A PROJECT REPORT

On

Compatibility of TRIZ and Axiomatic Design using the Substance Field (Su-field) Analysis of TRIZ

Submitted by

Ram Kishor Singh

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Axiomatic Design has been developed as a general design framework during the past two decades and TRIZ has been developed as a design tool for over 50 years. Axiomatic design is quite excellent in that design should be decoupled. When a design matrix is established, the characteristics of the design are identified according to the coupling properties. If the design is coupled, a decoupling process should be found. However, axiomatic design does not specifically indicate how to decouple a coupled design. In this project, the decoupling process is classified into six patterns. It is demonstrated that each pattern could be solved by an appropriate TRIZ module. The method is applied to the conceptual design processes of a beam adjuster of a laser marker, and the results are analyzed.

CHAPTER 1 INTRODUCTION

The Axiomatic Design is useful for identifying both structure of the system and problems of the system (specially, having multi-functions). However, this methodology does not provide specific tools for generating ideas. Thus, TRIZ tools such as Inventive principles and Standard solutions with some problem modeling process can complement the demerit of generating ideas for decoupling the design matrix in Axiomatic Design. If the system is coupled or decoupled and has same FRs and DPs, designer would rather check contradictions than just try to generate ideas by intuition or experience of designers. Or if the system is coupled because of the greater number of FRs than DPs, designer ought to apply the Su-Field modeling or search the effect database. Sometimes, the Law of technology evolution would be useful in predicting the next systems objectively. On the other hand, if engineers should analyze complex system, or are confronted with administrative contradiction, using Axiomatic Design would be one of the best choices. Therefore, for big or complex systems that have multi-functions, the relationship modeling between FRs and DPs using the Axiomatic Design with the design matrix, is strongly recommended as shown in fig. 1 with TRIZ. To decouple the design matrix or resolve the contradictions for improving the performance of system, the TRIZ tools are strongly recommended, too. For the new and innovative concepts using TRIZ and Axiomatic Design, the other many useful engineering methods in detail design and analysis stages are applied to develop the concrete products sequentially.

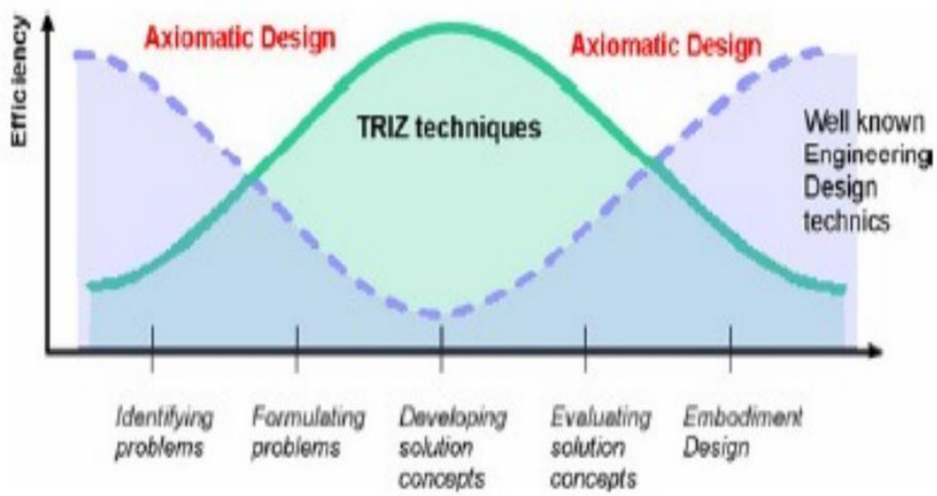


Fig. 1 AD, TRIZ and well-known engineering methods according to design stages (https://triz-journal.com/)

Currently, conceptual design is receiving much attention in industries. The capability of creating a new design becomes more important than ever before because the engineering environment is rapidly changing. A good design has a large impact on the entire engineering process. One useful design methodology is axiomatic design. The main distinction of TRIZ from creative methods that are based on the trial and error approach is that the TRIZ offers directed and algorithmic searching of solutions instead of chaotic generation of ideas. Axiomatic design has the advantage in deriving the initial design. When a design matrix is established, the characteristics of the design are identified according to the coupling properties. If the design is coupled, a decoupling process should be found. However, axiomatic design does not specifically indicate how to decouple a coupled design. In researches, the searching process is carried out for an uncoupled design from an initial coupled design. TRIZ modules are utilized for the searching process.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction of Axiomatic Design

The theory of axiomatic design is proposed by Suh, which is dedicated to constructing a design framework with a scientific basis and improving design activities with a logical and analytic thinking process. Basically, there are three essential parts of the axiomatic design that are Axiomatic design and TRIZ widely used in academic research and industrial applications, namely the zigzagging design process, design axioms and the design matrix. The Axiomatic design theory divides the design world into four domains, i.e., the customer domain (CAs), the functional domain (FRs), the physical domain (DPs) and the process domain (PVs) see in fig. 2. The design is gradually realized by mapping from one domain to another. As depicted in fig. 3, the mapping system works in a top down way. Each design parameter (DP) in the physical domain corresponds to each functional requirement in the functional domain at the same level. Then design parameters in this level derive functional requirements in the next level until it reaches the leaf level so that functions and solutions are decomposed and obtained during this process.

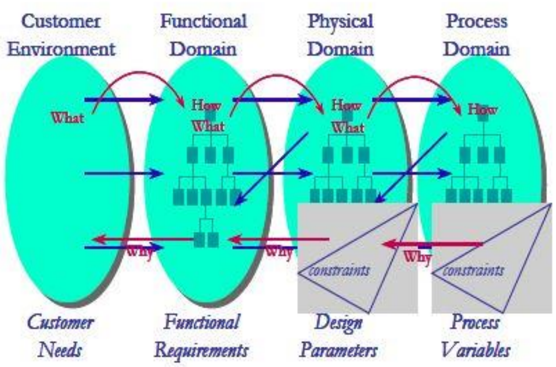


Fig. 2 Concept of domain, mapping and spaces (Shin and Park, 2006)

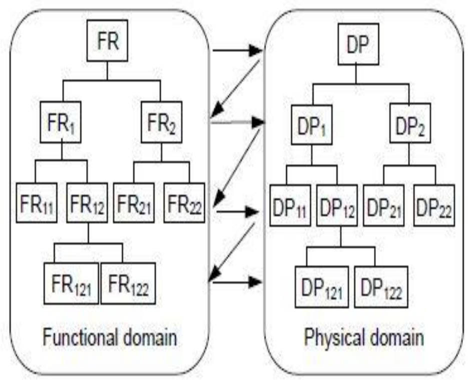


Fig. 3 Zigzagging mapping process between functional domain and physical domain (Suh, 2001)

There are two axioms recognised in design, namely Axiom 1: Independent axiom and Axiom 2: Information axiom, companied by related theorems and corollaries. Design axioms are the elementary part of axiomatic design and deemed as the basis of good design, which are used to guide the design process and evaluate alternative solutions. The independent axiom indicates that the function requirement should always be maintained independently so that any change of the corresponding DP of one FR will not affect functionalities of other DPs. As the basis of the axiomatic design theory, the independent axiom takes effect throughout the design process. The information axiom indicates that the best design solution should contain minimum information content. More information means being more complicated and more possible that the design parameter can't satisfy the functional requirement. Design matrix is a technique used to analyse the coupling relationships between a group of FRs and their corresponding DPs. Normally the matrix is populated in a binary way so that all the coupling relationships are recognized qualitatively. According to the independent axiom, only uncoupled and decoupled designs are acceptable. However in the design of some complex engineering products and systems, it is impossible to keep all FRs independent of DPs.

A design matrix is defined to pursue the relationship between FRs and DPs as following: FR=ADP, where FR is a vector for functional requirements, DP is a vector for design parameters and A is a design matrix. If we have three FRs and DPs, Eq. (1) can be shown as following:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \qquad (1)$$

Where X means a relationship exists and 0 means there is no relationship. When the Independence Axiom is satisfied, the design matrix has the form of a diagonal matrix or a triangular matrix. The diagonal matrix in Eq. (1) represents a perfectly uncoupled design and is the most desirable form. In this case, just one DP affects each FR because a modification on each DP only has influence on the corresponding FR. The triangular matrix represents a decoupled design. This form of design is also a proper design, but the DPs need to be rearranged in a specific order so as to satisfy the FRs. On the other hand, an uncoupled design does not require a specific order. The third form of a design is a coupled design. This pattern of design is undesirable because when a DP is modified, multiple FRs is changed. There is no effective solution for undesirable change on the FRs. The Information Axiom is related to the complexity of a design and implies that the simpler design is the better one. In the Information Axiom, the DPs are selected according to information content. The information content is defined by the probability of success to satisfy corresponding FRs. For example, the information content for the i-th functional requirement is defined as

$$I_i = log_2 \frac{1}{p} \qquad (2)$$

where p is the probability of success for the i-th functional requirement. The total information content is the summation of the information quantities. When multiple solutions satisfy the Independence Axiom, the Information Axiom can be well exploited. A solution with minimum information is selected.

2.2 Introduction of TRIZ

TRIZ is a Russian acronym for the theory of inventive problem solving. TRIZ was created and developed in the former USSR by the Russian engineer and inventor G.S. Altshuller. The basis of TRIZ is the hypothesis that 'most of the innovative solutions for technological problems can be found through analogical reflection of certain patterns or principles derived from previous cases of inventions.' To prove this hypothesis, patent cases have been investigated and a huge number of patent cases have been analyzed until now. TRIZ is composed of several analysis techniques. TRIZ is originated from extensive studies of technical and patent information. Studies of patent collections by Altshuller, the founder of TRIZ, indicated that only one per cent of solutions were truly pioneering inventions, the rest represented the use of previously known ideas and concepts but in a novel way. Thus, the conclusion was that an idea of a design solution to a new problem might be already known. TRIZ methodology includes the analytical tools for problem analysis and the knowledge base tools for system changing. fig. 4 illustrates the basic structure of TRIZ.

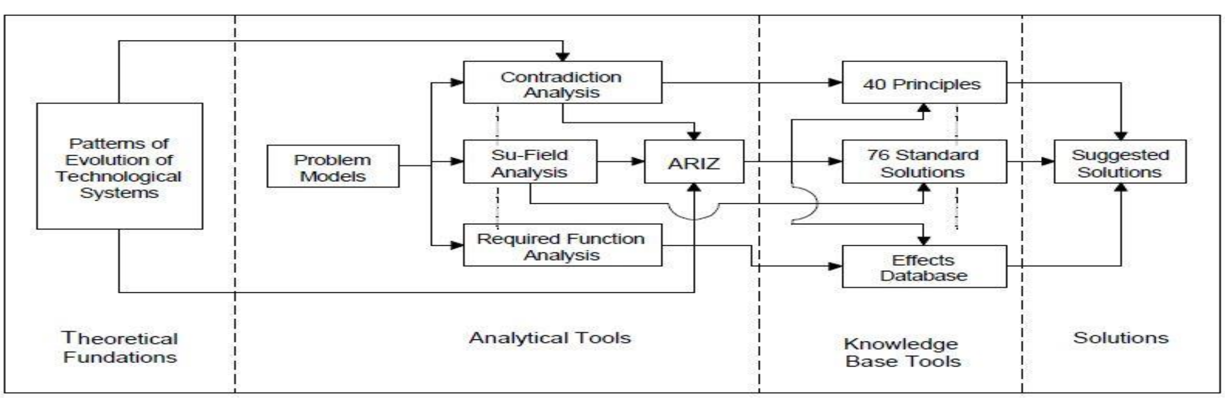


Fig. 4 Structure of TRIZ Methodology (Yang and Zhang, 2000)

Theoretical Foundations

The Patterns of Evolution of Technological System are the theoretical foundations of TRIZ methodology. These patterns indicate that there exist basic laws for engineering system development, and understanding them enhances one's ability to the design problem solving.

Triz Analytical Tools

TRIZ analytical tools, which include ARIZ, substance field (Su-field) analysis, contradiction analysis and required function analysis, are used for problem modeling, analysis and transformation. These analytical tools do not use every piece of information about the product where the problem resides. The way they generalize a specific situation is to represent a problem as either a contradiction, or a substance-field model, or just as a required function realization.

Substance-field analysis is a TRIZ analytical tool for building functional model for problems related to existing or new technological systems. Each system is created to perform a certain function. Typically, a function represents some action toward a certain object, and this action is performed by another object. This situation can be modeled by a triangle whose corners represent objects and an action or interaction (called a field). A substance may be an article or tool and the field may be some form of energy. In general, any properly functioning system can be modeled with a complete triangle as shown in fig. 5. Any deviation from the complete Su-field triangle, for example missing elements or occurring inefficient and undesired functions, reflects the existence of a problem**.**

To formulate such a model, we need to clarify insufficiency in beneficial interactions and the occurrence of harmful ones. A standard solution expresses the direction of problem solving using the same substance-field model for problems presented through substance-field analysis (in case there are a pair of substances and a field between them and their interaction is harmful or insufficient or the effector is absent). There are a total of 76 patterns of standard solutions, and five steps from step 1 for composition and decomposition of substance-field model to step 5 for the application of the standard solution. Breaking them down into smaller parts, the solutions are divided into 18 groups from 1-1 the composition of substance-field to 5-5 the acquisition of substance particles and 76 standard solutions from standard solution 1-1-1 to 5-5-3. To draw an actual solution, we should select the optimal standard solution, and from the solution, derive effective ideas by solving real problems.

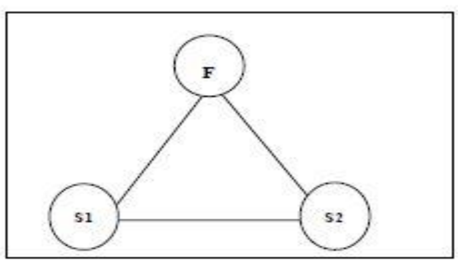


Fig. 5 Substance Field Model (Yang and Zhang, 2000)

Contradiction Analysis is a powerful tool of looking problem with the new perspective. In TRIZ standpoint, a challenging problem can be expressed as either a technical contradiction or a physical contradiction. A technical contradiction might be solving using contradiction table that identifies 39 characteristics most frequently involved in design process. A physical contradiction might be solved by separation principles. A technical contradiction may be transformed to a physical contradiction in some circumstances. Contradiction analysis is the fundamental step to apply 40 inventive principles, one of the knowledge base tools

Required function analysis refers to select the objective of the system and match it with the function list in the TRIZ Effect Knowledge Base. Required function analysis is the first step to use this knowledge base to search for the recommendations for accomplishing the objective.

ARIZ refers to Algorithm for Inventive Problem Solving; (ARIZ) is the latest technique of classical TRIZ developed by Altshuller. It is made by rearranging all classical TRIZ techniques and a set of successive logical procedures directed at reinterpretation of a given problem. In TRIZ standpoint, a technical problem becomes an invention one when a contradiction is overcome. However, "real world" problems do not always appear as contradictions. Furthermore, Su-field analysis and required function analysis may not be applied directly in some situations.

Knowledge Base Tools

TRIZ knowledge base tools include 40 Inventive Principles, 76 Standard Solutions and Effects of Knowledge Base. These tools are developed based on the accumulated human innovation experience and the vast patent collection.

Forty Inventive Principles are used to guide the TRIZ practitioner in developing useful "concepts of solution" for inventive situations. Each of solutions is a recommendation to make a specific change to a system for eliminating technical contradictions.

Seventy-six Standard Solutions were developed for solving standard problems based on the Patterns of Evolution of Technological Systems. These Standard Solutions are grouped into five classes according to their objectives. To use these tools, one identifies (based on the model obtained in Su-field analysis) the class of a particular problem and then chooses a set of Standard Solutions accordingly.

Effects of Knowledge Base is probably the most easy to use tool in TRIZ. Very early in his research, Altshuller recognized that given a difficult problem, the ideality and ease of implementation of a particular solution could be substantially increased by utilizing various physical, chemical and geometric effects.

TRIZ is a very useful method for creative problem solving. However, planning and designing products involves multiple requirements, multiple functions, multiple contradictions, while TRIZ problem solving methods are effective for single problems. Therefore, the use of TRIZ in product design must involve transformation of complex into simple problems. Therefore combination of AD and TRIZ will combine the advantages of both approaches to successfully manage complexity while creating innovate solutions to complex problems. This is because the AD approach has a wider scope as a process model, covering the whole design process from task clarification to detail design as well as systems design, while TRIZ focuses on solving the inventive part of a design problem. When a designer has selected an FR and a contradiction and wants to identify alternative DPs, TRIZ can be helpful in generating alternatives. Nordlund (1996) suggests this hypothesis about the integration of AD and TRIZ: Working within the proposed framework, the theory of inventive problem solving provides a synthesis tool complementary to the analysis rule provided by the independence axiom within the proposed framework. Nordlund (1996) proves his hypothesis by giving an example of how AD and TRIZ can be integrated to find the optimum solution. Both Tate (1999) and Suh (2001) also state that AD and TRIZ are complimentary to each other. Mann (2002) suggests that AD has much to offer TRIZ in terms of better understanding of both the hierarchical nature of design and the need to pay due attention to the inter-connections which exist between successive hierarchical layers.

CHAPTER 3 METHODOLOGY

3.1 The Substance-Field Model of TRIZ

The Substance-Field (shortly Su-Field) analysis model is picked up in this project in order to clarify the coupling relationships during the zigzagging design process of Axiomatic design. The Su-Field analysis model is based on the minimal technological system which is also known as the triad 'object-tool-energy'. The triad system is composed of a tool, an object and the energy and describes that the tool performs action on the object by the force coming from the energy. Through the analysis of the triad system, interactions between elements within this system can be clarified. Along with the triad system, four kinds of actions are also identified which include unspecified action, specified action, inadequate action and harmful action. For example, the Su-Field analysis model of driving nail into the wall is depicted in fig. 6. In this system, mechanical force is performed on the hammer by the user, and then the hammer performs mechanical force on the nail

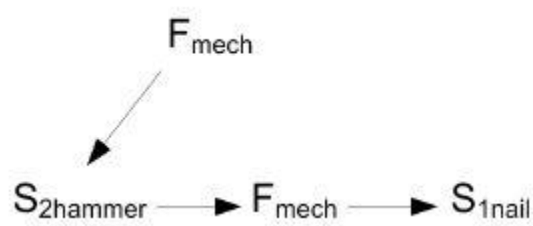


Fig. 6 Su-Field model example (G. Fei et al., 2009)

In this project, direct or indirect interactions between DPs in the Axiomatic design methodology may be identified using the Su-Field analysis method.

3.2 Su-Field Analysis

The Substance-Field (Su-field) Model

Su-field Analysis provides a fast, simple model to use for considering different ideas drawn from the knowledge base. Su-field Analysis works the best for well-formulated problems, like those developed with the formulation. Individuals starting to use TRIZ find it useful to use the models to present the Standard Solutions. A different format has been chosen to present the essence of the Standard Solutions. The analysis can be applied to system as well as component levels of abstraction. This is often at the interface between the two substances. For complex systems there is a Su-field Model for all the zones of interest. Two substances and a field are necessary and sufficient to define a working technical system. The triangle is the smallest building block for trigonometry, as well as for technology.

There are four basic models:

1. Effective complete system
2. Incomplete system (requires completion or a new system)
3. Ineffective complete system (requires improvement to create the desired effect)
4. Harmful complete system (requires elimination of the negative effect)

If there is a problem with an existing system and any of the three elements are missing, Su-field Analysis indicates where the model requires completion and offers directions for innovative thinking. If there is an innovative problem and the system has the three required elements, Su-field Analysis can suggest ways to modify the system for better performance. Following the analogous thinking of TRIZ, a triangular technical system should have its own set of rules within the geometry of problem solving. These few basic rules and the 76 Standard Solutions permit the quick modeling of simple structures for Su-field Analysis. The substance-field (S-F) analysis is a TRIZ analytical tool for modeling problems related to existing technological system. Every system is created to perform some functions. The desired function is the output from an object or substance (S1) caused by another object (S2) with the help of some means (types of energy, F). “Substance” is used in TRIZ literature to refer to some objects of any level of complexity from a single item to a complex system. The action or means of accomplishing the action is called a field. S-F analysis looks at the interaction between substances and fields to describe the situation in a common language.

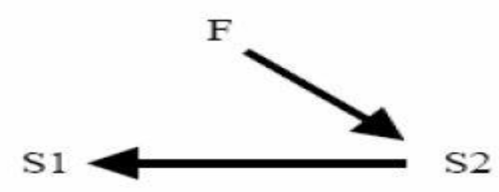


Fig. 7 S-field (https://triz-journal.com/su-field-analysis/)

In the fig. 7, S1 and S2 are substances and F is a field. Substance S1 is an article, material, or object to be controlled or processed. S2 is a tool or an object to control or process the article S1. F is a kind of energy, which is used for control or interaction. So the S-field means that an "energy" (F) acting on a "tool" (S2) to modify a "material" (S1). There are 76 standard substance-field solutions in the TRIZ patent database. Substance-field analysis and the standard solutions are used to solve problems with existing systems to identify which of the three elements are missing and how to complete the system [Hu et al., 2000].

3.3 Making a Model

The field, which is itself often some form of energy, provides some energy, force or reaction to guarantee an effect. The effect could be on S1 or the output of the field information. The term field is used in the broadest sense, including the fields of physics (that is, electromagnetism, gravity and strong or weak nuclear interactions). Other fields could be thermal, chemical, mechanical, acoustic, light, etc. The two substances can be whole systems, subsystems or single objects. They can also be classified as tools or articles. A complete model is a triad of two substances and a field. The innovative problem is modeled to show the relationships between the two substances and the field. Complex systems can be modeled by multiple, connected Su-field Models.

There are four steps to follow in making the Su-field Model:

1. Identify the elements. The field is either acting upon both substances or is within substance 2 as a system.
2. Construct the model. After completing these two steps, stop to evaluate the completeness and effectiveness of the system. If some element is missing, try to identify what it is.
3. Consider solutions from the 76 Standard Solutions.
4. Develop a concept to support the solution. In following Steps 3 and 4, activity shifts to other knowledge-based tools

3.4 Analysis Nomenclature

The identification of substances (S1 and S2) depends upon the application. Either substance could be a material, tool, part, person or environment. S1 is the recipient of the systems action. S2 is the means by which some source of energy is applied to S1.
The source of energy, or field (F), which acts upon the substances, is often:
(Me) - Mechanical, (Th) -Thermal, (Ch) - Chemical, (E) - Electrical, (M) - Magnetic, (G) - Gravitational
The letter(s) associated with the applied field will be used in the Su-field Model of the different systems. Relationships between the elements in the Su-field Model are depicted by five different connecting lines shown in below fig. 8.

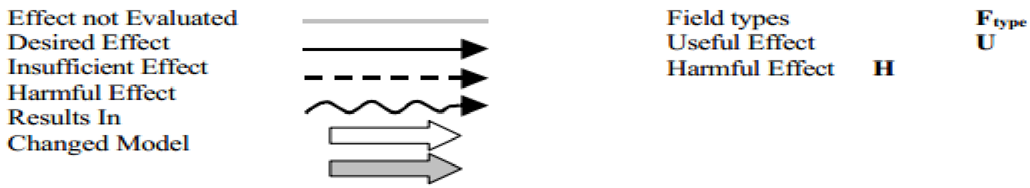


Fig. 8 Letter(s) used in the Su-field Model (https://triz-journal.com/su-field-analysis/)

3.5 The Seventy-Six Standard Solutions:

The “76 Standard Solutions” of TRIZ were compiled by G.S. Altshuller and his associates between 1975 and1985. They are grouped into 5 classes as follows:

1. Improving the system with no or little change	13 standard solutions
2. Improving the system by changing the system	23 standard solutions
3. System transitions	6 standard solutions
4. Detection and measurement	17 standard solutions
5. Strategies for simplification and improvement	17 standard solutions

3.6 The use of TRIZ According to the Axiomatic Design Pattern

When a design is analyzed axiomatically at the early stage of conceptual design and it is found not to be a coupled design, we need to adopt a better pattern of design. For this, design parameters are added or changed frequently. In adding or changing design parameters, if the designer relies on only one’s experiences, it may not be a satisfactory design. In such a situation, we can draw a design using either axiomatic design or TRIZ or combining the two complementarily to each other. Fig. 9 shows a design process that uses the two axioms and TRIZ together. A diagram showing how the problem solver would apply this TRIZ tool is seen in fig. 10.

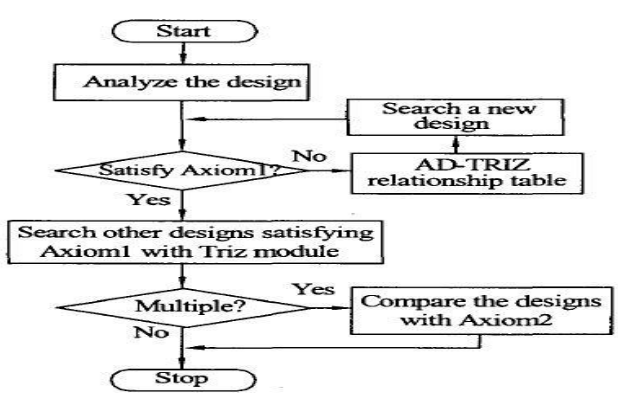
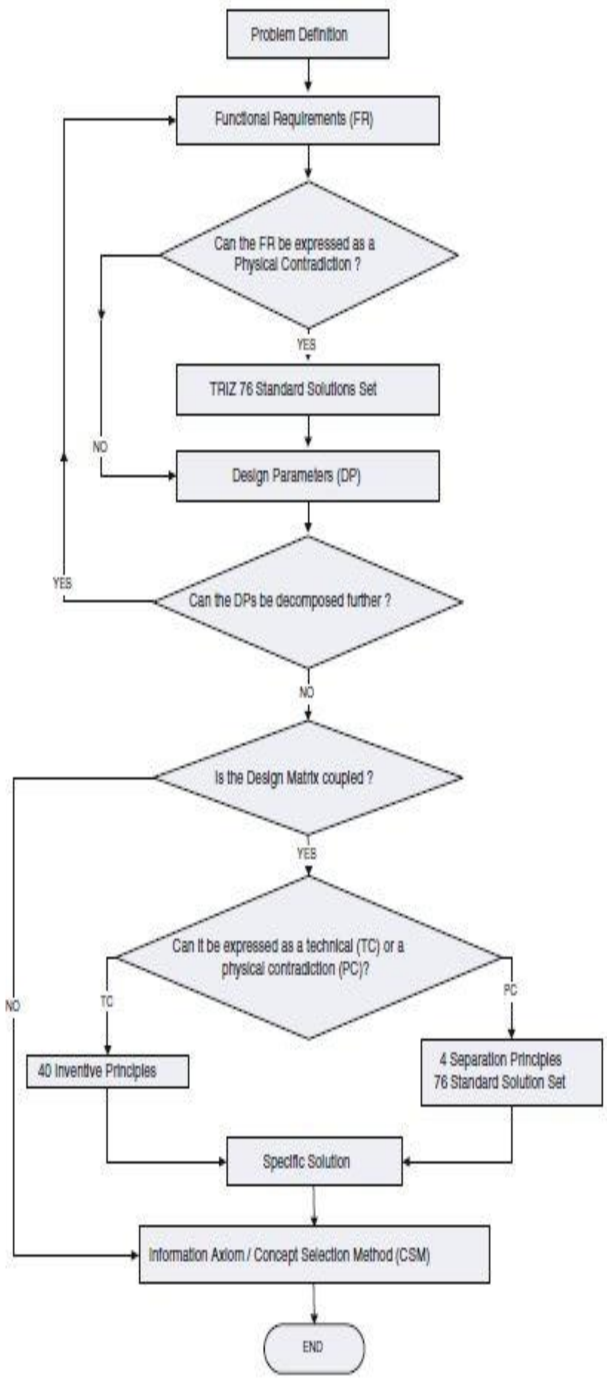
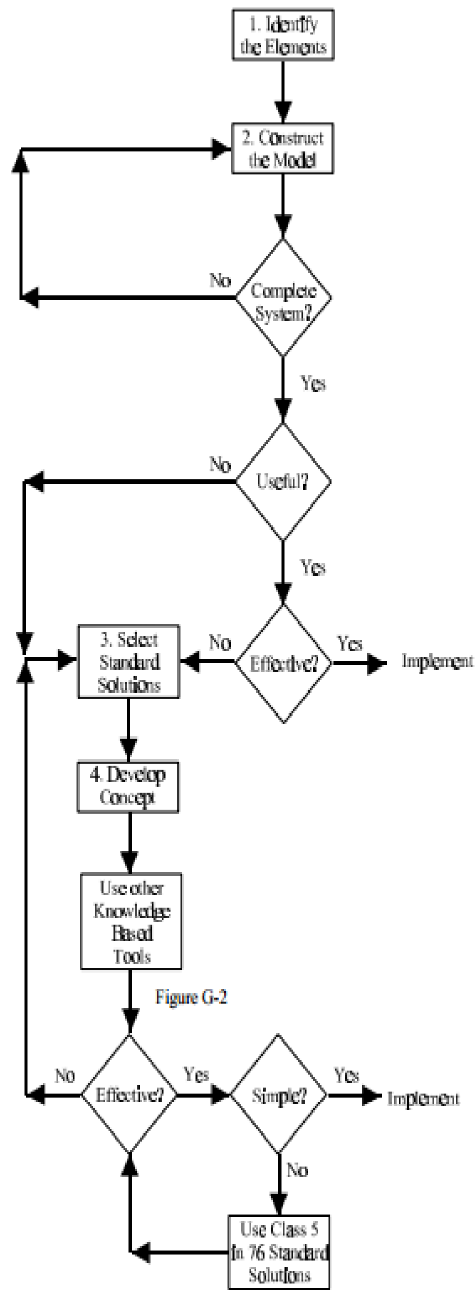


Fig. 9 Flow chart of the proposed design process (Shin et al., 2006)





(a) (Shirwaiker and Okudan, 2007)

(b) (https://triz-journal.com/su-field-analysis/)

Fig. 10 Flowchart for the synergistic problem solving approach using TRIZ and AD

When a design does not satisfy the Independence Axiom, it is a coupled design and a new design is required. TRIZ is employed for a decoupling process of a coupled design. The coupling phenomena are classified into six patterns. Each pattern could be decoupled by an appropriate TRIZ module. The six patterns are shown in Table 1.

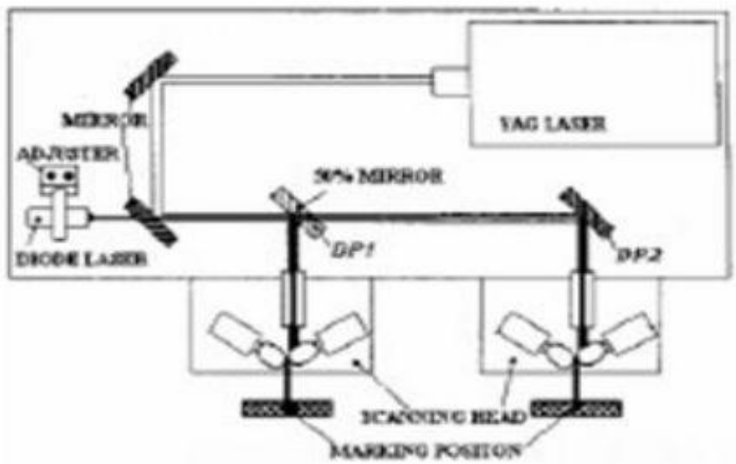
Table 1 AD-TRIZ Relationship Table

Axiomatic Design pattern	**Action needed**	**Related TRIZ modules**
Coupled Design with Insufficient Design Parameters **(AD1 Pattern)** Eq. (3) $\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}$	**Necessary to add a DP** • Separate a DP to add a DP - Separation Rule • Use the effect database to add a DP -Effect • Import the substance to add a DP - SFM Class 5	• Separation Rules • Effect • SFM class 5
When Functional Requirements are added **(AD2 Pattern)** Eq. (4) $\begin{Bmatrix} FR_1 \\ FR_2 \\ (FR_3) \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \\ (0) & (0) \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}$	**Need to generate a new idea for the new FR** • Use the effect database to make a new idea-Effect • Combine the new substance field model - SFM Class 1 • Combine the new measuring system - SFM Class 4	• Effect • SFM class 1 • SFM class 4
Decoupled Design with Large off Diagonal Terms **(AD3 Pattern)** Eq. (5) $\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & X & x \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$	**Enhance or change the insufficient DP** • Enhance the insufficient system efficiency - SFM Class 3 • Evolution of the substance field model - SFM Class 2	• SFM class 3 • SFM class 2 • Contradiction Table
Coupled Design with Technological Contradiction **(AD4 Pattern)** Eq. (6) $\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & X \\ 0 & X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$	**Need to change a DP for uncoupling** • When something gets better, something else gets worse - Contradiction Table	• Contradiction Table
Physical Contradiction Coupled Design with excessive design parameter **(AD5 Pattern)** Eq. (7) $\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \end{Bmatrix}$	**Need to unify excessive DPs** • Enhance the efficiency through decreasing the components - SFM Class 3 • Decrease unnecessary resource - System evolution law	• SFM class 3 • System evolution laws
Other Coupled mixed Designs **(AD6 Pattern)** Eq. (8) $\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & 0 & X \\ X & X & 0 \\ 0 & 0 & x \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$	**When causes are mixed** • Divide the Substance Field Model - SFM Class 1 • Need to apply various methods - ARIZ	• SFM class 1 • ARIZ

CHAPTER 4 CASE STUDY

4.1 Problem Description

This case study illustrates that when system design is coupled due to the greater number of FRs than DPs, designer can apply Su-Field model to make them decouple design. In Axiomatic Design, if number of DPs is equal to the number of FRs, system design is regarded as ideal design. Thus, when a design is coupled due to the greater number of FRs than DPs, designer should add new DPs so as to make the number of FRs and DPs equal to each other. Gwang Seob Shin et al. published an article about beam splitter for laser marker that improved by applying Axiomatic Design and TRIZ methodologies. Former laser marker layout and its Axiomatic Design matrix are shown in fig. 11.



$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \\ X & 0 \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \quad (9)$$

Fig. 11 Dual type laser marker (Won et al., 2006)

DP_1 (50% mirror) splits the laser beam equally and reflects 50% of the beam. DP_2 reflects the beam that was divided by DP_1. As shown in fig. 11, its design is coupled. To split the beam equally, angle of the DP_1 should be adjusted. However, if user changes angle of the DP_1 to divide the beam, direction of the right beam is also changed.

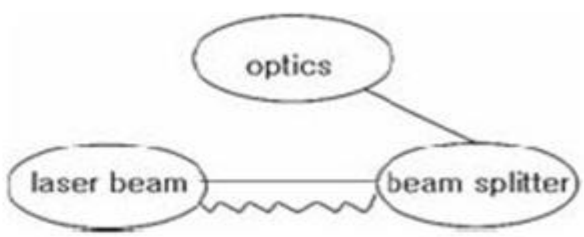
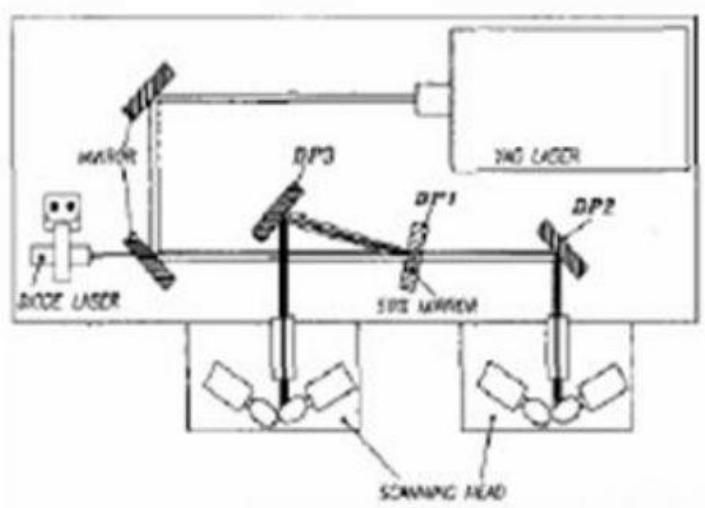


Fig. 12 Su-field model of laser marker (Won et al., 2006)

To settle this problem, Gwang Seob Shin et al. applied Su-Field analysis as fig. 12. Then, they got an idea that was guided by 76 standard solutions. To eliminate harmful effect, the mirror (DP_3) was brought in the system as fig. 13.



$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \qquad (10)$$

Fig. 13 New laser marker (Won et al., 2006)

4.2 Design of a Device for Adjusting the Laser Marker Beam

The usage of beam scanning type laser marker is rapidly increasing in the field of semiconductor equipment. A device called “beam adjuster” is employed to adjust the visible diode laser, which points the marking position for various setting. The device is very sensitive to manufacturing tolerance and assembly condition. Axiomatic approach has been applied to the design of the device. An existing design is analyzed based on the Independence Axiom. The existing design is found to violate the axiom. Three new designs are proposed to satisfy the Independence Axiom. The Information Axiom is utilized to evaluate the designs. A design is selected to have the minimum information content.

4.3The Laser Marker and the Beam Adjuster

A marking process resides in the back end assembly line for a semiconductor. The character logo and the device number are usually engraved. Among various marking equipment, the beam scanning YAG laser marking is widely used. It is used with a laser beam and the direction of the beam is controlled by a reflecting mirror. The YAG laser is a solid-state laser using crystal of yttrium, aluminum and garnet. The laser marker consists of a beam generating part and a scanning head as illustrated in fig. 15. In the beam generator, the laser beam is produced and reflected by the mirrors as illustrated in fig. 16. One laser beam is divided into two beams by an optical device. The optical device is a mirror which reflects 50 % of a beam and passes the rest. It is illustrated in fig. 16. It is efficient in that two semiconductors are marked with one generator. This type is called a dual laser marker and is widely used in the field of semiconductor surface marking.

In the scanning head, there are other mirrors controlled by high-speed motors. The fixed beam from the beam generator can be re-directed by these mirrors to mark certain logos. If the beam direction is determined by the beam generator, the mirrors and motors in the scanning head make the detailed marks and the motors are controlled by a computer program. If we use the YAG laser in this process, the surfaces of semiconductors are damaged. Therefore, a simulation with low-cost is carried out by a diode laser. The diode laser sheds a weak light beam and the simulation can be easily carried out. Test plates are placed at the marking positions in fig. 16. The YAG laser is turned on. The mirrors in the beam generator are positioned to make the beam go through the scanning head and mark points on the plates. The points are starting points of the marking process and illustrated as hollow points as illustrated in fig. 19. The YAG laser is turned off. The diode laser is turned on. The solid points in fig. 19 (a) would be the final destinations of the diode laser. The adjuster of the diode laser is utilized to make two identical points as illustrated in fig. 19 (b).

The function of Laser Marker is mark the logo, text or other information on the surface of various IC packages sees in fig. 14.

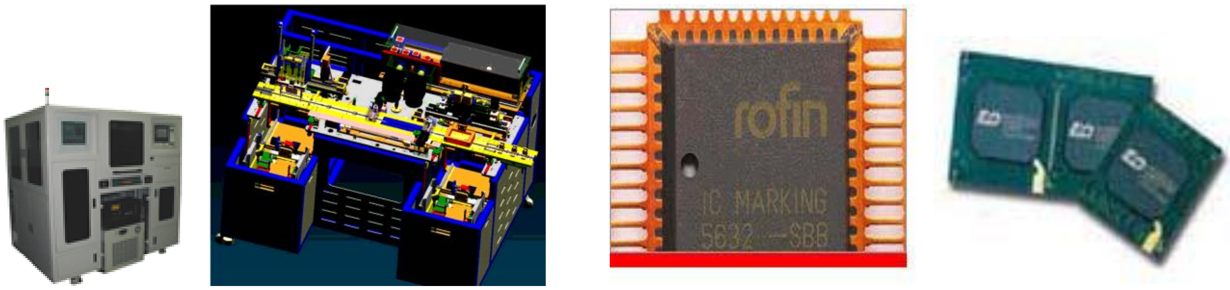


Fig. 14 various IC packages (Shin and Park, 2006)

Function of a Beam Adjusting Device

• Adjusts the diode laser with the path of a YAG marking laser

• The vertical and horizontal positions and the angle of the beam adjusting device should be adjusted to the right datum point of marking.

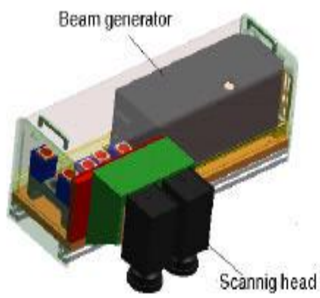


Fig. 15 Beam scanning type laser marker (Shin et al., 2002)

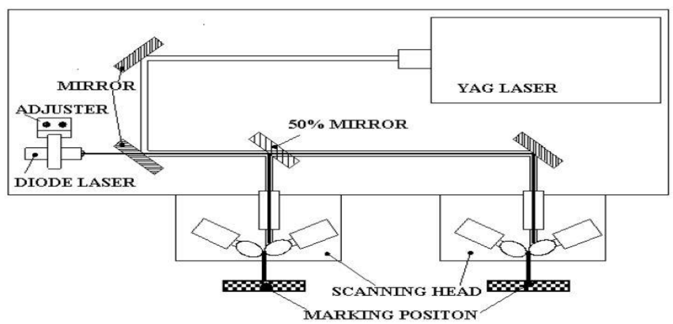


Fig. 16 The component layout of laser marker (Shin et al., 2002)

In many cases, it is not easy to use an adjusting device due to fine errors made in the manufacturing process. Sometimes, the problem is not solved even with the use of high-precision components or investment of a long assembly time. Therefore, it requires a design that can adjust the position and angle of the adjusting device precisely.

4.4 Axiomatic Evaluation of an Existing Design

The relationship between the FRs and DPs can be expressed by a design matrix of an existing design for the diode beam adjuster. The FRs of the existing device is defined as follows:

FR_1 : Align the vertical position of the diode laser beam

FR_2 : Align the vertical angle of the diode laser beam

FR_3 : Align the horizontal position of the diode laser beam

FR_4 : Align the horizontal angle of the diode laser beam

FR_5 : Fix the beam alignment

Fig. 17 illustrates each functional requirement and fig. 18 illustrates the Coupled design of existing product of a beam adjuster and DPs

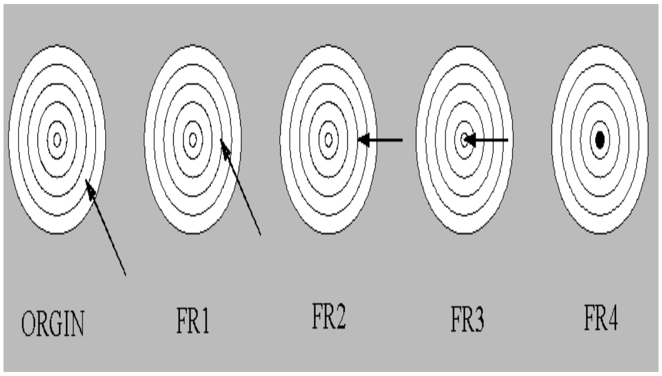


Fig. 17 Illustration for the functional requirement (Shin et al., 2002)

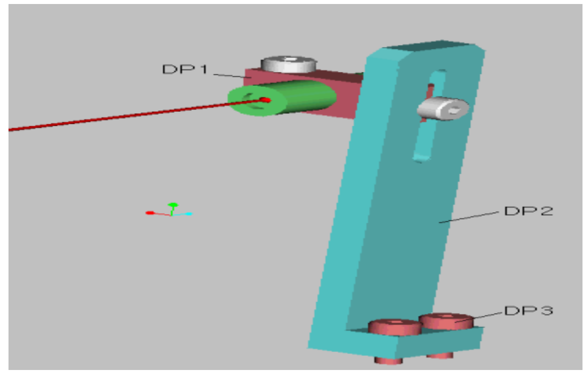


Fig. 18 A beam adjuster and DPs (Coupled design) (Shin and Park, 2006)

DPs corresponding to FRs are defined as follows:

Cs
C_1 : Install space
C_2 : Manufacturing cost

DP_1 : Vertically moving component
DP_2 : Supporting block
DP_3 : Fixing screw

The design matrix is

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \\ FR_5 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & 0 & 0 \\ 0 & X & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \tag{11}$$

The design in Equation (11) is a coupled design of AD1 pattern because the number of DPs is less than the number of FRs. When we move the solid points in fig. 19 (a) (DP_1), the vertical angle also varies because FR_1 and FR_2 are coupled by DP_1. In a similar manner, when we move the horizontal position (DP_2) the aligned angle can vary. If a design is coupled in the way of Equation (5), it can be decoupled by adding new DPs to make the numbers of FRs and DPs equal to each other.

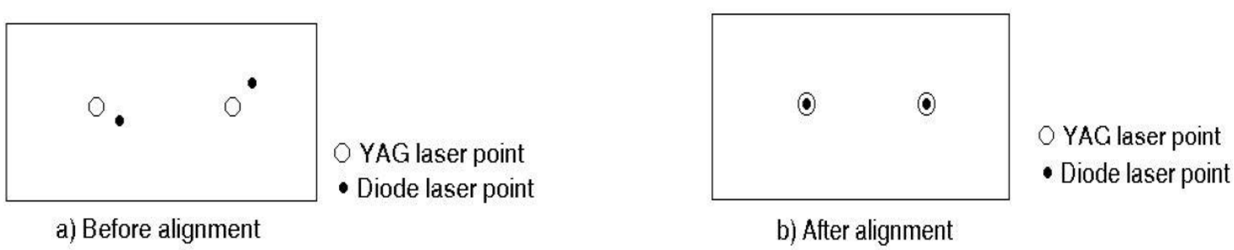


Fig. 19 The alignment of diode laser (Shin et al., 2002)

4.5 Development of New Beam Adjuster Using Axiomatic Design

4.5.1 New Design Using the Independence Axiom

The existing design does not satisfy the Independence Axiom, hence a new design is searched with new design parameters as illustrated in fig. 9. By separating the coupled terms, Equation (11) can be decomposed as follows:

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X \\ X \end{bmatrix} \{DP_1\} \tag{12}$$

$$\begin{Bmatrix} FR_3 \\ FR_4 \end{Bmatrix} = \begin{bmatrix} X \\ X \end{bmatrix} \{DP_3\} \tag{13}$$

$$FR_5 = [X] DP_5 \tag{14}$$

Where DP_3 in Equation (13) is equivalent to DP_2 in equation (11) and DP_5 in equation (14) is equivalent to DP_3 in equation (11). From equation (12), it is required that one DP be added. Two designs are created as illustrated in figs. 20-21. In fig. 2 DP_1 and DP_2 are the holes. Screws are inserted in the holes and the positions of the holes can be changed by the movement of the screws and fixed by the fastening function of the screws. A designer can determine FR_1 by DP_1 and FR_2 can be determined by DP_2. The design matrix is defined as following Eq. (15).

In the current design, the vertical shift block should be moved to adjust the vertical position. Then the preset vertical angle changes accordingly. Likewise, when adjusting the horizontal position, the movement affects the horizontal angle and this makes it difficult to adjust them simultaneously. It is attributed to the AD1 pattern and a part of Eq. (11) can be

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X \\ X \end{bmatrix} \{DP_1\} \tag{12}$$

A TRIZ module for Eq. (12) is a substance-field model 5-1-2. In this module, when it is difficult to change the system to meet requirements, the device is changed to interacting subdivided elements for application. When this design is applied and a new concept that distinguishes between the design parameter for deciding the vertical position and that for deciding the horizontal position, we can obtain a basic first design as illustrated in fig. 20.

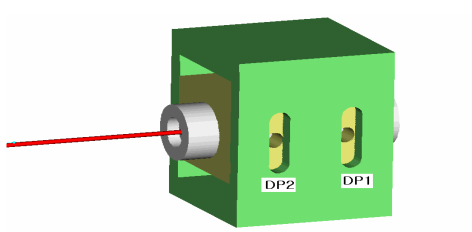


Fig. 20 New design No. 1 (Shin and Park, 2006)

The proposed first design in fig. 20 has the design parameter of the rear joint for adjusting the vertical position from which the beam starts and that of the front joint for adjusting the vertical angle. A screw can be fastened to each hole and each position can be fixed after adjustment. The design matrix for this design is as in Eq. (15).

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} = \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \tag{15}$$

The design in equation (15) is a decoupled design. Therefore, it satisfies the Independence Axiom. The second design is illustrated in fig. 21. The functions of the DPs are similar to those of fig. 20. The movement is carried out by the rotation of the screws instead of the translation in figure 20. Therefore, the design matrix is defined in figure 21 and it also satisfies the Independence Axiom. In the same manner, equation (13) can be modified to satisfy the Independence Axiom. Fig. 24 illustrates the final design via the extension of the idea in fig. 21. For the FRs in above Section, DPs are defined as follows:

DP_1 : Upper low screw
DP_2 : Upper front screw
DP_3 : Rear side screw
DP_4 : Front side screw
DP_5 : Fixing screw

The design matrix is defined as a decoupled one as following:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \\ FR_5 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ X & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 \\ 0 & 0 & X & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \end{Bmatrix} \tag{16}$$

If we replace DPs in fig. 24 with those in fig. 20, then all the movements are carried out by translations. Therefore, we have two designs. The one has the concept in fig. 20 and the other has the concept in fig. 21. As mentioned earlier, the Information Axiom can be utilized a superior design. Thus, if we evaluate the designs of Figs. 20-22 in the context of the Information Axiom, we can determine the final design.
Eq. (15) is a decoupled design and it has the AD3 pattern. The first conceptual design can be improved further by using appropriate TRIZ modules applicable to the pattern. Eq. (15) for the improved design is design pattern AD3. Among applicable modules in TRIZ, substance-field model 3-2 reinforces system efficiency at a certain stage of system development through transition from the macro level to the micro level. Two new designs are derived as illustrated in figs. 21 and 22. In the two designs, the rear screw for adjusting the vertical starting position of the beam is separated from the front screw for adjusting the vertical angle of the beam. In fig. 21, a fine adjustment is enabled by the screw without direct change of the beam. Actually, the design is reinforce by transition to a micro level. The third design in fig. 22 uses a coil, the temperature of which is adjustable, instead of a screw to control the position at a more microscopic level by adjusting the length of the metal bar. This design can determine the position more precisely than the design in fig. 21.

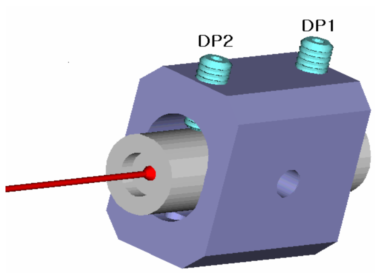


Fig. 21 New design No. 2

(Shin and Park, 2006)

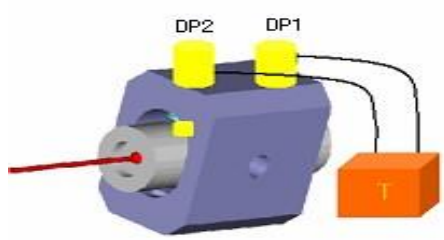


Fig. 22 New design No. 3

(Shin and Park, 2006)

4.5.2 Now Select the Final Design Using the Information Axiom

In the last we will choose one of the three derived designs. Third design is discarded due to its high cost constraint however it is excellent. The designs in figs. 20 and 21 are compared by using the Information Axiom. When the information contents are compared, the one in fig. 21 has less information, thus the design in fig. 21 is selected as the final design. The design in fig. 21 is expanded to the entire system and the final design in fig. 23 is made.

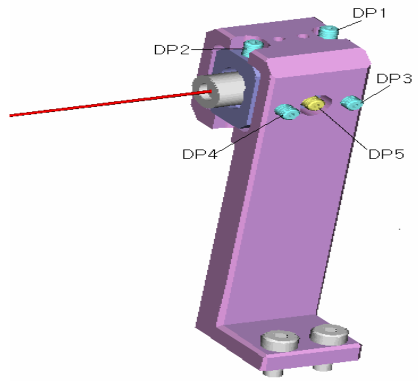


Fig. 23 Final expanded design (Decoupled design) (Shin and Park, 2006)

4.5.3 Compare the information contents: The information content for a decoupled design is obtained by using the conditional probability. However, when the system range is given by the probability density function see in fig.24, it is not easy to use. Therefore, specific methods have been developed. There are two methods according to the distribution and the tolerance: the graphical method and the integration method. When the probability density function does not have uniform distribution or there are more than two functional requirements, the graphical method cannot be used. But the integration method can be used in many cases.

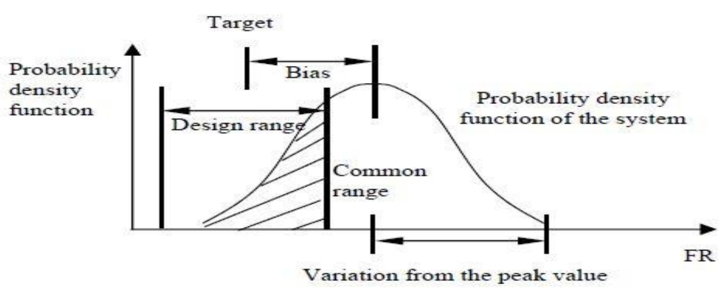


Fig. 24 Calculation of the information content using the probability density function (Suh, 2000)

From integration method (Shin et al., 2002) the probability of success is 1.5% and information content is 6.05 for the design in fig. 20. In the design of fig. 21, the probability of success is 58.2% and information content is 0.78. Therefore, the design in fig. 21 is superior. Hence, the design in fig. 24 is the final design because it is the extension of the design in fig. 21.

CHAPTER 5 DISCUSSION & CONCLUSIONS

The Independence Axiom is utilized to obtain good design candidates. If multiple design candidates are found, the Information Axiom is used to select the best design. This is a full cycle of the axiomatic approach. However, the full cycle is rarely applied. It is because multiple solutions may not be found or the information contents are not appropriately defined. The full cycle is executed for the design of a beam adjuster in a laser marking machine. At first, two design candidates are found to satisfy the Independence Axiom. The design solutions are evaluated by the comparison of the information contents. The final design selected has less information content and is also robust. Many researches have shown that robust design generates less information. In the future, this relationship should be systematically investigated.

Recently a number of engineering designs are being suggested and efforts are being made to improve design methods. In this context, various decoupling methods for coupled designs are developed by using TRIZ modules. From the research, the following statements are concluded:

(1) TRIZ modules can be exploited well for the decoupling process of coupled designs. The coupled manner is classified into six patterns according to design equations and characteristics. In addition, TRIZ modules applicable to each pattern are identified. A flow chart is defined to use design axioms and TRIZ modules.

(2) An auxiliary beam adjusting device used in laser markers is designed. The current design is found to be coupled. The coupled design is decoupled by using TRIZ. In this case, multiple designs are made and the final design is determined based on the developed flow chart.

REFERENCES

[1] Shin, G.S., Yi, J.W., Kang, B.S. and Park, G.J., 2002. "Axiomatic Design of a Beam Adjuster for a Laser Marker," ICAD 2002 Second International Conference on Axiomatic Design, MIT, USA.

[2] Shin, G.S. and Park, G.J., 2004. "Supplementary beam adjuster for laser device", Korean Patent, No. 10-0453984-0000(in Korean).

[3] G. Fei, J. Gao, and X.Q. Tang, "A TRIZ Based Methodology for the Analysis of the Coupling Problems in Complex Engineering Design" Proceedings of the 19th CIRP Design Conference-Competitive Design, Cranfield University, 30-31 March 2009, pp285.

[4] Gwang-Seob Shin and Gyung-Jin Park "Decoupling process of a coupled design using the TRIZ module" Proceedings of ICAD2006, 4th International Conference on Axiomatic Design, Firenze - June 13-16, 2006

[5] Kai Yang and Hongwei Zhang, "A Comparison of TRIZ and Axiomatic Design" Proceedings of ICAD2000 First International Conference on Axiomatic Design, Cambridge, MA – June 21-23, 2000.

[6] Rohan A. Shirwaiker and Gül E. Okudan, "Triz and axiomatic design: a review of case-studies and a proposed synergistic use" Journal of Intelligent Manufacturing, February 2007.

[7] Gwang-Sub Shin and Jeong- Wook Yi, "Axiomatic Design of a beam adjuster for a Laser Marker", Proceedings of ICAD2002, Second International Conference on Axiomatic Design, Cambridge, MA – June 10-11, 2002.

[8] Nam P. Suh, 2003. "Introduction to Axiomatic Design Principles", Complexity: Theory and Applications.

[9] Suh, N.P., 1990. The Principles of Design, Oxford University Press, New York.

[10] Suh, N.P., 2001. Axiomatic Design: Advances and Applications, Oxford University Press.

[11] Kyeong Won, Lee and Young Joon, Ahn, 2006. "Mutual Compensation of TRIZ and Axiomatic Design".

[12] https://triz-journal.com/