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On-site dismantling of large transformers

Master's thesis in Product Development

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Abstract

With so many products being made everyday, the demand for materials keep increasing. This keeps stress on digging the earth to get more material. While the earth is a natural source of getting the material, there are other ways in which it can be obtained. Some material like wood in renewable within a shorter timeframe when compared to other material like oil or metals. This emphasises on the future requirements of the material for domestic and industrial purposes. But recycling the expired products, the already available material can be reused instead of utilizing the resource from Earth. Almost every product manufactured has a certain life time after which it just doesn't work as expected. Such products which reached the end of their life time only loses the working capability but the material it is made of remains intact. By recycling such products, the need for material can be partially met. When products with huge dimensions reach the end of their life time, the recycled material can often be in hundreds of kilogram.

Stena Recycling does the same work. The company only recycles expired transformers ranging from small to very huge sizes. To recycle the transformer, the lid has to be removed. The lid is made of steel and is either fixed with bolts or welded to the steel walls of transformer. To remove the lid, the welded part has to be cut out without letting any sparks go into the transformer which can set the oil inside to fire.

The current thesis aims at solving the problem of dismantling huge electric transformers on site and also at the facility owned by Stena Recycling. Interviews were performed and literature review was done to get to a solution for the problem. To get to the solution, a product development process was followed. The result of this thesis was a concept with several modules which can be developed parallel to each other and come up with a final solution. The final solution dismantles the transformer by cutting the lid of transformer. This is done by using milling technology which cuts the metal without producing any sparks and thus preventing the transformer from catching fire due to flammable substances present inside. The following report explains how the solution was developed from the requirements provided by Stena Recycling

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Table of Contents

1. Introduction

This chapter provides a brief information about the company and what it does. Followed with this information is an explanation of the problem which the current thesis aims to solve.

1.1 About the company

Founded in 1939, Stena recycling offers recycling solutions to all kinds of industries from small traders to multinational companies. They design and customize a solution along with the client and also provide training and recovery statistics.

Stena Recycling is a part of a bigger company called Stena Metall. Stena Metall has their business in Recycling, Oil, Trading, Electronics recycling, Sale of scrap, Aluminium, Steel and Finance. The Recycling business is handled by Stena Recycling. Stena Recycling has their facilities located in Finland, Denmark, Sweden, Norway and Poland.

In Sweden, Stena Recycling has about 80 facilities. The current thesis focuses on the facility located at Karlstad, Sweden.

The company goes to the location where an expired transformer is present and then depending on the size of it, either brings the transformer as it is to the dismantling facility or dismantles it onsite and bring the parts separately to the facility. The facility has cranes and other equipment required for dismantling of transformers and also separate containers to differentiate the pieces of transformer. All copper parts go into one container, all iron into another and so on. These separated materials are then sold to industries/customers.

1.2 Problem description

The current thesis concerns the recycling of electrical transformers. At the end of life their life time, transformers are usually dismantled. The large modern transformers are enclosed in a metal casing closed by welding rather than screws. These casings are easily removed at a dismantling facility. But the problem comes when the dismantling needs to be performed away from the facility. Dismantling the transformer or allowing a person to get into the transformer is harder due to the welded lids. Once the welded lids are removed, the other works can be performed with ease. As the transformers can't be carried to a dismantling facility every time a solution to open it on-site is of a higher importance.

The transformers come in various shapes and sizes. The dimensions vary between 2 to 3 meter for the shorter side and 3 to 7 meter for the longer side. There are basically two different shapes that the transformers come in: rectangular and curved.

A rectangular transformer is a normal one which is in shape of a cuboid represented in Figure 1. A curved transformer looks similar to the rectangular transformer but the shorter sides are curved as shown in Figure 2.

Figure 1: Rectangular Transformer shot at the facility of Stena Recycling

Figure 2: Picture provided by Stena Recycling

As the transformer is filled with oil, the oil is removed in tankers but there is some residue left over. The current cutting solutions produce sparks which when come in contact with the oil can produce fire and burn down the whole transformer. To prevent this the transformer is filled with foam to prevent sparks.

2. Background

At the moment, Stena uses a Hack Saw to cut open the welded lids of transformers. This method is problematic since the hack saw produces small amount of sparks. These sparks haven't been causing any damage but are still dangerous and should be eliminated. In addition to the sparks, the hacksaw is unstable. As it is used by the human, it is very shaky and also takes a long time of about 4 to 12 hours to cut open the transformer depending on the size.

The other method used by Stena is to cut the transformer by using a weld. This is a risky process. A firefighting team has to fill the transformer with foam before the walls can be cut by weld. Once the cutting starts, the foam flows out through the open spaces and needs to be refilled. This is a costly process.

The weld is a relatively small equipment when compared to huge metal cutting machines. And so is the hack saw. They are very portable and easily operable by two members. The hack saw is not reliable and the weld produces lot of heat and consumes cost in terms of foam. The company uses hacksaw more than the weld.

3. Methodology

The Methodology section describes the several methods that were used during the whole process of the Thesis work. The methods are described based on their origin and bystating the extent to which the method was used, why that method was chosen and what results were expected from using that method.

The methods are chosen from various fields of customer requirement analysis, idea generation and also the technical methods employed to check the reliability of the ideas.

3.1 Data Collection Methods

Data Collection Methods, as the name suggests, are used to collect data. The type of method employed depends on the type of data required. There are two types of data namely Qualitative and Quantitative [3]. For the current thesis, considering that Qualitative data is of higher importance, the data collection methods for obtaining qualitative data were used. They are Interviews and Expert Consultation. There are other types of methods but were not used as the selected methods do the required job.

Interviews:

Interviews played an important role in getting the information. Since this is a Breakthrough product [2], the focus was kept on utilizing available technologies to make a product that could satisfy the needs of customer. Going through several technologies that are available is a long time consuming process. For this purpose, interviews were selected to get quality information [3]. There are three different kinds of interviews: [3]

a) Structured
b) Semi Structured
c) Unstructured

A structured interview contains an interview guide which has a predefined set of questions. What makes the interview structured is the way the guide is followed. The whole interview follows the guide and the questions are asked in the same pattern. Also only the questions from the guide are asked without any deviation [3]

A Semi Structured interview follows the structured interview except the fact that follow up questions are asked wherever seems required by the interviewer based on the answers given by the interviewee. There will be some kind of deviation but the guide will be followed [3]

An Unstructured interview is led by the answers of the interviewee. The interviewer does not get prepared in advance about the questions that need to be asked but knows the purpose of the interview and asks questions according to the ongoing discussion until the required information is obtained.[3]

Only the Semi Structured interviews were followed for this thesis.

A total of three long interviews and four short interviews were done followed by frequent skype meetings with the company.

The first interview was with the company official which happened at the company in Karlstad. This was the first interaction with the company where more information about the thesis and why the company wants a new product to be developed were discussed. This can be considered as a customer visit as well because a chance to see the facility and access to several transformers was obtained. The visit was helpful as so much of information was recorded.
The second and third interviews were online interviews with the company. This is to discuss the ongoing process of the thesis and to get approval for the decisions taken along the way and to get an input from the company.

Expert consultation:

This was another data collection method suggested by Ulrich [1]. The purpose of this method is to get the information from experts dealing with similar situations. Their knowledge source is enormous and is a lot helpful. This is also time saving as the literatures studies involved in getting similar knowledge/solutions take up so much effort [1].

The consultations were done in person via face-to-face interviews or through emails. A total of three such consultations happened. One through interview and the other two through emails.

3.2 SWOT Analysis:

SWOT stands for Strength, Weakness, Opportunity and Threat. It is a tool that helps find out the key points and focus on the most important issues that affect the business of the organization [4]. It has 4 blocks for Strength, Weakness, Opportunity and Threat. By filling in the blocks, the key points that helps develop the next step can be determined.

Since the current thesis is about developing a new product, this tool was used to find out the important factors that could affect Stena Recycling. These factors especially focus on the impact on the resources of the company and the market availability. Four strategies were developed for the product and a SWOT analysis for each strategy was performed to select the strategy that will benefit Stena Recycling the most in terms of financial and human resources, and the future business aspects.

3.3 Blackbox model

This model breaks down the problem into different functions. Each function is written in a particular format of “Verb + Noun” [5]. These functions are connected by series of arrows and pointers which describe the whole dismantling process [5]. This model was used since the process of how the transformer is being dismantled now is important to be understood. This information helps in dividing the problem into different functions and the most important functions that can solve the problem are selected.

3.4 Brainstorming

This technique is used to produce ideas without any limits. This method is used because of the freedom. The ideas produced are not limited to anything and even impossible or craziest ideas can be suggested. The advantage is that based on one idea, many followup ideas can be produced and a sort of chain reaction in ideas can take place. The freedom in the beginning of a project is very high [13] and to exploit this freedom, brainstorming seems to be a very good method. This is used to produce ideas for several of the function categories explained in the Idea Generation chapter. Several ideas were produced which in a combination can reveal different solutions [1].

3.5 Morphological Matrix

This is a matrix with several functions in the column and ideas for each function in the row. So, this matrix has various solutions for each function [14]. By selecting different solutions from each row, many configurations can be produced that help in generating several concepts [14]. In this thesis Morphological matrix was used to create the configurations.

3.6 Concept Screening

This method screens away the unwanted configurations that are not feasible [1]. This is done through a set of criteria. Once the initial screening is finished, more criteria are added to screen out the other configurations and final concepts are chosen.

3.7 Decision Matrix

This is a method used in concept screening. This method was the criteria against the concepts. The score of each criteria for each concept is noted and the final score for each concept is calculated and the concepts are screened out based on this score [1].

3.8 System Level Design

This phase of Product Development concentrates on making the initial developments of the selected concept [1]. This includes making the product architecture where the details about contact between various parts are decided and also the overall structure of the concept is dealt with [1].

4. Product Development Process

This section explains the complete process followed in this thesis to come up with a concept to solve the problem. Using the methods explained above in the Methodology section, the process is explained.

4.1 Division of the Problem

It is important to define the problem before starting to work on a solution [2]. Based on the information available, all the methods that were expected to be helpful were collected. To collect this information, the problem was divided into the Product Development process phases as suggested by Ulrich [1]. The requirements at each phase were defined in the beginning of the particular phase and followed.

The solution is planned to contain various modules as it would be easier to work on independent parts which can be joined together to form the solution. The reason is the time constraint and the future developments of the final solution.

4.2 Customer Requirements

Methods used: Interview, SWOT Analysis, Black Box Model

Customer requirements are required to set the goals of the final product. The final product must satisfy all the customer needs in order to be successful. Of the several methods available to gather the customer needs, interviews were chosen. All the data needed was collected through interviews. The process followed was to make up questions for the interviewee and get the information. The person interviewed was the supervisor at the company. He was interviewed at the company's facility in Karlstad.

Based on the information obtained from interview, a Black Box model was created explaining the process of how a transformer is dismantled on site. The model looks as shown in Figure 3.

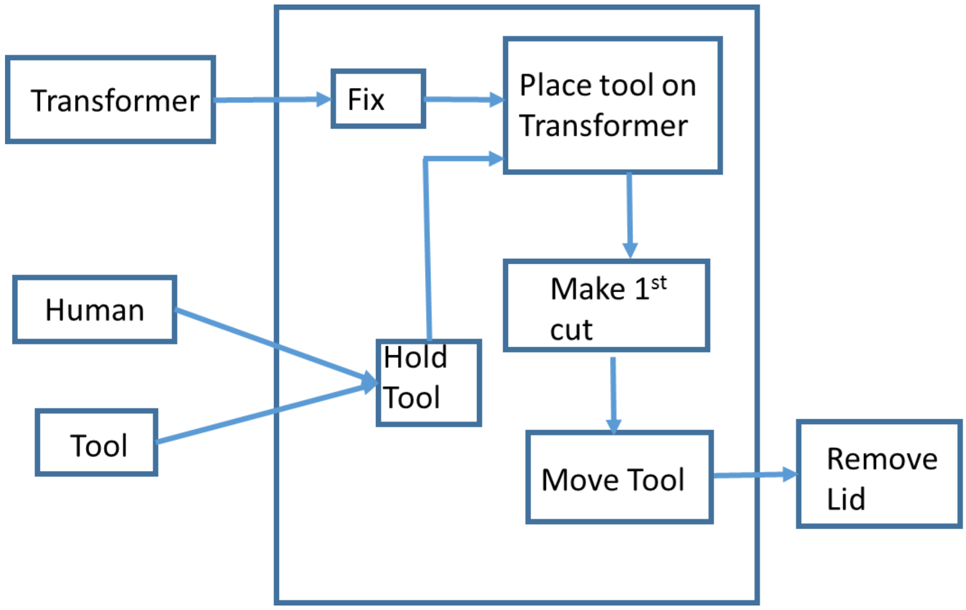

Figure 3

This model contains functions written in “Verb+Noun” format [5]. From this model, three important functions were selected such that when they are replicated with help of other mechanisms/machines, provide the same result. The selected functions are

1. Cut Metal
2. Hold Tool
3. Move Tool

Cut Metal: This function of the solution cuts the metal. Since cutting the metal casing of the transformer is the whole purpose of solution, this function is selected to find the alternatives. Cutting the metal sheet which is 15mm in thickness requires strong cutting tool and heavy forces. This means that there should be a strong construction which can make the cutting steady and controlled. These issues are important but do not come under this function. This function only concentrates on cutting the metal casing of transformer. The whole device/solution that cuts the metal is covered under this function

Hold tool: The purpose of this function is to hold the tool. The tool here is not the part that comes in contact with the metal but the whole device. To hold the whole device without unnecessary degrees of freedom is the meaning of this function. This is selected considering its importance in creation of new solution. Due to heavy forces acting on the tool, a strong holding mechanism is an important integral part of solution.

Move Tool: The function is clear about its meaning. To move the whole metal cutting device according to the required shape is the meaning of this function. This function is selected because its replication with another mechanism will provide an idea about the complete solution.

To find possible alternatives for the above functions, several ideas need to be generated. These solutions when placed into a Morphological matrix, produce several configurations which then can be refined to find out the best solution.

For the first function, the same tool which is used today can be used or a new tool can be utilized. Also the same black box model which is being used now can be followed and the ideas can be generated according to it or a completely new method can be developed.

Based on the alternatives, to go further into the process of developing a new solution based on the above functions, 4 different strategies were made such that by selecting one/two of them, the next steps can be figured out.

Answer to the following question will decide the further steps which will be taken in this thesis.

“Should the same method be used or a different one? And should it use the same tool or a new one?”

To find the answer, following 4 strategies are developed:

1. New Tool, New method: This strategy implies developing some sort of mechanism/model to use the tool while a new type of method is to be developed to use the tool

2. New Tool, Old method: This strategy implies developing a new type of mechanism. Model such that it can be incorporated in the current method used for cutting the lids.

3. Old Tool, New method: This strategy implies using an already existing tool in the market which is either used/not used by the company and follow a new method for using that tool.

4. Old tool, Old method: This strategy implies using the already available tools in the market with already available methods that can be employed to cut the lids.

To select the final strategy**, SWOT analysis** was done on all of them. The main purpose of choosing a SWOT analysis to select one of the strategies is because of the fact that the project is in the initial phase and by performing a SWOT, the positive and negative impacts of a particular strategy can be anticipated easily [4]. This is the main deciding factor as the subsequent actions depend on the outcome of this analysis.

Though the SWOT analysis wasn't done in detail, the main points that causes the difference were covered. These main points are the ones which differentiate one strategy with other. These are explained in the following paragraphs:

SWOT for New Tool, new method:

The result of this strategy will be a new cutting device.

Strength:

Strengths of this strategy include a very high level of optimization which in turn bring a huge savings in terms of operating costs. With the new tool and method being developed in house, the knowledge about the process and production is kept within the company which can result in a patent application thereby giving the chance to actually sell the solution to other companies.

Weakness:

Considering that Stena Recycling is a service oriented company, the competency needed to implement this strategy might not be enough. A very high competency is required to implement. This involved high cost of research and many development teams and equipment

Opportunity:

With a new technology, doors to new opportunities will open. Stena can enter into new markets to which the services can be provided. With the new knowledge obtained, this knowledge can either be sold or improved to get new products.

Threat:

The new technology means new training required for the users. There might be a market failure which can result in false return of investment thereby causing a total failure of the investment. With the new technology, there might also be some changes which need to be done to the facility if it has to be implemented.

SWOT for New Tool, Old Method:

Strength:

With a New Tool and an Old Method, one of the biggest strength involved is the technology. It becomes a new invention with all the strengths of New Tool. But since an old method is used, there is no need to train the users about the method. With a new efficient tool, the morale of the users will be improved and will add value.

Weakness:

With the old method used, the freedom for the new tool is very limited and requires lot of work to be done. This also means that the cost of developing will be high.

Opportunity:

This technology can be sold to other customers and enter new market segments. This also allows the company to enter new market segments.

Threat:

Since this is a new tool employed in to practice, there might be some rejection among the users. Since Stena has to depend on other people with competency for developing the product, this might become little challenging. Once the final product is made, getting the permission and approvals can also seems a daunting task.

SWOT for Old Tool, New Method

Strength:

With a new method for an already existing tool, the company can save lot of financial resources by not creating a new tool. Since the already available tools are used, they are easy to buy and since they are provided by a supplier, the testing costs and resources for the tool can be saved.

Weakness:

Since it is a new method which is being used, the testing can be harder as methods are not tangible. Creating all the safety rituals and sub methods can be challenging. A lot of time might be needed for planning phase to make the method fit for commercial use

Opportunity:

By using a new method, the company can gain attraction in terms of efficiency and environment friendliness. As the work will be done on creating a new process, the knowledge obtained can be helpful in implementing to other factors of the company's operations.

Threat:

This new strategy will require the employees to work in a new way which can receive certain criticisms.

SWOT on Old Tool, Old Method

This strategy is to use an existing tool with an existing method.

Strength:

The knowledge about the process and tools is already available and there are no additional costs involved in developing them. The tool is readily available and can be bought from the market suitable to needs.

Weakness:

There might not be much change with respect to how the dismantling is done currently. Also there is nothing new as the methods and tools are already available.

Opportunity:

There is an advantage in terms of cost. A new solution available in the market can be used with lower need for testing and legal requirements.

Threat:

The available solution can be costlier than when developed within the company. Solution is limited to the expertise of the provider and may not satisfy all needs.

The black box model and the SWOT analysis files were sent to the company and an online meeting was arranged with the supervisor of company.

The black box model was confirmed by the company and the SWOT analysis of each strategy was discussed to select a final one. After finishing the consultation, two strategies were selected.

They are: **New Tool, New Method and Old Tool, New Method.**
From this it is clear that Stena Recycling is looking for a New Method with either a new tool or an existing one.

After the interviews and other methods to getting data, the customer requirements are collected as follows

- The final solution does not use foam to be filled inside transformer
- The final solution can be assembled with a crane and 2 employees
- The final solution can cut metal of 15mm thickness
- The final solution can be transported
- The final solution do not produce sparks while cutting
- The final solution can cut transformer lids with curved sides
- The final solution can cut transformer lids with straight sides
- The final solution can be used on site
- The final solution can be used at the dismantling facility
- The final solution can work with the power produced from a portable generator
- The final solution can save costs per operation compared to conventional methods.

4.3 Idea Generation (Model)

Methods used: Division of Problem, Black box Model, Brainstorming, Morphological matrix, Expert Consultation

After the problem was defined and requirements taken, an initial brainstorm was done to generate quick ideas. The initial ideas were

a) Initial heating to make the material soft and cutting with conventional methods
b) Using a rotating anti spark cutting tool
c) Liquid cooling and then cutting the metal
d) Using a scissors kind of working mechanism
e) Using a drill bit to perform lateral cutting
f) Laser cutting technique
g) Clean the insides with water and then perform the cut with a welding machine
h) Cold saw technique
i) Weakening the initial layers of metal with water jet cutting and then use a drill or saw to cut the weakened metal layer
j) A chemical that can eat the metal thus producing the required cut.

Since the ideas generated were random without any particular criteria for guidance, other ideas that are actually used in metal cutting were explored. To do this, a method called External Search as proposed by Ulrich was employed [1]. As part of it, the search was done online and by consulting experts.

Few more ideas were developed by searching online and they are added to the already obtained list from brainstorming.

To get further information about the generated ideas and to get to the solution, a semi structured interview was conducted with an employee from Sandvik Coromant. The interview lasted for 1.5 hours. After the interview, it was considered that milling is the right solution to the problem. One main reason being that milling operation doesn't produce any spark though huge amount of heat gets produced. Different kinds of milling operations were discussed and the suggested operation was end milling. Suggestions about the type of tools and the makers was also discussed. Information regarding this can be seen in the Appendix 3.

The following information about milling machine and its operations was obtained.

Theory of Milling machine

A milling machine is a very good solution for metal removal as it can handle various shapes of surfaces [10]. A typical milling machine consists of base, column, knee, saddle, overarm and table.

A typical milling machine looks as shown in the Figure 4 [14]**.** There are different kinds of milling machines.

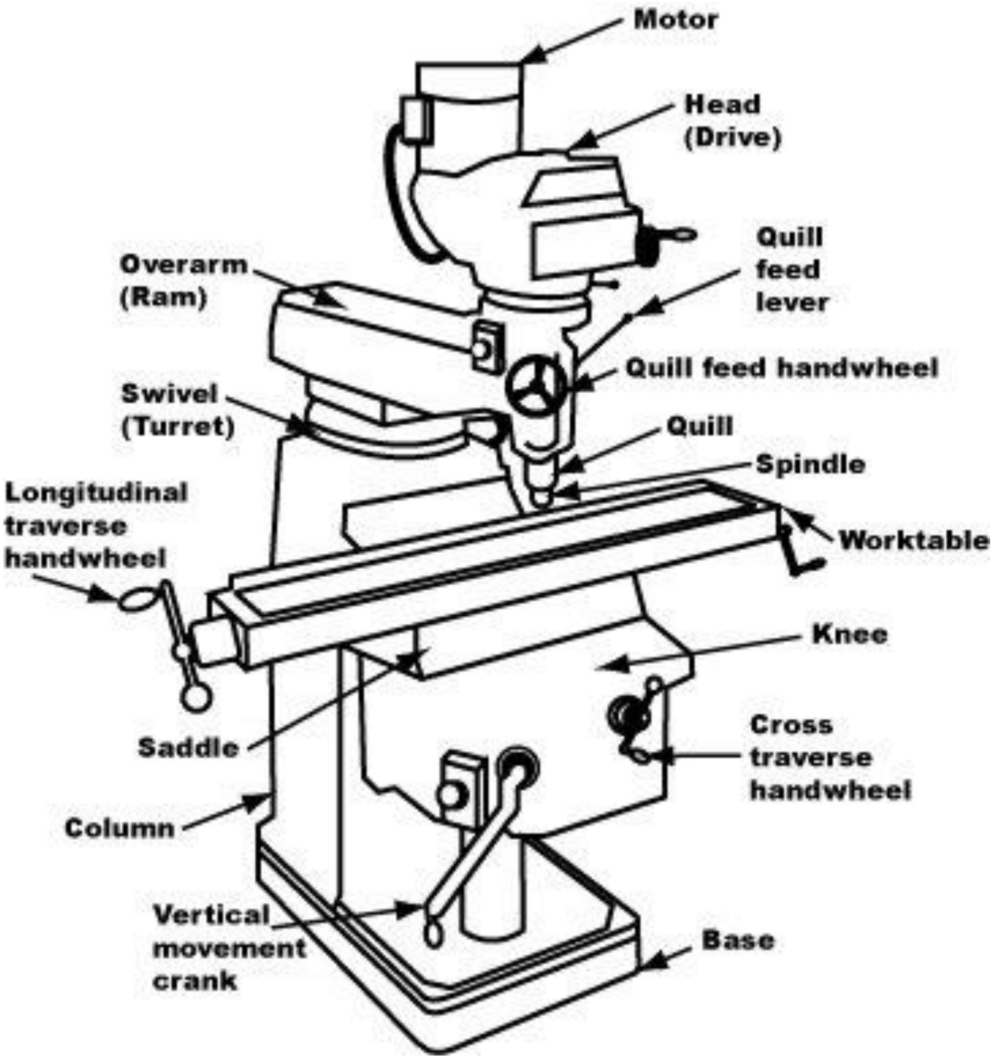

Figure 4

Base: It acts as a support for other components of the milling machine.[11]

Column: Emerging from the base, column has the spindle and the driving mechanism associated with it.[11]

Knee: It travels vertically up and down along the column. It also holds the saddle.[11]

Saddle: It is placed on the knee and it helps in the movement of the workpiece along the horizontal plane[11]

Overarm: This is placed on the column with help of turret. The milling head is attached to this overarm and helps to place the milling head in position by sliding over turret.[11]

Table: The table supports the work piece by holding it and moving along one axis with help of T slots provided.[11]

Operations performed:

Of the various operations performed on a milling machine, end mill was the suggested operation. End milling is an operation where the cutting tool which resembles a drill bit is dug into the metal up to a required distance and the tool moves along the horizontal axes.[6]

According to Sandvik Coromant, there are three kinds of end milling [6]

- Conventional
- Trichoidal
- Plunge

Conventional Milling: This type of end milling is the normal milling. The rotating cutting tool goes through the metal workpiece in a straight line. [6]

Trichoidal milling: This type of milling follows the same process as explained but the tool makes small circular motions along its journey. By making such kind of motion, the area of contact is reduced and the life of tool will be improved [6]

Plunge milling: This type of milling is rather slow process. The tool makes a vertical cut by digging into the metal. It then comes out and moves little distance along the line of cut and then performs the vertical cut again. This continues until the while line of cut is finished [6]

Since Trichoidal operation requires complex accurate movements and Plunge milling is a slower and time consuming operation, the conventional milling operation was chosen for the solution.[6]

From the milling machine mechanism, it is clear that spindle is the part that cuts the metal. By separating the spindle, the same milling operation can be performed on the transformer lid. The transformer is fixed part, which means the workpiece is fixed and the spindle will have to move to perform the necessary operations. This eliminates the need to have table of the conventional milling machine. However, the knee and saddle has to be modified to perform similar operations on the spindle. This requires them to be moulded in to the over arm.

Solution through Modules:

By generating the solutions for key functions, it is easy to divide the problem into several modules. Solution for each function here can be called as a module. All these modules attached together can solve the problem. By dividing into modules, it is easier to produce greater number of variants and improved quality [7]**.** Lack of information from one module will not affect other module

Greater modularization is not acceptable as interfaces also take up cost.[7] One advantage with modularization is that since the solution will have to be portable, there should be several parts which needs to be assembled and dissembled. This in itself gives rise to modularity.

To generate the final solution, solutions to each function were to be developed. The first function chosen was the tool. One of the strategies was to use old tool. For this purpose, external searching as proposed by Ulrich was done [1]. Among all the methods proposed for external search, expert consultation and literature review were considered.

From expert consultation it was known that milling is the right solution. After acquiring enough information about the theory of a milling machine, its details were found out through another interview which was done with a professor from Chalmers University.

The data obtained is as follows.

- During a milling operation, 80% of heat is removed by the chips. It is important not to let the chips fall into the transformer. Heat is not a problem
- The cutting temperature of the workpiece is to be checked.
- At the cutting point, the temperature for a steel will be about 500-800 degree centigrade. This requires cooling liquid to prevent the oil inside transformer reach the burning temperature
- It is not advisable to let the human hand control the cutting mechanism. This rules out the idea of having a milling machine that can be handheld.
- Due to the huge amount of forces, it is important to make a machine tool like construction
- The motor used is about 10-15 KW power

Thus the solution for one function was obtained. Now it is time to find solution for the other functions.

As the strategy selected by the company included a new method with existing/new tool, Milling Machine and Hacksaw were selected for the first function. Solutions for the other functions were developed individually.

The generated solutions for the function Hold are

1. Clamp
2. Crane Hook
3. Screw
4. Vacuum Holder
5. Magnet
6. Hand
7. Rope
8. Gum
9. Integrated

The generated solutions for the function Move are

1. Motor
2. Gear
3. Human
4. Friction wheel
5. Car
6. Rail
7. Potential energy
8. Chain
9. Belt

By joining each solution of Hold to Move, at total of 9*9 = 81 combinations were made. And since two different tools were chosen, the total number of solution combinations developed are 81*2 = 162.

These combinations only give answers to few functions in the whole process and an interface is needed to join them. As can be seen from the black box model, the tool is directly connected to the function Hold and the Hold is directly connected to the function Move.

As the three functions are dependent on each other, it is important to consider how they will be connected. For this purpose, the connection interfaces are defined as X, Y and Z. X being the interface between the tool and the solution to Hold. While Y is the interface between the solutions for Hold and Move and Z is the interface which attaches the final product to transformer.

The Figure 5 shows how the connections take place between functions and the interfaces

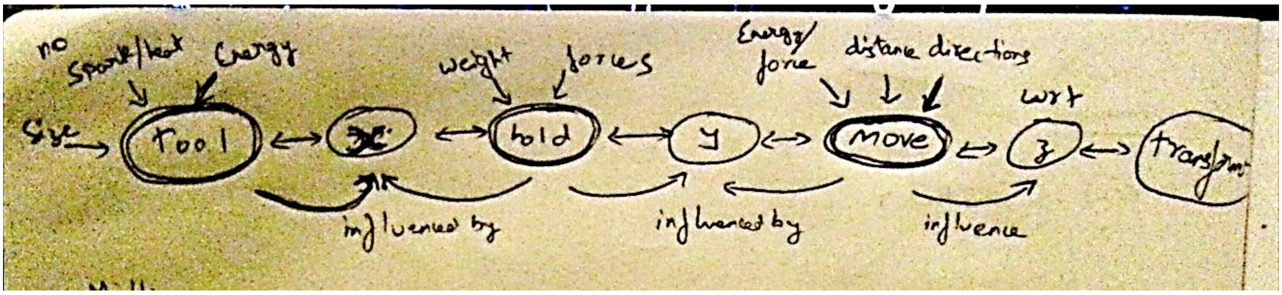

Figure 5

4.4 Screening

Screening was done using the decision matrices. The initial screening was done with just the feasibility based on the human understanding. Since the total combinations are 162, this would be the fastest and easiest. A column with 'Yes' or 'No' was made in Microsoft Excel putting a 'Yes' after every combination that has a chance of being feasible and a 'No' after every combination that is not feasible. This sheet can be seen in the Appendix 1

Consider the following way to combination where the first column represents the solutions for Cutting Tool, the second column represents solutions for Hold Tool and the third represents solutions for Move Tool

Cutting Tool	**Hold Tool**	**Move Tool**
Milling machine	1. Clamp	a) Motor
Hack saw	2. Crane Hook	b) Gear
	3. Screw	c) Human

	4. Vaccumm Holder	d) Friction wheel
	5. Magnet	e) Car
	6. Hand	f) Rail
	7. Rope	g) Potential energy
	8. Gum	h) Chain
	9. Integrated	i) Belt

As can be observed from the table, all the solutions for Hold are denoted using numbers and the solutions for Move are denoted using letters. A one by one possibility of selection can be found in the **appendix**

The combinations that passed the initial screening for Milling machine are

1a	1b	1e	1f	1h	2a	2b	2c	2e	2f	2g
2h	3a	3b	3e	3f	3h	4a	4b	4e	5a	5b
5e	7a	7b	7e	7f	7h	8a	8b	8e	8f	8h
9a	9b	9e								

The combinations that passed the screening for Hack saw are

1a	1b	1e	1f	1h	2a	2b	2c	2e	2f	2g
2h	3a	3b	3e	3f	3h	4a	4b	4e	5a	5b
5e	6c	7a	7b	7e	7f	7h	8a	8b	8e	8f
8h	9a	9b	9e							

At the end of the screening, a total of 73 combinations are selected for further screening.

4.5 Further Screening

This screening was done with more constraints to screen out maximum number of combinations. As mentioned in the Idea Generation chapter, the interfaces X, Y and Z were considered to make the screening.

The method used for this screening is the AHP Tool. This has 4 steps: [8]

1. Define Criteria
2. Apply weights to criteria
3. Synthesis
4. Concluding the analysis

By using this method, steps 1,2 and 3 are applied on each of the selected combination. To be able to apply this method in this situation, it is tweaked a little to suit the needs of this thesis.

X is the interface between Tool and Hold Tool solutions.
Y is the interface between Hold Tool and Move Tool solutions

A value from -2 to +2 is assigned to X and Y where -2 stands for a negative impact and +2 stands for a positive impact and 0 being neutral and the sum of these values is assigned to Z. This value of Z is used to screen out the combinations. While the value assigned to X was determined based on the strength of attachment, the value for Y was the average of the values assigned to 4 categories explained below:

a) number of moving parts
b) ability to attach
c) firmness and
d) ease of movement

They are selected as they are important for DFA. With more moving parts, the time taken for assembly increases [12]. So it is an important factor to be considered. Similarly, the ability to attach is another area in the process of assembly [12], its importance is also regarded. Firmness is considered only due to the fact that the huge forces acting while cutting the metal should not disturb the assembly. Ease of movement is another factor given importance as there are only 2 employees to take care of the system and the cutting process must be as simple as possible.

These factors were chosen to make the screening process harder and screen only those combinations that satisfy the customer needs mostly.

The above categories are also given a number from -2 to +2 to determine the effect of that category on the combination. The impact is measured again based on perception limited to human capabilities. But with specific categories being considered, the acceptance of the decision can be high. The sum of all the values assigned to each category for each combination is calculated and the combinations achieving a sum greater than 2.5 are screened into the further steps of the process. Appendix 2 shows the whole table where this screening is made.

The total combinations that were screened for further phases of the process are 17. Since some of the combinations are redundant, few of them are eliminated due to repeating ideas and the final number of combinations left out were 10. Six for milling tool and 4 for hack saw.

They are
1. Milling + Clamp + Motor
2. Milling + Crane + Motor
3. Milling + Crane + Gear
4. Milling + Screw + Motor
5. Milling + Integrated + Motor
6. Milling + Integrated + Gear
7. Hack saw + Screw + Motor
8. Hack saw + Hand + Human
9. Hack saw + Integrated + Motor
10. Hack saw + Integrated + Gear

4.6 Concept selection

After the second round of screening, many concepts were eliminated. The remaining of them were selected to be made into sketches to make it easier for selection.

For each concept, the pros and cons were written and then discussed with the company to find out the final concept which is to be sent to the next phase.

The following are the concepts.
1. Milling + Clamp + Motor

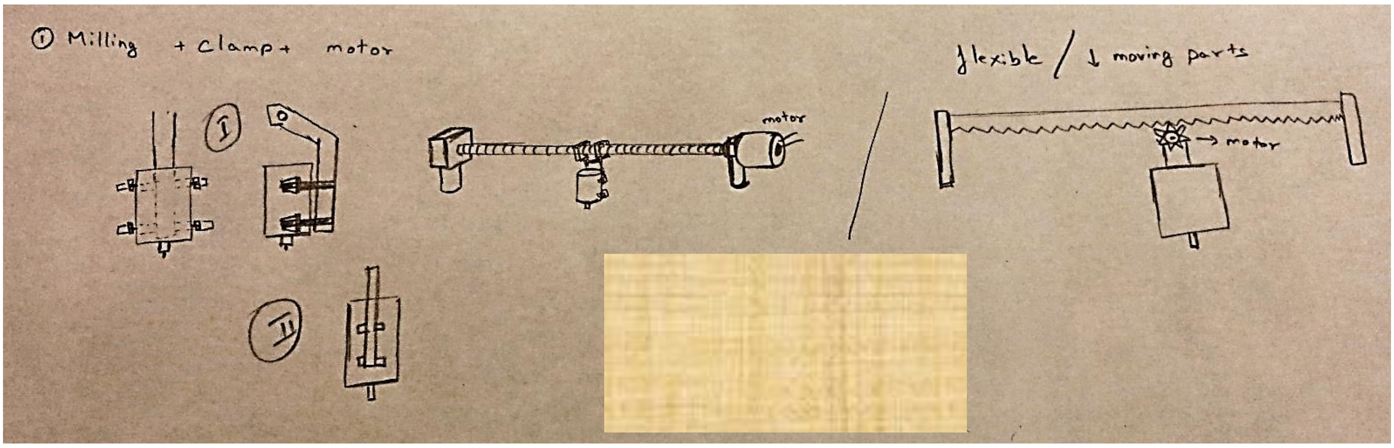

Figure 6

As can be seen, there are two solutions for the same combination. With the milling machine held by clamp and its movement happening over with the help of motor, there are two solutions generated.

a) This solution has the motor fixed at one end of a screw rod and the spindle moves along as the motor rotates the screw rod.

As shown in Figure 6, the spindle is held with help of clamps. The part with clamps holding the spindle has a hole through which a screw rod goes through. This rod controlled by motor helps move the spindle in required direction. Though this doesn't work for a curved transformer, through further working, this solution can be fit for it.

The advantages with this model are

- Less weight
- Easy to assemble

The disadvantages are

- Can cut only in a straight line
- The screw rod can not be folded/joined without a connection thus making it harder to carry rods of various lengths
- Vibrations from the spindle might actually have an effect on the screw rod thus causing unnecessary movements
- Extra supports might be needed to hold longer screw rods.

b) This solution is the right one in the Figure 6. The motor is attached to the part holding the spindle. The motor has a gear which runs over a rack that is present on the top.

The advantages of having this model are

- Less moving parts when compared to the previous model
- The rack can be dismantled due to the fact that the opposite of geared side is not used and can be helpful to attach more racks without disturbing the motion of spindle
- Easy to assemble
- This makes it portable

The disadvantages of this model are

- It needs extra support
- The vibrations from spindle can have serious effect on the rack
- It can cut only in a straight line making it harder to cut curved transformers which can be done through extra mechanism

2. Milling + Crane + Motor

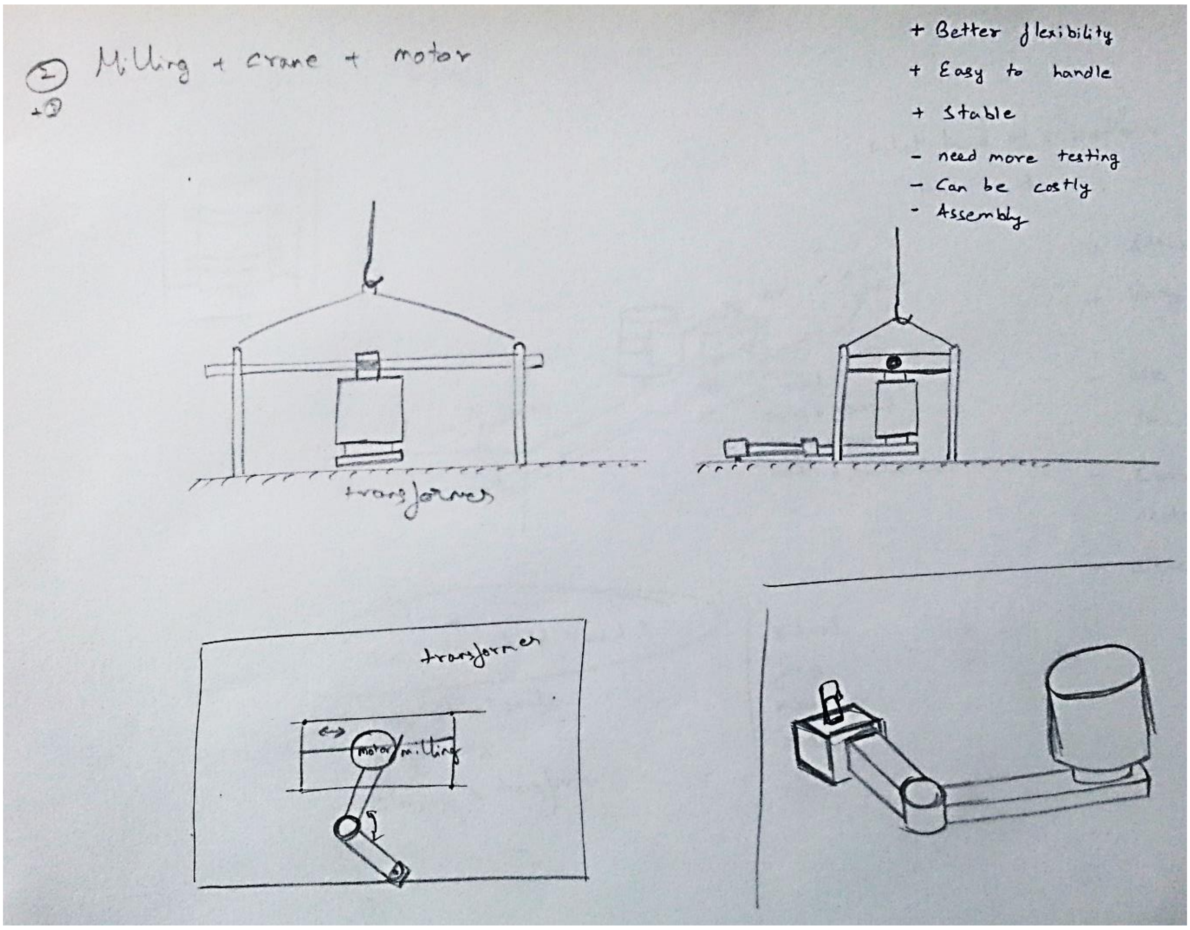

Figure 7

This solution has 2 models.

a) This model is represeeented in Figure 7. The figure shows the model in front view, top view and side view. There is a spindle of milling machine placed in the center. On the top of this spindle is a screwhole through which a sccrew rod passes thus providing a chance to move the spindle. It can be seen that the supports of the screw rod come from 4 different locations.

These are the hooks on the transformer lid which are used to hold the supports. The spindle is suspended from the screw rod.

The bottom of the spindle has an arm which has one joint. This arm is controlled by a human with the help of control box located at the end of the arm. The control box also hosts the cutting tool which is powered by the torqe transferred from the spindle with help of transmission mechanisms. The advantage of having transmission mechanisms is to increase or decrese the torque and speed of rotation of the cutting tool.

With the extended arm and control by a human, it is easier to cut different types of shapes of the curved transformer. If the end is not reachable, the screw rod can make it possible to reach by moving the whole set of spindle.

Advantages of this models are

- Flexibility
- Ease of control
- Stability

The disadvantages include

- Heavy testing
- Cost
- Assembly
- Might need more safety precautions if need to be handled by a human
- The location of the human while operating must also be considered.

b)

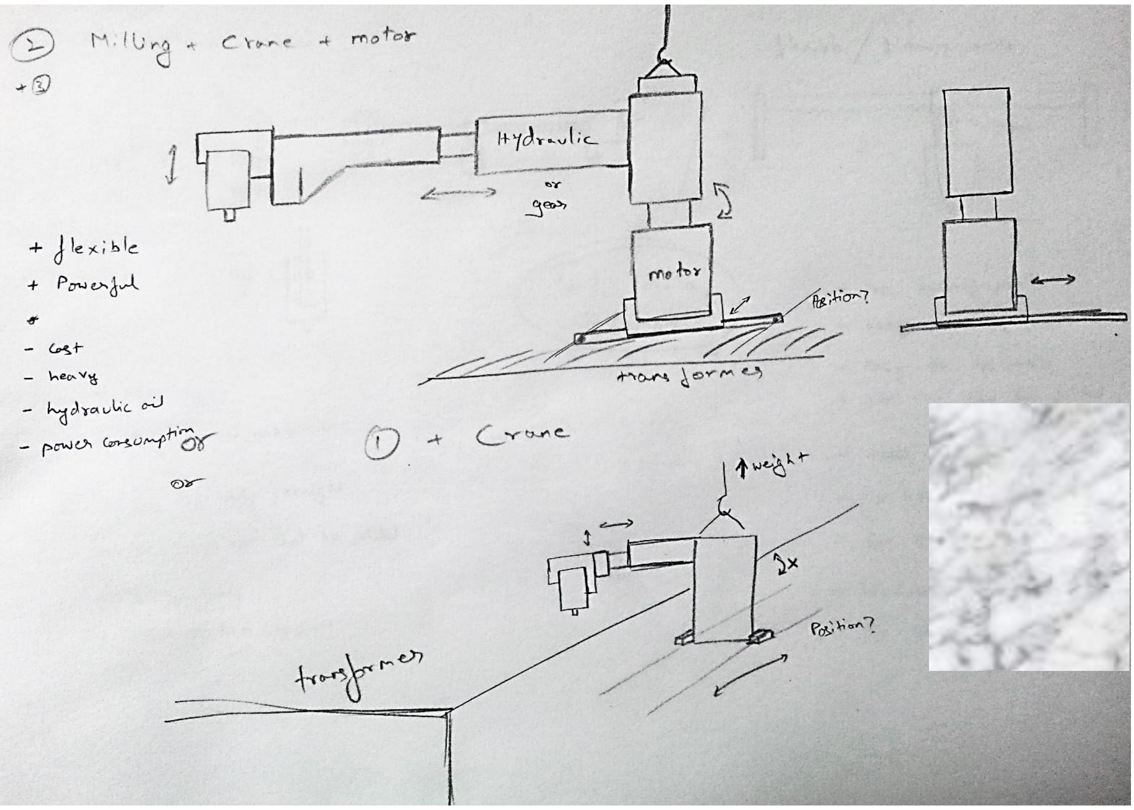

Figure 8

This model is represented in the top most diagram os Figure 8. As can be seen, the spindle is attached to an arm. At the middle is a motor to which a support is attached. The movement of motor controls the angular deviation of the arm.

The arm is a hydraulic arm with with lateral movements along one axis. With the angular movement of the motor in the middle and the lateral movement of the arm, any kind of shape of the transformer can be reached. At the end of the arm is the spindle which can be move in the vertical axis.

The weight of the central piece is held by a crane so the weight acting on the transformer is minimized.

The advantages of this model are

- Flexible
- Powerful

The disadvantages are

- Cost
- Weight
- Hydraulic maintenance
- Lack of portability
- Power consumption

3) Milling+ Crane + Gear

This model is as presented in the lower diagram of Figure 8**.** The milling is held by a crane but the the movement happens through gears. It can also be considered that the gears will be driven with help of motor. Thus this makes the solution a part of the previous solution.

The central part of the solution is housed outside of the transformer rather than the roof. Because of this, an extra railing is required in order to hold and make necessary movements. As can be seen, an arm extending from the central part holds the spindle which then cuts the metal lid of transformer by placing it on the lid. The whole arrangement is held by the rope from a crane. So the weight of the solution is not of a priority. However, inorder to move the arrangement along the required shape, a base is needed. This is made with help of extra railing which can be arranged either with help of scaffolding or by attaching it to the walls of transformer. The bottom part of the central piece has gears attached to it which are driven with help of motor. The railing built also contains a rack which in combination with the gears of central piece gives required movement. While this combination works best for a straight line cutting requirements, a curved edge transformer requires the railing to be made such that it is cutomisable for every kind of curves. This requires different kinds of racks with various curvatures. A solution to this problem can be obtained by using a similar hydraulic arm from the solution 2.b explained above. With this arm, Different curves can be cut while the central piece move along a straight line.

The advantages of this model are

- Power
- Portability
- Flexibility

The disadvantages are

- Extra railing
- Weight if using hydraulic arm
- Power consumption
- Cost
- Vibrations

4) Milling + Screw + Motor

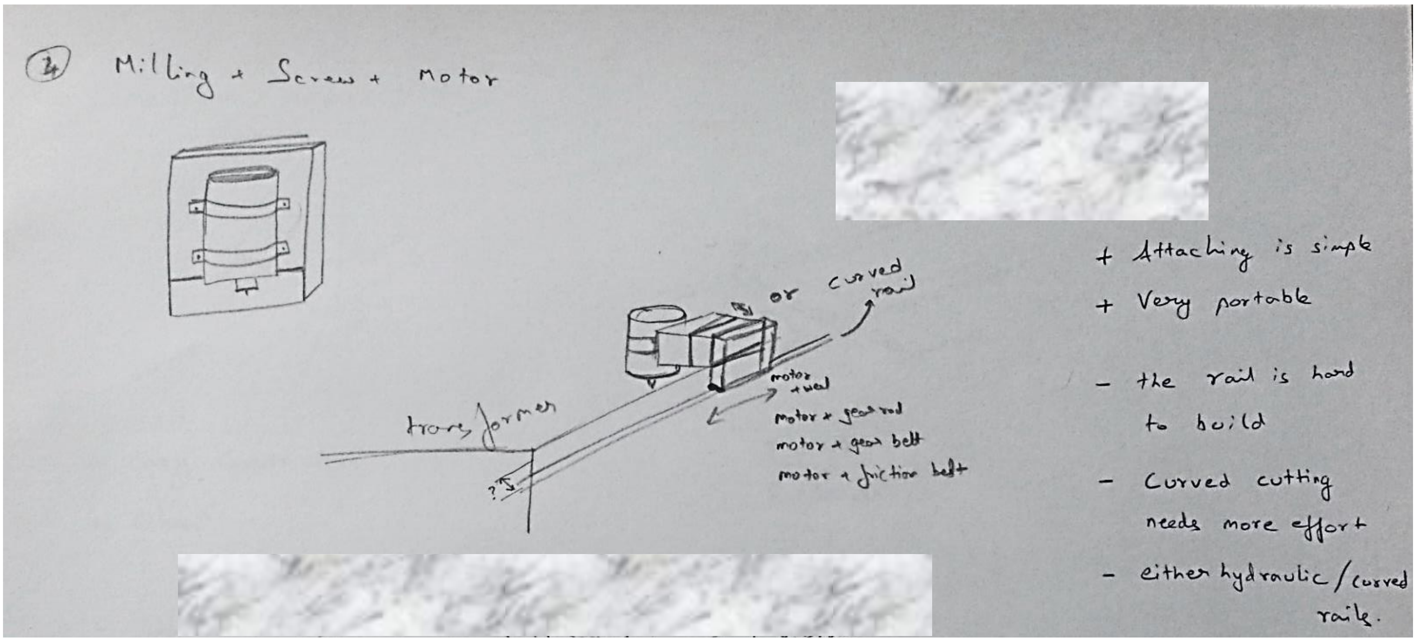

Figure 9

This solution is formed by holding the Milling spindle with help of screws/bolts and moving it with help of a motor. This follows the similar mechanism as in the solution number 3. The spindle is attached to a block with help of screws. The block which is in L shape as shown in Figure 9 has the base of inverted L equipped with motors which are attached directly to a railing. This railing can have a gear rod or a belt which goes around carrying the L block.

This solution also faces the same kind of issues when it comes to the curved edges of transformer. The solution being a curved railing or an arm that can extend up the required lengths while holding the spindle.

The advantages are

- Simple attachment
- Portability

The disadvantages are

- Extra railing
- Cutting curved edges of transformer

- Curved railings or hydraulic arm required
- Power Consumption
- Hydraulic arm maintenance

The integrated milling solutions are eliminated as the working mechanism will be the same except the way the spindle is integrated into the support

5) Hacksaw + Screw + Motor

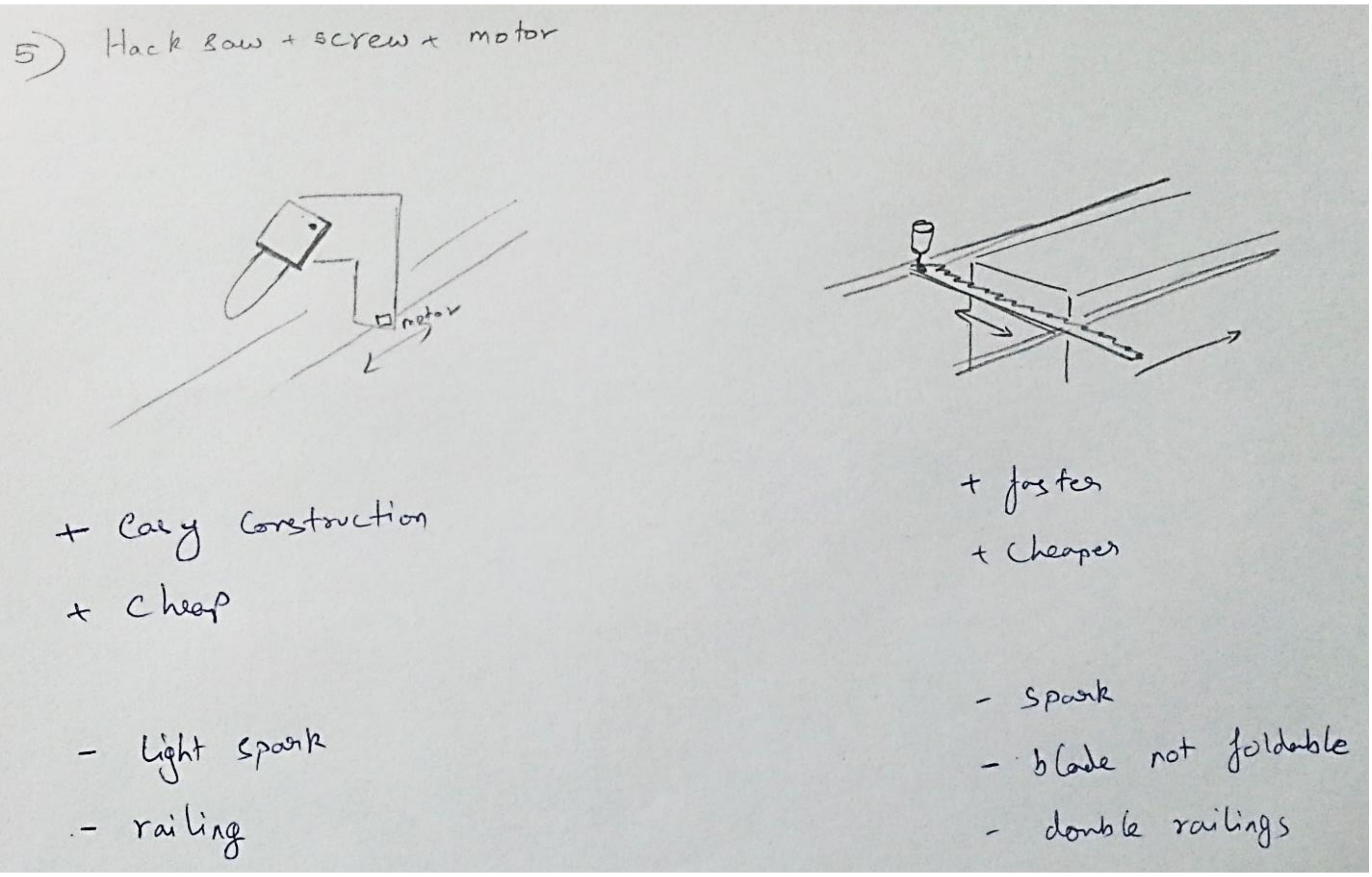

Figure 10

This a solution for a hack saw being used for cutting the metal lid. There are two models for this solution which are displayed in the Figure 10

a) This the represented in the left side of the Figure 10. Since it is a screw and motor used for holding and moving the arrangement, the design similar to solution 4 is used.

The advantages being

- Easy construction
- Cheap

It should be noted that the hacksaw is the original solution and the chances of sparks still exist. So some of the disadvantages with this concept are

- Sparks
- Railing requirements for the movement of arrangement

b) This concept is shown in the right side of Figure 10. This concept employs a huge blade which moves to and fro along the length of cut and cuts away the lid of transformer by going along a set of guideways.

The advantages of this model are

- It is faster
- It is cheaper
- It is easier to assemble
- Much less items to carry

The disadvantages associated with this model are

- Sparks
- The blade is not foldable and a big blade has to be carried everytime
- The cutting happens slowly

Random Idea 1

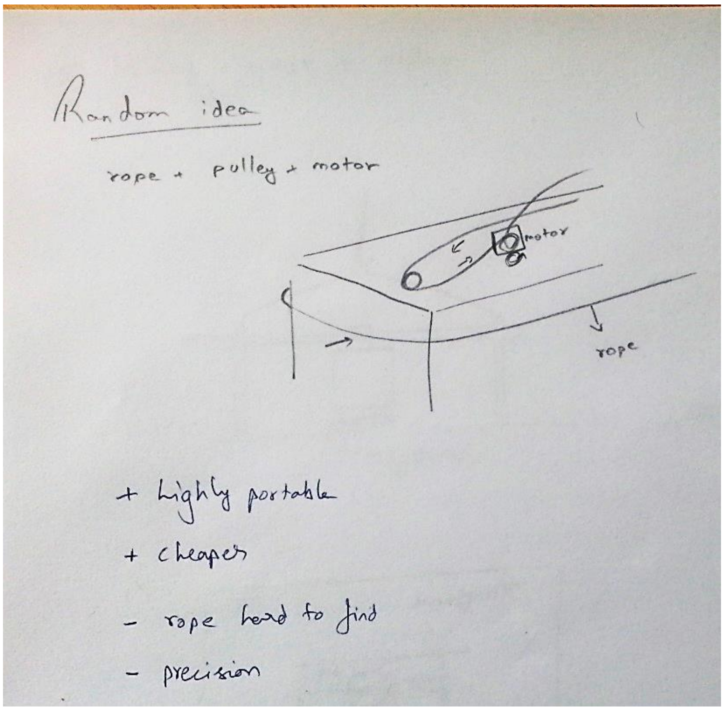

Figure 11

This concept is a random idea generated during the working process of other concepts. This is a relatively easy concept and requires some arrangement for a rope and a motor. The rope is arranged with pulleys and put around the transformer. One end of the rope passes through the motor which rotates at high speed and puts the rope in motion. This rope then cuts the metal through friction generated due to high speed motion and as the motor pulls the rope, it goes through the lid of transformer cutting it.

The advantages of this model are

- High portability
- Cheaper
- Easier arrangement
- Only one motor to be powered

Disadvantages are

- The rope is a special rope which is hard to find
- It is hard to get accurate cutting point as the rope needs to be balanced and cannot be placed wherever needed
- Once the lid is chopped off, a way to lift the core needs to be found out

This idea is inspired from a model of Husqvarna named CS 10

Random Idea 2:

The second random idea was generated while working for concept 2.a.

As shown in Figure 7, the power from central core is transferred through an arm to the cutting tool. This happens through the basic gear and chain mechanism within the arm. But the same power can also be transferred through a liquid, either air or water, to the cutting tool. With this, the power can be transferred through a flexible pipe and the core power generating part can be kept on the ground without the need to lift and put it on the transformer. Since the pipe is flexible, a strong holding mechanism is required in order to ensure stability.

All these ideas were given to the company and the pros and cons were discussed. After the discussion, the concept number 1 was selected and the company also showed interest in the air compressor concept which is the Random Idea 2. The concept 1 was selected due to the simplicity in construction and design, this concept was chosen under the condition that it is to be suited for curved transformers. This again led to the concept development stage but at a higher convergence of the idea. More ideas were explored as the System level design was continued.

4.7 System Level Design

After finalising on the concept from concept selection phase, the system level design phase started. Overall details of the concept are considered here. As the concept needs to be adapted to the curved transformers, brainstorming on how that can be done was performed. This brainstorming session was quite limited as the principal design was made and a way to move it around the curves has to be formulated.

This resulted in some more rough designs made in Alias. The designs are shown in Figures 12, 13 and 14.

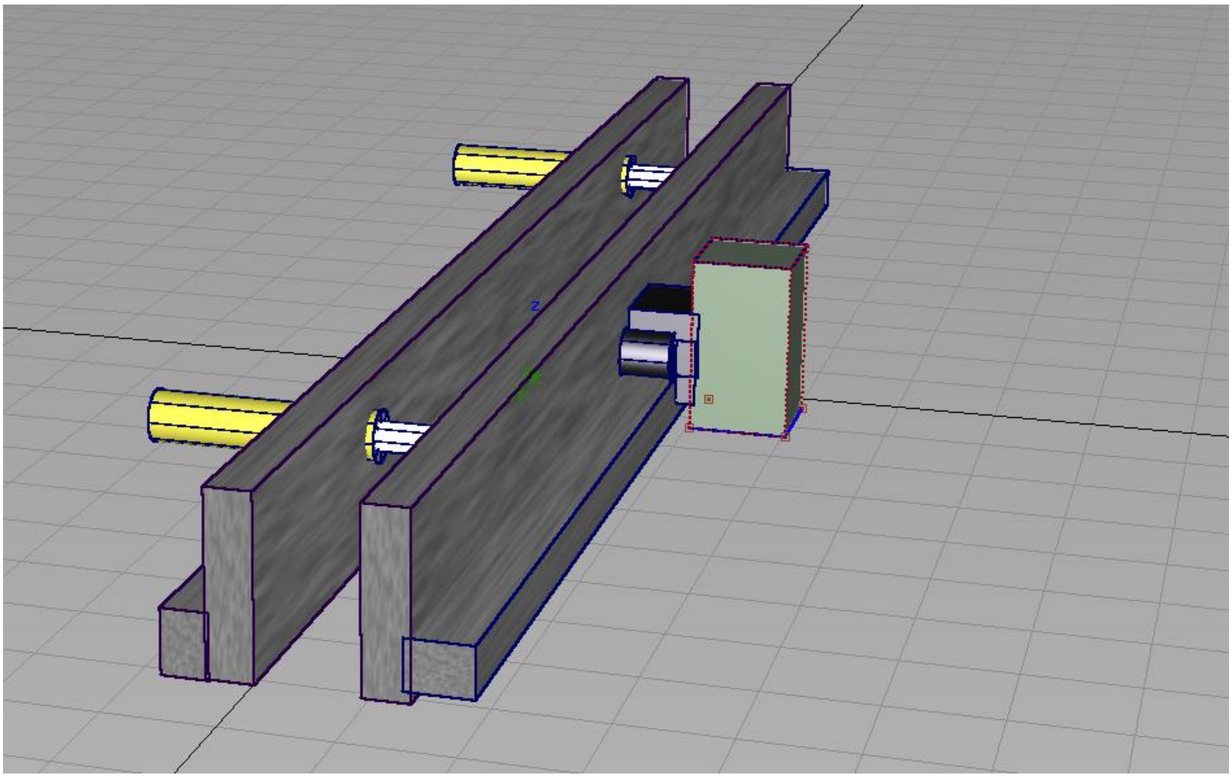

Figure 12

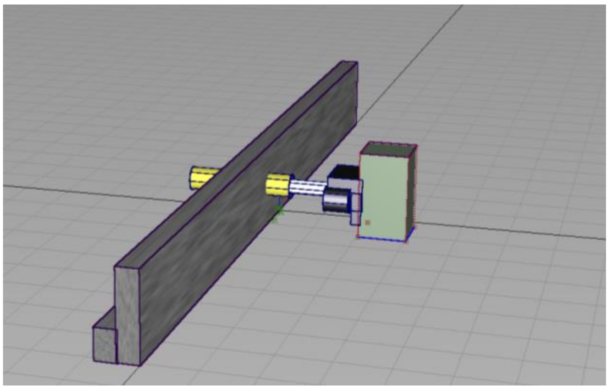

Figure 13

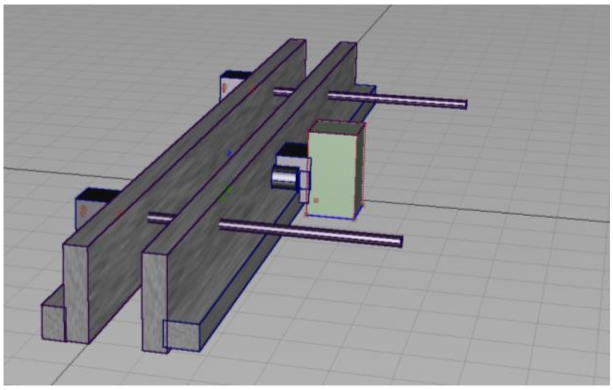

Figure 14

From the above ideas, the solution is divided into 4 modules. These are divided based on the working of the final solution. Since the spindle is provided by a supplier, a separate module for it ensure better spindle selection without worrying about its effect on the design. The support for the spindle is made into a module considering the portability requirements. The base for the support is made into another module so that the development can be easier and parallel [15]. All there three modules need to work with respect to a static point which can act as a holder. This holder is made into another module.

Thus the total modules the final solution is divided into are

- Milling
- Support
- Base
- Holder

4.7.1 Milling

Milling was chosen based on different suppliers.

Expert suggestion was used here to talk to different suppliers and get information. While most of the information obtained from the website, the suppliers who seems to provide the right spindle were contacted. They are Setco and Ugra. Setco replied quickly and gave the document with a 2D CAD diagram of a spindle which can cut steel metal sheets. The requirement given to Steco was to provide the spindle of smallest size which can cut steel. It comes with an integral motorised spindle. Thus the spindle was chosen. The CAD model of this spindle which was provided by SETCO is attached in the Appendix 4. As this module is connected to the support, there are chances for the spindle to be changed if a better one was found later.

The spindle provided is made into a CAD part and attached to the support which looks as shown in Figure 15.

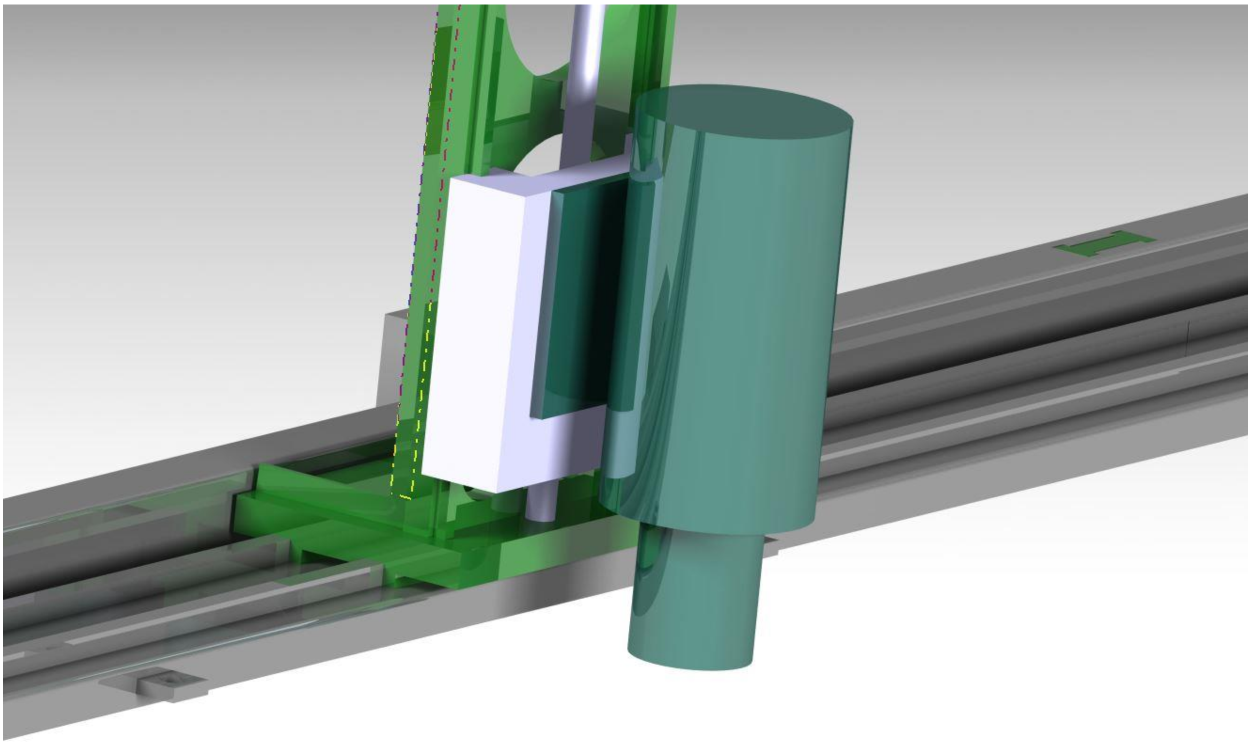

Figure 15

The details of spindle are as follows.
Model number : 6101.5 – 36
HP – 1.5HP at 3600 rpm
Weight – approx. 34 Kg
Cost - $8,725
Shipping cost to Sweden (Variable) - $1,725

The spindle is selected for a cutting tool having 2-3 blades. These tools are provided by Sandvik Coromant. A 2-3 blade cutting tool was selected to minimise the cutting forces that act on the tool and get transmitted to the spindle and other parts. The spindle has the ability to attach a tool with the help of ER Collet. During the interview with Göran, an employee from Sandvik, it is known that the tools provided by Sandvik Coromant can be attached with ER Collet.

For a 10mm dia end mill cutter, the depth of cut is proposed to be 5mm by Setco company representative.

For a tool having 2 blades and with 10mm dia, considering the feed rate per tooth to be 0.05mm, cutting speed Vc is given by equation

$$Vc = \frac{\pi \times Dc \times n}{1000} \text{ [9]}$$

Substituting the value of 3.14 for π, 10mm for Dc and 3600 for n, the value of Vc can be obtained as 113.04mm/min.

With a feed per tooth value of 0.05mm, the feed speed can be obtained with the equation

$$v_f = f_z \times n \times z_n \text{ [9]}$$

Where n is the rpm of spindle, z_n is the number of teeth and f_z is the feed per tooth. Substituting the values of 2 for z_n, 3600 for n and 0.05 for f_z, the value of the feed speed can be obtained as v_f = 360mm/min

4.7.2 Support

A supplier made support was also available with the same company providing the milling spindle. However, using the new support means certain changes need to be made in order to be useful. The current model works with a long straight gear rack while the original milling machines work with a screw rod. This deviation from the original milling machine requires another motor to be mounted on to the support for which the supplier provided model doesn’t have the space. An additional support to hold the motor and gear need to be made. This condition is eliminated with the custom made support as this need is anticipated and required space is provided. The support looks as shown in Figure 16.

Figure 16

The support must have the ability to support the spindle and move along the guideways. These guideways are company provided and can be used directly without further testing. These guideways are placed on another set of guideways which act as a pair and slide one over the other. These are located at the bottom of the support and they sit on the guideways of Base as shown in Figure 17.

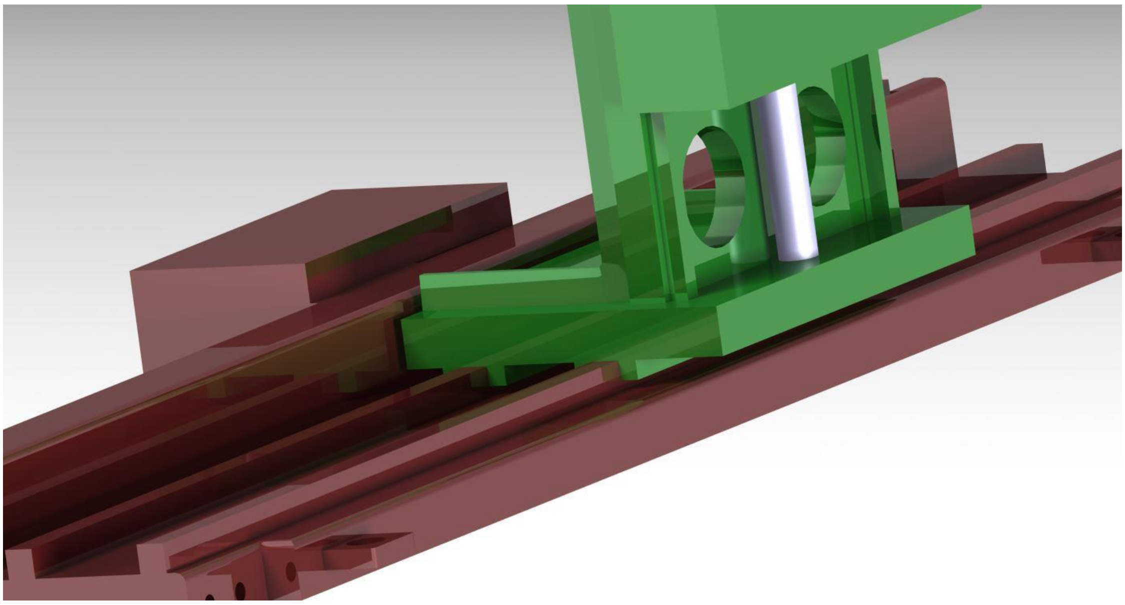

Figure 17

The support also must be able to move the whole spindle along vertical direction with a precision of at least 1mm. This precision is required when the tool cuts into the steel. Since several cuts need to be made, each cut must have a depth of about 2 mm and it is very important to have such precision. This is obtained by using a screw mechanism. The mill holder is attached to the support through a set of guideways as sown in Figure 18 and screw rod to control its motion. The whole support and mill holder mechanism looks as in Figure 19.

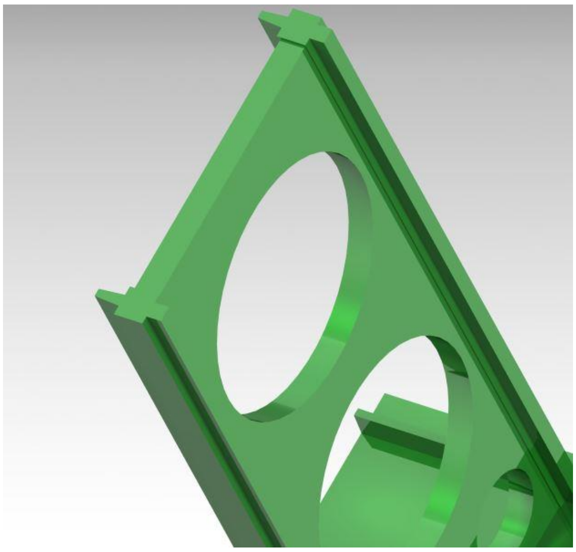

Figure 18

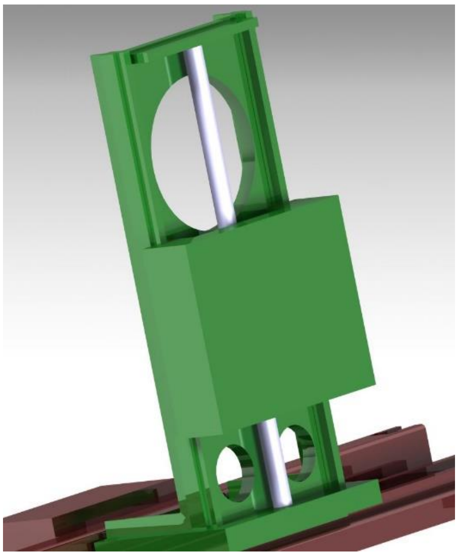

Figure 19

In addition to the above mentioned features, the support must also be able to accommodate a coolant sprinkler mechanism for future purposes. This include a motor to sprinkle coolant and a storage for coolant.

4.7.3 Base

Base is the part on which the support rests and moves. The Base must also be strong enough to bear all the forces that are transmitted from support during the cutting operation. In addition to bearing the forces, it should also be able to provide the necessary movement to cut along a curve.

Due to the varying sizes of transformer, it is also important to have bases of various sizes. To make is easier for transportation and assembly during work, two sizes of bases were suggested. Bases of 2 meter and 1 meter length can cover different sizes of transformers by certain combinations. It was known from the company that the maximum size of the transformer is 7 meter. So, it is suggested to have two of the 2 meter long bases and three 1 meter long bases.

The 1 meter base looks as shown in Figure 20 and the 2 meter base looks as shown in Figure 21.

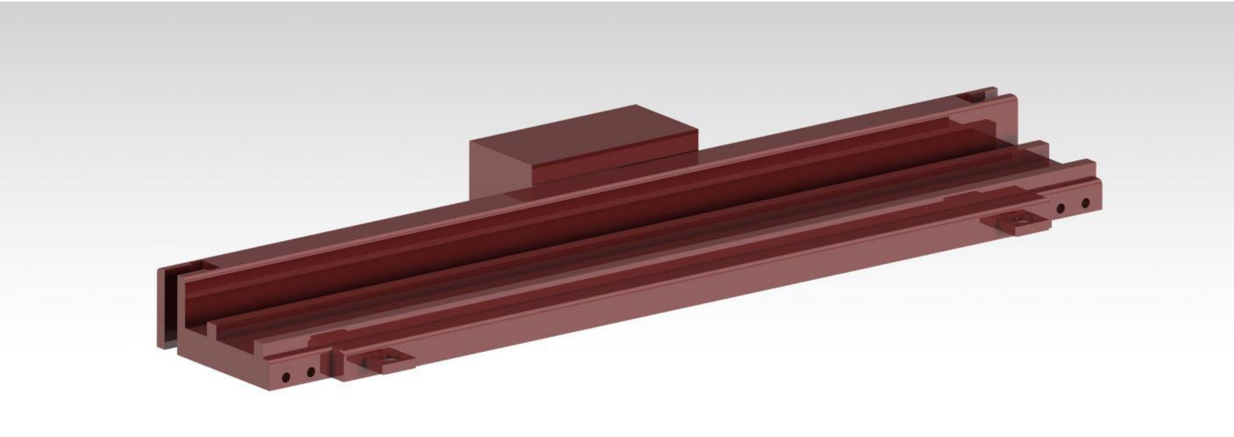

Figure 20

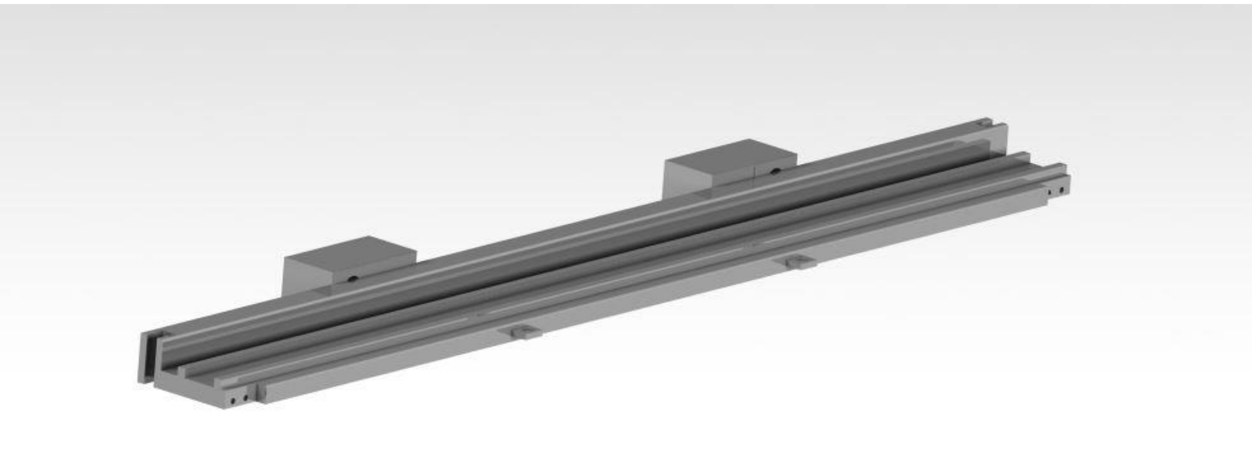

Figure 21

The important aspects of the base are to be modular and maintain strength at the same time. The base faces more compression force due to the heavy weight it carries.

Due to its physical and functional proximity to the support, the Base also needs to accommodate the following components.
1. Linear Slides
2. Connecting Interface
3. Motors
4. Wheels
5. Carrying hooks
6. Wiring
7. Electronics

Each of the component is explained below
1. Linear Slides:
Linear Slides are a set of metal slides which allows uni axis motion by fixing one set of the guideways and the other slides over it. [16] There are various suppliers of Linear Slides with various specifications.

There are 4 different types of linear slides [17]
1. Sliding Contact
2. Rolling element
3. Hydrostatic/aerostatic
4. Magnetic

The above types are differentiated based on the mechanism used to slide one surface over the other. Due to less number of moving parts and easier construction, Sliding Contact Linear Slides are suggested to be used for the product.

These Linear Slides are fixed on to the base as shown in Figure 22**.** They are highlighted in orange.

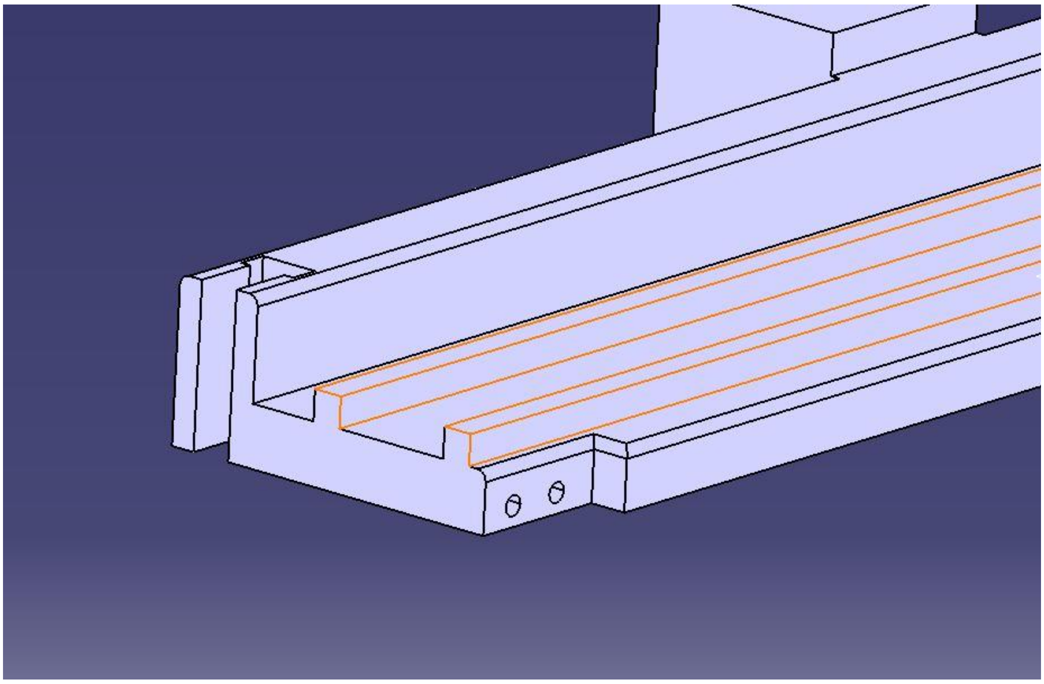

Figure 22

The slides are fixed by using the bolt mechanism included into the slide depending on the supplier. The suggested suppliers for the slides are Hepco Motion. The reason for suggestion is that they are present in Sweden in the name of Mekanex and have a huge varieties of linear slide systems.

2. Connecting Interface:

The purpose of the Connecting Interface is to form a secure connection among the bases to work as a single unit while maintaining the strength.

Different interfaces were created by brainstorming. As the base is 100mm wide, just fixing up one end is not sufficient. Both the edges of a side must be fixed in order to maintain stability. Due to the weight of the base, having a connection at the bottom of the base is dangerous considering the assembly process. So an interface slot is made on the rear edge as shown in Figure 23**.**

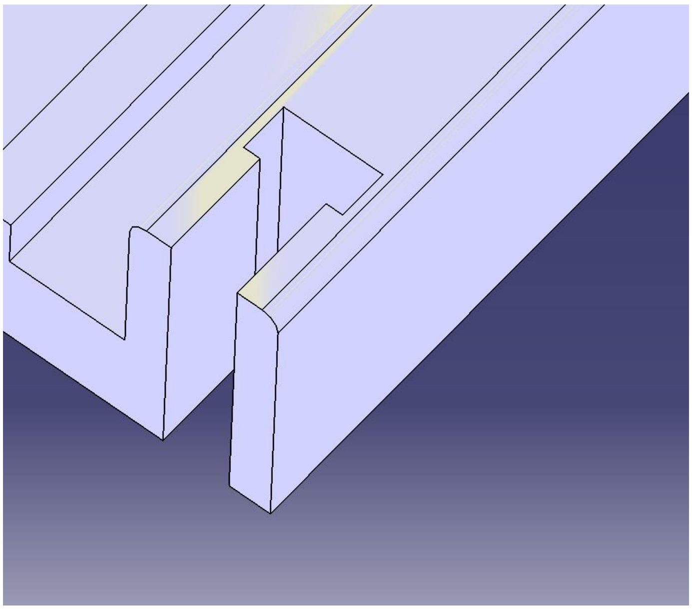

Figure 23

This slot is made on both the sides so that when the two bases meet, the connection can be finished by using a connector as show in Figure 24.

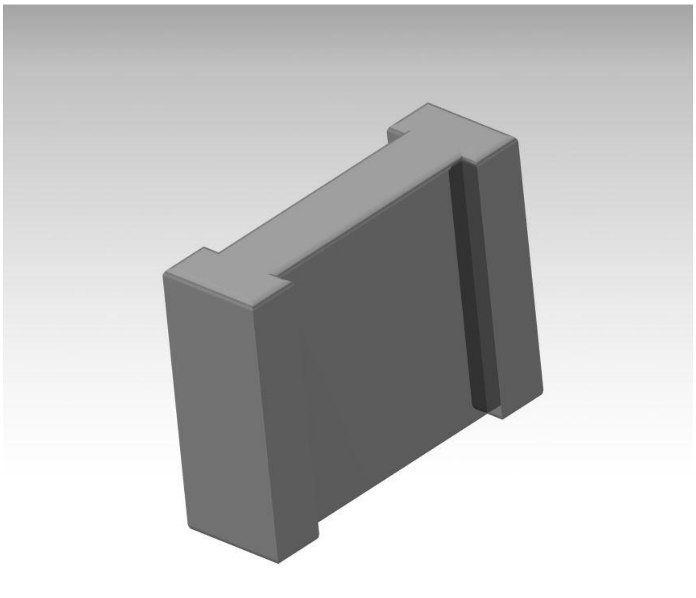

Figure 24

The connector to the rear is “ I ” shaped. This is due to the forces that were expected to be acting on this joint. One of the forces is the tension and compression which acts due to the pull of the motor to drive the Support. While these forces are weak due to the heavy friction from the wheels, an unneglectable moment tries to break the continuity of the Bases which arises from the twist produce when the support is at the edge of the Base and the motor located 500mm away starts to move the base forward as seen in Figure 25**.**

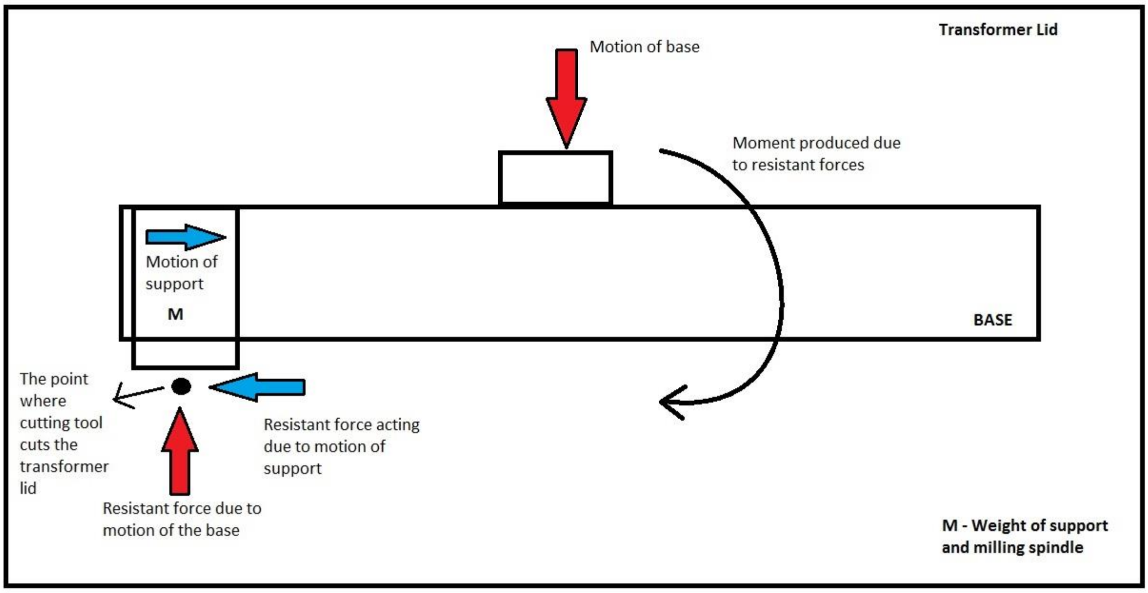

Figure 25

The I-connector fits into the slot provided on the base connecting the two bases as shown in Figure 26.

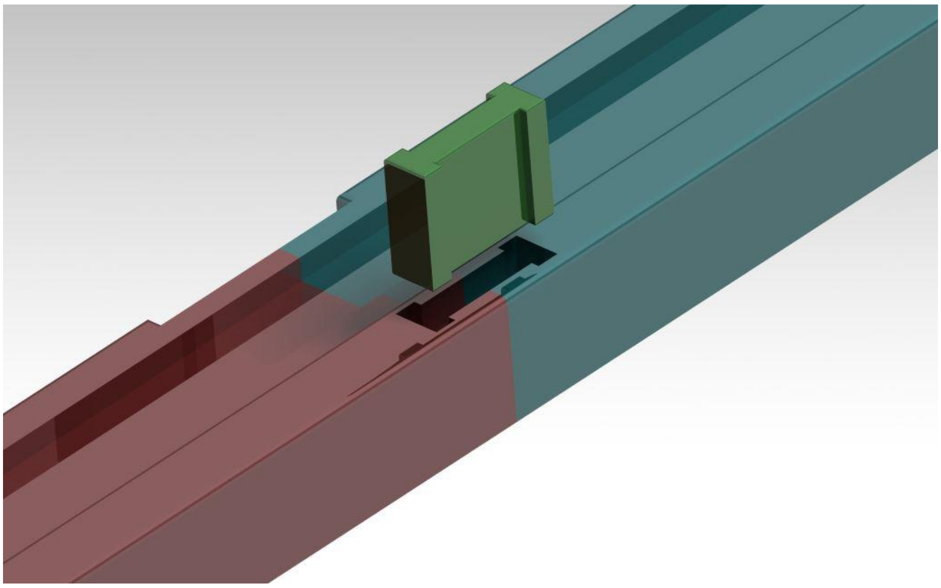

Figure 26

In addition to the rear connector, another connector was added to the front. This is a simple connector and is in the shape of a cuboid and is connected as shown in Figure 27.

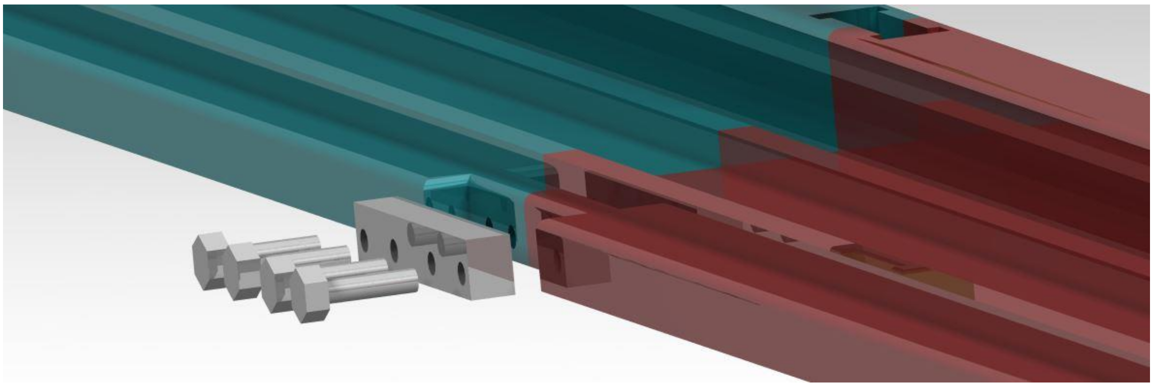

Figure 27

These two connectors help hold the Bases together and keep the slides on both the Bases along the same line.

3. Motors:

The motors are arranged to the rear of the Base at fixed distances from the edge. The purpose of the motors is to push the Base forward to maintain a particular distance from the Clamp and also to move the whole Base at a particular velocity while cutting the curved ends of a transformer. The working of these motors is explained below.

The placement of motors is as show in Figure 28.

These are attached to a long screw rod which ends at the Clamp. The motors turn the screw rods at required speed and they in turn move the Base forward as the Clamp is fixed.

The total weight of the Base is about 160 Kg and the additional weight of the support and spindle and the force required to cut the transformer needs to be considered while selecting the power of the Motor. The gear mechanism employed can be put to good use to get the required power output. The gear mechanism depends on the placement of motor. Since the motor provides a torque, the best way to place the motor is to its side as shown in Figure 28**.**

Figure 28

The torque produced by the motor presses the base to the lid of transformer thus providing maximum friction.

Multiple motors are used to distribute the weight of the base proportionately. But the moving Support applies a variable weight distribution on the base and the power supply to motors need to change accordingly.

4. Wheels:

Wheels are placed under the base to provide movement along one axis while restricting the movement perpendicular to the wheels through friction. The movement along one axis helps to move the spindle to the required location along the curved sides of a transformer. The Base has two rows of slots made at the bottom. Each slot is 30mm wide and 60mm long. The 2 meter base has 39 number of wheels and the 1 meter Base has 20. This number can change depending on the type of wheel chosen and also the motor size as the base of motor might need more wheels. The slots are as shown in Figure 29.

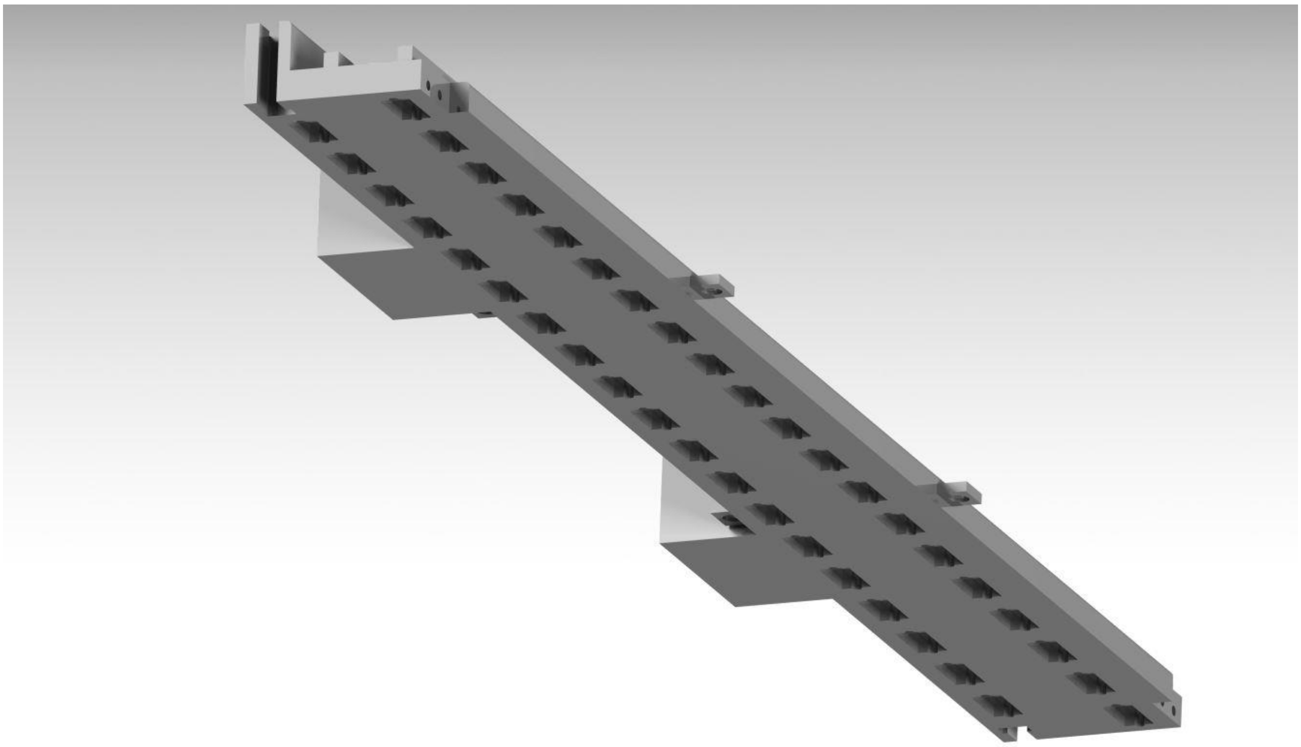

Figure 29

The formula for frictional force is

F= μ.m

Where μ is the frictional coefficient of the material and m is the total load acting on the surface of contact.

Since the mass of Base is fixed, the variable here is the friction coefficient. Selecting a high friction coefficient material for the wheels can give the maximum friction.

5. Carrying hooks:

Carrying hooks are needed to lift the Base and keep it on the transformer. The hooks are placed such that they doesn't disturb the free motion of the Base on the lid of transformer.

The placement is as shown in Figure 30 representing the top view of a 1 meter base. The hooks are highlighted as shown.

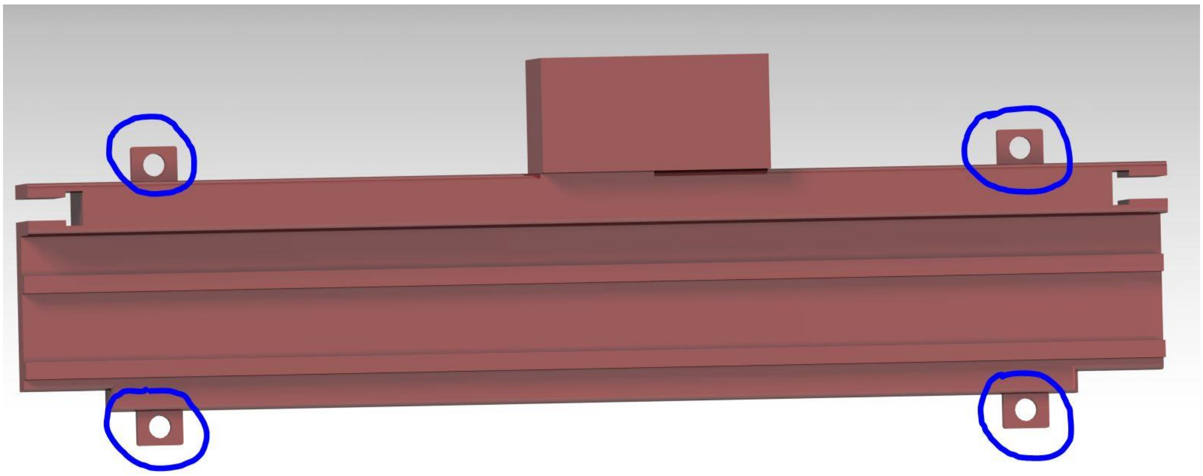

Figure 30

The hooks are attached through welding. There are four hooks welded near to the ends of the base. This divides the load acting on each hook by 4 considering that the hooks are attached equal distances from the Centre of Gravity of the Base.

6. Wiring:

The wiring wasn't worked upon in the thesis but is an important factor while making the design. Wiring should be flexible and must be able to move along with the support to power the motor and spindle.

This is one factor which was considered while taking the decision about the placement of motors for the movement of base. One solution is to place the motors on the holder and the other was to place them on the base. By placing the motors attached to the base, all the electric components get to be concentrated at one place and it is easy to make one set of wiring and electric controls than to distribute them. This is explained more in detail in the Discussion section of this report.

7. Electronics:

Electronics include power supply and control blocks, the control systems of the motors, Support movement and the input accessories. It should be remembered that the motors on the Base only need to be working while cutting the curved ends of transformer. During the cutting of straight edges, the motors need not be moved except to align the spindle to right position. To align the spindle to right position during cutting the straight edge, all the motors should be working simultaneously moving the same amount of distance. Once this is done, the Support can move by itself independently.

While cutting the curved ends, the motors on the base will be moving at the same pace but the support should move according to the speed of the motors of the Base. Depending on the curvature of the curve, the speeds of motors and support are dependent on each other. The person controlling must be able to give the required inputs to make the right cut. Since the spindle will not be able to cut the while thickness of lid in a single go, the shape of cut must be reproducible with highest accuracy possible.

Transport

With the Bases made in 2 meter and 1 meter long variants, the modularity is high as it can handle transformers with sizes of a side varying from 1 meter to 7 meter. As the transformer details are obtained prior to the dispatch of recycling team from the facility, the number of Bases of each length required can be calculated and only the required number of bases can be transported.

As the available size of transport within the car is 3 meter maximum, the 2 meter Bases can fit properly leaving 1 meter for other appliances. By placing the Bases one over the other along the horizontal in pairs of two, the transport can be made efficient.

4.7.4 Holder

This module of the product acts as a reference from where the Base starts. The Holder tool is a set of Lego inspired metal bars with clamps that hold firmly to the lid of transformer. With the metal bars fixed rigidly, the other parts can be assembled at required positions. These metal bars look as shown in Figure 31**.**

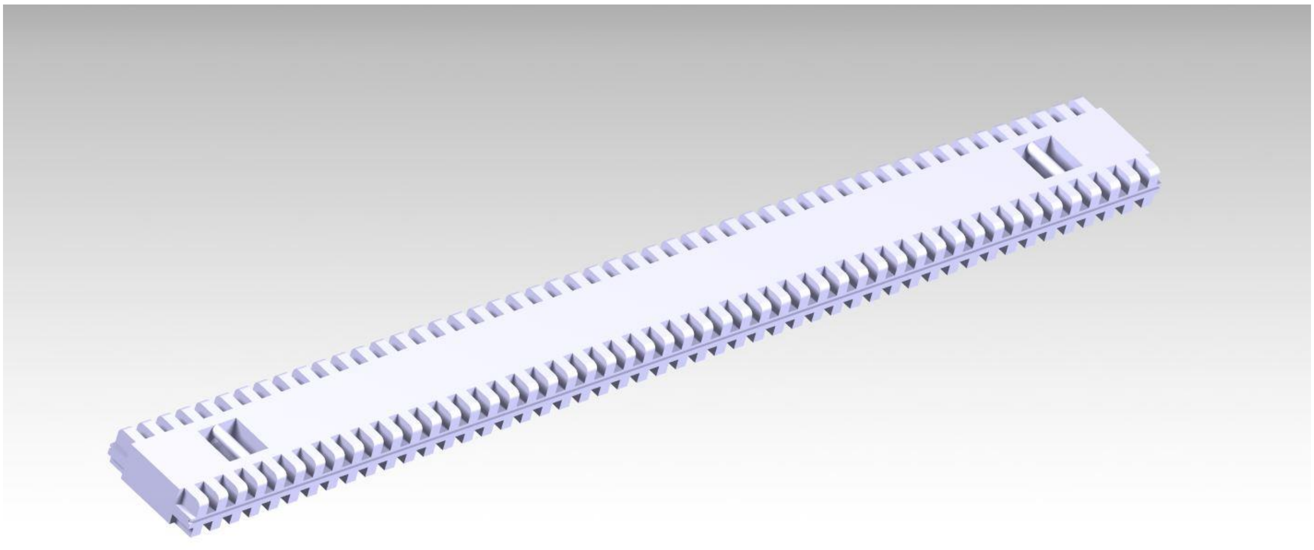

Figure 31

These metal bars have two different gear racks on the top and bottom. The gears on the top mostly are used to hold other parts while the gear at the bottom is used by the clamp to fix itself tightly to the transformer walls. These metal bars are available in one and two meter lengths. They are equipped with a provision to lift them with help of crane. These hooks are shown in Figure 32.

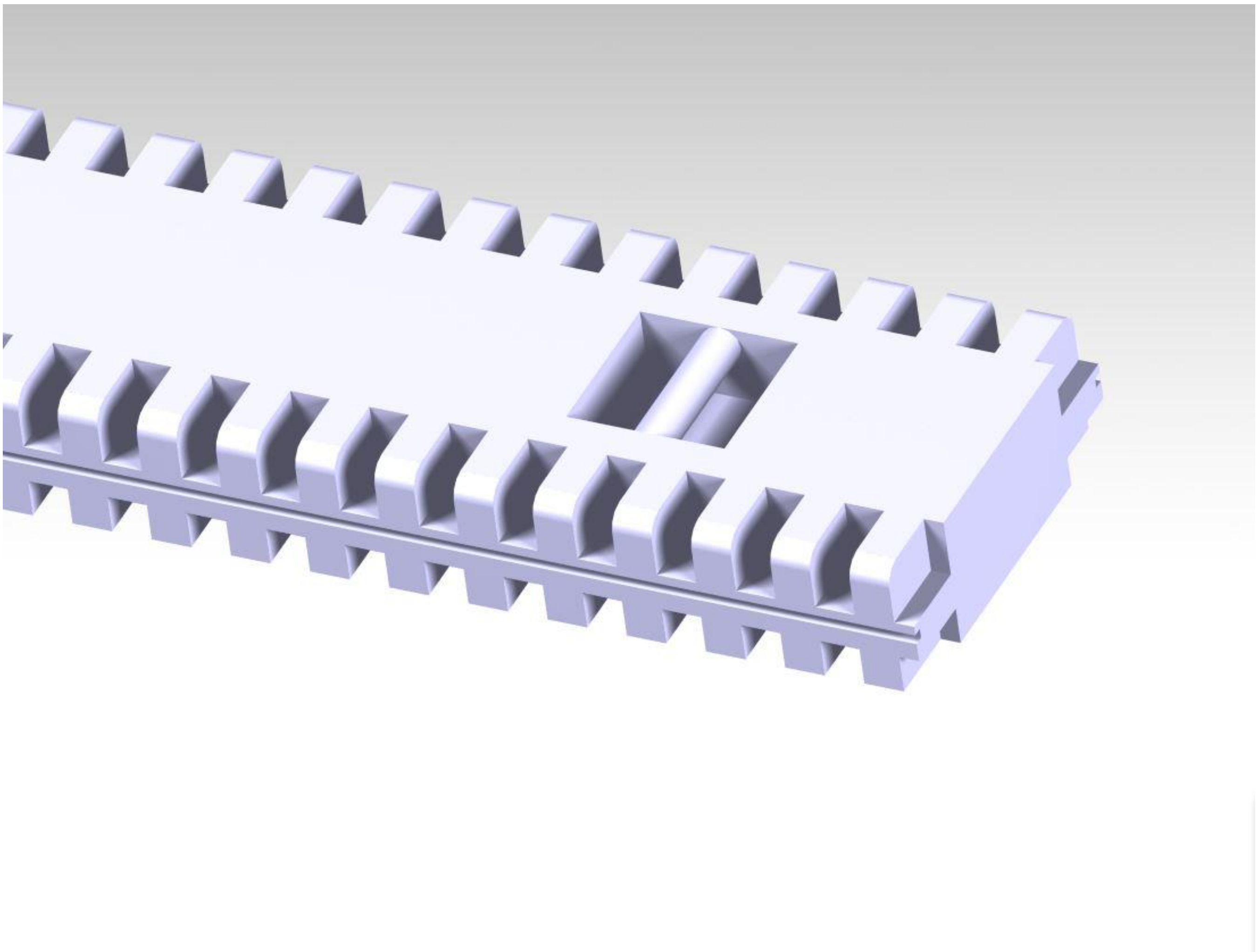

Figure 32

The other parts which are fixed to the metal bars are as follows

1. Nut
2. Connecting block
3. T-Hook Clamp (T for Transformer)
4. Main Clamp

These parts are fit on the Holder with help of the teeth present on the upper side. The parts has the other set of teeth which fits perfectly into the teeth of the Holder thus forming a fixed set.

There is also a groove which supports the Main Clamp and Nut which is explained clearly in their respective sections.

1. Nut: This is the coupling part of the Screw Rod from the motor of the Base. The Screw Rod which is attached to the motor goes through the nut first. The Nut has screw threads which help the Screw Rod to move forward or opposite depending on the direction it rotates. The Nut look as shown in Figure 33.

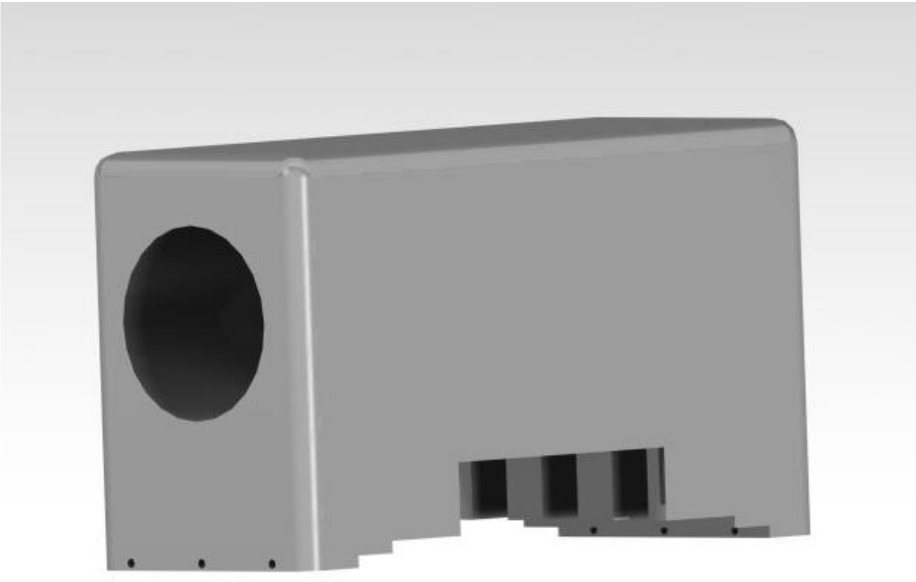

Figure 33

The Nut is placed upon the Holder with the help of counter teeth as shown in Figure 34. Considering the forces acting on the Nut, a mechanism is introduced which can hold the Nut rigidly. While the movement along the length of the metal bar is curbed with the teeth, still the movement along the breadth of the bar is possible due to the moment acting when the Screw Rod gets pushed. This is explained in Figure 34. This is a locking mechanism which locks into the groove with the help of screws provided.

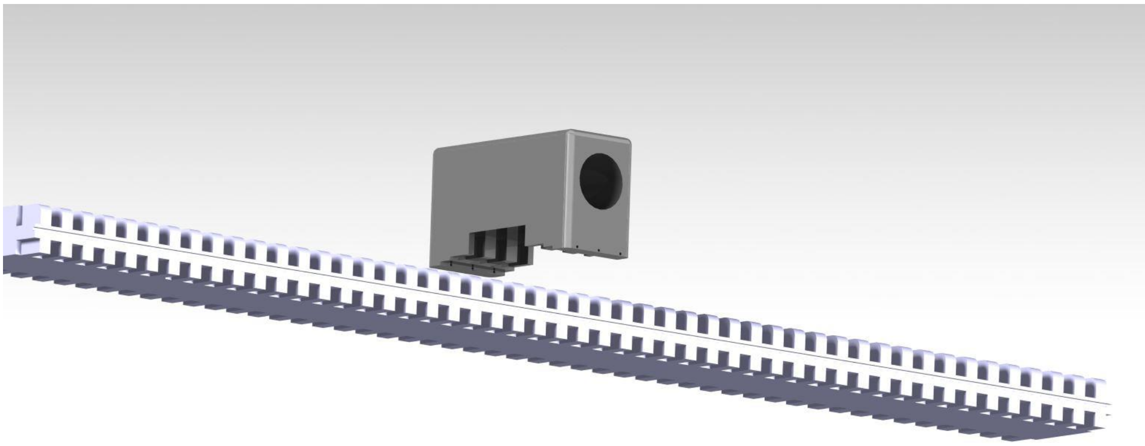

Figure 34

2. Connecting block

The role of Connecting Block is to hold the two metal bars together. The anti-teeth present on the block fits directly into the teeth of the metal bars. The anti-teeth are represented in Fig 36**.** Since the connecting block experiences mostly tensile forces, the teeth fitting into each other can hold the two metal bars tightly.

The connecting block looks as shown in Figure 35**.**

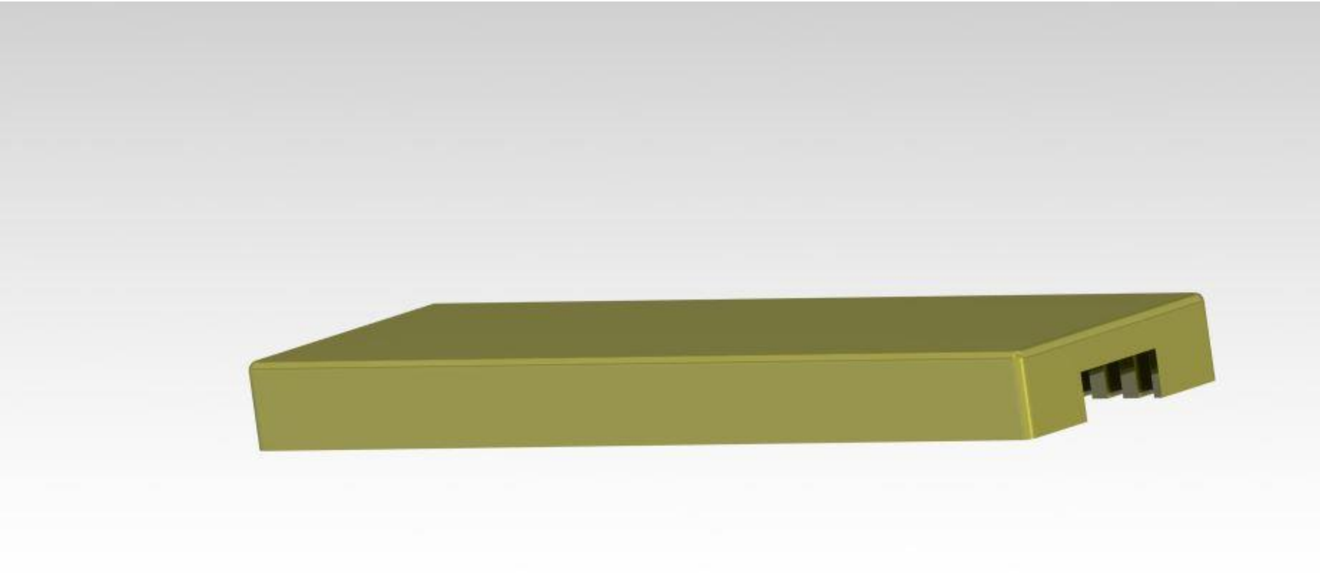

Figure 35

By placing the connecting block over two adjacent metal bars, the metal bars can be held rigidly. The Figure 36 shows how the connecting block can be put over a metal bar.

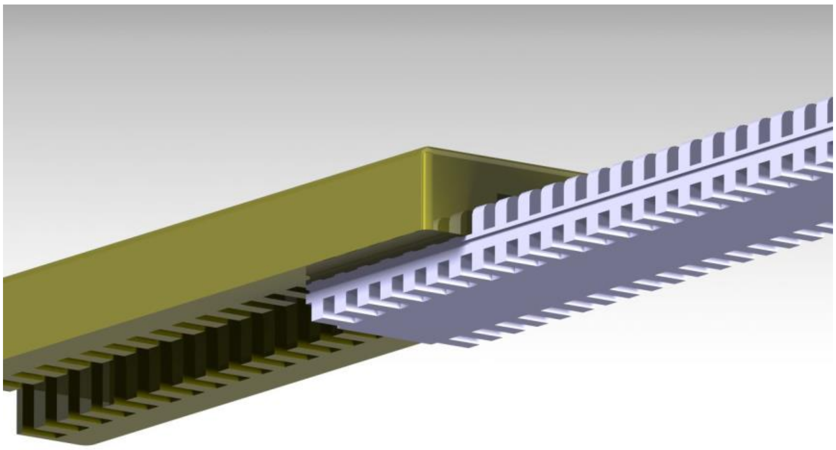

Figure 36

3. T-Hook Clamp (T for Transformer)

The T-Hook Clamp attaches to the hooks of the transformer which are used for lifting it. This clamp also has the anti-teeth which helps it hold on to the Holder metal bars and prevents unnecessary movement shown in Figure 37.

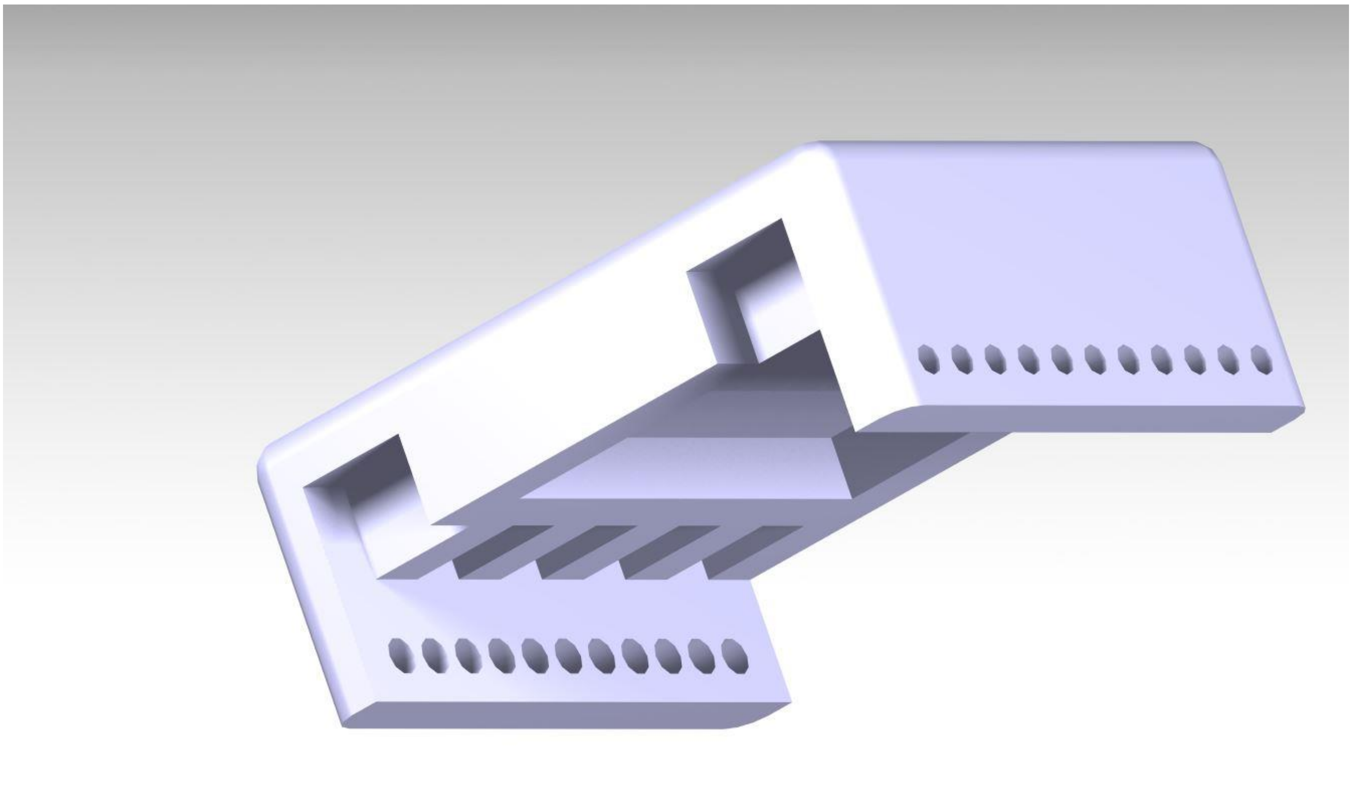

Figure 37

This is used only when the lengthwise cut is being made on the transformer. Since the Main Clamp can not be used to hold the Holder tightly for a curved transformer, the hooks are used for stability.

The T-Hook Clamp looks as shown in Figure 38.

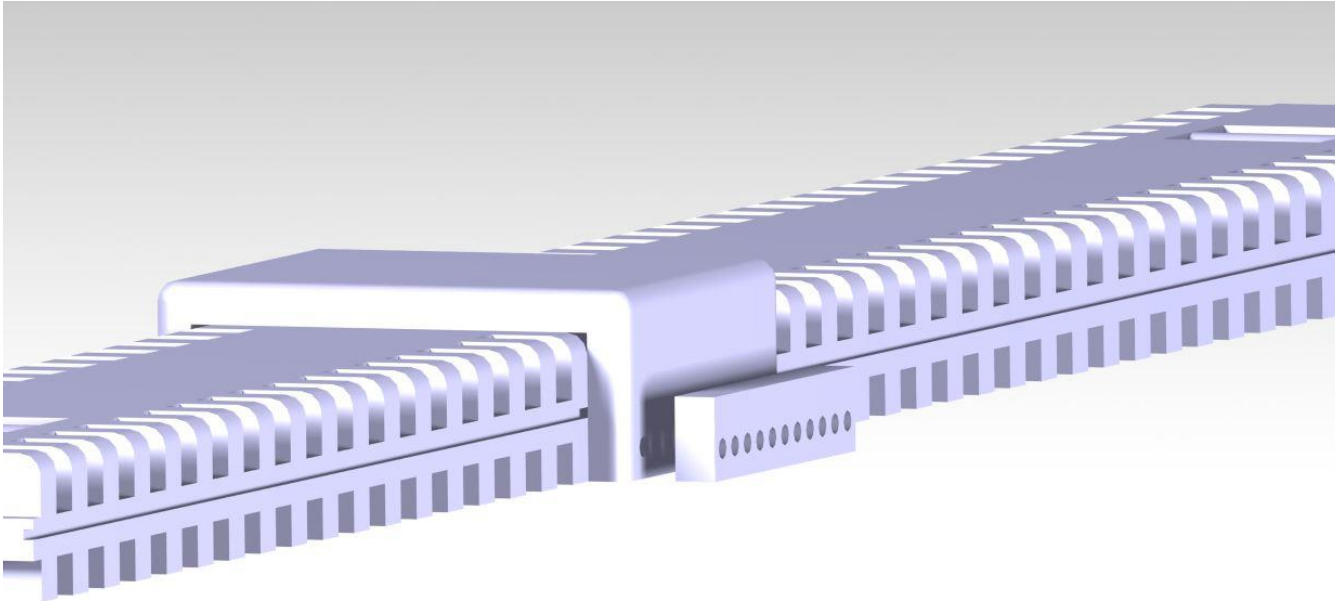

Figure 38

4. Main Clamp

The Main Clamp looks as shown in Figure 39.

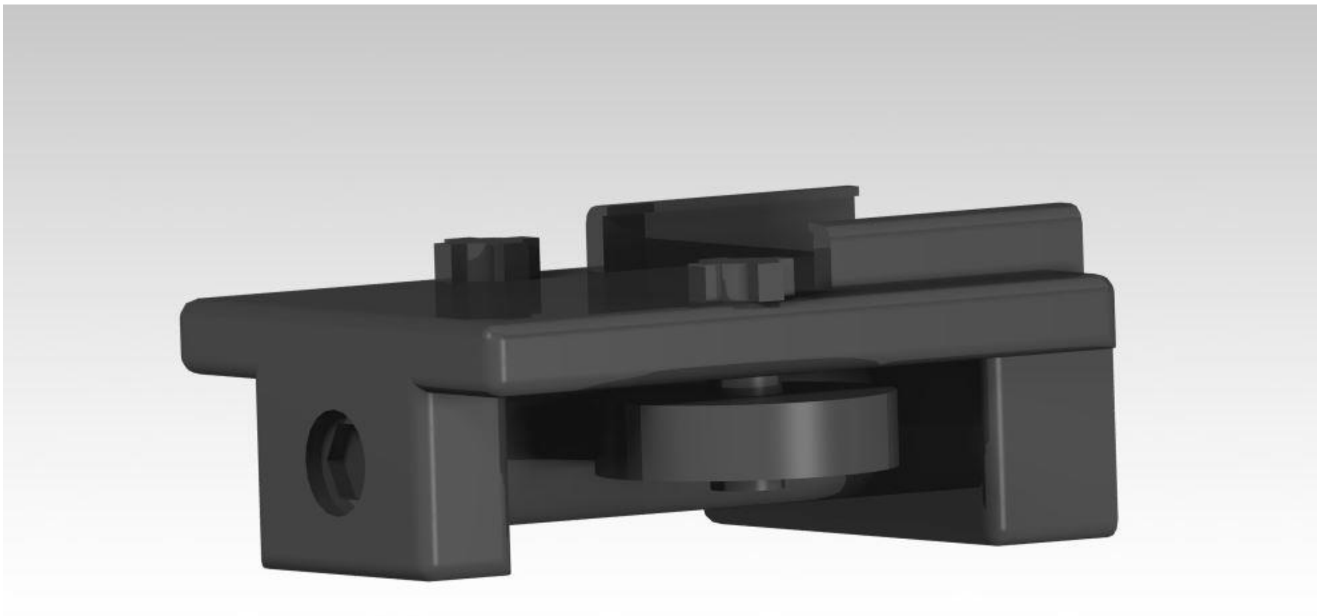

Figure 39

The purpose of this clamp is to hold the Holder tightly to transformer. Two of these clamps are required in either side of the Holder to work.

The Main Clamp works on the principle of screw-gear mechanism. This mechanism can be seen from the down view of the clamp in Figure 40.

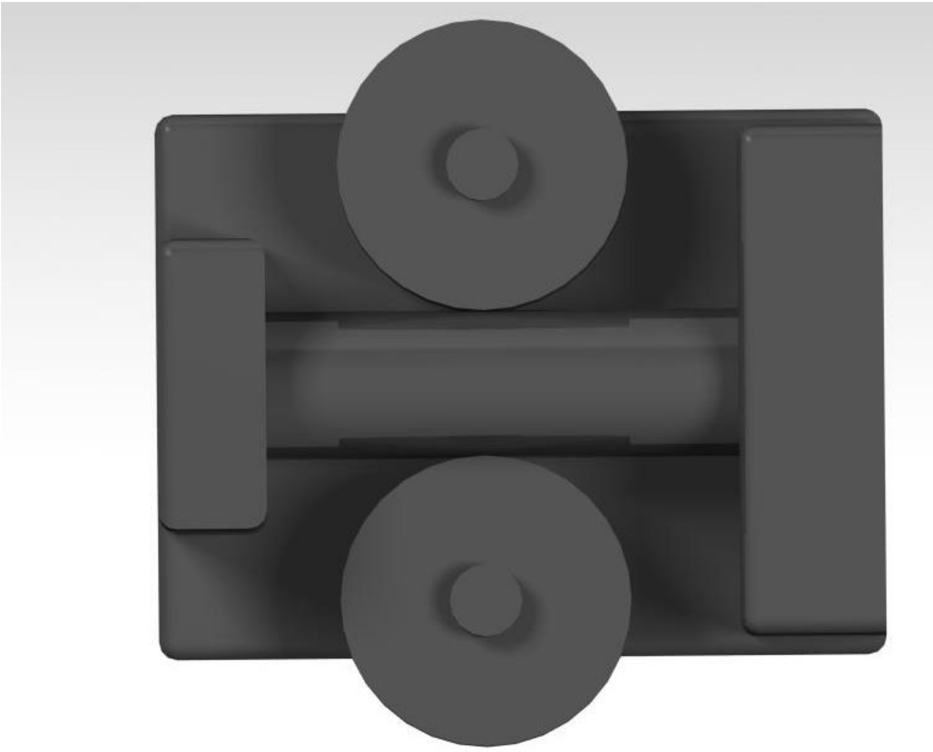

Figure 40

By turning the screw rod in the middle in either direction, the large gears connected to it rotate. While the gears rotate, they also rotate the cylinder to which they are attached which is shown in Figure 41.

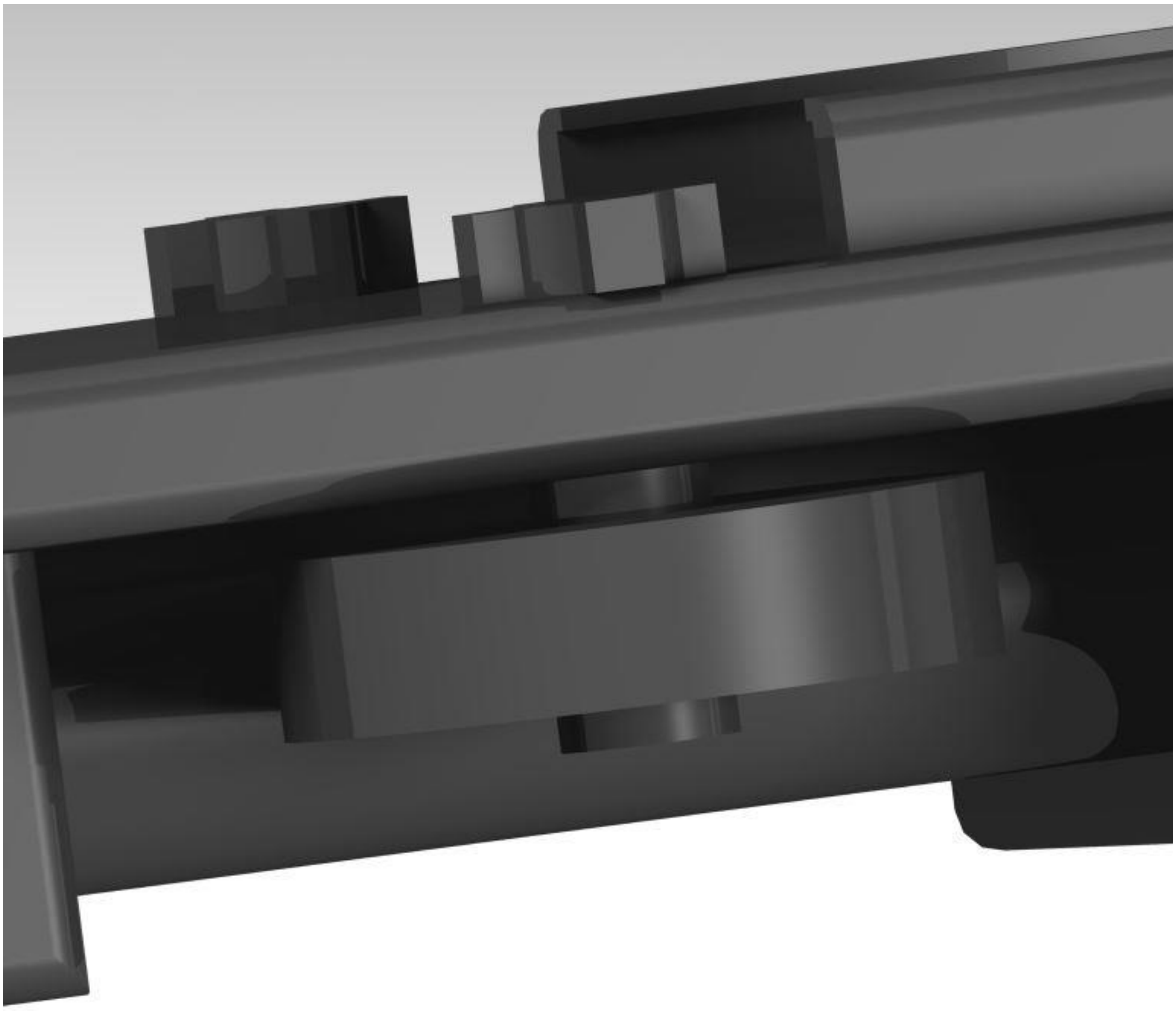

Figure 41

The other end of cylinder has another set of gears which are connected to the teeth provided at the lower side of the Holder metal bars. The large gears rotate only when the screw rod is rotated and the screw rod doesn’t rotate when the large gears rotate due to the mechanism employed. This forms a locking mechanism such that by placing two Main Clamps at either end, the Holder can be firmly placed atop the transformer. This is shown in Figure 42.

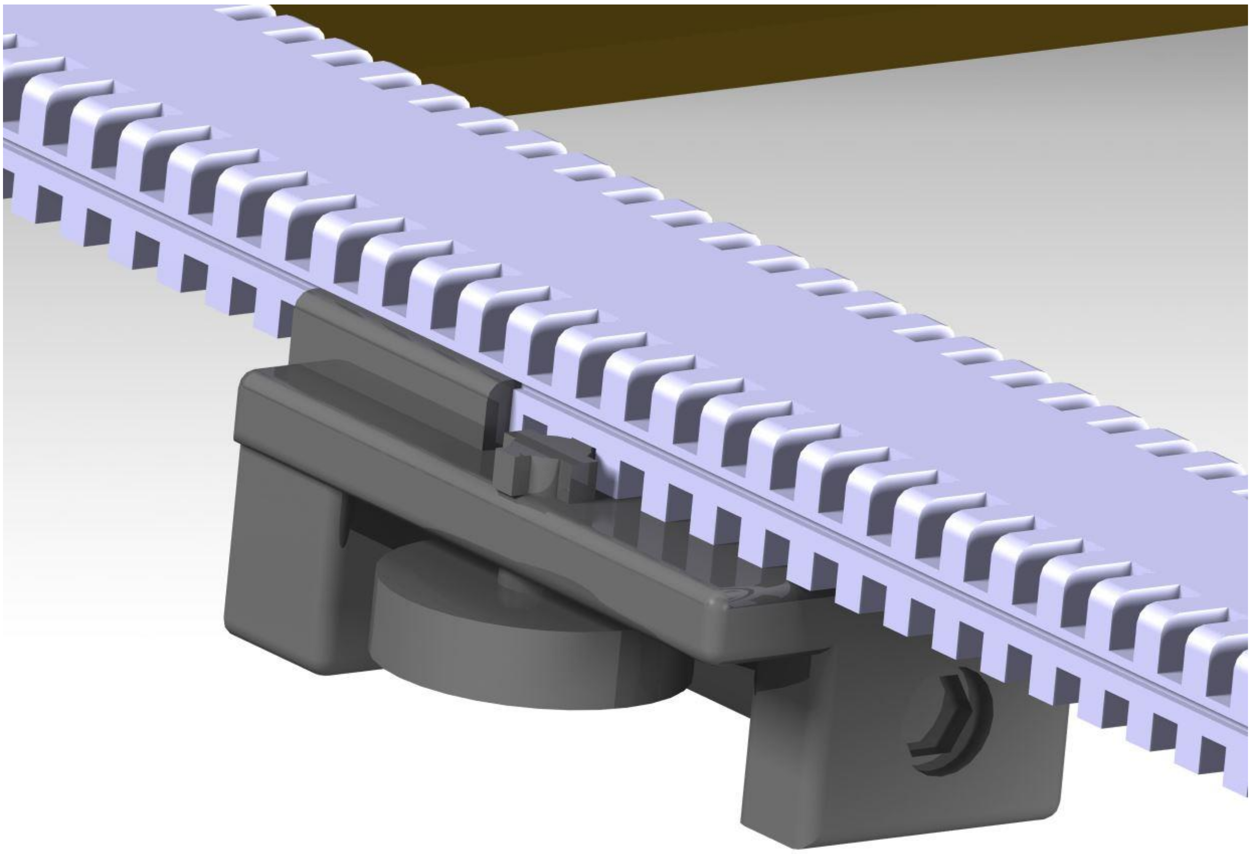

Figure 42

5. Final product

The Final product will look as shown below in Figure 43 and 44.

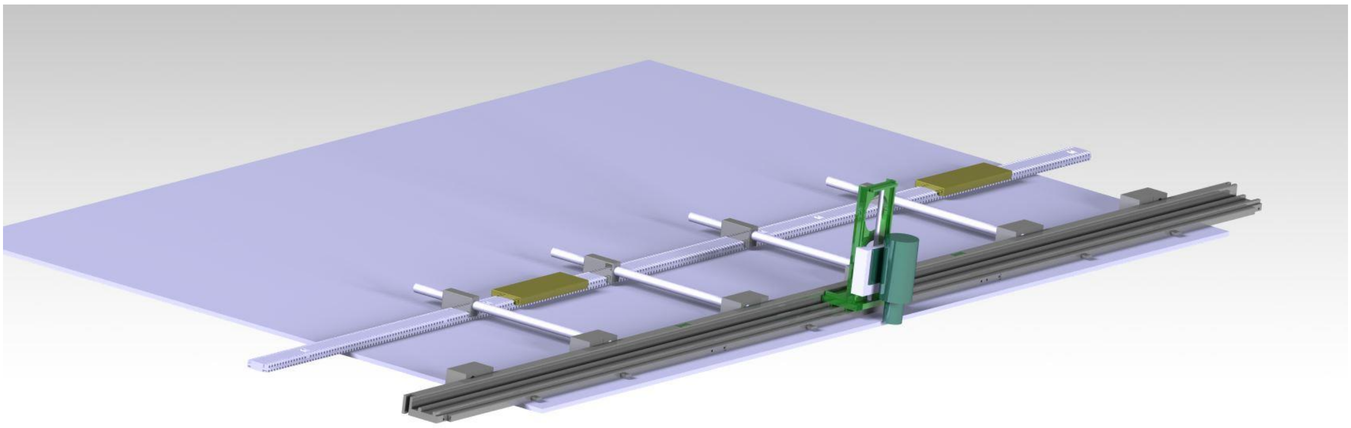

Figure 43

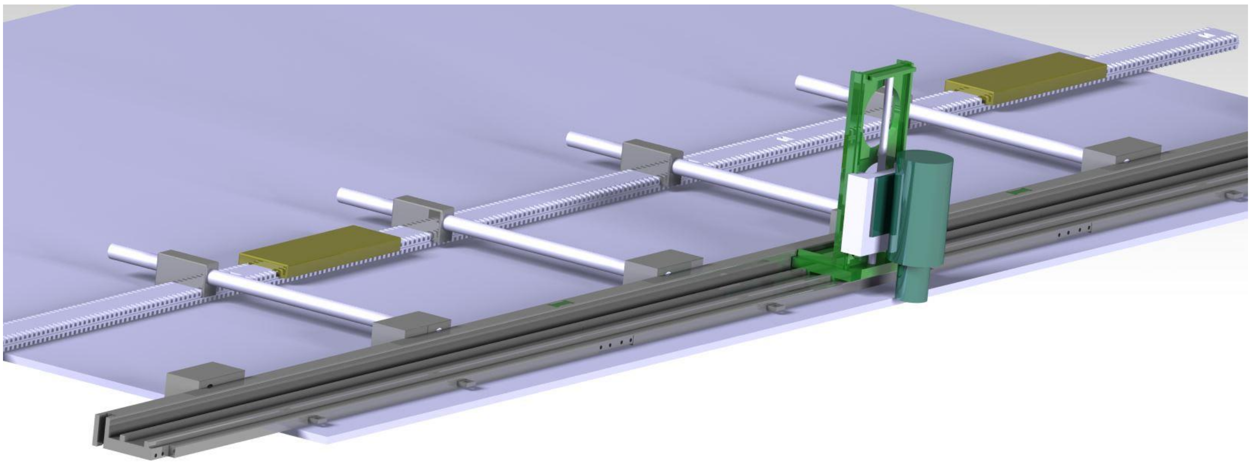

Figure 44

6. Discussion

It should be observed that the above concept is developed until the system level design. The interfaces are defined and are given an idea of how the arrangement can be made. But the dimensions or the accuracy of details is not yet done. These will be done in the next phases which are explained below

- Detailed Design

  This has to be performed once the System Level phase is finished. The important points to consider are the tool requirements, power of motors, coolant incorporation, size of wheels, material, connection interfaces, clamp dimensions, details of screw rods, electronics integrations
- Testing

  Testing can be done digitally. Using the advanced analysis software, the best dimensions of the parts can be chosen. The original testing can be done with individual modules. By producing prototypes of the independent modules, testing can be done and a passed module can be fit into the final product and tested
- Production Ramp up

  Depending on the number of such products required, manufacturers can be chosen and given the drawings to make the product a reality

At every phase, the final outcome must be inspected thoroughly before going into the next phase. The inspection can suitably be more about the satisfaction of customer needs.

Since it is important to consider the customer needs, the satisfaction of the requirements until now are discussed below

- The final solution does not use foam to be filled inside transformer
  - With the milling technology being used to cut the metal, there is lot of heat produced but precautions can be taken to prevent sparks from going into the transformer. So this needs can be satisfied by introducing coolants to the concept.
- The final solution can be assembled with a crane and 2 employees
  - As the assembly is much simpler, the heavy weights can be carried by the crane and 2 employees can do the assembling.
- The final solution can cut metal of 15mm thickness
  - By making several rounds, the milling technology will be able to perform the required cut
- The final solution can be transported
  - The sizes of the bases are made such that they fit into the car being used for transportation by Stena. But the arrangement of all the modules still has to be worked upon.
- The final solution do not produce sparks while cutting
  - The milling machine does not produce any spark while cutting the metal
- The final solution can cut transformer lids with curved sides
  - With the screw rod mechanism, the solution is capable of handling various curved sides of transformer
- The final solution can cut transformer lids with straight sides
  - The bases are made in a straight line which will make the spindle go in a straight line cutting the straight sides of transformer

- The final solution can be used on site
  - The solution being modular can be transported and can be assembled with the resources available on site. Since the whole design is made to make it useful on site, this requirement is completely fulfilled
- The final solution can be used at the dismantling facility
  - As the solution is made to be working on the transformers onsite, it usability at the facility needs to be worked on.
- The final solution can work with the power produced from a portable generator
  - Satisfaction of this requirement is sceptical as more information is needed to confirm this.
- The final solution can save costs per operation compared to conventional methods.
  - Once the solution is operable, it will not cost as much as the conventions methods being used by Stena as the cost required for the foam will completely be eliminated.

As can be seen above, the satisfaction of the requirements cannot be completely decided as yet. While some requirements can be said to be met, some requirements need more information to be gathered. This can be obtained in the further stages of the development process.

Other Ideas

Robotic base:

One improvement for the future development of this concept can be to introduce robotic base. Instead of having many bases of different sizes, a single base of approximately 2 meter size can be used to replace all the bases. This robotic base can have wheels which are controlled by a set of motors that move the base forward and backward replacing the screw rod mechanism. By having heavy weight on the rear side, the weight of the spindle can be counter acted. A concept of this robotic base looks as shown in Figure 45 and 46.

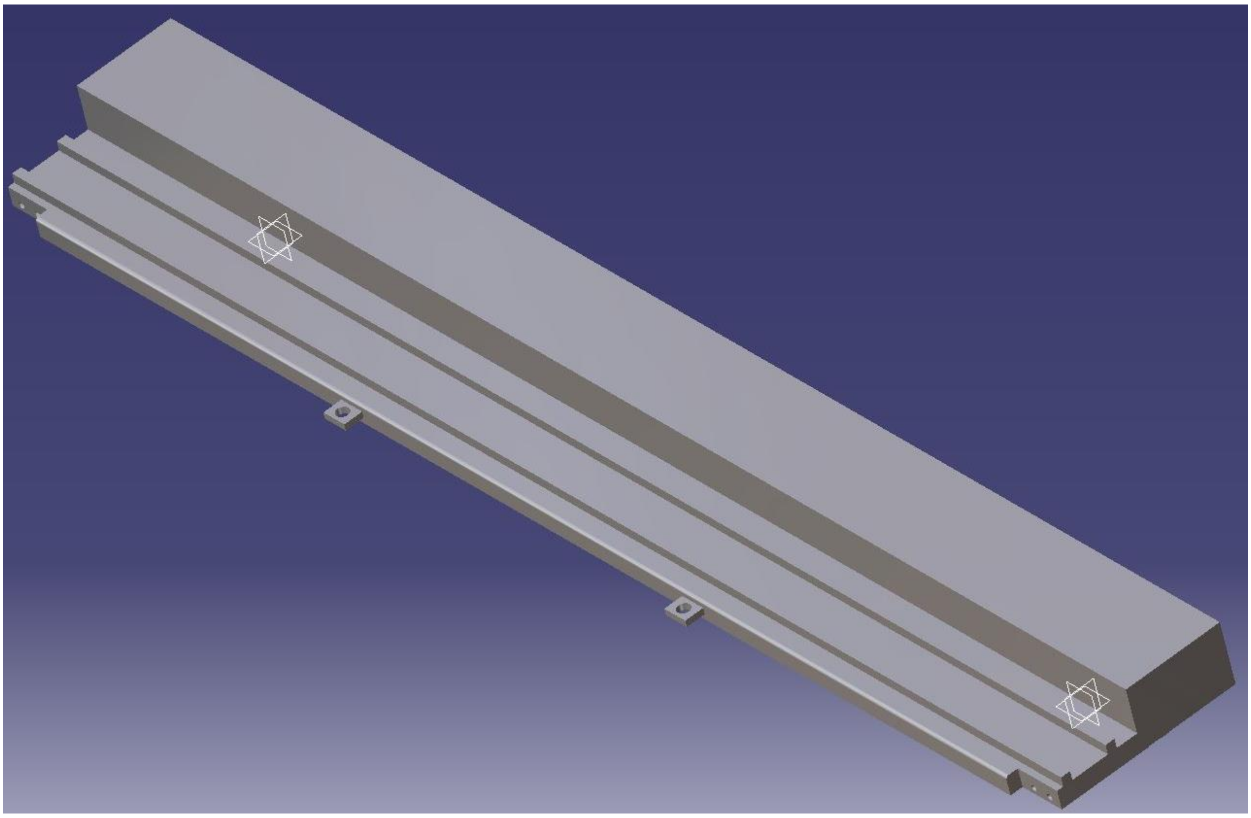

Figure 45

The motors are replaced by heavy metal along the length of the rear edge. The position of wheels looks as shown in Figure 46 with the empty spaces filled with motors to drive the wheels. After making a cut, the base will be shifted to another position to continue the cut.

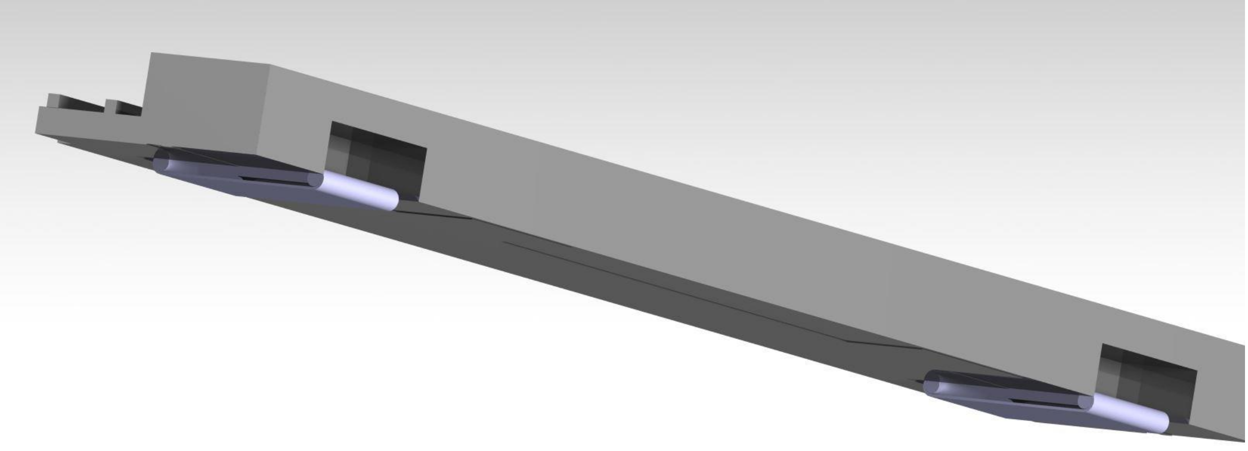

Figure 46

Eliminating the momentum:

In Figure 25, it is explained how a momentum might be caused that can induce some bending moments in the bases. Since this problem appears only for the 1 meter bases, a simple solution to eliminate this problem is to make the motors modular. By having the ability to keep the motors at different places at the rear side of the base, the problem of moment can be solved.

Coolant System

A coolant system is very important point to be considered. It is skipped in the working of this thesis but should be given priority while developing the whole solution. One possible place to setup this system will be at the back of support so it is easier to adjust the spraying mechanism exactly to the point where needed.

7. Conclusion

The thesis work started with an aim to find a solution to dismantle huge transformers on site. It is easier to dismantle the transformers using conventional methods. But the flammable items inside makes it harder as the conventional methods produce sparks which can put the transformer on fire. This is one of the biggest challenges answered. To not produce sparks implies to not utilize high speed cutting tools which means a very high force is needed to tear the metal apart. To face this high amount of forces, a simple structure is not sufficient. A strong metal structure is needed in order to perform the operation. Since the operation of dismantling has to be performed on site, it is important to make the structure portable. So, the challenge faced is to find a solution that can cut 15mm thick metal sheets capable of resisting huge forces while being portable.

There is no one solution which is like an answer to the problem. The solution proposed may or may not be the best solution with highest efficiency. There always is room for improvement and as more and more ideas are obtained, various solutions that can solve the same issue can be made.

The current thesis work being the beginning of a new project, there are many options left open ended in order to not limit the range of ideas. With open ended options given to Stena, various perspectives can be sort out before going further in the process.

The thesis started with gathering the customer requirements through interviews with Stena. With this information, a model on the process followed at Stena was made. Three important functions from the model were selected and many alternate solutions to these functions were developed. By various combinations, various solutions were produced. These combinations are limited to individual solutions generated for each function. With higher and more varied solutions for each function, even more complicated and more number of combinations can be developed.

The screening of these combinations had to be done in two stages in order to maintain the quality of the results. The first stage of screening consisted of removing the combinations that can in no way be constructed. The second stage was done by assessing different factors which resulted in combinations that can be constructible and suits the customer needs. By doing these two stages of screening, the huge number of combinations were screened quickly while making sure the customer needs are satisfied.

This screening is followed by System level design of the selected concept. The modules were defined here and each module is worked upon separately. This helps in the further phases where lot of work needs to be done on each module by various engineers from different fields. Since the modules are separated, the work can be performed simultaneously on all modules at a time thus making the development faster.

Finally, the concept is to dismantle the transformer by opening its lid. Due to the flammable materials inside that might catch fire, the lid is cut with the help of milling technology without causing any spark. As the forces acting during the milling operation are very huge, a strong assembly was made that can handle the forces while still being portable. The movement along the curves was obtained with the help of a screw mechanism and the movement perpendicular to it was made by using slides. With the help of this combination, different shapes of curves can be handled.

Only the concept was developed in this thesis work and more effort to develop the smaller details is needed for the final product to be made a reality.

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Appendix 1: Initial Screening

This table describes the initial screening that is done. All the combinations that can be possible to build are selected with a "y" in the last column and the combinations that are not selected are highlighted in red.

A		B		C	
Hack Saw		Clamp		Belt	
Hack Saw		Clamp		Car	y
Hack Saw		Clamp		Chain	y
Hack Saw		Clamp		Friction wheel	
Hack Saw		Clamp		Gear	y
Hack Saw		Clamp		human	
Hack Saw		Clamp		Motor	y
Hack Saw		Clamp		Potential Energy	
Hack Saw		Clamp		Rail	y
Hack Saw		Crane Hook		Belt	
Hack Saw		Crane Hook		Car	y
Hack Saw		Crane Hook		Chain	y
Hack Saw		Crane Hook		Friction wheel	
Hack Saw		Crane Hook		Gear	y
Hack Saw		Crane Hook		human	y
Hack Saw		Crane Hook		Motor	y
Hack Saw		Crane Hook		Potential Energy	y
Hack Saw		Crane Hook		Rail	y
Hack Saw		Glue		Belt	
Hack Saw		Glue		Car	y
Hack Saw		Glue		Chain	y
Hack Saw		Glue		Friction wheel	
Hack Saw		Glue		Gear	y
Hack Saw		Glue		human	
Hack Saw		Glue		Motor	y
Hack Saw		Glue		Potential Energy	
Hack Saw		Glue		Rail	y
Hack Saw		Hand		Belt	
Hack Saw		Hand		Car	
Hack Saw		Hand		Chain	
Hack Saw		Hand		Friction wheel	
Hack Saw		Hand		Gear	

Hack Saw		Hand		human	y
Hack Saw		Hand		Motor	
Hack Saw		Hand		Potential Energy	
Hack Saw		Hand		Rail	
Hack Saw		Integrated		Belt	
Hack Saw		Integrated		Car	y
Hack Saw		Integrated		Chain	
Hack Saw		Integrated		Friction wheel	
Hack Saw		Integrated		Gear	y
Hack Saw		Integrated		human	
Hack Saw		Integrated		Motor	y
Hack Saw		Integrated		Potential Energy	
Hack Saw		Integrated		Rail	
Hack Saw		Magnet		Belt	
Hack Saw		Magnet		Car	y
Hack Saw		Magnet		Chain	
Hack Saw		Magnet		Friction wheel	
Hack Saw		Magnet		Gear	y
Hack Saw		Magnet		human	
Hack Saw		Magnet		Motor	y
Hack Saw		Magnet		Potential Energy	
Hack Saw		Magnet		Rail	
Hack Saw		Rope		Belt	
Hack Saw		Rope		Car	y
Hack Saw		Rope		Chain	y
Hack Saw		Rope		Friction wheel	
Hack Saw		Rope		Gear	y
Hack Saw		Rope		human	
Hack Saw		Rope		Motor	y
Hack Saw		Rope		Potential Energy	
Hack Saw		Rope		Rail	y
Hack Saw		Screw		Belt	
Hack Saw		Screw		Car	y
Hack Saw		Screw		Chain	y
Hack Saw		Screw		Friction wheel	
Hack Saw		Screw		Gear	y
Hack Saw		Screw		human	
Hack Saw		Screw		Motor	y

Hack Saw		Screw		Potential Energy	
Hack Saw		Screw		Rail	y
Hack Saw		Vaccum Holder		Belt	
Hack Saw		Vaccum Holder		Car	y
Hack Saw		Vaccum Holder		Chain	
Hack Saw		Vaccum Holder		Friction wheel	
Hack Saw		Vaccum Holder		Gear	y
Hack Saw		Vaccum Holder		human	
Hack Saw		Vaccum Holder		Motor	y
Hack Saw		Vaccum Holder		Potential Energy	
Hack Saw		Vaccum Holder		Rail	
Milling		Clamp		Belt	
Milling		Clamp		Car	y
Milling		Clamp		Chain	y
Milling		Clamp		Friction wheel	
Milling		Clamp		Gear	y
Milling		Clamp		human	
Milling		Clamp		Motor	y
Milling		Clamp		Potential Energy	
Milling		Clamp		Rail	y
Milling		Crane Hook		Belt	
Milling		Crane Hook		Car	y
Milling		Crane Hook		Chain	y
Milling		Crane Hook		Friction wheel	
Milling		Crane Hook		Gear	y
Milling		Crane Hook		human	y
Milling		Crane Hook		Motor	y
Milling		Crane Hook		Potential Energy	y
Milling		Crane Hook		Rail	y
Milling		Glue		Belt	
Milling		Glue		Car	y
Milling		Glue		Chain	y
Milling		Glue		Friction wheel	

Milling		Glue		Gear	y
Milling		Glue		human	
Milling		Glue		Motor	y
Milling		Glue		Potential Energy	
Milling		Glue		Rail	y
Milling		Hand		Belt	
Milling		Hand		Car	
Milling		Hand		Chain	
Milling		Hand		Friction wheel	
Milling		Hand		Gear	
Milling		Hand		human	
Milling		Hand		Motor	
Milling		Hand		Potential Energy	
Milling		Hand		Rail	
Milling		Integrated		Belt	
Milling		Integrated		Car	y
Milling		Integrated		Chain	
Milling		Integrated		Friction wheel	
Milling		Integrated		Gear	y
Milling		Integrated		human	
Milling		Integrated		Motor	y
Milling		Integrated		Potential Energy	
Milling		Integrated		Rail	
Milling		Magnet		Belt	
Milling		Magnet		Car	y
Milling		Magnet		Chain	
Milling		Magnet		Friction wheel	
Milling		Magnet		Gear	y
Milling		Magnet		human	
Milling		Magnet		Motor	y
Milling		Magnet		Potential Energy	
Milling		Magnet		Rail	
Milling		Rope		Belt	
Milling		Rope		Car	y
Milling		Rope		Chain	y
Milling		Rope		Friction wheel	
Milling		Rope		Gear	y
Milling		Rope		human	

Milling		Rope		Motor	y
Milling		Rope		Potential Energy	
Milling		Rope		Rail	y
Milling		Screw		Belt	
Milling		Screw		Car	y
Milling		Screw		Chain	y
Milling		Screw		Friction wheel	
Milling		Screw		Gear	y
Milling		Screw		human	
Milling		Screw		Motor	y
Milling		Screw		Potential Energy	
Milling		Screw		Rail	y
Milling		Vaccum Holder		Belt	
Milling		Vaccum Holder		Car	y
Milling		Vaccum Holder		Chain	
Milling		Vaccum Holder		Friction wheel	
Milling		Vaccum Holder		Gear	y
Milling		Vaccum Holder		human	
Milling		Vaccum Holder		Motor	y
Milling		Vaccum Holder		Potential Energy	
Milling		Vaccum Holder		Rail	

Appendix 2: Further Screening

This is the second part of screening. This table represents the scores for each combination. The value assigned for Z is the final score for that particular combination.

A	X	B	Y	C	Z	Firmness	Number of moving parts	ability to attach	ease of movement
Milling	1	Clamp	2	Motor	3	2	2	2	2
Milling	1	Clamp	1	Gear	2	2	0	0	2

Milling	1	Clamp	1.75	Car	2.75	2	1	2	2
Milling	1	Clamp	0.75	Rail	1.75	2	-1	0	2
Milling	1	Clamp	0	Chain	1	1	-1	0	0
Milling	2	Crane Hook	1	Motor	3	1	0	2	1
Milling	2	Crane Hook	1	Gear	3	2	0	1	1
Milling	2	Crane Hook	0	human	2	-2	2	0	0
Milling	2	Crane Hook	1.25	Car	3.25	2	0	2	1
Milling	2	Crane Hook	0.5	Rail	2.5	1	-1	0	2
Milling	2	Crane Hook	0.25	Potential Energy	2.25	1	0	0	0
Milling	2	Crane Hook	-0.25	Chain	1.75	0	1	-1	-1
Milling	1	Screw	1.5	Motor	2.5	2	2	1	1
Milling	1	Screw	1	Gear	2	2	0	1	1
Milling	1	Screw	1.75	Car	2.75	2	2	2	1
Milling	1	Screw	1	Rail	2	1	1	1	1
Milling	1	Screw	0.5	Chain	1.5	1	0	0	1
Milling	-2	Vaccum Holder	0.25	Motor	-1.75	0	2	-1	0
Milling	-2	Vaccum Holder	0.25	Gear	-1.75	0	0	0	1
Milling	-2	Vaccum Holder	0.5	Car	-1.5	0	1	0	1
Milling	-1	Magnet	0.75	Motor	-0.25	1	2	0	0
Milling	-1	Magnet	0.25	Gear	-0.75	0	0	0	1
Milling	-1	Magnet	1.25	Car	0.25	2	1	1	1
Milling	0	Rope	0.25	Motor	0.25	-1	2	1	-1

Milling	0	Rope	0	Gear	0	-1	0	0	1
Milling	0	Rope	0.25	Car	0.25	-1	1	0	1
Milling	0	Rope	0	Rail	0	-1	0	0	1
Milling	0	Rope	-0.25	Chain	-0.25	-1	-1	0	1
Milling	-1	Glue	1	Motor	0	2	2	0	0
Milling	-1	Glue	1	Gear	0	2	1	0	1
Milling	-1	Glue	1.5	Car	0.5	2	1	2	1
Milling	-1	Glue	0.75	Rail	-0.25	2	0	0	1
Milling	-1	Glue	1	Chain	0	2	1	0	1
Milling	2	Integrated	1.5	Motor	3.5	2	2	0	2
Milling	2	Integrated	1.5	Gear	3.5	2	2	0	2
Milling	2	Integrated	1.5	Car	3.5	2	2	0	2
Hack Saw	0	Clamp	1	Motor	1	2	2	0	0
Hack Saw	0	Clamp	1	Gear	1	2	0	1	1
Hack Saw	0	Clamp	1.5	Car	1.5	2	1	2	1
Hack Saw	0	Clamp	1	Rail	1	2	0	1	1
Hack Saw	0	Clamp	0.75	Chain	0.75	1	0	1	1
Hack Saw	-1	Crane Hook	0.5	Motor	-0.5	0	1	0	1
Hack Saw	-1	Crane Hook	0.25	Gear	-0.75	0	0	0	1

Hack Saw	-1	Crane Hook	1.75	human	0.75	2	2	2	1
Hack Saw	-1	Crane Hook	1	Car	0	0	2	1	1
Hack Saw	-1	Crane Hook	0.75	Rail	-0.25	0	1	1	1
Hack Saw	-1	Crane Hook	0	Potential Energy	-1	0	0	0	0
Hack Saw	-1	Crane Hook	0.5	Chain	-0.5	0	1	0	1
Hack Saw	1	Screw	1.75	Motor	2.75	2	2	1	2
Hack Saw	1	Screw	1.5	Gear	2.5	2	1	1	2
Hack Saw	1	Screw	1.75	Car	2.75	2	2	2	1
Hack Saw	1	Screw	1.25	Rail	2.25	2	1	1	1
Hack Saw	1	Screw	0.75	Chain	1.75	1	1	0	1
Hack Saw	-2	Vaccum Holder	1	Motor	-1	0	2	1	1
Hack Saw	-2	Vaccum Holder	0.25	Gear	-1.75	0	1	0	0
Hack Saw	-2	Vaccum Holder	1.25	Car	-0.75	1	2	2	0
Hack Saw	-2	Magnet	1	Motor	-1	0	1	1	2
Hack Saw	-2	Magnet	0	Gear	-2	0	-1	0	1
Hack Saw	-2	Magnet	1	Car	-1	0	1	2	1
Hack Saw	2	Hand	2	human	4	2	2	2	2
Hack Saw	0	Rope	1.25	Motor	1.25	1	2	1	1

Hack Saw	0	Rope	0	Gear	0	1	-1	0	0
Hack Saw	0	Rope	0.5	Car	0.5	1	1	2	-2
Hack Saw	0	Rope	-0.25	Rail	-0.25	0	-1	0	0
Hack Saw	0	Rope	1	Chain	1	1	2	1	0
Hack Saw	-1	Glue	1.5	Motor	0.5	2	2	1	1
Hack Saw	-1	Glue	1.25	Gear	0.25	2	1	1	1
Hack Saw	-1	Glue	1.25	Car	0.25	2	2	1	0
Hack Saw	-1	Glue	1.25	Rail	0.25	2	1	1	1
Hack Saw	-1	Glue	1.25	Chain	0.25	2	2	1	0
Hack Saw	2	Integrated	1.25	Motor	3.25	2	2	0	1
Hack Saw	2	Integrated	1.25	Gear	3.25	2	2	0	1
Hack Saw	2	Integrated	1.5	Car	3.5	2	2	1	1
Milling	1	Clamp	2	Motor	3	2	2	2	2
Milling	1	Clamp	1.75	Car	2.75	2	1	2	2
Milling	2	Crane Hook	1	Motor	3	1	0	2	1
Milling	2	Crane Hook	1	Gear	3	2	0	1	1
Milling	2	Crane Hook	1.25	Car	3.25	2	0	2	1

Milling	1	Screw	1.5	Motor	2.5	2	2	1	1
Milling	1	Screw	1.75	Car	2.75	2	2	2	1
Milling	2	Integrated	1.5	Motor	3.5	2	2	0	2
Milling	2	Integrated	1.5	Gear	3.5	2	2	0	2
Milling	2	Integrated	1.5	Car	3.5	2	2	0	2
Hack Saw	1	Screw	1.75	Motor	2.75	2	2	1	2
Hack Saw	1	Screw	1.5	Gear	2.5	2	1	1	2
Hack Saw	1	Screw	1.75	Car	2.75	2	2	2	1
Hack Saw	2	Hand	2	human	4	2	2	2	2
Hack Saw	2	Integrated	1.25	Motor	3.25	2	2	0	1
Hack Saw	2	Integrated	1.25	Gear	3.25	2	2	0	1
Hack Saw	2	Integrated	1.5	Car	3.5	2	2	1	1

Appendix 3: Notes from interview with Sandvik Employee

1. The task is to dismantle eletric transformer (T) casing.
2. Teja is writing Master Thesis in Product devolpment, Chalmers University of Technology. Examinator Björn Johansson.
3. The client is Stena Recycling, Karlstad. Project manager Jesper Olsson.
4. The T are to be dismantled for recycling of the steel and copper. The thickness is 15-20 mm.
5. When T arrives it is containing transformer-oil.
6. The lid could be nailed or welded. To dismantle the nailed one it´s easy.
7. The welded ones are more difficult and today Stena uses a handheld hack-saw and it takes 1-4 hours for dismantling. It is not permitted to use circular saw because of the sparks and heat produced.

8. The first suggestion from Coromant is using an endmill (Plura) or a milling-cutter, grooving and parting of (CoroMill QD, T-Max Q, CoroMill 329, CoroMill 331 for heavy duty.) with tungsten-carbide inserts. Sandvik Coromant only supply with cutting tools, no machining.
9. Metalock AB is a maintenance company making similar processes in turning and boring in process-industry on site.
10. Coromant suggest that Teja try to get a piece of the material from the tranformers and make milling-tests in an ordinary milling-machine to find cutting-parameters e.g. cutting speed, feed per tooth, coolant/non-coolant, insert geometry and insert grade. The transformer-oil may contain PCB and it is of great importance that the test material is well-cleaned.
11. It´s important to show Stena the result of the cutting data before being in contact with other companies.
12. There are several manufacturer of milling-units on the market. And one has to find out after making tests what power needed, rpm:s and outher properties.
13. When testing it is not important to find the right machine-interface. But when one decide to use endmill or millingcutter or both it is important to decide what kind of machine-interface. An endmill is put into a ER-collet or Weldon-adapter. A millingcutter is fixed on an arbore. The tool-interfaces may be integrated in the milling-unit.
14. If one uses an endmill, the lifetime is depending if it´s possible to use trochoidal milling. If one uses a milling cutter it is usually most efficient to use downmilling and it also gives much longer toollife.
15. Teja swill contact Ljungek later if more information or discussions are needed.
16. When it comes to Testtools, Teja will ask Coromant and Ljungek for supporting.

Appendix 4: STECO provided CAD model of Spindle