Improvement of Routine Test Process of High Voltage Power Capacitors

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Abstract

The capacitor test process at ABB Capacitors in Ludvika must be improved to meet future demands for high voltage products. To find a solution to how to improve the test process, an investigation was performed to establish which parts of the process are used and how they operate. Several parts which can improves the process were identified. One of them was selected to be improved in correlation with the subject, mechanical engineering.

Four concepts were generated and decision matrixes were used to systematically select the best concept. By improving the process several benefits has been added to the process. More units are able to be tested and lead time is reduced. As the lead time is reduced the cost for each unit is reduced, workers will work less hours for the same amount of tested units, future work to further improve the process is also identified.

The selected concept was concept 1, the sway stop concept. This concept is used to reduce the sway of the capacitors as they have entered the test facility, the box. By improving this part of the test process a time saving of 20 seconds per unit can be achieved, equivalent to 7% time reduction. This can be compared to an additional 1400 units each year.

Acknowledgements

First and most I want to thank my supervisor Felix Bandalo and ABB Capacitors in Ludvika for giving me the opportunity do my thesis at their facility in Ludvika.

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Table of Contents

1 Introduction

ABB is the world's largest manufacturer of electrical components for electricity transmission grids. They are active in many sectors with its core business in power and automation technology.

The ABB Power Products division incorporates several different manufactures of different products for high voltage power transmission. Some of these products are transformers, swhichgears, cables, capacitors and additional high voltage equipment. Medium voltage equipment is also available such as digital relays, capacitors and motors. Power Products have their key markets in components to transmit and distribute electricity. The division Power Products is divided into three business units, High Voltage Products, Medium Voltage Products and Transformers.

1.1 Project background

What are the origins of the project?

At ABB Capacitors the manufacturing of the capacitor units is a demanding process. All the components are individually tested. After assembly, they are again tested to ensure their quality and their functionality, according to both ABB standards and IEC standards.

At the final test, the capacitors are tested at voltages according to the technical specifications.

In the development laboratory, the units are tested manually. At the automatic testing equipment, the “box”, the same testing process takes place, however it is done automatically by a computer.

Some of the problems with the box are:

- It cannot test capacitors with voltage above 50k Volt Direct Current (kVDC), 54kVDC depending on transformer temperature [6], and 30k Volt Alternating Current (kVAC). In the laboratory, a voltage of 120kVDC can be achieved; this is due to the usage of different transformers.
- Future bigger capacitor and bushing models may not fit inside the box.
- Some capacitors have only one bushing. This makes the testing of the capacitor in the box more difficult. Manual adjustments are needed.
- Sometimes, the capacitor is not completely vertical, making it difficult for the box to attach the connectors to the bushings.
- Long lead times.

1.2 Problem

The capacitors are routine tested to assure good product quality. Today's process is not robust enough which results in some manufacturing disturbances.

The objective of the thesis is to improve today's test process. By improving different steps of the process, time can be earned and the lead time will be reduced.

By reducing the lead time, the effectiveness of the overall manufacturing process will increase and costs will be reduced.

1.3 Objective

The test process equipment of the capacitors has been the same for 15 years. When the system was installed, solutions to problems might not have existed at that time. Faster computers and more advanced systems have been developed during the last 15 years.

The problem with the process is that it is 15 years old. Due to increasing demand on ABB Capacitor products, service and maintenance time has been reduced and the equipment is used more often. To meet the increasing product demands, investments and development of the test box is needed

The goals for this thesis are:

- Enhance test process, such as reducing lead times and solving current problems in the test process.
- Make improvements to the testing apparatus if it improves the lead time and the overall process.

With this in mind, a lot of benefits are achieved:

- Faster testing of the capacitors increasing overall capacity. In the end, saving money.
- Reducing testing lead time.
- Newer and bigger capacitors are able to be tested.

- New systems requires less maintenance compared to older systems. Saving money in maintenance.

1.4 Delimitations

In an industry, independent of the area, most of the things could be done in a better more efficient way.

This thesis is limited to the testing process of the capacitors and its mechanical parts; it will not address the operations of the box itself. Exact drawings and blueprints will not be made, only an overall look of the concept solutions will be made.

The test process will be looked upon, flaws corrected and improved.

The programming of different governors and PLC’s will not be looked upon.

1.5 Approach

The method used for this project will be based on the method described by KT Ulrich and SD Eppinger.

They describe a five step method during the concept generation stage. This will help developers to follow a structured method to obtain the best result. The steps are as follows;

1. *Clarify the problem.*
    a. Understanding the problem
    b. Decompose problem into smaller subproblems
    c. Focus on critical problems
2. *Search externally*
    a. Contact leaders in the current field
    b. Consult experts
    c. Search patent databases and literature
    d. Benchmarking
3. *Search internally*
    a. Ideas to solutions inside the company
4. *Explore systematically*
    a. Combination tables or selection tables
5. *Reflect on the results*
    a. Improve results
    b. Concept selection and evaluation

The method described is only one of many different approaches to problem solving. These steps are not guidelines, they are more as recommendations.

1.6 Report Outline

The fist chapter describes the project background and is the introduction to the thesis work report. It also describes the approach; the method which is used in this thesis work.

Chapter two explains the working principles of a capacitor. Further, it describes how ABB Capacitors manufacture the capacitor units and how they are tested.

In chapter three, the surrounding processes are shortly described. The conveyor system is described as well as the painting and the blasting process.

Chapter four describes in detail how the test process works and how its different stages interact with each other.

The result of the thesis work is described in chapter five. The improvements and concepts are also described. The selection methods as described in chapter one are used to screen the concepts as well as select the most appropriate concept.

Chapter six explains the economical aspect of the selected concept and the cost to implement it.

The conclusions are presented in chapter seven.

Discussions about the theses work is presented in chapter eight.

Chapter nine discusses the issues of future studies. Some parts in this thesis work were not addressed due to the delimitations of the theses work. The future works chapter explains further improvements to the test process.

References are presented in chapter 10.

2 Design and construction of Power Capacitors

ABB is the world leader in the area of power transmission and power technologies. As of the end of 2008, ABB had over 120000 employees stationed in approximately 100 countries. Their main goal is to improve the customers industry performance and minimize the environmental effects.

ABB have approximately 8700 employees in Sweden located in 35 different cities. The two largest are Ludvika, with 2400 and Västerås with 4500. [1]

ABB Capacitors is the world leader in the manufacture and development of high voltage power capacitors.

There are five existing divisions in ABB and these are as follows; [1]

- Power Products is the key component in the electrical distribution. The division has units which manufacture transformers, breakers, and additional electrical equipment. ABB Capacitors is a subdivision of Power Products.
- Power Systems offers systems and services for power transmission, substations, and distribution networks.
- Automation Products produce world leading motors, generators, low voltage products, instruments, and power electronics. More than one million products are shipped to customers in the industry every day.
- Process Automation supplies the customers with integrated solutions for controlling, optimizing and branch specific applications. The solution gives increased productivity and energy savings.
- Robotics has the world's largest base of industrial robots and produces software and accessories.

2.1 Capacitor principles

A capacitor is a apparatus with a certain ability to store energy in form of electric power.

The basic working principle of a capacitor consists of two plates called electrodes, insulated from each other by a material called a dielectric. The property of the capacitor is defined by the capacitance (C), the voltage (U), the dielectric constant (ε), the area (A) and distance (h) between the electrodes.

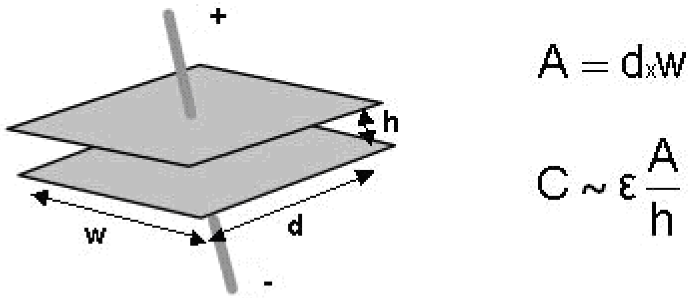


Figure 2-1 Schematic view of capacitor electrodes

The research and development of new power capacitors, as of today, have usually meant finding new materials with better dielectric properties or to reduce the distance between the electrodes by using thinner dielectrics. By doing this the dielectric stress will increase and so the power density of the capacitor. [2]

Where the dielectric stress is the ratio between the voltage across the dielectric, and the thickness of the dielectric. The SI unit used is volt/meter. [3]

As stated above one of the properties that determine the amount of charge a capacitor can hold is the capacitance. The charge (Q) in coulombs stored in a capacitor is proportional to the charge voltage (U). As defined by T Longland, TW Hunt and A Brecknell, the unit of capacitance, farad (F) is “the capacitance of a capacitor between two plates of which there appears a difference of potential of one volt when it is charged by a quantity of electricity equal to one coulomb”. The following relationship is obtained.

$$C = \frac{Q}{U} \qquad \textit{[eq. 2-1]}$$

Where

C = Capacitance in farads, Q = Charge in coulombs and U = potential difference in volts.

In most practical use the unit farad is too large. Most common used is, microfarad (μ F), nanofarad (nF), and picofarad (pF).

When using a capacitor in electrical power distribution, the value of the capacitor is not given in farads but in volt-amperes reactive (VAr). In this case, the capacitors are used to compensate for loss of reactive power in the electrical power web. [2] [4]

Active power is the power doing the work, active power is measured in watts (W). Reactive power it is not of use in power transmission, reactive power is measured in volt-ampere reactive (VAr). Apparent power is the combination of active and reactive power, apparent power is measured in volt-ampere (VA). Power factor, also called cos φ, is an indicator of the efficiency of the system. 1=100% and 0=0% efficiency. The power factor is also a relationship between the active and reactive power.

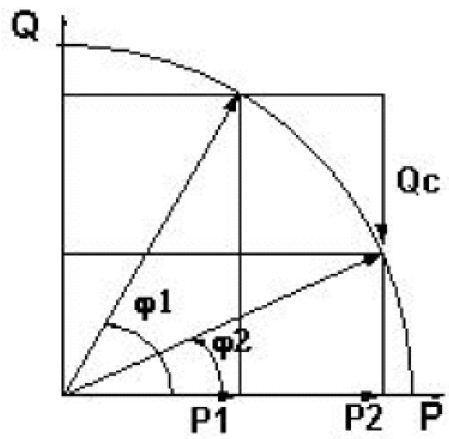


Figure 2-2 Explanation of active power P and reactive power Q

As shown in figure 2-2, P is the active power, Q is reactive power, the arc is the apparent power, and φ is the angle between active and apparent power.

A theoretical system might have an active power usage as P1. When adding reactive power (Qc) to the system by adding a capacitor, the reactive power will decrease, the active power will increase, to P2, and the apparent power will stay constant. In this way the power factor will increase and the losses in the system will decrease. [4]

Normally a capacitor is rated in kilovar (kVAr) and it can be calculated using;

$$kVAr = 2\pi fCU^{2} \cdot 10^{-9} \quad \textit{[eq. 2-2]}$$

Where

C = capacitance in μF, f = frequency in Hertz (Hz), U = Line voltage

In all electrical systems there are losses present. In a capacitor, if the dielectric is vacuum, no losses will emerge. In that case the current taken by the capacitor leads the applied voltage exactly by 90^{o}, hence cos90^{o} = 0, the power will be zero. Practically this is impossible and there will be losses in the dielectric called the dielectric losses. This implies that the current will not lead the voltage by 90^{o}. The angle of drag is called the loss angle. Usually the loss angle is defined as δ, which will make the phase angle (90^{o} - δ) [15]. The power factor is cos(90^{o} - δ) which is the same as tan(δ). Losses in a capacitor are measured in watts per kVAr. For instance tan(δ) = 0,0005 equals a loss of 0,5 watts per kVAr. [3]

2.2 Capacitor manufacture

The manufacture process at ABB Capacitors uses state of the art equipment and material to produce a world leading product, ABB's high voltage power capacitors.

All the material needed during manufacture have been tested according to ABB's standards. Each one of the suppliers has been certified by ABB Capacitors. The material is tested at the supplier's factory according to the certificate standards, only a few tests are performed at ABB Capacitors. One of these tests is the analysis of the capacitor impregnation fluid. Different parameters are checked to ensure the quality of the fluid. [6][7]

The process starts with the arrival of the electrodes and the dielectrics. At ABB Capacitors the electrode material is aluminum foil with an average thickness of 5 μm. The dielectric is a polypropylene film with a thickness of 10 - 40 μm. [5]

These are after arrival, placed in one of the two machines which fabricate the capacitor elements.

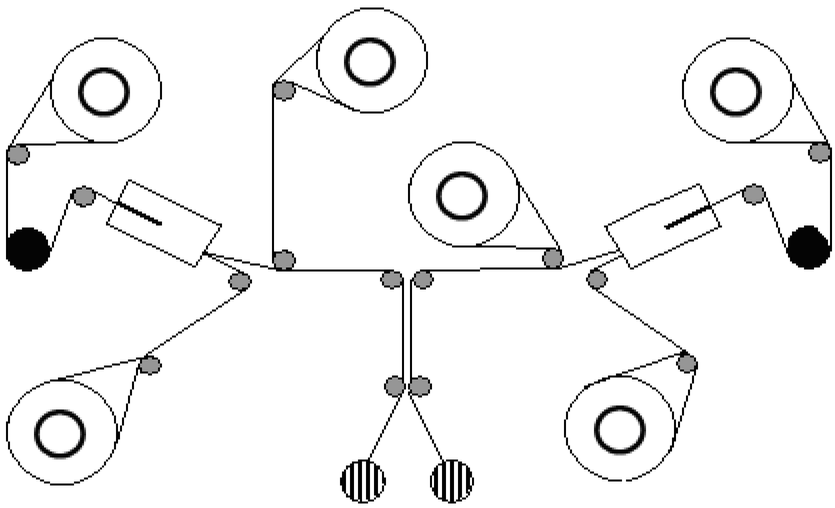


Figure 2-3 Electrode and dielectric schematic layout.

A picture of the machine can be seen in appendix A.

After manufacture, each element is tested at 5kV for 1 second. [5]

After leaving the machines, the elements looks as illustrated in Figure 2-4.

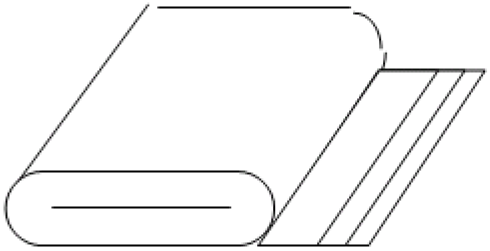


Figure 2-4 Schematic view of element before presoldering and insulation wrapping.

The next step of the process is the presoldering of the elements. Here, a thin layer of tin/zinc is applied to both ends of the element. See figure 2-5.

Figure 2-5 Presoldering of element.

After presoldering, the elements leave for sweep insulation and, depending on the type of the capacitor, attachment of internal fuses.

Next step is to solder the internal fuse and connection wires to the element. This is done in a similar way as the presoldering of the elements. At this point, every 400 element is tested to ensure good quality in the soldering. The soldering must withstand a predefined pulling force according to ABB Capacitors specifications..

After the insulation and an eventual fuse have been placed on the element they are stacked in packs. The sizes of the packs depend on the specification of the capacitor. See figure2-6.

Figure 2-6 Stacking of the elements.

Following the stacking, all the elements are connected together according to the specification. Before the packs are wrapped in insulation and canned, see figure 2-7 and figure 2-8, resistors are placed on the stacks according to specifications of the capacitor.

Figure 2-7 Wrapping of the element packs.

After wrapping, the packs are canned inside a stainless steel container.

Figure 2-8 Canning of the insulated stacks.

Next operation is the welding of the lid; this is done by a robot. The welds are inspected and corrected if there is a flaw in the weld. See figure 2-9.

Figure 2-9 Welding of the lid, done by a robot.

After the welding the containers are tested for leakage by the use of compressed air. The capacitors are now ready to be sent to the next step of the manufacturing. Impregnation and testing.

The impregnation process starts with the preparation of the capacitor units to enter the vacuum furnaces, autoclaves, for 24 hours. Here, the units are dried and filled with the impregnation fluid Faradol 810. Afterwards the containers are sealed hermetically and are sent for testing.

At testing they are tested according to IEC (International Electric Committee) standards and specifications. Most failures occur due to overvoltage created in the dielectric or flashover in the insulation. There are also errors by wrong capacitance and wrong resistance in the unit. More detailed testing routines can be found in chapter 2.4. Figure 2-10 shows a capacitor inside the automatic routine testing, the box.

Figure 2-10 Capacitor inside the automatic routine testing unit, the box.

After the rigorous tests, the capacitors are sent to sand blasting and painting. Here they receive two layers of paint. After every layer of paint the capacitor is dried in an IR-oven. The tichness of the paint on every capacitor is manually measured. The thickness of the paint is also measured to ensure satisfactory quality.

When the capacitors are dry they are sent to packing and are shipped to customers across the world.

2.3 Capacitor models

All capacitors are built to standard measurements, the only difference between the units are measurements A, B, and *.

As seen in Figure 2-11, A is the height of the unit excluding the bushings, B is the height from the fixing brackets to the lid and * is the length of the bushings. The length of the bushings is associated to the rated voltage of the capacitor. The size of the capacitor unit is related to its power.

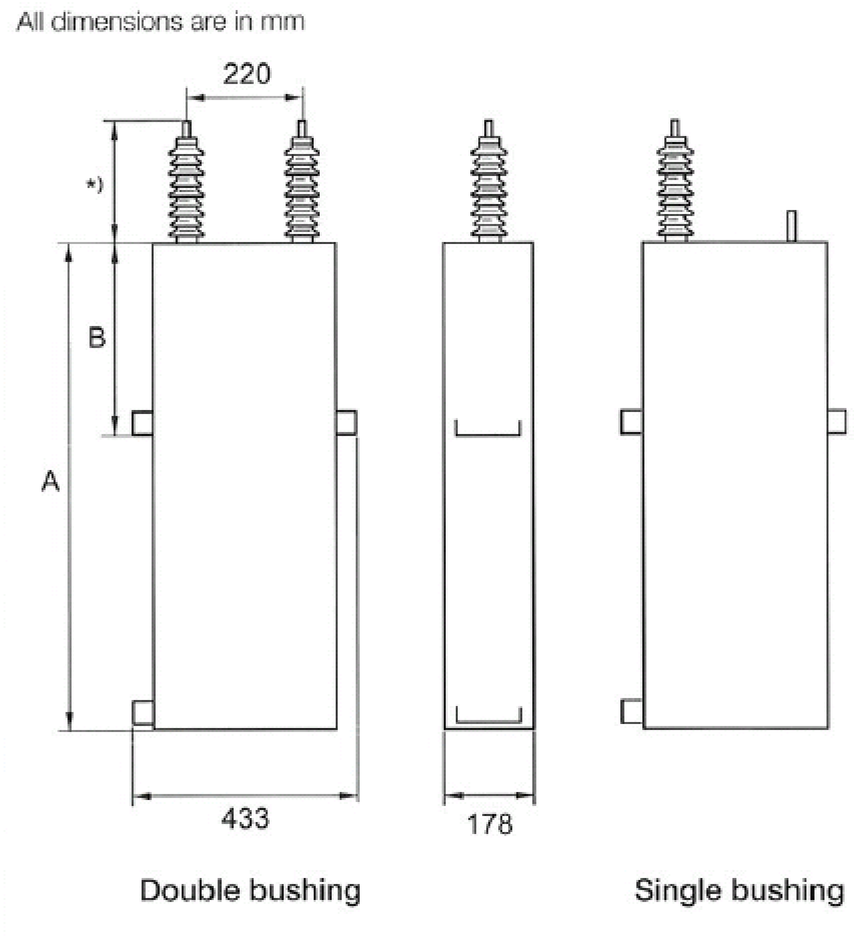


Figure 2-11 Capacitor standard measurements

Standard lengths, as shown per table one. [8]

The dimensions of bushings are shown in table two. Complete drawings of the S5 bushing is found in appendix A. The other bushing models are exactly the same except for the difference in height.

Table 2-1 Capacitor dimensions

Size	A	B	Weight	Power (kvar)	
	mm	mm	kg	50 Hz	60Hz
220	240	140	23	155	185
330	295	140	28	220	260
440	345	140	32	270	325
550	405	190	39	310	370
660	460	190	44	360	430
770	525	350	49	410	490
880	635	350	59	540	645
990	685	350	63	595	715
130	750	350	67	660	790
140	820	370	73	725	870
160	920	320	82	800	960
180	1030	430	90	900	1080
200	1140	535	100	1000	1200

Table 2-2 Bushing lengths

	*
Bushing	mm
S1	215
S3	295
S5	355

2.3.1 Future models

Future capacitor models might be of larger size, but it does not need to be so. New material could be developed so the power of the capacitors, the total ammount of kVAr, will increase without affecting the size of it. A larger bushing is being developed; this will enable a higher voltage in the capacitor. With this in mind, the total length of the capacitor will increase.

Future models of capacitors have already been developed, the DryQ. These capacitors do not use any impregnation fluid; they are so called dry capacitor. This model was developed in 1998, and was estimated to have 50% of the market in 10 years. 2008 the DryQ had only 5%. The reluctance of customers to use a new system is the answer to why the DryQ do not have more market shares. [4]

2.4 Routine Testing

All the capacitors are tested according to the IEC (International Electrotechnical Commission) and ABB Capacitors standards. This is done to ensure good quality and minimize the possibility of a capacitor failure on site.

The routine test starts with the arrival of the units. After arrival, the units are put on a conveyor and the serial number of the capacitor is entered in the computer. When the computer has the serial number, it knows the size of the capacitor unit, and what test voltage the unit requires.

The automatic test cycle can be divided into to 8 basic steps.

1. After the unit is placed on the conveyor, the unit enters the box.
2. Inside the box the unit is locked in place so it cannot shift its position during testing.
3. The capacitance of the unit is measured at low voltage. The result is compared by the computer to the nominal value in a database. If it deviates outside the interval the unit is rejected.
4. DC (direct current) or AC (alternating current) for 10 seconds over the dielectricum (between the terminals). All electric test are done according to the International Electric Committee standards, IEC 60871-1.
5. AC container test to check the insulation between the casing and the elements.
6. A discharge test is done to check the fuses and soldering inside the capacitor.
7. Capacitance and the tan delta loss is measured at nominal voltage and current.
8. Resistance is measured.

These tests are the same for all capacitors except those with only one bushing. Hence the elements are connected to the casing; no container test can be performed.

3 Linked processes

Once the capacitor units have been placed on the conveyor they will follow the conveyor through different processes. Theses processes are of great importance for the quality of the product.

3.1 Conveyor system

As previously mentioned, ABB Capacitor uses a conveyor system to transport the capacitor units through the different processes during the manufacturing. See Appendix E on page 64. The conveyor is of accumulating type, this means that each wagon can move independent by others.

The capacitor units are stored at the stock, and the box operator takes the units from the stock and places them beneath elevator 1. The capacitor units are placed on the conveyor wagon as mentioned in section 4.1 on page 27. The conveyor itself moves at a constant speed and the wagons use a so called, "beaver tail". The beaver tail system utilizes the simple law of moving subsequent to the wagon in front. Same principle is applied at a standstill, if the wagon in front is standing sill, the following wagon will be standing still. [14]

The speed of the conveyor is never changed and the conveyor is only stopped if an error is detected in the system. Such error can be; overload of the conveyor motors, missed reading of the escort memory connected to the wagon, different problems in the blaster or painting facilities, and problems in the IR owen.

The conveyor system is constructed in such way so as a wagon arrives at a process station, such as the box or the blasting, the wagon is disconnected from the conveyor system. Subsequently the wagon can travel at a speed unrelated to the speed of the conveyor. As the wagon is disconnected from the conveyor, the wagon is subsequently connected to a pneumatic cylinder so as to control the speed of the wagon.

3.2 Blasting

At the blasting process, the capacitors are blasted using stainless steel shots as medium. The capacitors are blasted to remove dirt from the surface as well as to roughen the surface to facilitate the attachment of paint on the surface. The cycle time for the blasting is approximately 270 seconds (4,5 minutes). The cycle time is independent of the size of the capacitor unit.

The blasting uses sling wheels to accelerate the medium towards the capacitors. As the sling wheels are blasting the capacitor unit the unit rotates inside the blast chamber to evenly blast it on all sides. At the end of the process, compressed air is blown on the capacitor to remove eventual residual blasting medium located on the capacitor.

3.3 Painting

After the blasting, the operators remove the blasting protection from the bushings and replace them with a paint protection to prevent any paint to reach on the bushings.

The units are painted and sent through the IR owen. Each unit is painted twice, and after each painting, the units are directed into the IR owen automatically. Experiments are being conducted to investigate the possibility to reduce the painting time by altering the painting sequence.

4 Test process

The test process has been broken down using the black box method. As stated by KT Ulrich and SD Eppinger, “The first step in decomposing a problem functionally is to represent it as a single black box operation on material, energy, and signal flows”. An illustration of the basic black box approach is seen in figure 4-1.

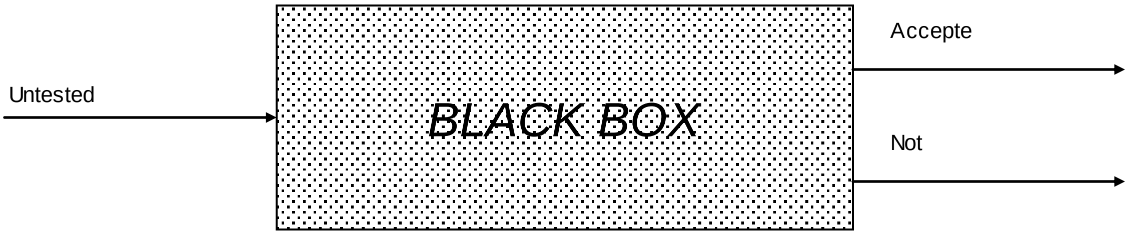


Figure 4-1 Black box

Once the basic black box has been created, a more accurate model can be made. This model is shown in Appendix D on page 63.

The black box on Appendix D on page 63, shows the functional decomposition when breaking down the black box into sub functions. This is done so a more accurate description of each subfunction can be seen and understood. This method can again be used to break down the subfunctions into even more functions. [10] [13]

This method is very similar to the role activity diagrams (RAD). The RAD focuses on peoples aspects of a process in relation to the organization [16]. As for the function diagram, it is an overall “cause and effect” diagram, in this case for mechanical machinery and computer controlled actions.

A principle used when working with the black box model is not to specify any technical working principles, only describe the function.

The test process is divided into three different categories; the manual sequence, automatic sequence, and the gripping sequence. These three sequences are described in more detail in section 3.1, 3.2, and 3.3.

4.1 Manual sequence

The manual sequence is the only sequence where the operators are required to input information of the capacitor units into the computer.

When the capacitors arrive at the test facility they usually arrive on pallets. Every capacitor has its own unique serial number on a tag attached to the bushing. The tag is also equipped with a barcode to facilitate the input on the computer. The operator uses a barcode reader to input the data to the computer. Simultaneously, the wagon number on the conveyor is connected to the serial number of the capacitor unit, trough the use of an escort memory, this memory will always stay with the wagon [14]. The escort memory is an identification which is attached to the wagon such as barcodes, magnets, or chips. In this case, a steel plate with holes. Furthermore, the computer identifies which capacitor unit is attached to the wagon. Also, at this time, if the capacitor unit is a model with a single bushing, an adapter is placed on the stem so it will be of the same height as the existing bushing.

Before the start of the automatic sequence, depending on the capacitance of the unit, the high voltage tap might need to be changed. The tap is a gearbox to regulate the current and voltage from the transformer depending on the capacitance of the capacitor unit. This procedure requires a manual input into the PLC. If this is not done, the computer will try to balance the system without success and the test will be needed to be repeated. The balance is achieved by increasing or decreasing the air gap in the transformer, by doing so the reactive effect of the capacitor is cancelled by the air gap in the transformer and the system is balanced.

If a single bushing capacitor is placed on the conveyor, a reprogramming of the PLC is required. A removal of the AC terminal container test must be performed. In addition, the connector to the earth on the earth plate must be removed.

Following the input of the capacitor unit, unless there are no errors, no further manual input from the operators is required.

This sequence is illustrated, on Appendix D on page 63, as the yellow area in the black box.

At the end of the automatic sequence, if a capacitor unit does not pass the test, the unit needs to be removed from the conveyor by hand.

4.2 Automatic sequence

After the manual sequence all operations are automated. The capacitor unit which is attached to the wagon, follows the conveyor track and enters the box. As soon as the capacitor unit arrives at the designated test position, the wagon stops. Due to the moment of inertia of the capacitor unit the unit will sway back and forth. At this point the test sequence is programmed to halt the test for approximately 30 seconds to wait until the sway of the capacitor has ended.

Afterwards, the gripping sequence commences. This sequence is described more in detail on section 4.3, page 30.

After the gripping devices have been attached to the stems of the capacitor, a low voltage capacitance measurement is performed. At this point the voltage reaches approximately 1kV. The measurements are done by a Tettex 2877 bridge. The result of this measurement will ensure that all the elements are connected properly inside the capacitor unit. If not, the capacitance will diverge from the technical specification, due to malfunction inside the capacitor, and the unit will be rejected.

The measuring equipment is always connected to the test facility. Disconnectors, connects and disconnects the equipment to measure the capacitors. If an error occurs, the system might connect the measuring equipment despite the fact that high voltage is still present in the capacitor unit, and damaging the equipment. The loses in the system may possibly increase due to the fact that the disconnectors are greased to reduce friction, hence false tan delta readings were observed.

The second step of the automatic sequence is the terminal-terminal test, the high voltage test. Depending on the type of the capacitor, DC or AC, the test cycle varies. The sequence inside the computer is built up as follows; [6]

- DC terminal-terminal
- DC direct discharge
- AC terminal-terminal
- AC terminal-container

The DC direct discharge is performed on all capacitor units. The AC terminal-container is only performed on capacitor units with two bushings. Capacitor units with only one bushing have the elements connected to the casing; therefore no AC terminal-container test can be performed

On a DC capacitor the AC terminal-terminal test is not performed, so the cycle will be DC terminal-terminal, DC direct discharge and finally AC terminal-container.

On the other hand, on an AC capacitor, the cycle commence with the DC direct discharge, thus skipping the DC terminal-terminal sequence. This is followed by AC terminal-terminal and AC terminal-container tests.

The order of the test sequence is never altered. Depending on the type of the capacitor unit; different steps in the sequence are removed. The result of this test is sent to a database to be stored by the computer.

After the high voltage test, a measurement of the capacitance at nominal voltage and dissipation (tan delta) are performed. This is done by the Tettex 2877 bridge, the same bridge which measured the capacitance at low voltage in the beginning of the process. The results are again sent to the database.

Subsequently, the resistance of the capacitor unit is measured. This is done to ensure the correct function of the resistors inside the capacitor unit.

If the capacitor unit passes the entire test accordingly, the unit is sent out of the box and accepted, else the unit is sent out and not accepted. If the capacitor unit is not accepted, it is sent for repair.

When a capacitor unit is repaired it is sent through the test process again.

4.3 Gripping sequence

As stated in 4.2, the test sequence is halted to wait until the sway of the capacitor has stopped. After the 30 seconds, the sway has probably been reduced to acceptable levels or has stopped completely. At this moment, the capacitor is secured in place by a so called earth plate.

Figure 4-2 Earth plate in the bottom of the box

This plate is located in the bottom of the box, see bottom of Appendix C on page 62, and it is made of aluminum and plastic. The plastic pieces are wedge shaped to allow the capacitor to slide into place more easily as the earth plate rises to secure it.

Below the earth plate, two springs are located to hold the plate and a light swhich is positioned to make the earth plate pressure sensitive.

As the earth plate is raised, the capacitor slide into position and as the plate continues to raise the weight of the capacitor compresses a spring, when the light beam in the light swhich is interrupted the earth table stops. As the earth plate is stopped, a brass plate is pressed against the capacitor container; this will insure a good connection to earth on the container. Furthermore, the capacitor should be in such position that the main weight of the capacitor is supported by the conveyor and the earth plate only supports a small portion of the weight and mainly corrects its misalignment, from a vertical position.

Afterwards, the gripping device is positioned above the stems on the bushing, as seen in Figure 2-10 on page 20, and lowered into position. A pressure swhich is located inside the gripping device. As the gripping device is lowered on the stems, the stems press on the swhich and the gripping device stops and the clam shells grab the stem. The connection is made and the capacitor unit is ready for testing.

Sometimes problems involving the earth plate and the connection to the stems are observed. If the capacitor unit is very misaligned from the vertical position, as it enters the box, it will not slide into place as the earth plate rises. The weight of the capacitor unit will compress the springs on the earth plate and activate the light swhich. The computer will believe the capacitor unit is in place. As the gripping device is positioned it will fail to connect to the stems due to the fact the unit is not vertical. This is illustrated on Appendix C on page 62.

Another problem arises when the weight of the capacitor is reduced. As the earth plate is raised towards the capacitor the weight of the capacitor is not enough to compress the springs to activate the light swhich. This results in the capacitor being lifted of its hook on the conveyor wagon and falling on the floor.

A further issue comes up with the earth plate. Some operators state the problem of alignment of the capacitor unit does not lie in the fact that the capacitor unit does not slide onto the earth plate. However, the problem lies with the actual state of the earth plate.

It has been used for long time; explosions, falling capacitor units, and other objects have damaged the earth plate in such way so the plate itself is not horizontal. Hence aluminum is much softer than steel, the plate has become oblique. Consequently making the capacitor unit miss its vertical position, even when correctly placed on the earth plate, this will result in a missed connection.

5 Results

When companies perform improvements in their processes many companies attempt to locate the source which increase lead times the most. By doing so, lead times will decrease but not to the largest possibly extent. The correct approach would be to look at the overall process and study every step of the process; even short steps can be improved. If a few seconds is saved on every step of a process, a larger reduction of lead time can be achieved. [17]

If a process has 30 steps and two seconds is saved on every step, one minute will be saved for each unit passing through the process. Furthermore, if 100 units pass the process every day, 100 minutes will be saved every day. This means that productivity can increase and more units can be produced.

In this stage, the systematic exploration of the concepts, the different concept will be compared to each other and the existing solutions using Pugh matrixes. The Pugh matrix is a simple and efficient tool to filter unsuitable concepts systematically. [18] [19]

The improvements in the test process will reduce the time it takes for each capacitor unit to be tested. To study the effect of size, current and capacitance, a case study of two different orders were timed in the box. The fist capacitor, a model 202, size 200 with two bushings (8059-05-101). See 2.3 Capacitor models. The second one, a model 992, size 990 with two bushings (8472-03-001).

Table 5-1 Capacitor specification

	202	992
Hight	1140 mm	685 mm
	355 mm	295 mm
Bushing	(S5)	(S3)
Nominal voltage DC	13097 V	7210 V
Capacitance	18,25 uF	37,91 uF
Terminal-Terminal DC	52,29 kV	28,84 kV
Discharge test	22265 V	12257 V
Terminal-Container AC	28 kV	38 kV
Resistance	4,500 Mohm	3,000 Mohm

Measurements were done to establish the actual lead times for each part of the process. By doing so, solutions to improve the lead time were generated. 13 units on every order were measured, and a mean value for every order was calculated and compared according to Figure 5-1, for detailed lead times in the process see appendix G and H.

The time measurement started with the selection of two different orders. The difference in these two orders, such as voltage, height, capacitance, and forth, should be as large as possible so the effect of any specification, will be noticed during the time measurement. The process was broken down into 9 different steps.

1. *Positioning*, at this point in the process the capacitor is oscillating. The PLC is programmed to wait 30 seconds before commencing the gripping sequence.
2. *Gripping Sequence*, during this stage the capacitor is locked into place and the gripping device attach to the stems on the bushings.
3. *Capacitance Measurement Low Voltage*, at this step the capacitance is measured at low voltage
4. *DC Terminal-Terminal*, DC test between terminals
5. *Discharge*, discharge
6. *AC Terminal-Container*, at this stage an insulation test is conducted
7. *Capacitance and Tan Delta at Nominal Voltage*, on this stage the capacitance and tan delta bridge carries out measurements at nominal voltage on the capacitors.
8. *Resistance*, the resistance is measured
9. *Disconnect and sent out*, at this point in the process the unit is disconnected from the gripping device and sent out from the box.

With every one of the steps are defined, the measurement starts. As the capacitor unit enters the box the timing begins. After each step of the process the time is written down and a table according to appendix G and H is generated.

The different sequence times are illustrated in Figure 5-1 Process lead times.

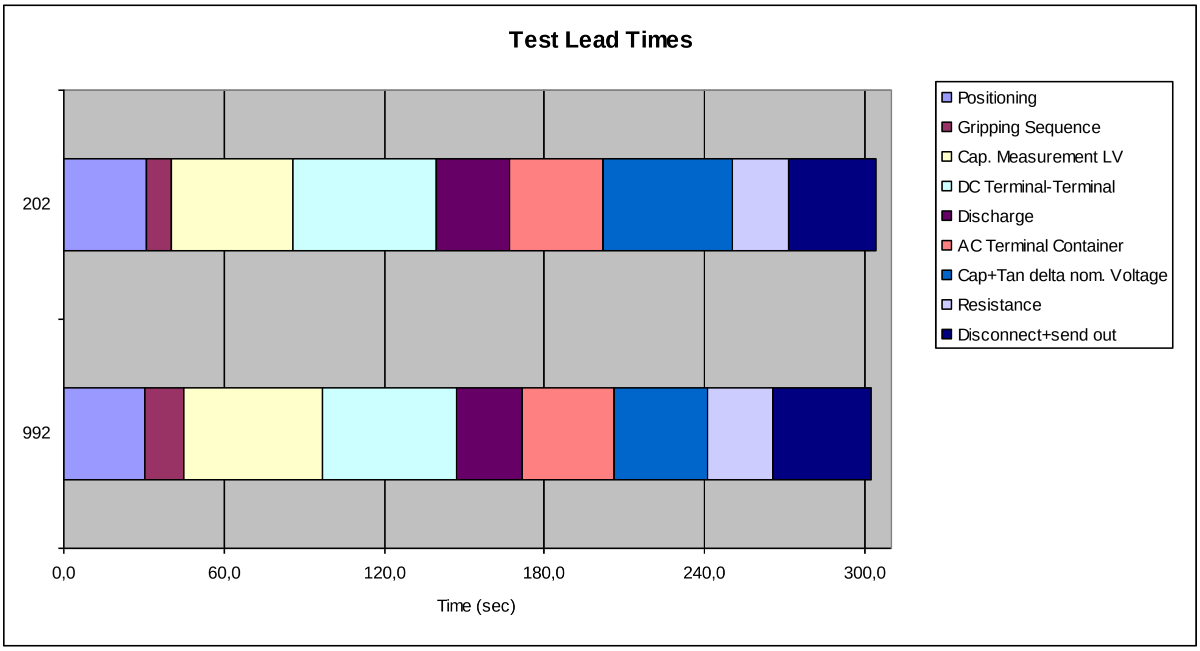


Figure 5-1 Process lead times

As seen in Figure 5-1 the total lead time for the process is almost the same, 304 seconds for 992 and 302 seconds for 202. The total lead time for the test process is shown in Figure 5-1.

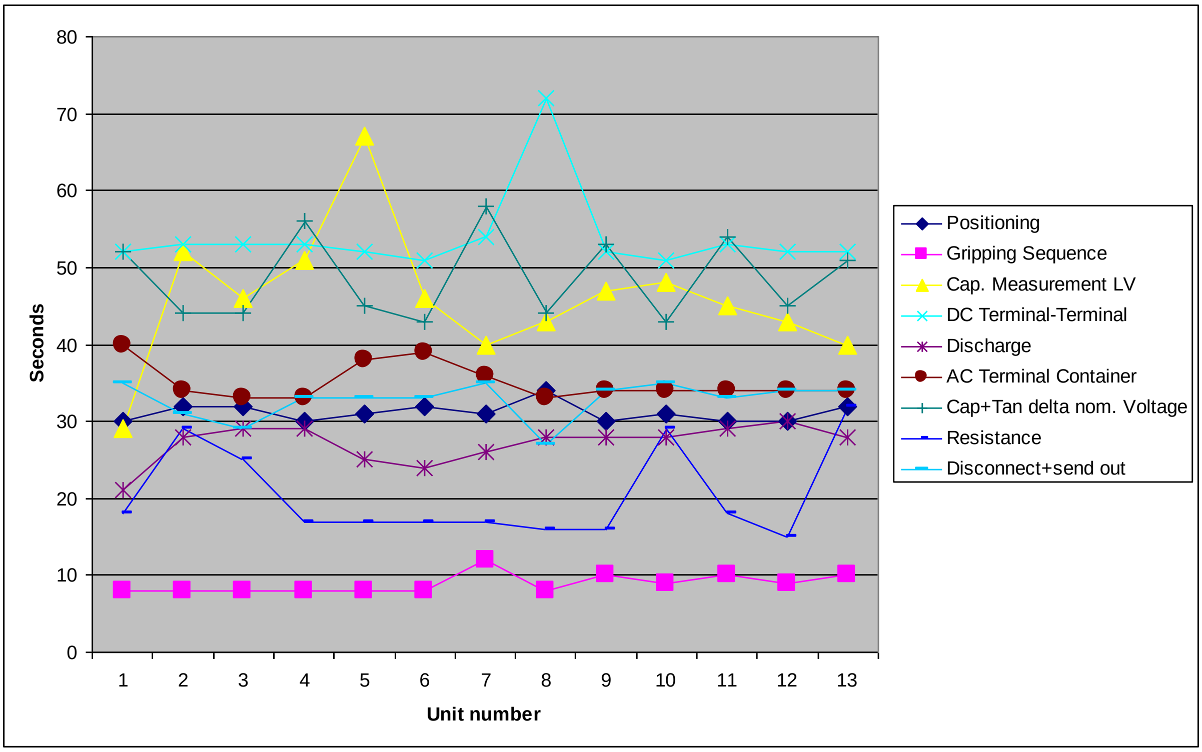


Figure 5-2 Process step lead times 202

Figure 5-2 shows the lead times for each step of the process. For a stable and robust process, the lines must be as straight as possible. As seen in Figure 5-2, the triangular yellow line, cap measurement lv, is not stable compared to the other processes.

Figure 5-3 shows the same as previous figure except for the different unit size, 992.

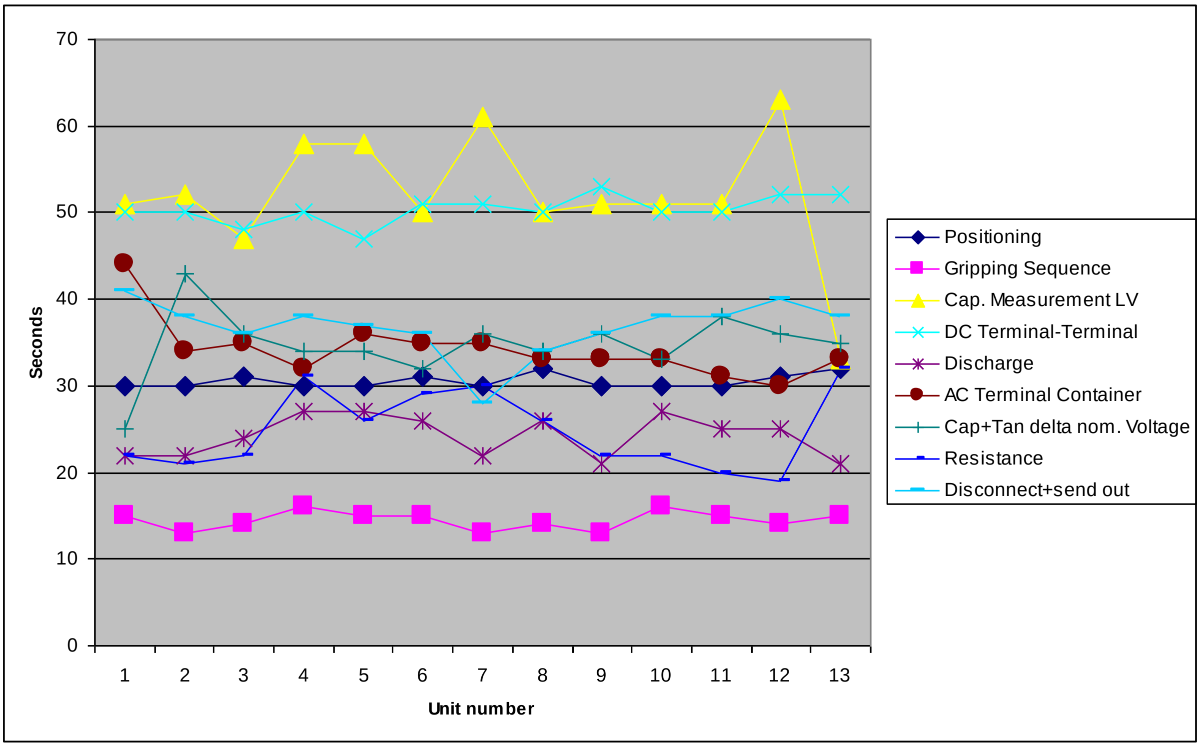


Figure 5-3 Process step lead times 992

When comparing Figure 5-3 and Figure 5-2, there are many similarities between them. From the sequence DC Terminal-Terminal up to Cap+Tan delta nom voltage, the differences between the two measurements are low.

There is also a slight difference in the time for the gripping sequence due to the size of the capacitor. A smaller size of the capacitor unit will lead to a longer traveling distance for the gripping device and will increase the lead time for that particular part of the process. Same rule applies to disconnectd+send out, a longer distance to travel will result in longer lead time.

As only the steps of the process consigning of mechanical parts will be looked upon, for this reason some of the curves on the graph might be removed.

When all the curves concerning electrical tests have been removed, the graph will look as Figure 5-4 and Figure 5-5.

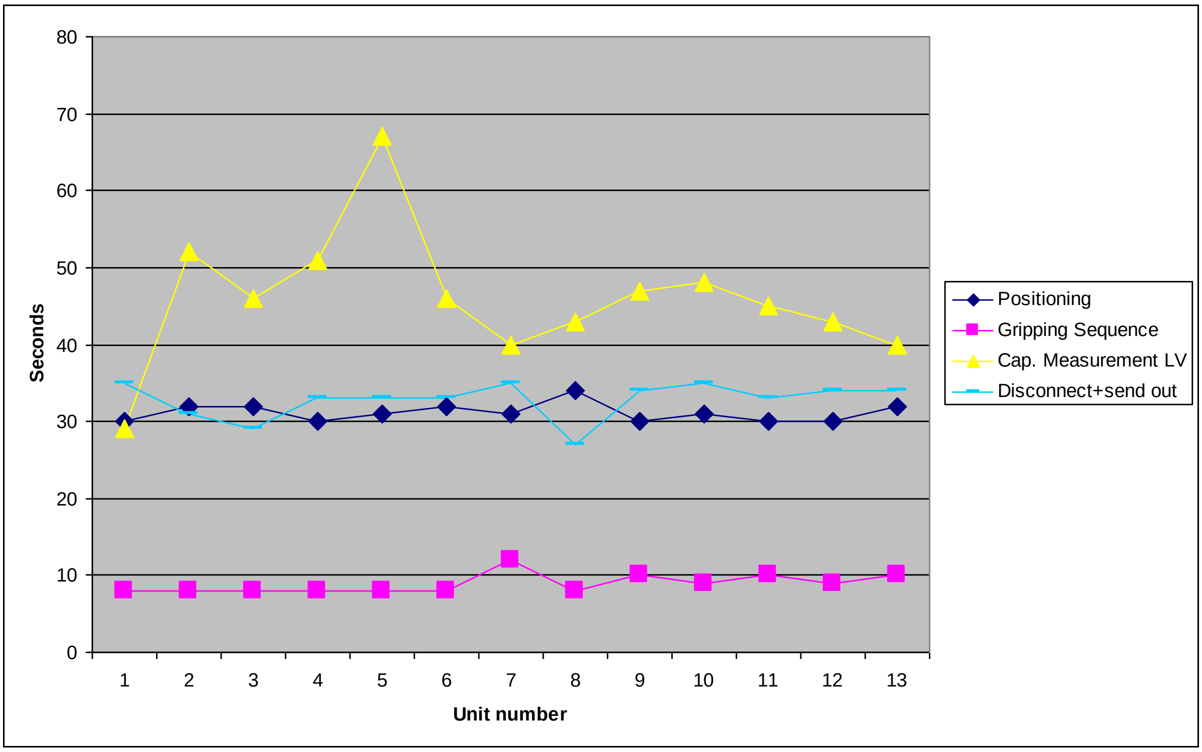


Figure 5-4 Process step lead times 202

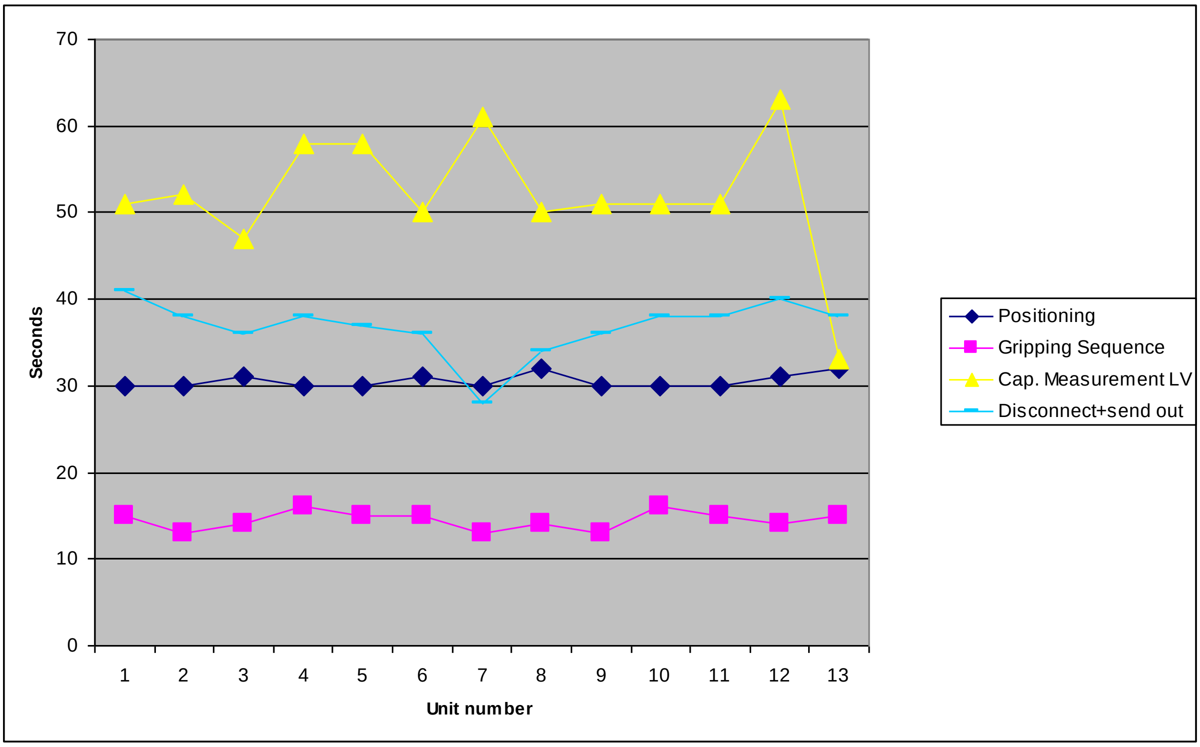


Figure 5-5 Process step lead times 992

The yellow curve shows the capacitance measurement at low voltage as well as the balancing of the system.

The system must be balanced every time a new capacitor unit is connected to the system. The reactive effect of the capacitor will be evened out by the magnetic field created by the gap in the transformer, thus making the system balanced. If the system is not balanced properly the current will increase faster than the voltage and the system will not be able to deliver the proper voltage to the capacitor. The more unbalanced the system is the higher the current and lower the voltage will become.

In order to improve the yellow curve, capacitance measurement low voltage, it must be more stable, robust, and the time must be reduced. According to experts [20], this has happened before and the probable cause of this problem is one of three different options. There are high losses in the reactor caused by insulation malfunction, a motor in the exciter is malfunctioning, or there is an error in the circuit board of the transformers gap control motor.

The solutions to these problems will not be addressed according to the delimitations; however they are being presented in chapter 9 Future studies on page 55.

The magenta colored curve describes the gripping sequence of the capacitors. This part of the process, as shown on Figure 5-4 and Figure 5-5 is very stable. The only parameter affecting the duration of this process is the size of the capacitor unit. A larger capacitor unit will decrease the traveling distance of the gripping device thus reducing the time. A smaller unit will increase the distance and increase the time. This effect is seen when comparing Figure 5-4 and Figure 5-5.

By changing the speed of the gripping device time will be saved on the smaller capacitor units. When reducing the time used for every capacitor unit, money will be saved and more units are able to be tested. To improve this stage of the process a change in the program controlling the gripping device is needed. This will be presented as future work in chapter 9.

The light blue curve describes the process of disconnecting and sending out the unit from the box. As the test is completed, the gripping device, as well as the earth plate, is disconnected from the capacitor unit inside the box. Following, the pulley system is attached to the wagon and sends it out from the box.

By reprogramming the sequences of this operation the lead time will be reduced and in the end saving money. As stated in the delimitations the programming will not be addressed in this thesis, however, it will be addressed in chapter 9 Future studies on page 55.

The dark blue curve illustrates the positioning of the capacitor inside the box. As the capacitor unit enters the box a pulley system is attached to the wagon, and pushes the capacitor into position, "pulley in" is used, see Figure 5-6. As the wagon is pulled in, the wagon stops at its destined location and the attached capacitor unit commences to sway due to the inertia of the capacitor unit. This oscillating motion, the sway, is not actively reduced. This is described in detail in chapter 4.2 Automatic sequence on page 28. When the test is finished, the "pulley out" is attached to the wagon and pulls it out, see Figure 5-6.

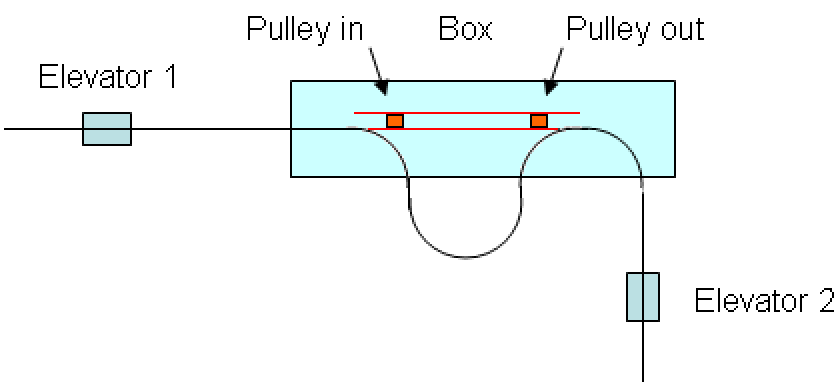


Figure 5-6 Pulley system in the box

This part of the process can be greatly improved. When looking at the dark blue curve, the process itself is very stable due to it being programmed in the PLC to wait for 30 seconds. By lowering the curve, a substantial amount of time can be saved compared to the time it takes today. By applying changes to this part of the process the total lead time for the product will be lowered, the efficiency of the box will increase and money will be saved due to a reduction in lead time.

5.1 Improvement concepts

The improvement proposals are developed with the reduction of the sway of the capacitors in mind. As described in 5 Results, the sway needs to be actively reduced. Four proposals have been generated and decision matrixes are generated according to KT Ulrich, SD Eppinger 2008.

While developing the concepts several criteria are needed in order to accurately be able to compare the different concepts to each other.

The criteria are as following.

1. *Stop the sway*, all the concepts must in some way reduce the sway. By doing so the lead time for the process decreases.
2. *Small install operation*, when installing the system, the reconfiguration of exixting equipment in the box must be as small as possible, the more complex the system the greater the cost.
3. *Reduces lead time*, just because the system reduces the sway it does not mean the lead time will decrease. If the system reduces the sway to 10 seconds it must not take the system 20 seconds to do it.
4. *Components are reparable*, as much components as possible must be reparable. The concepts should not include components impossible for ABB Capacitors to repair.
5. *Operates with different bracket configurations*, many capacitors have brackets mounted at different locations on the container. The system must be compatible with any one of these configurations.
6. *Minimize process errors*, the system itself must not be complex so it causes errors in the process.
7. *Compatible with current and future capacitor sizes*, there are thirteen different container sizes; all of them must be compatible with the system.
8. *Not sensitive to high voltage*, the system must not be sensitive to high voltage or disturb the high voltage process in any way.
9. *Easy access when repairing*, access to the system must be easy if repairs are needed to be done

5.1.1 Concept 1

Concept 1 consists of an oscillation, or sway, stop. The basic principle is to prevent the capacitor unit to begin the oscillation. As the conveyor wagon stops the oscillation of the capacitor unit must not begin. This can be achieved by stopping the capacitor unit at the same time the wagon stops.

The construction would consist of a plastic or metallic part, which is raised from the earth plate as the wagon stops; this will prevent the capacitor unit to sway. Afterwards the part will retract and will not intervene in the process until the next unit enters the box.

An additional system is needed in the box for this concept to work. There are approximately 30 different container configurations, three different bushings, and three different attachments to the conveyor wagon. The distance from the earth table to the bottom of the container must be the same. Concept 1 is called the sway-stop concept.

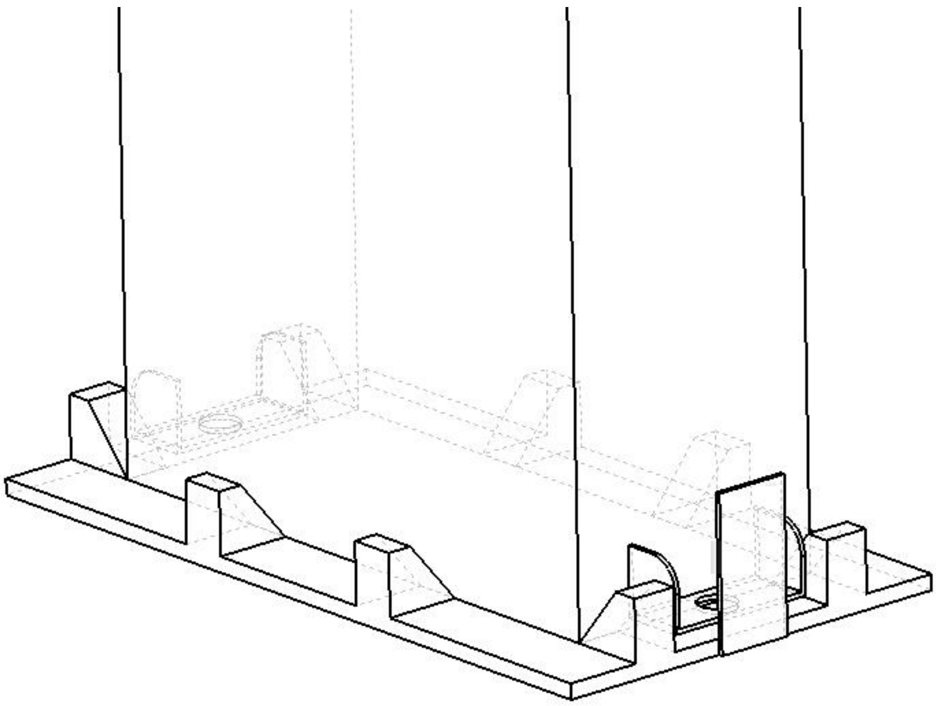


Figure 5-7 Concept 1

5.1.2 Concept 2

The second concept consists of a system of two gripping arms. As the capacitor unit stops in the box the sway will begin, at this point, the gripping arms will rise and attach and hold the capacitor unit to stop the sway. Subsequently, a few seconds later, it will release the capacitor unit and the process will continue. This concept is more complex than concept 1 hence there are more moving parts. Concept 2 is called the gripping arm concept.

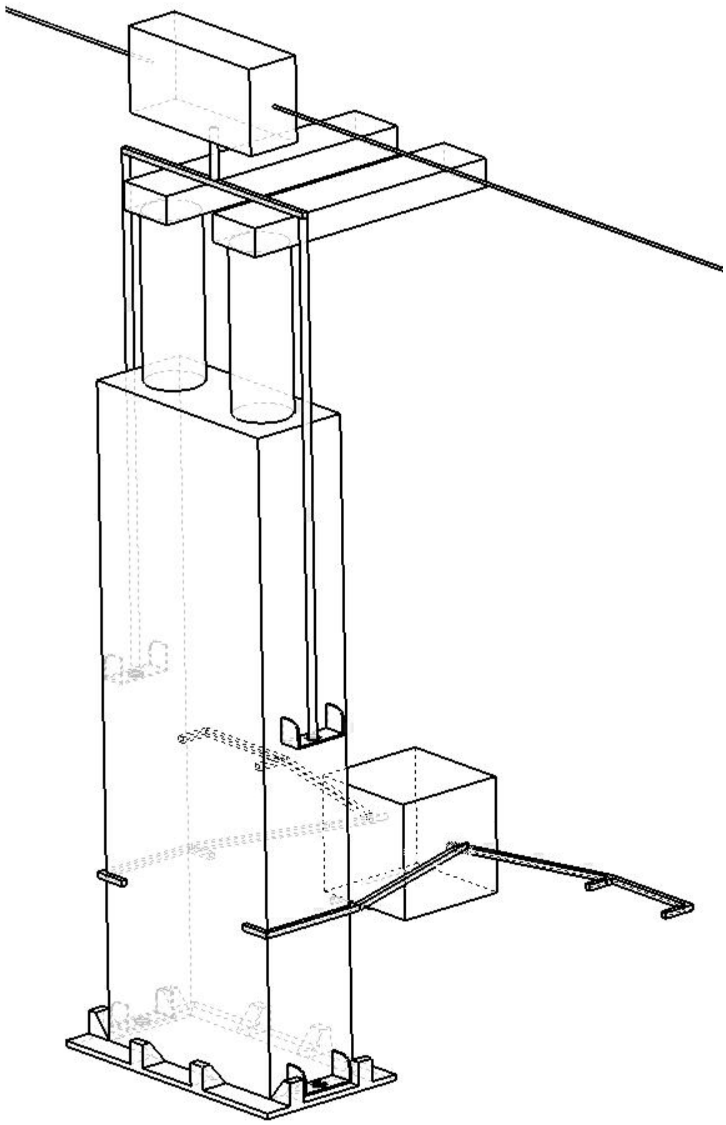


Figure 5-8 Concept 2

5.1.3 Concept 3

Concept 3 consists of a method which impend the capacitor to sway. The basic working principle of the concept is to use a belt to prevent the sway. As the capacitor enters the box, a belt system, on both sides of the capacitors rolls over the container. The speed of the belt can either be the same as the conveyor wagons or be independent. As the wagon stops the wheels will stop and the capacitor will be in the correct spot immediately.

The positioning of the capacitors will not be a problem for the gripping device and there will not be any capacitor oscillation present as the belt always will be in contact with the capacitor container. Concept 3 is called the belt concept.

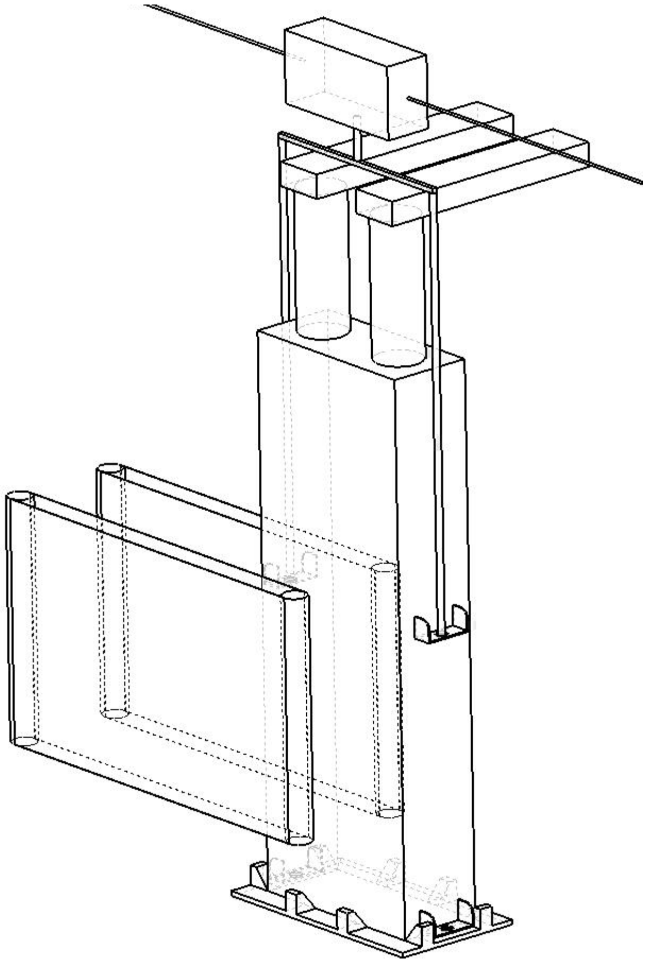


Figure 5-9 Concept 3

5.1.4 Concept 4

The forth and last concept is a concept already in use. In consists of a spring loaded break, placed on the conveyor as seen in Figure 5-10. As a conveyor wagon passes, the break is pressed against the wagon and will reduce its speed over a pre defined distance. In comparison to a regular stop which stops the wagon immediately causing it to sway; this break will reduce the speed in a manner in which the oscillation motion of the capacitor will not be as great as if the common stop is used.

Concept 4 is called the wagon break concept.

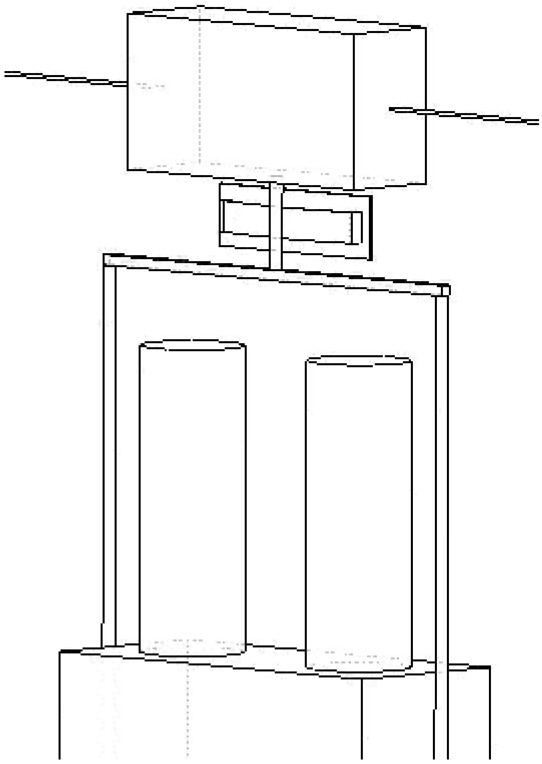


Figure 5-10 Concept 4

5.2 Concept screening

The concept screening is done as explained in 5 Results on page 32. By using the decision matrix the concepts will be raked and ordered and the best concept can be selected and improved. The screening is done to remove the less viable options.

The basic principle of the following decision matrix, Table 5-2, is to compare the different concepts. The reference can theoretically be any of the mentioned concepts. However, the reference should be a well known concept, preferably an existing concept as explained in 4.3 on page 30. [10]

Table 5-2 Decision matrix

Kriteria	Alternative				
	Reference	1	2	3	4
Stop the sway	DATUM	+	+	+	0
Small install operation		+	-	-	+
Reduces leadtime		+	+	+	0
Komponents are reparable		+	+	+	+
Operates with different backet configutarions		0	0	0	0
Minimizes process errors		+	+	+	0
Compatible with current and future capasitor sizes		0	0	0	0
Not sensitive to high voltage		0	0	0	0
Easy access when reparing		+	+	-	-
Σ +		6	5	4	2
Σ 0		3	3	3	6
Σ -		0	1	2	1
Netto value		6	4	2	1
Rank		1	2	3	4
Improve concept		Yes	Yes	No	No

When the datum has been established the concepts are scored with wither “better than” (+), “same as” (0) or, “worse than” (-) for each criterion. The theory is to compare the actual concepts criteria to the datum. If the concept fulfills the criteria better than the datum a “+” is plotted in the designated location. If it is equal to the datum a “0” is plotted, or if it is worse than the datum a “-” is plotted.

Afterwards the sum of the “+”, “0” and, “-” is calculated and a netto value is calculated. Following, a rank is made of all the concepts and a selection of which concepts to improve is made. The number of concepts selected for improvement is based on the available resources; personnel, money, time, etc. [10]

Since none of the new concepts are in existence, the claims on the criteria are theoretical. An estimate has been made of how the product fulfills the criteria. Each criterion is ranked on all the concepts before moving on to the next, thus making the rating easier. On the other hand, if there are a large number of concepts, a faster approach can be used. Each concept can be rated completely before rating the next one. [10]

In this case, concepts 1 and 2 are selected to be evaluated and improved.

5.3 Concept evaluation and improvement

Two of the concepts have been selected for further examination and improvement. The positive and negative aspects of both concepts will be looked upon and evaluated.

5.3.1 Concept 1

When comparing the concepts, concept 1 requires less rebuilding of the box to install. The requirement to install this concept is to rebuild the earth plate. As seen in Figure 5-7 on page 40, a small steel or plastic rod is required.

Furthermore a system to raise and lower the rod is required. This system is preferred to be a pneumatic system hence there already is a pneumatic system installed in the box.

Difficulties arise when the container is attached with brackets at the bottom. The brackets come in two variants, either at 6mm from the bottom or 40mm from the bottom. As seen in 1Appendix I, the earth plate have wedges mounted on all sides. When the capacitor is placed on the earth table the bracket is located between the wedges. If the sway-stop is in contact with the bracket, the capacitor unit will not be vertical. When the sway-stop is lowered the capacitor will begin to sway and a missed connection may occur.

A modification of concept 1 is done to prevent this mishap. Two of the wedges are removed from the earth plate so the bracket is located in between the two sway-stops, see Figure 5-11.

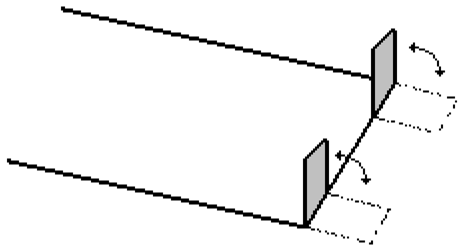


Figure 5-11 Concept 1, the two sided sway-stop

The improvement done creates more moving parts in the concept. Larger number of moving parts increases the probability of malfunction in the concept.

An additional concept improvement has been generated which uses only one sway-stop and allows the bracket to be located in front it. Additionally it allows the capacitor unit to be placed vertical over the earth plate. As Figure 5-12 shows the basic principle is the same as the basic concept 1 displayed in Figure 5-7. In this case an additional 90 degree angle has been added to allow the brackets to be located beneath the sway-stop.

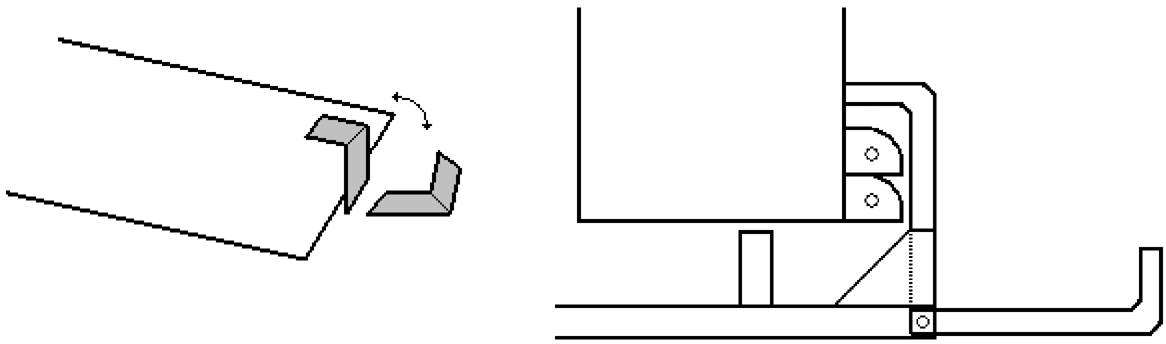


Figure 5-12 Concept 1, 90 degree sway-stop

5.3.2 Concept 2

Concept 2, the gripping arm concept, is more complex compared to concept 1. More moving parts in comparison to concept 1 will make this concept more expensive.

The great variety of container sizes and locations of the brackets makes it difficult to find a common reference on the capacitor unit. A common reference is needed in order for this concept to function properly. The common reference is a location on the capacitor container, which is the same for all sizes of the container. Additionally the reference must be independent of the location of the brackets on the capacitor unit.

The advantage of using this concept is the reliability in the reduction of the sway. Hence there are two gripping arms holding the capacitor unit from both sides, as seen in Figure 5-8, the unit is hold in place more firmly than in concept 1.

Another advantage is the installation of the gripping arms; the platform on which the equipment will be installed is the same as the earth plate is connected to. No additional equipment to rise and lower the gripping arms will be needed.

5.4 Concept selection

When comparing the two concepts, several new criteria are taken into account. Afterwards a selection of the best concept is made. A new matrix is done where the new criteria are inserted. [18]

The procedure is repeated again in the same matter as in 5.2 Concept screening, however only concept 1 and concept 2 will be in the matrix.

The new criteria are as following:

1. *Component size*, the size of the components should preferably be as small as possible.
2. *Additional systems needed*, in order to have a fully operational concept an additional system is needed. As mentioned in 5.1.1, a system with the ability to locate the bottom of the container is needed.
3. *Number of moving parts*, every one of the concepts has a number of moving and stationary parts in order for it to work. A large number of parts will increase the probability of failure in a system. The amount of moving part is preferable as small as possible.
4. *Cost*, cost is the essential issue for all manufacturing. If the cost is to high the payback time will be too long, and the concept is not implemented. The cost must always be kept as low as possible.
5. *Used volume inside box*, the volume used inside the box must be as low as possible (note difference between size and volume). If a large volume is present inside the box flashovers might occur. If the volume is too great inside the box, the griping device might not be able to move to a needed location.
6. *Sway reduction reliability*, how reliable is the reduction of the sway? If a stop is used on both sides of the unit the reliability is higher compared to using only one side.

Table 5-3 Decision matrix

Kriteria	Alternative	
	1 (ref)	2
Stop the sway	0	0
Small install operation	0	-
Reduces leadtime	0	0
Komponents are reparable	0	0
Operates with different backet configutarions	0	0
Minimizes process errors	0	0
Compatible with current and future capasitor sizes	0	0
Not sensitive to high voltage	0	-
Easy access when reparing	0	0
Component size	0	-
Additional systems needed	0	0
Number of moving parts	0	-
Cost	0	-
Used volume inside box	0	-
Sway reduction reliability	0	+
Σ +	0	1
Σ 0	15	8
Σ -	0	6
Netto value	0	-5
Rank	1	2
Select concept	Yes	No

As seen in table 6-3, concept 1 is the concept chosen to be used to improve the test process.

By implementing concept 1 an estimate reduction of lead time in the test process will be 20 seconds for each capacitor unit. According to the investigations an average of 302 seconds for each capacitor is needed. The time of the sway is reduced 66% and the total lead time for the process is reduced approximately 7% for each capacitor unit.

6 Economy

At ABB Capacitors a payback time of no more than 5 years is implemented.

The payback method is a simple way to calculate how long it takes for an investment to pay off its own investment cost. The drawback of the method it is simplicity [21]. The method does not account for interests or inflation. Investment calculations using interest is mostly used in large projects. [22]

As stated in 5.4, the time reduction for each capacitor test is estimated to be 20 seconds. Approximately 30 000 capacitor unit were produced at ABB Capacitors during 2008. 70% of the units are tested in the box and 30% in the laboratory. Consequently, during 2008, 21 000 units were tested in the box. A time reduction of 20 seconds at 21 000 units equals to a time a time reduction 117 man-hours in the process each year.

The economic benefits can be viewed in two different ways. The first option is to look at it as a pure profit. The same amounts of workers are used to test additional 117 hours. During 117 hours approximately 1400 additional unit tests can be performed every year. The cost for testing the additional units will not increase; the worker-cost will be the same as before the implementation of concept 1.

The second option is to look at it as money saving in the production. The same amount of units can be tested with a smaller workforce.

A worker costs 400 SEK per hour. When producing the same amount of units, the worker cost reduction will be 47000 SEK every year excluding additional payment for working shifts and weekends. 117 hours is not enough to reduce the number of workers or change the workers shifts. However extra hours will not be needed if orders are late or extra capacity is needed during a few weeks.

The investment cost to implement concept 1 in the box will be approximately:

Material cost: 5 000 SEK

Assembly cost: 15 000 SEK

Installation cost: 15 000 SEK

Run-in period and calibration: 10 000 SEK

When calculating the payback time using the described method, formulas are used as stated by Bergknut, 1993. If the yearly payment surplus is the same, equation 7-1 is used.

$$n' = \frac{G}{a} \qquad \text{[eq. 7-1]}$$

Where

G is the investment cost for the project.

a is the payment surplus every year.

n' is the payback time.

If the yearly payment surplus varies every year, the payments (a) are added until the investment (G) is covered, equation 7-2 is used.

$$G = \sum_{i=1}^{n'} a_i \qquad \text{[eq. 7-2]}$$

Where

G is the investment cost for the project.

a is the payment surplus every year.

n' is the payback time.

The method described in equation 7-1 will be the method used to calculate the payback time.

G= 45 000

a= 47 000

$$n' = \frac{45000}{47000} \approx 0{,}95$$

According to the used model the payback time for ABB Capacitor will be one year if concept 1 is implemented.

7 Conclusions

As seen in 5 Results, 4 different concepts were generated to solve the problem in the box. Concept 1 and concept 2 was selected to be improved while concept 3 and concept 4 was eliminated during the first concept screening.

Concept 3 and concept 4 were not selected due to several facts.

When looking at concept 3, one of the big drawbacks of the concept is the great reconstruction needed in the box to install the belt equipment. Not only will that, but the fact that there is not much space to place the belt equipment make the reconstruction of the box even greater. Another drawback is the cost, as this concept is more complex to install the cost will rise resulting in longer pay back time. An advantage is the belt function, its position is independent of the size of the container and no adjusting of the belt will be required for any of the container variants.

Concept 4 is the simplest of the four concepts. The concept only needs one, already in use, part added; a spring loaded conveyor break. The essential problem of using the spring loaded break is the oscillation; it will still be present, since it has not been reduced mechanically on the container, and must still be decreased in some form. The great benefit with concept 4 is the price and the fact that it already exists and is used on other parts of the conveyor. It is very cheap to install and use, no modification to the conveyor and box is needed to install the break.

On concept 3 and concept 4 the drawbacks were greater than the benefits, as seen in Table 5-2 Decision matrix on page 44, by that fact neither concept 3 or concept 4 was selected to be improved.

For concept 1 and concept 2 the same procedure was done as with concept 3 and concept 4. They were systematically compared to the system in use. According to the box operators, there is no common reference available due to the large numbers of different container configurations. When a small capacitor unit is tested, the gripping arms will be located too low to secure the capacitor unit.

As explained in 5.1.3 on page 42 and 5.1.4 on page 43, a drawback for both of the concepts is that the location of the bottom of the container must be known. To achieve this, a system measuring the location of the bottom of the container is needed. When the system knows the location of the bottom, the earth plate can be raised to a determined height and the distance form the earth table to the bottom of the container will always be the same. This is needed due to the fact that the sway stop and the gripping arms are located at fixed locations in relation to the earth plate.

Another problem is the location of the gripping arms on concept 2. The apparatus is located underneath the gripping device. When a small capacitor unit is tested the distance from the high voltage equipment might to be too small and flashover may occur.

Before selecting the two best concepts, at the concept screening, an important fact must be taken into account. Should a concept with the same netto value be ranked the same? Hence this was not a fact in this case, no measurements had to be taken. However if it was a fact, should the concepts be ranked the same if one only had "0" and the other had half "+" and half "-". The netto would have been the same. If this scenario had occurred, additional statements or weights of the criteria had to been used.

A second matrix was done where concept 1 and concept 2 were compared again. This was done so the two concepts were able to be compared against one another. This can be compared to the first matrix where all the concepts were compared to the system in use today. Additional improvements had also been done to the concepts to improve there functionality. Moreover, additional criteria were added to the matrix so a more detailed decision matrix could be made.

As stated in 6 Economy, the cost to implement the selected concept 1 is 45000 SEK. Savings on reduced work hours will be 47000 every year. Increased capacity for the box is 7% which is compared to 1400 additional units every year. The pay back time for the installation is only 1 year. Even if the investment cost is the double, the pay back time will be 2 years; which is far below the 5 year standard ABB Capacitor implements.

8 Discussion

When the test process has been improved the capacity will increase in the box. The additional capacity will be difficult to make use of since all of the following processes are connected through the conveyor. This means that the bottleneck will be moved to a different location in the process. Even tough the box capacity has increased; the blasting and painting must also increase their capacity.

Additional improvements can be done to the conveyor system. Today every process from testing to blasting and painting is interconnected through a single conveyor system. If there is an error in the painting, the entire conveyor system is stopped until the error is corrected. This will result in the process being stopped at both the blasting and the box. To prevent this effect, each process should have its own independent conveyor system with buffers. If this system is used, the processes are independent from each other and even if one fails, the other two can continue and fill the buffer until the error is corrected.

As being described in 9 Future studies on page 55, to further improve the test process in the box additional work is needed to be done. The investigation of variances during balancing and capacitance measurement at low voltage must be looked upon. As stated in 5 Results and as seen in figure 5-4 and 5-5 the yellow curve has a big spread. To reduce the spread and decrease the lead time further, this must be investigated. Additional investigations can be made on different parts of the process as stated in 9 Future studies.

The cost of improving the process might be high; it might be as high as designing a completely new test box. If this is the case and a new box is manufactured, all the difficulties are known today after using a similar system for 15 years.

Regardless of how the process is done, the process of automatically testing the capacitors is a very difficult and complex operation which requires a lot of knowledge and skills.

9 Future studies

The future studies of the test process are described. To improve to process further, all these different parts of the process can be looked into.

- Title: Investigation of variances during balancing and capacitance measurement at low voltage.
- Description: During the test process the system is balanced before every capacitor test. This is done to ensure the proper voltage and current is sent to the tested unit. The time it takes for the same type of capacitor varies greatly. The problem can be caused by one or several factors. Some of them are; high losses in the reactor due to isolation problems, problem with the exciter voltage, or the control unit of the transformers gap motor. An investigation is needed to find the cause.
- Knowledge entry requirements: High voltage electrics, mechanics
- Duration of project: 5 - 10 weeks

- Title: Programming of conveyor system
- Description: It takes too long for the capacitor unit to exit the box. By reprogramming the PLC, the pulleys could be activated sooner and the unit will exit faster. This will allow the next unit to enter sooner.
- Knowledge entry requirements: Programming, electrics
- Duration of project: 1 - 3 weeks

- Title: Programming of gripping device
- Description: The gripping device can be reprogrammed to have a higher speed during long transports. Smaller capacitors have larger distance to travel compared to larger ones. Time can be saved if speed is increased.
- Knowledge entry requirements: Programming, automation
- Duration of project: 2 - 4 weeks

10 References

[1] www.abb.se

[2] ABB High 5 education

[3] T Longland, TW Hunt, A Becknell, 1984, Power Capacitor Handbook, Butterworths, ISBN 0-408-00292-1

[4] Bandalo, F, 2009, Senior Specialist, ABB Capacitors, Sweden, phone +46 (0)240-783686, e-mail; felix.bandalo@se.abb.com, interview on January 19, 2009.

[5] ABB Capacitors info slide, Magnus Bergqvist, 2000

[6] Cyrillius, F, 2009, Capacitors Development, CPU, Sweden, phone +46 (0)240-82023, e-mail; fredrik.cyrillius@se.abb.com, interview on January 20, 2009.

[7] Pralica, L, 2009, Production Manager, CP3, Sweden, phone +46 (0)240-83747, e-mail; ljubomir.pralica@se.abb.com, interview on January 19, 2009.

[8] HiQ Capacitor unit data sheet (2006-08)

[9] Marcus Lind, Operator CP2, 0240-84186, interview on January 30, 2009

[10] KT Ulrich, SD Eppinger, 2008, Prodict design and development, Mc Graw Hill, ISBN 978-0-07-310142-2

[11] B Bergman, B Klefsjö, 2007, Kvalitet från behov till användning, Studentlitteratur, ISBN 978-91-44-04416-3

[12] Edwards E, 1997, Accounting for design, IEE/IEEE, Manufacturing Engineer, ISSN 09569944, Vol 76, pp 69-71

[13] Olhager J, 2000, Produktionsekonomi, Studentliteratur, ISBN 91-44-00674-8

[14] Harrel C, Tumay K, 1995, Simulation made easy, a manager's guide, IIE, ISBN 0-89806-136-9

[15] Ahmad M, 2004, A simple scheme of loss angle measurement of a capacitor, IEE/IEEE, IEEE Transactions on energy conversion, ISSN 08858969, Vol 19, pp 228-229

[16] Bal J, 1998, Process analysis tools for process improvements, Emerald (MCB), ISSN 0954478x, Vol 10, No 5, pp 342-354

[17] Petersson P, Johansson O, Blücher M, Alsterman H, 2008, LEAN Gör avvikelse till framgång, Part Development AB, ISBN 978-91-633-2795-7

[18] Johannesson H, Persson J G, Pettersson D, 2004, Produktutveckling effektiva metoder för konstruktion och desing, Liber, ISBN 91-47-05225-2

[19] W F Lu, J Sun, H T Loh, C W Chua, 2008, Concept selection for market potential using fuzzy selection approach, IEE/IEEE, 2008 IEEE International conference on industrial engineering and engineering management, pp 1699-1703

[20] Malmgren L, 2009, Engineer DAC, Sweden, +46 (0)70- 9625387, interview on march 13, 2009.

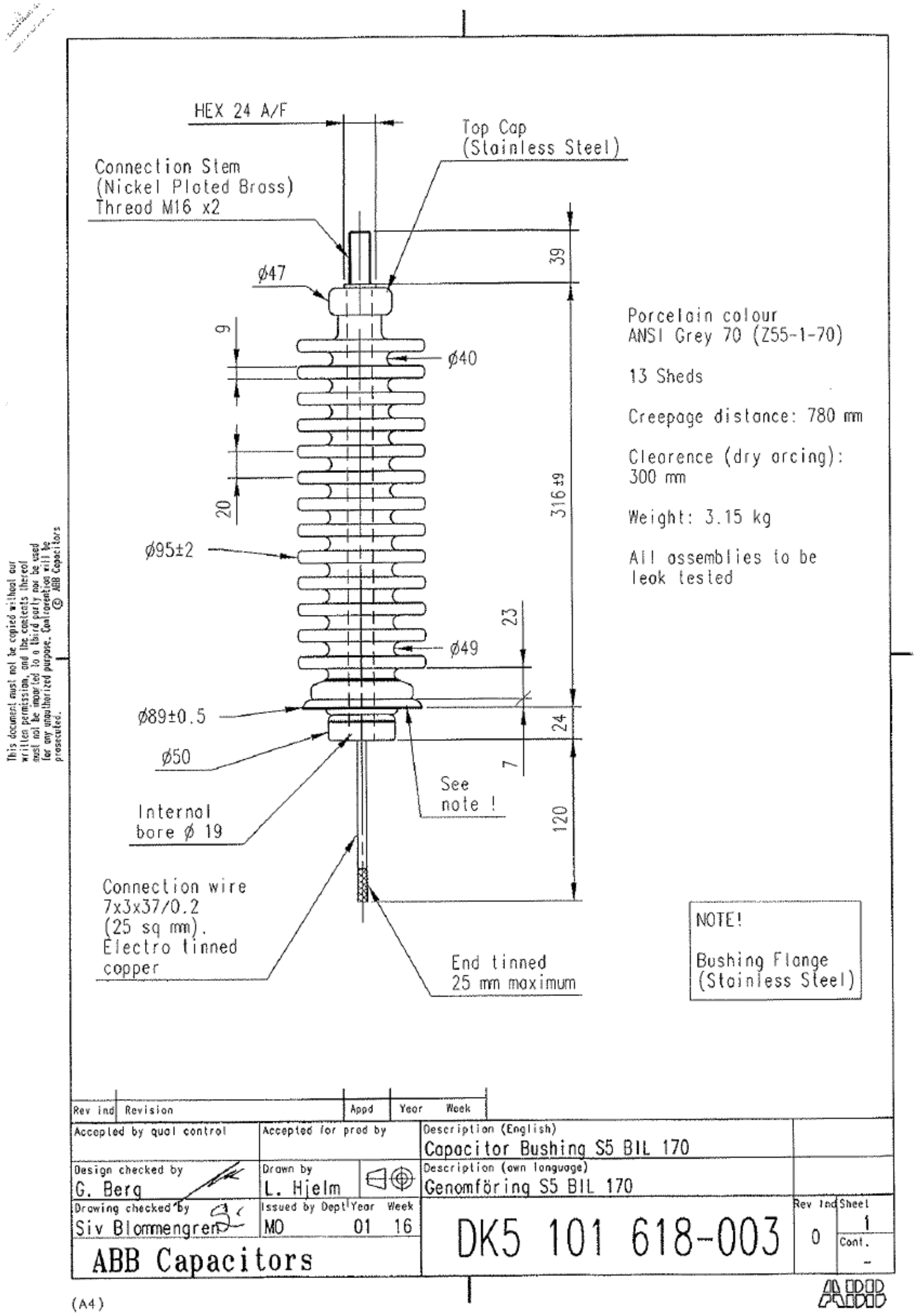
[21] Moore R, 2001, Payback method – too simple and too expensive, Reed Business Information, ISSN 0032082x, Vol 55, No 7, pp 28 -30

[22] Bergknut P, Elmgren-Warberg J, Hentzel M, 1993, Investering I teori och praktik, Studentlitteratur, 5th edition, ISBN 91-44-40475-1

Appendices

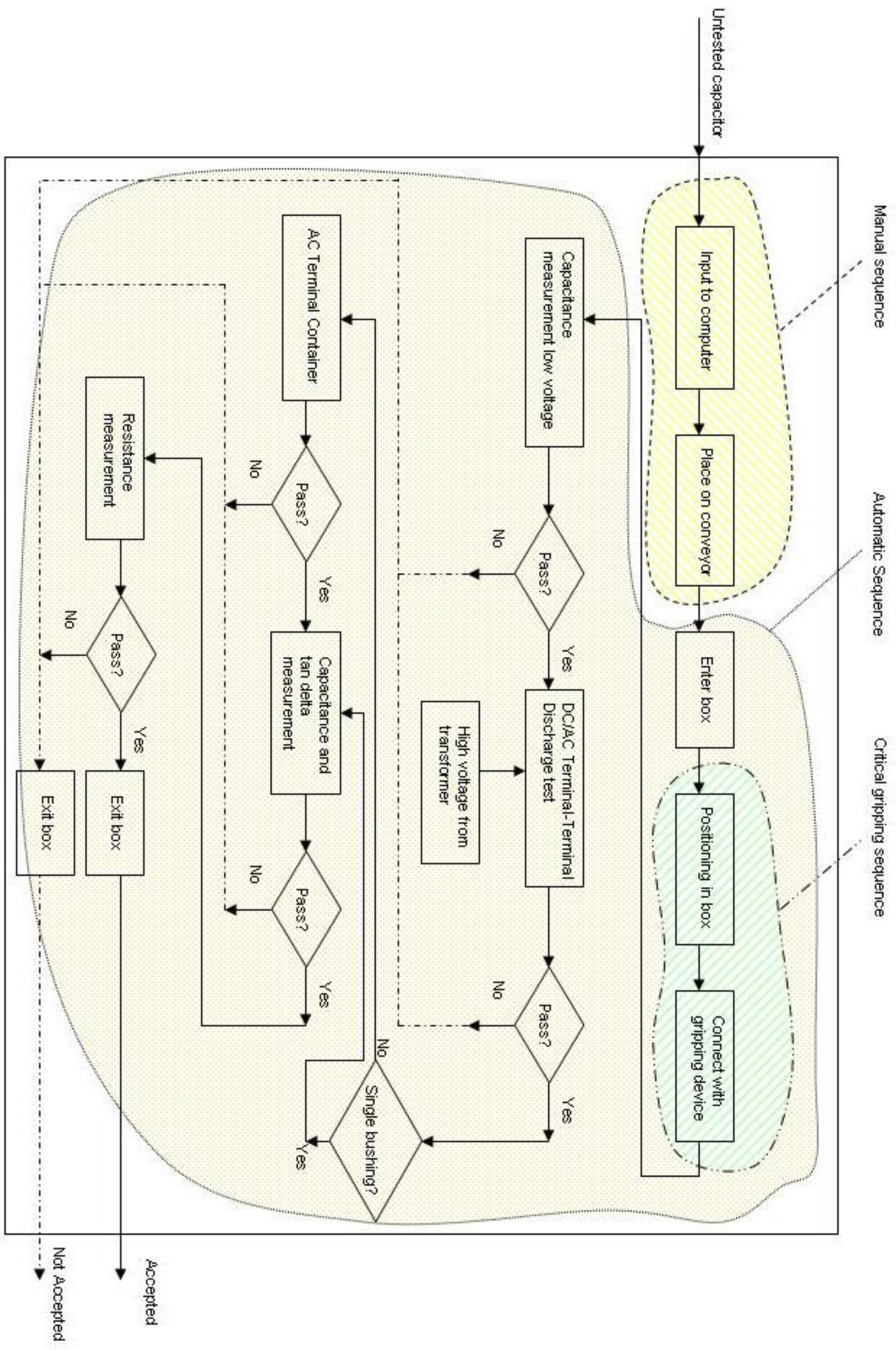
Appendix A Machine layout

Appendix B Drawing S5 bushing

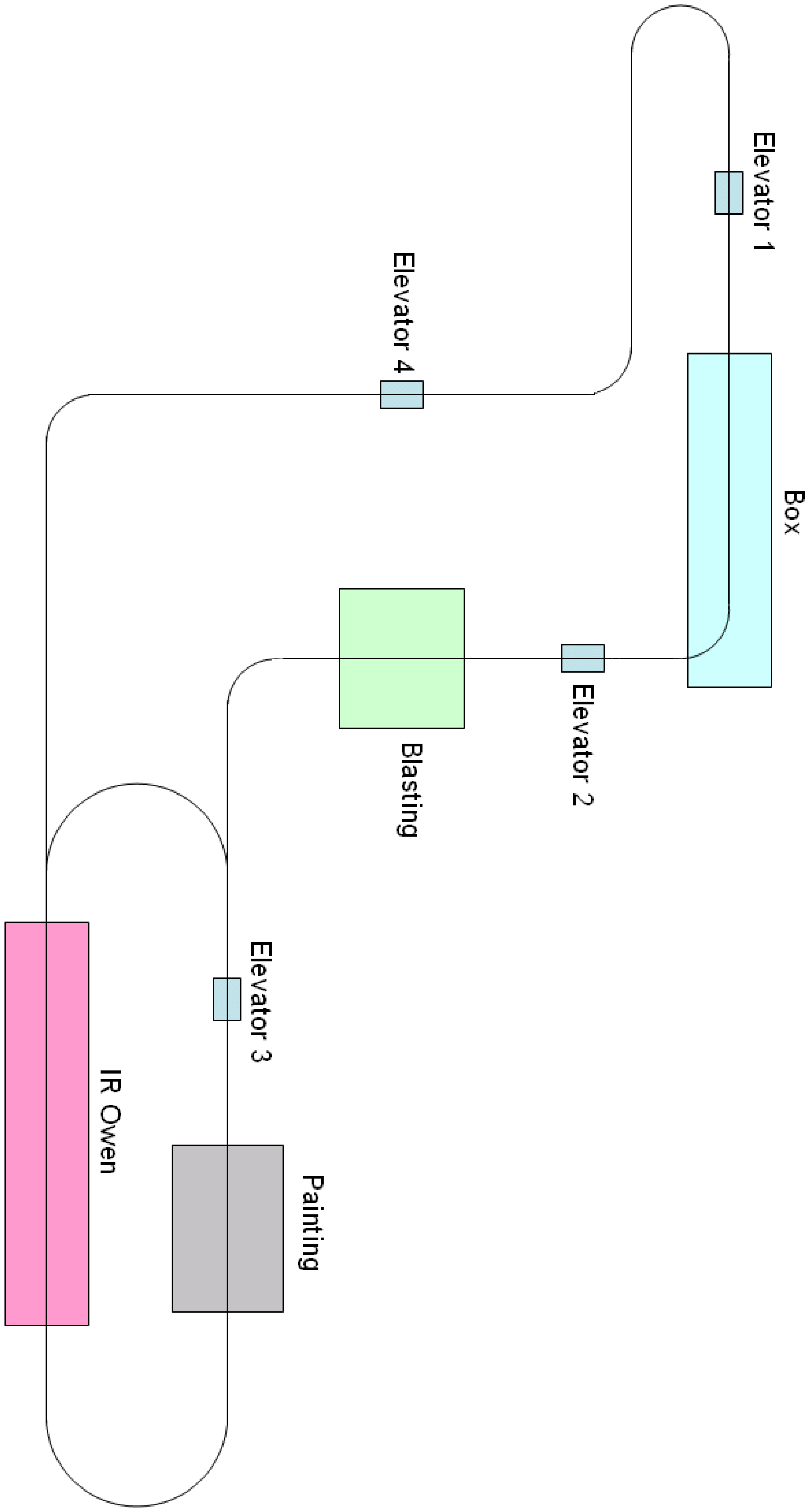


Appendix C Missed connection

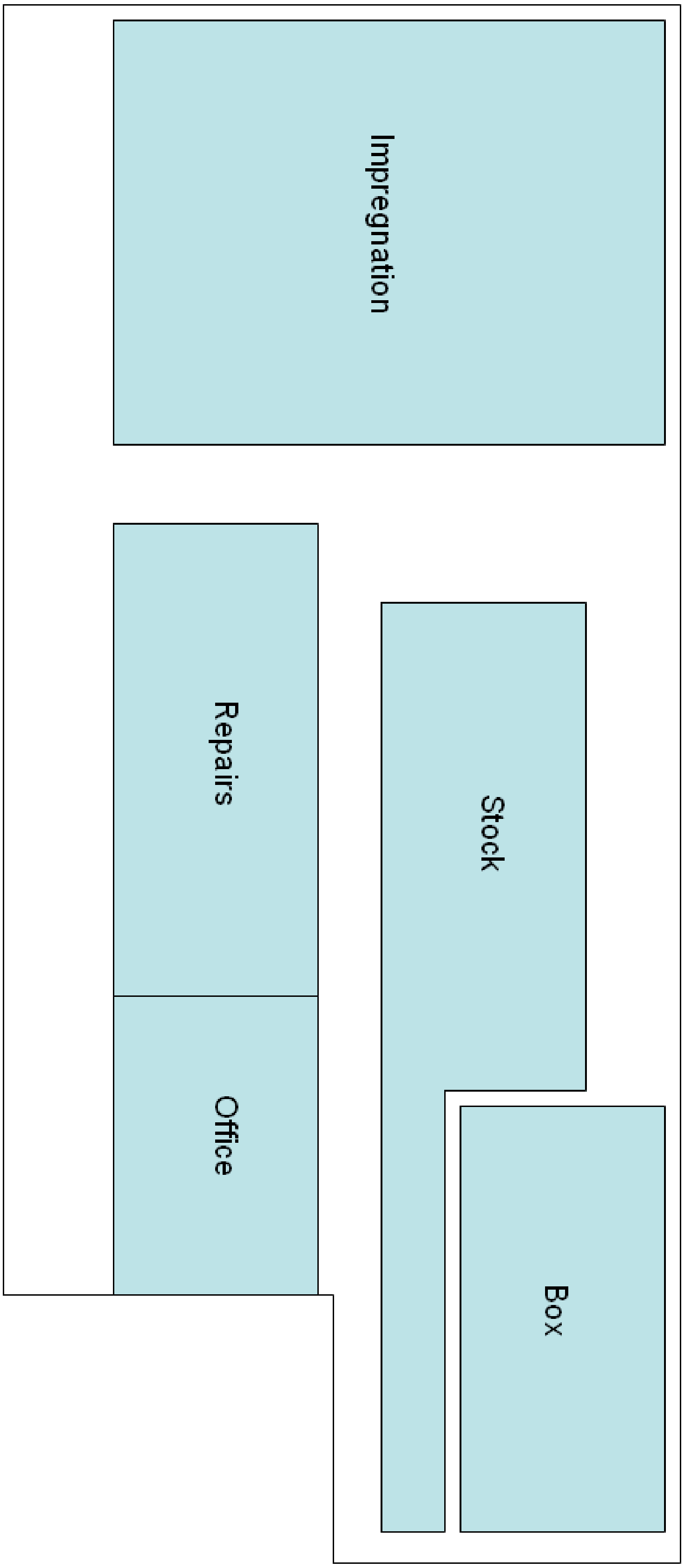
Appendix D Black box of testing process



Appendix E Conveyor track



Appendix F Layout P2



Appendix G Lead time table 202

	Reduce Sway	Gripping Sequence	Cap. Measurement LV	DC Terminal-Terminal	Discharge	AC Terminal Container	Cap+Tan delta nom. Voltage	Resistance	Disconnect+send out		total
1	30	15	51	50	22	44	25	22	41		300
2	30	13	52	50	22	34	43	21	38		303
3	31	14	47	48	24	35	36	22	36		293
4	30	16	58	50	27	32	34	31	38		316
5	30	15	58	47	27	36	34	26	37		310
6	31	15	50	51	26	35	32	29	36		305
7	30	13	61	51	22	35	36	30	28		306
8	32	14	50	50	26	33	34	26	34		299
9	30	13	51	53	21	33	36	22	36		295
10	30	16	51	50	27	33	33	22	38		300
11	30	15	51	50	25	31	38	20	38		298
12	31	14	63	52	25	30	36	19	40		310
13	32	15	33	52	21	33	35	32	38		291
mean	30,5	14,5	52,0	50,3	24,2	34,2	34,8	24,8	36,8		302,0

Appendix H Lead time table 992

	Reduce Sway	Gripping Sequence	Cap. Measurement LV	DC Terminal-Terminal	Discharge	AC Terminal Container	Cap+Tan delta nom. Voltage	Resistance	Disconnect+send out		total
1	30	8	29	52	21	40	52	18	35		285
2	32	8	52	53	28	34	44	29	31		311
3	32	8	46	53	29	33	44	25	29		299
4	30	8	51	53	29	33	56	17	33		310
5	31	8	67	52	25	38	45	17	33		316
6	32	8	46	51	24	39	43	17	33		293
7	31	12	40	54	26	36	58	17	35		309
8	34	8	43	72	28	33	44	16	27		305
9	30	10	47	52	28	34	53	16	34		304
10	31	9	48	51	28	34	43	29	35		308
11	30	10	45	53	29	34	54	18	33		306
12	30	9	43	52	30	34	45	15	34		292
13	32	10	40	52	28	34	51	32	34		313
mean	31,2	8,9	45,9	53,8	27,2	35,1	48,6	20,5	32,8		303,9

Appendix I Gripping device and earth plate inside the box