate physical contradiction is to seize the very essence, the core of a problem, something that makes it a problem. Thus physical contradiction, impossible as it may seem, always prompts the best solution – the one which eliminates the contradiction completely ("without remainder").

The most common mistake of novice inventors is that in seeking the solution they satisfy only one requirement of the physical contradiction, overlooking the other one.

Teaching practice has revealed another common mistake: having formulated a physical contradiction one thinks it is impossible to solve it and gives up. Daring thinking is evolved gradually, by solving dozens (or even hundreds) of problems. At first one has to keep in mind a taboo on compromise solutions. It is possible to find the right solution only by breaking compromise and excluding every slightest possibility of reconciling contradictory properties.

There is a simple rule: the more acute the contradiction, the quicker it is solved and the more effective and ingenious the inventive solution is.

Thus, in S-field formulas technical (and often physical) contradictions are solved in implicit form, and the transformed technical system contains no contradictions. But in case of a snag one has to thoroughly analyze the technical contradiction, find the physical contradiction and apply the appropriate physical effect.

HOW ARE YOU GETTING ALONG in finding solutions to the training problems? You must confess that you failed to solve most of them. We have to confess too: you were not supposed to manage. If you solved easy problems (easy, now that you know the S-field analysis rules), such as 26 (using well-known transformation of water) or 28 (using the liquid that is familiar to you, a drop of which will "glue" to the feeler and won't freeze) etc., and if you took the challenge of solving more complicated problems and perhaps have coped with some of them – you are doing fine! Soon you will be able to solve all the problems that you have failed to solve up to now. They will require some more sophisticated analysis.

It is both easy and difficult to use S-field analysis. It is easy when a problem is solved "straight" according to the rule and you know an analogous problem or physical effect. But it is difficult when you have to use some distant analogue (you don't know how to do that yet) and you are not aware of physical "tricks" that can help eliminate the contradiction. You must admit that playing a musical instrument "with one finger" (listening to the prompter: press this key, then that key…) differs greatly from virtuoso playing…To imagine an inventive virtuoso's playing we shall have to study a lot of things.

'SMART' PEGS REQUIRED

When metal sheets are cut with a torch, a sheet is placed on an assembly table, but in this case the torch cuts the table. It was suggested that some pegs should be welded on the table and the sheets be laid on the pegs. But there should be a lot of pegs so that the sheet would not sag, but on the other hand there should be few pegs so that the torch wouldn't spoil them. What could be done? Formulate a physical contradiction (area where the contradiction is resolved – a peg)

4.2. FIVE LEVELS OF CREATIVITY

To make an invention it is essential to eliminate a contradiction. But among recognized inventions we come across a lot of simple, even trivial design solutions.

For example, the holder of Soviet Patent no. 355 668 suggested to produce electroconductive glue of epoxy and soot. To increase the conductivity of the glue the amount of soot should be maximized (possibly up to 100%), but to improve its adhesive properties the amount of soot should be minimized (possibly to zero). The contradiction is not resolved, and "acceptable" compromise solution was adopted. So, is it an invention or not? From the TRIZ viewpoint it is not, but in legal terms it is.

Solve the following problem, which is even difficult to call a problem (so we number it with a zero):

Problem 0 (problem 43, see page 66; problem 44, see page75). Imagine that you are a member of a commission tasting food products. You slowly proceed along the table with different delicious food products. In one hand you hold an evaluation form for different dishes. In the other hand… What do you hold in the other hand? True, it must be some "device for tasting". Admittedly, holding a spoon and a fork in one hand is not very convenient. So, can you think of a more handy tool?

If it crossed your mind to tie up the handles so that there is a fork at one end and a spoon at the other, congratulations... you are an inventor! This invention has already been registered (Soviet Patent no. 207470): "1. A device for tasting food products which is a rod with one end being spatula-shaped, and the other having the shape of an arrow-head for convenience in use. 2. The invention is that the device (as in 1) is made of plastic".

Convenient, isn't it? You could "pierce" a morsel "with an arrow" and spoon up some sauce. The most astounding is the concern for saving valuable materials (it's not silver or nickel silver, but cheap plastic). The taster is also taken care of, so that they don't waste effort on holding something heavier than a ball-point pen).

Such "non-inventive inventions" are numerous. Maybe, all of them date back to the1960s? No. For example, these Soviet inventions were made in the late 1980s:

- Soviet Patent no. 1 251 837 – a spoon-bait which has the only distinguishing feature: its float has uplift power of 0.1 – 0.9 of the spoon-bait weight (and can a float be heavier than a spoon-bait?);
- Soviet Patent no. 1 253 600 – a rucksack where the upper parts of the strips are cut out of one piece of material to ensure load

carrying (remember the knapsack of a wanderer – a sack with a rope tied on the neck, the ends of the rope being tied to the bottom corners of the sack);

- Soviet Patent no. 1 279 585 – pincers with two notches on one jaw and two holes on the other.

We have only mentioned the Russian inventions. Maybe foreign inventions are better? Unfortunately, not. This tendency is observed around the world. Compare mentioned inventions with a "masterpiece" of inventive art: an anti-theft device for an airliner, distinguished by the cockpit having a separate entrance from the outside, which is inaccessible from the inside. (Federal Republic of Germany, patent no. 2 210 312). Or another invention: a device for wiping babies' noses. (application of France, no. 2 562 424)

Protection of patent rights of "non-inventive inventions" has deep historical and economic roots. Patent law started by granting privilege of producing and purveying goods to an individual or a group. Others didn't have the right to produce such goods ("establishing similar factories by other people is prohibited within a specified period of time").

The first privilege in Russia (the first patent) was granted to three merchants in 1748. They were entitled to establish factories and produce paints using their own method. The secrecy policy of the privilege was specially emphasized. The first Invention Privilege Act in Russia was adopted in 1812 and was in line with corresponding acts in other countries. In a year, the first certificate was granted to Fulton "for producing and utilization of innovative vessel set in motion by steam".

Up to now economic interests are of prime importance in patent law. Thus, one of the basic requirements is keeping the idea secret until the documents are drawn up. That is why the experts of a patent office will always start their work with checking on the novelty of an invention. Sometimes quite distant analogies can be drawn to discredit novelty. For example, a German company couldn't patent the idea of lifting sunken ships with the help of plastic air-cushions, because not long before a patent expert had seen a Disney film, where the same operation was performed with the help of a table-tennis ball.

The notion of a <u>*level of creative solution*</u> is practically unheard of in patent law. "Only general recommendations can be given on determining the level of creative invention", says German patent expert G. Kerbel. "It is impossible to work out a universal rule."[8]

In legislation, there have been a lot of attempts to set a barrier on the way of recognizing poor technical solutions as inventions (using the criteria of "substantial differences" and "obscurity"). But these criteria are indiscriminate, they can be interpreted very subjectively by each expert. Consequently, failures to assess the creative aspect of this or that technical solution are quite common. Below is a typical example.

Since the Neolithic Age cattle has been driven with bullwhips. But how is it to be driven on modern farms? Three authors of a veterinary institute

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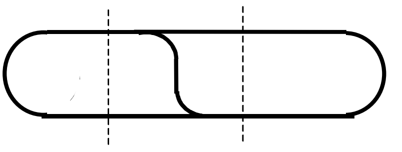
[7] Izobretatel I Ratsionalizator, No 8, 1979 - p.39

adopting the "whip principle" decided to automate this process: "Driving mechanism for farm cattle, consisting of a barrier forming a corridor and a stationary lever. One end of the lever is hinged on a base, the other end has a flexible element connected with a drive of the lever, which is an electromagnet. The invention is that the device has guides which are installed over the corridor along its axis, and the base of the lever is a trolley placed on the guides"(Soviet Patent no. 1 074 457).

In short, a bullwhip hangs down from the trolley under the ceiling, and the trolley moves over the corridor. Isn't this a brilliant example of mechanization of labour-intensive processes in farming with the help of "flexible elements"?

Sometimes absolutely improbable things happen. What would you do if you were to make a hose of polymeric band, would you join the two edges? And what if you need a hose with two passages? Then fold the edges to the centre of the band, and glue or weld them and the centre together.

But this means that the partition between the passages would be made of two sheets of the band, which is a waste of material. As many as 33 inventors, aflame with creativity to solve the problem, in their bold aspirations they gave birth to "a method of using band material for producing hoses" (Soviet Patent no. 891505), which says that only one edge of material is joined to the centre of the band, and "the other edge is joined to the outer side of the above edge of the band".



TRIZ distinguishes five levels of inventive problem solving.

All examples listed above belong to <u>the first level</u> (trial and error method would require no more than 10 attempts) – solutions of this kind occur undisguized to any specialist (and often, an outsider); they are trivial and do not contain, or require elimination of any contradictions. The problems and methods of their solution belong to one professional field (or specific branch). These are micro inventions ("<u>non-inventive inventions</u>").

<u>The second level</u> (10 – 10^2 attempts) covers <u>common inventions.</u> The problem and the methods of its solution are easily found within one area of study (e.g. an engineering problem is solved by borrowing methods known in a different section of the same engineering science). The solution is not obvious to anyone; a specialist who is not trained in inventive problems solving could give up after a dozen of fruitless attempts.

<u>Problem 44.</u> A device to check impermeability of different products (instruments, vessels, etc.) is a tank with liquid, into which a product undergoing check is dipped. If bubbles emerge, the item is leaky. But what if a whole batch of items is examined simultaneously in many tanks? Performing the check, the inspector may simply fail to notice bubbles in a tank. Were it possible to fix the bubbles in the tank, one could even measure the leakage. It was attempted to cover the surface of the liquid with glass, but since the waterline was changing it was difficult to set the glass right to the water surface. Besides, if the glass is not fixed in a strictly horizontal position, the carrying power pushes a bubble to one of the edges and it disappears… What could be done?

Before finding the target solution a person who is not aware of TRIZ usually goes over a lot of variants. First come the attempts to position the glass horizontally (even using automation), then to keep the water still, or to use floats, and so forth. Then comes the realization that the glass surface should be rough for the bubbles to stick to it (but how can you keep the glass transparent then?) etc.

The target solution is based on a simple physical phenomenon: impermeability of products is verified using a water-filled tank with a floating gauze. The size of the gauze cells is chosen so that "the surface tension force acting on the bubbles exceeds the lifting force" (Soviet Patent no.1 193 478).

Other examples of the second level problems are: 1, 2, 3, 5, 8, 11, 17, 18, 20, 22, 23, etc.

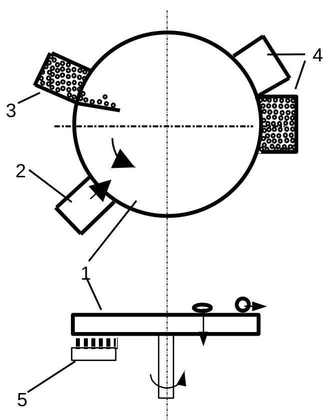
<u>The third level</u> ($10^2 – 10^3$ attempts) deals with average inventions. The problem and the methods of its solution belong to one area of study (for example, a problem in mechanics is solved using the principles of mechanics, etc.). These are solid inventions in that they totally transform an element of the system (for example change the phase state of the working element thus liquefying a solid material). Often, the solutions are attained through combination of several physical effects (which often are known only to a few), through 'tricky' methods or ingenious utilization of well-known physical phenomena.

The examples of such problems are: 14, 15, 16, 19, etc.

Below are some more examples.

In many theatres, spotlights use color filters, which are changed with loud clang during the performance. It was suggested to provide the spotlight with a single transparent glass, which is not needed to be changed. This glass consists of ten layers of electrochromic materials: each layer gets colored on receiving electric current (electrochromic materials are dusted layers of metals, organic and inorganic compounds).

<u>Problem 45.</u> When micro-balls are produced, not all of them are of



Target solution to problem 45.
1 -disc; 2 –feeder-tank; 3 –tank for the reject; 4 –tanks for balls; 5 -brush.

spherical shape. The task is to separate standard balls from non-spherical ones. The plant producing balls has an output of 10 thousand balls per hour, so the separating machine should also be highly efficient. There was an attempt to pour the balls onto an inclined plane, the spherical balls were to roll down, while the reject balls should stay where they were.

A good idea, but the production rate wasn't sufficient, because the balls are light and their rolling speed is low. Vibrating the inclined plane didn't help. Then, to increase the speed of rolling, it was suggested to pour the balls onto a revolving disc for centrifugal force to speed up the process of sorting. But there emerged a technical contradiction: at a high rotation speed the required output was achieved, but a lot of reject balls fell off the disc alongside with spherical ones. When the speed was lowered, only spherical balls rolled off at the expense of production rate. What could be done?

The target solution is found in Soviet Patent 539 517: "A mechanism for sorting spherical and non-spherical items, containing a disc revolvable around the vertical axis, a feeder and a tripper that pose items into pockets on the disc periphery, fixed over the disk. The key innovation is that the mechanism has brushes touching the lower plane of the disc, the disc and the brushes being made of dielectric materials".

An ingenious solution – the disc gets electrified, the items stick to it (some of them stay where they are, the spherical ones roll off affected by centrifugal force), and no extra source of energy is required.

<u>The fourth level</u> (mory than 10^3 – 10^4 attempts): <u>macro inventions</u>. It's a synthesis of a new technical system. As it doesn't contain any technical contradictions, one may think that their elimination didn't come into making these inventions. In fact there was a technical contradiction, but it existed in the father technical system. In the fourth level problems the contradictions are eliminated using methods belonging to another field of science (e.g., a problem in mechanics is solved using the principles of chemistry). Quite often a newly found principle helps to solve a lot of other second and third-level problems (for example, the use of magnetic fluid).

Below some examples are given.

In 1963, G.M.Grover (US nuclear energy commission) got US patent 3 229 759 for a new device possessing unique heat conduction which he called "heatpipe". It really looked like a metal tube sealed at both ends. The speed of heat transmission in this tube was tremendous (sound speed) – hundreds and thousands times higher than in a copper or silver bar of the same diameter.

Advertising his invention, Grover staged the following experiment: he inserted one end of the tube into the electric arc and the other end into the vessel of water; the water began to boil in a moment. Then the end of the tube was placed into liquid nitrogen and the water turned into ice. The heat tube was such a simple and effective system that its mass production began in 1964 and in 1967 it was adopted in spacecraft. Nowadays this system is widely used.

Hydro-extrusion treatment of metals (USSR, 1956–1958) made it possible to pass over from old technology of cutting metal which leaves much waste to a non-waste technology of plastic deformation (metal is pressed like plastic). Such machine replaced 400 press machines at one plant, and a whole workshop with 100 machine-tools at another. A hydro-extrusion plant weighing 25 tons replaces a press machine of 25,000 tons and recoups itself in… 20 minutes of operating.

A.Pilkington (UK) found a new method of producing sheet glass by casting it onto liquid base (molten tin) – a method, which is now used throughout the world. He didn't know that this method had been patented in the USA and in Britain as early as in 1902.

The fifth level (10^5 attempts): major great inventions. Inventions of this rank produce novel technical systems and design products. Methods of solving these problems lie beyond the scope of modern science (you have to make a discovery first, and then, armed with new scientific data, you can solve an inventive problem).

A new system gradually accumulates less important inventions thus forming a complex combination of systems (a supersystem). New branches of engineering, for example aviation (the airplane), radio engineering (the radio), computer engineering (the computer), quantum optics (the laser), cinematograph engineering (cinematography) originated this way.

Many of physical effects that have revolutionized modern engineering belong to lower sub-levels of level five; among them are:

- discovery of semi-conductor properties made by O. Losev in 1922,
- discovery of electrets by Japanese physicist M. Eguchi in 1924,
- discovery of shape memory effect of metals and alloys (G. Kurdyumov, L. Handrus, 1948),
- a novel method of inner-vision - tomography (V. Ivanov), the application for a patent was declined in 1960, patent was granted only in 1984 – Soviet patent 1 112 266),
- electrohydraulic effect (Soviet patent 105 011, 1950) etc.

Problem 46. You have to put forward an idea for an underground car which can move in the earth crust at 10km/h with running reserve of 500 km.

Here the peculiarities of the fifth level problems are well manifested: 1) at the moment of setting the task the methods of its solving lie beyond the scope of modern science; the physical effects, phenomena and principles that could help create such a system are unknown; and 2) the problem doesn't contain any direct indications of a contradiction, as there is no father technical system and thus there is nothing to be improved.

A contradiction emerges in the process of creating a totally novel technical system. But what are the steps to be taken first? To begin with, one has to analyze the character of other vehicles interaction with the environment: how different vehicles move in space (rockets), in rarefied air (there is still no idea for an aircraft for 30 – 100 km height), in the air (planes), in water and air (surface-crafts), in the water (submarines), in soil-watered mixes (there exist only reverse systems – for pipage of silt, ground, ooze), in surface soils (shaft sinking, pile ramming), in rock (drilling). What methods of penetration into metal exist (metalwork)? Analyzing, we do not merely borrow an idea – borrowing would lead us down a blind alley. The medium itself (the earth) restricts our search and compels to discard the idea of underground boat or underground rocket (which "floats" fusing the rock around itself). Such analysis could prompt some general idea of how an underground vehicle could interact with ground or rock.

Secondly, it is helpful to analyze the ideas that come from science fiction. Science fiction is the only sphere where underground cars have long existed and helped to go for fantastic trips…

MICHELAGNELO VS MEDICI

Michelangelo was one of the leaders of the Florentine revolt, which was violently put down by Duke Medici. All the leaders of the uprising were executed.

Michelangelo's own life was spared, but with a heavy sentence instead: the Pope demanded the sculptor to design a Medici chapel with sculpture portraits of all the Medicis.

Realistic sculptures would have immortalized the enemy, – a sluggish and despotic magnifico,– but a row of caricatures would have surely be dismantled. Cringing is disgusting, but mockery is impossible – an extremely keen contradiction.

What could be done?

"AND THERE CAME A THUNDERING VOICE" is a line from 'Ruslan and Liudmila', poem by Alexander Pushkin. This voice also thunders over the audience during a duet between Ruslan and the giant 'Head' in an opera by Michael Glinka based on the famous poem. Here, the head's part should sound louder than Ruslan's. But rules of opera singing prescribe that each soloist performs at the top of their voice anyway. What can be done to make the Head 'thunder'?

APPROACHING THE ARTS

Fifth level: inventing a new genre or even a new form of art.

Painting: the portrait, engravings (A. Durer), the landscape (P. Bruegel). Music: at the end of the16th century the genres of oratorio (G.F. Handel), the opera (A. Scarlatti), the symphony (J. Haydn). Literature: the poem, science fiction (J. Verne). Cinematography: the comedy, western, musical.

Fourth level: inventing a new type of expressive means, which quite often leads to a new subgenre.

Painting: profile portraits (Russian artists of the 17th century), historical landscape (A. Vasnetsov), linear perspective (F. Brunnelleschi), aerial perspective (L. Da Vinci). Music: new method of transition (Mozart), choral symphony (Beethoven). Literature: poems of everyday life (A.S. Pushkin "Count Nulin"), social fiction (H. Wells). Cinematography: soliloquy (A. Dovzhenko).

Third level. Inventing a particular expressive means or novel application of an old means.

Painting: to show the "glowing" face of a lady, A. Renoir in "Portrait of Actress Jeanne Samari" shadows the hands and the lower part of the figure so as to convey the "predatory" character of the attractive woman. Leonardo da Vinci paints an ermine, – an animal, known for its ill nature, – in the lady's hands and depicts the woman and the animal in identical attitudes ("A Lady with an Ermine") Music: M. Musorgsky introduces the vigorous Russian dance trepak in dismal "Songs and Dances of Death". In the "La Vida Breve, (Life Is Short)", an opera by de Falla, the choir, instead of taking part in the events, acts as a commentator. Literature: to overcome rhythmical monotony, A.Pushkin combines several meters into one stanza in his "Eugene Onegin". Cinematography: a typical way to show the death of a hero is through close up on his writhing figure. By contrast, in the film "Here Fly the Cranes" it is the world that starts whirling round the dying man.

Second level: wide use of well-known expressive means.

Painting: picture by G. Griva, “Zane” depicting a girl with a rabbit in her hands, the attitudes of the girl and the rabbit being identical (cf. “A Lady with an Ermine”). Music: Tchaikovsky uses *trepak* dance in his “The Nutcracker” to invigorate the scene. Literature: novel by J. Verne “Matiash Shandor” parallels Alexander Dumas’ “Count Monte-Christo” except for the images characteristic of J. Verne’s individual writing style, such as electric ships, etc. Cinematography: “Front Line in My Father’s Yard” takes advantage of the devices first used in the pioneering Soviet war “western” “Nobody Wished to Die”.

First level: duplication of ready-made expressive means, sometimes to the point of sheer plagiarism.

Examples are so abundant that it would be unfair to speak of a single specimen: 90% of music, literature, cinematography etc. utilize hackneyed devices, reiterate patterns of mass culture…

4.3. WHERE DOES A SYSTEM START?

The moment of conception of a technical system is crucial for its entire life. When a system is created, separate components are joined into one whole and thus a novel system property originates which cannot be brought down to the sum of the components. Thus the airplane system has the flying ability which is not present in any of the components of the plane. But a mere combination of components does not show this property either. To make a system operate, its components should be interrelated in a *special* way. Selecting and relating components is a purpose-driven process. This condition fulfilled, the expectant *system property (a super-property, a unique and decisive contribution to the totality of combined properties)* may come into being. What rules should a system formation follow?

Three simple laws are known to determine the appearance and survival of a technical system. Let us analyze the first law: The law of system completeness. It states that, for a system to be viable, its principal components should be present and display minimal working efficiency.

The Law of System Completeness: Every technical system should consist of four components: *engine, transmission, control unit and working unit.*

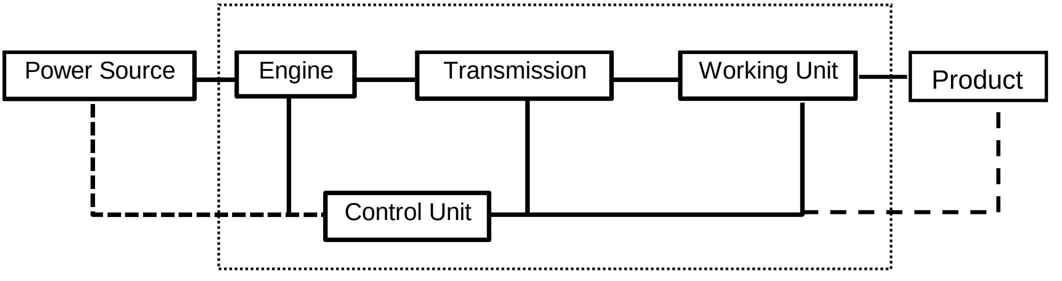
Synthesis of technical system requires all these components and their minimal capability to perform system functions. If any component is missing, the technical system does not exist, if any component fails, the system does not “survive”.

This definition of a technical system is broader than SFM notion. SFM is a model of a minimal technical system. It shows the interaction and conflicts of substances and fields that suffice as clue to the solution. Real technical systems should move, work on products and process data, transform energy, etc. Therefore, transition from an SFM model to actual system demands introduction of extra elements.

Early technical systems always evolved from tools: the useful function of working process needed to be optimized, but man was unable to provide the desired capacity of the system. Later, when manual labor was replaced by an engine, transmission was introduced (the link which transmits energy from the engine to the working unit), and the tool became the working unit of the machine. At this point, man only performed the function of the control unit.

For example, a hoe and a man do not form a technical system. The invention of a plough in the Neolithic Age brought about such technical system: the plough (*working unit*) furrows the soil, the cattle (*engine*) is harnessed to the pole (*transmission*) and the peasant (*control unit*) operates the lever. At first, the plough was only used for ripping. The environment (i.e. hardness, moisture, depth of the soil) provoked man to look for a better shape of the plough. As demands increased, it became necessary not only to rip the soil, but also to turn over each layer pulling up weeds. There followed the invention of the mouldboard (a board fixed aslant that pushes aside the layer of soil lifted by the ploughshare). Gradually, the mouldboard acquired streamlined curved shape (semi-cylindrical or spiral). All metal ploughs appeared in the 18th century and were later complemented by tractors in the 20th century.

The above law enables us to identify a given complex of components with a technical system. Technical systems emerge when transmission and an engine are “added up” to the working unit to replace manual labor. Here you should keep in mind that the engine and the source of energy do not necessarily coincide. Energy may have an external source, including man. The engine transforms this energy into the required form.



The minimal composition of a viable and operable technical system is delineated with a dotted line.

For example, the bow is a technical system possessing a working unit (arrow), transmission (bowstring) and an engine (tight bowstring and a drawn bow). Here, man operates as the source of power and the control unit. Note that one component (the bowstring) performs a dual function (that of engine and transmission). Combination of functions in a system is commonly observed both at the stage of expansion (evolution towards a complex system), and the stage of convolution (a highly advanced phase, when the system is simplified by replacing technical system and its subsystems with an ‘intelligent’ substance). The phenomenon of convolution will be described later.

Let us examine cases of partial overlapping of functions. In the problem on measuring the height of a cave, the balloon is the engine, the thread is the transmission and the working unit (i.e. a height measuring instrument), the man is the control unit. In problem 6, the force that breaks the ampoule is the control unit that 'triggers' the fragrant substance, the substance itself is the working unit, the ascending gas flow is the transmission and the engine while the human nose is the product exposed to action on the part of the working unit. In problems 11, 17, 23 and 25 magnetic field is the engine, the space of field transfer is the transmission, ferroparticles are the working unit while a man/ robot performs the function of the control unit.

Introducing the product into the model provides us with a fundamental scheme of working technical system.

The minimal composition of a viable and operable technical system is delineated with a dotted line.

Corollary to the Law of System Completeness: to make a technical system controllable, at least one of its components should be controllable. Such system is capable of changing properties in the way required by the operator.

For example, air-balloon (aerostat) for vertical ascent is a controllable technical system, since it allows to control its ascent and descent using an air discharge valve and sandbags (ballast). But once we attempt to take full advantage of the system, extending its useful function over horizontal movement, the system will turn uncontrollable. The aerostat will remain an unguided vehicle unless an extra element, such as engine with a propeller with engine, is added.

> **Problem 47.** Exhaust pipes of trucks have a big diameter and should be capped before parking. Otherwise the pipes get clogged with dirt or solid objects. In a movie, a group of boys put a beet-root in one such pipe. Removable caps often get lost. Flapping caps are ineffective, because their fixing hinges get covered up with dirt and soot and cease to work properly. Can you think of a more reliable cap?

According to S-field analysis, we only have one substance (the cap), and an entire SFM is needed. Why don't we use the existing field – the flow of hot exhausts? However, the previous attempt to use the mechanical field of the gas exhaust flow failed. Still, there is a cap (S_1) – a product to be treated (opened and closed) and a thermal field (F_{heat}) – the heat of exhausts (S_2). There is no engine, no transmission, no control unit. The control unit should issue a command to open the cap when exhausts come out, and to close it when there is no exhaust. Accordingly, the system should be controlled by gas (i.e. by its emergency and disappearance) and be driven by thermal field. The point in question is the engine that is to transform heat energy into mechanical energy (that opens and closes the cap). The essence of this simple task is to construct a T-S-Field. T-S-Fields always use the effects of heat energy transformation into mechanical energy by some substance. (See the Pointer to effects).

The easiest way is to use a *bimetal plate*. Heating will cause the plate to bend and open the cap, while cooling will shut the cap. In this case, the system will include a thermal field (source of energy, control unit), a bimetal plate (engine, transmission, working unit) and a cap (product). Furthermore, one can develop the system introducing nitinol (a nickel and titanium alloy with memory shape effect). Thus the system now will only consist of a thermal field (source of energy, control unit) and a nitinol cap (engine, transmission, working unit, product). The cap gets twisted upon heating and untwists upon cooling.

Any problems, whether easy or difficult, deal with engineering evolution. Thus, TRIZ is based on the laws of technical systems development. To solve practical problems it is essential to analyze them correctly, which requires their profound understanding. The first law is simple and obvious: *any technical system should have four functioning components, and at least one of them should be well controllable.* However, when technical systems are created and developed, this law will often be violated. Unlike violation of physical laws (which is impossible), or legal laws (which subjects the trespasser to punishment), violation of technical laws is relatively easy.

A PROBLEM PIPE

During the reconstruction of the city water supply system, a stretch of the pipeline was found which was made of wooden pipes hooped with metal bands and had long fallen into disrepair. The bands were destroyed, but the pipes themselves were strong enough to serve for another century. Replacing the pipes would be costly and time-consuming. Moreover, the City Planning Board prohibited any excavation to be carried out in the historical area of the city.

'We'd just patch them up, and that would be it!' the Chief of the Operating Department said to himself reading a circular sent by the Planning Board. 'But how? Who can you crawl through such narrow diameter'.

'If only we had a robot,' said the assistant wistfully. 'Just a tiny, brainy being, on little wheels…it would hold a tin of glue and some kind of film in its hands, hmm, mechanical arms, I mean…'

'Why robots?' exclaimed a trainee, 'what you need is just a fresh idea! In theory, we do have a substance here – the old pipe, don't we?' (He drew some formulas in his notepad). 'Now we'll complete the SFM, and we'll get…er…well, a complex SFM…And do you happen to have several dozen meters polymeric hose?' he asked…

4.4. FIGHTING MENTAL INERTIA: OPERATOR SIZE-TIME-COST

To use the TRIZ laws, rules and methods effectively, one has to possess certain qualities and skills, the first of which is non-trivial, bold thinking. While selecting and refining a problem, seeking ways to resolve technical and physical contradictions, you will often face the question: is this or that way possible?

Very often a person starts down a well-trodden path, guided by previous knowledge and experience, opinions of others, common don'ts that seem indisputable, personal psychological defense mechanisms (fear of ridicule), by underestimation of one's own abilities or dread of complexity. All this is peculiar to human thinking. From our early childhood a host of rules and habits (stereotypes of thought and action) are imposed on us so that we follow them blindly. Society and individuals obviously benefit from these rules, for they eliminate the need to solve such common problems as how to open a door or lace our boots. But in case of inventive tasks, stereotypes are detrimental.

Our inner watch safeguards us from a slightest venture to digress from conventional ways of thinking. Meanwhile, TRIZ dialectic logic often compels us to admit that white is black, a truism is an error, a cause is an effect, and vice versa. Apart from internal reasons, we are at large influenced by the conditions of the problem because an engineering task becomes an inventive problem as a result of a series of trials that have come to a deadlock. It is this deadlock situation that is most often formulated in the initial conditions. All this package of internal and external factors is referred to as **mental inertia.**

Mental inertia prevents a person from unconventional ("ingenious") mental operations, that is why TRIZ theory has developed a set of knowledge management and error diagnostic tools. *TRIZ distinguishes three basic types of mental inertia: terminological inertia, image inertia, inertia due to specific functional orientation.*

Problems are usually formulated in commonly used terms. Each term reflects old, known technical solution. Terms do not stay neutral, they impose their idea on the inventor. To invent means to reach beyond the limits of common knowledge, to give new meanings to old terms or replace them by new ones. But it is an illusion that you are free to choose any direction in solving a problem. We "think with words", and the words – though stealthily – keep pushing us in a certain direction.

> **Problem 48.** The ship anchor has long become a symbol of reliability. It has saved thousands of ships throughout the history of navigation. But it is not always reliable for modern huge vessels with displacement amounting to thousands of tons. The criterion of anchor reliability is the ratio between its holding power and its weight which should be not less than 10-12 (thus, the most famous Admiralty anchor and Matrosov anchor weigh 1 ton at the holding power of only 10 tons). But best ratios are only observed when the bottom soil is hard enough. And what if the soil is silty or rocky? In this case an anchor just can't cut into it. How can an anchor holding power be increased by, say, 10 times?

This problem seems quite neutral, but the word "anchor" immediately shows a certain direction: adding flukes, changing their shape, increasing anchor weight.

Thus one of the easiest and most effective ways *to put down mental inertia is to discard any special terms in solving the problem.* Use words that are devoid of definite meaning: "thing", "object", etc. (like *X* sign in algebra). For example: "we need an object to hold a vessel with the power of 100 tons".

Alternatively, "we should be able to attach the thing to any soil, so that it may only be detached by the power over 100 tons".

Terms assist us drawing rigid boundaries between the known and the unknown. Once we eliminate them, these boundaries vanish and our thoughts can proceed freely towards the unknown. We have got rid of terms in the problem formulation, and the notion of anchor has practically disappeared, so we are freed from the conventional idea of flukes, etc.

But mental inertia does not give in! We got rid of the words imposing old, conventional ideas, but the image remains. Even without uttering the word "anchor", you still have an "anchor-like" image on your mind; you still envision something that clings to hard soil, scratching, sticking, piercing its sharp claws into the ground…

Successful solutions to a problem largely depend on how well you manage to shatter and break the system of underlying notions. The better a person knows their subject, the stronger conventional image they have. Comprehensive knowledge of a subject makes a person resist any novel ideas in this sphere. It is not uncommon that an expert in a particular field will be overtly critical to ideas expressed by an "outsider", labeling them as "inconceivable", "rubbish, nonsensical drivel", "will never work", etc.

So do not be surprised if at first you are better off with problems of an "alien" domain of knowledge.

The only way to combat the inertia caused by the person's specific functional orientation is to "optimize" thinking. Broaden the scope of your knowledge, analyze solutions that come from different areas of study. Since it is impossible to master the terminology of all scientific branches, it is advisable to read popular science literature that provides a good exercise in unconventional thinking. The tyranny of a highly specialized field of study is typical for the 20th century only, it didn't exist earlier, and hopefully, will not exist in the 21st century.

The first step towards the solution is to avoid trite decisions, put down mental inertia. A useful tool here is so-called STC operator ("Size-Time-Cost", see Alsthuller G.S, *Algorithm of Innovation*, Moscow, Moskovski Rabochi, 1973, p123-125).

The Size-Time-Cost (STC) operator comprises 6 mental operations to recast the conditions of the problem:

Size of the object is increased ad finitum ($S \to \infty$); reduced to zero ($S \to 0$);

Time (or the rate of object movement) is increased ad finitum $T \to \infty$; reduced to zero $T \to 0$;

Cost (allowable costs) of the object is increased ad finitum $C \to \infty$; reduced to zero $C \to 0$.

To some extent, these experiments are subjective, as a lot depends on creativity of your imagination, the kind of problem and other factors.

However, even formal use of this technique will reduce mental inertia considerably.

General recommendations:

- every experiment should be continued until a new quality appears;
- every experiment is divided into phases so that the new quality is not overlooked; each phase marks modification of the object by an order of magnitude (e.g. by ten times).

Let us apply STC to Problem 48. Parameters of which element of the system (vessel, anchor, water, bottom soil) are to be transformed by STC? Obviously, we should transform the parameters pertaining to the element which is to be 'worked upon' (the vessel) to develop the idea of the new instrument ('the object'). For example, the original ship is 100 m long, its draught being 10 m (100m/10m), the ground depth being 1 km. Dropping and fixing the anchor requires one hour. The STC 'new-quality' options are outlined below:

1. $\mathbf{S} \rightarrow \infty$**.** Dimensions increased by 10^2 times, the relationship between the length and the draught of the vessel becomes 10km/1km. How is the problem solved in this case? The vessel "is seated" on the bottom and needs no fixing at all. How can this new quality be applied in the case of the ordinary ship? Can she be fixed to an iceberg? Can one submerge her lower part during stops? Is it possible to detach a part of the ship and bring it down to the bottom? What about a submarine sail that uses water to slow down the vessel?

2. $\mathbf{S} \rightarrow \mathbf{0}$. Reduction of dimensions by 10^3 times brings the the relationship between the length and the draught of the vessel down to 10cm/1cm. The boat becomes tiny as a chip, the length and weight of the rope (i.e. thin wire) greatly exceeding her lifting power. As a result, she will either be uncontrollable or will sink.

3. $\mathbf{T} \rightarrow \infty$**.** The anchoring time is extended to 10 hours. Fixing proceeds slowly, allowing the anchor sink deep into the soil, ram a column, or screw it into the ground. In fact, there exist spiral anchors. American patented vibroanchor cuts deep into the soil and is driven by electromotor. The holding power of vibroanchors exceeds their weight by 20 times. Such anchors are ineffective for rocky ground, though.

4. $\mathbf{T} \rightarrow \mathbf{0}$. Reduction of anchoring time by 10^2 times brings us to a situation where we have a very heavy anchor, which should be dropped very quickly. 10^3 times - fold reduction suggests the idea of a rocket-like anchor. Reducing time by 10^4 times leads us to consider fixing anchor by explosion: "welding" it with the bottom with the help of exothermic compounds.

5. $\mathbf{C} \to \infty$. Allowable cost of the "object" is so high that makes possible the use of most extravagant methods and devices (platinum anchors, rockets, submarines, bathyscaphs…)

6. $\mathbf{C} \to \mathbf{0}$. The "object" costs nothing, like water, for example. How can an anchor be made of water?

Target solution (Soviet patent 1 134 465) is the anchor that consists of a metal plate and a refrigerator. The weight of the machine is 1 ton, the power of the refrigerator is 50 kilowatt. The holding power of such an anchor amounts to 200 tons within one minute, and 1000 tons within 10-15 minutes!

STC operator is not supposed to drive you to the solution. It gives the chance to unchain your thinking towards a completely new idea. Having applied STC operator, you proceed to reveal and eliminate technical (and/or physical contradictions), use S-field analysis and other TRIZ tools. And yet, quite commonly, the solution will start taking shape right after conventional ideas have been discarded.

The typical cases of STC operator misuse are: a) stopping halfway for fear of overcomplicating the problem; b) conjecturing a solution, without going through all the steps.

STC operator is also an imagination-developing tool. A dozen of such cases change your thinking, facilitate overcoming mental inertia and develop the feel for bright ideas.

MAYDAY! MAYDAY!...

…A person avalanched by a snowslide needs a simple method to send a signal for help without resorting to any source of energy. Imagine something sticking out above the snow surface showing the location of the victim.

The most promising solution is using electromagnetic field, but the "beacon", instead of operating by a battery, should use the heat of the human body or dissipated energy of external environment, radiowaves penetrating into all parts of our planet, or the radio signals sent out specially to find casualties.

Incidentally, the problem of snowslide victims is merely an example of a more general situation. People get locked during earthquakes, fires, landslides, car accidents etc. Buried under ruins, trapped, lost in woods, mountains or deserts or underwater, casualties are often unconscious and helpless.

How can they be discovered and rescued?

A compact, service-free annunciator would be the best solution here. It would either switch on automatically, 'feeling' its owners helplessness, or respond to a command issued by its wearer or the rescue team. Where should the device be worn? Will it be a burden? Obviously, it should be a portable object, similar or rather complementary to jewelry (lockets, crosses, earrings, bracelets, false teeth, glasses, rings). People easily get used to wearing watches and other instruments of much less importance. What is your suggestion? This new device will definitely gain wide recognition!

Some attempts are already being made:

“Radiophare rescuer” invented in the USA. This is a plate which reflects radiowaves and can be attached to the boot of the mountaineer. The waves are easy to detect, because a radio beam sent from a helicopter browses the square of one hectare in one minute;

a British firm has created “radio-pills” for medical examination of the viscera. These were even used to analyze processes going in the washing-machine;

Reportedly, a quantum magneto-optical generator has been developed by the Fibre-Optic System Institute in Moscow. The generator enables a rescue team to find a person and determine whether they are dead or alive under the ruins or in a mine at a depth of 3 km; the only condition being that the person is wearing a magnet badge attached to the clothes;

Unfortunately, dogs may lose their scent at low temperatures and when other smells interfere, that is why electronic supersensitive instruments – “sniffers” – are being devised…

5. GUIDED IMAGINATION

5.1. NO WONDERS – JUST LAWS

The second law that ensures viability of technical systems is called **the law of energy conductivity.**

> **<u>The law of energy conductivity:</u> prerequisite to viability of a system is the free flow of energy through all system parts.**
>
> **<u>Corollary to the law:</u> to make a part of the system controllable it is necessary to provide power conductivity between given part and the control unit.**

Every technical system is a conductor and converter of energy. If energy does not pass freely through the entire system, a certain part of it will stay without energy and will not operate. The energy originating from outside or generated by the engine is spent on maintaining the performance of the technical system (all its parts), on compensation of losses and on monitoring the operating parameters of the system and the article being worked. Thus, it is desirable that technical system should not only be a suitable energy conductor but should also operate with minimal energy losses (such as losses incurred by transformation, production of useless wastes, withdrawal of energy together with artifact worked upon, etc.).

Energy between system parts might be transferred via a substance medium (shaft, gear, impact), a field medium (magnetic field, electric current, etc.) or a substance-field medium (e.g. flow of charged particles). Many problems deal with selecting the field and the kind of energy transfer to be most effective under given conditions. Selective procedure should comply with three following principles:

> **1. Upon technical system synthesis, it is desirable to use one field (one type of energy) for all processes of system operation and control. As the technical system evolves, every new subsystem should use the energy that circulates in the system, or the energy that is available free of charge (e.g. energy of the environment, wastes of another system).**
>
> **2. If the technical system consists of irreplaceable substances, it is necessary to use the field for which the existing substances have good conductivity.**
>
> **3. If the substances of parts can be replaced, then the field with sufficient controllability should gradually replace the field with insufficient controllability in the following order: gravitational – mechanical – thermal – magnetic – electric – electromagnetic. Replacement of fields is carried together with replacement of substances or introduction of the admixtures that secure good power conductivity (the substances should be 'transparent' for the chosen field).**

All inventive engineering problems fall into two categories:

- **Modification problems** (technical system synthesis or development)
- **Measurement problems** (detection, control of technical system parameters).

In the former, the direction of energy movement is always from the source of energy (engine) via transmission towards the tool and finally to the article being worked. In the latter, the other way round, it is necessary to detect the information (energy or modification of energy) that comes from the article. The article being worked here is a technical system's part or a natural of technical process which is subject to measurement/ detection/ monitoring.

In solving problems we are assisted by the law. The assumption that technical system needs energy conductivity throughout its parts and power conductivity between its control unit and the parts to be controlled is already part of the answer. Therefore, while working out a solution, it is helpful to ask the following questions:

- Does the technical system allow through passage of energy?
- Is there good conductivity between the parts and the control unit?
- For which field do substances of the technical system have the best conductivity?
- Is it possible to use a more controllable field?
- What field (already present in the technical system or available free of charge) can be best used for the new subsystem?

Let us consider Problem 4 which speaks of 'rebellious' robots. Is there good conductivity between the technical system (robot) parts and the control unit (human worker)? No. Insufficient conductivity constitutes the core of this problem, which leads to the question: how can one manipulate (switch off) the robot instantly? Mechanical manipulations (switches, buttons) should be rejected right away because of the time limits. An instant disconnection is necessary: click! - and the robot is off. Here, only electromagnetic field can be used, for it works at a distance. The operator carries a mini-transmitter with an LED light emitter (a small red bulb). Pressing the button, you send an encoded signal which turns the robot off or delivers another command. Another problem arises: how can you quickly direct the light into the robot's intake window? A witty solution was found: the transmitter is fixed on the eye-glasses of the operator. To orient it, the operator only has to look at the robot (eyes can sight an object in no time!).

Now you are sure to solve the next problem in a nick of time!

> **Problem 49.** Fire engines and ambulance cars cannot lose a single second on their way to the scene of accident. What if the traffic light shows red light? You either lose precious time or get in the way of other cars, endangering the traffic. What can be done?

The radiators of such cars are equipped with an extra infrared headlight. The detector (receiver) of the traffic light receives a signal from the car and shows green light (or prolongs it) to allow the car to pass through the crossroads. The car head-light works at the distance of up to 500 m.

> **Problem 50.** In winter, it is not practical to heat big rooms (store-houses, hangars, etc.), because people come there seldom and machines or spare parts do not suffer from cold. But sometimes people stay long in store-houses and hangars performing tasks that require quick and precise manipulations. Warm clothes restrain movements but cannot be taken off because of the cold. What can be done?

The idea of individual heating equipment (springs installed into thin working uniform) became known long ago. Although such clothes appear more economical than heating big rooms, it is inconvenient to move or walk being constantly connected to a source of power. An ideal solution would be the remote treatment of the 'article' (i.e. the worker). Energy is delivered through the air without any losses such as heating of the air and other objects in the room. Which field goes through the air without losses? Electromagnetic field. This gives the idea to use infrared rays (infrared heating) or microwave radiation (microwave heating).

Recently, experiments in using 1 cm microwaves for individual heating have shown that microwaves are absorbed by the molecules of water under the skin causing normal sensation of warmth. With this method, heating of one apartment requires less than 60 W, the power consumption of a single electric bulb. Individual heating can be used for other purposes too. For example, a device that keeps rooms (dining-rooms, bakeries, etc.) free from flies and other insects. The waves are harmless for humans but exterminate all insects within the range of 250 m^2. Another recent invention, the microwave iron, uses the same frequencies (Soviet Patent 538 074). The inner surface is covered with light-reflecting coating and the underside of the iron is transparent. This iron is ready immediately after switching on.

Also, the system should have good energy conductivity to allow a discharge of excessive energy; for example, the quick withdrawal of friction heat so as to avoid overheating of the technical system.

> **Problem 51.** Soviet Patent no. 597 378 describes a pair of skis equipped with heating system that improves waxing: an internal layer of each ski is made of glass fiber with current-conducting filling agent. The contact points are connected to the circuit and the ski is heated quickly; then wax is applied. Why is this system faulty? Because the ski may be overheated or under-heated accidentally. Besides, each ski should have a socket covered with a snow-protective lid. The lid can easily be lost. How can the system be improved?

Now the task is easy: the glass fiber should contain ferro-powder with Curie point within a required temperature range, so that the ski is heated under alternating magnetic field.

Below are two measurement problems that deal with using fields either present in the technical system or available free of charge.

> **Problem 52.** A primitive device to forecast hurricanes and thunderstorms is needed.

Certainly, one should use the field emitted by the core of the hurricane. Which field? Long ago, in the end of the 19th century, Alexander S. Popov gave the answer. His ‘storm-detector’ could effectively register atmospherics. The same principle is used in the device developed by Institute of Physics of Earth of Russian Academy of Sciences. A wire aerial picks electromagnetic radiation generated by strong atmospheric vortices. The induced electric current triggers a bell. A perfectly simple idea: the hurricane rings a bell, warning of its approach!

> **Problem 53.** Big power plants are entwined in a maze of pipes of various diameters. Each pipe should be regularly tested for leak-proofness. The pipes are filled with helium and the sensor of a special gas analyzer is applied to each weld and joint on each pipe. The method takes too much time and has poor results: possible leakage may appear in any spot. Besides, helium is expensive. It is stored in bulky cylinders that should be transported to the site. Instead of helium, air might well be used, but how are we to determine the point of leakage then? – the air is all around.

The problem carries a heavy load of mental inertia: because helium was detected, air should be detected too, with the help of some ‘tricky’ detection technique. But at the same time, it is far easier to use the free-of-charge field that becomes available when the air leaves the microcracks: the acoustic field, or, simply, the hiss. According to Soviet Patent no. 1 201 704, the point of leakage is determined with the help of a microphone fixed on a long boom. The hiss is audible in the headphones; the whole device weighs less hundred grams.

REEL OF MULTI-COLOURED THREADS

A consulting company was discussing a new problem.

‘We got an order from a clothing mill,’ said the project director. ‘Now that they have installed a new transfer line, they will be changing clothes’ designs very often. We are told that now the models and fabrics are to be changed every day. The re-adjustment of machines takes exactly one hour. Within this hour, only 10 minutes are spent on re-programming of the machine, and in the remaining time the workers are busy replacing the spools with those that have threads of the necessary color. And this is not the worst thing that can happen: they somehow managed to replace the spools during the breaks between shifts. But what if it is necessary to change several fabrics of different colors on one and the same pattern during one shift? Here we run into a serious problem: they work one hour and then there is an hour of waiting.’

‘Good if you only wait one hour,’ said the engineer, ‘If you apply STC operator, the color should be changing every second.’

‘Then you need to plan the entire shift, and use one spool only, with all the necessary threads reeled up on it successively,’ said another engineer. He thought and then added, hesitantly: ‘This isn’t a very good solution, though... I think you cannot do without an automated system.’

‘That’s it. Their director said he was at an exhibition where he saw a machine with an irreplaceable spool. The thread is reeled up on the spool from a big bobbin. Each time you reel up as much as you need for the operation. But this requires a memory unit, a computer. Too complicated,’ the project director took a thread reel out of his pocket. ‘You should make it simple, but how?’

‘Then you do it as follows,’ said the chief engineer, looking at the thread with scrutiny, ‘the spool should not be changed, but the color of the thread should change for each fabric all by itself! The idea is simple: you take...’

And what do you think?

5.2. THE COMMON SENSE OF FANTASY

As you may have noticed, TRIZ analysis does not put you face-to-face with the solution. There is still a gap that should be bridged by thought. Not everyone can fill this gap for two reasons: 1) the tools studied thus far are not supposed to give direct answers to any problem; 2) mental inertia remains...

As you are getting more familiar with elements of theory, the latter reason will become a greater hindrance to successful acquisition and application of TRIZ tools. Struggling with mental inertia is not as easy as it may seem at first. Technical terms are the frontier line of the enemy; a little practice helps to break it and learn to pose any problem avoiding specific terms. But the old image of the object, – the real stronghold of mental inertia, – lies behind. The more independence you gain from the mesmerizing power of the image, the more chances there are to find a perfectly novel solution. But it takes some training in creating new, out-of-the-ordinary images to unchain your ideas. It is not enough to say to a person: "Create this"; an explanation of *how* to create should be given. A system of exercises and a step-by-step learning experience of fantasy tools should be offered. This constitutes the goals of *ICI course*, – a course in *Improvement of Creative Imagination*.

The key to creative thinking is advanced imagination. The history of science, technology, engineering, arts and culture of the whole is **the history of human imagination.** One of the researchers into creativity mechanism quotes the words of Joseph Priestley (scientist who discovered oxygen): *'The most inventive and sophisticated experimenters are those who gave free rein to imagination and established connections between remotest concepts. Even though the parallels drawn by them are rough and chimerical, they may be a golden opportunity for great and important discoveries, unattainable by reasonable, sluggish and coward minds."*

Truly, a person with well-trained imagination will generate ideas that never occur to those whose imagination is uncultivated. However, in the realm of the unknown and the unrevealed, freely ranging imagination is of no use. What you need is *guided* imagination. *Fantasy management is a trait of well-organized thinking.*

> **Problem 54.** Test you fantasy: imagine a new fantastic biological plant. The plant should be entirely new. The time for daydreaming is unlimited, but normally 20-30 minutes are enough.

Imagination is the ability to create new images, of both real and fictional objects (systems, processes, concepts).

Three levels of imagination are distinguished:

- *creating a new (modified) image* of an object experienced earlier (e.g. a tree with different fruits and vegetables);
- *creating a new (developed) image* of an object that the person has not encountered earlier but has some initial information about (i.e. weightlessness, magnetic corn, glass rain);

- *creating (synthesizing) a new image* of a non-existent object of which no initial information is given (i.e. extra terrestrials, gaseous plants, solid echo, living smell, change of seasons inside the person).

The highest level is fantasy, the most complex kind of imagination.

Fictional ideas are the product of fantasy. People with advanced fantasy skills are hard to find. Usually they are science fiction fans. As a rule, beginners in the ICI course show poor level of imagination, regardless their age and background. In the course of several years of teaching ICI we have collected extensive statistical data on solutions typically offered to Problem 54 and other program tasks. Below are representative examples of fantasies acted out by a group of engineers: the pump-plant, hydro-electric-station plant, furniture-plant, moon cabbage, transparent plant, the sea water-melon with fresh water inside, 'the plant that has the shape of a convex-concave pyramid, with plasma pulsating inside, dumb-bells of the color of over-ripe cucumber suspended from above; the chiming of bells heard...', 'the plant sensitive to malicious thoughts: if someone breaks off a branch, it turns blue with indignation and stings the intruder; if someone caresses the plant, it turns green...' and so forth. There is little fun about it.

It appears that the level of imagination of ICI beginners is rather moderate and usually confined to two forms:

1. *mechanical amalgamation of homogeneous systems* (the examples above, as well as fairy-tales and myths: mermaids, centaurs, sphinxes);
2. *wild, uncontrolled fantasy* ('dumb-bells of the color of over-ripe cucumber suspended from above', nondescript fabulous monsters with enigmatic properties and unclear functions).

Problem 55. One more test: Think of a fantastic beast, not known from fables or science fiction.

The training is based on the deliberate assumption that all trainees possess poor imagination level. Even people with poor fantasy can use ICI tools to generate fantastic ideas of high rank.

We shall start with simple tools revealed by analyzing a substantial corpus of science fiction that served as a sort of 'patent file' of fantastic ideas. By and large, science fiction writers do not employ fantasy tools consciously, but a major part of fantastic ideas in their works conform with these tools.

- *Enlargement – reduction (modified parameter: size of the object)*. Seems to be the most popular method in science fiction. Once it gave life to giants, dwarfs and Gulliver's travels. Men grow enormously tall (*The Food of the Gods*, Herbert Wells), or shrink to dwarves (*Battleground*, Stephen King, *Uncle Julian's Meteorite*, Jan Weiss). Tiny aliens appear (*The Invisibles*, I. Kopylov) and a planet is a children's clockwork toy (*Restricted Area*, Robert Sheckley).
- *Acceleration – deceleration (modified parameter: time or speed)***.** The pace of life speeds up (*The New Accelerator*, Herbert Wells) or slows down (five years on Earth are just one second in aliens' life (*Meeting*

In the Desert, story by I. Rosokholvatsky). Writers imagine acceleration of Earth's rotation (*Over the Abyss*, A. Belyayev) or deceleration of the velocity of light.

- *Dynamics – statics (unchangeable object becomes changeable and vice versa)*. Person's appearance gets transformed (*The Twelfth Machine*, V. Antonov) or the person changes it purposefully (*Revealing the Self*, V. Savchenko). In Robert Sheckley's story *Shall We Have a Little Talk?* the language of aboriginal population on a planet changes so quickly that it is impossible to establish a contact with them.
- *Omnipotence – limitation of functions (the object's functions cover a large class of phenomena or, conversely, a universal fact has a restricted effect).* Robots with unlimited capabilities (I, robot., I. Asimov) and a robot meant exclusively for opening cans (*The Proud Robot*, H. Kuttner).
- *Fragmentation – unification (splitting into components or integration of components).* A human is decomposed into atoms and then re-assembled (*The Journey of Professor Tarantoga,* S. Lem); ball-shaped extra-terrestrials can join together and acquire any shape (*They walked like men*, C. Simak); sea-animal can decompose into separate one-cell organisms that unite for hunting (*Master of the Bay*, S. Gansovsky).
- *Quantization – continuity (continuous effect of an object becomes intermittent and vice versa)*. Quantization of aging: a person may be young through all his life but in the end grows old instantly (*A Farewell on the Shore*, E. Voyskunsky), human being gets food from the air saturated with nutritious substances (*Star Traveler*, G. Martynov).
- *Modification of properties (modifying the least changeable property of an object or medium)*. Reverting rotation of the Earth (Jules Verne), changing the direction of magnetic field of the Earth (*The Sixth Ocean*, G. Gurevich); changing the spectrum with the aim to send a (*Time in Advance,* W. Tenn)..
- *Inversion ("do it the other way round") – the most common device (a function, property or the entire object is changed to its opposite).* Instead of growing old, the person grows young (*Star Diaries,* S. Lem). Antigravitation (The First Men in the Moon, Herbert Wells). A person may serve a sentence and then get the right to commit a crime (Time in Advance, W. Tenn).

The list of devices could be continued but what matters is not their scope but the good command of these effective tools in controlling fantasy. The tools can be used separately, but it is advisable to combine them (the object is processed using one tool, the result is later processed by another tool, etc.). Consecutive application of 3-5 random tools to the object may lead too far from the initial image – if your mentality is bold enough. A few recommendations should be given here. Firstly, *do not reject the tool you chose,* only because it cannot be applied to the given object ("this makes no sense at all!"). Look for bold, bizarre solutions, because absurdity, impossibility of the contradiction is what you expect from the exercise. Secondly, *build the chain of tools until quantitative changes evolve into a new quality of the initial object,* which is interesting, unusual and unforeseen.

Problem 56. Think of a fictional natural phenomenon. For the initial object, take any natural phenomenon (rain, rainbow, earthquake, aurora borealis, etc.).

Using simple fantasy tools, solve Problems 54-56.

HOW TO DECEIVE A SYNTHESIZER

In one science fiction story the characters decide not to take thousands of necessary spare parts with them during the flight and instead start out with a synthesizer – a machine that can make everything. Landing on an alien planet, their spacecraft gets damaged. 10 identical spare parts are needed for repair works. As it turns out, the synthesizer can make one copy of any part. What can be done?

THERE SHOULD BE A WAY OUT

In another story, the characters examine the planet in a boat they purchased by chance. On the way, the boat keeps the temperature above 30 ^{0}C, cooks lunches from machine oil and clay and considers water to be a poison. The former owners of the boat for whom these conditions were quite normal set such parameters. The boat cannot be re-programmed. Sailing along seashore, it does not allow the crew to disembark because water is supposed to be a poison. What can be done?

THE LAST WILL

The hero rescues Jan, a super-robot, from confinement in a bottle. Tired of waiting for rescue, the robot has sworn to kill the one who would rescue him. He now is firmly resolved to fulfill his oath and keeps chasing the hero, and saying "No one but me shall kill you!" And though he is prepared to realize the hero's last will, the will should not go contrary to Jan's oath. Is there a way out of this situation?

5.3. CONTRADICTIONS FURNISH A CLUE: ALGORITHM OF INVENTIVE PROBLEM SOLVING

There are two popular fallacies about creative problems. The first fallacy is: "This problem lies beyond my competence. If you only gave me a problem in my sphere, I would..." The second fallacy: "The problem is posed incorrectly. Formulate the task precisely and I will..." Discussing the first fallacy we came to the conclusion that powerful solutions are found outside the well-studied sphere of knowledge. The second fallacy has much to do with the issue of problem's conception. Where do problems come from? How are they put into words? Should we trust the problem as it is presented?

No inventive problem has a precise formulation. A clearly-defined problem equals the formulation of its main physical contradiction and stands only one step away from the solution. But because the overwhelming majority of problems are phrased by people who are unaware of TRIZ, ordinary formulations should not be taken for granted. Somebody said that in science a clearly defined question makes 90 percent of the answer. You only need to put the question right... Indeed, the meaning of TRIZ-based solving process is in re-formulation aimed at pinpointing the conditions of the problem and at concentrating on the main question.

One source of erroneous, vague problem presentations is the complexity of structural hierarchies of technical systems. For instance, we run into a problem: while making sharp turns, the car starts wobbling. What is to be done? A keen inspection will reveal the wobbling of the rear wheels, namely the left wheel. Further, we may suspect that something goes wrong with the attachment point of the wheel. Furthermore, the cause of trouble may be found in a particular bolt that has a nut gone loose because it is obstructed by other components and could not be tightened properly at the assembly line. Which problem does the inventor face? The formulation of the problem may focus either on the technical system as a whole (the motor car), on a subsystem (the wheel), on a sub-subsystem (attachment point of the wheel) or on the subsystem of a lower rank (the bolt). Alternatively, the problem may transcend to the level of super-system (how is the assembly line to be improved?) or be viewed at another level of specialization. The situation is even more intricate if the inventor receives a problem from an expert who has attempted to solve it. What you receive then is a deadlock situation (although in presenting it to you the hapless expert is guided by best intentions, having gone to considerable lengths to facilitate your task). But the expert may have been misled at any level of the system.

The conditions of the problem as received by the inventor are called **initial situation**. Initial situation contains **administrative contradiction**, that is, a contradiction where you know *what* you need but do not know *how* to obtain it. Every initial situation requires making preliminary changes towards boiling a vague issue down to an inventive problem which, according to familiar rules, should contain a technical contradiction. To achieve this task, TRIZ offers a step-by-step procedure. To illustrate it, we shall be using the following problem as an example:

<u>Problem 57.</u> Joints of glass products such as parts of vacuum systems (e.g. pipes, freezers, etc.) are tested for air-tightness with the help of a high-frequency electric discharge. An electrode is inserted into the product (e.g. a glass tube) and another electrode is positioned outside. The two electrodes evoke a corona (crown-shaped) discharge – a shimmering glow of ionized air. Thus each tiny hole in the joint sparkles attracting the discharge. After that, the external electrode is removed and the hole is sealed with a high-temperature torch. This effective technique has one deficiency: when the electrode is removed the hole becomes invisible and sealing is performed blindly. To avoid temperature stresses in the glass, it is advisable to perform the sealing as quickly as possible. Instead of covering the entire area, the flame should slightly touch the hole. What can be done? (See "Enlightened with TRIZ", Nikkei Mechanical, June, 1998, p. 104.).

Restrictions: 1) No substances (fluorescent compounds) may be introduced into the hole, because they change the composition of refractory glass; 2) it is not advisable to expose the external electrode to flame, for it will damage it.

The conditions contain an administrative contradiction: we need to make the hole visible during the sealing but we do not know how to do it. The problem appears not to have been obscured by previous attempts to solve it, for it contains neither prescriptions as to which specific component needs to be improved nor bans on possible solutions.

<u>*This initial situation may develop into several problems*</u>*:* how can one detect the hole without electrodes? How can the electrode be protected? What material can be used for making electrodes with exceptionally high point of melting? How can the glow be caused without any substances introduced? How can we produce glass artifacts with absolutely tight joints (or without joints)? And so on.

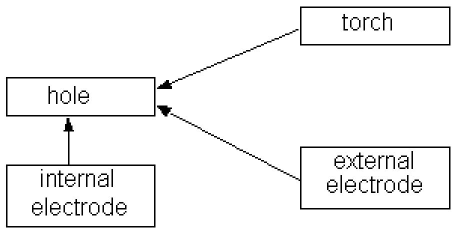
Here is a wide selection of mini- and maxi-tasks. Which should be chosen for solving?

Below we present another problem solving technique, known as **Algorithm of Inventive Problem Solving** (abbreviated as **ARIZ**) developed by G. Altshuller. ARIZ helps with presenting a problem in terms of physical conflict. It involves a number of steps for gradual problem reformulation – from determining technical contradiction to revealing physical contradiction. In addition, ARIZ suggests several techniques, which might be used to solve the problem.

We only present those parts of ARIZ which deal with formulating and solving problems[9].

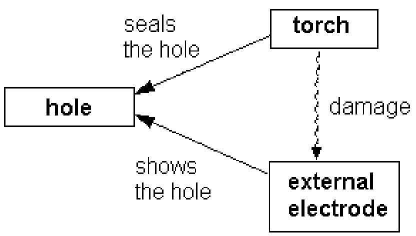
<u>ARIZ Step 1.</u> Evaluate the initial situation. This step involves building the hierarchy of a technical system or phase plan of technological process; locating the 'sore point' of the technical system or the process.

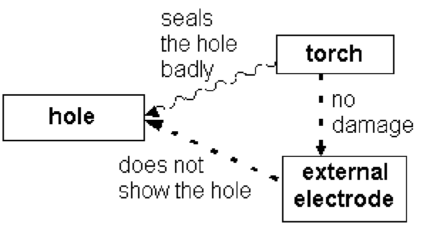
[9] Full text of ARIZ (version 85V) can be found in G.Altshuller's book *To Find Idea* (Nauka, Novosibirsk, 1985, in Russian).



How does this design of sealing process work? The internal electrode is inserted into the tube, while the external electrode moves past the joint. If a glow of a hole is detected, the point of glow is remembered. The external electrode is removed and the hole is sealed with a torch. Let us represent the process graphically.

Which part of the system displays the drawback ("the sore point") which needs to be rectified? It is between the torch and the external electrode: if not removed, the electrode shows the hole clearly during sealing, but gets damaged. If removed, the electrode remains intact but the target spot is invisible. Since nothing happens to the internal electrode, we shall withdraw it from the diagram. Below are diagrams demonstrating the two states of conflict between the electrode and the torch.





<u>ARIZ Step 2.</u> Define the mini-problem:

Technical system for (state the purpose), including (enumerate main components);

Technical contradiction 1 (description);

Technical contradiction 2 (description);

Minimal changes in the system should lead to... (state the desirable result).

The mini-problem is a scaled-down initial situation. This phase is extremely important in that it involves abrupt curtailing of possible directions of solution according to the principle: ***"All remains unchanged or is simplified, but the required effect/property appears or negative effect/property disappears".*** The transition from problem situation to mini-problem does not mean that we strive to solve a minor problem. On the contrary, the transition entails a complication in that it restricts the solution: the positive effect should be achieved without making any changes. The transition casts aside a multitude of trivial solutions that presuppose complicating the equipment (remember that it is easy to make a complex thing, but simple solutions are by no means easy).

Of course, not always does the solution of a mini-problem lead to the answer. Yet, *this is a very advantageous phase* and one should by all means go through it while solving a problem for the first time. If the answer is found, the solution is sure to be powerful ('*gain without too much pain*'). The solution to mini-problem will be easy to implement and will not require considerable changes in the technical system. It is only when the mini-problem yields no solution that one can proceed to maxi-problem.

Once again, a mini-problem results from initial situation after changes have been restricted: what we have minus the drawback, or what we have plus the necessary advantage.

Maxi-problem results from initial situation after the restrictions are lifted: initial system may be replaced with a new one.

Notes:

1. Drawing up a mini-problem it is necessary to enumerate not only the technical parts of the system, but also its natural parts interacting with technical parts (if any).
2. Technical contradictions are interactions within the system characterized by:
   - useful effect concomitant with a negative effect; or
   - introduction (intensification) of the useful effect or elimination (reduction) of negative effect causes deterioration (and also inadmissible complication) of the system or its part.
3. Technical contradictions are formulated two-fold (technical contradictions 1 and 2).
   - Technical contradiction 1 describes one state of the system and the positive and negative aspects of this state;
   - Technical contradiction 2 describes the opposite (inverse) state of the system and the negative and positive aspects of this state.
4. Sometimes, conditions of the problem contain a single component (i.e. what should be treated); that means that the technical system (the part which performs treatment) does not exist and therefore no evident technical contradiction is posed. In such cases, the system is completed by any simple and familiar method. Undoubtedly, the method will be deficient by its nature (for were it good, there would be no need to solve the problem); introduction of

familiar components will impair the system, but will later form the basis for the technical contradiction.

5. The mini-problem is formulated by replacing specific terms with common words with the aim to eliminate mental inertia.

With this in mind, let us formulate a mini-problem as follows from Problem 57:

Mini-problem. Technical system for detection and sealing of holes in glass artifacts, includes a glass product, a conductor, and the flame of the torch. It is necessary to provide quick and accurate sealing of the hole under minimal changes in the system. (To avoid words having specific technological means, the word "electrode" is replaced here by a more general word "conductor").

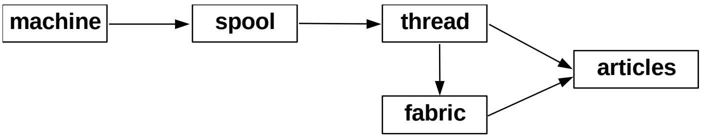
Technical contradiction 1: if ***the conductor is not withdrawn***, the hole is conspicuous during sealing (sealing is performed quickly and accurately), but ***the conductor gets damaged***.

Technical contradiction 2: if ***the conductor is withdrawn***, no damage to the conductor is done, but ***the hole is invisible during sealing*** (sealing is inaccurate and lasts longer). It is necessary at the minimal changes in system to provide fast and exact holes sealing.

The words in bold type demonstrate the strictly inverse character of the second contradiction against the first contradiction.

REEL OF MULTI-COLORED THREADS

Processing the initial situation. How does the clothing mill work? During one shift, the automatic line produced clothes of one pattern and color. Breaks between the shifts allowed to re-adjust it and change the thread spool to match the color of the next fabric. But when it became necessary to change fabrics more frequently (in order to expand the variety of clothes) the output fell down abruptly because it took long time to replace the spool. The system consists of the machine, the spool, the threads and (a variety of) clothes (articles being worked).



Several ***maxi-problems*** can be offered: installing new machines, modifying the spool, setting up high-speed winding, computerizing the process and etc.

If no changes are made, which part of the system will show a conflict?

Changing the fabric allows to expand the variety of products but requires prolonged replacing of threads. The problem is in the fabric: *changing it frequently we provide a wide variety of clothes but bring down the output while without changing the fabric, we secure high output but produce uniform clothes of one color.*

Mini-problem: technical system for producing clothes that includes a machine, a spool, threads, fabric, clothes.

Technical contradiction 1: if the fabric is changed frequently, versatile clothes are produced, but replacing the threads takes long time.

Technical contradiction 2: if the fabric is not changed, no time is spent of replacing the threads but uniform clothes are produced.

It is necessary to provide high output of versatile clothes with minimal changes in the system.

ON A ROAD TO INVENTION

The major mistake in problem solving is attempting to guess the answer. Random 'leaps and bounds' of thought are disadvantageous for two reasons: a) they bring you back to the framework of the trial and error method and gradually ruin the hard-gained skills of mind discipline developed by practicing S-Field analysis and the rules of technical system evolution, and b) a 'leap' may prompt a seemingly correct idea which will later create the mental inertia so difficult to beat.

It is necessary to approach the solution patiently and methodically. The systematic analysis launched for Problem 57 is a safer though somewhat longer way than S-Field analysis. The logic of the analysis is designed so as to *narrow the span of possible solutions*. In the course of analyzing there is less and less space for mental 'leaps'.

We started off with an ill-defined initial situation which opened a relatively wide area of search: something is going wrong with the existing technical system and nobody knows which part of the system is to blame. Having processed the initial situation, we tentatively defined the point of conflict and turned the situation into a mini-problem. In doing so, we discarded a multitude of possible solutions, preserving only a few components related to the conflict. The next step towards the invention is **building the problem model**. From now on, only two components will be borne in mind and the conflict between them will be intensified to full extent.

ARIZ Step 3. Define and formulate the conflicting pair of components: the artifact and the instrument.

Notes:

6. The artifact is the component which, according to the problem conditions, is subject to any kind of treatment (e.g. production, displacement, modification, improvement, detection, safeguarding, measuring). In measurement (detection) problems, the artifact may be the component whose chief function is that of an instrument (for example, a grinding wheel).
7. The *instrument* is the component with which the artifact stands in direct interaction (e.g. the milling cutter but not the entire milling machine, the flame but not the burner). In particular, a part of the environment may serve as the instrument.
8. One component of the conflicting pair may be coupled. For example, the artifact should be simultaneously treated by two instruments which hinder each other's work. Alternatively, two artifacts should be subject to the effect on the part of one instrument. The two artifacts are in conflict.
9. If the problem conditions suggest that one instrument may have two states, both states should be indicated.
10. If the problem contains more than one pair of interacting homogeneous components, it is enough to consider one such pair.

The purpose of this step is reviewing all components of a system and choosing the most important pair which is the source of the conflict.

Something needs to be done with this pair! This implies further narrowing of the analysis.

Most problem conditions give a clear indication as to which is the artifact and which is the instrument. Possible difficulties are usually caused by terminological inertia ('artifact', 'instrument'). The wording of the problem will not always coincide with the formulation of concepts as required for the present step.

Whether the component is the instrument or the artifact depends on its role in the functioning of the 'ailing' part of the system. It is helpful to resort to most general rules: **the instrument is the doer of the action, the artifact is the component which is acted upon.**

For instance, we encounter a problem where a surface should be covered with ice. Which is which? Evidently, the surface is the artifact and the ice is the instrument. In another problem, the degree of icing on the skin of an air-borne plane should be measured. Here the ice will be the artifact whereas the measuring device will be the instrument.

In problem 57, the artifact is the hole (because it is being treated) and the (coupled) instrument is the conductor and the flame (but not the entire torch).

In the problem about a clothing mill, the instrument is the fabric (for it has an effect on the condition of threads and clothes) whereas the (coupled) artifact is the threads and the clothes.

<u>ARIZ Step 4.</u> Graphical representation of technical contradictions 1 and 2 using the Table of conflicts in problem models.

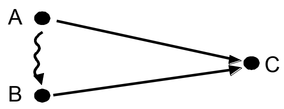
Because there is an infinity of inventive problems, one might imagine an endless variety of contradictions. In actual fact, for the majority of problems there exist but nine kinds of standard contradictions between the artifact and the instrument (see page 110). These typical patterns of contradiction are not rigid; they may be modified *ad hoc*. Moreover, new patterns may be created for certain problems inasmuch as they better reflect the core of the conflict. Let us select the patterns applicable to the conflicts in the cases discussed.

Problem 57 involves a coupled component. Coupled components are found in patterns 3, 4 and 6. Patterns 3 and 4 are not suitable in that they refer to conflicts with coupled artifacts. Pattern 6 exactly reflects the core of the conflict: detection of holes is incompatible with their sealing. Below are graphical representations of the contradictions (A stands for the flame, B for the conductor, C for the hole).

Technical contradiction 1

2

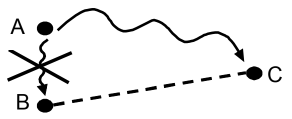
(conductor is not removed)



Flame has a useful (sealing) effect on the hole. The conductor has a useful effect on the hole (detecting it), but the flame has a negative effect on the conductor in that it damages it. Here, the standard scenario is supplemented by A-B effect.

Technical contradiction

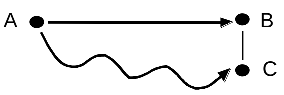
(no conductor)



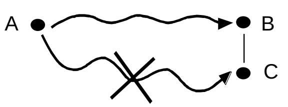
Flame has a negative (prolonged and inaccurate) effect on the hole; the conductor has no effect on the hole (the hole is not detected) but the negative effect of the flame on the conductor is avoided.

In the problem about a clothing mill, the conflict perfectly matches pattern 4 (where A is the fabric, B the clothes, C the threads).

Technical contradiction 1
(the fabric is changed)



Technical contradiction 2
(the fabric is not changed)



> **<u>ARIZ Step 5.</u> Select a conflict pattern which provides the optimal running of the main process (the foremost useful function of the entire technical system as specified in the problem conditions). Define the main process.**

<u>Note:</u>

11. In choosing between two conflict patterns we choose from two states of the instrument. Further decisions will be geared to the chosen state. For example, the state in which 'the conductor is not removed' cannot be compromised with the state where 'the conductor is almost not removed'. What analysis calls for is intensification (sharpening) but not alleviation of the conflict.

In **Problem 57** the main process is effective sealing of holes, highlighted by the pattern of Technical contradiction 1 only.

In the **Problem about a clothing mill** the main process is production of a variety of clothes. That is why the pattern of Technical contradiction 1 should be chosen here as well.

<u>ARIZ Step 6</u>. Intensify the conflict, defining the ultimate state/aktions of the components.

<u>Note:</u>

12. Most problems deal with conflicts involving 'too many' components and 'too few' components (or 'strong' component – 'weak' component). Upon intensification, conflicts of this kind should be uniformly brought to the state in which there are 'no components' ('missing component').

Conflict intensification in **Problem 57**: the conductor is not removed and remains at the hole even under very strong flame. What will happen to the conductor? It will deteriorate, or fully burn out and will cease to exist. Accordingly, we introduce a missing conductor.

Conflict intensification in the **Problem about a clothing mill**: the fabric changes every second, continuously.

<u>ARIZ Step 7.</u> Formulate the problem model that includes:

the conflicting pair;

the intensified conflict;

the actions of X-component in solving the problem (what X-component should preserve, eliminate, improve, provide and etc.).

<u>Note:</u>

13. Do not give much thought to what the X-component looks like. It may not necessarily be a substantial part of the system. X-component is any change in the system, an 'X' change that may mean a change in temperature, or in the aggregate state of a part of a technical system or in the external environment.

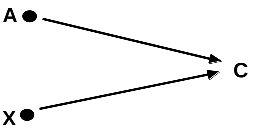
The Problem model is a representation of the problem that highlights the structure of the conflict point of the system. Transition from a problem to a problem model will later help to reveal the physical contradiction.

Problem model for **Problem 57:** Given are a hole, flame and conductor which is never removed (missing). The X-component should provide sparkling of the hole during sealing without a conductor.

Problem model for **Problem about a clothing mill**: Given are threads, fabric and clothes. The color of the fabric is changing all the time. The X-component should provide instant changing of the thread color with the fabric color changing every moment.

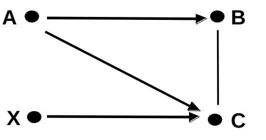
<u>ARIZ Step 8.</u> Specify the chosen pattern of conflict. The conflict is specified according to the problem model with respect to the effect of X-component.

Problem 57



The conductor is missing and is not shown in the diagram. X-element makes the hole sparkle with no conductor present.

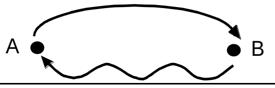
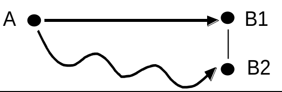
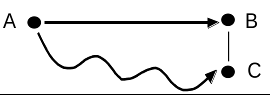
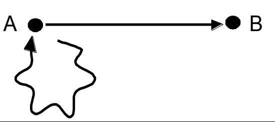
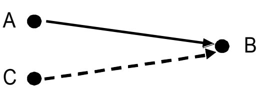
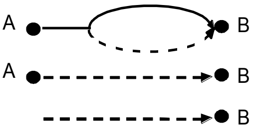
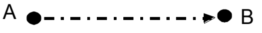
Problem about clothing mill



X-Element provides instantaneous replacing of threads to match the continuously changing color of the fabric.

Problem solving process with ARIZ will be continued in the next chapter.

TYPICAL CONFLICT PATTERNS IN INVENTIVE PROBLEMS

1. Counter action 	A produces useful effect on B (solid arrow), but permanently or at certain stages negative counteraction (wave arrow) occurs. It is necessary to eliminate the negative effect preserving the useful effect.
2. Coupled effect 	The useful effect of A on B turns out to be in some aspect negative for B (e.g. at different stages of work the same effect may be negative or positive). The negative effect should be eliminated and the useful effect preserved.
3. Coupled effect 	The effect of A on B is useful for one part of B but negative for another part of B. The task is to eliminate the negative effect on B_2 preserving the useful effect on B_1.
4. Coupled effect 	A has a positive effect on B but a negative effect on C (with A, B and C constituting a system). It is necessary to eliminate the negative effect and preserve the useful effect without destroying the system.
5. Coupled effect 	The useful effect of A on B is accompanied by A's own negative effect on itself (in particular, complication of A). It is necessary to eliminate the negative effect retaining the useful effect.
6. Incompatible effect 	The useful effect of A on B is incompatible with the useful effect of C on B (e.g. treatment is incompatible with measuring). It is necessary to provide the effect of C on B (dotted arrow) without changing the effect of A on B.
7. Incomplete effect or inaction 	A produces a single effect on B whereas two different effects are needed. Alternatively, A has no effect on B. A may not be given and then it is necessary to change B in an unknown way. It is necessary to provide the effect on B, with A being as simple as possible.
8. 'Silence' 	Information is missing (dotted waveline) about A, B or interaction between A and B. Sometimes only B is given. Missing information should be obtained.
9. Uncontrolled (including excessive) effect 	A has an uncontrollable (e.g. uninterrupted) effect on B whereas a controlled (e.g. varying) effect is needed. The effect of A on B should be put under control (dot and dash arrow).

5.4. FUNDAMENTALS OF ADVANCED THINKING

To a layman, exercises in imagination development may seem odd. But it only seems so. In fact, there is serious intensive work going on. Each new problem helps to develop new fantasy skills, from simple skills (magnification, reduction, inversion) to more complex skills (making the object properties changeable in time, changing the link between the object and the environment). Thus our thought learns to overcome psychological barriers. At the very beginning, it was very difficult to 'kindle up' fantasy; its 'sparkle' would burn out very soon. But gradually our 'mind trips' became longer and more independent. Now you are asked to put forward novel ideas and even write science fiction stories. But all this requires dozens of attempts to overcome the inhibition of thought.

> **Problem 58.** Imagine a planet that changes its size every 24 hours. In one phase the planet has dimensions similar to Earth but then it becomes twice as big in diameter. We will not go into detail as to how the pulsation mechanism works. Let us assume that the core of the planet shrinks and expands. The surface layers of the planet are loose; they stretch as the diameter increases. Describe the life conditions on the planet, its human dwellings and towns. What system of transportation is used? In other words, imagine the civilization of a pulsating planet.

To solve problems like this one you need to make the most of your fantasy. This exercise will make your imagination more flexible and dynamic.

Properly speaking, *flexibility of imagination* and *fantasy* are characteristic of ***advanced thinking*** (or "well-developed creative thinking", "cultured thinking", etc.). Another quality of advanced thinking is the strong command of ***dialectic method*** – a universal problem solving methodology. Dialectic thinking has three distinctive features: *a) the ability to see links between phenomena and objects, i.e. perception of the world as a system, b) the ability to formulate contradictions, that is, to pick out the 'sore' point, the core of the problem; and c) the ability to consider each object in evolution (and trace its past, present and future).*

Development of these two aspects of advanced thinking, – the flexibility of fantasy and the rigidity of dialectics – is the goal of ICI and TRIZ courses. Taken together, the two courses may be called "Fundamentals of Advanced Thinking".

Perception of the world as a system appears to be the chief merit of dialectic thinking. The clear and simple statement that 'everything is interrelated' bears deep significance and enables anyone who follows it to view every object as multifaceted, to conceive its past and future. Mental inertia pushes us backward, encouraging to regard a single familiar and evident property of the object.

Speculations on the subject of properties and possible practical applications of objects may be a perfect illustration to a seminar in 'Combatting terminological inertia'. For example, you may pose a question: "What is a chair?" Immediately you will get answers like "something to sit on". But one might as well sit on a log, a rock or on the ground. As the discussion goes, the meaning of each word expands gradually, accumulating new objects. Finally, somebody comes up with a general definition: 'any material surface on which one person can sit'. But if you ask the next question: "What if your pants are made of ferromagnetic substance and a source of magnetic field is placed nearby?", the 'material surface' will turn out to be suitable not only for sitting, but for walking as well. However, this is not the end of the 'terminology game'. To call it a day you might ask: "Can we endow humans with a somewhat fantastic faculty that makes redundant any 'things for sitting on'?" The same function might be performed by our muscles, or something else. The tool will disappear; its function will be performed by the object (man). One might even fancy that, as a result of evolution, man will lose the need to be seated at all...

> **Problem 59.** Describe a fantastic scenario in which the evolution of humans eliminates the necessity to have certain parts of the body, for their functions being delegated to the environment or to artificial objects used collectively. What changes in human psychology and lifestyles can be traced? What will the technosphere and our dwellings look like, and etc.?

> **Problem 60.** Describe a reverse fantastic situation where science and engineering development leads man to acquire the functions of the main technical systems. The main technical systems are those that directly meet the basic human demands, such as movement in space (automobiles, planes, etc.). These are distinct from auxiliary technical systems that provide for the functions of other systems, in the way as oil pipeline, oil refinery and gas-filling station provide for the work of the automobile. What functions, in your opinion, should primarily be delegated to man? What technical systems will consequently disappear for disuse? How will the world change (in the sphere of the relationship between nature and technology)?

TRIZ-based and ICI-based problems have much in common. The only feature of fantasy problems is that, in contrast to realistic ones, they are subject to no restrictions. In the process of solving fantastic problems the object is usually transformed beyond any resemblance.

Now we pass from elementary to more complex (and more effective!) fantasy tools. One such powerful tool is **transition from real object to ideal one.**

How the tool works: Any real object, fact or concept belonging to science, engineering, culture or nature is a system, i.e. a totality of constituent elements and at the same time a part of a larger whole. Each system has its *main useful function*, for the sake of which the system exists. But the life of any system is by no means gratuitous to the society or nature. Each system consumes energy, substance, information, occupies space and produces wastes. The general cost of a system is the sum of its Mass, Size and Energy consumption. The less the Mass-Size-Energy consumption, the cheaper the system. An utterly economical system performs its function at a zero Mass-Size-Energy consumption. Such systems are called ***ideal***.

Fantastic as they might seem, examples of such systems abound. The transition tool is very important and will later be discussed more than once. And below are three typical examples:

Changing a natural object: Chemical insecticides are now widely used to exterminate insects and pests of agricultural plants. However, their effect is non-selective (they kill both 'good' and 'bad' pests) and harmful to the environment. The ambitions to use biological means to protect crops (artificial breeding of pest-killers, dispersing of biological substances that work as natural poisons to insects) did not come true: the substances either did not enter the natural food chain or, being 'environmentally friendly', decomposed rapidly. In an ideal system of protection, the cells of agricultural plants produce substances that kill or ward off the insects and germs. Experiments have been started in many places. Bio-engineers build a protein into the cells of tobacco that enables tobacco leaves to produce highly toxic substances against pests.

Changing the technical object. Some electronic wristwatches have a convenient sound alarm ('beeper'). The beeper has a Mass-Size-Energy consumption. What can be done? The protective glass of the watch can be made of transparent piezoelectric plastic and be a sound emitter at the same time (the ideal sound emitter is that which does not exist but its function is performed).

The main disadvantage of electric motor cars are their heavy and bulky batteries. The technique developed by a British company allows to make batteries of any shape. Such batteries can be the material for making the frame, the chassis, the bearing members of the car (the ideal battery does not take space and has zero weight).

Stitching pieces of clothes together is a labor-consuming process. Gluing the pieces together is easier but glue tends to clog the pores of the fabric making it stiff. What can be done? If the fabric contains over 65 percent of synthesized fiber, the pieces can be 'stitched' by ultrasound, high-frequency current or laser rays. The fibers make a firm union with one another (the glue is only ideal when it is not there).

Changing objects in the arts. Before Michelangelo, artists and sculptors would often use the biblical subject where shepherd David triumphs over Goliath. David was traditionally depicted as treading on the vanquished giant. But in 1504 in Florence, Michelangelo erected a statue of David without Goliath beside him. Because the subject was so popular, there was no point in encumbering the statue with the figure of the giant. This way the 'function' of Goliath became even more frightening.

How the tool for transition to ideal objects is used:

1. Select the object to be changed.

2. Determine its main useful function.

3. Increase the degree of the object ideality:

- by transferring its function to other objects (Mass-Size-Energy consumption is zero);

- by transferring one/ some/ many functions of other objects to the chosen object (other objects disappear).

4. Describe the changes in the real situation and in the environment. What changes can be traced in the life of the person, the society and in the nature?

PATENT AGENCY OF SCIENCE FICTION

Many ideas generated by science fiction writers are nothing short of inventions. Dmitry Pisarev wrote that "If man were unable to envision the future in clear and vivid mental pictures, if man were unable to daydream, nothing would inspire the persevering ventures, the unrelenting struggle and even the sacrifices of humans made for the sake of the future."

In 1897 the following idea was described by Herbert Wells in his story *In the Abyss*.

Apparatus for deep-sea submergence. To increase the depth of submergence and duration of stay under the water the apparatus is made in the form of a watertight enclosure connected by wires and a cable to the vessel on the surface.

The first bathysphere was launched 14 years later, in 1911 and submerged 500 m under the water.

The author of the idea is V. Zhouravleva, story *Twenty Minutes Countdown* (1959): "The technique of prolonging the duration of stay under water: The body of the diver receives substances that decompose with release of oxygen."

The author of the idea is A. Bogdanov, novel *The Red Star* (1908): "A spacecraft that operates on the energy released by atomic decay."

5.5. INVENTIVE PROBLEM SOLVING DRILL

The meaning of drilling is to learn to purposefully use the theoretical tools such as S-Field analysis, contradictions, laws of technology evolution, and information databases. The motto is: "No guessing!" Otherwise, having solved dozens and dozens of problems by trial and error you gain no creative potential at all. With TRIZ, each problem will involve exploration and mastering of one universal rule which will be a key to a whole class of other problems.

Please also keep in mind the problems solved earlier. Now they are a part of your information database. The examples that illustrate theoretical material are not taken at random; they are typical specimens of present-day inventions. TRIZ calls them *similar problems*, i.e. the patterns that will later give analysis-free solutions.

At the present stage of learning, the following solution strategy is advisable:

Phase 1. Solution via simple analysis.

1. Use of similar problems.
2. S-Field analysis:
   a) determine to which class of S-Field transformations (synthesis, destruction, development) the problem belongs;
   b) build the S-Field model, trace the missing components, harmful links and malfunctioning parts;
   c) successively follow recommendations (S-Field formulas) of the necessary class.
3. Use the rules of application of the first two laws of technology evolution.

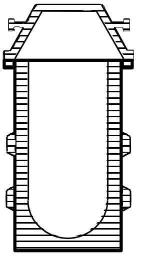
Phase 2. Problem solving via further analysis.

1. Use STC operator;
2. Go through steps 1 and 2 of ARIZ: process the initial situation, formulate a mini-problem;
3. Repeat the operations of the first phase;
4. Go through steps 3 to 8 of ARIZ;
5. Formulate the physical contradiction;
6. Use the Pointers to Effects index (see Appendix).

Problem 61. While shaving the client, the barber's hands should move quickly and accurately. But no one will allow a barber's apprentice to practice and pass tests on his own face. Give the idea of aт extremely low-cost device that adequately evaluates barber's performance. Essentially, this is a SFM synthesis task, where you have S_1 (razor) and F (the mechanical field of the hand that applies the razor). What is missing is... Draw the formula of the S-Field solution and think of the missing elements.

Problem 62. To repair the ingot moulds for steel (metal moulds where molten metal turns into an ingot) at the right time, one should know how many castings have there been since the last repair. The record-keeper usually logs each casting into a book. Think of a simple and cheap machine to perform mechanical recording of castings.

NOTE: Naturally, the recorder should be placed on the wall outside the ingot mould. What changes occur in the wall during casting? Each time there is a 'splash' of thermal field, which can be used for our purpose. Once the temperature goes up, the recorder registers one casting. Think of something sensitive to thermal field.



Problem 63. The tubular pins that link pistons with connecting rods in engines are made of expensive high-alloy steels. They have strengthened, well-polished surfaces with very inconsiderable deviations from standard external diameter. Nevertheless, in two seasons, the pins wear out by abrasion. When the margin of 0.01 mm is worn out, the pins are taken out and remelted. Millions of pins are so disposed of, only because their diameter is a bit smaller than the norm. To avoid remelting, engineers sought restoration methods. The following methods were introduced:

– expansion of pins with punches (columns driven into pins). One pin takes 34 minutes to process;

– chroming: a layer of chromium is built up on the pin surface using complex and expensive machines. In this case one pin requires 14 minutes;

– rolling: the pin is heated up to high temperature, put on a mandrel and rolled like dough. The method uses expensive and bulky machines; it is hard to trace the moment when the procedure should be stopped.

The above-described methods did not allow to increase the output of restored pins by more than 10 percent.

So, we need a method to restore piston pins, i.e. expand their diameter by 0.01 mm. What do you suggest?

Problem 64. The towers of power transmission lines rest on firm concrete footings. The footing, in turn, should be erected on hard surface. In northern regions one cannot choose but place the footing on a rock of permafrost. The footing is constructed below the thin upper layer of permafrost which melts away in summer. But occasionally the summers may be unexpectedly hot.

Warmed-up concrete heats the ground and the tower may lose balance or fall down. In such summers, a team of workers looks after the towers from a helicopter. The helicopter soars above the tower and a worker gets down to test the ground punching it in some places with a primitive instrument – a steel sharp-pointed rod. One can easily be mistaken, because the rod sometimes hits against a rock or a fragment of concrete. A reliable and simple method to test the depth of molten soil is needed. The method should not require manual labor. For example, a helicopter flies over the power transmission line and collects the results, or a red light on the map flashes on the operator's desk which means that the repair team should be sent to a certain tower. What do you suggest?

Problem 65. The aerial power line runs through an area where sometimes high temperature is observed. The heat causes the wires to stretch and sag dangerously close to the earth. If tightening compensators are used, the construction and maintenance of power lines is much more complex and expensive. It was suggested to make the lines 5-7 m higher, but again this would raise the cost of construction. What can be done?

Problem 66. During electric carbonization of coal the air is blown from below through a layer of lump coal placed on the bar screen. On the bar screen there is a layer of big lumps of coal and over it a layer of smaller lumps. The big lumps prevent the smaller ones from falling through the screen. But because coal is combustible, the big lumps ignite and heat the screen which should not be heated. If the layer of big coal lumps is replaced with non-flammable materials (quartzites, phosphate rocks, calcium carbonate), the screen is not overheated but the protective layer mingles with the coke (the final product). What can be done? Solve the problem using S-Field formulas.

Problem 67. Deficiency or excess of microelements in the pasture soil is often a source of diseases among cattle. The most important microelements for cattle are copper and molybdenum. They should be added into fertilizers or irrigation water in strictly measured and very low proportions. How can this be done? Factory-made microelements are supplied in grains of different size produced by grinding big lumps of molybdenum, copper or their alloys. It is practically impossible to mix the grains with fertilizers in required proportion. Therefore, one can never be sure whether the plants will receive the required portion of microelements. Some of the plants will get an excessive amount, some will be under-fed. The proportion of microelements should be so small that there is no point in rubbing the grains to powder; it will still be impossible to disperse them equally. That means that mechanical field (grinding) is not acceptable. What about using the magnetic field? But copper and molybdenum are devoid of magnetic properties... We need a field that delivers the micro-particles in strictly defined proportion into the irrigation water.

Problem 68. The laser rays used in surgery may cause a lot of trouble. Reflected by bright surfaces of surgical instrument, the powerful infrared ray penetrates even through clothes and causes burns, ignites tissues and clothes. What can be done?

Problem 69. School blackboard may be a good object of modification. Successively apply the TRIZ rules and ICI tools studied, trying each time to get a new idea (some rules can be skipped). Each time you set higher demands: the blackboard should either get new functions or increase its useful function.

Problem 70. A Canadian company markets a machine for in-operation testing of depth of refractory lining in steel converters. The machine consists of a laser, a testing head, a display, a control unit, a cantilever and a computer. The laser fixed on the cantilever is put into the converter. The lining reflects the laser ray and casts it onto the testing head. The signal is then processed by the computer and the depth of the lining is determined to an accuracy of 10 mm.

The system is expensive and bulky; the laser's presence in the converter makes it less durable whereas the accuracy leaves much to be desired. The system appears to be a typical 'electronic dinosaur'. The properties of the system are not used (thermal field, properties of liquid steel, the lining itself could signal its wear and etc.). What do you suggest?

FROM THE HISTORY OF INVENTIONS

In 1877, George Eastman, a bank clerk, decided to make extra money to his meager income and took up a homework. At home he covered glass photographic plates with gelatin. This monotonous job only brought one dollar per evening. Need made Eastman an inventor. Two years later he patented a machine that accurately covered glass plates with a layer of gelatin. Now the plates could be mass-produced.

Seriously involved in photography, Eastman came up with a simplified lightweight camera that used 10x12 cm frames. He arranged a production line and sold his cameras for $ 12 each. Press photographers were among his frequent customers. Once, a press photographer, praising the new camera, complained that changing of the plates was still a nuisance. Despite many attempts, Eastman failed to come to improve the camera.

The solution was found by H. Goodwin, priest and an amateur photographer. In 1887 he invented the plastic film of transparent cellulose nitrate and offered it to Eastman. The principle turned out to be excellent: the film took the light-sensitive layer much better than plates. This is how the film roll came into being. Eastman found a way to improve its light-sensitivity and set out to design a roll film camera. Trying to help his photographers, Eastman also invented the shutter for short exposures.

Finally, at the beginning of 1888, the first ‘Kodak #1’ roll film camera appeared. The wooden box only weighed 300 gram and measured 15x10x8 cm. The shutter could make several exposures, fragments of a second each. The film had 100 frames, more frames that are used in present-day films. The new cameras became so popular that Eastman had to open a whole factory. Most newspapers started using Kodak as a fast and reliable method.

Eastman was also the first to set up a photography service agency. He published leaflets informing that anyone could bring their Kodaks to one of the studios located all over the country. Anyone could have their cameras recharged with a new film, the film developed, and the snapshots printed and put into carton frame. It was in those days that the company slogan appeared:

You push the button, we do the rest

6. LOOK FOR HARD TASKS

6.1. IN A SINGLE RHYTHM: THE LAW OF COORDINATING RHYTHMS

The third law ensures viability of technical systems:

The law of coordinating rhythms of the system's parts: prerequisite to viability of a technical system is coordination or purposeful de-coordination of vibration frequencies (periodicity of operation) of all parts in a technical system.

This law is easy to understand: nothing in this world remains at rest. But among all things, technology is the most dynamic: every part of it is moving constantly, that is, vibrating at a certain frequency. This is true even of monolithic foundations, buildings and etc. From this perspective, all systems and their parts can be divided into those that vibrate '*properly*' and those that vibrate '*improperly'*. Correct operation and, consequently, good viability, is characteristic of those systems only, where vibrations are so selected that the system parts do not interfere with one another and the useful function is delivered in the best possible way.

Two kinds of vibrations are differentiated: *natural* and *forced*. In other words, a part either vibrates 'as it pleases' or 'as it is forced to' by an external force. Natural frequency of vibrations is an integral feature of any system's part; it depends exclusively on the object's own characteristics (dimensions, mass, elasticity of parts in mechanical systems, capacity and induction characteristics in electric systems, etc.). But, most interestingly, an external force/field effect may coincide in frequency with the object's own vibrations, giving rise to the well-known resonance effect. Resonance may be either useful or harmful. Therefore, to improve system's performance it is necessary to coordinate/de-coordinate the vibrations of its parts.

Utilization/prevention of resonance is a very promising tool: using this tool technical system operation is optimized through mere modification of the characteristics of its components (dimensions, mass, frequency). Nothing is introduced into the system. But in reality the above law is often ignored; that is why we encounter numerous technical solutions where rhythms are either ill-proportioned or not coordinated at all. Consequently, a whole class of problems deals with establishing a 'lawful' order in 'improperly' vibrating systems.

Problem 71. Circular saws are so noisy in operation that workers are advised to wear special sound-absorbing headsets. The invention described in Soviet Patent no. 519 320 is an attempt to find a way out: it is recommended to install spring-loaded pins with balls pressing to the revolving disc of the saw. This solution is a specimen of an unresolved technical contradiction: to eliminate vibrations the pins should squeeze the disc as tightly as possible, but to allow the disc to rotate freely, the pins should not be used at all. Moreover, the balls and the spring get clogged by chips and soon cease to operate. What can be done?

The law of rhythm coordination provides a series of rules:

> **Rhythm coordination rule one: in technical systems, the field effect should be coordinated/de-coordinated with natural frequency of the artifact/instrument.**

Examples of rhythm coordination (use of resonance):

- Soviet Patent no. 996 347: method of cutting glass by making notches on the surface and exciting vibrations of the frequency equal to the natural vibration frequency of glass. In other words, instead of tapping on the back side of the notch it is suggested to insonify the glass and this way make it crack along the notch line all by itself.
- Soviet Patent no. 940 714: method of microwave melting of crystallized honey in honeycombs. The microwave field frequency is equal to the resonance frequency of water dipoles. Because heating might decrease the quality of honey, it was suggested to heat only the molecules of water in it.
- Soviet Patent 639 546: method of local heating of neural fibers by thermal field varying in one rhythm with breathing;
- Soviet Patent no. 1 163 853: vibro-machine heart massage in the rhythm of heart contractions.
- Soviet Patent no. 1 175 778 describes a primitive and yet effective railway alarm system that signals that a train is approaching the station. The device consists of an enclosure, bar, membrane and horn resonator. The enclosure is fixed on one rail; the buzz of the rails is enhanced by many times.
- The same ‘resonator’ principle was once used in concert halls. In 1912 Fyodor Shalyapin, prominent Russian singer, came to see a such hall built in the town of Kamenskoye. When he took a high note, the candles in the sconces and wall lamps suddenly went out. The secret of the hall was discovered relatively recently. The walls and the ceiling are laid with glass fragments and under the floor there is a layer of bottles. These small resonators are tuned to a certain high frequency and at one moment they create a strong sound wave which puts out the lights.

Examples of rhythm de-coordination (anti-resonance).

- The circular saw squeaks because of the equal intervals between its teeth. The emerging sound waves sum up and create strong resonance vibrations. To eliminate resonance it is enough to locate the teeth at unequal intervals from each other or bend them at different angles of the plane of cutting.
- Soviet Patent no. 714 509: Wind shakes the wires of electric power lines. If the gusts coincide with the line’s vibrations, the wire may

break. To prevent wire breakage, one wire should be of a larger diameter than the others.

- During the WWII, the ice road to besieged Leningrad across the Lake Ladoga, – the famous Road of Life, – was under constant shelling of Nazi troops. Suddenly the thick winter ice began to crackle all by itself under the endless column of lorries. Physicists found the problem very quickly and suggested that the passing gap between lorries should be changed to dampen the emerging waves.
- An effective way to avoid resonance is to use swinging solid elements with displaced center of gravity. For instance, Soviet Patent no. 673 995 describes a pressure regulator with a weight with displaced center of gravity that dampens vibrations. The same principle is realized in the construction of two 520 m tall sky-scrapers (USA): a massive sliding counterweight is placed on the top floor of each building.

<u>Rhythm coordination rule two</u>: frequencies of fields used in technical systems should be coordinated/de-coordinated.

Examples:

- UK-produced silent fan has a built-in microphone and a loudspeaker: the droning of the motor and the blades is trapped by the microphone, transformed electronically into sound of the opposite phase and then reproduced by the loudspeaker. The drone is fully neutralized.
- In Japan this principle was applied in an original way. In spacious exhibition halls, hotel lobbies and airports it is necessary to broadcast simultaneous announcements for different parts of a room. Imagine the havoc occurring when dozens of loudspeakers on the walls and the ceiling begin to broadcast in different languages. What can be done? It was suggested to superimpose the voices of announcers onto ultrasonic oscillations generated by the loudspeakers (modulation). Each loudspeaker emits two oriented ultrasonic beams with opposite phases. The beams meet at a chosen point of the hall and dampen each other, leaving only the voice of the announcer.
- Powerful seismic waves of earthquakes are prone to resonate with natural vibrations of high-rise 8-15 storied buildings. This situation was once observed in Mexico (1985). Soviet Patent no. 1 067 147 suggests a method of dampening seismic vibrations by an underground screen made of magnetic permeable substance through which electric field impulses are transferred.

<u>Rhythm coordination rule three</u>: if two effects are incompatible (e.g. transformation and measurement), one effect should be exerted when the other effect pauses. More generally, a pause in one effect should be filled by another effect.

Examples:

- Teletext systems are used in many countries. The text signals are hidden between the frames of TV programs.
- Soviet Patent no. 343 722: lateral expansion of metal sheets is performed when longitudinal expansion pauses.
- In 1916 Anthony H.G. Fokker, famous aircraft designer, solved the problem of shooting through the airplane propeller by coordinating the speed of the engine shaft and the speed of machine-gun shooting (bullets fly through the gaps between the propeller blades).

RESONANCE IN MEASUREMENT PROBLEMS

Natural frequency of vibrations is a universal indicator. If we cause a body to vibrate and continuously change its frequency, resonance will occur at some point. Incidentally, resonance frequency reflects other characteristics of the body. For instance, we can measure weight without actually weighing the body:

Soviet Patent no. 271 051: method of measuring the mass of liquid in a reservoir by measuring the resonance frequency of the reservoir;

Soviet Patent no. 244 690: method of measuring the mass of a moving thread by measuring the resonance frequency of the leg between two rollers that guide the thread;

Soviet Patent 560 563: method of measuring the degree of emptying of cow's udder under mechanical milking by measuring the resonance frequency of the udder.

What if it is impossible to excite vibrations in the object? In this case the state of the object is determined by the change in natural vibrations of another object attached to it (or of external environment). Most often, air is attached.

For example, Markoni Avionics company has developed an instrument for measuring the level of coal in a bin with a depth under 80 m. According to technical specifications, the instrument consists of a coherent radar, microprocessor, display, control desk and other components. On the whole, the device appears to be rather complicated. Since old days doctors examine patients tapping on their chests. The same principle is used in the universal method of measuring the volume of loose or liquid materials in a reservoir by measuring the volume of air above them (Soviet Patents no. 321687, 507 781). One should simply insonify the reservoir, measure the frequency of the air and, using this figure, calculate the volume of the air, and consequently the volume of the material.

6.2. SOLUTIONS BY THE RULES: DYNAMIZATION TREND

Sometimes TRIZ is said to have accumulated the creative experience of several generations of inventors. This is only partly so. True, in the very beginning, TRIZ heavily relied on generalized community creative experience. But this experience did not go further than application of simple tools. TRIZ fundamental concepts such as technology evolution trends, S-Fields, and contradictions could not be derived from inventive practice because they lie beyond the 'selection-of-variants' tactics or morphological analysis.

Development of TRIZ went hand in hand with accumulation of extensive data on problem solving strategies in various branches of engineering. As it turned out, totally different problems may have strikingly similar solutions. Thus a system of standards (standard solutions, or Inventive Standards) was developed. The rank of standard is only conferred upon those combinations of tools and effects that insure high-level solutions for their classes of problems. We have studied some of these standards (S-Field analysis, rules of application of technology evolution laws and etc.).

Standards directly employ the laws and trends of technology evolution. Another trend of technology evolution is the **Dynamization Trend**.

Dynamization Trend: To improve their performance, rigid systems should become dynamic, i.e. pass to a more flexible and rapidly changing structure.

The standards (rules) offer detailed how-to procedures. As a result, a problem that 'cost' a thousand attempts now turns into a problem that requires checking on a few variants. And these few variants are of different kind. They are not the vague inventive ideas that are so hard to generate and even more hard to evaluate. Here, you only have to consider a few specific variants of how to best apply the answer to the problem at hand.

The Dynamization Trend articulates the desirable changes in the system so clearly that in some cases there will be no duality of decision: the solution becomes obvious.

The Dynamization Trend determines two standard strategies for making a system more dynamic:

***1). Dynamization of system substance*. Dynamization usually starts with dividing the substance into two parts connected by a hinge. Further on, dynamization proceeds in the following order:**

one hinge – multiple hinges – flexible substance – liquid – gas;

Sometimes dynamization terminates at replacing a link via substance medium by a link via a field medium;

2). Field Dynamization,* in the simplest case is realized as a *step from continuous effect to impulse effect.

The Dynamization Trend (as well as other TRIZ laws of technology evolution) allows to simplify not only the process of inventive problem solving but also the search for problems. Knowing the laws of technology evolution you can envision and clearly formulate inventive problems. If we know that any technical system goes through dynamization, we should determine at which stage of evolution the system is now, and then make one step further. The only difficulty is finding the 'sore point' of the technical system. Here, you should be aware of one simple rule:

The first part of the system to be dynamized is the part which stays under the strongest impact of factors which hinder its evolution.

These factors may be of natural or social nature, or may originate from other technical systems. In the simplest case it is a force that tends to break a part of the system. To protect this part, one should put a hinge in this place.

The household iron may serve as an example. Most often the integrity of its wire is broken at the point where the wire exits the enclosure. The wire is damaged due to twisting and excessive bending occurring when the iron is moved. The wire is broken by the force of the hand. Therefore, the first dynamization measure is installation of a hinge joint between the wire and the iron. This solution was offered in Soviet Patent no. 1 161 614. Amazingly, this invention was only made in 1985 and arrived a few decades late! The society pays dearly for ignoring the laws. Many similar mistakes can be cited from any branch of engineering, including the most 'sophisticated' areas.

Dynamization of the wire can be continued. The order of dynamization suggests the following steps: multiple hinges (if the whole wire consists of hinges, it will never get twisted) – flexible wire (though flexible already, the wire should be made **absolutely** flexible, flexible as a silk thread) – liquid wire (a perfect exercise in fantasy development!)… Of course. it is not obligatory to cover all the dynamization stages; some of them may be skipped. Nevertheless, the inventor should always strive to go all the way to the end. What about changing the wire for a field? – A bright solution, the underside of the iron can be made of ferromagnetic substance; a source of electromagnetic field can be placed nearby (on the ceiling, on the table). The field should be operating under pulsed conditions (due thermal inertia of the iron, the field only needs to be applied from time to time). Here we use the Curie point and so on, generating a whole series of inventions previously unknown to patent experts. However, these new systems are not perfect. For example, the field will heat not only the iron, but also the rings on your fingers, metal buttons and other objects. What can be done? Think of another field and another substance (semiconductors and microwave field, ferriclectric, etc.).

Examples of introduction of one hinge:

- French building crane model with a vertically adjustable cabin. The cabin facilitates the work of the crane operator providing a wider view while handling loads.
- Soviet Patent no. 742 639: nut with detachable thread. When the nut is removed from the bolt, the thread can be easily taken off without screwing it out.
- Soviet Patent no. 134 226: rotating skirt for performing feats in dancing (the skirt's belt consists of two parallel belts. The external belt is fixed to the skirt and can turn freely relative to the internal belt).

Examples of introduction of multiple hinges:

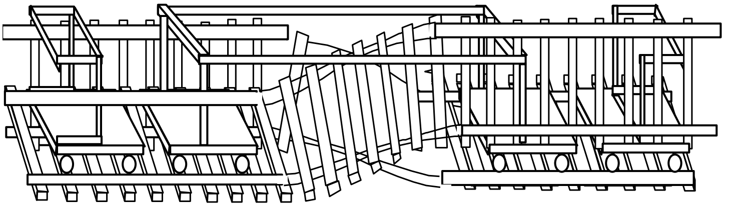
- US Patent no. 3 561 679: nozzle of jet engine in the form of a telescopic sliding tube which expands before the plane takes off, and collapses before transportation.
- Soviet Patent no. 497 381: anti-seismic house on cone-shaped hinges located between the frame and the columns of the basement.
- Finnish machine for clearing off small trees and shrubs on forest roads, through-cuts and hill slopes. Normal blades tend to break when they hit against rocks. Instead of blades, the new model uses a chain (the chain revolves at hundreds RPM, eluding the rocks and cutting the shrubs).

Examples of introduction of flexible components:

- Soviet Patent 965 789: instrument for treatment of blind holes. The instrument consists of a spring with diamond grains inserted into the edge coils.
- Soviet Patent no. 994 153: drill made of a multi-layer band coiled into a spring.
- Soviet Patent no. 889 113: filter for gases and liquids made in the form of a spring that has small gaps between the coils. The flow passes through the spring, leaving contaminants entrapped in the coils. When a critical amount of contaminants is accumulated, the pressure inside the spring increases and stretches the spring releasing entrapped particles.

- Solution to the problem of wave erosion of shores (USA). Sooner or later, massive coast-protecting concrete structures get destroyed by waves. Therefore it is better to plant artificial algae made of environmentally-friendly polypropylene. The algae are attached to a tube anchored near the shore and entrap sand particles. The drift builds up sands by 5-7 cm every day and the algae dampens the energy of waves.
- Mirrors with variable geometry are now widely used as rear-view mirrors, solar power stations and telescopes. Behind the flexible mirror surface there is a pneumatic or vacuum chamber with variable pressure.
- Soviet Patent no. 1 069 662: working unit of centrifugal fertilizing spreader. To spread fertilizers more evenly, the angle of the blades should be adjusted. The blades are positioned on an elastic liquid-filled chamber. The blade angle is adjusted by changing the amount of liquid in the chamber.

In this context it should be borne in mind that there are no absolutely rigid structures: any structure can be bent to a certain angle. Hence a useful tool: to add flexibility to a rigid element one should stretch it. For example, when pipelines are constructed, hundreds meter long pipes should be joined. But the head of the automatic welder can only turn for a quarter of a round. The entire pipeline cannot be rotated, so it is impossible to weld the underside of the joint. Soviet Patent no. 340 495 suggests that pipes be turned through 180 degrees because the line is so long that twisting will not damage them. The same tool is used in Soviet Patent 901 377 featuring a design of a rail builder that removes old rails and sleepers and lays new rails. Each section of the road is 800 meters long, so the rails can easily be bent into a spring and placed on the same platforms.



Dynamization of the telescope and other optical instruments turned out so effective that it developed into a new branch of science: adaptive optics (i.e. optical instruments that adapt to changes in the environment such as temperature, the changing position of the Sun and etc.). Among recent developments are membrane mirrors acquiring parabolic shape, liquid lens with adjustable zoom and even liquid telescopes which, instead of mirrors, use rotating liquids such as mercury.

BEST BAR IS NO BAR

Soviet Patent no. 1 020 141 describes a crossbar for high jumping. Instead of simply falling down the bar divides in two halves if the gymnast jumps too low (the two halves turn and cling to the uprights). A task for you; continue dynamization of this design.

A LONG FILE OF DUMMIES…

In tailor's workshops and fashion studios you always see a file of mannequins of all sizes and heights. When new clothes models are designed, the mannequins have to be resized to meet the necessary body shape. For this, designers use straps, wadding and etc. Then they adjust the new model for size and make pieces of fabric. What can be done?

DYNAMIZE A GYM

The ordinary springboard for jumping is a rigid structure. The only way a gymnast can adjust it is by stepping closer or farther from the jumping apparatus. It is not surprising that Soviet patent no. 618 118 appeared: the springboard is adjusted for stiffness by tightening/loosening the nut of the torsion spring placed between the base and the platform of the springboard. What is faulty in this design?

Gymnasts with different weights are put in unequal position, because during a tournament the stiffness of the springboard remains unchanged. Is it possible to design a springboard with variable stiffness that meets the weight of each gymnast?

HOW TO BEND A CRYSTAL

We usually think that crystals are breakable. Is it possible to bend a crystal (which is necessary for some instruments)? Specialists in strength of materials say that, in theory, crystals can be bent by a small angle. But to accomplish this we need to find a way to distribute the bending force absolutely equally throughout the surface and avoid cracks. How can this be done?

6.3. USE OF RESOURCES

Let us say it once more: every object possesses an infinite number of functions and properties, but its main function can be delivered by an infinite number of other objects.

The ability to see at least a part of these properties and functions (the more, of course, the better) is an important skill of advanced thinking. That being so, the theory should contain specific recommendations as to how not to overlook useful properties and functions, and where to seek them. The tool discussed below is called **analysis of substance and field resources.**

> **Resources are everything that remains idle in the technical system and its environment.**

The lack of ability to see resources is a vivid feature of mental inertia. On the whole, mental inertia has a number of characteristics:

- For the most part in the history of engineering, new functions of technical systems were developed through introduction of new substances and fields. This fact can be explained by the lack of variety of materials in the old days. Besides, the properties of materials (e.g. wood, stone) were hard to change. It is only in the past decades that technical systems started to be composed of a great variety of substances. These substances are not only able to perform mechanical work but also possess physical, chemical and biological properties. Extra properties of traditional materials were either unknown, or overlooked. The designer is used to considering and using one main property of the material.
- All engineering methods give detailed recommendations on how to withdraw wastes (excesses) of energy from the system. The wastes should be removed, otherwise they hinder the system's operation. But the label 'harmful factor' is strongly fixed in our minds. That is why, an electronic engineer may introduce a special heating subsystem for a certain component of the apparatus, ignoring the excessive heat that he/she was striving to get rid of at the previous stage.
- Rapid scientific progress has created the illusion that technical means can do everything. This may be true, but not always applicable. The misconception that every new function should be realized by technical means brings about uneconomical technical systems whose function might well be delivered by natural objects. There were times when natural forces (wind, water) were the only resources used by man. But nowadays these free-of-charge resources are often discarded. The rule that "the less technology, the better" (i.e. we should strive to use ideal systems) should become the guiding principle of engineering evolution. The reason for that is simple: once introduced, every new component begins to

contribute to energy consumption, often making the system less reliable and controllable and causing recycling problems.

Problem 72. Trawls are dropped from the ship on steel wire ropes. The ropes should be paid out from the winches simultaneously. If one rope goes ahead of others, the trawl may become unstable and cause a lot of trouble. The length of uncoiled rope is measured in the following way: at each winch there is a duty operator watching the hemp beads on the rope and signaling how many meters of rope are gone under the water. The method works in good weather and if there is no heavy pitching. But even so mistakes can be made: ropes get stretched by heavy loads. What can be done?

This problem was solved relatively recently: magnetic marks are put on the rope at equal intervals. The pulley registers the marks and the indicator displays the length of coiled/uncoiled trawl warp. The wire meter is more simple than a tape-recorder and uses similar magnetic heads. For decades mental inertia did not allow to see this, however evident, property of steel wire rope.

Problem 73. It is dangerous to transport turbojet engines on railway flat-cars. The jogging motion of flat-cars caused by rail joints may damage the rolling bearings on which the rotor rests. To avoid damage, the rotor should be rotating all the time, at least slightly. What can be done?

What resources can be used to make the rotor rotate? Apparently, anything: the wind, the Sun, the spinning of the flat-car wheels, etc. Soviet Patent no. 299 700 suggests to use the energy of the kicks caused by the rail joints. A pendulum with inertial mechanism is suspended from the engine; the kicks and waving of the flat-car are transformed into rotary motion that turns the rotor.

The same principle has helped to solve another serious problem of our days. How can we inhibit corrosion on steel gas pipelines that are thousands of miles long? The best method is cathodic protection. Applying 1,5-2 V to the pipe (the pipe has a negative sign, the earth has a positive sign), we practically get rid of corrosion. But to use this idea we need a great number of cheap, safe and service-free sources of power. Diesel power plants, accumulators and batteries are neither safe nor suitable to use in hot or cold climates. The only satisfactory resource is mechanical or chemical energy of gas itself. The most primitive source of power uses a thermocouple, a junction of two semiconductor alloys (bismuth-tellurium and antimony-tellurium alloys). Heating the junction we excite a direct-current electromotive force at the loose ends of the couple. The source of power can be placed at the pipeline together with a mini-burner. The system works automatically and needs to be tested once in a decade.

Thermocouples (junctions of dissimilar metals) are widely used as temperature-sensitive elements. If you are familiar with this property of thermocouples, you can always get weak electric current wherever you have a source of 'cheap' heat.

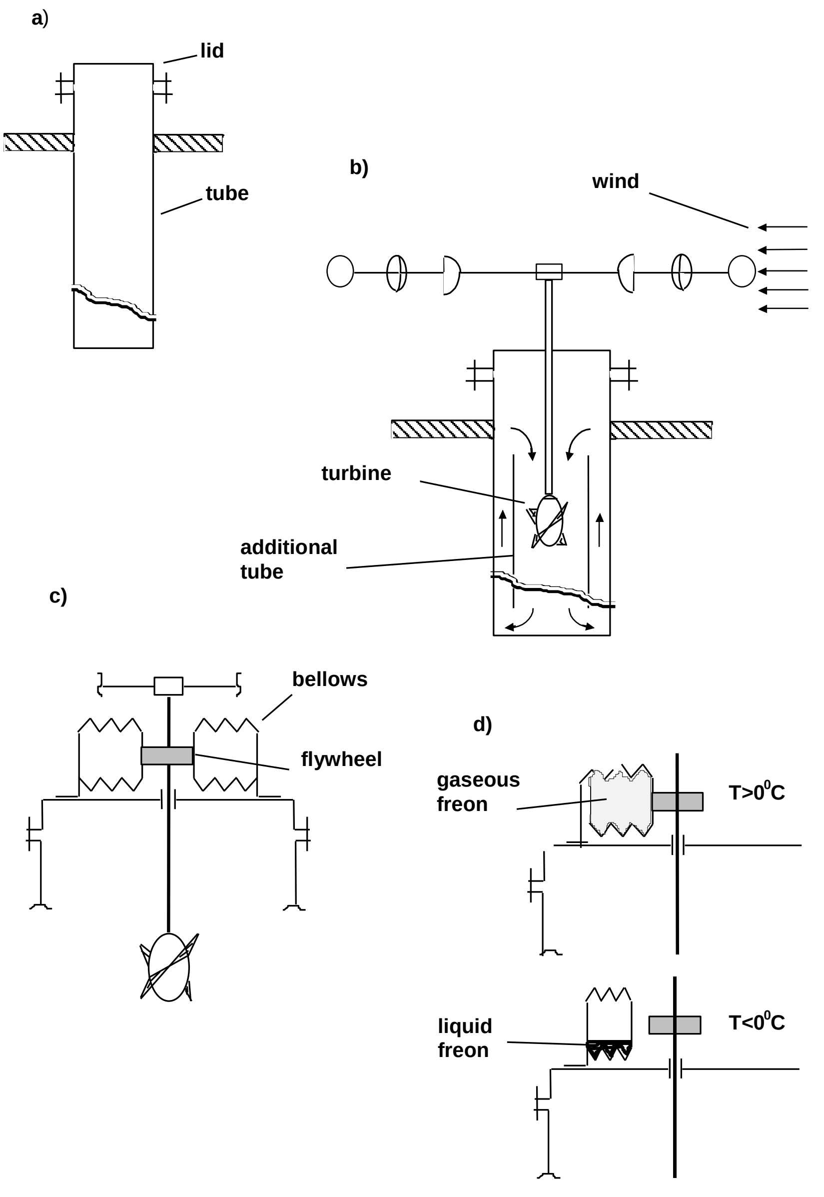
At a factory a group of engineers decided to play a practical joke on a trainee. They asked him to test 1000 galvanometers before the lunch break ("You know, they need it urgently!"). Each galvanometer should be carried to the test rig, connected to the source of power; this way the work would have taken at least a week. But the trainee decided to get even his seniors. He took a thermocouple (the warmth of the hand gave rise to a potential difference at the ends) and walked about the racks with galvanometers, plugging the ends into the clamps of each instrument and putting aside the burned-out ones. Half an hour later the work was done…

The technosphere is saturated with energy, though, as a rule, this energy is dissipated. Nonetheless, this energy can be used sometimes. For example, timepieces using radiowave energy are marketed in Japan.

Sometimes we can benefit from the turnover of natural resources.

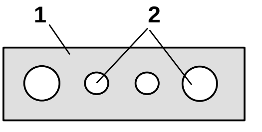
In northern areas, it is necessary to monitor the ground around the basement of the buildings. The ground there should not melt below a specified depth (constructions are erected on permafrost which, when frozen, is solid as rock, but once molten, turns into a "squash"). For that, additional cold should be accumulated. A well with a lid is made in the ground. In winter the lid is removed (accumulation of cold); in summer the lid is closed (the upper flow of warm air does not mix with cold flows below) (see Fig. a).

To improve cold accumulation it was suggested to set up a system of forced ventilation of the well. The upper part of the well tube contains an impeller which drives the air downwards. The impeller is driven by a primitive windmill. Wind is another boundless resource available freely (see Fig. b). What should be done in summer?


a)
lid
tube
b)
wind
turbine
additional
tube
c)
bellows
flywheel
d)
gaseous
freon
T>0⁰C
liquid
freon
T<0⁰C

The generator should be switched off by somebody; we need a person to take care of it. But the systems should rather work automatically: in cold weather the generator is turned on, but when the temperature exceeds a certain value (e.g. 0 ^{O}C) the generator is turned off automatically. What should be done? We need an automatic brake to restrain the axis of the generator in summer and release it in winter. The brake should use the temperature difference – another resource available free of charge. Obviously, here we deal with a T-S-Field (an SFM that uses thermal field). Bimetal or a material with memory shape effect is needed. Automatic bellows is another effective solution. Bellows is a corrugated airtight cylinder made of elastic material and filled with liquid that has a low boiling point (e.g. freon) (see Figs. c and d).

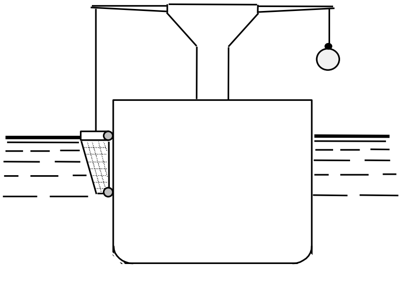
In places with a lot of ice, ice is the best building material. It was suggested to make ice pipelines, placing lightweight hoses into a trench and filling the trench with water (Soviet Patents no. 1 146 360, 1 780 848). Ice can be a building material for different constructions (see Soviet Patent 861 164), including sea ships.



1 - ice,
2 – lightweight hoses

Typical examples on using external environment:

Problem 74. Deck cranes differ from ordinary building cranes in that they do not rest on a firm support and may cause the whole vessel to tumble down while transporting a heavy load. Therefore, an intricate counterbalance is needed: as the crane boom carries the heavy load away from the center of gravity of the ship, the counterweight on the opposite side of the ship should be increasing. During reverse movement the counterweight should be decreasing, i.e. it should not be constant and vary, at times increasing, and at times disappearing. What can be done?



The problem is rather simple. Logically, the counterbalance should consist of water (Soviet Patent no. 1 202 960). On the opposite board of the ship there is a vessel (pontoon) with water. When the vessel is fully submerged in water, the counterweight is zero; hoisting the vessel from the water we can regulate its weight.

Problem 75. A chemical plant is in constant operation. The plant consists of two pipes, one inside the other. The space between the pipes is filled with circulating liquid which neither conducts electricity nor has magnetic properties. It is necessary to determine the speed of its spiral motion. The liquid cannot be heated or cooled. The pipe should not be opened. The plant should remain in operation. The pipes are made of glass, the spacing between them is 20 mm thick.

The problem is by no means easy. Its solution requires detailed analysis, elucidation of the contradiction, formulation of physical contradiction and its resolution.

To resolve the physical contradiction, we shall study another crucially important kind of resources: **void**. Naturally, no void exists all by itself; it is created in readily available materials and substances.

The physical contradiction is as follows: the spacing between the tubes should contain an indicator substance that helps to measure the flow speed and at the same time there should be no substance, because no substance may be introduced. Hence, we speak of a non-substance, or a void. Here is a model resolution of physical contradictions of this kind: a void can be obtained with the help of cavitation. Bubbles will originate in the focus of an ultrasound ray. Having spun several cycles with the liquid, the bubbles will disappear.

Problem 76. New models of parachutes are tested in a tunnel through which water is driven. The cords of the parachute are covered with paint because painted cords allow to make pictures of vortices that originate in the flow. But the thicker the coat of paint, the more distorted is the picture of vortices, although thick-painted cords are more durable. Besides, the thickness of the coating is changing constantly (melting of the paint), which increase the distortions. It is impossible to make cords in the form of pipes. What can be done?

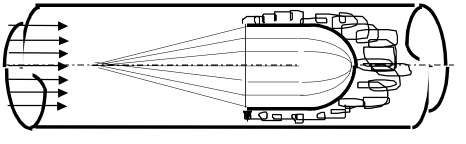


Fig. 27

Another difficult physical contradiction: the paint should be there and should not be there. Here again, the most ‘tricky resource’ – void – should be used. Bubbles can also be obtained through electrolysis (the cords are connected to one pole of the power generator and water is connected to the other pole).

Problem 77. Further experiments have shown that at low flow speeds, the bubbles come up and the experiment does not work. What can be done?

Here we should make a simple change in the technical system: the tunnel should be put horizontally and the bubbles’ movement will not affect the picture.

Problem 78. When new models of parachutes were tested (parachutes with canopy of variable geometry, pockets in the canopy, double canopy, etc.) the bubbles began to distort the picture of the flow. Flow separations and collisions of vortices caused bubbles to join and form gas cavities, folding the canopy. An even more ideal paint is needed; no void can be introduced. What can be done?

Since nothing can be introduced, the signal should be delivered by the medium itself. That means that the only resource left is water. No problem, let us use it as an indicator. Specialists say sometimes that “only ghosts do not cast a shadow”. When heated slightly, water changes its index of refraction. If the cords are made of thin Ni-Cr wire and put under weak electric current, we get an ideal paint made exclusively of water. A ray of light passing through the tunnel onto a screen will create phantasmagoric scenes of high-speed flows, jets and vortices. This method allows to get exciting pictures: drops of cold water being drowned in warm water, the inner side of fire, the heat emitted by a body…

THE SECRET OF INTEGRATED CIRCUITS

Competing for markets, electronic manufacturers sometimes use dirty tricks, particularly industrial espionage. Development of a new integrated circuit (IC) is very expensive and time-consuming, but the costs may not be justified if your competitors succeed in copying your IC and producing it. Besides, integrated circuits cannot be patented, but is copyright-protected. It is not difficult to obtain a new IC; one can simply take it out from a new product. Though it is somewhat difficult to copy integrated circuits, a medium-size laboratory can do it. The IC is opened and cut into layers with the help of a special device (microtome). Each layer is photographed under a microscope. Copying is a fine work: the layers are sometimes positioned at a 10 mm intervals; one needs to make 5,000 pictures copying a 5 mm thick IC. Electronic developers are now facing a problem: how can integrated circuits be protected from copying?

Apart from business matters, let us consider this problem as a drill task. As an IC engineer, you have to answer two questions:

1. In court, how can you provide irrefutable evidence that it is you, and not your competitor, who developed the IC?

Of course, the IC should be marked, but the mark will be noticed by pirates as well. What can be done?

2. What should be done to prevent pirate copies of integrated circuits from working, or, better, to make them deteriorate instantly?

6.4. MODELING WITH MINIATURE DWARFS

The negative role of mental inertia in creative problem solving is observed by many students of creative mechanics. The importance of imagination is repeatedly emphasized. Although failures and success stories were collected from the history of problem solving, no proper methodological conclusions were derived from them. For example, here are two well-known anecdotes concerning imaginative thinking, associated with the names of Friedrich August Kekulé and James Clerk Maxwell.

Once Kekulé was traveling in a London omnibus, thinking of how to make a structural representation of benzene molecule (C_6H_6) that would account for the properties of benzene. Suddenly he noticed a cage with monkeys. The animals were running about the cage, catching one another by the hand. At one moment they got together and formed a circle. Each monkey got hold of a cage bar with a hind leg, the other hind leg being in the hands of another monkey, the tail waving cheerfully in the air. This way the monkeys formed a chain. It occurred to Kekulé that the chain circle was a perfect representation of the circular molecule of benzene. This is how the well-known formula explaining the rigidity of benzene circle came into being.

The other story is even more famous. It is about a mind experiment conducted by Maxwell while developing the kinetic theory of gases. In this mind experiment Maxwell imagined two vessels with gases of equal temperature. He wondered if it was possible to have one vessel filled with quick molecules and the other filled with slow molecules. Since the temperature is equal in both vessels, molecules will not divide by themselves: at each moment of time there will be a certain proportion of quick and slow molecules. With his mind's eye Maxwell saw the two vessels connected by a pipe with a shutter which was opened and closed by 'demons' – fantastic creatures of the size of molecules. Demons allowed quick molecules to pass into one vessel but barred the way of slow molecules into it.

These anecdotes are quoted by many authors. They come from two different branches of science. A question arises: can they be converted into a method and used purposefully?

Kekulé's story would usually be told to illustrate the role of randomness in science and inventive practice. Maxwell's story would usually support the truism that the scientist needs imagination.

Developing brainstorming in the 1950s, Gordon (USA) devised synectics, an original methodology of creative problem solving. One tool of synectics was *subjective analogy (empathy)*. The designer is trying to imagine the best way of using his/her own body to achieve the desired result. For example, what would you feel if you were to perform the function of a blade of the helicopter rotor? What forces on the part of the air flow and of the rotor hub would you experience? How would you feel if you were a bed?

Indeed, there may be cases where subjective analogy is useful. But far more often subjective analogy creates another insurmountable psychological barrier. Involuntarily, the person takes into account only those variants which do not affect him/her personally, discarding 'harmful' solutions like being cut, flattened, dissolved in acid, etc. In addition, the indivisible nature of human body hampers the imaginative process aimed at a profound change in the object. At the same time, only profound changes are real inventions.

TRIZ uses a more effective and universal method: **Modeling with Miniature Dwarfs (MMD).** Why are miniature dwarfs preferred to molecules, balls or microbes? Because modeling demands that tiny particles should see, understand and act as a group. Using MMD, the inventor uses empathy at the micro-level, identifying himself/herself with the image of tiny particles of substance. The strong points of empathy are retained whereas its drawbacks are gone.

Use of Modeling with Miniature Dwarfs (MMD):

1. Single out the part of the object which fails to perform the necessary conflicting actions. Imagine the chosen part as a 'crowd' of miniature dwarfs;

2. Divide the dwarfs into groups acting (moving) according to the problem conditions (i.e. badly);

3. Analyze the problem model (diagram with miniature dwarfs) and rebuild it so as to perform the conflicting actions, i.e. resolve the contradiction;

4. Pass on to a technical answer.

Usually, a series of diagrams is made: "**was**", "**should be**", "**is now**" (the first two steps are combined). Alternatively, only "**was**" and "**should be**" diagrams are drawn.

Let us consider the following problem:

> **Problem 79.** The most frequent accident that may occur in testing of super-flywheels (inertial energy accumulators spun up to hundreds of thousands RPM) is the breakage of the flywheel into parts. The flywheel is torn apart due to deformities in its material (cavities, rolls) and inaccurate workmanship. These parameters (deformity and inaccuracy) cannot be improved. That is why at the last stage of production process the flywheel should be balanced: the ironworker grinds off excessive metal and fills the places with insufficient metal. Balancing takes hours, sometimes days. What can be done?

What is the core of the problem? Balancing the flywheel we make it homogeneous but lose time. No time is lost without balancing, but the flywheel remains heterogeneous. To put it simply, heterogeneity should be there, because it is impossible to get rid of it by present-day methods, and should not be there to avoid breakage.

Let us intensify the contradiction: deformities are always there and the flywheel spins up to enormous speeds without bursting. This is *the physical contradiction.*

The point of conflict is any part of the flywheel. Let us represent it as a group of miniature dwarfs. The "**was"** diagram (Figure 28b) shows a few 'odd' dwarfs among the normal ones. The odd ones have stepped aside from their positions (e.g. # 1 in the first row; 2,3 and 4 are also in wrong positions). All normal and odd dwarfs cling to one another, but the 'force of attraction' among them is small as against the centrifugal forces.

In the next diagram, **"should be**" (Figure 28c): all the dwarfs are where they should be. No deformities are observed. The first idea: in order to get back to their places, the dwarfs should be free, unbound by other dwarfs. But being free, the dwarfs will be driven away at the very beginning of spinning (so that even strong magnetic fields will not help).

How can we set the dwarfs free, at the same time preventing them from flying apart due to spinning? This is easy to do: we place a protective wall (Figure 28d). But the wall may have deformities too… That's right, the wall may have the same defects as the flywheel (cavities, rolls). What will the dwarfs do? They should reshuffle and get the deformities balanced. Because they are free, why cannot they come together in places with cavities, and run away from places with excessive material? (Figure 28e). Another idea: the dwarfs should not be simply movable, they should be nimble and light.

Consequently, the answer to the problem becomes obvious: the flywheel should be made hollow and filled with powder, or, better, with balls. To enable the balls reshuffle quickly in the wheel under centrifugal forces, we shall pour oil on them (US Patent 3 733 923, self-balancing flywheel).

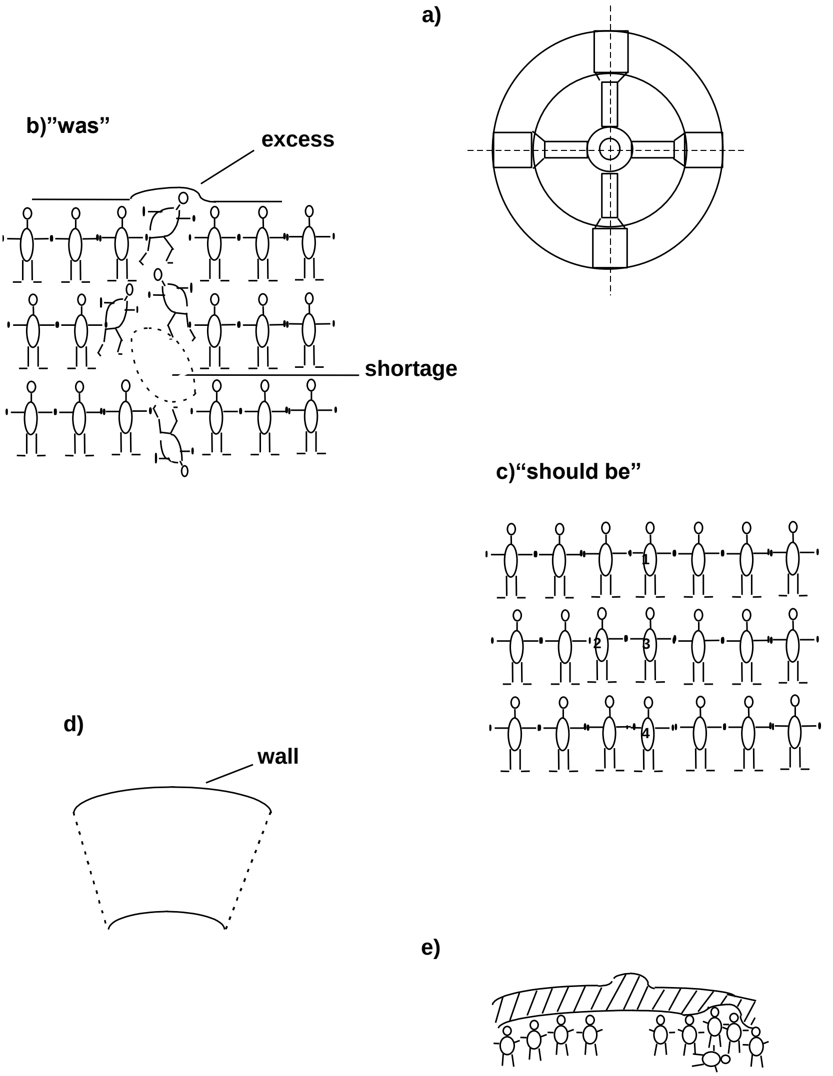
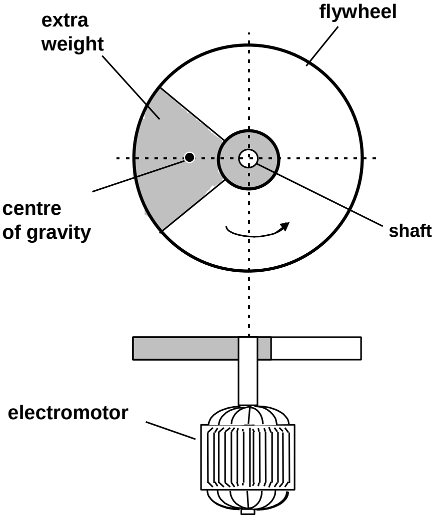


Figure 28. Modeling with miniature dwarfs

__Problem 80.__ Some vibration machines use unbalance vibrators: on the shaft of the electromotor there is an unbalanced mass – a flywheel with displaced center of gravity. The greater the extra weight, the more distanced is the center of gravity from the axis of rotation. That means a higher moment of inertia of the unbalanced mass and a higher efficiency of operation of the vibrator. But then it is more difficult to spin up the flywheel. One needs to install an electromotor with a power exceeding the required operation power by many times. The flywheel has a simple design: a hollow cylinder with unbalanced mass located inside. How can one provide high efficiency of operation at a minimal power of the motor?



Solve this problem yourself using MMD method.

The MMD method lowers down the mental inertia that stems from the usual visual image of the object. It reveals the physical lstructure of objects and the behavior of the object’s constituent particles. Using MMD you are more open to original solutions, since MMD models have no restrictions: everything is possible.

Essentially, MMD demands that there be many dwarfs in the picture.

Typical mistake: drawing one or several dwarfs. Only working with a large groups of dwarfs you can get a clear picture of how to resolve the contradiction.

7. IDEALITY

7.1. WAVES OF EVOLUTION

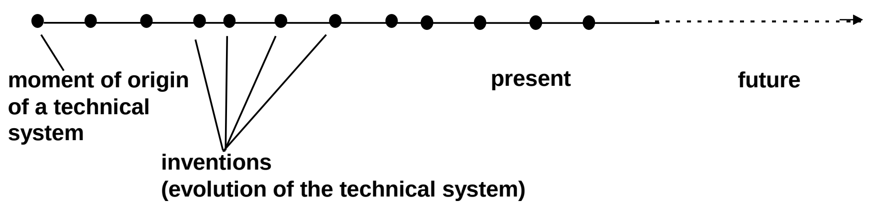
As we already mentioned, the principle of transition of a real technical system into an ideal one has an entirely materialistic basis. It is the main tendency of technology evolution, which has seen many examples in the history of technology and is true for all modern technical systems.

> **The main law of technology evolution: all systems evolve towards the increase of degree of ideality.**
>
> **<u>An ideal technical system is a system that does not exist but its function is delivered.</u>**

However, the method of changing a technical system into an ideal one (disappearance of the system) is much more complicated and difficult than the “magic” tool in the Creative Imagination Improvement course. Using the tool for the mental change of the object, we “skip” many intermittent transformation stages and get a regular “weird” idea. To come by such an idea one should possess a daring mind and some patience to get used to it.

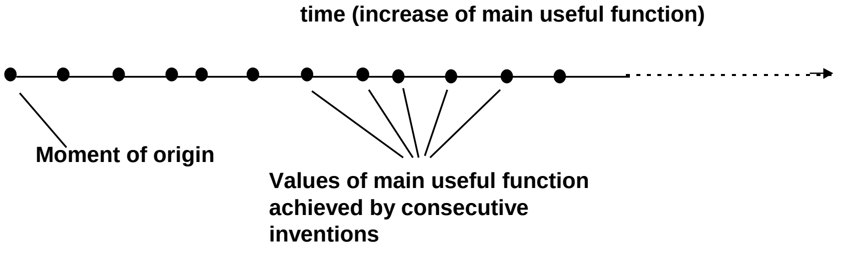
To be able to see the chain of these transitions we can use a simple method: place all the events (changes in technical system) along a compact (short) time axis and follow the changes of a technical system, watch the general regularity of its development. This study was conducted in different, heterogeneous (dissimilar) systems in heat engineering, transportation, communications, military engineering, etc.[10] Let us study the main aspects of the theory illustrating them with examples.

In general, the evolution process can be represented as a sequence of successive events (inventions) along the time axis from the moment of origin of a technical system to the present day and further into future:



[10] The study was conducted in collaboration with I.M.Kondakov

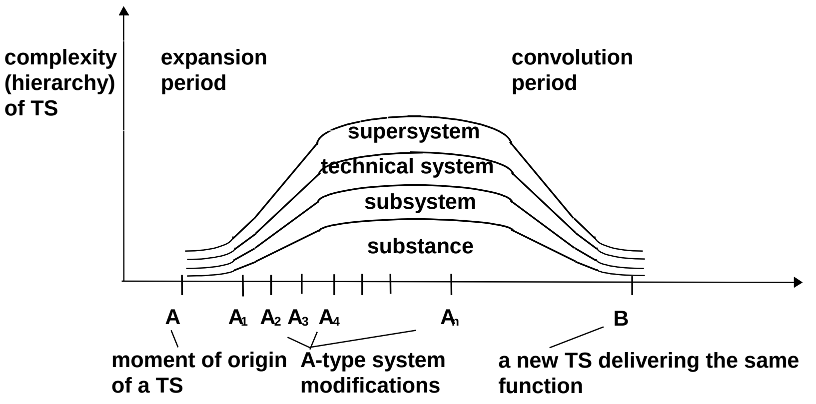
Since every invention is useful, i.e. incrementing ***the main useful function*** of the system, it seems sensible to combine the time axis and the scale of increase in the main useful function.



The whole history of technology evolution is, therefore, an endless chain of inventions and innovations with a sole unvaried goal: to increase the main useful function. However, one axis is not enough, it only shows the irregularity of development: the marks (inventions) are placed at different intervals.

Let us introduce vertical axis - **complexity of the technical system**. Complexity is a very general factor; it reflects the hierarchy of the system. Every technical system (a car, for example) emerges as isolated and consists of several simple elements (the law of integrality of system parts). Gradually, the system gets complicated, gathering a multitude of subsystems, which, in their turn, split into minor subsystems, and etc, down to the level of substance.

At the same time the number of equivalent technical systems increases (many cars) and special support systems become available (motorways, garages, service shops, etc.). These integrate into a supersystem (motor transport), which creates a lot of supplementary systems with the purpose of management (street lights, traffic police), manufacture (motor factories, oil refineries), servicing, staff training, sales, disposal of used technical systems, etc. As stated above, all these changes in technical systems aim to increase the main useful function. For instance, for a car the aim will be to increase speed, comfort and security of passenger/freight transportation in space. So, the second axis shows the complexity of a technical system.



Note: TS stands for ‘technical system’

Certain trends that rule the transition from type A to B do not allow the inventor to interfere with system development, for example, by forcing systems to change over from type A to type X or go backward from B to A. System A develops step by step, accumulating changes and reaching a stage when, being substantially modified, it turns into system B.

The regular character of technical systems evolution can be described in the following way. From the very beginning the system starts increasing its main useful function at the expense of simplicity, “picking up” a multitude of supplementary subsystems - **the expansion period of technical system**. Later evolution is confronted with objective constraints on physical, economical, ecological complication of the system and **the convolution period of technical system** begins. On the surface, the convolution of technical system may appear as simplification but in reality the useful functions acquired at an earlier stage and performed by supplementary subsystems are beginning to be delivered by an “intelligent” [ideal] substance. Ideal substance can incorporate one or more parts of a technical system. Such examples were studied earlier.

The most interesting task is to find out how this step from one invention to another is made. What mechanism brings the technical system from one stage to another? Answers to these questions will give us the understanding of the essence of development process.

The case studies of many technical systems show that each of them goes through a series of macroscopic steps in the following way:

1. Demand formation.
2. Formulation of main useful function and social demand for a new technical system.
3. Synthesis of new technical system.
4. Growth of main useful function: attempts to take from the system more than it can give.

5. With the increase of main useful function a certain part (or feature) of the system deteriorates, bringing a technical contradiction and a possibility to formulate an inventive problem.

6. The inventive problem is solved by using scientific and technical (wider -- cultural) knowledge.

7. Change of the technical system in accordance with the invention.

8. Increase of main useful function (i.e. going back to step 4).

Let us look at these steps in more detail.

Demand formation.

Whatever is being done in the field of technology is done to satisfy the individual and social demands. If there is no need in a technical system, it does not come into existence, but if the demand is formed with time it becomes more and more urgent and nothing can stop man from creating such a system.

Let us recollect the history of creation of aircraft.

Humans have been thinking (or rather dreaming) of flying since the time immemorial. In 1475, Leonardo da Vinci predicted for the first time the possibility of rotary-wing aircraft: "I say that when this device in the shape of a screw is properly constructed ... and is quickly rotated ... it screws into air and rises up." It was the idea of a helicopter. But da Vinci did not know about the reactive moment resulting from propeller rotation and had no idea that it had a serious problem to fly using the described device even with enough human power. Not only the rotor but also the nacelle would gain the rotation. M.V.Lomonosov in 1754 found the way to ease the contradiction, creating a model of "an aerodynamic vehicle" - two horizontally placed rotors rotated in opposite directions. His miniature model could rise up in the air with the spring engine delivering a thrust of 10 g. In 1768 Englishman Penkton published a book "The Theory of Archimedes' Screw", in which he described the rotorcraft (pterophore): one screw was meant for the ascent, the other – for translational motion. In 1782 Paris Academy of Sciences issued a resolution that apparatuses heavier than air could not possibly fly. In 1784 Frenchmen Lonois and Bienvenu made a model of a helicopter and demonstrated its operation to the academicians. The coaxial contra-rotating propellers had feather blades and were placed one under the other (this was a variant of M. Lomonosov's idea of which the French were unaware). In 1783 Mongolfier brothers launched the first balloon which carried the first air travelers (a cock, a duck, a sheep). Since then balloons captured public attention for a long time. In 1842 the Englishman Philipps made a model of steam jet helicopter (with Segner's wheel as rotor). The mechanism remained airborne for several minutes. In 1871 the Frenchman A. Penaux constructed a few ingenious models of aircraft. One of them got into the hands of young brothers Orville and Wilbur Wright. In 1870 A.N. Lodygin made the design of "Electrolet" (electric flying machine) and offered it to the

French Defense Committee wanting to help the French in the war against Prussians. The helicopter design was truly impressive, with the weight of 8 tons and a 300 horse power electric engine! You know what came later: A.F. Mozhaisky, the Wright brothers, etc.

It is evident that certain gifted individuals anticipate the demand for a new technical system; and later the demand becomes recognized socially. The contradiction between the existing technical level and the requirements of the society is resolved with the appearance of the first technical system possessing even a minimal working efficiency. But as soon as the system comes into existence the first challenges arise and motivate its further development.

On October 6, 1910 the All-Russia Aerostation Festival was held at St.Petersburg racecourse. Three Russian ace-pilots M.Efimov, L.Matsievitch and S.Outochkin arrested everyone’s attention by complicated air maneuvers. And suddenly an accident occurred: Lev Matsievitch fell out of the cockpit and crashed before everybody’s eyes. This came as a shock for all, but for one person’s life it was the turning point. Actor Gleb Kotelnikov committed himself to inventing and improving of the parachute - the pilot’s life saving equipment.

The demands of society are constantly growing (*the law of increasing demand*), and consequently, extra criterions are set for the system. An attempt to increase the main useful function leads to yet another contradiction, and the removal of this contradiction brings on the next step in the development of the technical system. Thus, one sole airplane of the Wright brothers gave rise to a complex hierarchical system of modern aviation.

The true demands of society should be distinguished from those which are factitious, artificial or even ridiculous. Toffler, American sociologist, holds that around 80% of goods manufactured in the USA in this century did not fulfill the true, if any, needs of the society.

Each modern technical system was preceded by dozens, hundreds, thousands of successive (gradually developing) inventions. A century long history of the car has seen more than 1 million inventions related to this technical system, there were more than 100 thousands inventions concerning the bicycle, and even such a “system” as the pen had more than 20 thousands improvements.

Increase of main useful function.

All inventions work to increase the main useful function of a system. But man needs the useful function, not the system itself. The technical system is a kind of “ransom” for its useful function. The car, for example, is used to transport passengers and freight. But we are forced – yes, “forced” is the word! – to “transport” the car itself as well. The degree of ideality of the car is inversely proportional to its weight, overall dimensions and energy consumption. The ideal car should only consist of a passenger compartment, a chair or “nothing” at all. This tendency is quite probable. Here is the data collected during the first forty years of car races: in 1895 the weight of the car per power unit (horse power) was 1000 kg; in 1896 – 166 kg/HP; in 1897

– 100 kg/HP; in 1899 – 65 kg/HP; in 1900 – 40 kg/HP; in 1908 – 10 kg/HP; in the 30-ties – 4-5 kg/HP. At present this tendency is practically indistinguishable as any gain in weight is used to increase not only the power of the engine but also convenience. However, the main useful function increase is quite noticeable: the racing cars of the past have become mass production today.

The main useful function increases not only "inside" motor transport but within a supersystem of a higher rank, i.e. transportation in general. Here are the examples of different transport types speed: horse-drawn transport – 30-60 km/hr; railroad – 10-120 km/hr; motor transport – 20-200 km/hr; piston engine aviation – 50-800 km/hr; jet aviation – 800-8000 km/hr; chemical propulsion rocket – 3000-70000 km/hr; nuclear rocket (design) – 8000 km/hr – 1 million km/hr.

The increase of main useful function manifests itself also at all the lower levels of the hierarchy. Let us take, for instance, the degree of energy conversion (efficiency) of the engine. The efficiency of the first Savery - Newcomen steam engines was 1-2%, Watt's engines had efficiency of 2-4%, improved steam engines - 5-15%, steam engines with triple expansion – 13-19%, first steam turbines – 17-30%, updated steam turbines – 25-40%, internal combustion engines – 30-50%, fuel cells (transformation of chemical energy into electrical) – 45-60%.

The same factors that inhibit the increase of the system's main useful function create the ***administrative contradiction (AC) – a contradiction between the demand and the ability to meet the demand.*** The initial situation is defined and the inventive problem is specified. Elimination of the technical contradiction promotes the progress of the system while a compromise leaves the technical contradiction where it is. The inventor is the one who helps the system to get away from challenges. In what way? The technical system adjusts (adapts) to the changing circumstances. This process resembles biological adaptation: species avoids total extinction in the changing environment through mutagenesis; the individual, which in the course of mutation acquires the necessary attributes, survives.

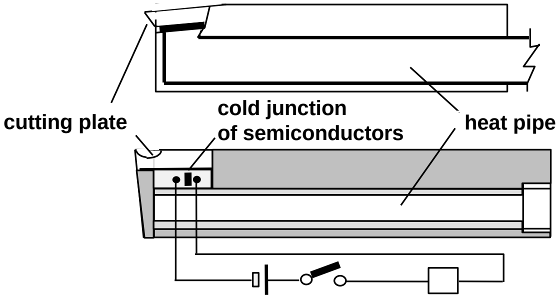
Here is an example: man tried to win the war against bacteria with a new weapon – antibiotics, but nature reacted by producing microorganisms resistible to the drugs, and thus antibiotics served as a means of natural selection leaving only the bacteria possessing the protecting enzyme. Extensive inventing by trial and error method is a kind of a "technical mutagenesis": survival, i.e. development into a real system is possible only for those technical systems that are the fittest for the environment (technosphere) and meet its economic, industrial and ecological requirements best. Inventing in compliance with the trends of technical evolution will need only tens or hundreds inventions instead of thousands.

Contradictions arising from the attempts to increase main useful function are the main driving force of technological evolution. This becomes especially evident in the military area: the history of weapons is in fact the history of competition of defense and attack systems.

Let us take a look at the history of the 'duel' between warships and artillery.

In the mid-19th century wooden ships gave way to steamers. The powerful steam engines made it possible for the ships to bear more armory. At the same time naval artillery was progressing too; mines and torpedoes were invented. In 1859-1860 the first samples of a new type of ships were launched – those were warships with 100-125 mm thick iron armor plates. Consequently, artillery caliber and power was increasing and it became necessary to build ships with even thicker armor plates. The age of smoothbore guns caliber and armor layer thickness lasted for about 20 years. In 1876 the cuirass of an Italian warship "Duillo" was 540 mm thick! In 1881 the English "Inflexible" had the 600 mm armor plates! The guns caliber reached its maximum too – 452 mm. Any further increase of caliber or armor thickness was impossible – the speed and maneuverability dropped dramatically. The quantitative growth of parameters (to increase the main useful function) in both systems reached its limits and qualitative changes were needed. In the 80-ties, the invention of armor made of a compound of steel and iron allowed to reduce the thickness of covering. Ships were accoutered with rifled guns of 280-305 mm caliber. In 1891 there appeared alloyed nickel steel plates and in 1894 a special chrome nickel molybdenum steel. And again, armor piercing capacity of the artillery had to be increased. But it was not enough to increase the caliber: the shells merely got split upon hitting the armor. Admiral Makarov solved the problem: he proposed to use tough steel for making shell caps. The invention proved so effective that by 1900 all countries had included the Makarov caps in their inventory. At the beginning of the 20th century armor thickness of destroyers was 150-200 mm and their hulls were divided by bulkheads to prevent sinking. Later submarines were invented, and new torpedoes, and the competition went on.

The increasing demands and contradictions arising from the attempt to increase main useful function always result in new features and functions of the system. During the first evolution period - the period of technical system expansion - new useful functions are delivered by new subsystems. Such was the case with the lathe. An attempt to increase its turning speed (its main useful function) led to undesirable overheating of the cutting tool. To avoid overheating a cooling subsystem was introduced. At first, such systems were rather simple – for example, a heat pipe to remove heat from the cutting plate (Soviet Patent no. 1 175 611) (see Fig. a). Later, a cold junction of semi-conducting materials was added to the pipe (Soviet Patent no. 1 175 612) (see Fig. b).



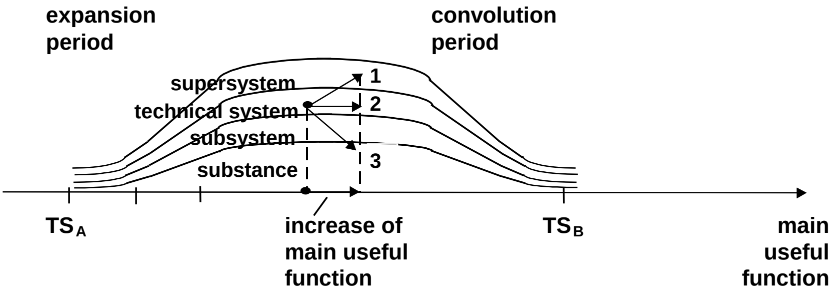
System expansion manifests itself in the development of simple technical systems and tools. For example, a screwdriver with vacuum suckers (to grip and hold the screw), with a built-in electric motor (50-1200 RPM), detachable blades (for screws of 0,4-7 mm in diameter) and electronic control unit. Soviet Patent no. 1 214 495 contains a description of an electronic fountain pen: the amount of ink fed into the capillary channel of the tip is controlled by a built-in pressure sensor and an electronic unit.

What are the limits of the technical system expansion? Sometimes it goes as far as to produce gigantic and complex technical systems (technological ‘dinosaurs’ and ‘monsters’). For example: a wheel tractor – 65 tons, a crawler tractor – 9000 tons, a crane with load capacity 1360 tons, a walking excavator – 1300 tons, a boiler with the height of 117 m and weight of 26 thousand tons. During the WWII several tanks (‘overland battleships’) weighing 68 tons each were let out onto the battlefield by Germans. In the very first fight all of them were put out of action, the designer of these ‘monsters’ F.Porsche lost his son in that battle.

The absurd gigantism in engineering is the result of a barefaced approach to the problem of the main useful function increase: the designers try to increase power by means of increasing in resources and energy consumption instead of introducing new principles and inventive solutions. That is why the technical systems of this kind reach their objective limits so very quickly.

In nature as opposed to science there are severe restrictions. It was concluded that in the history of the Earth not a single living being exceeded the weight of 100 tons. With the weight of, say, 140 tons it would have consisted of bones only and wouldn’t have been able to move.

So, ***the best technical system is an ideal system***. But how is the idealization process going? There are three possible strategies of idealization of a technical system in post-expansion period.



Note: TS stands for 'technical system'

Strategy 1 – the main useful function increases due to delegating part of its function to the supersystem.

Strategy 2 – further development of subsystems.

Strategy 3 – part of the technical system functions are delivered by its one of subsystems and further by a substance.

All three strategies lead to the same new system B, which delivers the same main useful function but has very low weight, dimensions and energy consumption. The third strategy is the shortest – convolution of the technical system into ideal substance. The second is quite logical – no changes are made in the structure of the technical system but the subsystems improve: some of them increase their main useful functions and thus sum up to increase the general main useful function of the system.

Convolution of the technical system into an ideal substance begins with merging of functions: one of the subsystems assumes the function of its neighbour, which is disposed of as irrelevant, and one substance takes up the functions of another substance, and the latter is eliminated from the system.

Merging of functions on the subsystem level: examples.

Car headlights illuminate the way in front of the car. For safety reasons it is desirable to have another lamp to shine sideways and a little bit upwards to light up the road signs. In the U.K. Patent no. 1 486 587 it was proposed to combine both functions in one device. A prism shaped protrusion is made for this matter on the inner side of the head light glass. The prism is designed in such a way that part of the lower beam light deviates up and to the side and lights up the road signs at a distance of 25 meters from the car.

In the USA, one can buy gloves with laminated flexible batteries and miniature light bulb sewn in at the wrist, the light conducting optical fibers run to the finger tips so that gloves could be used as a flash-light. Such gloves are very convenient for drivers (it is possible to read a map at night) and surgeons (the surgical space is well lit). Soviet Patent 1 225 525 describes a surgical glove that fulfills the functions of a measuring instrument to gauge the viscera: there is a flat magnet on the tip of one finger and a galvanomagnetic converter on another, the display is on the wrist.

When a wide communications network was constructed in the city of Tokyo, optical fibre cables were placed inside the existing waste water tubes, while in London the water pipes were used for TV cables with polymeric isolation. This technical solution (as well as in the case with gloves) shows only a partial merging of subsystems. It will be complete when one of the subsystems undertakes the functions of the other (try to imagine, say, a TV cable with running water).

Merging of functions of two substances in one substance: examples.

Both drivers and pedestrians know very well how difficult it is to see the colors of traffic lights on a sunny day. The reflection on colored glass create a false signal. That is why a special kind of traffic lights with black shutters was patented. When one light is switched off (red light, for example), the glass plate is automatically covered with shutters, and another light shutters (green light, for example) are raised. British Patent no. 1 454 386 presents a traffic light with a lamp glass covered by a liquid crystal film and electrodes on both sides. When the lamp is switched off the film holds off the light and has a dark flat surface, but as soon as the lamp is switched on the electric field established by electric current gets the crystal molecules reoriented and the blinds become transparent.

In electric motors and electric generators the current is conveyed to or drained from the rotor. This function is performed by current collectors: the rotor shaft has a commutator (the copper contacts arranged circumferentially) which is brushed by the tips of the carbon brushes – graphite rods, fixed on the motor (or generator) case. The opposite ends of the brushes have copper wires attached to them. The copper to graphite connection is the "weakest" place in the device. The problem is that it is impossible to connect the two substances with usual methods (welding or brazing), so they are sintered together: the wire end is put into the mould with carbon dust (black) and the carbon (black) is sintered at a temperature of 500–600 ^{O}C. But at this temperature copper develops an oxide dielectric layer. Therefore, a technical contradiction arises: carbon sintering requires a high temperature, but the high temperature damages the copper wire. Dozens of inventors tried to find a compromise and proposed vacuum or inert gas sintering (too expensive), substitution of graphite with a bronze flat spring (in Soviet Patent no. 915 145), which unlike graphite requires lubrication so a special lubricant feeding system had to be introduced.

What is happening in the system? Two substances are performing two functions: graphite is a good contact which needs no lubrication, and a copper wire is a good and flexible current conductor. The wire cannot serve as a contact, while graphite cannot conduct electric current. This contradiction was solved in French Patent no. 1 557 274: the conductor is a twisted bundle of carbon fiber with baked end which acts as a brush. One substance has two functions combined. Moreover, this did not end the improvement process (still, the brush rubs off and the contact has to be adjusted). Thus several different self-recovering brushes were patented: ferropowder and magnetic field, a drop of ferrofluid (Soviet Patents no. 1 023 471, 1 026 209). There is even an idea of a brush that does not wear out: jets of ionized gas, vacuum discharge, etc.

This course of development (idealization of a substance) comes naturally to all substances in technical systems but in order to notice and promote it the inventor should possess a daring mind and resist mental inertia. Once, a hydraulic engineering specialist was solving a drill problem on protecting water power station culverts from cavitation erosion (at high velocity cavitation occurs in the flow, and “evil” bubbles explode on the concrete surface, breaking loose the concrete particles). He came to the conclusion that the concrete culvert surface should acquire a “non-concrete” character. Analysis of inventions showed that the general trend was to make concrete soft and fibrous: at first different mineral admixtures were added to the concrete mix, then came polymers, later cement was excluded, and so on.

‘No,’ the specialist said, ‘all wrong! Our laboratory has done concrete strengthening for twelve years. We gave another several per cent to its service life. And we are sure to go on like this.’

Electric appliances usually have a heating coil and a heated element. According to Soviet Patent no. 1 273 221, it is the iron tip of the soldering iron of material with high ohmic resistance that should be heated. Polish Patent no. 106 109 describes an iron with a thin semiconductor oxide coating on the inner surface of the iron glass sole used as a heating coil.

To produce differently colored acetate fabric a certain quantity of colored acetate threads is needed. The threads are made by twisting a bundle of finest fiber which is fabricated by forcing spinning solution through spinnerets. To simplify the manufacturing process it was decided to color the spinning solution, i.e. to add the pigment to the bath with solution before it goes through the spinneret. This means that every time the color and the spinning solutions change it is necessary to wash the spinneret. The production rate declines, the unused solutions are wasted. This problem received an ingenious solution: it was decided to use only three colors – red, blue and yellow and achromatic solution; the combinations of threads give green, orange and purple colors ‘free’ and the addition of colorless threads produces an infinite variety of shades. The fiber is so thin that the human eye perceives this ‘medley’ as one color. (Attention! This is not the solution of problem about a clothing mill that we analyzed earlier.)

The substance idealization does not end with the ‘seizure’ of function of another substance and with the exclusion of latter from the system. What happens next is more important: the substance evolves to take over the functions of one subsystems, of several subsystems and finally of the technical system as a whole (“absorption” of the system by an ideal substance or, which is exactly the same thing, convolution of the technical system into an ideal substance.)

Convolution of subsystems into ideal substance: examples.

The landing lights on airport runways must be absolutely reliable, they should not blow or refuse to work because of rain or cold. This applies to their wires and generators as well. The ideal light was invented in the USA. It is a glass tube with a phosphor coating (zink sulphide) on the inner surface and an ampoule with tritium - a hydrogen radioisotope - in the centre (the half-value period is a little over twelve years). Thus, two ideal substances (luminophore and tritium) have ‘absorbed’ all the other subsystems. The lights are visible at a distance of 3 kilometers, are maintenance-free and have a ten years service life (the radioactivity level of tritium is harmless to people).

In order to find the fracture in a printed circuit board with radio components it is necessary to take measurements in dozens of points - each has to be touched with a test prod. This defect can be detected instantaneously: the circuit board should be covered with a liquid-crystalline film which responds readily even to a slightest change in temperature (temperature in the point of defect differs from that in other parts of the board).

The fans installed in cooling radiators of car engines should increase their efficiency with the increase of the ambient temperature. For this purpose automatic equipment accelerates the rotation velocity of the ventilator when the ambient air or cooling liquid temperature rises. A fan developed in England has blades which change their angle of incidence and therefore the angle of air delivery in response to the change of temperature. Three plastic rings with high coefficient of linear expansion adjust the angle of incidence. Depending on the temperature the rings get bigger or smaller and thereby turn the blades. The maximum turning angle is 30^{O}, which means a dramatic change in the airflow rate.

Soviet Patent 1 279 562 describes a self-regulating greenhouse. The green house has a frame, a translucent covering and adjustable ventilation windows with shutters in the sidewalls and in the roof. The peculiarity of the greenhouse is that, in order to increase the accuracy of temperature regulation, the shutters are made in the form of hermetically sealed hoses filled with a volatile liquid. Each hose along the generating line has one side fixed to the frame and the other to the load. Rising temperature causes liquid evaporation, the inside pressure goes up and the shutter rises opening the window.

The idealization process is clearly evident in microelectronics: extra-large scale integrated circuits include tens of thousands of units. New methods make it possible to program the semiconductor crystal properties so as to create micro-zones performing the functions of diode, triode, capacitor and resistor – all on one crystal. Thus, a complex electronic circuit fits into one crystal. Moreover, there is no need to assemble these circuits of separate parts, they can be built up into whole units for computers, TV-sets, etc.

The metal working technology also shows signs of revolution. The traditional technology used turning lathes, milling machines and other metal-cutting tools to “cut” metal into two uneven portions: the smaller portion served to make parts, the greater was turned into chips, i.e. waste. To produce 20-30 kg of parts a whole ton of ore was used. We’ve already tried to draw a comparison of this technology with the non-waste hydro-extrusion method. But some parts are impossible to extrude, and this is especially true for the parts of intricate shape. Therefore, the metal-cutting machines continued to develop, and acquire electronic equipment, automatic control units and increase in power. The peak was reached with the appearance of processing plants which combined tens and hundreds of tools. Productivity rose by 30-40% but the amount of waste remained the same. The ideal technology of the near future is in assembling parts atom by atom. The basis for this kind of technology is provided by the so called chemical transport reactions: metals interacting with gas form a gaseous substance which, after being transported to a different place, disintegrates at a high temperature and deposits the initial substance. This is used, for example, to make steel components: iron ore is treated with hydrogen chloride to extract atomic iron and the gaseous substance goes to a chamber with a primer, say, a segment of a tube. The iron atoms settle on the primer duplicating its shape and structure. As a result the chamber continuously produces a new tube with a perfect smooth surface.

The circuit growth, assembling parts atom by atom, introduction of self-organizing process into the technical system – all theseconstitute examples of the increase of the technical system's ideality level. It is the main trend of technology evolution. Nevertheless, many think that the more “beautiful” and “powerful” the machine is the closer it is to the ideal. This is a serious mistake, which creates a psychological barrier.

The notion of ideal technical system is a fundamental concept of the Theory of Inventive Problem Solving.

The difficulty of most problems results from the fact that they set requirements which are inconsistent with the main tendency of the technology evolution. Virtually every book about inventions contains the words: “To create a device which...” Yet the device is often redundant, the real task is to provide the required effect 'without anything' or 'almost without anything'.

All laws of technology evolution “work for” idealization of technical systems. We have discussed some of them, others have yet to be studied.

COMPONENT SHOULD BE AND SHOULD NOT BE AT THE SAME TIME

The painter V.A.Serov painted a portrait of actress M. I. Ermolova. The actress is entering a dim room, her figure is in the right part of the painting. According to the laws of composition the left part should contain a “counterbalance”: an object, a person, etc. But this would have overloaded the painting, distracted from the main idea. What was to be done? To make out the balance it was necessary to introduce a new detail, which was impossible.

“The figure of the actress is placed somewhat off the central line but there is no visual overbalance in the right part of the canvas due to a dark reflection in the mirror as if accidentally introduced into the scene. It balances off the composition and enhances the expression.” (*Fine arts* G.Smirnov, ed, Moscow, Prosveshcheniye, 1977).

INCREASING IDEALITY IN ARTS

The effect of artistic systems on the consumer (spectator, reader) increases with the ideality level: the smaller the system, the higher the ideality level, provided that the system retains its function. Idealization in art means a transfer of functions to the consumer. Michaelangelo’s ‘David’ is one such example.

7.2. IDEAL FINAL RESULT: A BENCHMARK IN THE CHANGING WORLD

Every invention promotes the development of a technical system. But in the pause between two 'pushes', the technical system remains stable. In the past the pauses were long, and the improvement process was very slow. At present technical systems mature at a much faster pace. Technological progress is continuous, and inventive problems are plentiful. The strategies to eliminate technical contradictions are also numerous: each problem can be solved in many different ways. Which one to choose? Is there a benchmark, criterion for the best solution? This becomes even more important today when science and technology make it possible to solve many problems "forthright", disregarding expenses and complex equipment with at times expendable automatic and electronic devices.

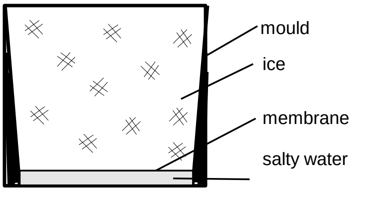
The inventive methodology has such a benchmark and it naturally complies with the main law of technology evolution – the increase of ideality level. It is the **Ideal Final Result (IFR).**

In trying to solve an inventive problem it is impossible to know beforehand how to eliminate the contradiction. Yet we can always formulate an ideal solution, imaginary final result. The IFR is the imagined ultimate outcome of the problem solving process.

The ideal final result is formulated according to the pattern: one of the elements of the system or environment eliminates a detrimental (superfluous, redundant) effect preserving the capacity to produce a useful effect all by itself.

The very core here is '**by itself**', i.e. without any human interference, energy inflow, new subsystems or interventions on the part of a supersystem. With absolutely nothing. To achieve this result as well as any ideal is impossible for obvious reasons. *The Ideal Final Result serves as a major guideline for the best solution.* As we have mentioned before, the best inventive decision combines a low "cost" and high efficiency of the changes in the system. The strive to reach the ideal final result radically cuts off the lower levels solutions.

Let us take, for instance, problem 21 (how to extract an ice-cube from a mould). This problem is aimed to destroy a detrimental S-field model: it is necessary to introduce another field (which counteracts to the harmful field) or a third substance. There can be several solutions handled by the same formula: from bimetal plates for pushing away the ice-cube to inflatable (or liquid) moulds. Let us try to find a more ideal solution.

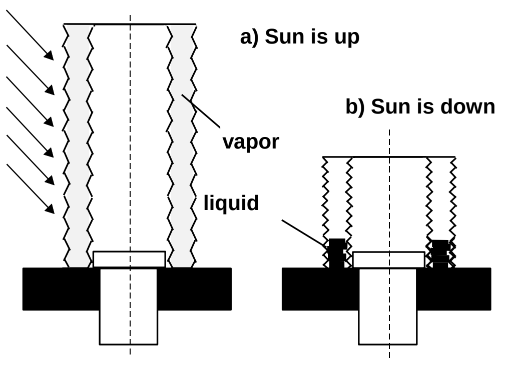


The technical contradiction can be formulated in the following way: *to become ice, the water in the mould should get frozen but frozen water expands and it is difficult to eject it from the mould.*

The IFR can be formulated: *'The ice hardens up and ejects itself from the mould.'*

What idea can be more ideal than this? No elements are introduced into the system, and the system does not get complicated, has no mechanical devices. The detrimental effect is eliminated while the useful effect comes forth. The Ideal Final Result offers a seemingly absurd solution where no compromise is tolerated. But how can this solution be implemented? Looking for a solution comparable to the IFR we have always to start by considering the existing resources. What can be used to obtain the necessary outcome? Resources are rather poor – water, ice, cold. But that is even better: we have fewer variants to analyse. What can create buoyancy force, for example? The volume of ice is by 9% larger than that of the initial water. The freezing process builds up a great force. Let this force eject the ice. This means that water should be divided into two portions: one portion will freeze to turn into ice and the other to create buoyancy force. Let us separate the freezing time of the two portions, so that the lower layer would freeze later and eject the upper-layer ice-cube after the cube itself hardens up. So the lower layer should contain salty water with a freezing point at, say, -4^{0}C. The technical design is quite straightforward: a double bottom mould with an elastic membrane separating the lower salty water layer.

Soviet Patent no. 1 044489 gives another example of this kind of solution. It describe the way hot ingots use their own heat converting it into electricity with an thermoelectric generator which is fixed on an electric trolley so as to transport themselves from one shop to another with the trolley. French inventors were granted Russian Federation Patent no. 506 282 for a windshield heater (to prevent sweating and frosting up) which switches on itself at the appearance of moisture; the moisture closes the thin electrode strip fastened to the windscreen.



Problem 82. Every residential and industrial building has ventilation ducts that release used air. But in winter they freeze up – the inner surface develops icing from condensed moisture of the flue air and this can block off the duct section. There are many mechanical devices to remove icing. All of them are not reliable enough (tending to frost up themselves) and require maintenance. A novel idea is needed.

The Ideal Final Result: *the duct removes the icing all by itself*. The idea seems absurd on the face of it. But every invention is a step beyond the “impossible”. In this particular case the “impossible” only means “impossible with existing methods”. The inventor should find a new method to make the impossible come true.

The problem of the air ducts is solved in the following way: the ducts have double walls of a corrugated flexible material (Soviet Patent no. 1 298 488), the exterior wall is transparent, the interior one is blacked out; cavity is filled with a volatile liquid. When the sun is up -- the pressure of the vapor straightens the pipe out, when the sun is down -- the pipe folds up. Thus the pipe throws the ice away and gets dry by itself while being stretched up.

> **<u>The main rule of the IFR strategy:</u> do not speculate beforehand whether or not it is possible to achieve the ideal result. When formulating the ideal final result, psychological barriers should be avoided.**
>
> **The ideal result formulation itself works as a powerful means to dispose of mental inertia. Switching from “impossible” to “it works” helps to overcome the fear of unusual, daring solutions.**

Academician I.L.Knounyants once recalled an interesting case from his own experience: “An acquaintance, who was an officer returning from war, brought a finest women’s stocking which he picked up somewhere. Apparently, the stocking was made of artificial silk. I brought it to the lab, treated it with hydrochloric acid and heated – the flask emitted the familiar odour of caprolactam”

That was how the Russian scientists learned that Germans had found the way to polymerize caprolactam (even the inventor of polyamide fiber W.H. Karosers considered it impossible) and started to manufacture nylon. There was no psychological barrier ‘it’s impossible’ as it was evident that 'it worked'. Knounyants continues his recollection: "... (Lab assistants) heated caprolactom in test tubes under different conditions with and without additives. The polymer didn’t come out. And one day I told her (assistant U.Rymashevskaya - *Yuri Salamatov*): let us try to seal the tube. Caprolactam is not a volatile substance and cannot escape from the tube, but who knows, perhaps the air interferes with the reaction? Early in the morning she comes in running and says – we got it!”

The best way to define an ideal final result in some cases is to change the question contained in the problem into an assertion. This is the case with the problem ‘how to bend a crystal?’ (Page 128) The ideal final result: *let it bend by itself*. As you see, the IFR definition is not influenced by considerations whether it is possible to achieve the ideal and how it is to be done. Imagine two movie frames: one has an initial situation (the crystal is streitht, not bent), the other has the ideal final result (the crystal is bent smoothly through a narrow angle). It stands to reason that some special effect should be found. But it is easier to find it if the ideal result is known. The target solution (Soviet Patent no. 799 959): a substance with a different coefficient of thermal expansion is deposited by evaporation on one of the crystal faces at a high temperature (miniature dwarfs of the substance take hold of the miniature dwarfs of the crystal), then the system is cooled and the crystal bends (the chain of miniature dwarfs of the substance “shrinks” more than the chain of the miniature dwarfs of the crystal). To obtain a concave crystal a substance with a bigger thermal coefficient is used, and to get a convex crystal one with a smaller coefficient is needed.

The same holds true for the IC problem (page 135). The ideal final result should be the following: the IC ‘testifies/proves’ the real authorship in court. This can happen only in one case – if the label (sign) is made from the same kind of integrated circuit elements. The development engineer initials are introduced into the circuit pattern (the elements are placed in a special way, imperceptible for the thieves). It is the ideal label which does not exist yet its function is delivered. To punish the thieves some redundant elements are added to the circuit: for example, a conductor between the elements in the consequent coats. The thieves imitate an unconnected connection, taking it for a mistake. Solutions close to ideal can be obtained by using the physical effects. For instance, to solve a problem about "smart pegs" Page 72), where the physical contradiction is "there are should be many pegs and not many pegs", we must choose an action which would provide the main useful function: cutting metal sheets. That is, there should be many pegs, but they must disappear in a proximity of fire. Answer: the pegs have to be made from the metal that has memory shape, for instance, nitinol. When a peg "feels" the approaching heat, it bends towards the table. After being cooled down, it will restore its original position.

LIFE OF A CREATIVE PERSON

I.F.Semmelweis (1818-1865). The problem: more than 30% of women died of puerperal fever in obstetrical clinics. The disease was believed to have contagious epidemic nature and 30 different theories tried to explain its cause (atmospheric, soil conditions, etc.) but every time the autopsy showed that the patient died of blood contamination.

In 1847 a Viennese doctor I. Semmelweis came to a conclusion that the lack of sterility and untidiness of the doctors was the cause of the disease. He offered a very simple solution: to wash hands with chlorinated water. Dr. Semmelweis spent his life trying to bring these ideas into practice.

Creative personality qualities. Semmelweis didn't choose his goal at random: at that time the problem was as urgent as cancer today. The program to attain the goal: in order to find the true cause of infection he successively eliminated the factors affecting the patient; tested his ideas on animals and on humans. The method used: at fist Semmelweis sent out private letters to all European hospitals, later published a book, and when it was totally ignored by medical community Semmelweis started writing letters of complaint demanding a thorough testing of his method. Working efficiency: all his time except sleep was dedicated to work. He worked himself to an obsessive neurosis. The working process: a systematic search followed by extensive testing (when he learned that in the neighboring hospital women were delivering in a sideways position, he tried to apply this method but it didn't help); death statistics study, analysis of different hospitals conditions. Then all of a sudden his friend died from a wound received at the autopsy of a women who had passed away of puerperal fever. The understanding of the real cause came gradually, and Semmelweis began to use chlorinated water. His discovery was made even before Pasteur published his works describing bacteria as the cause of infection. The ability to weather storms: Semmelweis lost his job and moved to Budapest where he continued his work. His discovery was offensive for obstetricians: the doctor himself was the cause of patients' death! Semmelweis was young and had no right to edify professors. In 1865 he was placed into a psychiatric facility and in a month he died there, ironically, from a wound received during his last operation. Semmelweis' theory was not recognized in his lifetime although it could be easily proved. (Pahner F. *Fight for the Mothers' Lives. The tragic life of I. Semmelweis*, Moscow, Gosmedizdat, 1963, in Russian).

7.3. 'LET US FACTOR THE TRIVIAL OUT'

There are no problems without solutions yet the story of invention often begins by declaring something to be impossible. Every important invention was claimed by some to be "impossible".

The reasoning for claiming something to be impossible differ. Sometimes it is plain ignorance. This was how the Paris Academy refused to accept the idea of the railroad, declaring that steel wheels would slip over the steel rails while the train remains steady. And even when the first Stephenson's steam engines ran on rails the number of doubters did not decrease. Here are some of their claims: chickens will stop laying eggs because of noise and hooting, the cows will have no milk, smoke and sparks will destroy pastures and woods, and people risk the boiler explosion and even mental disorders because of such speedy motion.

However, ignorance is not the main reason for saying "impossible". This judgement is often formed by people who are far from being incompetent.

In 1932 S.Lebedyev was the first to obtain synthetic rubber. His pilot plant was already functioning, while Edison, who himself studied the matter for a long time, stated: "It is impossible. And all news about it is a lie. From my own experience and the experience of others I know that it is hardly possible to obtain synthetic rubber anywhere, and in Russia in particular." His judgement set the synthetic rubber development in the USA back by 7 years. A.S.Popov knew very well the opinion of H. Hertz that radio waves would never find practical application. "I have discovered these waves, so I know better", –was the answer to all the attempts to get him interested in radio communication projects. In a few years Popov sent his first radiogram consisting of two words: Heinrich Hertz. The French philosopher A. Comte said that some things could not be conceived by human mind. For example, it is impossible to measure directly the velocity of a star moving towards or from us, because the calculations would require million years of waiting. Ironically, in several years the Doppler effect was discovered. It made it possible to measure velocity of approaching and receding stars by analyzing their spectrum. K.A.Timiryasev could not accept the chromosome theory of heredity. Moreover, W.Tompson denied electromagnetic theory all his life. Such famous scientists as Huygens and Leibniz mentioned that Newton's gravitation notion belonged rather to the domain of occultism than science.

Kolbe once called van't Hoff's stereochemical theory "the waste of human mind". Boltzmann thought that the atomic theory will not appear earlier than in 300 years, however, already in 5 years after his suicide it was universally recognized. One month before the first flight of Wright brothers (December 17, 1903) professor Newcomb, a vice-president of the US Academy of Sciences, published an article about man's inability to fly...

What makes an educated and on the whole an open-minded person refuse to believe in new technologies? Here is a typical example.

One of the managers of a big project in Aircraft Design Laboratory A.N.Tupolev told the story about designing a seemingly simple units disconnection sensor. It was to be an equivalent of a family refrigerator light switch -- when the door is closed the light is off and when the door is open the light is on. But the operating conditions were obviously much more difficult: cold, heat, vibration, dust, moisture, and what was more important – it had to be absolutely reliable. As a result the circuit consisting of two wires and a switch grew into a sizable control system with every component duplicated or even trebled. To screen false signals a logic circuit was introduced, etc. Suddenly there came a simple but ingenious solution: to use a umbilical connector, that is, to put it plainly, in case the units got disconnected, the wire would break off and the electric circuit would be interrupted. "The idea was met with resentment and ridicule. I was called an ignorant fool... There were many objections but no one said why we should not do it. Which laws of physics prohibit to do it? It was just that it should not be done because no one did it before!" He was even given some "killer" data showing that among the expendable sensors overflowing the markets and produced by well-known companies there were no such "slobbish" devices. However, Tupolev managed to have it his own way, the system "was put in operation and has been used ever since – for more than quarter of a century! – and with no complaints".

Usually experts are the first to face the unconventionality of a novel idea. The new idea breaks the customary rules and hardened beliefs, and naturally suffers a rejection, or at least misunderstanding and mockery. This is proved by the story of A.M.Lulka, the inventor of the first Soviet turbojet engine. According to him, in 1941 most people could not comprehend that a jet entering and then leaving "something" could serve as the driving force for the aircraft. Lulka and his team were considered charlatans making money out of the air. It seemed that the war should stimulate the interest in his engine that could provide the speed of 900 km/hr off-hand, so to say. But, alas... A. Lulka remembered that it was the leading aircraft and engine designers who doubted the future of the turbojet engines. Their opinions influenced decisions of administrators who, being limited in time and resources, had to choose one project among many. Unfortunately, an "imperative" balking of technical progress is a frequent phenomenon.

7.4. TREND FORECASTING

Well-grounded forecasts of technological evolution are indispensable to avoid mistakes in budgeting the resources for technological developments. It is important to know its main tendencies and regularities. The technological development is primarily an evolutionary progress with "mini"-revolutionary qualitative jumps (or to make it clear we can say that the absolute majority of inventions constitute "micro"-jumps). The real revolutionary changes are very rare. They are connected with scientific discoveries (laser, for example) or unforeseen pressing demands of society. The forecast of scientific discoveries is beyond our powers at present. But some of the future demands are easy to predict. One of their causes is the conflict between evolutionary trends of society. Different trends gradually grow, increasing their effect on public life and finally clash rising contradictions and tensions in society. These contradictions need to be solved, and this can be achieved by social, political, technical and other means. We only are interested in the technical side of the future contradiction of social development. They can be predicted by extrapolating existing trends of technology and society evolution using one of the methods described in the ICI (Improvement of Creative Imagination) course – ***the trend method:***

1. Choose two real but visibly unrelated trends of evolution of civilization (technology, science, culture, etc.)
2. Extrapolate each trend separately in the future till it acquires a leading position.
3. Reveal the contradiction between the two extrapolated tendencies.
4. Suggest a new idea to eliminate the contradiction using one of the known methods.

For example, the first trend is urbanization – the growth of megalopolises; the second – the printed products development, increase in circulation, number of editions, etc. Let's extrapolate these tendencies into the future: 1) the planet's population lives in cities, each city occupies an enormous area; 2) a large quantity of printed matter (1000 editions a day per person), all libraries are full, a large number of buildings in the city is used to store books and periodicals; humanity is divided into those who write and process information and those who read; however, it is impossible to absorb all the information.

And now we need to formulate several possible contradictions: a) a person needs information but it is difficult to find him/her in a big city and even more difficult to deliver information to him/her; b) information is delivered but a person is unable to read it (no time and energy) or find the small portion he/she needs.

Possible ways of eliminating contradictions:

- to change the physical method of information transmittal, to reject paper and use magnetic medium, to disseminate information via computer networks (the trend that is developing today); however, there may not be enough people to transfer information to magnetic media, so there is a need for a human intervention-free information system to transport data from computer to computer, with an individual receiving a small fraction of information he/she really requires;
- to create a "neural" data network of the city so that information could find the person who needs it;
- "a family print shop" – family members print out important information from the TV screen;
- to combine printed matter with other objects and substances – different products packages, wall-paper, clothes, etc.; edible information (food, pills);

- to unite individual and information system; for example, some parts of the body may be used as a library (subject to biological medium invention); a new stereotype: the heavier and taller the person is, the more he knows...

There is also another way: to bring up a question where all this information comes from. Let us imagine a rather extravagant development of the situation: information in a compressed form was received from an alien civilization – all the knowledge they accumulated in a million years. The information is divided between all scientific communities of the world, the university towns are growing rapidly due to the inflow of scientists involved in concept formation. All printing shops of the planet are busy printing it out, the new publishing houses are being opened...

The main point of this exercise is to present an entirely new technical idea. The generation and discussion of ideas help to resist mental inertia, break stereotypes, and get rid of the fear of future. People don't know *how it will be* and say that *it cannot be*, hence the "impossible" label. The words should be: "it will be so though we don't know how."

Problem 83. Apply this method to any two of the following trends:

- the population is aging, therefore the number of pensioners grows;
- knowledge quickly devaluates and needs to be constantly updated;
- the number of technological failures (sudden industrial releases, accidents, etc.) grows and increases human and environmental exposure to pollution;
- "free" (sun, wind, wave, tide, subsoil heat, etc.) power use becomes more extensive;
- microminiaturization of machinery;
- the cost of scientific and technological projects is growing (this concerns not only nuclear and space projects but other fields as well: in biology, for example, the cost of man's gene decoding project totals to $3,5 billion);
- labor is getting more specialized, the number of occupations grows;
- human brain is more effectively utilized, only a small part of its capacity is used at present while its full information capacity is 1000 billion bits which is equal to five hundred volumes of Britannica;
- people have more and more leisure time;
- domestic appliances become more numerous;
- standards of housing insulation increase to save more energy;
- more people are employed in tertiary industry;
- space exploration intensifies;
- stress situations become more frequent;
- global warming of the climate;
- admiration of personality development, health and nature is cultivated;
- increasing obsolescence of machinery.

The list of trends can be continued if only we take a closer look at our surroundings.

LIFE OF A CREATIVE PERSON

Alain Bombard. In the beginning of the 50-ties of the 20th century A.Bombard, a French medical doctor, put forward a theory that those who suffered a shipwreck and found themselves out in the open sea on boats or other rescue facilities died not from thirst or hunger but from fear of death. His arguments were as following: 90% of people die during the first three days when it is too early to speak of starvation. The rescuers arrived at the Titanic wreck place in 3 hours but the boats were full of corpses and insane people. Bombard's main idea: food and water should be obtained from the ocean; fish and plankton have all the necessary elements. To prove his idea Bombard decided to cross the ocean alone on a raft following Christopher Columbus' rout.

He made it. He survived. All the way he was fishing, conducting physiological research, studying fundamentals of navigation.

Bombard's experiment was a great act of self-sacrifice. His goal was to give a chance of survival to some fifty thousand people who involuntary get into the open sea and die slowly and painfully from lack of food and water every year. He played a losing game for the benefit of thousands of strangers and didn't consider it an act of heroism.

7.5. MASTER YOUR SKILLS

Your TRIZ toolkit has enlarged now: you have learned three more laws of technology evolution (rhythm coordination, dynamization and ideality), specific methods of their application, acquired new techniques in the Improvement of Creative Imagination course, understood the idea of substance and field resources, some physical effects and their application; you have expanded your examples and problems stock. Inventive drills will help you to develop the skills you acquired.

The problems as was the case before are related to the material discussed above. But this does not mean that they can be solved using the familiar material as a single basis, most of inventive problems should be viewed in a broader sense, and the solutions can be reconsidered at any stage of learning TRIZ. Among the problems presented below there are some that haven't been solved yet, and, therefore, have no target solution. However, this does not mean that they have no solution at all.

Problem 84. Three problems: all of them are different but have similar solutions.

A. Niobium nitride (a refractory compound) is obtained by burning a niobium compacted powder tablet in nitrogen. To have a tablet burning across the whole width it should contain some non-combustible ballast (20-30%), which damages the final product. What can be done?

B. During a laboratory experiment it was necessary to melt solid oxygen in a flask. To heat it from the outer side was impossible - the vessel had a special vacuum thermal insulation. From inside? But any heat-transfer medium (water vapor, for example) would contaminate oxygen. What can be done?

C. During ultrasonic degassing of metal melt a special waveguiding rod - an ultrasonic conductor – is run into it. This rod gradually succumbs to attack by high-frequency oscillations and contaminates metal. What can be done?

Problem 85. Soil sticks to the excavator bucket during operation and its capacity is used ineffectively. What can be done to prevent soil sticking to the bucket?

Problem 86. Hundreds of trucks work in mining opencasts at the same time and the exhaust gases pollute the air in these enormous pits hundreds of meters deep so much that ventilation becomes a serious problem. Heavy dump tracks loaded with coal, timber, clay, ore go up the spiral road along the flank of an opencast leaving a dark plume of smoke behind. Filters could be fixed on the cars to prevent air pollution. But filters mean expenses for their istallment and maintenance... The filter should be and should not be present at the same time – what can you suggest?

Problem 87. In 1885 R.Stevenson wrote a short novel “The Strange Case of Dr. Jekyll and Mr. Hyde”. It related a story of Dr.Jekyll who found a drug that temporarily could transform him into the evil Hyde, the embodiment of all negatives of doctor’s character. The “evil self” was growing stronger and more independent until finally “devil Hyde” became the only image of Jekyll.

In a screen adaptation by Ruben Momulyan (1932) there is a scene when a respectable faultlessly tidy and sleek doctor changes into the dreadful Hyde. The episode was shot with subjective camera, without splices or breaks in shooting. The spectator identifies himself with Jekyll who having taken the drug is looking into the mirror. The transformation happens right before our eyes: streaks, wrinkles and lines gradually show through on the face of Jekyll changing into Hyde...

How was this scene shot?

Problem 88. An instrument that was to operate in liquid acid medium was made. To protect the instrument from acid its metal surface was coated with polymer. How can we check whether the coating has any through holes?

The usual method implies coating the tested surfaces with luminipherous or ferromagnetic suspension. After washing suspension stays in the cracks (if there are any). But in this case the method is not effective for it detects all kinds of cracks including blind cracks. So, we need to find a way to reject instruments with a faulty coating. How can this be done?

Problem 89. Industrial machines are cooled with an open spring water which is fed by a centrifuge pump. The water temperature in the spring changes so the amount of cooling water needs to be regulated. There are several ways to change the feed amount but all of them require manual control or, which is worse, pump disassembling and wheel blade angle change.

An automated unit was proposed. It included temperature sensors, electric engines, control unit, etc. The size, weight and energy requirement increased, the duty fitter was replaced with a servicing engineer, but the amount of failures and errors didn't change.

Ideally, the pump should control its work without man interference and without electronic equipment. What can be done?

Problem 90. Analysis of meteorology data collected during 300 years showed that the Earth displays a clear trend of climate warming. One hypothesis holds that it is caused by the so called greenhouse effect – the increase of atmospheric content of carbon dioxide (due to industrial releases) reduces the planet's heat radiation. How can we prove that the hypothesis is true, where can we get samples of the air of the last century?

Problem 91. Fountains keep us spellbound by the quiet music of water streaming down, elaborate cascades, eternal motion. Different cities of the world for centuries have competed in the fountains architecture and decorative effects: Peterhof, Dresden, Italy...

What innovations have been introduced into the "art of fountains"? The height of jets has increased, the intersections have become more intricate, the water is tinted and color organs are used – among the non-inventive solutions that seems to be all. As to inventions, they are very few.

Here are the most interesting: the soap bubbles fountain in the shape of a water flower or with big and small bubbles rising to the sky and dancing atop the waves (Soviet Patent 774 661); some luminescent pigment may be added to the soap solution which will give a beautiful dynamic light effect; a device to create a dome-like water film for decoration was proposed (Soviet Patent 787 102); some surfactants reducing hydraulic resistance may be added to the water polyacriamide, for instance, which makes the water 'slippery' – this may increase the jets height using the same pumps; the fountains may produce sounds, 'sing' (Soviet Patent 1 214 239).

Try to work out new functions for the fountains using the effects stock, standard solutions, ICI techniques.

Problem 92. One of the most dangerous and catastrophic kinds of oil and gas pipe destruction is a rapid development of a gigantic crack along the pipe. The length of such crack may reach several miles, and its velocity – hundreds of meters per second. The causes and principles of the cracks development are not quite clear. The failures happen with the pipes designed to meet the strength standards. What is to be done?

So far it has been suggested to build several parallel pipelines with smaller diameter rather than one big pipe. This increases construction and maintenance expenses, more reinforcement is necessary, etc. There's also a technical solution of crack "interception". Ring-shaped washers are welded onto the pipe at some distance from each other. The crack gets to the closest washer and stops there. But this is only a partial solution as a technical contradiction arises: the more washers are welded to the pipe the safer the system is, but they are very expensive and labor-consuming process.

Problem 93. How can we find out if the food left by the owner in the freezing chamber was defrosted during his absence? Food may be kept in freezers for several months on the condition that it does not get defrosted. Find a simple solution, accessible to all.

PLASTIC SPRINKLER

To coat the surfaces with a polymeric resist a hot-melt plastic unit is used. The hot air blast picks up the melt, its swirling flow breaks it into a fine mist and the air-jet nozzle helps to spray the surface.

‘Do you see the problem?’ the process engineer asked a TRIZ consultant. He took the measurements of the coating thickness. ‘Here we have two millimeters, in some parts – three. It is too much, the coat should be 0,5 or even 0,1-0,3mm. The drops are too big which means a waste of plastic. What can we do about it?’

‘And why can’t you get microdrops?’

‘For a very plain reason. The plastic is a viscous substance, as thick as honey. We tried to increase the air-jet velocity, raised the melt temperature, heated the coated parts, amplified the air swirling but all in vain.’

‘Is it possible to add any agents into polymer substance?’

‘You can add whatever you like as long as the two main properties of the coating remain constant: adhesion (sticking to the coating surface) and continuity, i.e. there shouldn’t be any peeling, bulging or bare areas. We have already tried this – added solvents, fluidizers... Nothing helped. Adding more solvent we get a thinner melt but at the same time more bulging and discontinuities due to solvent evaporation...’

‘... and less solvent (or no solvent at all) – means a better but thicker coating. It is a typical contradiction! Now the problem is clear - we have to eliminate this technical contradiction,’ said the consultant.

8. STRATEGY PLUS TACTICS: SOLVING PHYSICAL CONTRADICTIONS

8.1. READINESS TO ACT: CONTIUNE WITH ARIZ

Russians say that a good housewife will put to use everything but a cock's crow. And a good inventor will put to use even the noise coming from the street! The traffic lights marketed by Philips are equipped with batteries charged absolutely for free by traffic noise. More than that, it is suggested to use noise at home, making wallpaper from special piezoelectric film (mechanical-to-electric transducer). That means that, the more clamor you hear coming from your neighbors' apartment, the more electric energy you save.

In this sense, nature can be compared to a good housewife: nothing is lost, the natural 'production process' works smoothly and without wastes. Natural turnover consists of living systems – technologically ideal multi-functional components. The substance turnover in the biosphere can be cited as an example. The 'Ockham's razor', a logical and philosophical principle, is now getting recognition in science (William of Ockham, 1280-1349, theologian and Franciscan leader). Ockham's razor states that it is useless to use greater means to achieve a goal attainable by fewer means.

Incidentally, this principle has long been used in arts. Designing sets for one of his first performances, V.F. Ryndin, popular Russian artist, placed a boot on a village fence. The scene with a boot on the fence created a perfect image. Filled with inspiration, the artist decided to add another boot. This time he was criticized: "One boot is an image, but two boots are nothing but a pair of boots!". In military art, where ambitious claims force commanders to use any resources available on the battlefield, even the enemy can be used as a resource. Such cases are known from history: during the Deli battle Tamerlane ordered to send camels laden with hay against the enemy's elephants. The burning hay caused panic among the elephants that fled from fire and crushed Indian troops.

A good command of *Substance and Field Resources (SFR)* characterizes a state-of-the-art inventive skill. Only a few people develop this ability after years of inventive practice. But in the theory of inventive problem solving, utilization of substance and field resources is considered a powerful but yet an ordinary tool (see page 129); it can be practiced successfully after some training. SFR analysis and utilization is a very effective part of increasing the degree of ideality of technical systems. With nothing (or nearly nothing) introduced into it, a technical system begins to perform new functions and display new properties. Delegation of functions performed by substances, sub-systems and by the whole system to components of the environment always distinguishes an invention of a high rank. Such inventions come as a result of mobilization of SFR.

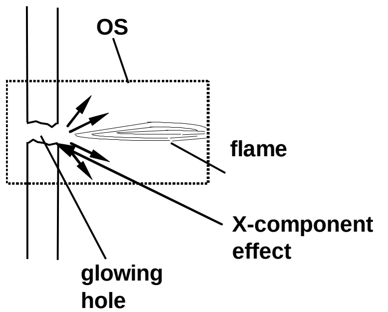
Substance and field resources are always at hand. But they should be determined and made to contribute to the main useful function. If SFR properties do not fully meet the given requirements, it may be necessary to improve their 'combat readiness' by transforming them in the necessary way. So, here we encounter three important issues: a) revealing the resources; b) determining their function; c) utilization of all resources available free of charge and, if the problem is not solved, further mobilization of resources.

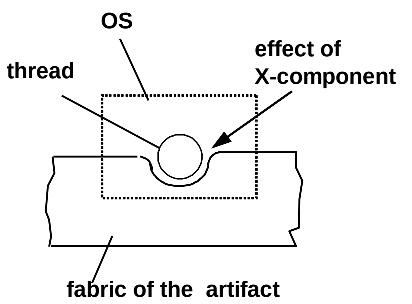
We have already learned (in pages 99 through 110) the Algorithm of Inventive Problem Solving (ARIZ) for the steps to formulate the problem and clarify the contradictions (steps 1 - 8). To eliminate such contradictions, we should fully use the concepts of substance and field resources. Thus, let us study the algorithms to eliminate the contradictions by utilizing SFR in accordance to the latter steps of 9 - 19 of ARIZ.

For illustrating the steps, we shall continue to study Problem 57 and the problem about a clothing mill. Their solution should be brought down to mobilization of substance and field resources.

ARIZ Step 9. Determine the operational space (OS)

In the simplest case, operational space is the space where the conflict described in the problem model (steps 7,8) occurs.





ARIZ Step 10. Determine the operational interval (OI)

Operational interval is the time resources available. These are: the time preceding the conflict (T1) and the conflict time (T2). The conflict, especially a short-term, momentary one, may sometimes be eliminated (prevented) during T1.

Problem 57:

- T1 is the time required to ascertain the position of the hole; the hole is glowing while the flame is at some distance from it.
- T2 is the time when the flame is coming close to the glowing hole.

Problem about a clothing mill:

- T1: the thread is at some distance from the fabric, the colors of the thread and of the fabric do not match.
- T2: the thread is on the fabric, both have the same color.

ARIZ Step 11. Analysis of substance and field resources

Substance and field resources are substances and fields that are already available or can be obtained easily according to the problem conditions. Three kinds of SFR are distinguished:

1. Internal SFR:

a) SFR of instrument

b) SFR of artifact

2. External SFR:

a) SFR of the environment specific of the problem, for example: water in the problem about parachute testing;

b) SFR common for any environment, for example: air, ground, 'background' fields, such as gravitational, magnetic and other fields of the Earth.

3. Supersystem SFR:

a) waste of another system (where such system is available according to problem conditions);

b) cheap SFR: other cheap objects of negligible cost.

Note:

14. While solving each mini-problem, it is desirable to achieve a result at a minimal introduction of the SFR. Therefore, internal SFR should be used first, then external SFR and at last supersystem SFR. While developing the answer and solving the maxi-problem, it is helpful to employ a maximum number of SFRs.

Problem 57:

SFR of instrument: the flame (flow of combustion products);
SFR of artifact: the hole, i.e. the glass around the hole (edges of the hole);
External SFR: air;
Supersystem SFR: not given.

Problem about a clothing mill:

SFR of instrument: the fabric

SFR of artifact: the threads and the clothes
External SFR: air
Supersystem SFR: not given.

ARIZ Step 12. Formulation of Ideal Final Result 1: "Without complicating the system or causing harmful effects X-component eliminates harmful effect (as specified) during operational interval (specify) and in operational space (specify) and provides the useful action of the instrument (specify)".

(The X-component represents some unknown substance or field, which should be clarified by the subsequent analysis of the problem. The familiar concept and expression of a variable x in algebra are introduced in ARIZ as the X-component.)

Ideal Final Result 1 in **Problem 57**: "Without complicating the system or causing harmful effects, X-component provides the glowing of the hole without a conductor and does not prevent the flame from sealing."

Ideal Final Result 1 in the **Problem about a clothing mill:** without complicating the system or causing harmful effects, X-component provides instantaneous changing of the color of threads at a continuously changing color of the fabric.

ARIZ Step 13. Intensification of Ideal Final Result formulation by introducing an extra requirement: *no new substances/fields may be introduced into the system; only the SFR should be used.*

NOTE:

15. While solving a mini-problem the SFR should be examined in the following order:
    - SFR of instrument.
    - external SFR,
    - supersystem SFR
    - SFR of artifact.

Because there are four different SFR, there may be four lines of further analysis. In reality, the problem conditions usually cut off some of these lines. While solving a mini-problem it is enough to carry analysis until we obtain some ideas for the answer: once an idea crops up, for instance, within the 'line of instrument', there is no need to check out other lines. While solving a maxi-problem, on the contrary, it is necessary to check out all of the existing lines of analysis.

Instead of analyzing the lines consecutively, it is possible to analyze all of them at the same time. In this regard, transference of lines, crossing or concurrence of ideas (lines of solution) may prove to be a useful effect.

Here we restrict our analysis to internal SFR only.

In **Problem 57** the Ideal Final Result 1 can be formulated only with respect to the SFR of instrument, because the SFR of artifact (the glass) may not be changed according to the problem conditions.

Intensified Ideal Final Result 1: the flame provides glowing of the hole without complicating the system or causing harmful effects when the conductor is absent.

In the **Problem about a clothing mill** internal SFR are only the fabric and threads; for the item of clothing is equal to fabric and threads.

Intensified Ideal Final Result 1: the fabric of continuously changing color provides instantaneous changing of the color of threads without complicating the system or causing harmful effects.

Or: the threads provide instantaneous changing of their color to match the continuously changing color of the thread, without complicating the system or causing harmful effects.

What do we get from formulating the Ideal Final Result 1? In each problem we have come very close to the solution. And though some more steps should be taken to get a clear picture of Problem 57, in the second problem it will suffice to blend the two formulations of Ideal Final Result 1 and the answer will be evident.

Still, it is always useful to carry the analysis to the very end.

ARIZ Step 14. Formulate the physical contradiction: "To do... (state one conflicting effect), the operational space should... (state the physical state of the OS, e.g. 'stay hot') during the operational interval; but to do... (state the other conflicting state or requirement), the operational space should... (state the opposite physical state, e.g. 'stay cold')".

Notes:

16. Physical contradiction describes opposite requirements to the state of the operational space.
17. If complete formulation of physical contradiction causes difficulties, a short formulation can be made: "The component (part of the system in the operational space) should be present to... (specify), and should not be present, so as to... (specify)".

Physical contradiction for **Problem 57:** during the operational interval, the operational space should be electro-conductive to provide glowing of the hole and non-conductive so as not to contain (and bring damage to) a conductor.

Physical contradiction for the **problem about a clothing mill**: during the operational interval and in the operational space, the thread should be of non-charching color, so that no time is spent on frequent changing of the thread, and should be of continuously changing color so as to acquire the color of the continuously changing fabric.

ARIZ Step 15. Formulation of Ideal Final Result 2: "During the operational interval (specify) the operational space (specify) should provide the opposite physical states (specify) all by itself."

Ideal Final Result 2 for **Problem 57**: during the operational interval, the flame should be electro-conductive to make the hole glow without a conductor (external electrode).

This constitutes the answer to the problem, because flame is a plasma, that is ionized gas, it serves as a perfect conductor of electricity.

Ideal Final Result 2 for the **Problem about a clothing mill**: at the moment of entering the fabric, the thread should acquire the color of the fabric all by itself.

This answer is also clear: the thread should be either transparent or reflecting. In practice, these two properties are combined: threads are made of thin and light (nearly transparent) brand of nylon with bright (partially reflecting) surface.

But some problems are by far more complex. Let us assume that you failed to grasp the hints given by formulations of the previous steps, or you do not understand a certain physical effect. Then you need to carry the analysis further.

ARIZ Step 16. Modeling with Miniature Dwarfs.

By now you are familiar with the rules of using MD method. This step is needed to get a clear picture of actions of substance particles in the operational space and around it. MD method allows to visualize ideal actions (*'what should be done'*) without going into physical analysis (*'how-to-do-it'*). MD helps to eliminate mental inertia and boost your imagination. Quite often, it brings you to solutions in engineering terms, because the distance between a picture and a required effect is very small.

In Problem 57, the following picture should be drawn:

a) miniature dwarfs of the glass form a hole, miniature dwarfs of the air surround the circle, miniature dwarfs of the flame are standing at some distance from the hole. The conflict: because there is no conductor (external electrode) available, there is no one to pass electric charges (sparkling balls) to the dwarfs of the air;
b) we need someone to pass the electric charges. The dwarfs of the glass cannot do this. Therefore, the dwarfs of the air or the dwarfs of the flame should work as carriers of charges.

Problem about a clothing mill:

a) the dwarfs of the thread are drawn black, the dwarfs of the fabric are drawn white. There is no agreement between the two groups of dwarfs, they are fighting all the time;
b) one group should win and start controlling the other group. Because the dwarfs of the fabric surpass in number the dwarfs of the thread, the latter do not have a color of their own and get the color of the winners.

Step 17. SFR mobilization.

The idea of this step is to introduce as few substances as possible into the system. If existing SFR cannot be used as they are, they should be changed. The following rules should be used:

1. *Use a mix of two resource substances or of a substance and void*. Void is an utterly important substance resource: there is always an unlimited amount of it. Void is also cheap and can be easily mixed with substances at hand, forming foam, bubbles, hollow or porous structures, etc. Mixing void with air we get air under low pressure. Void should not necessarily be vacuum. In a solid substance, void can be filled with liquid or gas. In a liquid substance, void can be a gas bubble.

2. *Use a bi- or poly-substance* composed of single *mono-substances* (e.g. a notepad instead of one thick sheet of paper).

3. *Use substances derived from resource substances (or a mixture of derivative substances with void)*. Derivative substances are those that are obtained from resource substances via a change in their aggregate state (e.g. ice and vapor are derived from water), via a decomposition (e.g. hydrogen and oxygen derived from water, elements of multi-component mixtures, combustion products, etc.). Ions obtained from atoms and molecules and, conversely, molecules obtained (built) from ions are also derivative substances.

Note:

18. Substance is a hierarchic structure with many levels. For practical purposes, the hierarchy of levels can be represented as follows:

- substance after minimal treatment (e.g. wire, sheet, etc.)
- molecular aggregates, crystal lattices, polymers,
- complex molecules,
- molecules,
- atoms,
- parts of atoms,
- fundamental particles,
- physical fields.

The rules show effective ways to get derivative substances from substances that are either there already or can be introduced easily. Substances are derived via destruction of large structures into small structures or via assembling of small structures into big structures. The rules help to find the physical effect required in each case.

4. *Instead of a substance, use electric field or interaction of two electric fields.* For example, the method of breaking tubes by twisting (Soviet Patent no. 182 671) is known long ago. To tear ends of a tube apart by twisting, the tube should be gripped mechanically. This

causes deformation of the tube. Soviet Patent no. 342 759 suggests that the torque should be excited in the tube at the expense of electrodynamic forces. Electrons are a ‘substance’ which is always present in the object.

5. *Use the pair: “field – field-sensitive additive”* (e.g. magnetic field and ferromagnetic substance, UV-light and luminescent substance, etc.).

So, the idea of applying substance and field resources is not to utilize all of them, but to obtain a powerful solution at a minimal consumption of SFR. The less SFR consumption is, the more ideal the solution is.

ARIZ Step 18. Use of the Principles for Elimination of Physical Contradictions.

If mobilization of SFR has not led to a solution, it is necessary to examine the possibility of eliminating the physical contradiction by standard transformations (see Table on Resolution of Physical Contradictions).

Many problems can be solved with the Principles for Elimination of Physical contradictions. They are listed at page 176.

ARIZ Step 19. Use the Pointers to effects.

Here we shall study the possibilities to resolve contradictions with the help of indexes of physical, chemical and geometrical effects (see the next section).

Elimination of Physical Contradictions

Principles	Examples
1. Separation of conflicting properties in space	Soviet Patent no. 256 708: dust suppression in mining. Drops of water used in suppression should be small, but small drops form a fog. It is suggested that small drops be coated in a cone of larger drops.
2. Separation of conflicting properties in time	Soviet Patent no. 258 490: the width of strip electrode is adjusted to the width of the weld.
3. Amalgamation of homogeneous/heterogeneous systems into a supersystem	Soviet Patent no. 722 624: slabs (rectangular ingots) are butt-jointed on a roller conveyer to avoid cooling of their ends.
4. Transition from anti-system to a system or a combination of a system with an anti-system	Soviet Patent no. 523 695: bleeding can be stopped by applying a tissue soaked in blood of another group.
5. The system is given property A where a part of the system is given property anti-A.	Soviet Patent no. 510 350: clamp of vice for items of intricate shape: each component of the vice (steel sleeve) is hard, but the whole clamp is soft and of variable shape.
6. Changing of phase state of a system part or of the environment.	Soviet Patent no. 252 262: supply of energy to gas-using equipment in mines by transporting condensed gas.
7. Transition to a system operating at a micro-level	Soviet Patent no. 179 479: use of ‘thermo-crane’ instead of mechanical crane. The ‘thermo-crane’ is made of two materials with different coefficients of thermal expansion. Heating causes a clearing between the materials.
8. Dual phase state of a system part (transition of a part from one state into another in accordance with operating conditions)	Soviet Patent no. 958 479: heat exchanger with nitinol lobes pressed to it. Rising temperature causes the lobes to bend, expanding the cooling area.
9. Use of phenomena accompanying phase transition.	Soviet Patent no. 601 192: transportation machine for frozen loads with supporting slabs of ice (ice decreases friction due to melting).
10. Replacing one-phase substance with two-phase substance	Soviet Patent no. 722 740: polishing method. The working medium consists of a liquid (lead melt) and ferromagnetic abrasive substances.
11. Physical-chemical transition: appearance/disappearance of a substance due to composition/decomposition, ionization/recombination, etc.	Soviet Patent no. 342 761: ammonia plasticization of wood. Wood is impregnated by ammonium salts that decompose under friction.

8.2. INFORMATION DATABASE: POINTER TO THE EFFECTS

Most above-mentioned problems suggest that solutions to many simple and difficult problems are based on physical effects.

What is the solution to problem about the pyramid of pharaoh Cheops? (page 9). It is simple and effective: a ditch filled with water is made around the periphery of the construction zone. The level of water surface equalizes the entire surface of the site to the accuracy of 0.1 mm! The ancients had no idea about physical laws but were good at using one primitive physical effect: horizontal position of free liquid surface under the gravitational field of the Earth. Builders of St. Isaac Cathedral in Saint Petersburg used the same method while aligning the upper ends of piles driven into the ground: the foundation pit was filled with water.

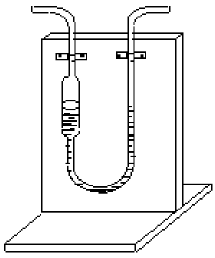
Nowadays this effect is familiar to every school student. Does this mean that it will be automatically used when a similar problem crops up? Unfortunately not. Not only are students and teachers unaware of the practical relevance of laws of physics, but neither are engineers. Physical laws exist separately from technical problems: the useful knowledge is lost.

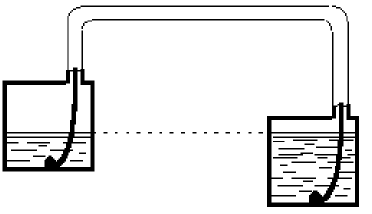
From this perspective, even a simplistic solution based on direct application of fundamental physical effects is acknowledged as *an invention, i.e. a novel, useful and totally different technical solution.* Such cases abound; pay a visit to a patent library, and you will find dozens and dozens examples.

What can be more primitive than the effect of communicating vessels? The ditches on the periphery of construction zone are, in principle, communicating vessels. Nevertheless, this effect is actively used by inventors. Below are just two examples:

1. Soviet Patent no. 351 112 (1972): Leak detector consisting of test prod, apparatus for measuring leakage connected to the prod via a flexible hose and exhausting machine to provide vacuum in the leak detector. Innovative features: for simplification and greater accuracy of measurements, the leak detector is made in the form of a U-shaped vessel filled with aqueous solution of indicator such as 1% phenolphtalein. One leg of the detector has a larger diameter. The diameter is chosen according to required accuracy.

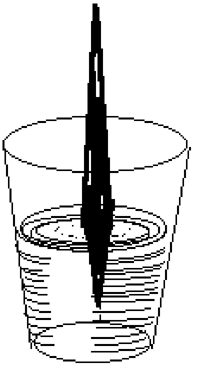
2. Soviet Patent no. 1 203 358 (1987): Hydrostatic level consisting of vessels partially filled with water. The vessels are connected by liquid and gas pipes one inside the other. Innovative features: in order to simplify assembly and utilization of the level by excluding the pipe located lower than the vessels, both pipes are located above the vessels. The liquid pipe is a bundle of capillary tubes (or fibers of wetted material) and is placed inside the gas pipe.





Compared with the classical experiment on communicating vessels, the former patent is different only in that it contains an expanded middle section of the tube. The innovative feature of the latter patent is replacing the liquid pipe with a wick.

"A body immersed in a liquid or gas is acted on by buoyancy force equal to weight of the liquid or gas expelled by the body". The famous Archimedes' principle is no less popular in inventive practice, because it guarantees cheap and witty solutions. Do you remember the problem about measuring the height of a cave, Problem 8 for measuring the volume of an electric bulb, problem about retrieving a ball from a gas expansion machine, Problem 41 about the counterweight for a deck crane, etc.? The solution to Problem 74 was also used in designing a universal load for testing cranes: the weight of the slab varies, as it is submerged/lifted from a water basin. Points on the slab wall determine the current weight of the slab. With this method you avoid keeping bulky concrete slabs at the plant.



Another simple but useful invention: a painting brush with float-type handle (US Patent 3 432 874). Indeed, it pays to know Archimedes' principle. For instance, your task is to transfer a car to the other bank of the river without bridges or pontoons. Elementary calculations will show that specific weight of a motor car packed into a rubberized bag is 0.1 tons/m^3 (with a draught of less than 20 cm!). The same values for other vehicles: Soviet tractor T-130 – 0.38 tons/m^3 (lighter than dry pinewood), 'Belarus' tractor – 0.17 tons/m^3, etc. In this fashion any machine can be transported across water.

Leo Tolstoy describes a tricky method used by French engineer Molar to straighten the walls of the Musee d'Arts et Metiers in Paris in the times of Napoleon. Molar drove bolts through the walls and, heating and cooling them, drew up the nuts. Thermal expansion of bodies is used so often that it may be called the ABC of the inventor. It helps to find simple and effective solutions to a wide class of problems that deal with micro-displacements and to save the efforts otherwise spent on creating high precision mechanical instruments (see Problem 9). Thermal expansion makes possible atom-by-atom accuracy unattainable in mechanics. The amount of heat evolving on the pusher (a metal rod) and therefore the change of its dimensions can be controlled by the best-controllable field – electricity.

> **Problem 94.** Final precision treatment of blind holes involves removal of the last 8-10 mm thick layer of metal. Holes are treated with a reamer, a special instrument with carefully calibrated external diameter of standard gauge. A question arises: how are we to insert the reamer into the rough hole if the hole diameter is by 10 micrometers smaller than the standard? The solution is simple: the instrument should have conical shape; the narrow end is inserted first. But clearly, this method will not work for blind holes (the narrow end will be stopped at the bottom of the hole and no treatment will be possible). What can be done?

Analyzing this problem we inevitably come to one of two physical contradictions:

- the reamer diameter should be smaller than the standard and pass easily into the hole, but should be equal to the standard and work on the hole;
- the hole diameter should be large and small at the same time.

Of course, the physical contradiction is to be resolved with the help of thermal expansion: by either cooling the instrument or heating the artifact (Soviet Patent no. 709 344).

This problem elucidates the ***mechanics of using physical contradictions***: there is no place for physics in the initial situation, the problem becomes a 'physical' one only after the physical contradiction has been revealed. At first we do not think of using a physical effect. However, when the physical contradiction has been formulated, it is easy to see the desired effect is a physical one.

Now it is time to answer the question: why is physical knowledge used so seldom? There are a number of reasons:

- before using a physical effect as specified, it is necessary to analyze the problem and reveal a physical contradiction;
- in the majority of problems, application of a physical effect deals with transformation of a technical system (elimination or introduction of elements, introduction of subsystems and new links). These kinds of transformation require knowledge of the laws of technology evolution and the principles of S-Field analysis.
- What the inventor needs is not the 'ordinary' physics taught at school, but an 'inventive physics' – the peculiarities and inventive resources of physical effects.

In this sense, physics cannot be effectively used in combination with trial and error method.

> **Problem 95.** Suturing of intestines is a long and tiring surgical procedure. Normally, two surgeons work in shifts suturing the sides of intestines layer by layer (see Fig. 38a).
>
> It was found out that if outer sides of intestines are connected (see Figure 38b), and their ends are clamped together, the layers of the intestine wall heal together

quickly. A special instrument resembling a ‘can lid’ was designed for such operations (Figure 38c). The method has some deficiencies: 1) the lid snaps injuring the sides of intestines, because the instrument is inside and the lid has to be pressed to the intestine through the wall; 2) the instrument is attached to a thread to pull the instrument out through the mouth. Usually, the patient walks and sleeps with the thread out of their mouth until the joint of intestines is healed completely. Depending on each case, the time of recovery can be from 10 to 15 days. The moment when the intestines are healed together is determined by X-ray tests – the clamped edges die off and the clamp moves under the suture. Quite often the patient swallows the thread and then the operation has to be repeated or the thread is tied up to a tooth. The withdrawal procedure is very unpleasant. What could be done?

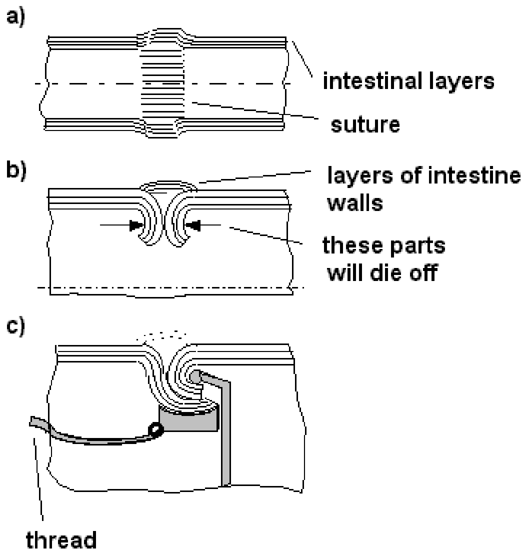


Figure 38.

If this problem is offered to TRIZ beginners, the solution process comes down to fruitless attempts to improve the ‘lid’ and the surgical procedure (for example, a clamp that gets dissolved within certain time. But again, healing time is different for every person and cannot be determined beforehand).

Having studied technical and physical contradictions and the index of physical effects, students, as a rule, formulate the following contradiction: **“The clamp should be large (equal to the diameter of intestines) in order to fix the lid tightly until the intestines heal, and the clamp should be small enough to exit the body in a natural way”.**

As a result, a series of solutions are suggested: two rings assembled from small magnetic segments with Curie point around 40-45 ^{0}C (heating is done by high frequency radiation or by a hot water bottle); clamp of metal with memory shape effect (under the same temperatures the components of the clamp unbend, disintegrate into parts, or turn into balls). Magnetic rings are now used in operations on children. Yet these rings do not disintegrate into smaller components. Other effective solutions are still waiting to be implemented.

The Pointer to physical effects[11] *bridges a gap between physics and engineering*, a body of knowledge on technical application of physics. It only nominates the effect and therefore can't substitute a book of physics. In the Appendix you will find an extract from the Pointer to Physical Effects[11]; a kind of table of contents of a full version index. The full version resembles a catalogue containing brief descriptions of effects, examples of their use, most frequent cases of combination with other effects, and major bibliography. Indeed, such index is inventor's pocket book of 'all physics'. Brief as it is, the Pointer is much bigger than the present book.

In the Appendix you will find a selection of effects most popular in today's inventive problem solving.

Even less known to inventors are ***chemical effects***[12]. At the same time, it is chemical effects that often lead to near-to-ideal answers. It often happens that the problem logically leads the inventor to confront invariable laws of physics. Trapped by physical laws, the inventor may spend years struggling with a sharp physical contradiction. Why not resort to chemistry, a collection of powerful tools that must have been created specially for 'cheating' physical principles? A great many chemical effects are stored in the backyard of chemistry, waiting for technical application. All of a sudden a lucky inventor may find a strikingly simple 'chemical' solution to a problem over which he/she has spent so much time. To increase your chances in problem solving, we have also placed here an extract from the Pointer to Chemical Effects.

The purpose of using physical and chemical effects is transformation of the substance in operational space and emergence of new system properties in the process of resolving a contradiction.

The same objective is achieved when you take advantage of ***geometrical effects.*** Incidentally the simplest solutions are very often geared to this group of effects. Changes touch upon the shape or relative positions of system parts while their physical and chemical nature remains unchanged.

Inventive application of geometrical effects is highlighted in an extract from the Pointer to Geometrical Effects[13] (see Appendix).

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[11] Author: Yuri Gorin.

[12] Author: Yuri Salamatov.

LIFE OF A CREATIVE PERSON

A.V. Dyakov (born 1911) created a new theory of weather forecasting that ensures a much greater probability than other existing theories. In the beginning of his career, Dyakov graduated from two universities and later conducted research work. In 1935 he found himself with a theodolite at the construction of Myndibash-Tashtagol railway. Later he was chief meteorologist of Gorno-Shorski railway ("in those days and in that project you paid dearly for a mistake: so severe were the weather and the epoch"). Dyakov's goal of life, – to improve the accuracy of weather forecasts, – was chosen under the influence of circumstances. His program was to realize mathematical methods in meteorology. How the program was implemented: in his letters, Dyakov was trying to convince his correspondents that the theory was true. Indeed, the theory worked despite the fact that experts ignored it. People from all over the world sent letters to Dyakov expressing their gratitude for correct predictions. Technique of problem solving: Dyakov discovered and calculated the correlation between the weather and solar activity. Personal strength and endurance: as a result of information written against Dyakov by his assistant, he was dismissed from work for five years. This did not stop his work: addresses around the world were still getting weather reports on a regular basis. He worked as a photographer to earn money for sending cables. Industry: every day in the course of 50 years Dyakov performed measurements, read literature and wrote weather reports. The probability of predictions was brought up to 90-95 percent; Dyakov succeeded in prognosticating around 50 weather anomalies around the globe earlier than 15 days before. In 1972 he predicted the drought in the USSR.

And here we see the unpublished manuscript of his book written 30 years ago: a second generation of meteorologists could have studied by it... (From: Yu. Rost, "A fighter with The Earth Gravity", Literaturnaya Gazeta, March 28, 1984 (in Russian).

8.3. A LOOK INTO THE FUTURE

Practical application of imagination development tools often gives rise to a question: which tool is the strongest tool? The answer is simple: the most powerful tools are those that are close in meaning with the laws of technology evolution. When generating new fantastic ideas we develop new systems. That means that it is always important to take into account the *system* properties of new fantastic objects.

Basically, system properties are applied to a new object when it is regarded from two perspectives: *horizontally* (that is, with respect to its past, present and future) and *vertically* (with respect to subsystems and supersystems of different ranks). Even if, in the process of using fantasy tools, you fail to alter the object fundamentally and to give it properties that were not observed in the initial object, systemic analysis of the object with respect to the above mentioned procedure is sure to give you sufficient fantastic ideas. Other ways of analysis also are possible: tracing the object's links and interrelation with neighboring systems, environment, etc. In doing these manipulations we analyze the possible alterations of other objects caused by the changes achieved in the given object (for in other objects these alterations may be more powerful and qualitative).

However, systems change according to universal principles of dialectics. Skillful application of these principles ensures new qualitative changes. The power of ICI tools depends on how true they are to the principles of dialectics ("Unity & Struggle of Opposites", "Quantity becomes Quality" and "Negation of the Negation"). All ICI tools that we studied meet the requirements of the first two principles: we repeatedly emphasized the necessity to reveal/create and resolve contradictions while developing (transforming) the objects of fantasy and the demand to obtain new properties in the process of quantitative alterations.

Even the tendency method, well-known outside the ICI course, is geared to dialectics. You need to create and resolve a clash of tendencies, a contradiction. It is in this respect that this method differs from similar methods used in other sciences. For example, futurology, the science about forecasting the future, uses the tendency method without any reference to dialectic laws, by merely projecting today's tendencies into the future and ignoring the possibility of conflicts of tendencies and of emerging contradictions. Below are typical examples of such prognoses: [13]

- a 1000-passenger airplane traveling ten times faster than sound (i.e. at 12 000 km/h) is expected to be designed by the year 2000;
- by the same time, vessels with carrying capacity of 1 mln tons are expected;
- passenger trains will travel at speeds about 300 km/h;
- the planet will be densely covered with a video telephone network;
- 3-dimensional television is expected.

[13] The World in 2000. – Moscow, Progress, 1973 (in Russian).

Recently, this method has been subject to justified criticism: the logic of it is prone to absurdities, such as the predictions that by the start of the next millennium all urban territories in the USA will be occupied by cars, the entire population of developed countries will be involved in scientific research and etc.

Dialectic method offers a different approach to forecasting. According to this approach, tendencies of systems development should be revealed, specific practical dialectic mechanisms formulated and verified on a given class of systems. Once a mechanism is verified, it can be used in the process of system's development.

The first two principles of dialectics elucidate the mechanism of evolution. They answer the question: How do systems develop? Incorporating this mechanism, the set of TRIZ tools are, in fact, a ***mechanism of technology evolution***. The third principle ("Negation of the Negation") shows the direction of development. Thus, it answers the question: In what direction do systems develop? The third dialectic principle underlies the law of increasing ideality of technical systems. The idealization wave is another projection of the universal spiral of evolution.

Do fantastic ideas follow any objective tendency? If so, can this tendency be used for finding new ideas?

In order to work out a universal tendency in fantastic ideas, it was crucially important to collect ideas scattered in literature. They were to be collected, classified and stored in a 'Index of Fantastic Ideas'. This work was carried by G. Altov (pen-name of G. Altshuller) during several years. His Index contains thousands of ideas divided into classes, subclasses, groups and subgroups. Before that, no one had ever collected and systematized fantastic ideas. The Index allowed studying the intricate and sometimes 'weird' process of origination of fantastic ideas.

For example, as it turned out, each fantastic theme, be it space voyage, contacts with alien civilizations, explorations of the ocean or any other theme, shows four distinct categories (or **levels**) of ideas:

Level I: *one object which bears a certain fantastic result;*
Level II: *multiple objects which collectively bear another result;*
Level III: *the same results, but attained without an object;*
Level IV: *description of conditions under which the need for results disappears.*

This scheme of development of fantastic ideas was called **level design (also known as "stepwise heurithm"**). Let us look into the scheme in detail:

Level I: Most fantastic ideas are found at this level: the 'Nautilus' submarine, one space rocket, one station in two oceans, one time machine, one robot, etc.

Level II: Squadron of spaceships (as in 'space operas' – once a popular trend in science fiction), underwater civilizations (A. Clark), mass telepathy. And yet, at this level we see much more free space...

Level III: Even more free space, and fewer ideas. For example, convergence of stars and their planet systems ('Starships' by I. Yefremov), communication via zero-space, exchange of minds between civilizations (R. Shekley), transmission of radio copies of human brain (V. Tendryakov), deep diving without diving-suits (A. Belyayev).

Level IV: Even fewer ideas than at the 3rd level. The task of space flights is to reach the stars. But when does it become unnecessary to reach the stars? When the stars are near or there are no stars. Idea no.1: a super-civilization creates star cities in the form of aggregates of balls ("Rocky Storm Port", G. Altov). The second idea (no stars) has not yet been employed by science fiction.

Why is this four-level scheme important?

Here is a series of popular ideas concerning fantastic transformations of human body: the invisible man, the amphibious man, the man passing through walls... If you think of other ideas, you will inevitably generate similar concepts: the man who sees electricity, the man who never gets tired, the man with prodigiously powerful memory. Mental inertia confines us to the domain of the first level, generating ideas belonging to the same group.

Level II: transformations of the human body: the man with a set of extra faculties (a certain 'idealization' of humans, overlap of many functions in one person). Alternatively, there may be a group of people, each of them possessing a highly developed extra faculty. Together they form a superman that can accomplish supertasks (highly complex tasks for all the civilization).

Level III: the task is accomplished without the object (without extra human faculties). Supertasks are solved by a group of ordinary people with ordinary talents and a lot of shortcomings. Questions arise: what kind of group are they? How is the group managed? Who is the leader? What supertask is being accomplished?

Level IV: No need to accomplish supertasks (a neighbor civilization has given answers to all possible problems, all supertasks are achieved and the civilization has lost a goal; or a civilization only accomplishes micro-tasks, etc.). Developing this situation, one can develop and elaborate a great many novel fantastic ideas.

The *heurithm* can be modified and detailed to expand the potential of the fantasy tool. For example it is possible to study the change in the system and in its function in the process of gradual transition from level to level. The number of levels will be increased (The level numbers I, II, etc. in the original version are changed into 1, 2, etc. for distinguishing from the levels in pages 184-185.).

<u>Level I (System+Function):</u> there is only one unique system (the only system in the world). It is sure to perform its function.

<u>Level II (super-System + Function):</u> supersystem incorporates a multitude of identical systems. There are even more systems than is necessary. OR: supersystem performs the function of the system.

<u>Level III (non-System + Function):</u> no system, the function is delivered by other systems.

<u>Level IV (anti-System + Function):</u> the same function, an opposite system;

<u>Level V (sub-System + Function):</u> the function is delivered by a subsystem of the initial system;

<u>Level VI (System + super-Function):</u> one system – many functions (in addition to the main function);

<u>Level VII (System + non-Function):</u> the system is here, but its function is redundant (or there is no need to achieve the goal);

<u>Level VIII (System + anti-Function):</u> the same system with an opposite function;

<u>Level IX (System + sub-Function):</u> incomplete (partial) function.

Technique:

1. **Choose the object to be changed;**
2. **Formulate the primary purpose (Function) of the system;**
3. **Change and study the System and Function at each level.**

<u>Notes:</u>

- At each level, provide an idea that realizes the level formula;
- A conceptually new idea should be obtained at each level.

For example, our system is the environmental suit. *The function of the suit* is to protect the wearer from exposure to harmful environment.

Level I.

A. There is only one environmental suit – the space suit on a being from another planet.

B. Modifications of humans allow exploring space and oceans without environmental suits (the only suit being exhibited in the Mission Training Center). Alternatively: there is no need to explore (no space? – or, maybe, there are no oceans on the Earth, only a deep crevice filled with water. Tourists can rent the unique suit and explore the crevice in it).

Level II.

A. Environmental suits are everywhere (at home, at school, in the shops, at the doors of buildings). People walk in these suits (due to excessive pollution of the environment, abrupt climatic changes, epidemic of an unknown virus, etc.). A special industry produces environmental suits for humans and animals; there are special fashion magazines about environmental suits.

B. All buildings are built air-tight and with their own microclimate (buildings that are environmental suits themselves). Cars are air tight too. A whole city may be placed under a tight cupola. The Earth is put under an insulated cover; cities and factories are located on the sea bottom.

Level III.

The function of air-tight suit is performed by ordinary clothes (air-tight fasteners, air-filtering fabric). Alternatively, the human body works as an air-tight suit (cyborgization of humans). Diving suit made of modified water.

Level IV.

Anti-suit, i.e. a system meant not for protection, but for maximum exposure to the environment (a suit that concentrates the fragrance of flowers in the wood, collects water from the air in the desert, traps medicinal substances from the environment).

Anti-suit that protects the user, but the user is outside the suit (anti-suit purifies the air, absorbs pollutants, dampens noise, 'attracts' impacts, bullets and meteorites). Anti-theft anti-suits for robots, anti-suits for cars that withhold fumes and dampen the droning of the engine, anti-suits for factories (full isolation from the environment), for volcanoes, living suits...

Anti-suit not for protection, but for isolation of the person from the society (for criminals, patients with contagious diseases).

Level V.

Protection from exposure to harmful factors with the help of a part of an environmental suit (jackets, helmets creating an impermeable field around the user; knapsacks creating a thermal or air jacket around the user in outer space or under water).

Level VI.

Environmental suits can be used for different purposes: as means of transportation, as training system, solar plant, computer, individual rocket. Convertible suit that can be turned into tents or even apartments (the concept of portable dwelling). Balloons, elevators, medical environmental suit, suit that serves as a control desk of a complex system (with its sensors connected to nerve receptors).

Level VII.

Changing environment eliminates the need for environmental suits (the entire solar system is filled with air of normal temperature and pressure; vertical air wells are constructed in the ocean: people can reach the bottom in a balloon or a helicopter).

Level VIII.

Environmental suit with an opposite function. We have no sympathy for anti-humanitarian ideas and this level will be omitted.

Level IX.

Partial protection of humans (protection of single body parts); in addition to well-known systems (gloves, eyeglasses, gas masks, footwear) new ideas can be offered: 'suits' for protection of the brain from overloads, anti-failure suits for hearts, suits that safeguard cells of the body from radioactive radiation.

Problem 96. Using *the stepwise heurithm* generate new ideas on how to change the following objects:

1) lifebelt; 2) pencil; 3)briefcase; 4) hammer; 5) combine harvester; 6) bicycle; 7) helicopter; 8) nail; 9)scissors; 10) sculpture; 11) iron; 12) road; 13) lamp; 14) house; 15) boat; 16) pipeline; 17) parachute; 18) clock; 19) book; 20) photographic camera; 21) elevator.

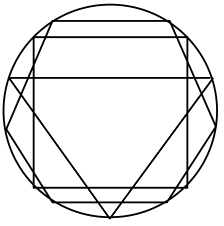
EVOLUTION OF TECHNICAL SYSTEMS CAN BE PREDICTED

Knowing the laws of development it is possible to envision transformation potential even for efficient systems. Laws can be used not only for solving evident problems, but also for predicting problems that may arise in future:

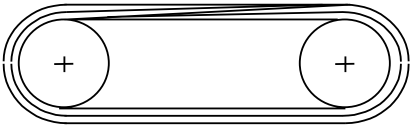
Solution to Problem 25: Soviet Patent no. 305 445 describes a method of making special effects: "mixing heterogeneous substances with different colors, e.g. iodine solution and dichloroethane. The unusual picture of blending of two substances is photographed."

This invention was implemented when Solaris movie was created. But here, synthesis of a new system violated one important law. What law was violated? What problem should be formulated? How is this problem to be solved?

EVOLUTION OF THE ABRASIVE BELT



If an abrasive belt is turned into a Moebius strip, its dimensions will remain, but the working surface will increase twofold. The strip can be three dimensional and have a triangular cross-section, which also expands the working surface. Square or hexagonal cross-sections can be used too. Below is a formula from Soviet Patent no. 1 119 603: "abrasive belt consisting of a base with a twisted run, joined to form a circle. The cross-section of the base has the form of a regular polygon with abrasive coating on each side. Innovative features: the polygonal run of the base is twisted through two sides to increase durability." Ultimately, the working surface of such belt can be increased by



π times (circular cross-section). But it may be necessary to increase the working surface by 7, 8 or 10 times. What should be done? Is this possible at all? What do you suggest?

BATHING IN A ... VOLUMETRIC FLASK!

During medical examinations it is often necessary to know the volume of the patient's body. The volume is determined by immersing the patient in a special tank with a scale on the wall. But this 'wet' method based on Archimedes' principle is rather inconvenient. Hot water should be changed very often, clean towels should be at hand and patients do not relish taking an extra bath. Problems with adult patients are nothing to speak about, compared with measuring the volume of infants: screaming, fidgeting and splashes of water all around the room... The measurements are distorted because of the hands of the nurse and the mother, fluctuations of the water level. It is very difficult to read the scale.

The 'wet' method is even more difficult to use in mass measurements made at farms during fattening of bull-calves, pigs and during zoological observations of wildlife.

What can be done?

9. FORECASTING UNEXPECTED: EVOLUTION OF SYSTEMS

9.1. SYSTEMS: RAISING TO A POWER

Imagine you are given the following problem: “A new technical system A1 is designed. What will be its further modifications – A2, A3 and so on?

Quite naturally, such formulation causes your confusion bordering on irritation: “Can this be a problem? ... You are asking for a solution, but you don’t even tell me what kind of system it is! There is no solution, that’s it”.

Let us put it another way. You are driving a car in a foreign city. You see a ‘right-hand turn’ sign in front of you. You are heading to your destination following a map. Looking at the signs you choose the best way. What you are doing is also finding a solution, i.e. the way to your destination.

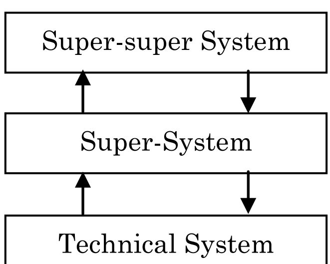
One trend in technical systems evolution for idealization is transition to a super system: technical systems merge, forming bi- and poly-systems.

> **The Law of Transition to a Supersystem: During evolution, technical systems merge and form bi- and poly-systems.**

Merge of systems into a supersystem is advantageous for the technical system, because:

- some functions are delegated to a supersystem (for example: repairing all TV sets at one service center);
- some subsystems are withdrawn from the technical system, and, consolidating into a subsystem, become part of a supersystem;
- upon their integration into a supersystem, the constituent systems begin to display new properties and functions (one TV antenna used by a whole block or village provides high quality cable television and allows to set up video communications via the same cables).

Upcoming bi and poly-systems do not stop ‘halfway’. Instead, their evolution continues ‘upwards’ (formation of large-scale super-super-systems) as well as ‘downwards’ (convolution of several systems into one system or, ultimately, into an ideal substance). This two-way, reciprocal process can be graphically represented as follows:



Evolution of engineering and evolution of life on Earth have many common features:

- Continuous **integration** of organisms into larger supersystems in the following order: "cell – organism – population – ecosystem – biosphere";
- **Overlap of functions**. For example**,** the leaf of the plant is a converter of solar energy into chemical energy, a pump maintaining pressure in the capillaries, a temperature regulator and accumulator of nutrients. The liver performs over 20 functions.
- **Convolution of systems** with useful functions into an ideal substance. For example, the mechanism of genetic data replication was first 'tested' at the level of cells and organisms and later 'convoluted' into genetic mechanism.

Yet, essential differences between evolution of life and evolution of engineering should be noted. K. Sagan quotes an example: the computers of each Viking spacecraft landing on Mars in 1976 were programmed with instructions amounting to megabytes. Each Viking's 'genetic pool' was slightly bigger than that of primitive bacteria, but much smaller than that of algae. Indeed, a bacterium can be likened to a Viking in terms of complexity, accuracy and efficiency. An ordinary cell of a living organism should be therefore paralleled with a Viking assembly line. In this context, the prototypes of modern apparatuses are among the most ancient living organisms (bacteria) and elementary 'subsystems' (cells) of the present-day fauna. Thus, no direct analogy can be drawn between the laws of life and the laws of engineering; one can only speak of certain trends governing the evolution of any system. *The law of transition to a supersystem* is one of such trends.

Let us see how this law manifests itself in the evolution of technical systems (see Figure in page 193). Duplication of the initial **single system** *(mono-system)* results in a **bi-system**, or, with more than two systems involved, in a **poly-system**. Integration is observed not only among identical (homogeneous) systems, but also among **systems with biased (slightly different) characteristics**, among **heterogeneous systems** (systems with varying functions) and **inverse systems** (systems with opposite functions). In all cases, integration and merge of systems passes through the same stages.

This *mono-bi-poly transition* may occur at any stage of evolution and at any level of the technical system hierarchy (supersystems, subsystems, substance).

Formation of bi- and poly-systems involves quantitative modifications of three parameters: **properties, links, internal medium.**

> **The main purpose of using mono-bi-poly transitions: quantitative change (integration of systems) is only justified, if new properties emerge.**

Problem 97. Hothouse is a well-known system. Think of new modifications of this system. Use transition to a supersystem.

Formation of a bi-system brings about a unique **new property** (a super-property, an unexpected add-on), only observable in this particular consolidated system. Development of new properties is the most important criterion of correct mono-bi-poly transition.

For example, the knife has certain properties, but the scissors (knife + knife = bi-system) display another property, non-existent in two separate knives. If a metal plate with one coefficient of linear expansion is joined with another plate with another coefficient, we get a bimetal plate (bi-system with biased characteristics) and a new property: bending under heating. Serial joining of plates with opposite (negative and positive) expansion coefficients yields an inverse bi-system with another new property: zero expansion coefficient.

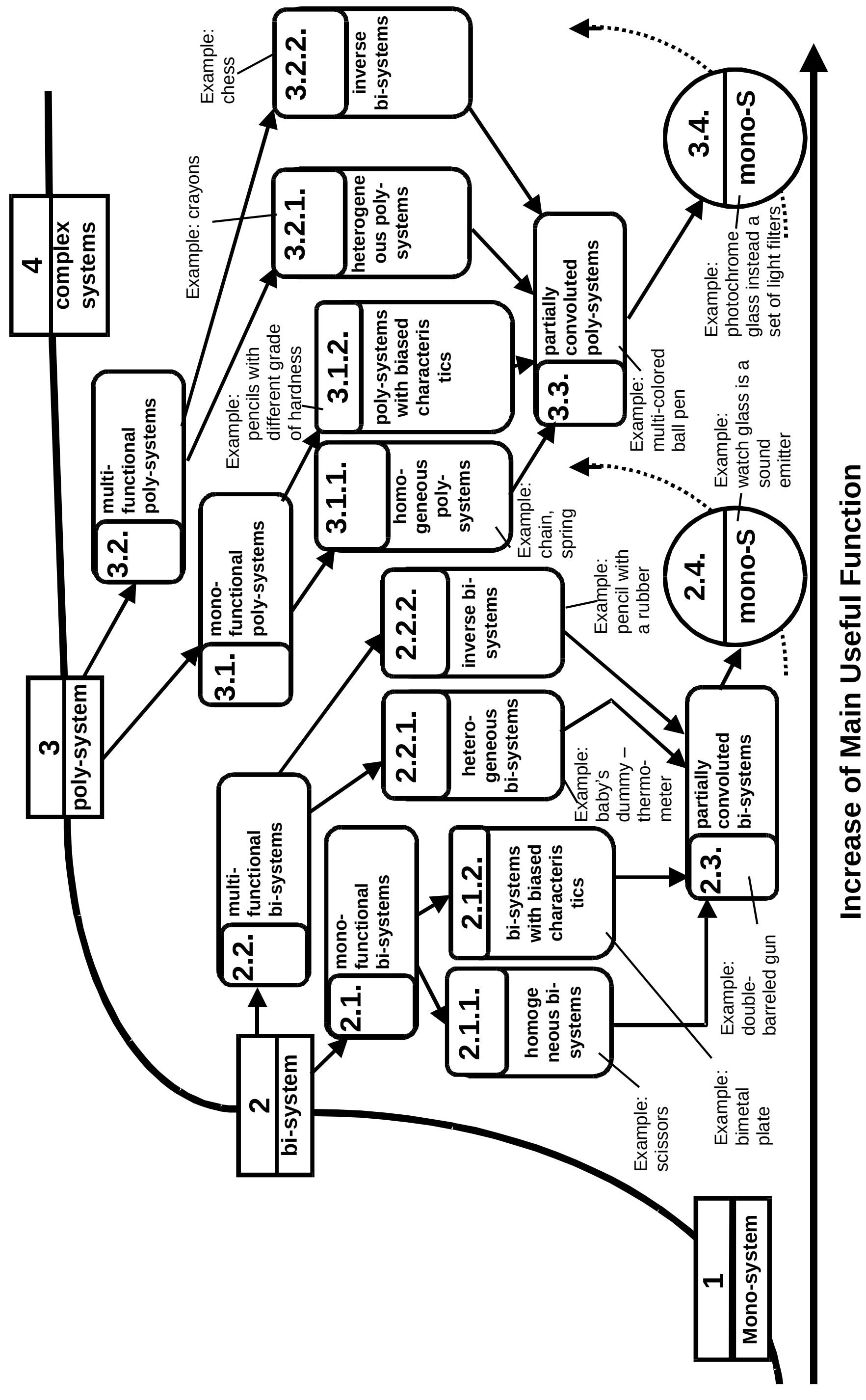


Figure 40. Evolution of technical systems

High-speed armored airplanes appeared as a result of Ilyushin's brilliant idea to resolve a sharp technical contradiction by using airplane armor as a load-carrying structure. The opposite system – armor-piercing 7,62 and 12,7mm bullets – appeared in response to armored airplanes. This, in turn, gave rise to the next sharp contradiction: to protect planes from the new bullets it was necessary to use 15 and 35 mm thick armor plates weighing 120 and 280 kg persquaremeter respectively. Such armor would not allow planes to travel at required speeds. The contradiction was resolved through transition to a bi-system: the planes were covered with two thin sheets with an air clearing between them. Hitting the outside sheet, the bullet started tumbling between the two sheets and even could be broken due to the asymmetrical shape of the hole made by the bullet in the outside sheet. Thus it could not break through the second sheet behind.

In 1921, designing his *termenvox* (electric musical instrument) L.S. Termen faced a technical contradiction: if the instrument was to generate sounds within the audible band, it would be buzzing during pauses and before the playing was started. Indeed, it was impossible to keep switching the instrument on and off all the time. Termen came up with a witty solution: a bi-system with biased characteristics. He installed two high-frequency generators producing high frequencies (for example, 100 and 102 KHz – frequencies that lie within the inaudible band) and a detector deriving the difference between the two frequencies (2 kHz within the audible band). The difference was derived only at the moments of playing.

To increase the motion speed of a robot's grip, we need an effective braking system to prevent the grip from hitting the stationary base at the end of the motion cycle. In a simple braking system, the grip presses a piston which, in turn, expels oil from a chamber through a narrow slit. The grip's kinetic energy is dampened but the oil gets heated in time and, losing viscosity, seeps through the slit without resistance. According to US Patent 3 791 494 the slit should be a self-controlling bi-system with biased characteristics: it is formed by two elements with contrasting coefficients of thermal expansion. While heating, the elements narrow the slit area by themselves but the total resistance remains unchanged.

Another example of how a new property emerges from parallel connection of homogeneous systems with biased (slightly different) characteristics is two electromotors driving a drilling machine. Usually, the feeding mechanism of automatic drilling machines should be adjusted to the drill diameter, speed of rotation and new material. The UK firm DESOUTTER designed a drilling machine that selects a feed regime automatically depending on the new parameters. The machine requires no readjustments when the type of article under treatment is changed (Figure 41). It consists of a lead screw, two pulleys connected separately via belt transmission with a separate electromotor and a set of controlling microswitches. The A pulley is fixed stiffly on the screw so as to set it in rotation. The B pulley is a nut placed on the thread of the lead screw so as to set it in reciprocating motion. The electromotors X and Y are connected via belts with the pulleys A and B respectively. They rotate in the same direction, but the rotation speed of the Y motor is by 20 percent lower than that of the X motor.

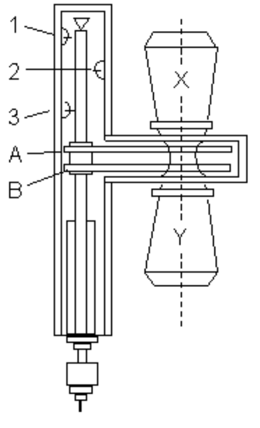


Figure 41. Diagram of the automatic drilling machine
1,2,3 – microswitches; A,B – pulleys; X, Y – electromotors

Displacement of the lead screw is operated by microswitches 1, 2 and 3. The X motor switches on first. It feeds the drill to the article at the expense of the lead screw rotating in the immovable nut-pulley B. When microswitch 2 is turned on, the Y motor is switched on. Due to the difference in rotation speeds between the A and B pulleys, the rate of feeding the drill drops down by five times. When the drill touches the article, the rotation speed of X motor decreases while the Y motor speed does not change. The smaller difference in speeds brings down the rate of feeding the drill to a speed at which the X motor still possesses sufficient force to maintain this speed. The correspondence between the torque and the rate of feeding the drill provides optimal conditions of drilling.

If the drill gets clogged by chips slowing down the rotation speed by more than 20 percent, the B pulley starts rotating quicker than the lead screw. The lead screw is automatically withdrawn and the drill is cleared of chips. The whole machine is operated by a microprocessor. Drilling heads with self-regulating feed turned out to be the most suitable for making holes in articles with internal cavities or in articles consisting of layers of different materials. Treatment time of such articles can be reduced by five times.

Formation of heterogeneous systems is more effective than formation of homogeneous systems. While homogeneous systems perform one function only, heterogeneous systems have two functions. Examples: baby's dummy – thermometer, stereo-hairdryers (hairdryers in hair salons with built-in headphones).

Nevertheless, integration of heterogeneous systems does not always bring about a new property:

- Soviet Patent no. 71 918: "cylinder-shaped pencil-case with a multiplication instrument (Pythagorean table)";
- Soviet Patent no. 74 300: "pen and pencil tray with a clock";
- Desk lamp with a clock.

There is nothing innovative about these inventions, only a small material gain (saving in material). That is why they remain at the lowest level of innovation.

Below is one more case of mechanical combination in which joining of inverse elements into a bi-system did not cause a new property. Soviet Patent no. 1 227 511 describes a combined mechanical pencil with a cup at the tip containing an eraser. For convenience, the cup is joined to the pencil by a hinge.

As early as at the end of the 19th century, US Patent Office canceled a patent describing a pencil with a rubber at the tip. The court considered the patented invention to be a mere aggregation of components known previously (pencil and rubber), because there was a lack of interaction between them and their combination provided a sum of effects but not a qualitatively new effect.

How does the new quality manifest itself in a bi-system? Systems should be integrated so that the linking of properties of components goes two directions: *some (useful) properties sum up and strengthen one another (contributing to the new system property) while other (harmful, or non-needed) properties are dampened, withdrawn, mutually neutralized.*

As a result, the life of the new system is dominated by its system property. Quite unexpectedly, this property may emerge out of a combination of inconspicuous or neutral properties of components. A simple example: imagine that you want to block a small creek with bricks scattered around. The bricks on the ground are rubble, not a system. You lay one brick so that its longer side blocks the water stream. The creek begins to flow around the shorter sides of the brick. The shorter sides are the harmful (bad, undesirable) properties. To eliminate them, you put two more bricks on both sides of the first brick. The 'harmful' sides disappear. Before that, the three bricks had six short sides and now there are only two sides: the other four sides are mutually neutralized, while the useful property (the ability to block the creek) has increased. In other words, the necessary properties have summed up.

'Addition' or 'subtraction' of useful/harmful properties is typical not only of homogeneous bi- and poly- systems. This system effect is realized to the fullest degree in formation of inverse systems. Take reinforced concrete, a typical bi-system at the level of substance: the bars work in tension, the concrete works in compression. In this context, positive properties complement one another while negative properties are mutually compensated. Concrete protects steel from corrosion while steel prevents concrete from crumbling.

The following situation is often encountered in some industries. A piping system may consist of two kinds of pipes: some pipes are used for feeding alkaline liquids which build up sediment on the pipe walls and block the pipes while other pipes are used for acid liquids that attack the walls. This problem situation invites integration of the pipes into a bi-system. According to Soviet Patent no. 235 752, acid and alkaline liquids can be supplied alternately through each pipe: acid attacks sediments while alkaline liquid builds up a protective layer.

Soviet Patent 950 241: two-compartment hothouse. One compartment has a transparent roof and is meant for oxygen-producing plants, the other is dark and is meant for plants producing carbon dioxide. The new property: gas exchange between the compartments without fans. Additionally, if there is a correct proportion of plants in each compartment, it is possible to make the hothouse airtight. Such a hothouse can be set up at a space station or combined with a house: carbon dioxide and heat will flow into the hothouse and the rooms of the house will be filled with oxygenated air.

Soviet Patent no. 728 941: roller for paint-coating. The bristles of the roller is made of two unlike materials that give opposite static charges to the particles of paint. As a result, the particles stick together better and form an even layer, securing quality coating.

Two more examples concerning *inverse systems:*

Soviet Patent no. 1 260570: fastening device with tightness indicator as in Soviet Patent no. 496 384. The device simplifies measurements of the tightening effort and allows to control its time variation. It is equipped with an extra indicator in the form of a plate sensor made of optically active substance. The sensor is located under a Polaroid film and connected with the main component via a gasket of elastoplastic material. The sign of the fringe pattern on the extra indicator is opposite to that of the main component. The fringe pattern of the main component corresponds to the preset tightening torque.

Soviet Patent no. 615 927: method of protection and observation of (chiefly manual) welding and cutting. The reflectors are placed so that their vertical planes face one another and their focal points are displaced. Innovative features: to increase safety of welding, one reflector is placed on the welding helmet and the other on the electrode holder; the focal point of the latter is brought into coincidence with the direction of sight of the welder looking at the point of welding.

In partially convoluted bi-systems, several subsystems are replaced with one subsystem.

For example, the catamaran with one sail for two boats; double-barreled gun with one buttstock for two barrels; the drawing pen with one shank, etc.

In a fully convoluted bi-system, one subsystem/substance performs the function of the whole system.

For example let us take a lens (mono-system) – a simple optical system, – and trace its transformations during bi-system evolution:

- Step 2.1.1. spectacles (volumetric sight is the new property not observed in a single eye-glass);
- 2.1.2.: bifocal spectacles; the lens consists of two halves, each with its own focal distance. Here, two mono-systems are joined in parallel. Serial joining of lenses with biased characteristics

results in a perfectly new technical system: e.g. eye-piece plus objective lens results in a primitive telescope or a microscope.

- Step 2.2.1. lens plus prisms (binoculars), or lens plus mirror (mirror telescope);
- Step 2.2.2. lens plus a diaphragm (camera lens);
- Transition from 2.1.1 to 2.3: lens with variable geometry (in a flexible envelope);
- Transition from 2.2.2 to 2.3: spectacles with lens changing opacity depending on the light intensity;
- Step 2.4: camera lens of variable geometry. The surface of the lens is covered with black electrochrome/liquid crystal layer that becomes transparent under electric potential; artificial crystalline lens.

Soviet Patent no. 1 211 599 describes a specimen of <u>optical system with high degree of convolution</u>. For precise measurement of the turning angle of an object it is suggested to attach to the object a transparent plate with holographic recording of all possible turning angles in degrees and minutes. The laser ray of light is refracted passing through the holographic plate and showing the turning angle in digital information on the screen. Angles can be measured without angle indicators, scanners, converters, electronic indicators, etc.

Below is another perfect example of <u>convolution of heterogeneous systems.</u> The systems are: the lamp (light emitter) and the mirror (light reflector). The resultant system is the new energy-saving lamp designed in the USA. The internal surface of its bulb is covered with two coatings of titanium dioxide and a very thin layer of silver. The titanium dioxide coatings let visible rays pass through but reflect infrared rays. The curvature of this 'transparent' mirror makes infrared rays focus on the filament and heat it. With the same light flux, the bulb consumes twice as little energy.

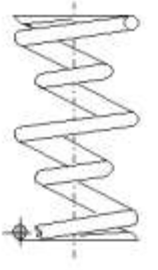
Not always are bi-systems formed from two systems. Sometimes it is more advantageous and far more easy to make a bi-system out of a mono-system. The mono-system is separated into two identical systems which are then joined in a special way. This procedure is aimed at getting the same benefit: new properties and exclusion of harmful properties, solution of an inventive problem.

For example, the idea of a new colander, where the holes are formed by perpendicular slits of two plates. You need not spend time cleaning each hole: one plate can be easily removed.

Mono-systems are often separated due to external factors – dynamization (introduction of a hinge).

Thus, the idea of a tractor with innovative turning mechanism was discovered by F. A. Blinov when he worked as a mechanic on board the paddle wheel steamboat 'Hercules'. The Hercules was transporting goods from Astrakhan' to the fair in Nizhny Novgorod when her main shaft driven by the cylinders of the steam engine broke suddenly. The situation was critical and fraught with bankruptcy of steamboat's owner. Blinov found an ingenious solution. He suggested to clean the place of breakage and link the parts of the shaft by a hinge. As a result, each cylinder of the machine began to drive its wheel separately. With the same cruising characteristics, the steamboat acquired better maneuverability. This principle was later implemented in caterpillars. ("Priveledge 2245, granted to Fyodor Blinov, peasant, for a carriage of special design with endless rails, meant for cargo transportation on cart roads and dirtroads".

New properties also emerge when bi-systems progress through steps 2.1.1 - 2.1.2 - 2.2.1 - 2.2.2, i.e. towards intensification of the difference between components.



Example: transition from the cylinder-shaped (homogeneous) spring to a spring made of components with biased characteristics (Soviet Patent no. 1 190 110). Innovative features of compression-tension spring: with the purpose of increasing the deflection of the screw, the coils of the spring have two alternating diameters. The internal sides of coils of larger diameter are cut along a longitudinal plane; the cross section of their cut decreases down according to the diameter of the spring coil.

In addition to the increase in main useful function, another property is developed: in fully compressed position the spring occupies twice as little space as the cylinder-shaped spring with the same number of coils.

In 1930, B. Shmidt, Estonian inventor of optical instruments began to improve the telescope, – reflector with a parabolic mirror. After a series of efforts he decided that, in order to get rid of parabolic aberration (coma), parabolic mirrors should be rejected in favor of spherical mirrors. Moreover, spherical mirrors are easier to produce. But the drawback of spherical mirrors, – spherical aberration – had been precisely the reason why parabolic mirrors were introduced. The contradiction was resolved by a **transition from a mono-system to a bi-system** made of inverse components. The aberration which was introduced into the system is equal to the spherical aberration of the main mirror but has an opposite sign. This can be easily realized: a corrective plate (later given Schmidt's name) is put into the diaphragm. Dmitry Maksutov improved the system further in 1941.

Problem 98. Select an object for modification and lead it through all stages of bi-system evolution process. Please remember to mention the new properties that emerge. Do not worry if your technical or scientific knowledge is not enough or you have doubts concerning the realization of your new idea: this problem can also be practiced as an ICI task.

Evolution of poly-systems goes in a similar way, the only difference being that when a poly-system is formed, there appears an internal medium or conditions for such internal medium. This medium possesses peculiar characteristics that can be used in developing of extra properties.

For example: transportation of glass in bags to the building site (*primitive poly-system)* causes many difficulties: glass sheets stick to each other, a high portion of glass is crushed, the efficiency of glazing is low, and so on. It was suggested to lubricate the sheets with oil (i.e. internal medium). As a result, the breakage decreased, each sheet could be easily detached from the pile. Additional convenience: oil is washed off after the painting of the window frames.

Examples of simple poly-systems formation(Step 3.1.1):

- Soviet Patent no. 996 216: sawing of rock materials (e.g. crushed stone). Crushed stone is joined with binding material to form a monolith slab which is later sawed into plates. The binding material is molten and withdrawn thereafter;
- Soviet Patent no. 1 006 151: method of simultaneous treatment of piston rings gathered in a stack by one pass of the instrument;
- Soviet Patent no. 1 313 659: treatment of potteries (glass, earthenware, crystals) by adhesive bonding of thin items into one slab;
- Soviet Patent no. 1 005 718: harvesting of cereal crops. Mowing and thrashing is performed at the stage of complete ripeness. To prevent losses and grain-shed of uncut crops, the crops should be sprinkled over with liquid glue before mowing.

Transition to a poly-system with biased characteristics (Step 3.1.2):

Soviet Patent no. 843 808: herbs and fodder crops are seeded in parallel lines lengthwise on the field, but mown crosswise. The tanker of the harvester collects a ready mix of herbs and it is not necessary to use some fodder-mixing machines at cattle farms. The method is optimized in Soviet Patent no. 1 058 538: herbs are seeded in lines, each 0.7-2.2 meter wide. The harvester moves diagonally across the field cutting herbs. In this way it collects a well-proportioned mix of at least three herbs.

Examples of partially convoluted poly-systems (Step 3.3):

- At home, vacuum cleaning of dust is very effective, but how can dust be collected at plants with high standards of cleanliness, such as microchips assembly lines? In such places, dust content should be minimal; cleaning should be continuous. Indeed, it is impractical to keep dozens of vacuum cleaners working on the site. There should be one vacuum cleaner with a network of pipes distributed around the entire plant.
- The same idea was realized in France for private dwellings. The pipes are distributed around the entire block of flats; each flat has a wall outlet to which a hose with an cleaning extension is connected. In this instance, the age-old problem of cleaning filters of vacuum cleaners is solved at the level of a supersystem.
- For a long time we have adjusted our watches listening to standard time signals broadcast on the radio. Despite the fact that nowadays watches and clocks are often combined with radios, they are still adjusted manually. The wrist watches designed recently have a

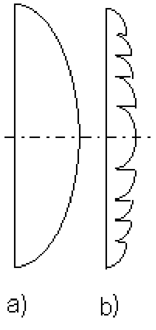
microchip which works as a watch and a radio receiver at the same time. The system will convolute fully when millions of watches correct themselves by the time signals sent by radio stations from one standard atomic clock.

- Other examples: the boiler house (one stove instead of thousands), telephone stations, TV stations, etc.

In electronic equipment heat is withdrawn via holes with gates made in the enclosure (*a typical poly-system*). If the device is overheated, the gates are opened and later closed to prevent excessive dust from accumulating inside the enclosure. Soviet Patent no. 1 066 053 offers a **fully convoluted poly-system:** the enclosure has one wave-shaped hole made of material with memory-shape effect. The flaps of the wave-shaped hole bend under heating and close under cooling.

Let us continue the line of evolution of optics:

Recently a new branch of optics has appeared that uses so-called flat components. For example, the Institute of Automation and Electrometrics (Academy of Sciences, Russia) has designed flat lenses, or phase-only synthetic holograms. One such optical components replaces a complex and bulky construction consisting of many lens. The surface of the flat glass plate is covered with embossed lines with the height of several light wave lengths.



Focusers:
a -- ordinary lens
b -- flat plate

The two components in the figure will have identical properties if the thickness difference of the second component from step to step makes an integral number of wavelengths of focused light radiation. Besides a high convolution of optical systems, flat components also allow to obtain new properties. Thus, A.M. Prokhorov of the Institute of General Physics for Russian Academy of Sciences has developed new flat components that can convert incident radiation with arbitrary wave front into radiation with a specified wave front or concentrate radiation energy on a specified curve with specified intensity distribution (Kvantovaya Elektronika, vol 11, 1984, p.155, in Russian). Cast on the component at any angle, the light will be focused at a specified point or line. The line may have any chosen configuration (ring, ellipse, sinusoid), intensity of energy concentration along the line can also be selected.

How transition to a poly-system is used:

1. Multiply the chosen technical object 'by itself'.

2. What has changed?

3. Has internal medium appeared?

4. How can its properties be used?

5. Describe the new properties emerging in the poly-systems at each step: from homogeneous system to inverse system.

6. What should a partially convoluted poly-system be like?

7. Can the system be fully convoluted?

> **Problem 99.** Choose an object, make a transition to a poly-system. Has internal medium appeared? How can its properties be used? Describe the new properties at each step from homogeneous to inverse system. What should a partially convoluted poly-system be like? Can it be fully convoluted?

Let us take TV set as an example. Community aerial is the first step towards convolution. Furthermore, it is practical to have one television unit for a whole block of flats, neighborhood or even a town (with one power unit, broadband transmission channel, signal processor). Households only have picture tubes and control units (turret tuners and features control). One more step can be taken: the image is transmitted from TV station into homes via an fibre-optic light conduit; the homes only have screens and control units (subscription networks such as this one have long been established for radio, why cannot there be a similar TV network?).

Televisions are being combined with other systems: TV set plus VCR, plus video-camera (home television), plus newspaper (teletext), plus telephone (videophone), plus information center and so on. It is possible to foresee that television, monopolizing major information systems will be developing simultaneously with home computers and the Internet. At length, television and computers are likely to convolute into a single home information center.

Parallel with centralization, evolution will touch upon the feedback system, i.e. the degree of subscribers' influence on the TV station. At present, we can only 'control' TV-stations via mail and telephone, and sometimes via e-mail. But even now, in some countries TV sets are connected to terminals (control desks with keyboards) wired to a central computer. At the beginning of a show, the viewer is asked to choose a song from the list appearing on-screen. Then the computer compiles a show program based on the rating of each song.

The next step will be editing programs at home, for example with the help of a VCR. But to do this you need a substantial home collection of videos and CDs. You also need to browse it looking for a piece to play. Indeed, the home computer comes in very handy here. And yet there is another way: centralized video collections with user access to any recording via a terminal. At the same time, a part of the screen at home will be showing reviews of currently running TV programs and news.

The next step in intensification of ‘viewer feedback’ in the ‘TV - viewer’ system will be home screenplaying, casting, etc. In C. Simak’s story "Shadow Show” the crew members of a spaceship are watching an endless movie during a very long journey. Each of them has created their own screen character, the plot is evolving spontaneously depending on the situation. Most interestingly, no one knows (but tries to guess) who stands behind each character of the movie. The number of characters is the same as the number of the crew. Suddenly one crewmember dies, but the number of movie characters remains the same!

Recreation time during flights lasting for years is sure to become a serious problem in future. Videos, chess, books, computer visions of picturesque lakes with singing birds will not deliver the crew from the unavoidable boredom of flying. The thrilling idea of the writer is in line even with today’s science.

10. INVENTIVE PROBLEM SOLVING WITH TRIZ

The theory of inventive problem solving distinguishes between two types of problems:

- Problems that can be solved through direct application of the laws of technology evolution, principles for elimination of contradictions, or inventive standards.
- Problems that can not be solved with above-mentioned techniques.

The problems, therefore, can be classified as **standard** and **non-standard.** This classification is somewhat fuzzy – it depends on the present state-of-the-art of TRIZ and the degree of understanding of its components. The problems that seem to be non-standard today will become standard after some unknown-at-present factors are discovered and existing TRIZ techniques are upgraded or new techniques are created.

The same applies to personal understanding of the art of invention. Each successful solution aids in the experience of problem solving, thus simplifying difficult tasks.

Therefore, there are two approaches to inventive problem solving: standard procedures and ARIZ (Algorithm of Inventive Problem Solving) program (steps 1-19).

The regular procedures and techniques (laws of technology evolution, principles for elimination of contradictions, and inventive standards) are recommended in the beginning. However, if the problem cannot be solved by regular procedure, the ARIZ should be employed.

During the analysis of the problem with ARIZ, the initial conditions undergo a substantial change. For instance, a problem model might considerably differ from the original vague and sometimes even incorrectly described problem model.

The problem becomes even more manageable after the substance and field resources are specified – in this case the regular procedure is most effective. Therefore, to achieve best results, a mixed strategy should be employed: regular procedures and techniques have to be used together with ARIZ.

TRIZ is a tool used for delicate and complex mental operations. A successful solution of a single problem only does not change the mode of thinking. Usually, hundreds of problems are solved during TRIZ training course. The thinking undergoes a gradual change and is stimulated by a special ICI course included in the TRIZ training program.

Thousands of TRIZ training courses conducted worldwide has proven TRIZ effectiveness: everybody can invent with TRIZ, no matter what inventive experience he or she possessed before.

The following strategy can be recommended to solve problems with TRIZ:

Solving Problems with TRIZ

<u>Step one</u>

1. Use the solutions of similar problems.

2. Formulate a technical contradiction, use the matrix and the collection of inventive principles.

3. Formulate technical function, and use the Pointers to the effects.

<u>Step two</u>

1. Analyze the problem, according to the first part of ARIZ program (steps 1-8), create a problem model.

2. Use inventive standards and Pointers to the effects.

<u>Step three.</u>

1. Analyze the problem, according to the second part of ARIZ program (steps 9-13), specify substance and field resources, define the ideal final result.

2. Use the regular procedures and the index of effects.

<u>Step four</u>

Analyze the problem, according to the third part of the ARIZ program (steps 14-19).

<u>Step five</u>

Return to the first part of ARIZ and change the way the inventive situation is analyzed – select a more general problem, thus avoiding the need to solve this particular problem.

<u>Note:</u>

Each item should end with: “If the problem is not solved go to the next item of the procedure.”

COLLECTION OF PROBLEMS

Problem 100. A shop for production of molded plastic parts of intricate shapes was set up at a factory. The method of their finishing treatment caused certain difficulties. The inner surface of molded pieces needed polishing and removal of the molded particles stuck to the plastic. A strong air stream with abrasive particles (e.g., sand) was used for this purpose: the whirl of particles "licked off" all the roughness and dirt. However, afterwards the inner cavities and crevices were filled up with smoothing materials which had to be shaken out. An attempt was made to use steel grit and magnets but the operation only slightly improved at the expense of the time spent to remove all the grit. What can be done?

Problem 101. The efficiency of a commonly used sucker for attaching hooks, etc. to smooth surfaces depends on the weight it can hold. This is contradictory in nature: the sucker must be soft (flexible) to be attached to the wall (displacing the air), and hard (rigid) at the same time to be able to hold a heavy load. The useful function of the sucker is to withstand load, therefore it should be rigid. Consequently, how can it be attached to the wall? The air under the sucker should be forced out to vacuum as soon as the device contacts the wall.

Problem 102. In order to prevent little children from playing with drugs and other toxic household substances it was suggested to supply the packaging with a picture of a sad teary face. The label might keep children from getting in trouble.

However, the problem can be approached in a more general sense as well: the adults need to get a warning about the drugs (or canned foods, etc.) expiration date. How could this be accomplished? All other possibilities must be taken into consideration: the expiration dates could range from several days to several years. Moreover, light, heat, cold, etc could damage drugs.

Problem 103. First tennis-balls were made of solid rubber. Then the balls were filled with gas under a slightly elevated atmospheric pressure becoming hollow to increase elasticity. Two stamped halves of the ball (of natural rubber with sulfur) are joined and heated together. Vulcanization of rubber welds them together. By the end of the vulcanization process the ball should already contain pressurized gas inside. How can this be done? It is impossible to perform the whole operation in a specialized pressure chamber. The gas should not also get inside the ball before the vulcanization process is over (rubber is not strong enough). How can this be accomplished?

Problem 104. In March 1834 two merchants from the Valdai region, I.Sharvin and N.Terekhov, made one of the heaviest bells weighing 9,6 tons. They faced a problem of transporting this huge bell from Valdai to St. Petersburg during the spring time lack of good roads. The skid or wheel mounted platforms were of no use and there was no waterway either. What would you come up with if you were in their place?

Problem 105. The mining profession is still one of the most dangerous – it is impossible to foresee all possibilities below the surface. The two most dangerous problems are fire and explosions.

a) The cause of the explosion is the accumulation of methane and coal dust. The blast wave travels very quickly along the drifts and adits of the coal pit sweeping away everything that crosses its path. Therefore, partition walls (made of canvas, wood, plaster, etc.) are placed in certain areas to suppress the blast wave. However, the partitions may be placed in dead mines only as they interfere with the miners' work.

Physical Contradiction: partition should exist and it should not at the same time. The contradictory requirements could be separated in time – the partition appears only during the explosion. Your idea?

b) In case of a fire a cart supplied with a water engine and a fire hose should be sent there immediately. It is impossible to locate the place where the fire starts, thus, the cart path cannot be programmed. High temperature and smoke prevent the use of electronic devices and manual controls. The cart should get to the fire site on its own so that a person could switch on the water supply from a safe place. What can be done?

Problem 106. How could a drug poisoning be prevented in case of accidental or deliberate overdose?

Problem 107. The painting technique has almost remained unchanged over the centuries: at present 30-40 pigments are used instead of a dozen employed during the lifetime of Leonardo DA Vinci. This palette is said to be doubled. However, the rest remains the same: a canvas, a planar picture, a brush, an easel...

Consider all possible questions, increase requirements for this human-technical system – you'll find a great number of inventive problems.

Siqueiros expanded his "canvases" to gigantic sizes and, therefore, confronted a contradiction: in order to be able to view the whole composition he had to stand back at a distance that required an enormously long brush – too heavy for the hand. He resolved this contradiction by switching to fluid brushes – sprayers and jets.

Chemist Berzelius used to show his guests a "magic" picture he painted himself (with thermochrome paint). The picture revealed a summer landscape (with green grass, leaves) in a warm environment and further transformed into a winter view (with snow) in the cold.

A brand new idea was registered by Soviet Patent no. 971 685: the paint is applied to the canvas layer by layer separated by a transparent film which helps to achieve the three-dimensional effect. The invention is a simple one (a simple transition to a polysystem) but since this field is underdeveloped almost any invention would be considered a daring innovation.

A single question could be asked: what can be called a dynamic picture? "Animated" paint? "Sound" pictures? Paintings that change depending on the author's or viewer's mood? and so on.

Problem 108. Suggest a new ball game using the tools of the technical evolution.

One can take a ball as the initial system and develop an S-field (to obtain a new system and develop it) or to start off from the available S-field (a ball, a foot, mechanical impact field) and try to elaborate the famous football game. The main requirement is the following: the game should be interesting providing new qualities and opportunities.

Among the examples of the changes could be 1) a ball with a shifting gravity center (with a small spring suspended sphere inside); the weight of the sphere and the spring resistance force could be changed for each match; a new quality – comic and unexpected situations, game new techniques, tracking the "deflected" ball trajectory; 2) a magnetic ball and magnetic deflection devices utilized by players.

Problem 109. A wire unit for cutting of crystal (rock crystal or semiconductor materials, for example) contains a steel thread 60 μm in diameter. It makes 400 revolutions per minute and thus cuts solid body into pieces. The precision of the cut and the width of the slit depend on the tension in the thread (it does not deflect this way). It also helps to reduce waste which becomes especially important in the operations with precious metals. However, the thread under a strong tension tears more quickly. What could be done?

Problem 110. According to Soviet Patent no. 936 957, the swing could be improved in such a way that not only it swings as a pendulum but moves in a wave-like motion. Numerous other functions could be added to modify this basic attraction. Lets try to develop it further. The only basic requirement is the simplicity of the system without any external power sources (though energy could be stored internally).

Problem 111. Blasting has been used in mining for more than 300 years. Till present time the results were estimated in the following way: the ground rock samples were screened through mechanical sieves and the fractions studied to find out whether the rock was ground finely enough. It takes several days to make an analysis (the rocks are collected, sorted out, and measured) – a process which is too time and labour consuming. A new fast (one hour!) method of analysis is required. Your suggestion?

Problem 112. Enclosed pastures are more convenient than open ones because one herdsman can monitor several herds on neighboring fields. A more simple system of "electric herdsman" exists – it is used in many countries: a weak electric current runs through the fence. However, this system requires a constant supply of electric current (electric sources are often located too far away, and a step-down transformer is needed as well, etc.). Small wind or solar power operated plants are undesirable since they can't guarantee a constant electric power supply. Ideally, the animal touching the fence would trigger the electric current to run through the fence. What could you suggest here?

Problem 113. Little children often accidentally swallow toys when playing and trying to taste one. If the toy is made out of plastic it is impossible to detect it in the child's body with x-rays. The surgeons are forced to guess while every minute lost may cost a little patient his/her life.

This is a typical administrative controversy which could help to develop several inventive problems: to provide an opportunity for the doctors to locate the toy, to prevent the toy from being swallowed, to avoid operation – to make the toy dissolve inside, etc. Choose one of the problems and try to achieve the ideal result with your own solution.

Problem 114. A series of medical tests that examined the spread of infectious diseases demonstrated a burning necessity to count a number of drops of mucus produced by different people while sneezing during different stages of the disease. The research literature showed a wide range of values given by different authors: figures varied from 100 drops (for little children) to over 20 000 (for adults when sneezing hard). The validity of the data was questionable since the methods used in obtaining results were not discussed. It was necessary to create a new method and produce a simple measuring device.

What could be done? What could you suggest? There was no shortage of "sneezing"-volunteers (the flu epidemic was at its peak) who could be invited to the laboratory. But what is the next step? How can we quickly calculate the number of drops spattered with each sneeze?

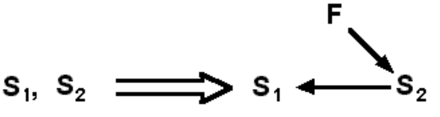
APPENDICES

A. SOLUTIONS TO PROBLEMS.

In this section you will find target answers or possible solutions to the problems which were not explained in the main text of the book.

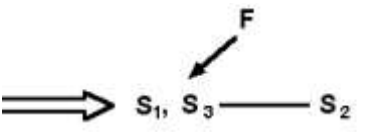
Flaunting Flag Wanted. The S-field in this problem lacks a field. The field should drive the air over the flag (F should act on S_2). Now you have an S-Field Model for the problem. But which namely field should be used? Can it be a mechanical field? The problem conditions forbid, however, to use an air blower or a compressor with a hose attached to the flagpole. Soviet Patent no. 800 332 describes a tiny fan placed inside the flagpole. Yet it seems more practical to use a thermal field creating a temperature difference which, in turn, would create an ascending flow of air like in a chimney stack. Inside the base part of the pole it is possible to put a gas burner or another source of heat.

THE STORY OF A HAPLESS GAS-EXPANSION MACHINE. In the S-Field Model, the brass ball

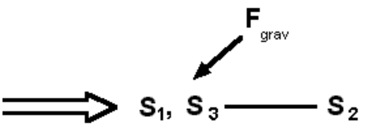


should be gripped by a second substance. The easiest way is to use glue. But the glue drop should be large enough to lift the heavy ball. A drop like that cannot stick firmly to the end of the cord and tends to fall down before the cord reaches the bottom. Dropping of the cord takes a long time, because, in order to touch the ball, one should position the cord very carefully. Moreover, it is undesirable to leave blots of glue inside the machine. So, all the three SFM elements are there, but they are not in good combination. In this situation the interaction between SFM elements should be improved. Let us construct a complex SFM wherein we shall introduce a third substance to keep the glue at the end of the cord so that it does not drip down at all. Capillary or porous materials (sponge, felt, etc.) are the best options: they hold the glue firmly until it sets.

AN ORDER FROM THE AGRICULTURAL DEPARTMENT. The drops should be large and small at the same time: how is this contradiction to be resolved? Let us draw a clear picture of the problem: dispersed liquid consists of tiny drops (S_1) slowly driven down by gravity (F_{grav} has insufficient effect); the wind (S_2) blows them away (i.e. has negative effect too).



To make this SFM work, we should enlarge the drops. For example, they might be put in capsules (external complex SFM):

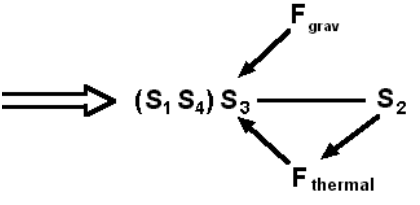


In this way F_{grav} has a positive effect on the drops (making them descend fast) whereas the harmful S_1-S_2 link is gone.

But this is far from the end. On reaching the earth the drops should turn into tiny splashes and scatter evenly around the territory. This means that each drop (capsule) should burst before landing. It is dangerous to introduce explosives into the capsules; even so we would have no idea about how to set them off and what field to use for this. It is easier to use the field which is at hand

– the thermal field arising from rubbing of the capsules against the air. That means that a substance sensitive to a slightest $F_{thermal}$ should be introduced into the capsules (mixed with the liquid). For example we might think of volatile substances like freon (used in refrigerators, sprays, etc). Freon is non-toxic and harmless. Some freons have boiling point between 3 to 28 ^{0}C. Thus, in addition to the external S-Field, an internal complex S-Field should be formed. The drop becomes a rather complex object of the following structure: (S_1 S_4) S_3, where S_4 is freon and S_3 is the capsule.

The final formula with respect to thermal field has become a dual S-Field:



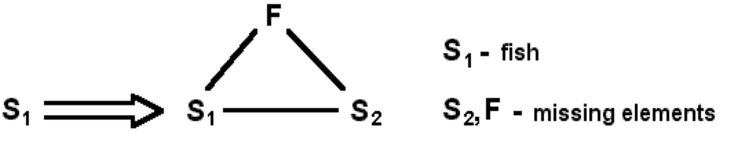
Problems of this kind cannot be solved 'on the spot' by a beginner. They require considerable experience in problem solving. This one was presented with the purpose to demonstrate how to use S-Field formulas freely, and to stress the fact that sometimes you need to do substantial analytical work while finding a good solution. At any rate, any attempts are useful because they expand your experience of S-Field analysis.

Problem 24. Instead of water, it is necessary to use a magnetic liquid which does not pour out of the chute at any angle under magnetic field.

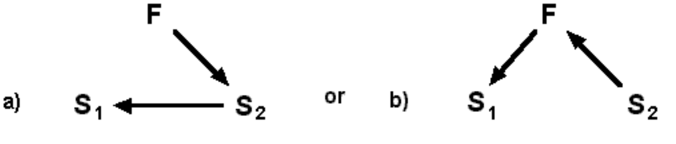
Problem 25. Use finely dispersed ferro-powder or magnetic liquid to make the system more controllable. The same fantastic scene can be repeated many times, sometimes with slight changes, etc. Where it is impossible to use magnetic substances, you can resort to using an effect with similar manifestations. The electrolytic solution can be put under subject to electric current with magnetic field being applied from outside.

Problem 26. The protective substance should share the same properties with water. US Patent 4 036 591: the workpiece is frozen into ice.

Problem 27. Something *has* to be introduced to complete the SFM:



What should the missing elements be like? Two kinds of interaction are possible within this SFM:



a) describes the methods already tried (S_2 is water, F is mechanical field, ultrasound and etc). According to b), S_2 should be creating a field which is sure to affect the fish and make it move all by itself. An instinct, such as survival instinct, should be activated. In this sense S_2 should be a carnivorous fish. It is even better to impose a 'permanent threat' – a pill containing either a ferment of anxiety or a powder smelling of a carnivore.

Problem 28. Instead of using great amounts of water, it is enough to use a teaspoonful of magnetic liquid. The liquid sticks to the ball and rolls with it along the weld without making a clearance.

Problem 29. US Patent 2 888 117: elastic pipe with magnetic liquid in it. The key has a screw press that creates pressure and makes the key take the shape of the keyhole's internal space. When electromagnet in the handle is turned on, the key is solidified and can open the lock.

Problem 30. Peppers can be peeled by air. The pods are put in an air-tight container, then the pressure is lifted up to 8 atm. Each pod is compressed and forced downwards, which causes the fragile bottom of the pod to crack and let in compressed air. Once the inside and outside pressures become equal, the pressure is released. The pod burst and, being the most fragile part, the bottom flies apart, carrying the insides (Soviet Patent no. 340400).

Problem 31. Use the simple effect of electrostatic repulsive forces. The quilts are blown over by a flow of ionized air. The surface and the fluffs of wadding receive charges of the same sign. The fluffs bounce off the quilt and can be accumulated by a vacuum cleaner. This effect is widely used in cases like this. For example, Soviet Patent no. 1 150 273 describes the method of separating the down and the shaft of a feather in a flow of ionized gas.

Problem 32. Fish can be protected from a blast wave with a 'screen' of air bubbles. This screen effectively dampens the energy of hydraulic impact. A perforated hose is laid on the bottom. Another option is the electrolysis effect: the bottom is lined with pieces of metal wastes (tubes, bars, etc.) connected to a power source. A similar solution is given in Soviet Patent no. 494 901: the explosion is dampened by foam (under 50-cm-thick coat of foam, detonation of a hand grenade is as dangerous as a pop-gun).

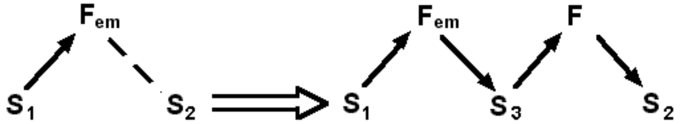
Problem 33. No target solution.

Problem 34. Electric field should be used. A corona-forming electrode (an electrode in the form of a wire brush under high voltage) gives the fiber electrostatic charges of one sign. The other electrode attracts the fiber (Soviet Patent no. 543 365). This same solution applies for Problem 31.

Problem 35. The same solution as in Problem 30. Compressed air blown into the pipe penetrates into the pores. Then the pressure is decreased abruptly and the dust is removed from the filter (Soviet Patent no. 514 650). A similar method is used according to Soviet Patent 1 004 765: loosening of packed powder in a hopper.

Problem 36. Electric current should pass through the grape. A plate electrode touches the grape, the other electrode sliding along a wire. The current passes through the vine, the stem and the grape, but because the vine and the grape have a much lower impedance than the thin fibrous stem, the stem blows like in a short circuit. The grape-picker is a tractor with a small generator that produces electric current of 4,000-6,000 V. In the same fashion, harvesting of cucumbers, aubergines and etc. can be done.

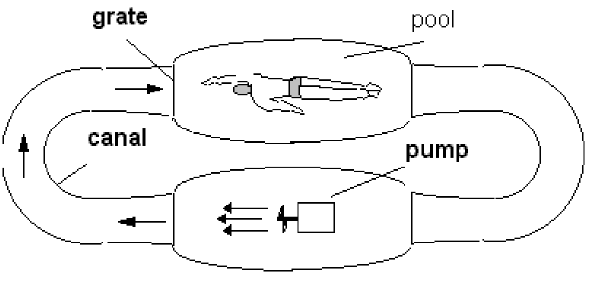
Problem 37. It is necessary to use the existing alternating electromagnetic field. However, this field has no effect on man and should therefore be transformed into another field (S_1 is the wire, F_{EM} – electromagnetic field, S_2 – is the maintenance worker).



It is necessary to introduce S_3 to transform F_{EM} into a field that has an effect on the person. Why not introduce ferro-particles? (Ferroparticles can be put into a special hand ointment, shirts, bracelets, etc.). The ferroparticles create instant heating making the person withdraw his/her hand. According to German Patent 105 340 (DDR), electromagnetic induction produces an alarm signal (e.g. sound). But any information given by light, thermal or sound fields may pass unnoticed in strenuous working conditions. All information and measurement systems tend to develop into '*systems for changing'* (systems that act without reporting to the user). With this in mind, it is easier to generate electric current (a loop of the wire in the clothes) that will control the worker's muscles. For example, the ends of the wire can be attached to plate electrodes sawn into the clothes at the underarms. When current is generated, the muscles will contract and secure the 'hands off' movement from the source of high voltage.

Problem 38. A fully worn-out wheel is powder. Imagine wheels made of powder. Instead of tires, ferro-powder should be used; electromagnets should be used as rims.

Problem 40. Soviet Patent no. 187 577: swimming trainer with a closed-loop canal. The swimmer remains on the same place, no matter how far they swim.



Problem 41. Soviet Patent no. 841 959: use the Archimedes' principle! A hoisting gear lifts the billet vertically and gradually submerges it in a reservoir with water or oil. The volume of expelled liquid indicates the weight of the submerged part. Accordingly, the billet can me marked. The authors who recalled this famous law still complain that the method is very difficult to put to use in the existing industrial conditions. There is no space for a hoisting gear and a reservoir; it takes too long to submerge and lift the billet. An ideal method would be measuring the weight of the billet parts in horizontal position: the billet is put into the reservoir through the side doors and marked afterwards… But then the liquid will pour out. How can you stop it? You should know what liquid to use...

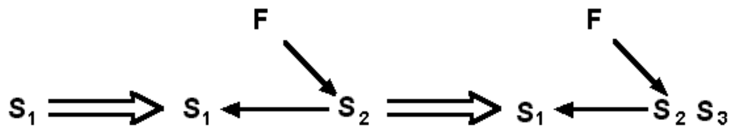
Problem 42. No target solution.

Problem 43. No target solution.

Michelangelo and the Medicis. The sculpture should be a sarcastic parody on the Medicis and should not be a parody so as not to cause their revenge. Michelangelo gave the faces ideally regular features and their bodies have the postures of great thinkers. Being aware of the ugliness and stupidity of the Medicis, you immediately got the point.

And there came a thundering voice. Glinka's solution: the Head's part is performed in unison by a choir hidden in the wings (i.e. a polysystem of homogeneous components).

Problem Pipe. If S_1 is the leaking tube, the SFM should be completed and then developed into a complex SFM:



S_3- patch , S_2 - glue

But the exact location of the hole is unknown; that is why the patch should cover the entire tube, i.e. another patch tube should be inserted into the tube. A plastic tube (hose) made of glue-coated film can be used. The hose is blown up with hot air and kept that way for some time.

Alternative solution: a fabric hose is put through two neighboring wells and blown up with compressed air. Liquid cement-lime mortar is then pumped in between the hose and the pipe. The mortar sets in 72 hours firmly covering the damaged spots.

How to deceive a synthesizer? After a series of strenuous attempts, the characters did find a way out. They ordered the synthesizer to reproduce itself. The second synthesizer makes another spare part, then another synthesizer and so on.

There should be a way out. The characters drink water and pretend they are dead. The boat makes a solemn burial ceremony in the shallow waters near the coast.

The last will. The hero should say to the robot: "Kill me 100 years later".

Problem 61. A rubber balloon will burst, splashing flakes of foam on the clumsy barber…

Problem 62. Idea of the easiest solution: a transparent cylinder is fixed on the wall of the mould. The cylinder is divided into lower and upper parts by a partition with a hole covered with a bimetal sheet. The upper part of the cylinder is filled with balls. Once the temperature goes up, the bimetal sheet bends allowing one ball to fall through. The instrument works like a sand glass. In reality, the design should be more intricate: two sheets are made, one above the other at the distance equal to the diameter of the ball so that only one ball falls through.

This instrument has been modified a few times; each technical system develops to meet the growing requirements to the *main useful function*. Below is the formula of Soviet Patent no. 1 069 931. "Meter for counting mould castings". The main components are: a gear wheel and a bimetal plate. Innovative features: for safety reasons, the instrument is equipped with a platform of heat-insulation material located on an revolvable axis, and an additional corrective bimetal plate fixed on the platform together with the main plate. At the loose end of the corrective plate there is a rotating device in engagement with a gear wheel. Both metal plates have fixing stops; the main plate has a heat line.

Problem 63. Imagine two pictures: the pin before and after restoration. Restoration builds up another 0.01 mm to the diameter. How can this be realized? One hundredth of a millimeter is a micro-displacement. The easiest way to create a micro-displacement is to heat the object. OK, let us heat the pin: the diameter has increased. But on cooling the pin shrinks again. How can we fix the diameter when it is increased? This is the core of the problem.

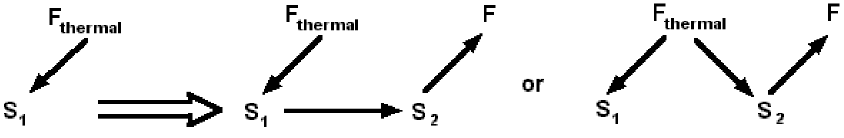
Can the heated pin be put on a mandrel? But it will be impossible to take it off afterwards. The mandrel should be and should not be at the same time.

One good tool is :*delegating the function of the instrument to a part of the artifact.* In this case the role of a mandrel can be performed by the internal layers of the pin. If the internal surface is cooled very quickly, the external surface will not lose in diameter while cooling. The inventors did just that: the pin is heated up to 800°C and then a jet of cold water is fed inside the pin. The internal layers stiffen very quickly forming a stiff ring and thus preventing the external layers from shrinking. Note also the precise distribution of functions, characteristic of this solution: first the internal layers are cooled abruptly while the external layers prevent them from shrinking; after that, when external layers are cooled, the internal layers prevent them from shrinking. This solution was described in Soviet Patents no. 495 367, 550 437.

Problem 64. An SFM consists of S_1 – the ground (frozen and molten) and $F_{thermal}$ – thermal field. The SFM should be build up to the so-called measurement S-Field:

In other words, S_2 should react either to the effect of molten ground (S_1) (sending a signal, or F field) or directly to the effect of the thermal field ($F_{thermal}$).

Both variants should be considered:



1. Melting reveals mechanical and physical characteristics of the ground: it acquires liquid properties and electroconductivity, changes its acoustic characteristics, the particles are not linked to each other, water appears. Hence are the possible solutions:

- water closes a pair of contacts and turns on a lamp/sends a radio signal;
- losing its ice coating, a piezocrystal changes its vibration frequency;
- a spring becomes unfrozen and pushes out a visible sign, etc.

The S-Field model can be further developed by either changing S_2 or adding a third substance such as a wick. The lower end of the wick is dipped in a solution of bright paint frozen in the ice at a critical depth. Molten paint seeps upwards along the wick and disperses in the form of a wide and visible spot.

2. If thermal field is to be directly transformed into a signal field, one should use physical effects such as thermomechanical effect (bimetal, nitinol), thermoelectric effects (generation of a thermo-electromotive force) thermomagnetic effects (transition through the Curie point).

Among others, thermo-chemical effects can be employed here too: at the critical depth there is a vessel filled either with gas with a boiling point at 0^0C or with a gas-evolving solution. The gas will pass through a hose and reach the earth surface, filling a flashy balloon. For example, hydrogen can be stored in hydride form (see Index of Chemical Effect in Appendix). The water of molten ice can dissolve salts placed between two electrodes and make a primitive chemical source of power. The source of power will switch on a radio transmitter.

Problem 65. A short stretch of the wire (or a bar holding the wire) is made of nitinol (an alloy with memory shape effect). The shape-change point of nitinol lies within a required temperature range. When critical temperature is reached, the nitinol element will shrink (bend, acquire the form of a wave) and tighten the wire.

Problem 66. This problem deals with destruction of a harmful S-Field through introduction of a third substance. This substance should share the same properties both with coal and the final product. This substance is coke (Soviet Patent no. 722 934).

Problem 67. Irrigation water should be passed through an electrolyzer with electrodes made of an alloy of manganese (75 %) and copper (25 %). Because they are made of an alloy, the electrodes contain the same proportion of above-mentioned microelements in any section. Thus water gets a strictly measured amount of microelements: proportioning is done at the atomic level.

Problem 68. No satisfactory answer can be given. One should destroy the harmful S-Field. But how can this be done? What if the instruments have black color? Absorbing radiation without reflecting it, the instruments will get overheated. Can this radiation be scattered? Physicists finally came to the following solution: corund balls of 40-50 microns diameter should be attached to the surface of the instruments. They scatter the beam without being heated. But the surface will become rough and hard to clean.

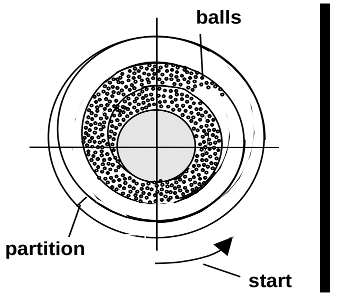
Problem 69. So far, only a primitive solution is available (Soviet Patent no. 1 273 264): a blackboard in the form of an endless belt between two cylinders. The upper (driving) cylinder is submerged into a bath with water. The brushes of the bath clean the belt and wash off chalk powder.

Problem 70. The easiest solution: at the critical depth of the lining there is a layer of substance that can tint flame, a fluorescent substance, or small amount of radioisotopes. When the lining becomes inadmissibly thin, it sends a visible signal or another signal which can be easily picked up.

The best bar is no bar at all. No target solution.

A file of dummies. Soviet Patent 612 679: inflatable mannequin.

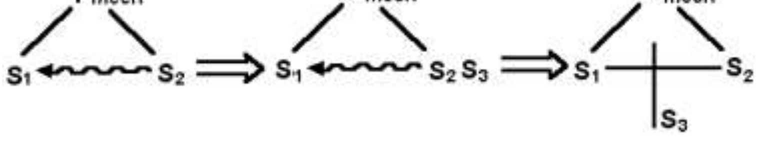
Dynamize a gym. No target solution.



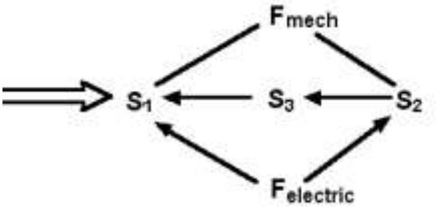
Problem 80. Soviet Patent no. 845 871: the hollow flywheel contains an Archimedean screw and an unbalanced mass in the form of balls. When the flywheel is in rotation, the centrifugal force drives the balls along the screw towards the periphery, where they are stopped by a partition.

Problem 84. All the three problems are solved using one rule: the substance should be identical with the product. That means that this very product should be used. Niobium nitride is used as ballast. Heating is done by gaseous oxygen. The rod is made of the same metal which is being melted.

Problem 85. The harmful S-Field should be destroyed: a third substance between the bucket and the soil should be introduced. This third substance should be a modification of either the first substance (the bucket) or the second substance (the soil). The third substance will be disposed of in each digging cycle. That is why there is no point in using the substance of the bucket. Let us use soil and its components. Dry soil is not sticky and wet soil contains water. That is why wet soil should be used as an interlayer.



Water should stick to the bucket and this way serve as an interlayer between the metal and the soil. It is necessary to use the physical effect of electroosmosis: when a negative potential is delivered to the bucket, water will move from the pores in the soil to the metal surface:



Final model of the solution: dual S-Field for destroying a primary harmful S-Field.

Problem 86. Soviet Patent no 1 024 311: exhaust fumes go from the silencer into the load of the dump truck, getting purified as they pass through a thick layer of rocks.

Problem 87. The actor was wearing a make-up of red color (wrinkles and strokes). The first shots of the scene were taken through red light filters. Then the filters were gradually removed bringing to light the wrinkles and strokes on the face of the character.

Problem 88. First, instrument should be submerged in acid medium – a good electrolyte and the working medium of the instrument. Then, it should be connected to one end of a source of weak current and the solution to the other end; if current can be detected, the instrument coating has penetration defects.

Problem 89. Soviet Patent 1 076 637: the blades of the pump wheel should adjust their angle to the temperature of liquid. The hollow blades are made of elastic material and filled with gas with low boiling point. When the pressure in the hollow increases, the blade slightly changes its inclination.

Problem 90. Use substance and field resources: the air of past centuries can be found in bricked-up tombs of Egyptian kings, in antiques such as sand glasses, compasses, telescopes and spy-glasses, in sealed bottles retrieved from ship-wrecks. In the museum of a company producing hollow metal buttons for military uniforms one can see production samples dating back to 1812.

A similar solution was used by Swiss glaciologists and geographers who studied the history of Alpine glaciers. They examined about 500 landscapes of the Alps made during the past 350 years.

Problem 91. No target solution.

Problem 92. The most promising methods: 1) the explosion method developed in Federal Republic of Germany: a sleeve with explosive substance is attached to a section of the pipe. The pipe walls are squeezed together by explosion; 2). the method of strong currents: thousands of amperes can stop a crack in fragment of a microsecond.

Problem 93. US Patent 4 114 443: a transparent plastic bottle is half-filled with water and put into the freezing chamber. The water should preferably be colored. When the water freezes, the bottle is laid on one side. After being frozen, the bottle is put upright. If thawing occurs, the water forms a horizontal layer. After the refrigerator is turned on again, the horizontal layer freezes again. The depth of the horizontal layer indicates the time of thawing.

Problem 100. Use ice pellets.

Problem 101. Use the chemical effect of water formation. A drop of water can be formed from hydrogen and oxygen. Oxygen disappears from the sucker, reducing the pressure inside and making the sucker stick firmly to the wall. The water-forming reaction is activated by an electric arc between two thin wires (electrodes) built into the sucker and connected from outside to an ordinary battery. In order to trigger the reaction, it is enough to touch the wires with the battery. Hydrogen can be obtained in a number of ways. For example, the internal surface of the sucker can be covered with a thin layer of hydride. Heated by electric current, the layer gives off hydrogen.

Problem 102. No target solution.

Problem 103. Use a chemical effect: inside the tennis-ball there are tablets containing a mix of sodium nitrite and ammonium chloride. Heating causes vulcanization accompanied by a nitrogen-forming redox reaction.

Problem 104. The bell was turned into a wheel – a simple geometrical effect. "This bell is carried in a special way, packed into wooden logs in the manner of a wheel. The whole load is up to 2 sazhen wide and weighs up to 1500 poods with all its binding. It is driven by 15 horses..." (1 sazhen is 2.134 m ; 1 pood is 16.38 kg).

Problem 105. a) A parachute is placed in a small groove in the drift wall. Another small (signal) parachute is suspended over the passage. The blast wave jerks the signal parachute which, in turn, opens the bigger parachute blocking the passage and dampening the blast wave. The big parachute can be easily folded afterwards; b) The center of fire is a strong absorbent of oxygen. It always attracts a strong air draught. The draught can be used for driving a cart with a sail.

Problem 106. The tablets contain emetic powder.

Problem 107. No target solution.

Problem 108. No target solution.

Problem 109. Electric current is transferred through the wire. Outside a strong electromagnet is turned on.

Problem 110. No target solution.

Problem 111. Use copies (e.g. photographs).

Problem 112. Use the piezoeffect: stretching of the wire causes the block head to hit a piezocrystal. The animal receives an electric shock.

Problem 113. No target solution.

Problem 114. Target solutions:

Soviet Patent no. 1 004 819: analysis of dispersed composition of sprays by precipitation of particles on a filtering surface. Innovative features of the method: to speed up the process, the quantity of sediment is measured by the electric charge transferred by the particles under a potential difference. Filtering surface is regenerated by periodic changing of potential difference on the entire surface.

Soviet Patent no. 1 635 073: 1). Analysis of dispersity and particle index of sprays created by atomization of liquid. The particles are trapped and measured on a transparent polymer base. Innovative features of the method: in order to simplify the method, increase the efficiency and precision of measurements, the base is made of polymer material dissolvable in the liquid which is atomized. The imprints of liquid drops are measured. 2). The same method as in 1); the only difference being that the base of the water spray is made of polytheneoxide.

Soviet Patent no. 896 394: Analysis of drop index and mean drop dimensions. The patent offers a quick method to measure the parameters of drops of fog. The method determines the difference of light fluxes passing through negative images of the base before and after the drops are fixed on the base.

B. INVENTIVE PRINCIPLES

Recommendations on using Inventive Principles and Altshuller's Matrix.

1. **Select a product you want to improve.**

   I want to improve a coffee cup.

2. **If a product consists of many parts, try to separate and focus on a specific part which causes problem.**

   A cup does not keep coffee warm for a long time. Therefore, we are interested in a new design of the cup, and not in improving coffee beans or the coffee maker.

3. **Identify a parameter you want to improve.** Try to be as much specific as possible. For instance, if you want to improve reliability, think of what component of your product is unreliable, and think of what technical parameter is responsible for reliability. Select such a parameter that is related to the reliability and use it for further analysis. Remember that the term "parameter" should be understood in a very generic sense. It might be also a property or some feature of a system. In addition, the verb "improve" means any useful effect that has to be provided. Depending on a situation, both "increase speed" and "decrease speed" can be regarded as improvements.

   I want <u>to keep coffee in the cup warm as long as possible</u>. In other words, to make the <u>temperature</u> of the coffee stable as long as possible).

4. **Propose any method which will improve your technical parameter**.

   I can keep coffee warm, for instance, <u>by placing the cup on an electric heater</u>.

5. **Think of why you can not reach the desired improvement in a straightforward way by using the method proposed**. What interferes with the improvement? What part of the product or surrounding environment gets worse? What is a negative effect that accompanies the desired improvement? Identify it with another technical parameter of your product or environment.

   In the case of using the heater, <u>more electric energy will be consumed</u>.

6. **Formulate a contradiction in the following form: "I want to improve the parameter X. I can do it by doing (put what you can do) but the parameter Y gets worse.**

I want to improve a <u>stability of the temperature</u> of the coffee <u>by providing external heating</u>, but in this case <u>energy consumption grows</u>.

7. **Use Altshuller's matrix (see the matrix in Appendix E).** Identify the parameter you want to improve with one of the generic technical parameters located along the left vertical column. Respectively, identify the parameter that gets worse with one of the generic parameters located along the horizontal row of parameters.

   To improve: <u>temperature</u>. Gets worse: <u>energy waste</u>.

8. **Find a cell in the matrix which is the intersection of vertical column and horizontal row for respectively the parameters you selected.** You see several numbers which indicate which inventive principle(s) to use to solve your problem.

9. **Use the list of inventive principles.** The principles in a selected cell of the matrix are listed in the order of most frequent usage to solve this type of contradiction.

10. **Interpret the recommended inventive principles in terms of your product.** The recommended principles are very general. Regard them as guidelines for further thinking and searching for a solution to your problem.

11. If no solution can be proposed in terms of formulated contradiction, return to step 5 and try to change the parameter that gets worse. Formulate a new contradiction. Repeat the problem solving process (steps 5 - 10).

12. If no solution can be found, redefine the parameter that you want to improve and formulate a new contradiction. Repeat the problem solving process (steps 3 - 11).

13. If the Altshuller matrix does not help after several attempts, use Inventive Standards, Pointer to Physical effects or ARIZ.

LIST OF TRIZ INVENTIVE PRINCIPLES

1. SEGMENTATION

- Divide your object into independent parts.
- Divide your object into parts so that some its part can be easily taken away.
- Increase the degree of the object's fragmentation.

2. TAKING AWAY

- Take away an interfering part of your object.
- If some property of the object is undesired, find out what part of the object is a carrier of the undesired property and separate it from the object.

3. LOCAL QUALITY

- Instead of uniform structure of your object, use non-uniform structure of the object.
- Instead of uniform structure of environment, use non-uniform structure of the environment.
- If two functions are to be performed by the same object but this causes problems, divide the object into two parts.
- Redesign your object and environment so that each part of the object must be in conditions proper for operation.

4. ASSYMETRY

- If your object has symmetrical shape, make it asymmetrical.
- If your object is asymmetrical, increase the degree of asymmetry.

5. COMBINING

- Merge identical parts or components of your object in space.
- Merge identical parts or components of your object in time.

6. UNIVERSALITY

- If you have two objects which deliver different functions, design a new single object that would be capable of delivering both functions.

7. NESTING

- Place one object inside another.
- Increase a number of nested objects.
- Make one object dynamically pass through a cavity of another object when necessary.

8. COUNTERWEIGHT

- Compensate for the weight of your object with merging it with another object that provides lifting force.
- Place your object into environment that provides aerodynamic, hydrodynamic or other lifting force.

9. PRIOR COUNTERACTION

- If your object is subjected to harmful factor(s) of environment, subject it to antipodal action beforehand. This will compensate with the harmful factor.

10. PRIOR ACTION

- If your object is subjected to harmful factors of environment, create conditions that will prevent the object from harmful factors beforehand.
- If your object has to be changed and this is hard to achieve, perform the required change of the object (fully or partially) beforehand.

11. EARLY CUSHIONING

- If your object is unreliable, create conditions in advance that will prevent the object.

12. EQUIPOTENTIALITY

- If your object has to be lowered or raised, redesign the object's environment so that the necessity to raise or lower the object ceases.

13. OTHER WAY ROUND

- Instead of actions defined perform opposite action.
- Make the movable part of your object fixed or the fixed part movable.

14. SPHEROIDALITY

- Instead of linear parts of the object, use curve parts.
- Use rollers, balls, spirals.
- Use rotary motion.
- Use centrifugal forces.

15. DYNAMICITY

- If your object is immobile, make it movable.
- Divide your objects into parts capable of moving relatively each other.
- Increase the degree of free motion.
- Make your object or environment dynamically change in accord with the required conditions at each stage of operation.

16. PARTIAL OR EXCESSIVE ACTION

- If it is not possible to precisely achieve the required change, or to perform some action, reformulate the problem: how to make slightly less or slightly more and then achieve the required result.

17. ANOTHER DIMENSION

- If your object moves along a line, consider movement within two-dimensional space.
- If your object moves in plane, consider movement within three-dimensional space.
- Rearrange objects so that instead of one-storied arrangement a multi-storied arrangement can be achieved.
- Tilt the object.
- Use other side of the given area.

18. MECAHNAICAL VIBRATIONS

- Make your object or its part vibrate.
- If the object is in oscillatory motion, increase the frequency of oscillations.
- Use resonance frequencies.
- Use ultrasonic frequencies.
- Use piezoelectric vibrators instead of mechanical ones.
- Use ultrasonic oscillations in combination with electromagnetic field.

19. PERIODIC ACTION

- Instead of continuous action use pulse actions.
- Vary periodicity according the conditions.
- Use pauses between impulses to perform some other action.

20. USEFUL ACTION CONTINUITY

- All parts of the object must work continuously.
- Eliminate all idle running.

21. SKIP

- If your object is subjected to harmful or hazardous actions within some process, conduct the process at a very high speed.

22. TURN THE HARM TO ONE`S GOOD

- Use harmful factors to achieve positive effects.
- Eliminate a harmful factor by adding it with another harmful factor.
- Amplify the harmful factor to such degree so that it would stop to bring harm to your object or environment.

23. FEEDBACK

- Introduce feedback.
- If the feedback is available, vary it in accord with operating conditions.

24. INTERMEDIARY

- Use an intermediate carrier to provide necessary actions if it is not possible to use existing objects or parts.
- Temporarily merge your object with another one that will provide the required action and then decompose them.

25. SELF-SERVICE

- The object must serve itself by performing tuning, adjusting and repair operations itself.
- Use available resources or waste resources.

26. USE OF COPIES

- If you need to undertake some actions with respect to unavailable, fragile, complicated, or dangerous object, use its simpler and cheaper copy,
- Instead of real objects, use their optical images (pictures, holograms).
- Use infrared or ultraviolet copies.

27. CHEAP SHORT-LIFE INSTEAD OF COSTLY LONG-LIFE

- Replace an expensive object with many cheap objects which deliver the same function.

28. MECHANICAL PRINCIPLE REPLACEMENT

- Replace mechanical principle behind your system or object with another physical principle: optical, acoustic, magnetic, electromagnetic, thermal, etc.

29. PNEUMATIC AND HYDRAULIC STRUCTURES

- Instead of a solid object or its parts, use gases or liquids: inflatable and filled with liquids, air cushion, hydrostatic and hydro-reactive.

30. FLEXIBLE SHELLS AND THIN FILMS

- Instead of heavy three-dimensional structures use flexible shells and thin films.
- Use flexible shells and thin films to isolate the object or its part from environment.

31. POROUS MATERIALS

- Make your object porous.
- Use porous coatings.
- Use porous inserts.
- If the object is porous, fill the pores with other substance, liquid or gas to achieve positive effect.

32. CHANGING COLOR

- Change the color of the object, its part or environment.
- Change transparency of the object, its part or environment.

33. HOMOGENEITY

- Make interacting objects of the same material or the material with identical properties.

34. REJECT AND REGENERATION OF PARTS

- If a part of an object that has delivered its function had become unnecessary or undesired, eliminate it by dissolving, evaporating, etc. or modify so that the interfering property will cease to exist.
- Restore consumable parts of the object during operation.

35. CHANGE OF PHYSICAL AND CHEMICAL PARAMETERS

- Change the object's aggregate state.
- Change concentration or composition of the object.
- Change the degree of flexibility of the object.
- Change the temperature of the object or environment.

36. PHASE TRANSITIONS

- Use physical phenomena accompanied by phase transitions: change of volume, emission or absorption of heat, etc.

37. THERMAL EXPANSION

- Use thermal expansion or contraction of materials.
- Merge two materials with different coefficients of thermal expansion.

38. STRONG OXIDIZERS

- Replace regular air with enriched air.
- Replace the enriched air with pure oxygen.
- Ionize air or oxygen.
- Use ozonized oxygen.
- Use ozone.

39. INERT ATMOSPHERE

- Use inert gases instead of usual ones.
- Add neutral parts or additives to the object.

40. COMPOSITES

- Use composite materials instead of uniform ones.

INVENTIVE STANDARDS

Recommendations on using Inventive Standards

1. Problem Definition

1.1. Select a product or a system you want to improve.

1.2. Localize a part of the product where a problem arises. It might as well include components of a surrounding environment which interact with the product.

1.3. Select one or two substance objects of the product which cause problem, or have to be changed, or which properties have to be measured or detected.

1.4. Define what type of your problem is. Is it a modification problem or a problem which deals with detection or measurement? Or you want to predict the evolution of the selected component or a product? Every situation refers to classes of the standards which have to be used use: Modification problem: Classes 1 and 2, Measurement/ Detection problem: Class 4. Prediction problem: Classs 2 and 3. Class 5 specifies how to introduce new components to a system under restrictions on introduction of new components.

2. Modification Problems

2.1. If your problem involves a single component you want to change, use Standard 1-1-1 and go to the phase of verification of a solution.

2.2. If the problem includes interaction between two components, define what type of physical interaction exists between the two selected components. What physical field provides the interaction?

2.3. Draw a substance-field model of a part of your problem. Indicate what type of unsatisfactory interaction is between the components. Is it missing, excessive, harmful or insufficient? Draw a corresponding line between the components. A type of the line indicates your problem.

2.4. Select which group of Standards you will use. If the problem involves a harmful interaction, go to the standards of Group 1-2. If the interaction is missing insufficient or excessive, go to Group 1-1.

2.5. Browse each inventive standard until you find a standard with the left part matching your substance-field model.

2.6. Complete or change your initial substance-field model as recommended in the right-hand side of the selected inventive standard.

2.7. If it is unclear what new substance or field to choose, use lists of substances and fields (i.e. the list in page 170 and Class 5 of Inventive Standards) to find out if the fields or substances listed can be introduced and solve the problem.

2.8. It is recommended to use the Pointer to physical effects if any specific interaction you want to improve refers to one of the functions listed in the Pointer.

3. Measurement problems

3.1. First, use Group 4-1 to check if you can avoid measurement or detection.

3.2. If measurement/detection is not avoidable, identify exactly what component is a carrier of a property you have to measure or detect.

3.3. Browse inventive standards of Class 4 until you find a desired solution pattern. Use lists of substance and fields (i.e. the list in page 170 and Class 5 of Inventive Standards) to find out if the fields or substances listed can be introduced and solve the problem.

4. Prediction Problems.

4.1 Most of standards of Class 3 do not deal with substance-field models. They are drawn from TRIZ trends of the technology evolution. It is recommended to use these standards after you have obtained a satisfying solution with standards of Classes 1, 2, and 4.

5. If a problem is not solved.

Try to use the standards of Class 5, or try to refine the problem formulation.

CLASSIFICATION OF INVENTIVE STANDARDS

CLASS 1. COMPOSITION AND DECOMPOSITION OF SFMS
GROUP 1-1: SYNTHESIS OF SFMS
GROUP 1-2: DECOMPOSITION OF SFMS

CLASS 2. EVOLUTION OF SFMS
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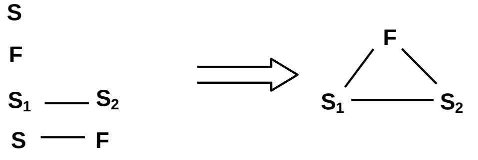
CLASS 1. COMPOSITION AND DECOMPOSITION OF SFMS

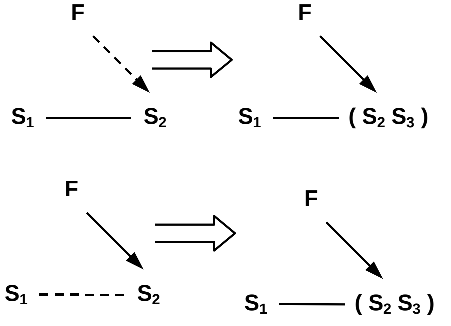
GROUP 1-1: SYNTHESIS OF SFMS

STANDARD 1-1-1. If there is an object which is not easy to change as required, and the conditions do not contain any limitations on the introduction of substances and fields, the problem is to be solved by synthesizing a ***SFM***: the object is subjected to the action of a physical field which produces the necessary change in the object.



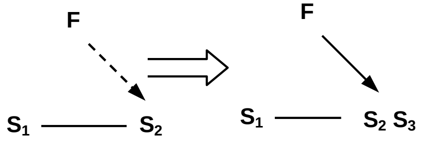
Example: To remove air (S_1) from a powdered substance, the substance (S_2) is subjected to centrifugal forces (F).

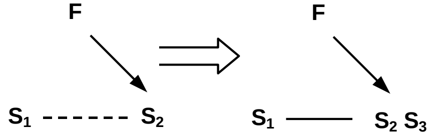
STANDARD 1-1-2. If there is a SFM which is not easy to change as required, and the conditions do not contain any limitations on the introduction of additives to given substances, the problem is to be solved by a transition (permanent or temporary) to an ***internal complex SFM***, introducing additives in the present substances enhancing controllability or imparting the required properties to the SFM.



Example: To detect very small drops of liquid (S_2) in a liquid (S_1), a luminescent substance is added to the liquid (S_2) in advance.

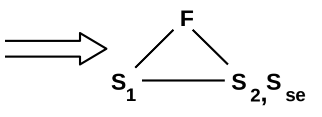
STANDARD 1-1-3. If there is a SFM which is not easy to change as required, and the conditions contain limitations on the introduction of additives into the existing substances, the problem can be solved by a transition (permanent or temporary) to an external ***complex SFM***, attaching to one of these substances an external substance which improves controllability or brings the required properties to the SFM.



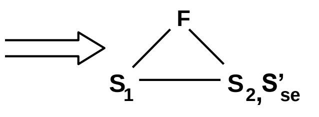


Example: To detect a leakage of gases (S_1) from a pipe (S_2), an outer surface of the pipe is covered with a substance (S_3)

STANDARD 1-1-4. If there is a SFM that is not easy to change as required, and the conditions contain limitations on the introduction or attachment of substances, the problem has to be solved by synthesizing a SFM using external environment as the substance.

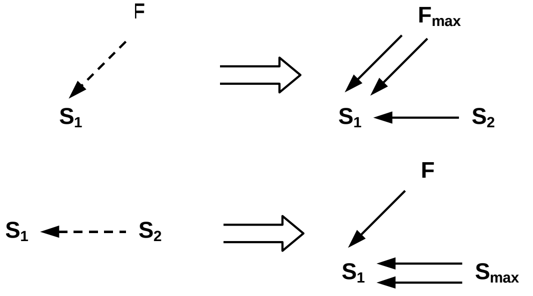


STANDARD 1-1-5. If the external environment does not contain ready substances required to synthesize a SFM, these substances can be obtained by replacing the external environment with another one, or by decomposing the environment, or by introducing additives into the environment.



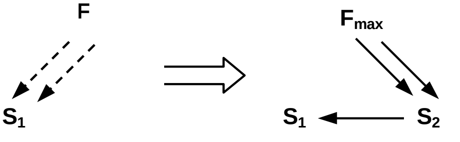
Example: To improve a coefficient of sliding effect, a liquid lubricant is aerated.

STANDARD 1-1-6. If a minimum (measured, optimal) effect of action is required, but it is difficult or impossible to provide it under the conditions of the problem, use a maximum action, while the excess of the action is then removed. Excess of a substance is removed by a field, while excess of a field is removed by a substance.



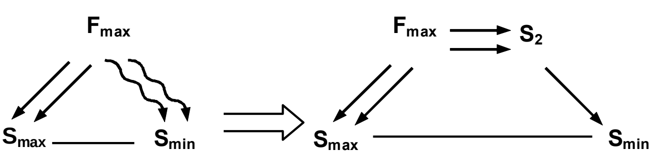
Example: To paint a part accurately, the part first loaded into a container with the paint, and then subjected to rotation. Excess of paint is removed due to centrifugal forces.

STANDARD 1-1-7. If a maximum effect of action on a substance is required and this is not allowed, the maximum action has to be preserved but directed to another substance attached to the first one.



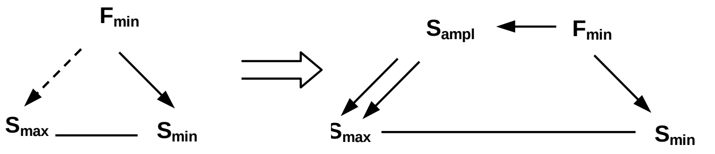
Example: When manufacturing reinforced concrete, it is possible to use metal wire instead of rods. But the wire has to be stretched. To do this it has to be heated up to 700C what is not allowed. The wire is connected to the rod that is heated while the wire remains cold.

STANDARD 1-1-8-1. If a selective effect of action is required (maximum in certain zones, while the minimum is maintained in other zones), the field has to be maximal; then a protective substance is introduced in places where a minimum effect is required.



Example: When sealing a glass ampoule with liquid medicine, an overheated glass might destroy the medicine. The ampoule is put into water leaving the ampoule's tip above the water. Water protects the rest of the ampoule from overheating.

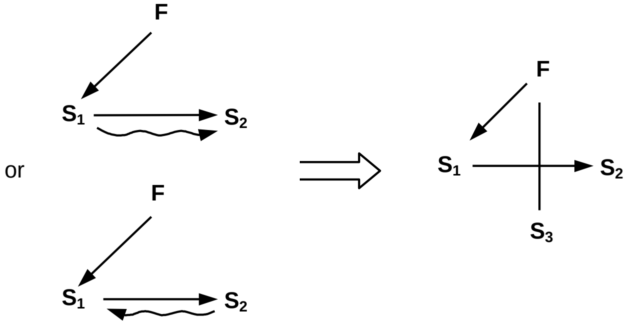
STANDARD 1-1-8-2. If a selective-maximum effect is required (maximum in certain zones, and minimum in other zones), the field should be minimal; then a substance that produces a local effect interacting with a field (e.g. thermite compounds for thermal action or explosive ones for mechanical action) is introduced in places where a maximum effect is required.



Example: To weld two metal parts, an exothermic powder producing extra heat is introduced between the parts.

GROUP 1-2: DECOMPOSITION OF SFMS

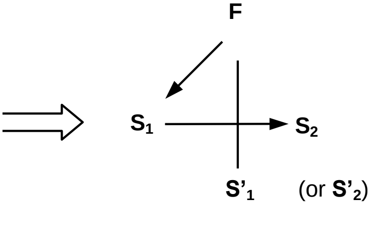
STANDARD 1-2-1. If useful and harmful effects appear between two substances in a SFM and there is no need to maintain a direct contact between the substances, the problem is solved by introducing a third substance between them.



Notes: The third substance can also be obtained from the present substances by exposure to the existing fields. In particular, the substance to be introduced can be bubbles, foam, etc.

Example: To compact walls of a borehole, gases produced during explosion are used. However, the gases also may cause cracks in the borehole's walls. It is proposed to cover the walls by plasticine that transmits pressure but prevents the walls from crack formation.

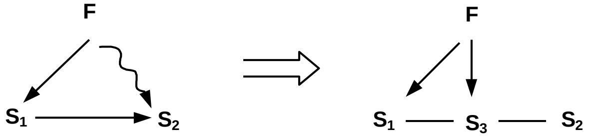
STANDARD 1-2-2. If there are a useful and a harmful effects between two substances, and there is no need to maintain direct contact between the substances, and it is forbidden or inconvenient to use foreign substances, the problem can be solved by introducing a third substance between the two, which is a modification of the first or the second substances.



Note: The third substance can be obtained from the existing substances by exposure to the present fields. In particular, the substance to be introduced can be bubbles, foam, etc. Besides, a modification of the substance may bring about a change in the law of its movement: movable-fixed parts, etc.

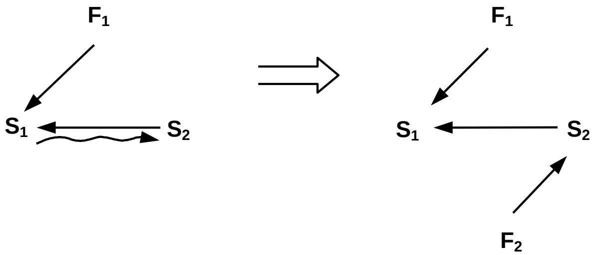
> *Example: A hydrodynamic foil's surface might be destroyed by a cavitation produced by the friction between the foil and the water when moving at a high speed. It is proposed to refrigerate the surface of the foil. Surrounding water will freeze and form an ice layer on the foil.*

STANDARD 1-2-3. If it is required to eliminate the harmful effect of a field upon a substance, the problem can be solved by introducing a second substance that draws off upon itself the harmful effect of the field.



> *Example: To protect underground cables from stresses of ground occurring during frost, cavities are formed in the ground beforehand.*

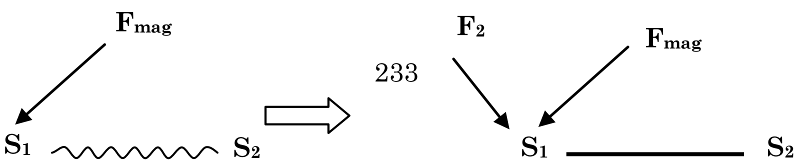
STANDARD 1-2-4. If useful and harmful effects appear between two substances in a SFM, and a direct contact between the substances must be maintained, the problem can be solved by transition to a ***dual SFM,*** in which the useful effect is provided by the existing field while a new field neutralizes the harmful effect (or transforms the harmful effect into a useful effect).



> *Example: To help with pollination of a flower, airflow is used. However, it also closes the flower. It is proposed to open the flower with electrostatic discharge.*

STANDARD 1-2-5. If it is necessary to decompose a SFM with a magnetic field, the problem is solved by using physical effects, which are capable of "switching off" ferromagnetic properties of substances, e.g. by demagnetizing during an impact or during heating above Curie point.

Notes: The magnetic field may appear at the right moment if a system of magnets compensating the effect of each other's field is used. When one of the magnets is demagnetized, a magnetic field arises in the system.

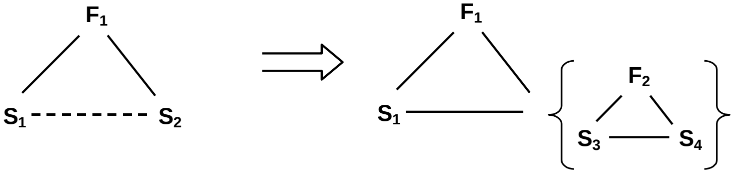


Example: During welding, it is difficult to insert a ferromagnetic powder in the welding zone: an electromagnetic field of a welding current makes the particles move away from the welding zone. It is proposed to heat the powders above the Curie point to make them non-magnetic.

CLASS 2. EVOLUTION OF SFMS

GROUP 2-1: TRANSITION TO COMPLEX SFMS

STANDARD 2-1-1. Efficiency of SFM can be improved by transforming one of the parts of the SFM into an independently controllable SFM, thus forming a ***chain SFM*.**



Example: A tractor with movable center of gravity to work on steep slopes.

STANDARD 2-1-2. If it is necessary to improve the efficiency of SFM, and replacement of SFM elements is not allowed, the problem can be solved by the synthesis of a dual SFM through introducing a second field which is easy to control.

Example: It is proposed to increase control over a melted metal by rotating the metal in a centrifuge.

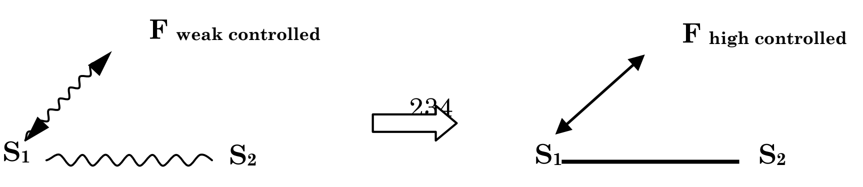
GROUP 2-2: EVOLUTION OF SFM

STANDARD 2-2-1. Efficiency of a SFM can be improved by replacing an uncontrolled (or poorly controlled) field with a well-controlled field, e.g. by replacing a gravitation field with mechanical field, mechanical field with an electric, etc.

Notes: In certain situations, controllability of a field may be improved not only by replacing a given field with another one, but also by modifying the present field along the following line:

Permanent field -> monotonically changing one -> pulsed one ->

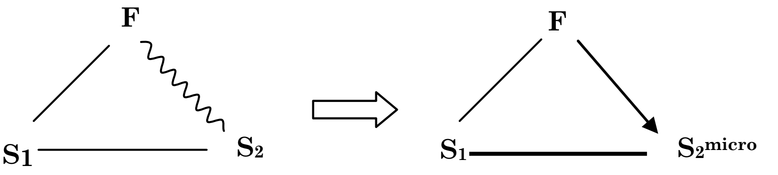
variable one -> variable in frequency and amplitude -> etc.



Example: Instead of a metal blade for non-uniform metal cutting, a water jet can be used.

STANDARD 2-2-2. Efficiency of a SFM can be improved by increasing the degree of fragmentation of the object which acts as an instrument in SFM .

Notes: The standard displays one of the major trends of the technology evolution, i.e. fragmentation of the object or its part interacting with the product.

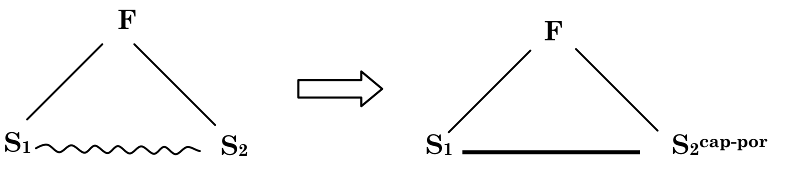


Example: A knife with teeth, then with the abrasive coating.

STANDARD 2-2-3. Efficiency of a SFM can be improved by transition from a solid object to a capillary porous one. The transition is performed as:

solid object –->
object with one cavity –->
object with multiple cavities (perforated) –->
capillary porous object –->
capillary porous object with a predefined porous structure.

Notes: Transition to a capillary porous object enables a liquid substance to be placed in the pores and use physical effects.



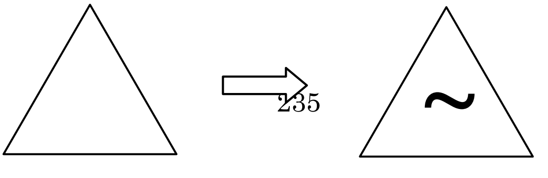
Example: A bunch of capillaries apply liquid glue more accurately on a surface to be glued than a single large-sized tube.

STANDARD 2-2-4. Efficiency of a SFM can be improved by increasing the degree of dynamics of SFM, i.e. by transition to a more flexible, rapidly changing structure of the system.

Notes: Making a substance dynamic starts with dividing it into two joint-coupled parts and continues along the following line:

One joint –-> many joints –-> flexible object.

A field can be made more dynamic by transition from a permanent field (or of the field together with a substance) to a pulsed field.



Example: A door made of hinged segments -> "Accordion" door ->.

STANDARD 2-2-5. Efficiency of SFM can be improved by transition from a uniform field or fields with a disordered structure to non-uniform fields or fields with a definite spatial-temporal structure (permanent or variable).

Notes: If a certain spatial structure is to be imparted to a substance object, the process can be conducted in a field having a structure that matches the required structure of the substance object.

Example:To mix two magnetic powders, a layer of the first powder is put in the layer of the second powder and the non-uniform magnetic field is applied.

STANDARD 2-2-6. Efficiency of a SFM can be improved by transition from substances that are uniform or have a disordered structure to substances that are non-uniform or have a predefined spatial-temporal structure (permanent or variable).

Notes: In particular, if an intensive effect of a field is required in certain places of a system (points, lines), then substances that produce the required field are introduced in these spots beforehand.

Example: To make a porous material with oriented spatial structure the field threats are inserted into the soft material beforehand. After the material solidifies these threats are burned out.

GROUP 2-3: EVOLUTION BY COORDINATING RHYTHMS

STANDARD 2-3-1. Efficiency of a SFM can be improved by matching (or mismatching) the frequency of acting field with the natural frequency of a product (or tool).

Example: 1. The rhythm of massage is synchronized with a pulse of a patient. 2. In arc welding, the frequency of magnetic field is equal to the natural frequency of a melting electrode.

STANDARD 2-3-2. Efficiency of a complex SFM can be improved by matching (or mismatching) frequencies of the fields being used.

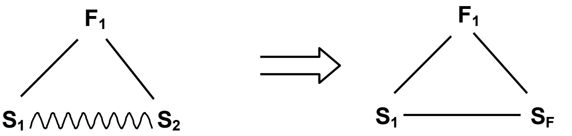
Example: To coat a part with a material, the material is applied as a powder. To provide a high degree of regularity, the frequencies of pulses of an electrical current and pulses of magnetic field are made equal.

STANDARD 2-3-3. If we are given two incompatible actions, e.g. changing and measuring, one action should be performed during the pauses of another one. In general, pauses in one action should be filled with another useful action.

Example: To provide accuracy of contact welding, measurements are conducted during the pauses between the pulses of an electrical current.

GROUP 2-4: COMPLEX-FORCED SFMS (F-SFMS)

STANDARD 2-4-1. Efficiency of a SFM is enhanced by using a ferromagnetic substance and a magnetic field.



Notes: 1. The standard indicates the use of a ferromagnetic substance that is not in a fragmented state. 2. F-SFM is a SFM system in which a disperse ferromagnetic substance and a magnetic field are interacting.

STANDARD 2-4-2. Efficiency of control over a SFM can be improved by replacing one of the substances with ferromagnetic particles (or adding ferromagnetic particles) - chips, granules, grains, etc. - and using magnetic or electromagnetic field.

Notes: Efficiency of control rises with a higher degree of fragmentation of ferromagnetic particles and of the substance in which they are introduced.

ferroparticles: granules –> powder –> finely dispersed particles –> magnetic liquid;

substance: solid –> grains –> powder –> liquid.

STANDARD 2-4-3. Efficiency of a ferromagnetic SFM can be improved by using magnetic fluids - colloidal ferromagnetic particles suspended in kerosene, silicone or water.

STANDARD 2-4-4. Efficiency of a ferromagnetic SFM can be improved by using a capillary porous structure inherent in many F-SFMs.

STANDARD 2-4-5. If it is required to raise the efficiency of control and replacement of substances with ferromagnetic particles is not allowed, one has to compose internal or external complex ferromagnetic SFM, introducing additives in one of the substances.

STANDARD 2-4-6. If it is required to raise the efficiency of control and replacement of substances with ferromagnetic particles is not allowed, the ferromagnetic particles should be introduced in the external environment. Then, using the magnetic field, the environment parameters should be changed so that the system becomes more controllable.

STANDARD 2-4-7. Controllability of a ferromagnetic system can be improved by the use of physical effects.

STANDARD 2-4-8. Efficiency of a F-SFM can be improved by increasing the degree of dynamics in the system, for instance, by transition to a more flexible, rapidly changing structure of the system.

Notes: Making a substance more dynamic begins with dividing it into two joint-coupled parts and continues along the following line:

One joint –> many joints –> flexible substance.

A field is made dynamic by going over from a permanent effect of the field (or of the field together with a substance) to a pulsed effect.

STANDARD 2-4-9. Efficiency of F-SFM can be improved by transition from fields that are uniform or have a disordered structure to fields that are non-uniform or have a definite spatial-temporal structure (permanent or variable).

Notes: If a certain spatial structure is to be imparted to a substance object, the process can be conducted in a field having a structure that matches the required structure of the substance object.

STANDARD 2-4-10. Efficiency of F-SFM can be improved by matching the rhythms of the system's elements.

STANDARD 2-4-11. If it is not allowed to introduce ferromagnetics or to perform magnetization, an *E-SFM* has to be synthesized using: a) interaction of an external electromagnetic field with currents or b) fed through a contact or induced without a contact, or c) using interaction between these currents.

Notes: An E-SFM is a SFM in which electric currents interact with each other. The evolution of E-SFMs repeats the line of evolution of complex-boosted SFMs:

Simple E-SFM –> complex E-SFM –> E-SFM in the external environment –> E-SFM Dynamisation –> structuring –> matching the rhythms.

STANDARD 2-4-12. If a magnetic fluid cannot be used, one can use an electrorheologic fluid (a suspension of fine quartz powder in toluene, for instance, with viscosity being changed by the electric field). A SFM with an electrorheologic fluid is a special form of E-SFM.

CLASS 3. TRANSITIONS TO SUPERSYSTEM AND MICROLEVEL

GROUP 3-1: TRANSITIONS TO BISYSTEM AND POLYSYSTEM

STANDARD 3-1-1. System efficiency at any stage of its evolution can be improved by combining the system with another system (or systems) to form a bi- or polysystem.

Notes: For a simple formation of bi- and polysystems, two and more components are combined. Components to be combined may be substances, fields, substance-field pairs and whole SFMs.

Example: To process sides of thin glass plates, several plates are put together to prevent glass from breaking.

STANDARD 3-1-2. Efficiency of bi- and polysystems can be improved by developing links between system elements.

Notes: Links between elements of a bi- and polysystem may be made either more rigid or more dynamic.

Example: To synchronize a process of lifting a very heavy part by three cranes, it is proposed to use a rigid triangle synchronizing the cranes moving parts.

STANDARD 3-1-3. Efficiency of bi- and polysystems can be improved by increasing the difference between system components. The following line of evolution is recommended:

similar components (pencils of the same color) –->

components with biased characteristics (pencils of different colors) –->

different components (set of drawing instruments) –->

combinations of the "component + component with opposite function" (pencil with rubber)

STANDARD 3-1-4. Efficiency of bi- and polysystems can be improved by "convolution" (integration of several components into a single component) by reducing auxiliary components. Completely convoluted bi- and polysystems become monosystems again, and integration can be repeated at another level of the system.

Example: Instead of three separate indicators on a dashboard, a single indicator can be used in which indicating arrows are made of different colors.

STANDARD 3-1-5. Efficiency of bi- and polysystems can be improved by distributing incompatible properties among the system and its parts. This is achieved by using a two-level structure in which the system as a whole has a certain property A, while its parts (particles) have property anti-A.

Example: A working part of a vice is made of segmented plates capable of moving relatively each other. Parts of various shapes can be gripped quickly.

GROUP 3-2: TRANSITION TO MICROLEVEL

STANDARD 3-2-1. Efficiency of a system at any stage of its evolution can be improved by transition from a macrolevel to a microlevel: the system or its part is replaced by a substance capable of delivering the required function when interacting with a field.

Notes: There is a multitude of microlevel states of a substance (domains, crystal lattice, molecules, ions, domains, atoms, fundamental particles, fields, etc.). Therefore, various options of transition to a microlevel and various options of transition from one microlevel to another, lower one, should be considered when solving a problem.

Example: Instead of a microscrew, a microscopic table can be positioned by fixing it on a metal rod that is subjected to a thermal field. The rod expands and contracts relatively the value of the temperature due to the effect of thermal expansion.

CLASS 4. MEASUREMENT AND DETECTION STANDARDS

GROUP 4-1: CHANGE INSTEAD OF MEASUREMENT AND DETECTION

STANDARD 4-1-1. If a problem involves detection or measurement, it is proposed to change the problem in such a way, so that there should be no need to perform detection or measurement at all.

Example: To prevent a permanent electric motor from overheating, its temperature is measured by a temperature sensor. If to make the poles of the motor of an alloy with a Curie point equal to the critical value of the temperature, the motor will stop itself.

STANDARD 4-1-2. If a problem involves detection or measurement, and it is impossible to change the problem to eliminate the need for detection or measurement, it is proposed to detect/mesure properties of a copy of the object (e.g. picture).

Example: It might be dangerous to measure the length of a snake. It is safe to measure its length on a photographic image of the snake, and then recalculate the obtained result.

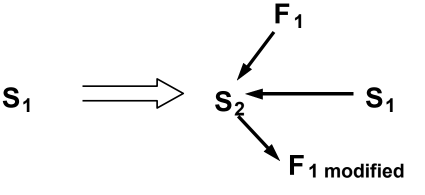
STANDARD 4-1-3. If a problem involves detection or measurement, and the problem cannot be changed to eliminate the need for measurement, and it is impossible to use copies or pictures, it is proposed to transform this problem into a problem of successive detection of changes.

<u>Notes:</u> Any measurement is conducted with a certain degree of accuracy. Therefore, even if the problem deals with continuous measurement, one can always single out a simple act of measurement that involves two successive detections. This makes the problem much simpler.

Example: To measure a temperature, it is possible to use a material that changes its color depending on the current value of the temperature. Alternatively, several materials can be used to indicate different temperatures.

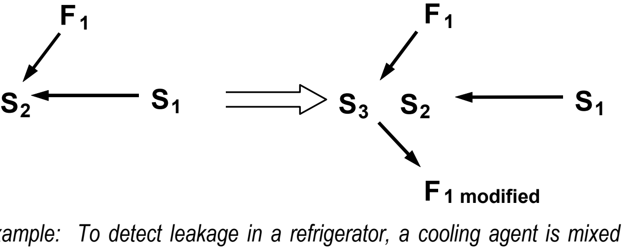
<u>GROUP 4-2: SYNTHESIS OF MEASUREMENT SYSTEM</u>

STANDARD 4-2-1. If a non-SFM is not easy to detect or measure, the problem is solved by synthesizing a simple or dual SFM with a field at the output. Instead of direct measurement or detection of a parameter, another parameter identified with the field is measured or detected. The field to be introduced should have a parameter that we can easily detect or measure, and which can indicate the state of the parameter we need to detect or measure.



Example: To detect a moment when a liquid starts to boil, an electrical current is passed through the liquid. During boiling, air bubbles (S_2) are formed - they dramatically reduce electrical conductance (Fmodified) of the liquid.

STANDARD 4-2-2. If a system (or its part) does not provide detection or measurement, the problem is solved by transition to an internal or external complex measuring SFM, introducing easily detectable additives.



Example: To detect leakage in a refrigerator, a cooling agent is mixed with a luminescent powder.

STANDARD 4-2-3. If a system is difficult to detect or to measure at a given moment of time, and it is not allowed or not possible to introduce additives into the object, then additives that create an easily detectable and measurable field should be introduced in the external environment. Changing the state of the environment will indicate the state of the object.

Example: To detect wearing of a rotating metal disc contacting with another disk, it is proposed to introduce luminescent powder into the oil lubricant, which already exists in the system. Metal particles collecting in the oil will reduce luminosity of the oil.

STANDARD 4-2-4. If it is impossible to introduce easily detectable additives in the external environment, these can be obtained in the environment itself, for instance, by decomposing the environment or by changing the aggregate state of the environment.

Notes: In particular, gas or vapor bubbles produced by electrolysis, cavitation or by any other method may often be used as additives obtained by decomposing the external environment.

Example: The speed of a water flow in a pipe might be measured by amount of air bubbles resulting from cavitation.

GROUP 4-3: IMPROVEMENT OF MEASUREMENT SYSTEMS

STANDARD 4-3-1. Efficiency of a measuring SFM can be improved by the use of physical effects.

Example: Temperature of liquid media can be measured by measuring a change of a coefficient of refraction, which depends on the value of the temperature.

STANDARD 4-3-2. If it is impossible to detect or measure directly the changes in the system, and no field can be passed through the system, the problem can be solved by exciting resonance oscillations (of the entire system or of its part), whose frequency change is an indication of the changes taking place.

Example: To measure the mass of a substance in a container, the container is subjected to mechanically forced resonance oscillations. The frequency of the oscillations depends on the mass of the system.

STANDARD 4-3-3. If resonance oscillations may not be excited in a system, its state can be determined by a change in the natural frequency of the object (external environment) connected with the system.

Example: The mass of boiling liquid can be measured by measuring the natural frequency of gas resulting from evaporation.

GROUP 4-4: TRANSITION TO FERROMAGNETIC MEASUREMENT SYSTEMS

STANDARD 4-4-1. Efficiency of a measuring SFM can be improved by using a ferromagnetic substance and a magnetic field.

Notes: The standard indicates the use of a non-fragmented ferromagnetic object.

STANDARD 4-4-2. Efficiency of detection or measurement can be improved by transition to ferromagnetic SFMs, replacing one of the substances with ferromagnetic particles (or adding ferromagnetic particles) and detecting or measuring by the magnetic field.

STANDARD 4-4-3. If it is required to improve the efficiency of detection or measurement by transition to a ferromagnetic SFM, and replacement of the substance with ferromagnetic particles is not allowed, the transition to the F-SFM is performed by synthesizing a complex ferromagnetic SFM, introducing (or attaching) ferromagnetic additives in the substance.

STANDARD 4-4-4. If it is required to improve efficiency of detection or measurement by transition to F-SFM, and introduction of ferromagnetic particles is not allowed, ferromagnetic particles are introduced in the external environment.

STANDARD 4-4-5. Efficiency of a F-SFM measuring system can be improved by using physical effects, for instance, Curie point, Hopkins and Barkhausen effects, magnetoelastic effect, etc.

GROUP 4-5: EVOLUTION OF MEASUREMENT SYSTEMS

STANDARD 4-5-1. Efficiency of a measuring system at any stage of its evolution can be improved by forming bi- or polysystem.

Notes: To form bi- and polysystems, two or more components are combined. The components to be combined may be substances, fields, substance-field pairs and SFMs.

Example: It is difficult to accurately measure the temperature of a small beetle. However, if there are many beetles put together, the temperature can be measured easily.

STANDARD 4-5-2. Measuring systems evolve towards measuring the derivatives of the function under control. The transition is performed along the following line:

measurement of a function —> measurement of the first derivative of the function —> measurement of the second derivative of the function.

Example: Change of stress in the rock are defined by the speed of changing the electrical resistance of the rock.

CLASS 5. HELPERS

GROUP 5-1: INTRODUCTION OF SUBSTANCES UNDER RESTRICTED CONDITIONS

STANDARD 5-1-1-1. If it is necessary to introduce a substance in the system, and it is not allowed, a "void" can be used instead of the substance.

Notes: A "void" is usually gaseous substance, like air, or empty space formed in a solid object. In some cases a "void" may be formed by other substances, such as liquids (foam) or loose bodies.

STANDARD 5-1-1-2. If it is necessary to introduce a substance in the system, and it is not allowed, a field can be introduced instead of the substance.

STANDARD 5-1-1-3. If it is necessary to introduce a substance in the system, and it is not allowed. an external additive can be used instead of an internal one.

STANDARD 5-1-1-4. If it is necessary to introduce a substance in the system, and it is not allowed, a very active additive can be introduced in very small quantities.

STANDARD 5-1-1-5. If it is necessary to introduce a substance in the system, and it is not allowed, an additive can be introduced in very small quantities, and concentrated in certain parts of the object.

STANDARD 5-1-1-6. If it is necessary to introduce a substance in the system, and it is not allowed, the substance can be introduced temporarily and then removed.

STANDARD 5-1-1-7. If it is necessary to introduce a substance in the system, and it is not allowed, a copy of the object can be used instead of the object itself, where introduction of substances is allowed.

STANDARD 5-1-1-8. If it is necessary to introduce a substance in the system, and it is not allowed by the system's operating conditions, the substance can be introduced in a form of a chemical compound which can be later decomposed.

STANDARD 5-1-1-9. If it is necessary to introduce a substance in the system, and it is not allowed, the substance can be produced by decomposing the external environment or the object itself, for instance, by electrolysis, or by changing the aggregate state of a part of the object or external environment.

STANDARD 5-1-2. If a system is not easy to change as required, and the conditions do not allow to replace the component acting as an instrument or introduce additives, the artifact has to be used instead of the instrument, dividing the artifact into parts interacting with each other.

STANDARD 5-1-3. After the substance introduced in the system has fulfilled its function, it should either disappear or become indistinguishable from the substance that was in the system or in the external environment before.

<u>Note:</u> The substance that has been introduced may disappear due to chemical reactions or change of phase.

STANDARD 5-1-4. If it is necessary to introduce a large quantity of a substance, but this is not allowed, a "void" in the form of inflatable structures or foam should be used as the substance.

<u>Note:</u> Introduction of foam or inflatable structures resolves a contradiction 'much substance - little substance'.

<u>GROUP 5-2: INTRODUCTION OF FIELDS UNDER RESTRICTED CONDITIONS</u>

STANDARD 5-2-1. If a field has to be introduced in a SFM, one should use first of all the present fields for whom the media are those substances that form the system or its part.

<u>Note:</u> The use of substances and fields which already present in the system improves the system's ideality: number of functions performed by the system increases without increasing the number of used components.

STANDARD 5-2-2. If a field has to be introduced in a SFM and it is not possible to use the fields which already present in the system, one should use the fields of the external environment.

<u>Note:</u> The use of external environment fields (gravitation, thermal field, pressure...) improves the system's ideality: the number of functions performed by the system increases without increasing the number of used components.

STANDARD 5-2-3. If a field has to be introduced in a SFM but it is impossible to use the fields which already present in the system or in the external environment, one should use the fields for whom the substances present in the system or external environment can act as media or sources.

<u>Notes:</u> In particular, if there are ferromagnetic substances in a system and they are used for mechanical purposes, it is possible to use their magnetic properties in order to obtain additional effects: improve interactions between components, obtain information on the state of the system, etc.

GROUP 5-3: USE OF PHASE TRANSITIONS

STANDARD 5-3-1. Efficiency of the use of a substance without introducing other substances can be improved by changing its phase.

STANDARD 5-3-2. "Dual" properties are provided by using substances capable of converting from one phase to another according to operating conditions.

STANDARD 5-3-3. Efficiency of a system can be improved by the use of physical phenomena accompanying a phase transition.

Notes: Structure of a substance, density, thermal conductivity, etc. also change along with the change of aggregate state during all types of phase transitions. In addition, during phase transitions, energy may be released or absorbed.

STANDARD 5-3-4. "Dual" properties of a system are provided by replacing a single-phase state of the substance with a dual-phase state.

STANDARD 5-3-5. Efficiency of systems obtained as a result of replacing a substance's single-phase state with a dual-phase state can be improved by introducing interaction (physical or chemical) between parts (phases) of the system.

GROUP 5-4: USE OF PHYSICAL EFFECTS

STANDARD 5-4-1. If an object is to be alternating between different physical states, the transition is performed by the object itself using reversible physical transformations, e.g. phase transitions, ionization-recombination, dissociation-association, etc.

Note: A dynamic balance providing for the process self-adjustment or stabilization may be maintained in the dual-phase state.

STANDARD 5-4-2. If it is necessary to obtain a strong effect at the system's output, given a weak effect at the input, the transformer substance is placed to a condition close to critical. The energy is stored in the substance, and the input signal acts as a "trigger".

GROUP 5-5: OBTAINING SUBSTANCE PARTICLES

STANDARD 5-5-1. If substance particles (e. g. ions) are required to solve a problem and they are not available according to the problem conditions, the required particles can be obtained by decomposing a substance of a higher structural level (e.g. molecules).

STANDARD 5-5-2. If substance particles (e.g. molecules) are required to solve a problem and they can not be produced by decomposing a substance of a higher structural level, the required particles can be obtained by combining particles of a lower structural level (e.g. ions).

STANDARD 5-5-3. If a substance of a higher structural level has to be decomposed, the easiest way is to decompose the nearest higher element. When combining particles of a lower structural level, the easiest way is to combine the nearest lower elements.

POINTERS TO EFFECTS

Problems involving change of a system.

Function	Physical effects	Chemical effects	Geometrical effects
Accumulation of cold		Decomposition of gaseous hydrates; Hydrides; Hydrogen; Endothermic reactions; Dissolution.	
Accumulation of mechanical energy	Inertia; Deformation; Gyroscopic effect; Phase transitions.		
Accumulation of heat	Radiation; Phase transitions.	Hydrogen; Transport reactions.	
Apply one substance to another substance		Transport reactions; Hydrate state; With hydrides; Oxidization – reduction; Photochromism; Electrochromism; Molecular self-assembly; Liquid membranes; Hydrophility – hydrophobity; Plasma deposition of thin films.	
Change of substance concentration		Transport reactions; Adsorption – desorption; Transition to chemically-bound state; Bias of chemical balance; Semi-transparent membranes; Liquid membranes; Complexones.	
Change of density	Change of density and viscosity of fluids under magnetic and electric fields.	Gaseous hydrates.	
Change of distance			Ellipse.
Change of electric properties		Hydration; Reduction of oxides; Dissolution of salts; Self-Propagation High Temperature Synthesis (SHS) ; Bias of chemical balance; Electrization by oxidation; Electrochromes; Complexones; Hydrophile layer.	
Change of magnetic properties	Screening; Curie Point.	Hydration; Clusters; Self-Propagation High Temperature Synthesis (SHS).	
Change of mass		Transport reactions; Thermochemical method;	

		Transition to chemically bound state; Transition to hydrate state; Transition to hydride state; Exothermic reactions.	
Change of optical properties		Reduction of oxides; Change of color; Light generation; Change of transparency; Molecular layers.	
Change of shape	Shape memory effect in alloys and polymers.	Transport reactions; Thermochemical processing; Gaseous hydrates; Hydrides; Melting – solidification.	
Change of area			Single-surface bodies (Mobius sheet).
Change of sizes	Thermal expansion; Shape memory effect in alloys and polymers; Deformation; Magnetostriction; Electrostriction; Piezoeffect.		
Change of surface properties	Friction; Adsorption; Diffusion. Bauschinger effect; Electric discharge; Mechanical and acoustic oscillations; Ultraviolet radiation.		
Change of velocity	Inertia, Sorption,	Gaseous hydrates, Electrolysis.	
Change of volume	Phase transitions; Change of density and viscosity of fluids under magnetic and electric fields; Thermal radiation; Ionization by electric field; Ultraviolet; X-rays; Deformation; Diffusion; Bauschinger effect; Thermoelectric phenomena; Thermomagnetic phenomena; Magnetooptical phenomena; Cavitation; Photochromism; Intrinsic photo-effect.	Transport reactions; Dissolution in compressed gases; Transition to hydrate state; Transition to hydride state; Thermochemical reactions; Transition to chemically-bound state; Exothermic reactions; Dissolution.	Ellipse
Control over clearance between objects	Thermal expansion; Electrostrcition; Magnetostriction; Piezoelectric effect.		
Control over motion of disperse particles	Electrostatic field; Electrical and magnetic fields; Light pressure.		
Control over displacement of solid bodies (substances)	Thermal expansion; Electro- and magnetostriction; Piezoelectric effect; Memory shape effect; Magnetic field; Pressure	Gaseous hydrates; Hydrogen; Electrolysis.	Spherical bodies; Brushes; Loose bodies.

	generated by liquids and gases; Mechanical vibrations; Centrifugal forces; Acoustic and hydraulic shock; Electromagnetic induction; Interaction of electric charges; Light pressure.		
Control over displacement of liquids and gases	Capillary evaporation; Capillary pressure; Osmosis; Electroosmosis;Thomson effect; Bernulli effect; Wave motion; Centrifugal forces; Weissenberg effect.		
Control over electromagnetic field.	Screening; Change of electrical conductivity of medium; Change of shape of objects subjected to electromagnetic fields.		
Control over friction	Johnson-Rahbeck effect. Radiation. Effect of stability of a liquid ring layer. Oscillations. Kragelsky effect of non-wear friction.	Electrolysis	
Control over liquid surface	Inertia; Gravitation.		
Control over heat flow	Heat pipe		
Control over light flow	Light refraction and reflection; Electrooptical phenomena; Magnetooptical phenomena; Photoelasticity. Kerr Effect; Faraday Effect; Gunn effect.		
Deformation of bodies	Inertia; Centrifugal forces; Deformation; Pointing Effect; Alexandrov's Effect; Memory shape effect in alloys; Memory shape effect in polymers; Thermal expansion; Phase transitions; Magnetic fluids; Infrared emission.		
Destruction of bodies	Alexandrov Effect; Memory shape effect; Cavitation;	Transport reactions; Thermochemical reactions;	

(substances)	Mechanical vibrations; Break-down of dielectrics; Electrical discharge. Acoustic and hydraulic shock waves; Resonance; Ultrasound; Coherent light; Deformation; Pressure.	Hydrogenation; Destruction of oxides; Burning; Explosion; Dissolving; Bias of chemical balance; Oxidization; Complexones.	
Dosage of substances (defining exact amount of substance)	Thermal expansion; Capillary-porous materials; Fluid condenser; Piezoelectric effect; Corona discharge.	Gaseous hydrates.	
Fixation of solid bodies	Friction; Capillary-porous materials; Use of magnets; Use of ferromagnetic powder and magnetic field.	Electrolysis.	Spherical bodies; Eccentrics; Brushes, Loose bodies.
Generation of pressure (forces)	Inertia; Alexandrov Effect; Phase transitions; Thermal expansion; Centrifugal forces; Changing the magnetic fluid density; Memory shape effect; Thermal expansion; Hydraulic shockwave; Electro-hydraulic shockwave; Pressure gradient in magnetic and electrorheological fluids; Explosions; Acoustic shock waves; Osmosis; Magnetic field; Swelling of metals.	Decomposition of gaseous hydrates; Decomposition of hydrides; Decomposition of liquid ozone; De-hardening of metals.	
Generation of cold (extraction of thermal energy from a system)	Heat pipe; Capillary-porous materials; Phase transitions; Joule-Thomson effect; Electrets; Ferromagnetics; Ranque effect; Magnetocaloric effect; Thermoelectricity; Dufour effect; Corona discharge; Stirling principle.	Decomposition of gaseous hydrates; Hydrides; Endothermic reactions; Dissolution.	
Generation of heat (introduction of thermal energy	Friction; Heat pipe; Mechanical vibrations; Infrared light; Electromagnetic induction;	Burning of gaseous hydrates and hydrogen; Hydrides; Exothermic reactions; Strong oxidants;	

to a system)	Surface effect; Dielectrics; Ferromagnetics; Electric discharge; Absorption of radiation by a substance; Electric heating; Thermoelectricity; Dufour effect.	Decomposition of ozone; Self-Propagation High Temperature Synthesis (SHS).	
Generation of electromagnetic energy	Electric discharge; Josefson effect. Induced radiation; Tunnel effect; Luminescence; Gunn effect; Cherenkov-Vavilov effect.		
Decreasing activity of substances		Chemical binding of gases; Transition to hydrate state; In compressed gases; In hydrides; Melting – solidification; In adsorbents; Complexones.	
Mixing gas with liquid	Mechanical vibrations; Electrets; Diffusion.		
Intensification of burning		Ozone.	
Joining heterogeneous substances	Effect of memory shape.	Use of hydrates and hydrides; Welding; Melting/solidification; Molecular self-assembly.	
Placing one substance inside another one		Transport reactions; Chemical binding of gases; Gaseous hydrates; In compressed gases; In hydrides; In adsorbents; Dissolution; Complexones; Liquid membranes; Molecular self-assembly	
Purification of substances and obtaining pure substances	Interaction of electric charges; Corona discharge.	Gaseous hydrates; Ozone; Electrolysis; Transport reactions; Extraction from compressed gases; Extraction from hydrides; Molecular self-assembly; Liquid membranes; Complexones.	
Regeneration of heat	Heat pipe		
Separation of substances	Inertia forces; Capillary-porous materials; Ultrasound, Acoustic waves; Piezoelectric effect; Centrifugal forces; Electrets; Corona discharge; Magnetic field; Adsorption; Diffusion; Osmosis; Electroosmosis; Electrophoresis.	Transport reactions; Extraction of chemically bound gases; Extraction from compressed gases; Extraction from ozonides; Extraction from hydrides; Reduction from oxidants; Bias of chemical balance; adsorbents; Hydrophobe and hydrophile substances; Semitransparent membranes; Complexones; Liquid membranes.	
Spraying	Interaction of electric charges;		Brushes.

substances	Piezoelectric effect; Electrets; Corona discharge.		
Suppression of mechanical energy	Capillary-porous materials; Cavitation; Foam; Mechanical vibrations; Electromagnetic induction; Piezoelectric effect; Electrolysis.		Spheres; Ellipses; Brushes; Loose bodies.
Temperature Stabilization	Phase transitions; Curie Point; Foam; Electromagnetic induction; Ferromagnetic powder.		
Thermal switch	Heat pipe		
Transformation of thermal energy to mechanical	Effect of memory shape; Thermal expansion; Phase transitions; Heat pipe; Transition through Curie point.		
Transformation of electrical energy to mechanical	Piezoelectric effect.		
Merging of two substances to a single substance		Transport reactions; Thermochemical reactions; Chemical binding of gases; Gaseous hydrates; Oxidization – reduction; Exothermic reactions; Thermochemical reactions; Dissolution; Combination of active substances; Ozonation; Complexones; Photochromism.	
Transport of one substance through another one	Phase transitions; Capillary-porous materials; Osmosis; Diffusion.	Transport reactions; Hydrates and hydrides; Hydrogen through metals; Thermochemical reactions; Bias of chemical balance; Adsorption; Semitransparent membranes; Liquid membranes; Complexones.	
Transport of mechanical energy	Deformation. Oscillations. Alexandrov effect. Waves.		
Transport of light energy	Light conductors. Induced radiation.		
Transport of electrical energy	Electromagnetic induction. Conductivity. Superconductivity.		
Heat transport	Heat pipe; Radiation; Thermal conductivity; Convection.		

Withdrawal of static electricity	Corona discharge	Metallization of fabrics; Ozone; Hydrophile coating.	

Detection and measurement problems

Attribute (to be detected/measured)	Physical effects	Chemical effects	Geometrical effects
Acceleration	Mechanical Vibrations; Piezoelectric effect.		
Amount of gas and liquid	Cavitation		
Air-tightness	Interference; Visible light; Ultraviolet light and luminescent substance.		
Brittleness	Piezoelectric effect.		
Consumption	Cavitation, Mechanical vibrations.		
Compressibility of gases	Dielectric permeability.		
Corona discharge	Ozone		
Defects	Molecular sieve; Electrical Resistance, X-rays, Ultrasound.		
Density and viscosity	Archimede's force, Mechanical vibrations; Ultrasound		
Displacements	Electrets; Interference; Light reflection; Light emission. Heat radiation; Deformation; X-rays. Luminescence; Change of electrical and magnetic fields; Doppler effect.		
Distances	Electrets		
Forces	Inertia, Piezoelectric effect.		
Friction	Inertia		
Humidity	Corona discharge; Ultraviolet light.		
Leaks	Foam		
Level	Archimede's force; Mechanical vibrations.		

Mass	Mechanical vibrations; Magnetic fluid; Acoustic waves.		
Mechanical stresses	Visible light		
Pressure	Mechanical vibrations; Interaction of electric charges; Piezoelectric effect; Electrets; Corona discharge.	Gels.	Spherical bodies.
Pulsed actions	Piezoelectric effect.		
Radiation	Acoustooptic effect; Thermal expansion; Photoelectriceffect; Luminescence; Photoplastic effect.		
Roughness	Laminarity; Turbulence; Bernulli effects.		
Sharpness	Corona discharge		
Sizes	Corona discharge; Electrical resistance; Visible light; Mouare effect.		
Temperature	Thermal expansion; Phase transitions; Visible light; Transition through Curie point.		
Tension	Magnetic field		
Ultrasound		Gels	
Ultraviolet light		Photochromism	
Vacuum	Corona discharge		
Vibrations			Spherical bodies.
Visible light		Photochromism	
Volume	Electrical resistance; Light reflection; Change of refraction coefficient; Magnetooptical phenomena; Electrooptical phenomena; Polarized light; X-ray radiation; Nuclear magnetic resonance; Paramagnetic resonance; Transition through the Curie point; Hopkinson effect; Barkhausen effects. Measurement of natural frequency. Ultrasound. Hall effect.		
Wearing	Mechanical vibrations.		
X-rays		Ozone; Radiochromism	

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