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TALLINN UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING
MET70LT

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OPTIMIZATION OF THE TANK ROTATING MACHINE IN ESTANC AS

MAHUTITE PÖÖRAMISE SEADME OPTIMEERIMINE ETTEVÕTTES ESTANC AS

Author applies for degree of Master of Technical Sciences (M.Sc.)

Tallinn 2016

Author's Declaration

I have written the Master's thesis independently.

All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.

Master's thesis is completed under .... supervision

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Master's thesis is in accordance with terms and requirements

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Master's Thesis task

2015 /2016 academic year 2nd semester
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Master's Thesis topic (in Estonian and English languages):
Mahutite pööramise seadme optimeerimine ettevõttes Estanc AS
Optimization of the tank rotating machine in Estanc AS

Tasks and timeframe for their completion:

Nr	Task description	Completion date
1	Collect background data of rotating tanks in manufacturing phase	February 2016
2	Study the tank production related information based on selected company	March 2016
3	Research and comparison of the existing products on the market	March 2016
4	Setting the requirements and development of the concept	April-May 2016

Design and Engineering problems to be solved:

The objective of the Master’s Thesis is to analyse company current products related with the tank rotating equipment by covering both economical and technical aspects. The objective is to give input requirements and optimizes the equipment, which fulfils the company’s needs.

Defence application submitted to deanery not later than 20.05.2016
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Acknowledgment

I would emphasize knowledge base what I have obtained during the master program. The methods and tools gained through the studies provide the knowledge how to approach the case in structural terms.

I wish to express my gratitude to the people that supported with their knowledge and experiences during the process. I would thank supervisor Kristo Karjust for guidance. Also I would thank quality and development manager Tõnis Tuuder, production manager Alik Gerasimjak for providing primary data and consultation and other fellow colleagues.

1 Introduction

The initial input for this thesis comes from company called AS Estanc. This company has rapidly expanded over few years. Due to a new production building, there is a need for a new tank rotating equipment. The equipment effectiveness is taken into consideration by example of the existing equipment to increase productivity and meet the company's needs. The company has experience with other similar products on market and is familiar with their strengths and weaknesses.

The overview of the company and a closer look to the tank manufacturing process are given on the first half of the paper. This phase introduce the importance of the tank rotating equipment and restrict the scope of the paper. Following, the usage of the rotator and preparation steps is taken into focus. The bottlenecks are highlighted and analysed. The attention is also given to already existing products.

The second half of the paper includes the different solution generation, evaluation and detailed designing by support of various design tools and scoring charts. The strength calculations and economic calculations are done to validate the design from the engineering approach.

1.1 Goals and objectives

The expected outcome of this paper is to provide suggestions for improvements of the existing tank rotating equipment. The concept takes into consideration the aspects of the specific field production and the company's needs. The design is focused on the feasibility of construction based on company's production capability. Attention is also given to the main aspects of the tank manufacturing process: such as preparation work, assembling, including the support activities and jigs, final inspection and cost related topic.

The objective of the thesis is to improve current equipment that fulfils the company's needs and its feasibility to manufacture in-house in both aspects – economical and production capability.

1.2 Methodology

As an engineer, it is easy to deviate from one's path without having a structured plan to follow. There is no defined way of solving a problem, but there are generic steps that should be taken to move toward to desired goal. Haik and Shahin [1] suggest engineering students can be daunted by the varied sources of new information they are exposed to during their studies. Also, without guidelines or structure they struggle to organise information without a clear starting point and finishing line. Therefore, using the proven design process model is essential [Figure 1.1].

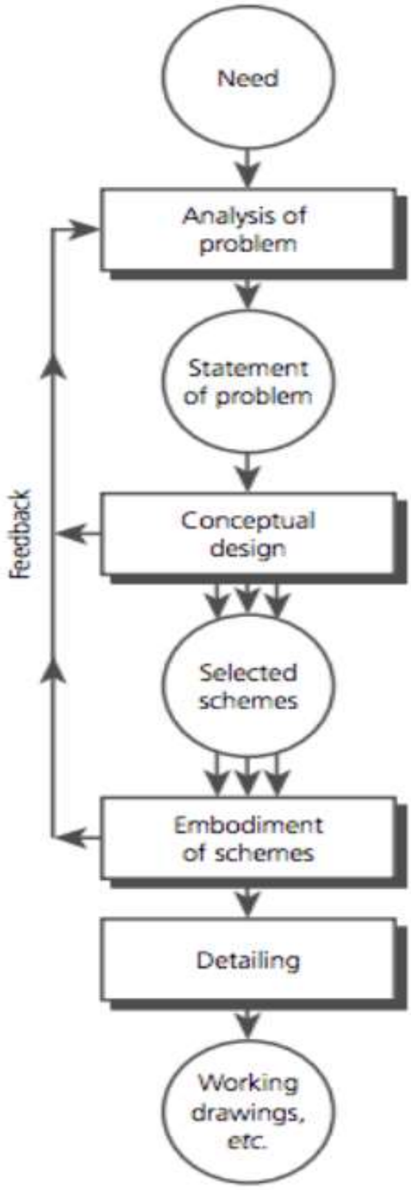

Figure 1.1 The design process [1]

The French design model is named after the British author Michael Joseph French [2] and shown on Figure 1.1. The block diagram shows the design process. Each step within the model has a number of headings that should be considered at each phase. The circles on the figure represent different phases. Each step should contain a number of headings within the model. The rectangles represent work in progress. The model is drawn as a Flow Diagram to emphasise the progression of the process; one stage requiring completion for moving to the next.

Analysis of the problem

The process begins with the observation of a market need. Usually this part consists of identifying the need, and the need is then analysed, which leads to an unambiguous problem statement. This takes the form of a list of requirements that the product must fulfil.
The analysis of the problem is a small but an important part of the overall process. The output is a statement of the problem, which consists of three elements:

- Statement of the design problem.
- Limitations placed upon the solution, e.g. codes of practice, statutory requirements, customer standards, date of completion.
- The criterion of excellence to be worked to.

Conceptual design

"It is the phase where engineering science, practical knowledge, production methods, and commercial aspects need to be brought together, and where the most important decisions are taken." (M. J. French, 1999).
During this phase, several concepts are generated. It is recommended that a designer produce several exclusively alternative ideas. Each concept represents a set of physical principles for solving the problem. These concepts are transformed into a more concrete representation to allow evaluation and comparison. The concepts are evaluated and one or more are chosen to form the basis of the final solution.

Embodiment of Schemes

Embodiment of schemes phase, "schemes are worked up in a greater detail and, if there is more than one, a final choice between them is made. The end product is usually a set of general arrangement drawings. There is (or should be) a great deal of feedback from this phase to the conceptual design phase." This is the most time consuming phase, in which the calculations and complete Finite Element Analysis are made, as well as the changes in the previous phases. Hence, the feedback loop in the model leads to reorganization, recalculation etc. of the whole phase.

Detailing

"This is the last phase, in which a very large number of small but essential points remain to be decided. The quality of this work must be good, otherwise delay and expense or even failure will be incurred: computers are already reducing the drudgery of this skilled and patient work and reducing the chance of errors, and will do so increasingly." (M. J. French, 1999).

2 Overview of the company

2.1 Company introduction

AS Estanc [3] is a leader in manufacturing tanks in Estonia. The main products are pressurized, non-pressurized, process and fuel tanks. The company's mission is to provide professional solutions for the storage and distribution system of industrial liquids and gases. It is based on project-centred production that offers technical engineering solutions for the client's needs – form the initial design to installation of completed product.

Figure 2.1 Company logo

The company was established in 1992 as a joint company with Finnish and Estonian owners. The initial name was Estonia-Tanc AS, which was replaced with current name, Estanc, purely for simplicity. The company started from scratch – it is not emerge from any pre-existing companies in Estonia. Initially, the company only did sheet preparation work for vessels, and then began to manufacture simple vessels and metal constructions as their product range began to expand. Since 1996, the company is based 100% on Estonian capital. Eventually, Estanc's production and offices moved to its current location in Männiku. AS Estanc exports its products all over the world – from Europe to Asia and United States – and has sales offices in Estonia, Finland and Sweden [Figure 2.2]. The majority of Estanc's products are exported abroad.

Figure 2.2 Geographical locations of sales offices

2.1.1 Organizational structure

Planning and controlling of production processes is key to ensuring that production moves smoothly at the desired level. AS Estanc develops and implements their management system according to the ISO standard and their own practices. The main process focuses on the satisfied customer and it includes sub-processes: sales, purchase, storage, manufacturing, product testing and delivery. The main process backing support processes are: product development, human assets, infrastructure and equipment maintenance, working environment, measuring and monitoring, rejected product management and data analysis.

Sale’s main task is to determine customer needs and product requirements, which provides a basis to conduct product risk analysis. The purchase sub-process includes material related topics and verifies outsourcing details. The manufacturing, product testing and delivery processes are explained in details on next chapter

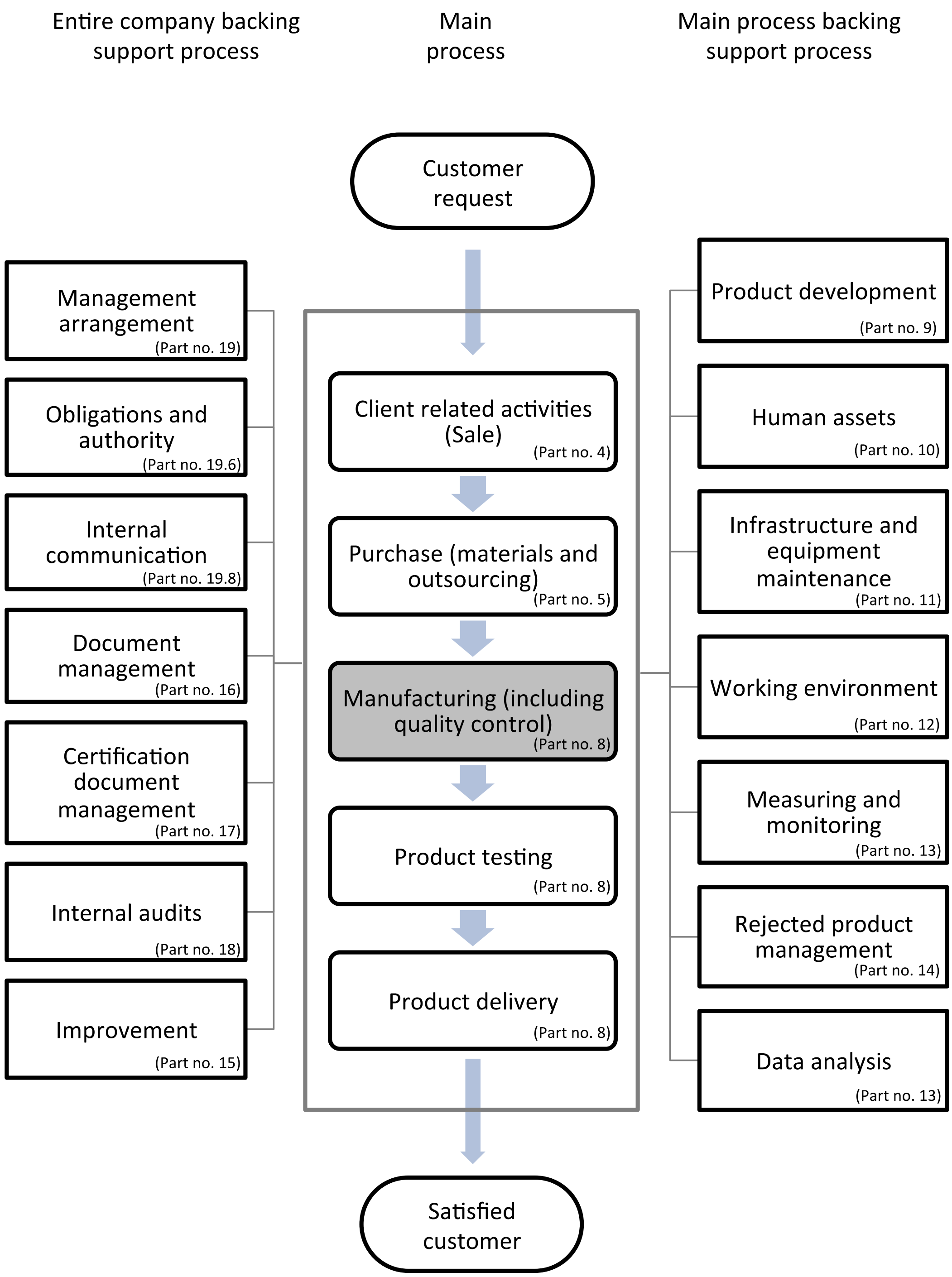

Figure 2.3 The structure of the main processes

2.1.2 Production capacity

The company has expanded in the past few years. In 2012, AS Estanc opened a new production building which is around 8 000 m^2 in Jüri Technopark to allow the firm to manufacture more complex process tanks and heat exchangers with the same quality and competence level. The building location was chosen based on the good infrastructure. More than 140 skilled workers, including the office staff, work in both production buildings. All welders have certifications and workshops are equipped with welding equipment, half of which are not older than five years. There are two departments in the production building: Carbon Steel workshop (CS) and Stainless Steel workshop (SS).

Figure 2.4 Estanc AS production building in Jüri Technopark, Estonia

The carbon steel workshop is able to handle products weighting up to 100 t. The maximum size of the manufactured product is limited by the size of the production building door. Therefore, the size of the products cannot be more than 7 m of a diameter and length up to 60 m. The workshop floor is equipped with rails, which provides the opportunity to implement a traversing system. The carbon steel workshop also includes top loaded shot blasting and painting chamber. The chamber size is 24 x 7 x 7 m. The stainless steel workshop lifting capacity goes up to 60 t. The size of the manufactured product is also limited by the size of the door that is same – 7 m in diameter and length up to 60 m. Stainless steel workshop includes an acid pickling chamber.

2.1.3 Examples of produced equipment

Between 2014 and 2015, the company successfully completed more than 350 different projects for the container market weighing from 0.5 to 120 tons. A pressure vessel is container designed to hold gases or liquids at a pressure different from the ambient pressure. The difference of the pressure is dangerous, and has been known to cause fatal accidents. The other important sector is fuel and other dangerous fluids tanks. The quality requirements are high due to the huge impact on the environment and human health if the above-mentioned tanks fail. Therefore, the market of pressure vessels and tanks set the highest inspection demands for designing and manufacturing of a container.

Estanc product range includes:

- Pressure vessels: feed water tanks, ammonia tank, steam accumulators, pressurized water tanks, compressed air tanks, columns, other pressurized tanks.
- Fuel tanks: underground double-walled tanks, on-ground tanks
- Heat exchangers: shell and tube heat exchangers, air preheaters
- Non pressure tanks: scrubbers, blow-down tanks, other non-pressure tanks
- Other products: chimney, piping
- Services: boring machine, insulation, installation,
- Tank head: manufacturing, selling

Feed water tank weight 76.5t; length 21.5m; diameter 4.5m; Finland

Condensing tower; weight 82t; length 33.6m; diameter 4.3m; Estonia

Chimney; weight 5.4t; length 27m; diameter 1m

Heat exchanger; weight 23.1t; length 6.1m; diameter 1.8m

Chimney; weight 25.5t; length 37m; diameter 1.9m

Figure 2.5 Example of produced equipment

Reactor Dump Tank; weight 82.5 t; length 14.6m; diameter 4.5m; Finland

Feed water tank insulated; weight 22.5t; length 13m; diameter 3.3m

Scrubber; weight 16.6t; length 9.8m; diameter 3.8m

Scrubber; weight 10.8t; length 10.4m; diameter 3.5m

Figure 2.6 Example of produced equipment

2.2 Tank manufacturing process

The product manager plans and controls the process of manufacturing so that process moves smoothly at the required quality level. Meanwhile, one must keep balance between the cost and quality objectives [4]. “Process control has two purposes: first, to ensure that operations are performed according to plan, and second, to continuously monitor and evaluate the production plan to see if modifications can be devised to better meet cost, quality, delivery, flexibility, or other objectives.” (W. K. Holstein, 2013). Manufacturing is based on the available equipment and resources. The company is established in-house rules and agreements to manage the production department. The manufacturing process consists of the following steps (Figure 2.7):

- Detail preparation
- Assembly and welding
- Inspection
- Surface treatment, finishing

Process starts when the approved drawings are delivered to the production department. Concurrently, the raw material, ready-made, and semi-finished products are ordered and delivered to the stock. The raw material heat number is used to identify and track material movement in the workshop. It is required for final documentation, which proves that suitable materials are used and meets the requirements for specific project.

The first phase is preparation of the details and ordered details for assembly. It begins with cleaning (shot blasting, pressure washing) the material. The shell material is cut to the dimensions using guillotine shears. The edge preparation for shell material is done due to welding reasons. Final step is rolling the shell to the desired diameter. This phase also covers the other detail preparations: pipes and other profiles are cut to the length according to the specification. It also includes pipe connection preparations: thrilling holes, flange and pipe welding and bevelling. Other details are cut to the right shape using the plasma-cutting machine. Details that needs after cutting mechanical treatment are done in this phase. The pre-inspection is done before details are handed over to the assembly phase. It is required to eliminate discrepancy details and minimize the mistakes beforehand. At this stage replacing or re-producing the discovered discrepancies are low costs and not time-consuming operations compared with other stages.

Second phase is the core phase of the tank manufacturing. Cylindrical sections are assembled and tank heads are installed. In this phase the tank stands most of the time on the rotator machine until the assembling is done. Therefore supportive activities and jigs cannot be underestimated to keep the process run smoothly. Production workers need to rotate the tank to the corresponding angle to cut the openings for pipe connections and for welding purposes. The reinforcement pads, brackets, lifting eyes, brackets and other details are installed. Final step is post-weld heat treatment. It is method for reducing and redistributing the stresses, which is caused during the welding.

Inspection is required to detect any discrepancy between required quality and reality. The Notified Body (NoBo)[5] must approve projects that require technical, design and manufacturing examination. Pressure vessels, tanks and other products follow the specific project requirements and corresponding country regulations or international standards according to the manufacturing phase. This phase also includes hydrostatic pressure testing. NoBo issue the declaration of Conformity that gives the right to label the product with the CE mark [6].

Final phase is surface treatment and finishing. The surface treatment (shot blasting, acid pickling, painting) is done in this phase according to the customer needs and wish- Finally the surface treatment report is created. The finished product is packed and delivered to the customer.

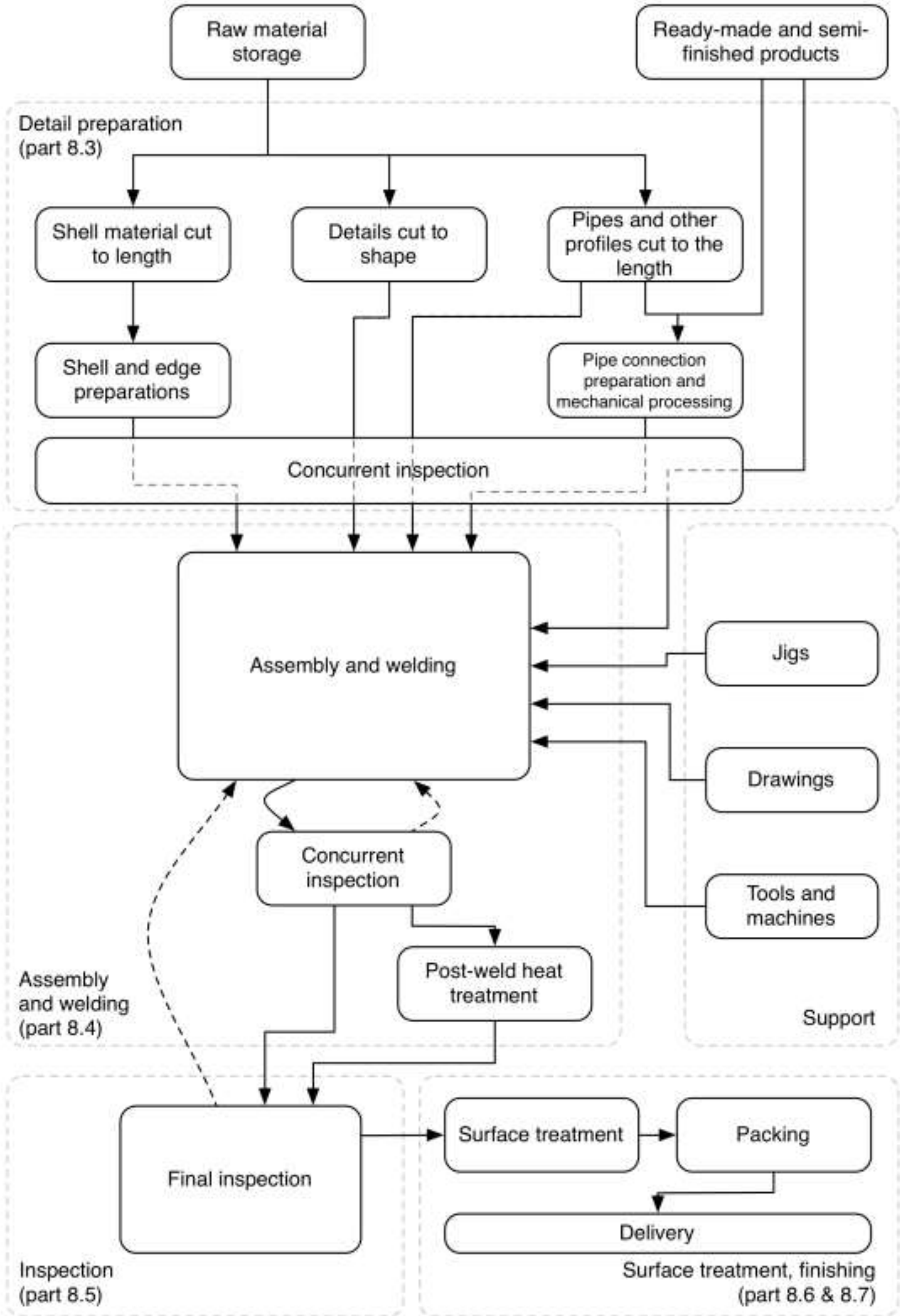

Figure 2.7 Tank manufacturing cycle

3 Rotator positioning and aligning analyse

This chapter takes into a focus the assembly and welding phase. The manufacturing cycle is divided into different phases and it is described on previous section. Retroactively are analysed three different projects, which are finished and delivered to the customer. These projects represent the cross-section of different types of product nomenclature. The projects are chosen correspondingly to the weight, diameter and the eccentricity of the vessel. The outcome of this is to detect and expose the bottleneck and time-consuming activities considering the use of tank rotating equipment in the manufacturing process. Therefore, a deeper look is taken at the assembly and welding phase where the rotators functionality and usability plays an important role.

The various steps must be done beforehand. The assembling starts with the preparation of the workshop floor and determining some of the key factors of specific project. Previously the manufacturing resource planning is needed to reserve workshop floor, planning the production workers and materials for the specific project. Also the production timetable is generated.

3.1 Carrying capacity determination

The tank rotator set typically includes driver and idler unit. The driver unit supports the vessel from one end and idler unit the other end. The driver unit transfers the rotational movement to the workpiece and the idler merely supports the workpiece. Each rotator has a maximum load capacity which cannot be exceeded. Therefore, it is necessary to determine the maximum weight of the specific vessel to choose the amount of rotators needed. The load of the symmetrical vessel can be equally divided to each roller bracket. Figure 3.1 shows a single set of rotator supporting the cylindrical shell with the centre of gravity is on the centre of rotation axis. The number of idler units is added if the rotator loading capacity is not enough to carry the vessel total weight [7].

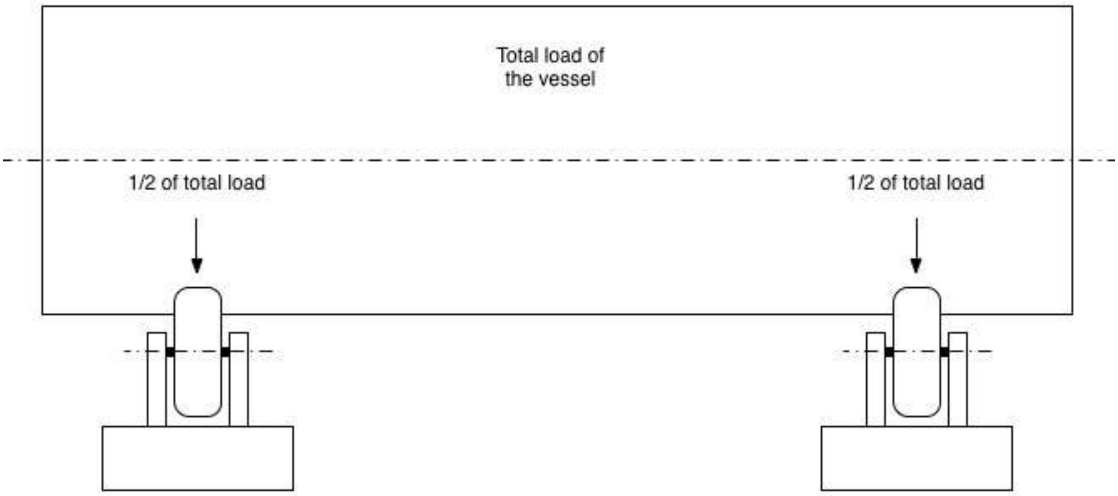

Figure 3.1 Vessel weight distribution

The placement of each of the turning roller unit is in relation to the workpiece nozzles and other pipe connection locations that must be taken into consideration before lifting the cylindrical shell onto the rotators. The rotator placement on the workshop floor must be positioned so that the rollers do not interact with any openings, connections or stiffening rings. It is necessary that rollers are in contact with the surface of the entire cylindrical shell perimeter and does not interact with the two cylindrical section circumferential welds. The workpiece and rollers should be checked during each operation for unobstructed rotation and inspected for interference from protruding parts. Any nozzle or other connections assembled during the assembly phase that can potentially be on the rollers requires the readjustment of the rotator.

Besides the rotator carrying capacity, the cylindrical shell thickness must be taken into consideration. It has been observed that the thin-walled cylindrical shells are more likely to get damaged on the rotators. The outer surface gets dents and leaves a trail during assembly. If the roller wheels are narrow and the contact surface between shell and roller wheel is small, then the weight of the shell presses a dent into the shell's surface. The other potential situation for dents occurs when the cylindrical shell is placed on the rotators. It is practically impossible for a crane operator to lower a shell so that the weight of the workpiece is transferred equally and smoothly to all the rotator wheels simultaneously. However, it does not occur on thick-walled cylindrical shell.

3.2 Alignment analysis

Previous project leftovers and trash are cleaned from the floor. The rotating machines, both driver and idler unit, are lifted to place using the overhead cranes. Then the alignment of the rotators becomes important. Each added idler unit increase the probability of misaligning the rotators. The one set of rotators is best combination to align the rotators compared to three or more sets of drivers and idlers used. The rotators must be on a flat, hard, level floor and are not bolted to the ground. Also rotators must be placed so that the rollers axes are parallel to the vessel centreline (Figure 3.2). These factors are important for aligning the rotators to prevent the rollers making a helix contact angle with the vessel surface. Helical contact between the roller and the vessel causes spiral movement of the workpiece that leads to overturning the vessel from the rotators. This condition is also referred as “end creep”[7].

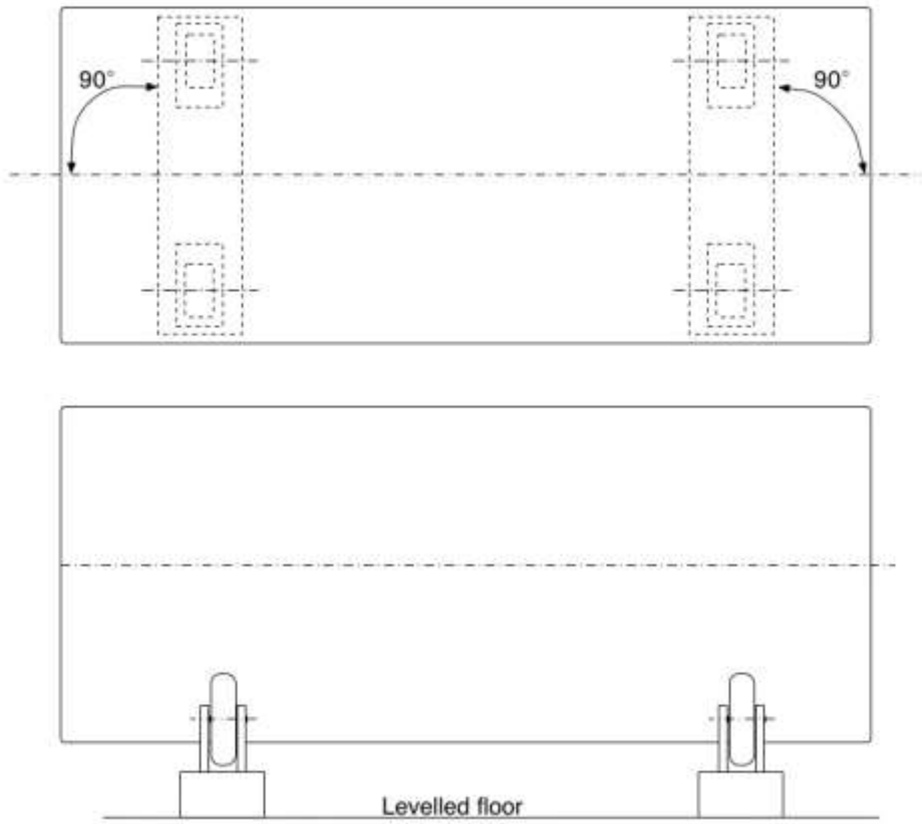

Figure 3.2 Proper setup for rotator alignment

The common placements of misaligned rotators are shown on Figure 3.3 that causes end creep. Having an incorrect rotator position cause numerous problems – the rollers scrub the workpiece surface and leaves a trail. The weight of the vessel is unevenly balanced on rollers, which damage rollers. Possible rotator misalignment situations that cause end creep are shown on Figure 3.3. The driver and idler unit are not parallel to each other. In other words the rollers axle are not parallel to the vessel centreline (Figure 3.3, a). The driver and idler unit are parallel to vessel centreline but driver and idler unit central axis are not on the same line (Figure 3.3, b). The floor is uneven so that the rotator rollers are on different level (Figure 3.3, c).

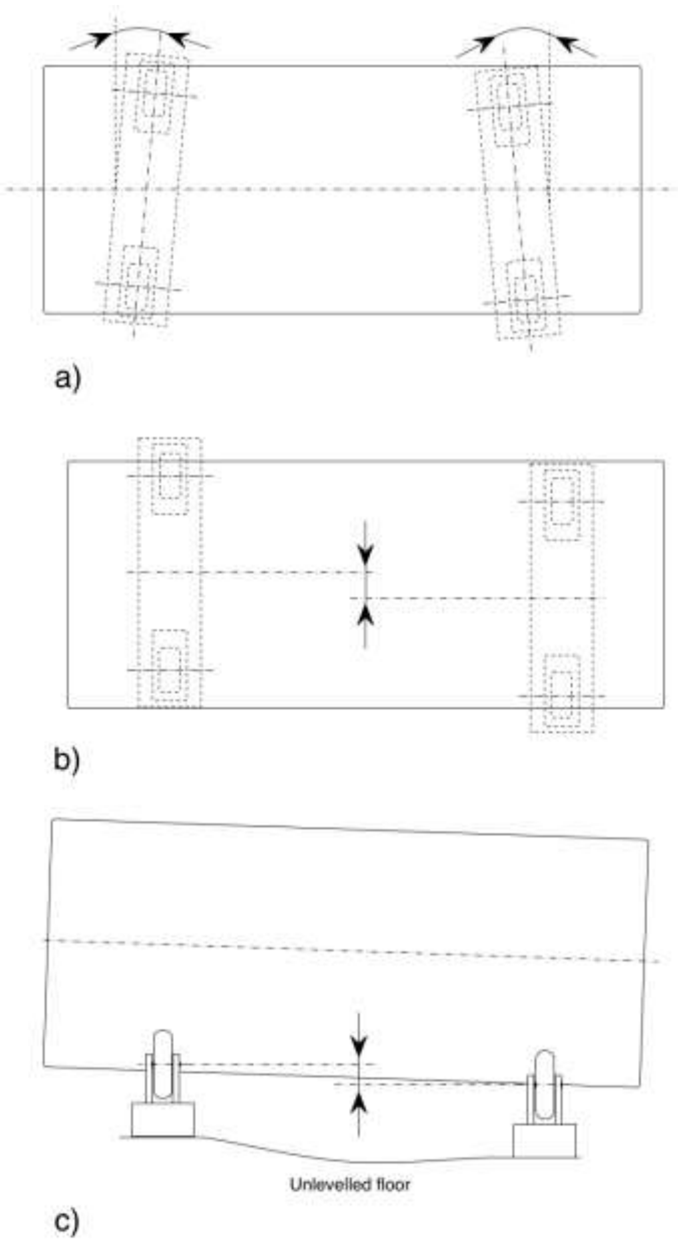

Figure 3.3 Common placements of misaligned rotators

Avoiding the previously described end creep conditions is crucial for smoother and safer manufacturing. It also avoids later readjustments of the rotator set, which can cause malfunctions of the device. Common practice to check the parallelism between driver and idler unit (X = Y, Figure 3.4) is checking the diagonals. Also in practise it is the quickest way to ensure that two rotator units are parallel to each other. The diagonal distance is measured from one corner of the driver roller axle to the opposite corner of the idler roller axle (Figure 3.4, distance A and B). Both diagonal measurements must be equal length for the rollers to be parallel (therefore A = B). If not then the adjustment is needed. This method assumes that the rotators wheels axles are parallel to each other.

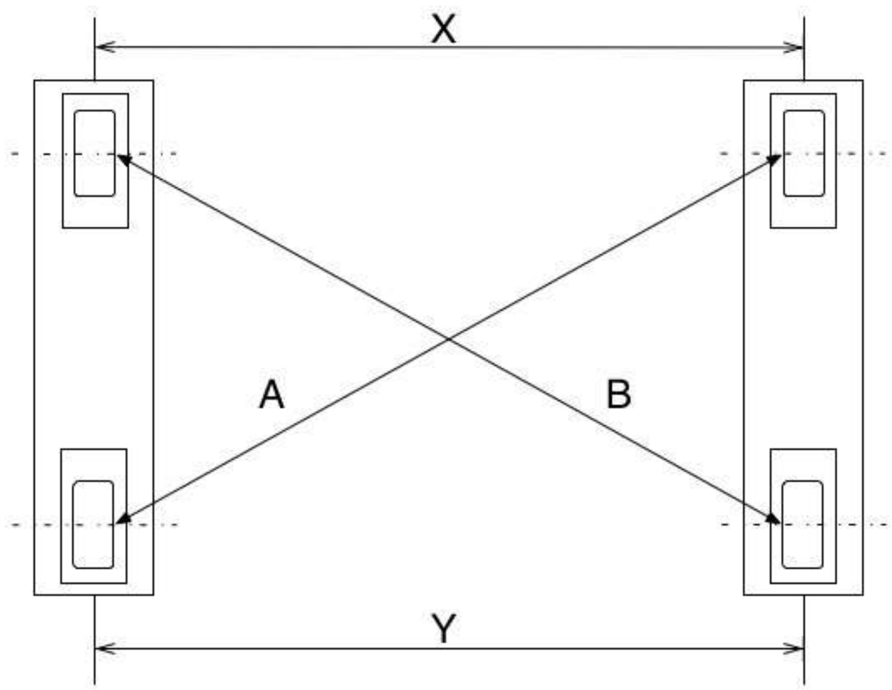

Figure 3.4 Driver and idler unit parallelism alignment check

3.3 Stability analysis

Before lifting the cylindrical shell to the rotator, the distance between the rollers needs to be clarified. The distance between rollers (length c, Figure 3.5) is important for supporting the workpiece and preventing workpiece becoming unstable and overturning from the rotator. The distance between rollers is in direct relation with the diameter of the workpiece. There are different types of rotators on the market - conventional and self-aligning rotators. These are more explained in the next chapter - Equipment research and analysis. The bigger the vessel diameter is, the greater distance between rollers is required. Therefore, the angle between two lines extended from the centre of the workpiece to the centre of each rotator roller axle is used (angle a, Figure 3.5). This angle is also referred as the "included angle" [7]. Figure 3.5 shows a balanced symmetrical load workpiece, where the centre of gravity is on the same line as the vessel rotation axis. The recommended included angle is between 30 degrees and 60 degrees [8]. A greater included angle can provide more stability of the workpiece, but additional torque is required to rotate the workpiece. Similarly a smaller included angle requires less torque to rotate the workpiece but the stability of the workpiece can become an obstacle.

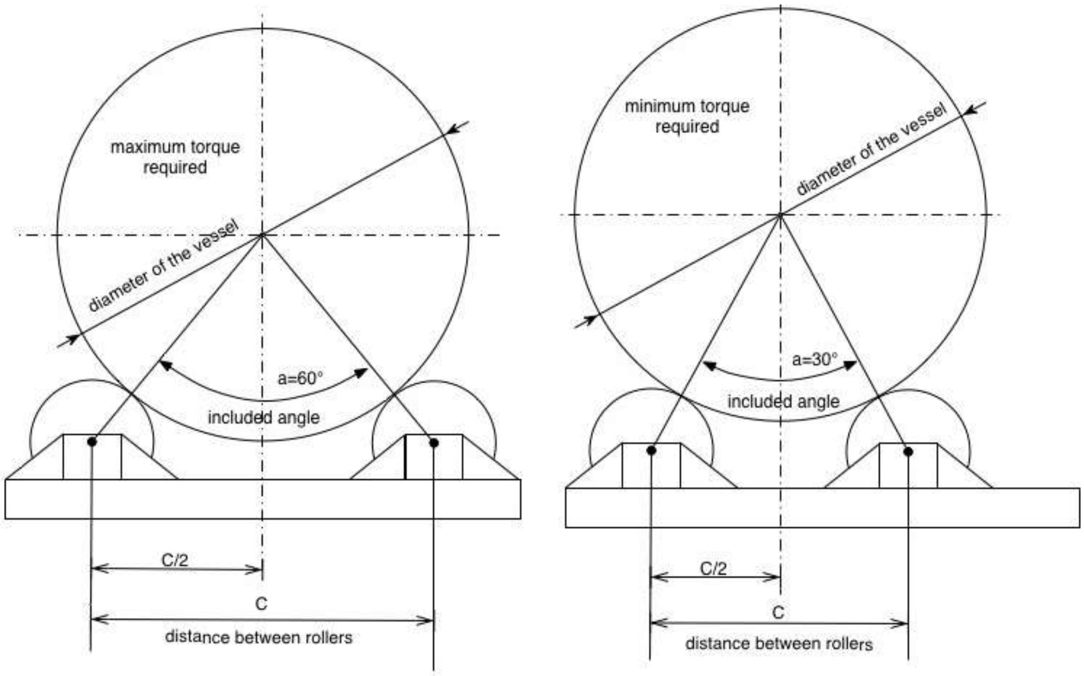

Figure 3.5 Distance between rollers

According to the observation, it is uncommon for the centre of gravity to be on the same line as the rotation axis. Vessels usually include connections, inspection manholes or other protruding parts. This affects the centre of gravity of the vessel and places it off from the vessel rotation axle. If the centre of gravity of the vessel exceeds the width or length of the rotator set spacing area, then overturning stability must be taken into consideration (Figure 3.6, hatched area). If the centre of gravity is close to the edge, then production workers can easily move the centre of gravity location by just leaning against the workpiece or assembling inside the vessel. It could be enough for the workpiece to become unstable. When an eccentric load or unbalanced weight is outside of the spacing area then it causes the workpiece to overturn horizontally or longitudinally as shown on Figure 3.7.

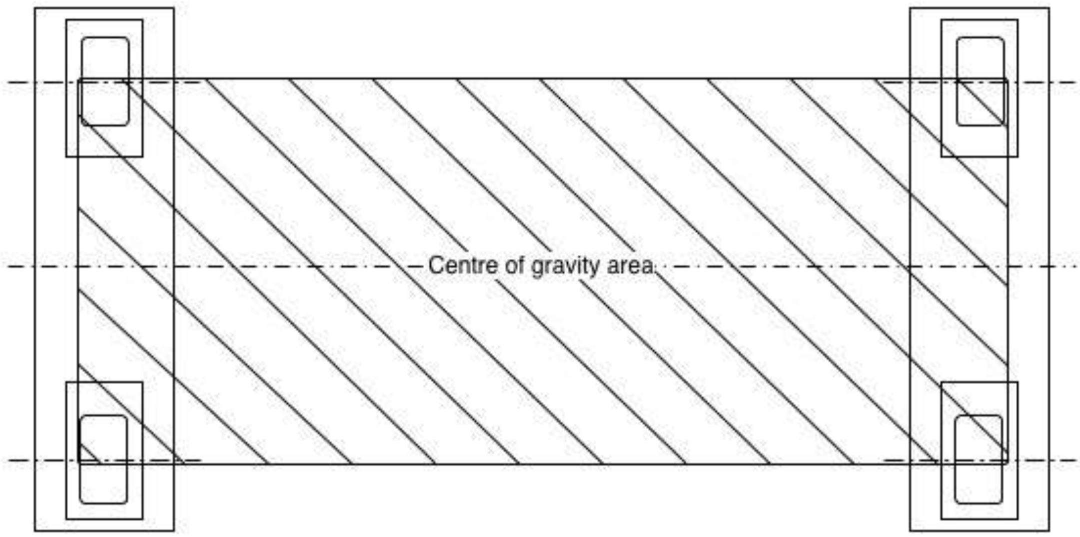

Figure 3.6 Centre of gravity within the width and length of the roller spacing area

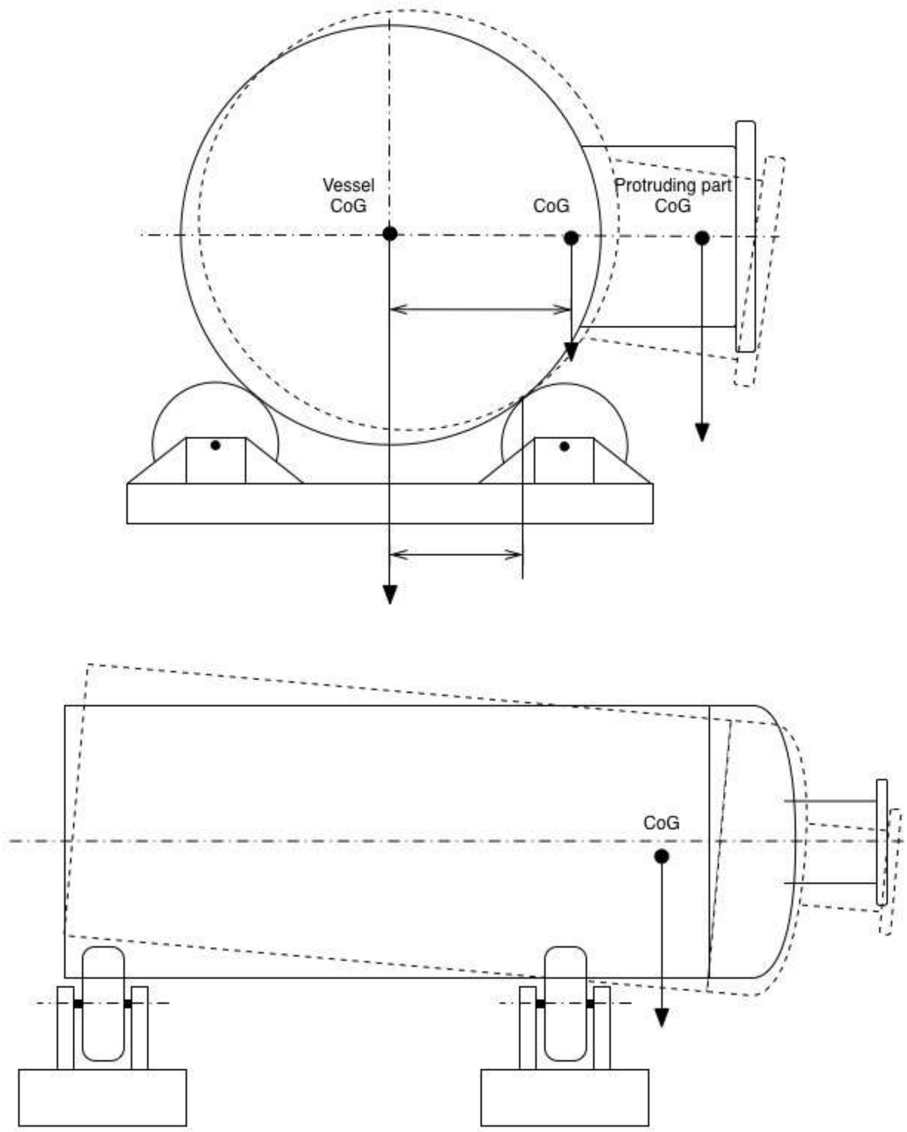

Figure 3.7 Overturning instability

An eccentric load requires more traction to keep the rollers from slipping. It has been reported in small (less than 1 meter of diameter) vessel production where protruding manholes or other connections are on the same side of the vessel. Widening the rotator rollers can be used to provide greater traction. It also brings the greater torque requirement for rotating the workpiece. The further the centre of gravity of the load is from the workpiece rotation axis, the greater torque is needed to rotate the workpiece. Greater torque could stall the driver unit. The offset counterweights are added to the eccentric workpiece to prevent the workpiece from overturning and reducing the amount of total workpiece imbalance. Alternatively, widening the rotator roller spacing can overcome the condition.

3.4 Cylindrical section assembly

A workpiece (i.e. chimney, columns) often has more than one cylindrical section thus requiring one driver unit and two or more idler units to support the workpiece (Figure 3.8). A driver and idler unit supports the first cylindrical section and two idler units support the second workpiece. The first two sections are aligned and tack welded. The circularity is checked before circumferential welding. Rotator equipment ensures smoother welds. Circumferential welding is done by having the cylindrical shell rotated on the rotator. Then the idler units are moved to the new location for another cylindrical shell. As the workpiece gets longer, then every added rotator unit is another source of misalignment [7]. Alternatively, a fit-up rotator is used for this step in the assembly and welding phase.

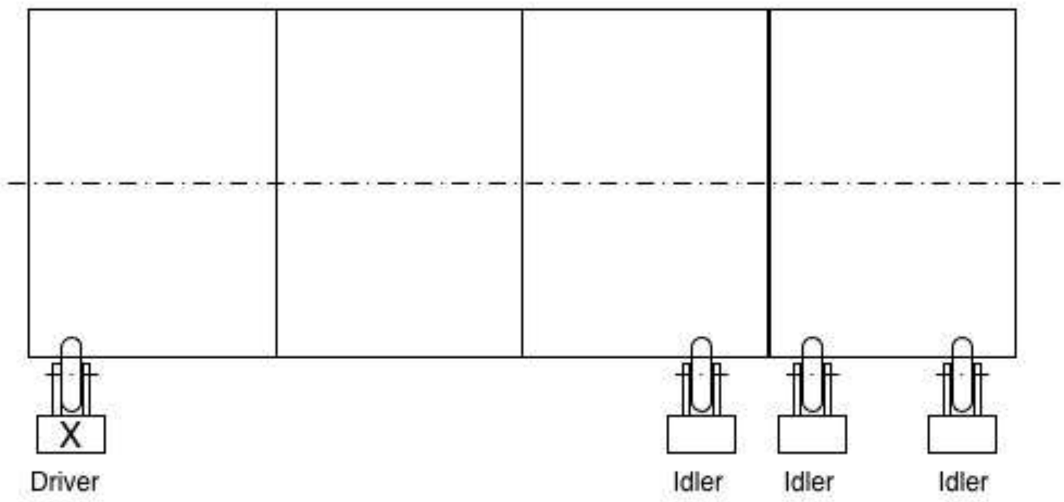

Figure 3.8 Workpiece with multiple cylindrical shells

The next step after putting the cylindrical shell together is to mark the shell for nozzle, bracket and stiffening ring locations, as well as cutting opening, preparing the edges and inserting the reinforcement pad and nozzle. The workpiece is rotated to the desired angle, which gives to the welder good position for marking and welding the protruding parts. In the next steps the rotators importance relies on the jig level, whose main function is to rotate the workpiece to the desired angle. The vessel is assembled and handed over for inspection and surface treatment.

3.5 Conclusion

There are various preparation steps to take before the cylindrical sector is finally lifted to the rotators. It starts with planning the workshop floor according to the size of the workpiece. The alignment of the rotator is next important step in the assembly and welding phase, as well as the basis for assembling the rest of the vessel. Therefore, care is taken with measuring out the diagonals and checking the placement of the rotators. Selecting the rotators must also not be overlooked. Suitable rotators are selected by the diameter and weight of the vessel and also the centre of gravity is taken into consideration.

Observation and interviews indicate that some bottlenecks do occur. Aligning the rotator is one of the most time-consuming activities in the preparation of the assembly and welding phase. Also, the readjustment of the driver and idler unit is occasionally needed due to various reasons – most likely because cylindrical workpiece protruding parts may be in the way of the roller's wheels. If the need appears during the middle of the assembling phase, then it is difficult to ensure the alignment of the rotator. The driver and idler unit both weight a considerable amount, requiring the use of overhead cranes to move them.

The workshop practices to handle these types of situations include the following steps: First, the workpiece is lifted up with the overhead crane from the side where the alignment of the rotator unit is needed. Second, the production worker uses a lever or a crowbar to adjust the rotator to the desired position using force. Finally, the workpiece is lowered to the rotator. Readjustment using this method is toilsome and more difficult to ensure the rotators are parallel. Also, the overhead crane is used to lift up the workpiece.

The other outcome is the use of the overhead crane: the overhead cranes are essential for moving heavy object inside the production building. They are used to move the raw material, semi-finished products, and workpieces around the workshop floor. A production outage may occur when the overhead crane is needed to align or readjust the rotators but is already in use for other projects. The readjustment of the rotator is sometimes needed due to miscalculations of the rotator placement, and aligning the rotators on the workshop floor takes between 30 to 60 minutes. This is on the assumption that the overhead crane is available and later readjustments are excluded.

It has been observed that cylindrical shells become damaged during the assembly and welding phase on the rotators. The outer surface of the shell gets dents when the shell is placed to the rotators. It is practically impossible to lower the vessel smoothly onto the rotator so that the load simultaneously contacts all the rollers at once. In actual use, a workpiece hits one roller wheel first before the load is divided equally on all other rollers. There is also the narrow roller wheel, which is in contact with the workpiece and increases the pressure on the workpiece surface. The dents occur where the roller contacts the vessel. A narrow roller wheel is important when the workpiece has several protruding parts on its surface which are close to one another.

The other issue that rises when the workpiece is lowered onto the rotators is the self-aligning rotators used by the company. This issue is more common when working with larger diameter shells (>5m). The rollers do not align automatically when the workpiece is lowered into place. In that situation, only the upper roller wheels touch the workpiece. Manual adjustments are required on the rollers before lowering the workpiece to ensure that both upper and lower rollers touch the workpiece.

The diameter of the cylindrical shell varies depending on the project. The stability of the workpiece and maximum use of the rotators should be taken into further development.

4 Equipment research and analysis

It is necessary to carry out research to identify different types of tank rotating machines that are available on the market. The tank rotating machines are referred to as welding rotators, roller beds, turning rolls or tank rotators. The market of rotators is wide, and various companies produce different types of machines. Welding rotators nominally come in sets or pairs consisting of a powered rotator (driver unit) and an idle rotator (idler unit). The further research is mainly grouped by the type of the rotator wheel and presented average technical and economical parameters. The main parameters and specification is obtained from the manufacturing company sites and direct communication with vendors. These machines are examined and evaluated by the product's various aspects.

There are several possibilities to categorize the types of rotators. One possible way is to divide rotators into main groups according the rotator wheel type – Conventional and self-aligning rotators (Figure 4.1). The subgroups are divided according to the type of the centreline – fixed or adjustable. Finally, the extra value added of the rotator. These added values could be represented in both types of rotators. The differences are explained in details on next sections.

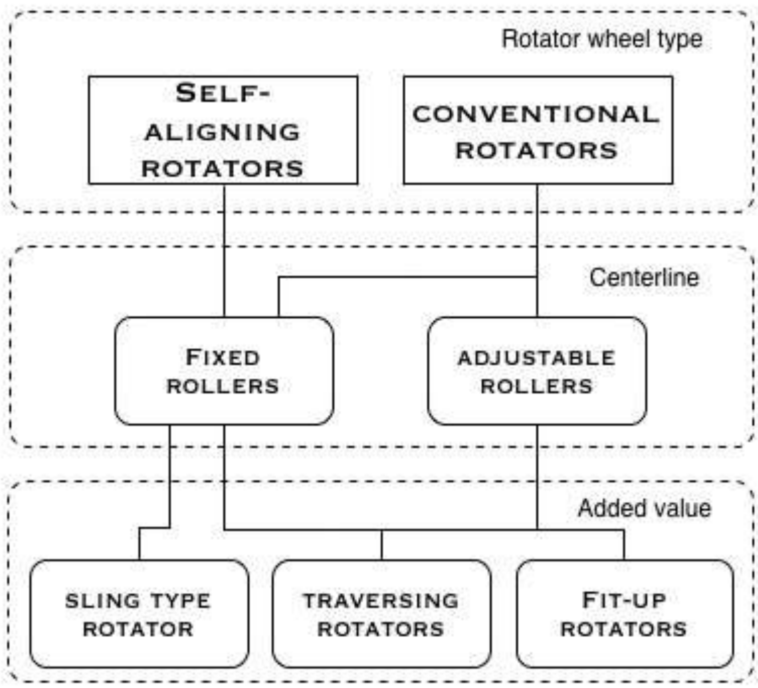

Figure 4.1 Types of rotators on market

4.1 Available equipment

4.1.1 Self-aligning rotating machine

Self-aligning rotators are mainly used in pressure vessel and tank manufacturing companies where the product diameter varies. The roller bracket assembly has two separate rollers, which are attached to the swing. The swing is hinged to the main frame that gives the freedom to rotate around its axis. Self-aligning rotator adjusts the swing angle by itself to the workpiece without the need for manual pre-adjustment. This ensures the item being worked remains central to the rotator frames and eliminates the need to adjust the welding head. Also, a bigger diameter – up to 6m – and irrespective of roundness or irregularity of shells, can be accommodated without need for any adjustment from a worker.

First, the rotators are placed using the lifting device on to the workshop floor according to the length of the shell. Ensuring the rotator units are parallel is crucial. Common practice is to measure the diagonals between drive and idler unit. Finally the worker places the shell on to the rotator.

Working principle

One possible solution is introduced on Figure 4.2. It is one motor synchronized driver system. The motors output is transferred to the both roller brackets via worm drive method. Gear drive, or optionally the chain drive, is used to transfer rotational movement power to the rollers, which is in contact with the workpiece.

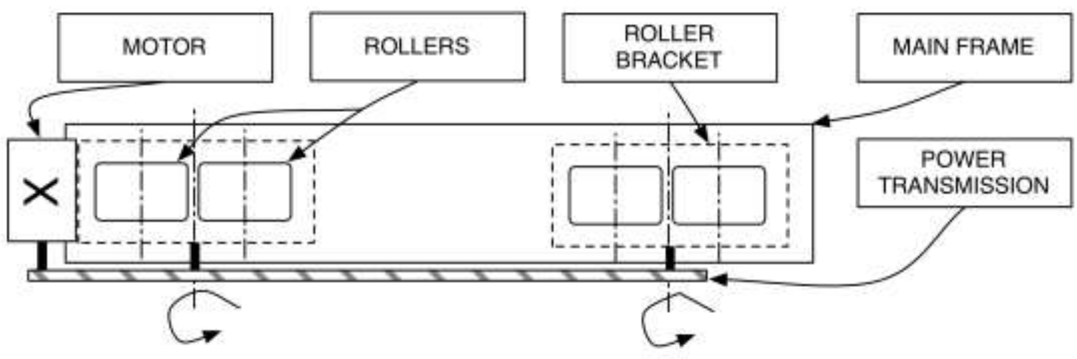

Figure 4.2 Working principle of self-aligning rotator

Figure 4.3 Self-aligning fixed rotator Bode drive & idler model SAR1200 [9]

Capacity

Table 1 Bode driver & idler model SAR1200 specification [9]

Max loading capacity	20+20 t
Max vessel diameter	5200 mm
Min vessel diameter	450 mm
Roller diameter	457 mm
Size (L x W x H)	3050 x 1000 x 1035 mm
Number of wheels	4 pcs
Motors	1 pcs
Variable speed	100 – 1500 mm/min

4.1.2 Conventional rotating machine

The construction of these types of machines have roller bracket assembly on both sides of the main frame. Compared to previous types of machine, the brackets are bolted on the main frame. The main frame is drilled on top faces of the roller bracket to provide accurate alignment and to secure the rollers. Therefore, both brackets have to be moved manually by the worker as the workpiece diameter changes. Powered rotators have two motors on both roller brackets to output higher torque for smoother rotation. Alternatively, there are also roller brackets with the lead screw that allows for sliding the roller brackets over the main frame equally in both directions. These are referred also as self-centering rotators or screw-adjustable rotators [10].

Similar to the self-aligning rotators, units need to place on to the workshop floor according to the length of the shell. Besides dimensioning the diagonals of two units, workers must also manually adjust the roller brackets according to the shell diameter.

Working principle

It is two motor synchronized drivers system, where both roller brackets are connected to independent motors. The output power is transferred to the rollers by the same methods as described on self-aligning rotators by either gear or chain drive methods.

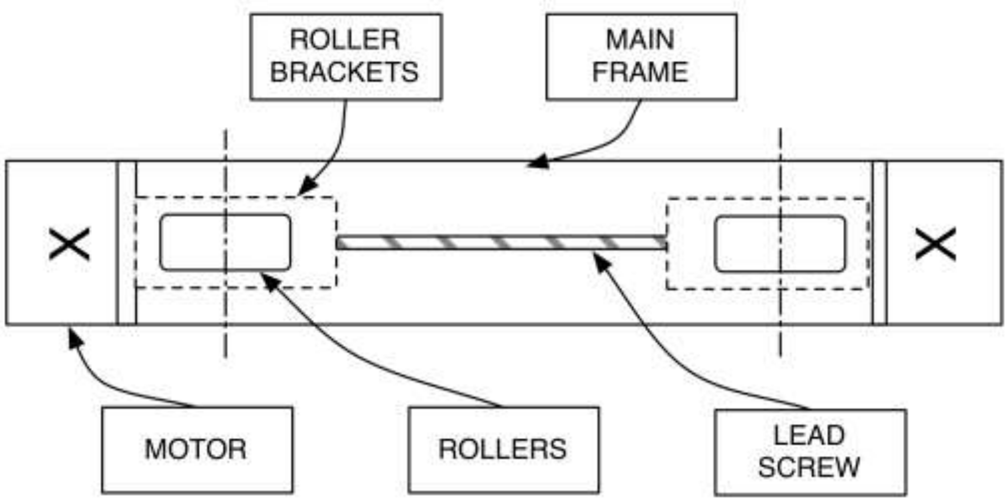

Figure 4.4 Working principle of conventional rotator

Figure 4.5 Conventional adjustable rotator ESAB CD-30 [11]

Capacity

Table 2 ESAB CD-30 specification [11]

Max loading capacity	15+15 t
Max vessel diameter	6000 mm
Min vessel diameter	500 mm
Roller diameter	520 mm
Size (L x W x H)	3920 x 765 x 892 mm
Number of wheels	2 pcs
Motors	2 pcs
Variable speed	125-1250 mm/min

4.1.3 Fit-up rotators

A workpiece has often more than one section. Fit-up rotators are used for assembling two similar or different diameter cylindrical sections together by tack welding. It is mainly used on wind towers, chimneys and generally in series productions where there is a need for assembling many cylindrical workpieces together. Fit-up rotators are specially designed to rotate, align and support two sections of the shells. The aligning feature reduces the handling and adjusting time. The construction of this type could be same as the conventional or self-aligning rotating machines with the extra feature added.

Working principle

The powered rotator is placed under one end of one cylindrical section and an idler rotator is placed under the opposite end of the other section. The two fit-up rotators are placed to the closer end of the both cylindrical sections. Moving the both fit-up brackets vertically (bringing the rollers closer or moving them apart) raises or lowers the cylindrical sectors. Moving one bracket shifts the shell left or right. Rollers are driven by the hydraulic cylinders to adjust and match the cylinders axis with the other. The tack welding and further adjusting is done for proper alignment. Finally the full circumferential welding is done.

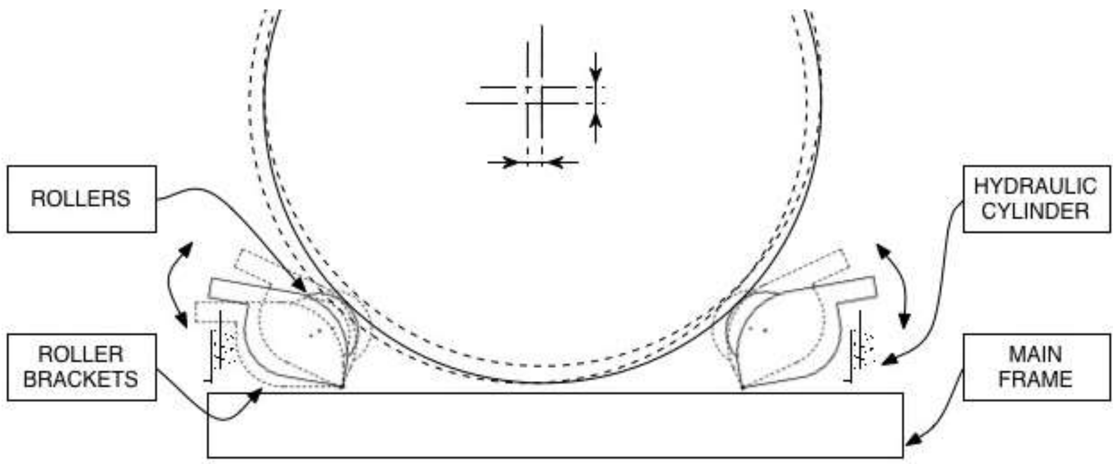

Figure 4.6 Working principle of fit-up rotator

Figure 4.7 Fit-up rotator ESAB FIR 35 [12]

Capacity

Table 3 ESAB FIR 35 specification [12]

Max loading capacity	35 t
Max vessel diameter	5000 mm
Min vessel diameter	2200 mm
Roller diameter	300 mm
Size (L x W x H)	2330 x 1600 x 1150 mm
Number of wheels	4 pcs
Motors	-
Variable speed	-

4.1.4 Traversing rotators

The traversing rotators range is to carry vessels of various lengths and to allow for longitudinal movement of the workpiece. Both types - self-aligning and conventional rotators are available on the market. The weight of the shell produces enough traction on the rotator's rollers to maintain the distance between driver and idler rollers when the vessel is moved longitudinally. Traversing rotators are mainly used together with fit-up and welding manipulators as a complex production line in the cylindrical sector assembling phase. The advance of the traversing rotators compared to other rotators is eliminating the need to use the lifting devices. Workpiece can be transported from one workstation to another by the traversing system. It can save several material-handling lifts of a vessel during the manufacturing. Therefore, the production could increase and provide safer material movement along the workshop floor.

Working principle

The driver and idler rotators are both installed on a rail-mounted car. The extra planning and preparation is required beforehand in the workshop floor to take into use the traversing rotators. The rails need to be installed to the workshop floor. The car wheels travel along the rails smoothly if the track is accurately aligned, flat, straight and levelled. Majority of the traversing rotators are designed to operate on standard 1435 mm gauge track [13].

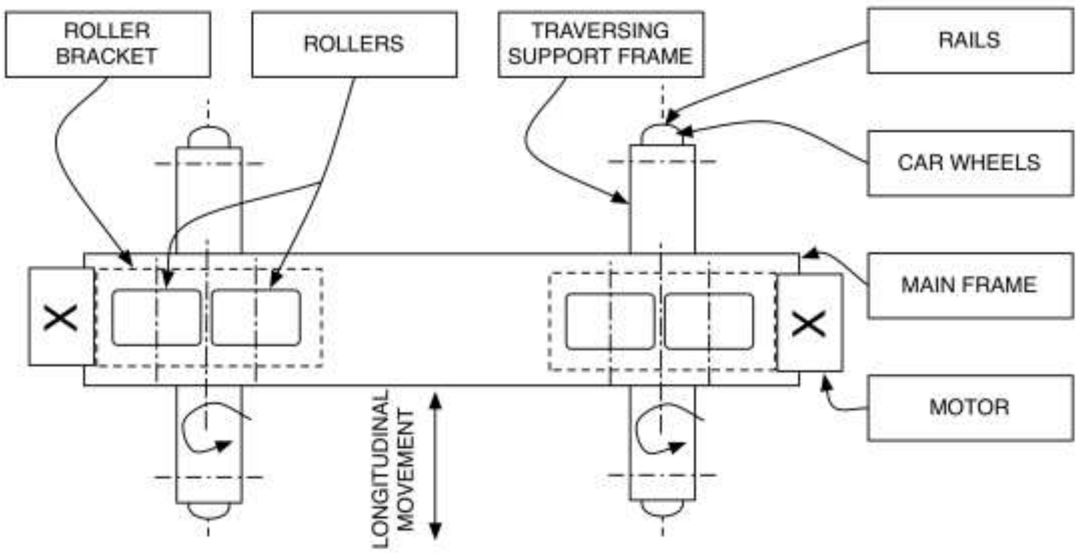

Figure 4.8 Working principle of traversing rotator

Figure 4.9 Traversing self-aligning rotator CORIMPEX AAR-30 [14]

Capacity

Table 4 CORIMPEX AAR-30 specification [14]

Max loading capacity	15+15 t
Max vessel diameter	4600 mm
Min vessel diameter	450 mm
Roller diameter	460 mm
Size (L x W x H)	3100 x 1900 x 1550 mm
Number of wheels	4 pcs
Motors	2 pcs
Variable speed	150-1500 mm/min

4.1.5 Sling type rotator

A chain or sling is used to handle thin walled vessels or precious surface cylindrical workpieces. This type of rotators is used mainly in milk coolers, silos production and it becomes great help in producing elliptically shaped workpieces. The sling provides more supportive surface on the workpiece while rotating compared to other rotator types. That provides extra supportive surface for the workpiece to prevent damage to its surface i.e. wrinkling or denting the outer surface of thin walled workpieces. The workpiece can be rotated only in one direction according to the chain location.

Working principle

Sling type rotators can be used on a common main frame. The workpiece must be placed on the rotator carefully. Sling type rotator chain adopts the shape of the workpiece that provide an extra supportive surface. It is one motor powered driver system. The chain transmits mechanical rotation from the motor side roller to the other roller.

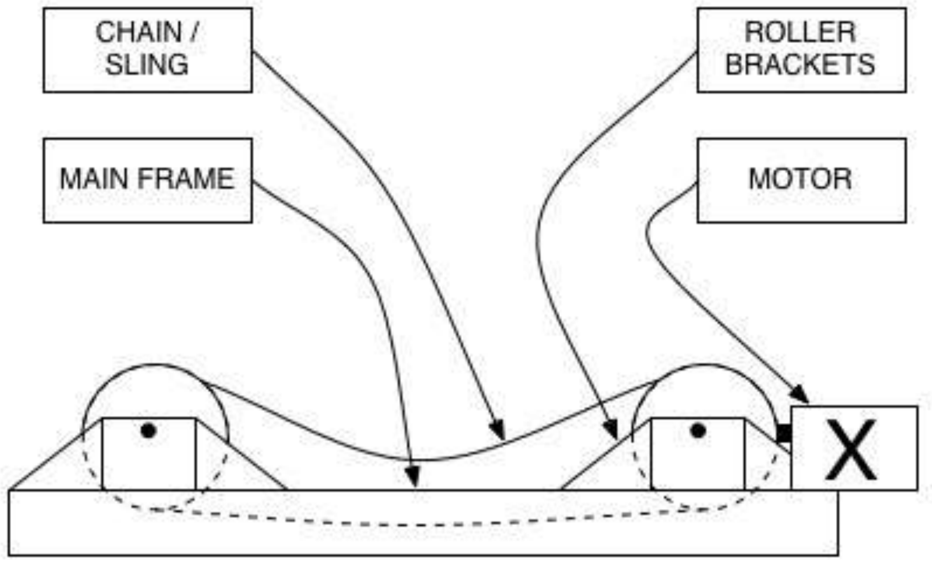

Figure 4.10 Working principle of sling type rotator

Figure 4.11 Sling type rotator Koike Trac-Tred T4 [15]

Capacity

Table 5 Koike Trac-Tred T4 specification [15]

Max loading capacity	10.8 + 10.8 t
Max vessel diameter	6100 mm
Min vessel diameter	4800 mm
Roller diameter	-
Size (L x W x H)	3660 x 1070 x 960 mm
Number of wheels	2 pcs
Motors	1 pcs
Variable speed	40 – 1880 mm/min

4.2 Equipment component analyse

The equipment research reveals that many different types, parameters and combinations of rotators exist in the market. To get full picture of the possible machines and variable combinations on the market, categorisation was done, based upon the type of rotator wheel: self-aligning rotator or conventional rotator. The subcategory determines if the rotator centreline is fixed or adjustable (see Figure 4.1). Also the different added value is listed in the category. All above-mentioned equipment have their strengths and weaknesses. The choice of the suitable type of equipment depends heavily on the workpiece parameters (weight, diameter etc.) and process is performed (See Table 6).

Self-aligning rotators

The result of the market research shows that the self-aligning rotators are manufactured mainly as a fixed centreline. This sets the limit of the maximum and minimum diameter of the workpiece. It does not require any adjustment of the roller brackets for fitting different size of the workpieces. Nevertheless, it has been noticed that working with bigger diameter workpieces then self-aligning roller brackets requires third party intervention. The maximum loading capacity varies on different types of rotators, as well as the maximum and minimum workpiece diameter, number of rollers various etc. The self-aligning rotators are available both type - as a traversing or stand-alone.

Conventional rotators

There are mainly two types of conventional rotators available on the market – fixed and adjustable centreline. Adjustable centreline conventional rotators need manually adjustment by the worker. In addition, there are also motorized types available but the adjustment is still needed beforehand to lower the workpiece. Also, in addition to the previously mentioned sling-type rotators should be also marked. It is designed especially for the thin-walled workpieces. The contact area is bigger compared to other types. The workpieces are fully supported under the lower part of the workpiece via belt or chain. The author does not have personal experience with this type of rotator, but according to the desktop study, it seems rather unstable for rotating different size of vessels. Further research and cooperation with the vendor is needed. The restriction sets the small range of cylindrical shell diameter which is suitable for sling type rotators.

Most used equipment type is adjustable centreline with various values added. The typical adjustable rotator brackets are bolted to main frame. Like all represented options, this type of rotators has disadvantages. The roller brackets have to be manually positioned across the frame to suit the diameter of the workpiece. It requires a production worker to find the parameters of the vessel and position the brackets distance according to the diameter of the workpiece beforehand.

Table 6 Table of work parameters

Rotator wheel type	Self-aligning rotators		Conventional rotators		
Centerline	Fixed		Adjustable		Fixed
Added value	-	Traversing	-	Fit-up	Sling type
Model	Bode drive idler MODEL SAR1200	CORIMPEX AAR-30	ESAB CD-30	ESAB FIR 35	Koike Trac-Tred T4
Max loading capacity (kg)	20 000 + 20 000	15 000 + 15 000	15 000 + 15 000	35 000	10 800 + 10 800
Max vessel diameter (mm)	5200	4600	6000	5000	6100
Min vessel diameter (mm)	450	450	500	2200	4800
Roller diameter (mm)	457	460	520	300	-
Width of the wheel (mm)	127	130	178	-	102
Size, L x W x H (mm)	3050 x 1000 x 1035	3100 x 1900 x 1550	3920 x 765 x 892	2330 x 1600 x 1150	3660 x 1070 x 960
Motors (pcs)	1	2	2	-	1
Variable speed (mm/min)	100 - 1500	150 - 2000	125 - 1250	-	40 - 1880
Net weight (kg)	1350+ 1050	-	1370 + 820	4850	-
Price (€)*	30 000 - 40 000	-	40 000 - 50 000	-	70 000 - 80 000

4.3 Requirements for tank rotating equipment

Different types of equipment positive aspects, usability and restrictions are taken into consideration, which is the outcome of the equipment component research. The needs and demands of the company are also taken into consideration – the design of the current equipment should remain and changes in the design should be done as little as possible but as much as needed. The side objective for the company is to implement the improvements to other already produced equipment, as well. The decision is made to improve the next batch of tank rotator equipment based on the result of the previous study. The components that should be pointed out and used in the further development:

- Alignment of the rotator

  The time spent on aligning the rotators.
- Overhead crane

  Reduce the usage of the overhead crane in any mean related with the rotators.
- The range of the rotator usability

  Maximize the usage of the rollers on different projects. The range of the workpiece diameters is increased, which suits with rotator equipment and consider the matter of the bigger cylindrical diameter workpieces.
- Workpiece outer surface

  Prevent the workpiece outer surface to get dents caused by the rotators.

5 Optimization of the tank rotating machine

The problem discussed in the thesis does not assume to generate a conceptually new solution. Rather, it is focused on developing suitable solutions to one specific company, which takes into consideration the needs and competence of the company. The components that are used in the development of the existing equipment are new for the company, but are not inventions. It is focused to maximize the benefits of the equipment and minimize the efforts, which is related with operating with the equipment.

Five years ago, the company has produced one batch of the rotators by itself. Difficulties and setbacks appeared in the production and early stage of the testing, due to a variety of reasons: mainly due to lack of the knowledge, bad quality of the assembly or detailed drawings, outdated technical information and the lack of availability of the ready-made products. It is out of this thesis scope, but the author is responsible for, besides the development, to update technical information according to the availability of the ready-made products (such as bearings, motor-reducer etc.) and to ensure that selected components fit to each other. Also, the assembly and detailed drawings are drawn upon the major focus of eliminating the previous production difficulties and defaults.

As previously mentioned, the production volumes are increased and therefore, there is a need for new set of rotators. The existing rotators are reviewed and modernized. The following development of the rotators takes into consideration the above-mentioned bottlenecks, which occurred by the time and usage of the equipment and external circumstances.

The SolidWorks 3D [16] modelling software is used to generate preliminary isometric views and detailed drawings.

5.1 The existing equipment

The equipment that is currently in use at the company is shown below (Figure 5.1). It is a typical self-aligning rotator with fixed centreline that is described on chapter 4.1.1. The difference is the number of rollers the equipment uses. It has double set of rollers on both brackets. That increases the contact surface with the workpiece to distribute the load more evenly.

Equipment uses two 0.37kW motors for both roller brackets. The main frame is from two parts that are bolted together. The maximum loading capacity is 12.5 t + 12.5 t and the maximum vessel diameter is 4800 mm, minimum 540 mm. Roller diameter is 410 mm and width of the roller is 150 mm. Variable speed 150 - 1120 mm/min, weight 1025 + 820 kg.

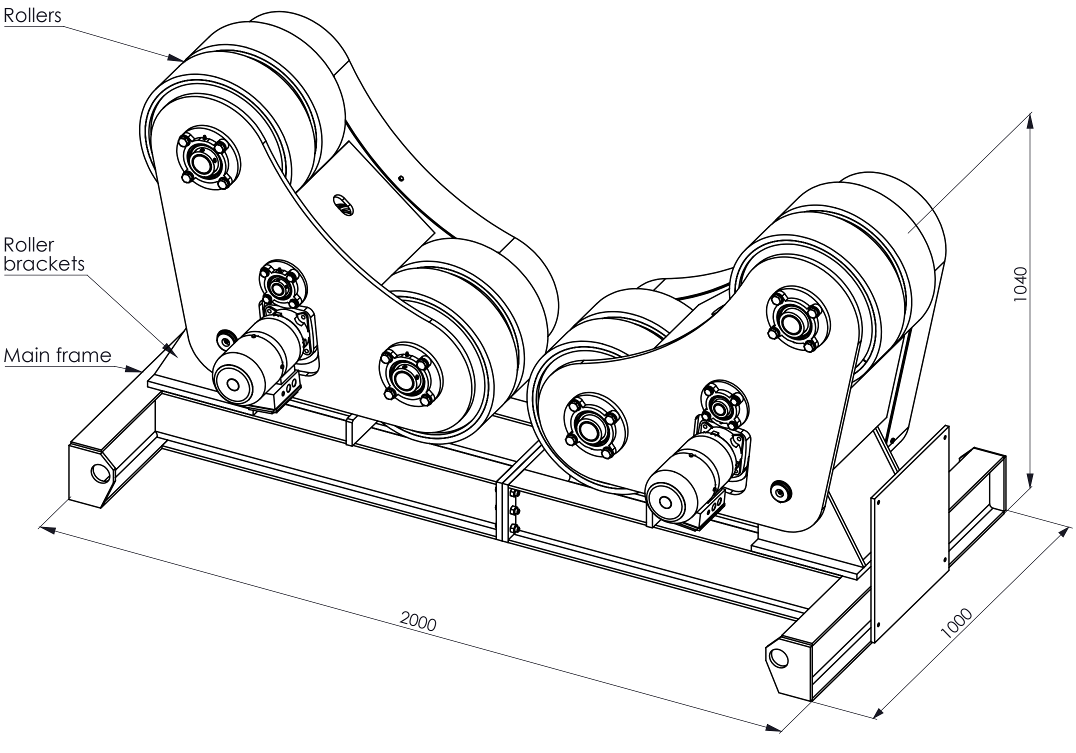

Figure 5.1 The self-aligning rotator that is use at the company

5.2 Equipment division to key components

Efficient optimization and design presumption is to specify different components on the rotator. Therefore, according to the outcome of the study, the existing rotator is divided into three different components, which are taken into further development. The components are examined separately and the solutions are proposed for each component. Nevertheless, the equipment's different components must be compatible with each other and form a complete solution. The key components are (Figure 5.1):

- Main frame
- Roller brackets
- Rollers

The final equipment is still a tank rotating machine, but according to the previous experience, it is better to divide these into separate key components. The order of the key components for further development is chosen according to the importance of the need and the influence to the overall design. The above-mentioned list is taken as a base for further development.

The main frame is most suitable component to provide ideas for speed up the alignment of the rotators. The design of the main frame must fulfil the need to decrease the time that is spent on aligning the rotators. The change in the main frame design determines the other key components design and sets limits for other components development. The roller brackets are taken into focus to maximize the usage range of the rotator. The changes in the main frame design have the most effect on the roller bracket design. Therefore, it is necessary to ensure the components are compatible with each other. The roller, which is not the most important but a still needed component in the further development point of view. The change in the design of the previous key components does not affect so much the roller design but cannot be overlooked.

5.3 General Morphological Analysis

The morphological analysis is a solution by combining design alternatives. This allows combining design options at the sub-function level to come up with suitable solution for improving the existing equipment [1]. The equipment is divided into key components, which is the base to create the morphological matrix. The functions are categorized based on the key components and the matrix is filled with different potential solutions. The provided solutions are randomly placed in the matrix. Therefore, the overall compatibility of the equipment components must be ensured before moving to detailing. The morphological matrix is generated and evaluated with the most suitable features according to the requirements (Table 7). Each function is analysed and the most suitable option is selected.

Table 7 Morphological Matrix for possible solutions

	Function	Solution		
1. Main frame	Moving the rotator	Permanently on wheels	Lifting	Temporary on wheels
	Moving force	Manually by operator	External equipment	Motorized
	Alignment locking	Stopper	Main frame	External stopper
	Moving component fixing	Permanently	Temporary	Bolting
	Position check	Check diagonals manually	Equipment on rails, no need	Paralleled lines marked on floor
2. Roller brackets	Adjusting roller brackets	Intermediate part	Independent	Lead screw
	Moving force	Extra equipment	Motorized	Manually
3. Rollers	Protecting workpiece	Narrower/wider roller	Change number of rollers	Keep current

1. Main Frame

The main frame is divided into sub-category by different functions. Moving the rotator for alignment purposes is important function of this category. The outcome of the morphological matrix reveals different solutions between to choose suitable approach. An option where rotator is permanently on wheels requires equipment to be on the wheels while it is in the working conditions (workpiece is lowered to the rotator). The wheels are required to bear the rotator weight and in additionally the workpiece weight. Option where the rotator is lifted to place is described and analysed in previous sections. Another option is to use the wheels when the rotator is set to the place. After the rotator is aligned then the wheels are removed.

The next function in the category is the moving force - the source or method how the rotator is transported from one point to another. One option is to manually move the rotator. It could be any form of movement where the effort of the production worker is involved. The other solution could be usage of the extra equipment. This involves a wide range of external resource to move the equipment.. Also other solution is to use motors that move the rotator to desired place.

Another function related to the main frame is the alignment component locking. It becomes important when the wheels or other movement are used for aligning the rotator. The alignment locking prevents the rotator to move away from the desired position when the workpiece is lowered onto the rotator. One option is to use stoppers, which are commonly used in furniture industry. These are typically attached directly to the wheel. The other option assumes that rotator does not stand on the wheels. The main frame is the stopper; the weight of the rotator prevents any movement. Finally, the external stopper can be used. These are any kind stand-alone stoppers, similar to chocks.

The one side request is to use developing solution to other existing rotators as well. Therefore the component fixing to the frame is taken into observation. The moving component could be easily just fixed permanently to the frame. The temporary fixing solution idea is to detach when the alignment is done. Finally, the bolting option is mixture of the two previous solutions.

The importance of the position check is described on previous chapter and cannot be overlooked. One of the most common solutions is to check the diagonals manually by the production worker. The position check is not required when there is a rotator on a traversing system. Only the distance between the two rotators is measured and parallelism is ensured by the traversing system. Other option is to mark the parallel lines on the production floor. It requires a one-time effort but later maintenance or marking again is required.

2. **Roller brackets**

The distance between the roller brackets is in direct relationship with the range of different workpiece diameter. The main function is adjusting distance between the roller brackets. One possible solution is to use intermediate parts to extend the frame and therefore distance between roller brackets. Other solution is to make the roller brackets removable. The roller brackets are independent units and could be removed from the main frame. Finally, the lead screw is one possible solution. The both roller brackets are attached to the lead screw and the distance between brackets is changeable via the screw.

The moving force for adjusting the roller brackets is also taken into focus. The possible solutions are similar to moving the main frame. These are: manually by the worker, use motors or some extra equipment to lift to the desired place the roller brackets.

3. **Rollers**

The rollers' importance is related to the protection of the workpiece from dents. One possible solution could be wider or narrower width of the roller. Wider rollers increase the contact area with the shell and decrease the pressure on the workpiece surface. Other solution could be adding more rollers to brackets. In other words use double or triple rollers on the brackets. Finally, the current solution is used.

5.4 Concept review

5.4.1 Solution 1

The manual forklift is used to move the rotator to desirable place (Figure 5.2). The corresponding holes are made in the main frame that provides access for forklift to raise the main frame. Nevertheless, an adjustment check is still needed. The intermediate part is used to change length between rotator brackets. The bolt connection between main frame and intermediate part requires additional preparation by production worker

The presented solution is low-cost and easily adaptable to already produced rotator. The time spent on aligning the rotator is estimated to be same as using the overhead crane.

Table 8 Solution 1

	1. Main frame					2. Roller brackets		3. Rollers
Function	Moving the rotator	Moving force	Alignment locking	Moving component fixing	Position check	Adjusting roller brackets	Moving force	Protecting workpiece
Solution	Lifting	External equipment	Main frame	Bolting	Check diagonals manually	Intermediate part	Extra equipment	Narrower/wider roller

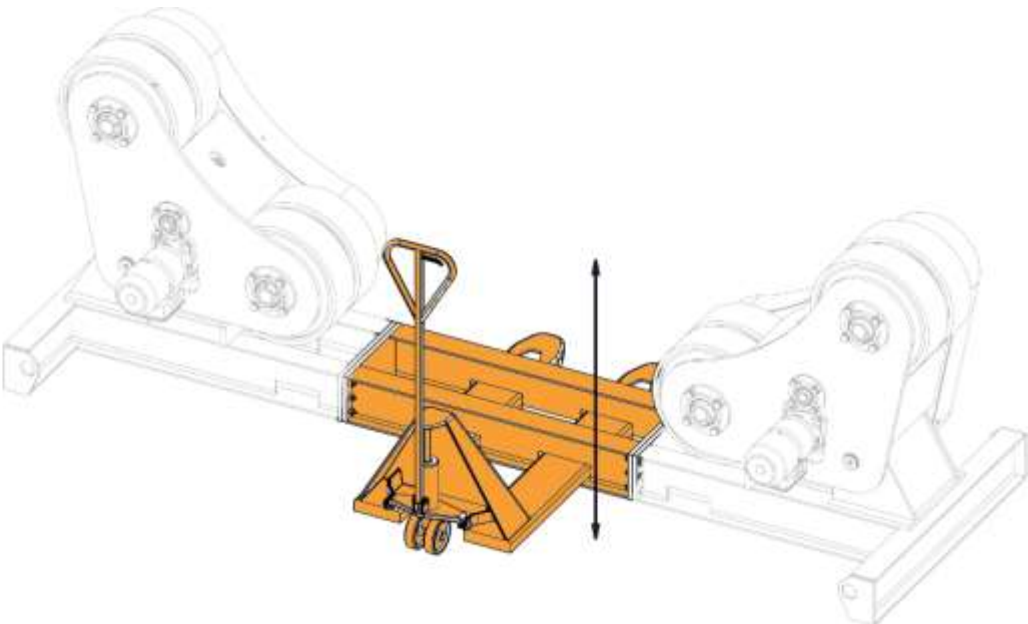

Figure 5.2 Solution 1

5.4.2 Solution 2

The temporary on wheels approach is a good choice for moving the main frame (Figure 5.3). The wheels are used only then, when the main frame is relocated to other place. The wheels are manually lowered to the ground by moving the handle bar. This causes the main frame to rise from the ground and it is movable. The distance between roller brackets is convertible by moving one of the brackets on the main frame. The bracket is fixed to the main frame with bolts.

A temporary on wheels solution decreases the time that is spent on adjusting the rotator and it eliminates the need to check the diagonals between the rotators. The wheels must only carry the weight of the rotator.

Table 9 Solution 2

	1. Main frame					2. Roller brackets		3. Rollers
Function	Moving the rotator	Moving force	Alignment locking	Moving component fixing	Position check	Adjusting roller brackets	Moving force	Protecting workpiece
Solution	Temporary on wheels	Manually by operator	Main frame	Permanently	Equipment on rails, no need	Independent	Manually	Keep current

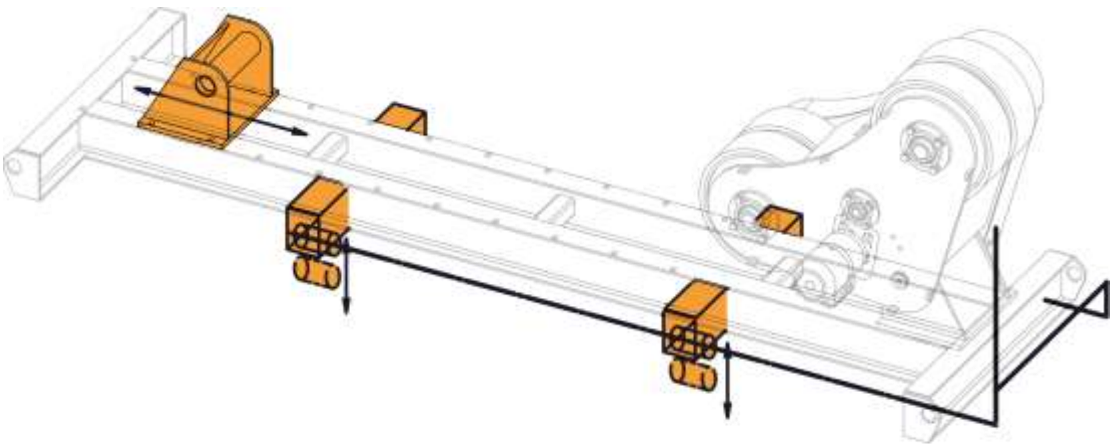

Figure 5.3 Solution 2

5.4.3 Solution 3

The permanently-on-wheels approach is similar to the traversing rotator. The wheels are attached to the main frame permanently. So the equipment is standing all the time on wheels. These must carry the weight of the rotator and weight of the workpiece. The motors are used to relocate the equipment. The wheels are along the rails and there is no need to check the diagonals after replacement. The distance between roller brackets is changeable by the lead screw.

The proposed solution is expensive due to the reason of using multiple motors. Nonetheless, the time that is spent on adjusting the rotator is significantly decreased. The need of using overhead crane is also eliminated

Table 10 Solution 3

	1. Main frame					2. Roller brackets		3. Rollers
Function	Moving the rotator	Moving force	Alignment locking	Moving component fixing	Position check	Adjusting roller brackets	Moving force	Protecting workpiece
Solution	Permanently on wheels	Motorized	Stopper	Permanently	Equipment on rails, no need	Lead screw	Motorized	Change number of rollers

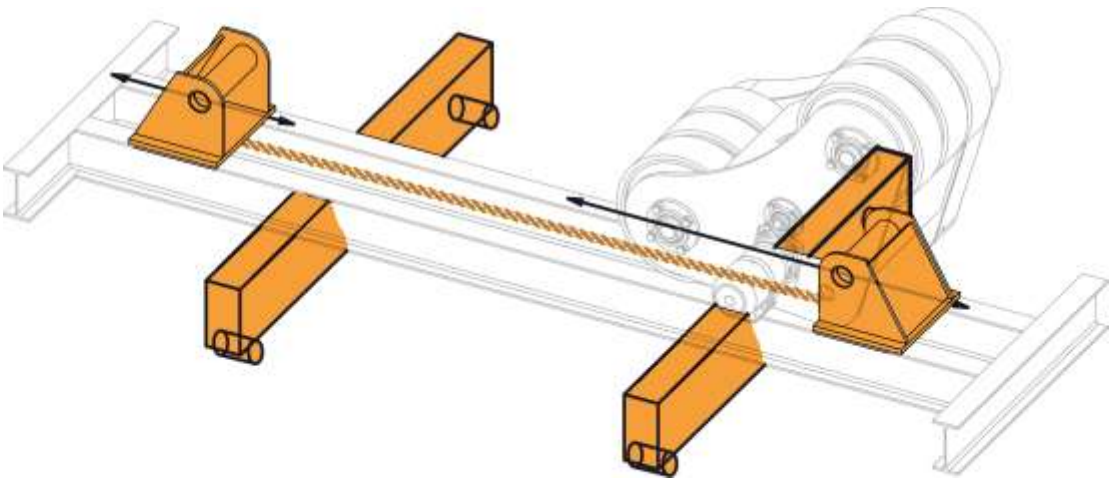

Figure 5.4 Solution 3

5.4.4 Evaluation matrix

The proposed solutions for different key components vary by the principal idea. Each of them affects the design of the current equipment. The proposed solutions have positive and negative aspects, which are taken into consideration. The evaluation matrix (Table 11) is used to select the solution to go further. The relevant criteria are selected based on the importance in terms of the previously mentioned needs. On the same basis, weighting of each criterion is carried out and assigned. Between 8 selected criteria 1,00 points is shared. Subsequently, the rating of each concept with respect to each criterion is carried out by people of different fields of work from the company. With a result of 3,85 out of possible 5,00 points the concept 2 is selected to work further with.

Table 11 Evaluation matrix

Criterias	**Importance (0-1,00)**	**Concept 1**		**Concept 2**		**Concept 3**	
		Rating (0-5)	Score	Rating (0-5)	Score	Rating (0-5)	Score
Number of parts	0,15	4	0,60	3	0,45	2	0,30
Functional reliability	0,10	4	0,40	4	0,40	3	0,30
Maintenance	0,05	4	0,20	3	0,15	2	0,10
Alignment	0,25	2	0,50	5	1,25	5	1,25
Production	0,15	5	0,75	4	0,60	2	0,30
Weight	0,10	4	0,40	3	0,30	3	0,30
Cost	0,10	4	0,40	3	0,30	2	0,20
Ease of use	0,10	2	0,20	4	0,40	5	0,50
Total	**1,00**		**3,45**		**3,85**		**3,25**

5.5 The main frame improvement

The further development is guided by the selection of the morphological matrix. The wheels are used only for moving the rotator. When the alignment is done, the wheels are not used, and raised up. The load from the equipment and workpiece carries the mainframe, similarly to typical conventional or self-aligning rotators. Therefore, there is no need to consider any load caused by the workpiece while designing the wheel mechanism. The rails are available on the workshop floor to use, which services the alignment function.

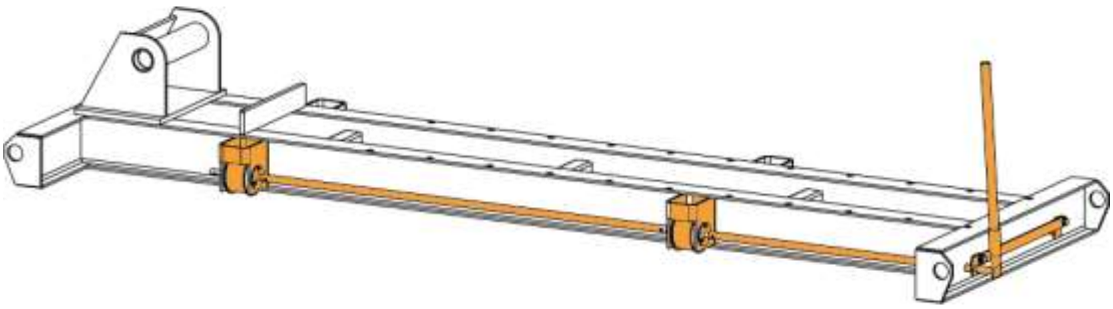

Figure 5.5 Main frame improvement

The possible solution is shown on Figure 5.5. The working principle is similar to belt tensioners, which are used on the car industry (Figure 5.6). The wheel is installed to the eccentric shaft and the shaft is supported from both ends by the main frame. The eccentric shaft is used to raise or lower the wheels. Two wheels are used on both side of the rotator to ensure the stability while the wheels are in contact with the floor. Maximum distance between the ground and the wheel is distance l. It is two times of the distance between the eccentric shaft on the main frame side and on the wheel side – distance a.

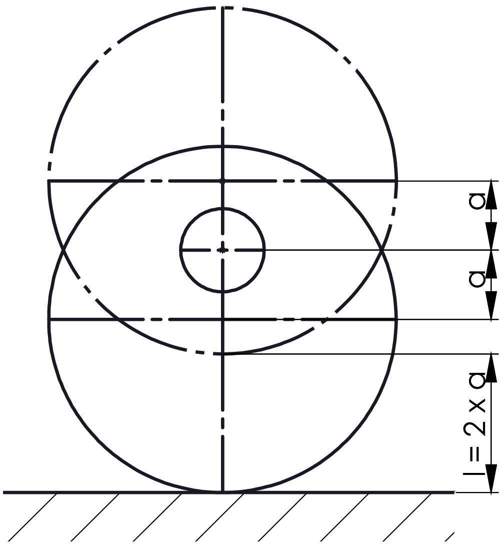

Figure 5.6 Eccentric shaft

The required force, that exceeds the rotator its own weight for raising the rotator, is given by the wheel and axel method. The mechanical advantage of this is the ratio of the distances from the fulcrum to the applied loads. The length of the handle bar is in direct relationship with the distance between the wheel and shaft axis. The bigger distance between two axles of the eccentric shaft is, the longer handle bar is needed. Therefore the distance between the ground and the shaft axis is chosen so that it lifts up the rotator from the ground with small reserve.

Figure 5.7 Wheel kinematic diagram

Movement analyse

The rotator wheels are lifted or lowered manually by the production worker. Therefore, it is necessary to get an overview of the forces that applies to the mechanism and determine the handle bar length that is needed to lift up the rotator. The assumption is made that the weight of the rotator is equally divided to all four wheels. There are no exceptional situations where only one or two wheel must carry the rotator weight.

Therefore load that applies to one wheel:

$F_T = 11000\ N$ – total weight of the rotator

$$F_w = \frac{F_T}{4} = \frac{11000}{4} = 2750\ N \quad (5.1)$$

F_W – load that applies to one wheel (N)

The critical situation is shown on the simplified kinematic diagram (Figure 5.7). In represented situation, the torque is maximum that is caused by the equipment weight. The 3D model is generated concurrently with the kinematic diagram to specify the needed dimensions.

Load that applies to one side of the rotator

$$F_B = F_G = 2 \cdot F_W = 2 \cdot 2750 = 5500\ N \quad (5.2)$$

F_B, F_G – load that applies to one side of the rotator (N)

The torque that is generated at the current situation:

$AB = HG = 10\ mm = 0{,}01\ m$ – distance between the wheel and shaft axis

$F_D = 200\ N$ – generated force by human [17]

$$T_A = T_H = F_B \cdot AB = 5500 \cdot 0{,}01 = 55\ Nm \quad (5.3)$$

T_A, T_H – generated torque (Nm)

The required length for the handlebar:

$$AD = \frac{T_A + T_H}{F_D} = \frac{55 + 55}{200} = 0{,}55\ m = 550\ mm \quad (5.4)$$

AD – handlebar distance (mm)

Locking mechanism

The wheels need to be locked on desired positions (Figure 5.8 position 1: wheels are carrying the rotator load; position 2: wheels are lifted and the main frame carries the load). The wheel locking mechanism is resolved by tilting the eccentric shaft out from the vertical position for both positions. The weight of the rotator (position 1) or weight of the wheels (position 2) that are tilted away from the vertical line generates the circular motion which needs to be fixed. Therefore, the stopper is necessary to prevent the eccentric shaft from making the full turn around its axle and fix the wheels at the desired position. The biggest load is applied on position 1, while the wheels carry the weight of the rotator. The stopper in this case is the main frame; the inner surface of the UPE-profile is used to prevent further movement. The stopper for other position is tube that connects the wheels.

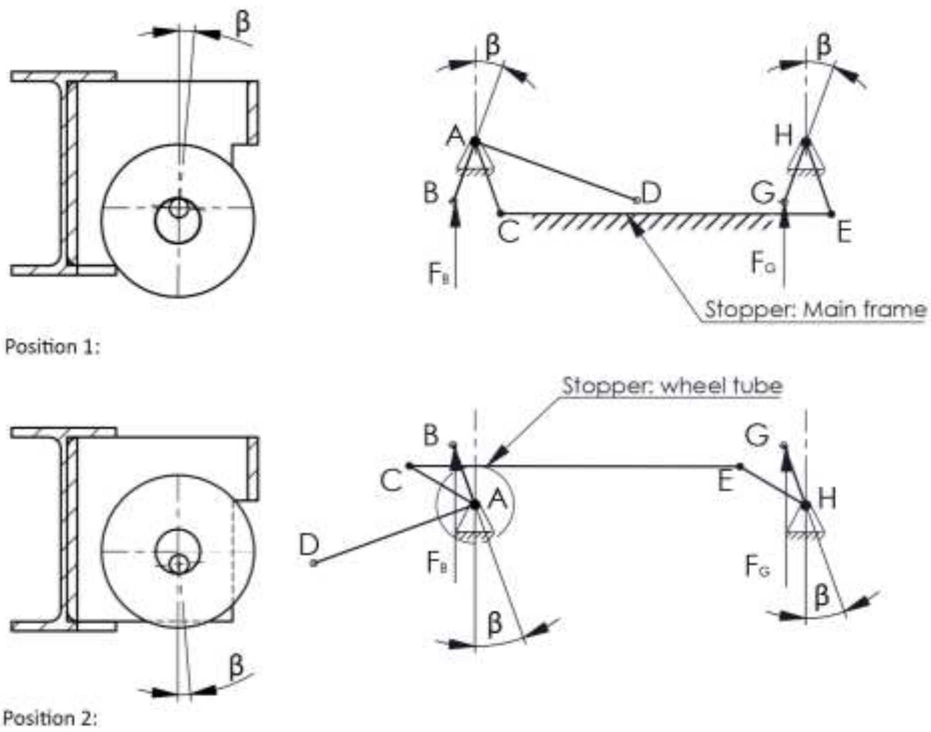

Figure 5.8 Wheel locking mechanism; Position 1: Wheel is lowered to floor; Position 2: wheel is lifted up

Strength calculation

The section with the biggest loads are applied is the critical section. The assumption is made that the section is where the wheel tube is connected to the handle bar. At this point, torque is generated from all four wheels and loads are biggest. Two unknown parameters in one operation are not possible to calculate. Therefore, additional data is needed and the wheel tube is selected based on the experience. Strength calculations are made to check if the selected tube withstands the loads. The selected tube that connects eccentric shafts is D21,3 x 2,6.

$D_t = 21{,}3\ mm$ – outer diameter of tube
$d_t = 16{,}1\ mm$ – inner diameter of tube

$$\tau_{max} = \frac{T_A + T_H}{W_0} = \frac{(55 + 55) \cdot 10^3}{1277{,}4} = 86{,}1\ MPa \qquad (5.5)$$

$$W_0 = \frac{\pi \cdot D^3}{16} \cdot \left[1 - \left(\frac{d_t}{D_t}\right)^4\right] = \frac{\pi \cdot 21{,}3^3}{16} \cdot \left[1 - \left(\frac{16{,}1}{21{,}3}\right)^4\right] = 1277{,}4\ mm^3 \qquad (5.6)$$

W_0 – polar moment of inertia (mm^3)

The material is S235, therefore the yield limit is $R_{eH} = 235\ MPa$

$$\tau_y = 0{,}6 \cdot R_{eH} = 0{,}6 \cdot 235 = 141\ MPa \qquad (5.7)$$

τ_y – allowable shear stress (MPa)

Safety factor:

$$S = \frac{\tau_y}{\tau_{max}} = \frac{141}{86{,}1} = 1{,}6 \qquad (5.8)$$

S – safety factor

Bearing selection

Selecting the suitable bearings is crucial to carry the rotator weight. The load that applies to the bearings must not exceed the allowable dynamic or static load. The selection is based on the SKF catalogue [18]. That sets limits to the bearing inner diameter and overall selection that is available on the market. The Figure 5.9 illustrates the bearing scheme. The equipment is used indoors mainly; therefore the working conditions are close to the room temperature. The load that applies to the bearing:

$$F_{br} = \frac{F_W}{2} = \frac{2750}{2} = 1375\ N = 1{,}375\ kN \tag{5.9}$$

F_{br} – bearing load (N)

Selected bearings are SKF 6202-2RSH – $C = 8{,}1\ kN$ and $C_0 = 3{,}8\ kN$;
SKF 62207-2RS1 – $C = 25{,}5\ kN$ and $C_0 = 15{,}3\ kN$ (Annex I).

Eccentric shaft double-check calculation

The selected bearings set limits on the eccentric shaft diameter. It is necessary to double-check the loads that eccentric shaft must carry is necessary. The Figure 5.9 shows the loads that apply to the shaft. The diameter of the eccentric shaft on the main frame side is 15 mm and on the wheel side is 35mm. The loads are chosen from the centre of the bearings. Check the loads in the dangerous cross-section.

$l = 22\ mm$ – distance between main frame and wheel bearings
$d_s = 15\ mm$ – shaft diameter on the main frame side

$$\sigma = \frac{M}{W} = \frac{30{,}2 \cdot 10^3}{331{,}2} = 91{,}2M\ Pa \tag{5.10}$$

$$M = F_{br} \cdot l = 1375 \cdot 0{,}022 = 30{,}2\ Nm \tag{5.11}$$

$$W = \frac{\pi \cdot d_s^3}{32} = \frac{\pi \cdot 15^3}{32} = 331{,}2\ mm^3 \tag{5.12}$$

The torque that is generated from one side of two wheel is previously calculated on equation (5.3):

$$\tau_s = \frac{T_A}{W_0} = \frac{55 \cdot 10^3}{662{,}3} = 83{,}1\ MPa \tag{5.13}$$

$$W_0 = \frac{\pi \cdot d_s^3}{16} = \frac{\pi \cdot 15^3}{16} = 662{,}3\ mm^3 \tag{5.14}$$

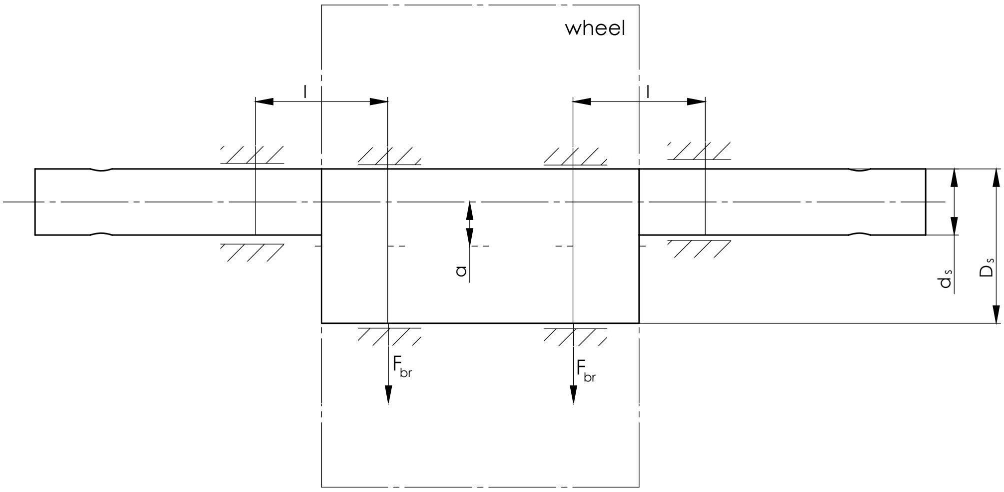

Figure 5.9 Eccentric shaft bearing scheme and applied forces

Handlebar

The length of the handlebar and the torque that is generated is calculated on equation (5.4) and (5.3). It is necessary to check the loads that apply to the handlebar while the wheels are turned (Figure 5.7). The selected tube is D33,7 x 2,6.

$d_h = 28{,}5\ mm$ – inner diameter of handlebar tube

$D_h = 33{,}7\ mm$ – outer diameter of handlebar tube

$$\sigma = \frac{T_A + T_H}{W} = \frac{(55 + 55)^3}{1834{,}5} = 59{,}9MPa \tag{5.15}$$

$$W = \frac{\pi \cdot D_h^3}{32}\left[1 - \left(\frac{d_h}{D_h}\right)^4\right] = \frac{\pi \cdot 33{,}7^3}{32}\left[1 - \left(\frac{28{,}5}{33{,}7}\right)^4\right] = 1834{,}5\ mm^3 \tag{5.16}$$

5.6 The roller brackets improvement

The roller bracket design is changed according to the result of the morphological matrix. The main frame is extended and holes are created on top of the frame for the fixing reason. One of the roller brackets design is changed so that the bracket is movable (Figure 5.10) along the frame. The bracket is fixed to the main frame by bolting or optionally with split pins. The distance within the roller bracket moves on the main frame is chosen virtually by testing different size of workpieces in 3d model. Also the included angle and size of the production door sets the limits for the workpiece. The self-aligning roller does not require to change the distance between the roller brackets. The rotator could work within wide range of workpiece diameter. The distance adjusting is needed if the workpiece diameter is in one or other edge of the diameter. The roller brackets is moved manually by lifting device.

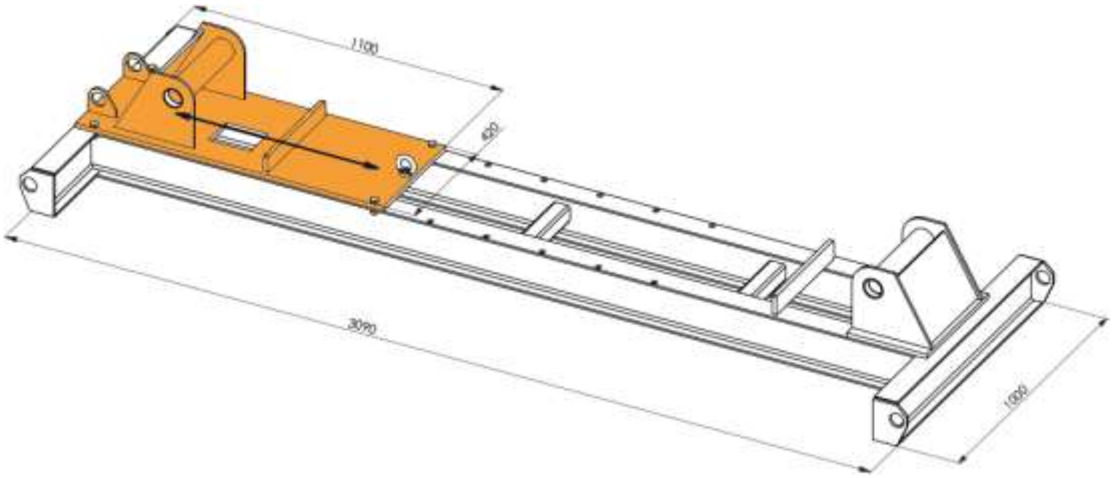

Figure 5.10 Roller bracket improvement

Strength calculation

The calculation is made to check any deformation while the roller bracket is moved. The changes in the design influence only the lower part of the brackets. The strength calculation is made only for lifting and moving the roller bracket because the design change does not affect the parts that carry the roller and workpiece. The shape and thickness of the side plates are taken from the initial design. The shape of the roller bracket is complicated to hand calculate it. The finite element analysis method is used to find out the loads and stresses impact the roller bracket. The Ansys strength calculation software is used to calculate the stresses.

The simplification of the model is done due the reason that the geometry and loads are symmetrical. Also the unnecessary parts are suppressed. The purpose of simplification is to reduce the analysis time. The calculation time goes up when the number of elements and nodes are increased. Higher number of elements used in the calculation gives more accurate results in the end. The Figure 5.11 represents simplified and meshed model. The element size is chosen 6 mm and used elements: 316 302. Also the applied force is half of the total load because of the model is cut to half.

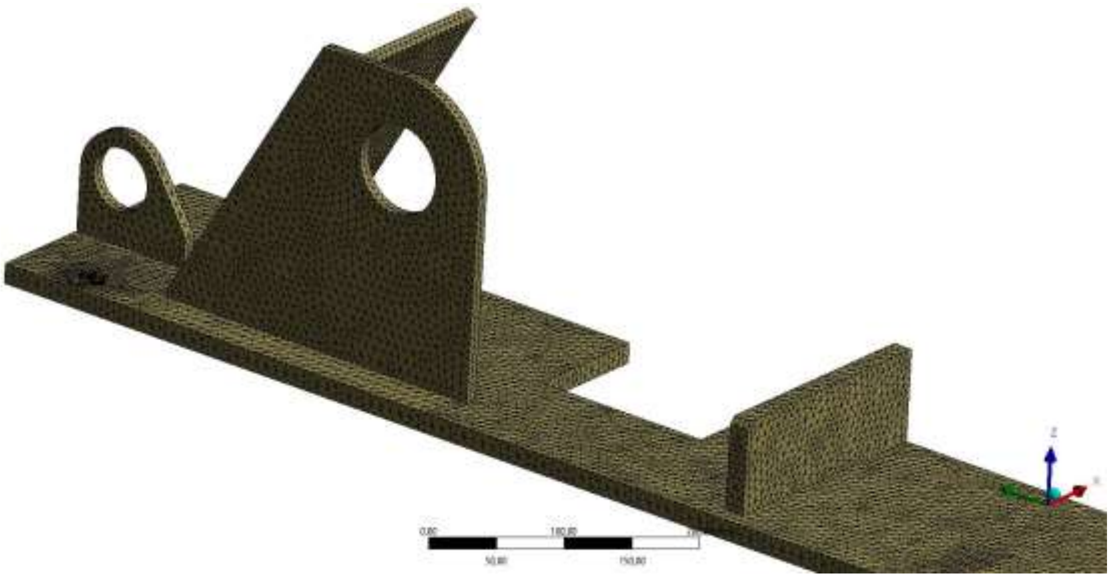

Figure 5.11 Meshing of the model

The change in the design geometry does not affect roller bracket strength on the working conditions. The roller brackets rest on the main frame and the loads generated by the workpiece are transferred to the main frame. Therefore the analysis is done only when the roller brackets are moved. The strength of the roller bracket is checked in the situation when the brackets are lifted up from the main frame for the adjusting reasons. The loading diagram is chosen so when the roller bracket is lifted from the lifting eyes (Figure 5.12 – blue markings) and the weight of the rollers are applied to the brackets (Figure 5.12 – red markings). Also the gravitational force, which is generated by the brackets, is applied to the roller brackets (Figure 5.12 – yellow marking).

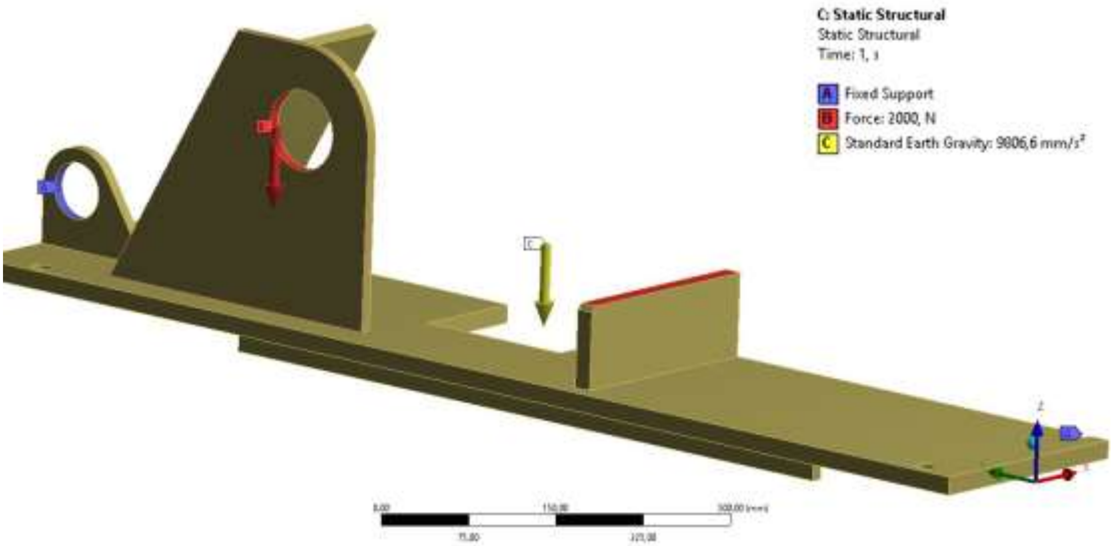

Figure 5.12 The boundary conditions

The Von Mises stresses indicate if the material exceeds its yield strength and design will fail. The assembly is welded together therefore the material is chosen S235 for this purposes – the most common structural steel The Figure 5.13 shows equivalent stresses for the roller brackets. The maximum point of stress is around the lifting eye. The maximum value is 108,5 MPa. That is below the structural steel yield strength. The safety factor:

$$S = \frac{\sigma_y}{\sigma_{max}} = \frac{235}{108{,}5} = 2{,}1 \qquad (5.17)$$

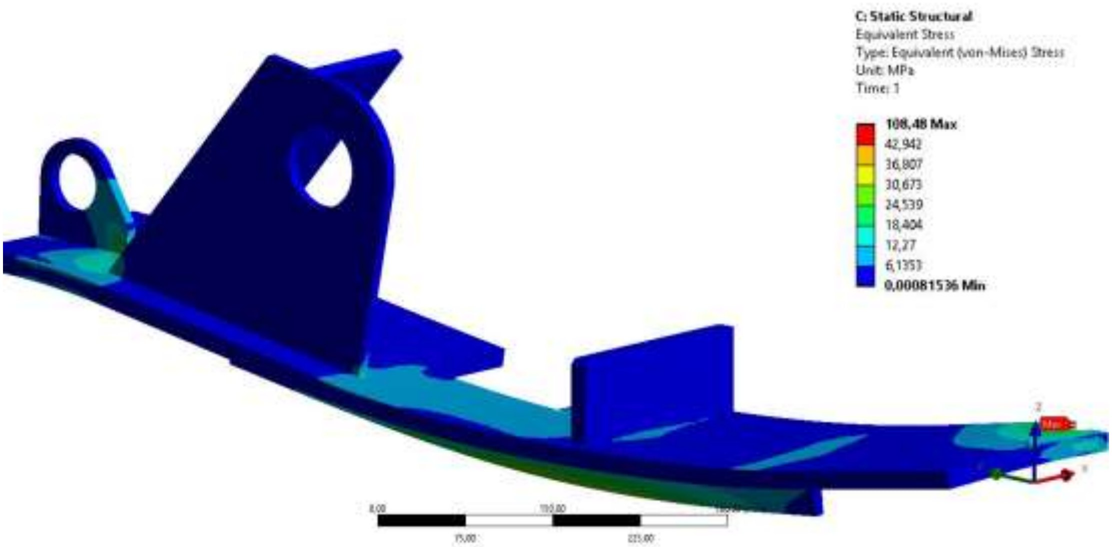

Figure 5.13 Von Mises stress result

The Figure 5.14 shows total deformation of the brackets. The maximum deformation is 0,3 mm and it is located in the middle of the bracket plate. There is an elastic deformation – if the load is removed then it recovers the initial shape.

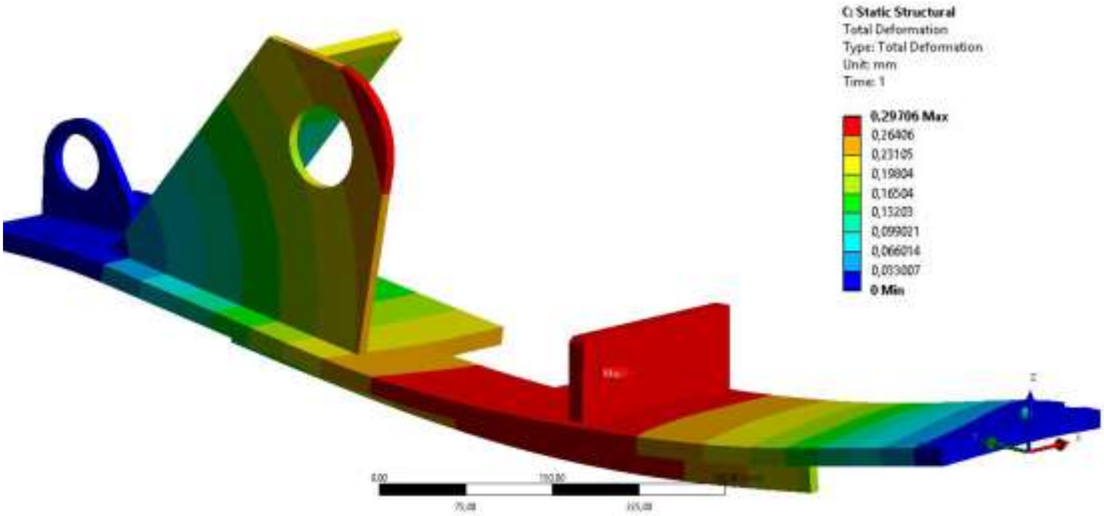

Figure 5.14 Total deformation

The figures above show that the desired design is safe to work under the given loads. The charts presented on the figures also shows that there is space for optimization in order to save material. It is not done due to desire to keep the different material usage low in the design. So it is possible to minimize the leftovers and get the effective usage of the metal plate. Therefore the bracket plate's thicknesses are chosen according to the materials that are used in the design already. The Ansys strength calculation is used to check if the design with given plate thicknesses will fail or not under given loads.

5.7 Economic calculation

The cost price of the product is calculated on the basis of a 1 set of rotators. A set of rotators includes 1 driver and 1 idler unit. The cost price forming factors are broken down:

- Material cost
- Manufacturing cost
- Overhead cost
- Total cost

Material cost

The total need of the raw materials is grouped together by the thickness of the plate and size of the profile on Table 12. The fixings are grouped together on Table 13 and ready-made products on Table 14. The detailed bill of material table is shown in section: Annex 2 – Material quantities by the details.

Table 12 The cost of raw material

Material type	Dimensions, mm	Material	Quantity	Unit	Price per unit, €/unit	Cost, €
Sheet	16 x 2000 x 6000	S235JR	0,61	pcs	775,00	472,29
Sheet	12 x 2000 x 6000	S235JR	0,26	pcs	550,00	141,09
Sheet	10 x 2000 x 6000	S235JR	0,53	pcs	532,00	284,59
Sheet	5 x 2000 x 6000	S235JR	0,06	pcs	257,00	16,65
Sheet	2 x 1250 x 2500	S235JR	0,72	pcs	23,00	16,54
					TOTAL	931,15
IPE	160	S355J2	15,93	m	10,00	159,32
PIPE	D21,3 x 2,6	P235	9,08	m	2,20	19,97
PIPE	D26,9 x 2,6	P235	1,20	m	2,10	2,52
PIPE	D33,7 x 2,6	P235	0,30	m	2,80	0,84
PIPE	D48,3 x 4	P235	1,58	m	10,40	16,43
PIPE	D82,5 x 20	S355J2H	4,12	m	45,00	185,40
L	100 x 65 x 9	S235JR	0,38	m	6,90	2,62
SHS	60 x 60 x 4	S355J2H	2,00	m	4,40	8,79
RHS	150 x 100 x 8	S355J2H	1,16	m	10,50	12,18
KEY	12 x 8	C45K	0,10	m	2,10	0,21
KEY	14 x 9	C45K	0,10	m	2,90	0,29
ROUND BAR	D60	C45	6,80	m	31,60	214,88
ROUND BAR	D12	S235JR	3,69	m	1,40	5,17
					TOTAL	623,45

Table 13 The cost of fasteners

Material type	Dimensions, mm	Material	Quantity	Unit	Price per unit, €/unit	Cost, €
BOLT	M4 x 30 DIN 933	8.8 ZN	12	pcs	0,06	0,72
BOLT	M6 x 16 DIN 933	8.8 KZN	62	pcs	0,16	9,92
BOLT	M10 x 30 DIN 933	8.8 KZN	4	pcs	0,23	0,92
BOLT	M10 x 45 DIN 933	8.8 KZN	8	pcs	0,29	2,32
BOLT	M12 x 30 DIN 933	8.8 KZN	8	pcs	0,32	2,56
BOLT	M12 x 35 DIN 933	8.8 ZN	4	pcs	0,25	1,00
BOLT	M12 x 50 DIN 933	8.8 KZN	8	pcs	0,41	3,28
BOLT	M12 x 90 DIN 931	8.8 ZN	2	pcs	0,80	1,60
BOLT	M14 x 50 DIN 933	8.8 KZN	64	pcs	0,42	26,88
BOLT	M16 x 45 DIN 933	8.8 KZN	12	pcs	0,75	9,00
EYE BOLT	M20 DIN580	Zn	2	pcs	3,33	6,66
LOCK NUT	M12 DIN985	Zn	6	pcs	0,10	0,60
NUT	M16 DIN934	8 KZN	28	pcs	0,21	5,88
NUT	M20 DIN934	8 ZN	2	pcs	0,27	0,54
NUT	M4 DIN934	8 ZN	12	pcs	0,01	0,12
WASHER	M10 DIN 125	KZn	12	pcs	0,03	0,36
WASHER	M12 DIN 125	KZn	28	pcs	0,05	1,40
WASHER	M14 DIN 125	KZn	64	pcs	0,10	6,40
WASHER	M16 DIN 125	KZn	8	pcs	0,13	1,04
WASHER	M4(DIN 125	Zn	24	pcs	0,01	0,24
SPRING WASHER	M16 DIN127	Zn	12	pcs	0,04	0,48
THREADED BAR	M16 x 130 DIN975	Zn	0,52	m	9,59	4,99
SOCKET SET SCREW	M10 x 20 DIN916	CS	6	pcs	0,14	0,84
SOCKET SET SCREW	M10 x 40 DIN916	CS	12	pcs	0,37	4,44
					TOTAL	**92,19**

Table 14 The cost of ready-made products

Detail	Dimensions, mm	Material	Quantity	Unit	Price per unit, €/unit	Cost, €
CIRCLIP	35 x 1.5, DIN472	CS	4	pcs	0,10	0,40
CIRCLIP	40 x 1.75 DIN471	CS	2	pcs	0,15	0,30
CIRCLIP	50 x 2 DIN471	CS	24	pcs	0,22	5,28
BEARING	Deep Groove Ball Bearing	-	4	pcs	6,5	26,00
BEARING	SKF 6202-2RSH	-	16	pcs	5,58	89,28
BEARING	SKF 62207-2RS1	-	16	pcs	23,3	372,80
BEARING UNIT	4-Bolt Piloted Flange Units	-	2	pcs	7,32	14,64
BEARING UNIT	4-Bolt Piloted Flange Units	-	2	pcs	8,2	16,40
BEARING UNIT	4-Bolt Piloted Flange Units	-	16	pcs	12	192,00
SLIDE BEARING	SKF, DIN 4379	-	8	pcs	17,8	142,40
CHAIN	12B-2 DIN8187	-	2	m	16,2	32,40
GEAR MOTOR	Nord Clincher shaft mount gearmotor	-	2	pcs	739	1478,00
SPROCKET	12B-2 with hub (for chain acc. to DIN 8187)	-	4	pcs	14	56,00
SPROCKET	12B-2 with hub" (for chain acc. to DIN 8187)	-	4	pcs	62	248,00
WHEEL	Drawing No.: W15123.100.02.003	-	8	pcs	35	280,00
ROLLER WHEEL	Drawing No.: W15123.300	-	16	pcs	95,7	1531,20
ECCENTRIC SHAFT	Drawing No.: W15123.100.02.002	-	8	pcs	67	536,00
GREASE NIPPLE	M6 DIN71412-A	CS	8	pcs	0,2	1,60
					TOTAL	**5022,70**

Manufacturing cost

The table below grouped together different working centres operating times and cost.

The detailed tables that every working centre is shown separately are pointed out in section:
Annex 3 – Operation time. The operating rate includes the cost of the equipment, tools cost, labour cost, fixed overhead, maintenance costs and interest rates.

Table 15 Manufacturing cost

Nr	Working center name	Working hours, h	Operating rate* €/h	Operating cost, €
1	Plasma cutting machine	11,05	17,00	187,92
2	Band saw	4,35	14,00	60,97
3	Rolling machine	3,41	20,00	68,12
4	Machining center	17,58	55,00	967,04
5	Welding & assembly	15,80	42,00	663,55
			TOTAL	**1947,60**

Overhead cost

The additional costs are included besides to material and manufacturing costs. These are surface treatment, packing and designing costs. The equipment is used in the same company therefore there is no packing and transportation costs.

Table 16 Overhead costs

NR	Cost item	Cost, €
1	Surface treatment	450,00
2	Packing	0,00
3	Transportation	0,00
4	Designing	4950,00
	TOTAL	**5400,00**

Total cost

The total cost consists all the costs that are related with the rotators. These are raw material, fasteners and ready-made products cost, in addition manufacturing and overhead costs.

Table 17 The cost price of the rollers

NR	Cost item	Cost, €
1	Material	1554,60
2	Fasteners	92,19
3	Ready-made products	5022,70
4	Manufacturing	1947,60
5	Overhead cost	5400,00
	TOTAL	**14017,09**

6 Further developments

The above-mentioned improvement and implementation of the existing rotator is a step forward to maximize the usage of the roller bed and meet the company's needs. Even so, it is still necessary to build a life-scale and fully functioning prototype. One side is the theoretical solution on the paper that fulfils the requirements. The other side is the experience gained from working daily with the equipment. These two aspects could be different and should not be underestimated, as well as testing the equipment with full loads to ensure the safety of the rotator.

The movable roller bracket provides a greater range of different workpiece diameters to work with. At the same time, the wiring is exposed to lacerations. The greatest risk of damaging the wiring comes while moving the roller brackets to the desired position. This situation will be tested with the prototype, and if it turns out that this going to be a problem, then the appropriate measures are taken into action.

The rollers are another possible development. The current solution did not change the roller design, and the width of the roller is kept the same. Increasing the width of the roller decreases the chance that the outer surface of the workpiece will be dented. It also increases the chances that wider rollers could be in the way of the protruding parts.

Optionally, one could investigate further and redesign the rollers to increase the load capacity for heavier tanks. It will be put on the agenda when the need arises.

7 Summary

The aim of this paper is to provide suggestions for improvements of the existing tank rotating equipment. The subject is underscored by the company Estanc AS, which brings attention to the need for the new rotators. The company has expanded rapidly over the past few years, which increased the need for new equipment. The paper is focused more on generating technical solutions to an actual problem from an engineering point of view, rather than design. Despite that, the methods and tools gained through the studies of the D&E curriculum provide the knowledge to identify, define and solve a problem in a structural way.

The first part of the work is focused on the tank manufacturing process and gives a brief overview of the company. The process is taken into pieces and different phases are studied to get the full picture of the manufacturing process. In general, the process is divided into four different phases: Detail preparation, when the materials are cut to the required length, shells are rolled and edge preparation are done; Assembly and welding phase is the core of the tank manufacturing process during which, the tank is assembled together and connections are welded; Inspection phase, when it is important to detect any discrepancy between reality and the required quality; and the final phase, the surface treatment and finishing during which the tank is cleaned, painted if needed, packed, and delivered to the customer.

A deeper look is taken into assembly and welding phase. This phase reveals several steps that must be done before the workpiece can be lowered to the rotators and assembling may begin. Parallel spacing between two rotators must be ensured, as well as the distance between the two rotators, because the slightest misalignment leads to the workpiece overturning from the rotator. Manually adjusting the rotators with the help of the overhead crane is time consuming, and pushing the rotators with lever damages the equipment. One of the bottlenecks in the process is the availability of the overhead crane, which could lead to a loss of time. Also, it is noted that the cylindrical shells get damaged during the assembly and welding phase. The damage is more noticeable on thinner workpieces with bigger diameters. A narrow roller wheel presses the dents into to the outer surface of the shell.

Further steps focused on finding existing solutions available on the current market and analysing their capabilities. Economic and technical aspects of the equipment offered by the enterprise showed that the equipment currently available in the market is unable to fully provide effective solutions. The components that are taken into further development are generated.

The second half of the paper is focused on generating suitable solutions. Three solutions are generated and analysed with the help of the morphological matrix. The temporary on wheels and the independent roller brackets solution is chosen to be examined in greater detail. Furthermore, the wheel motion is studied and strength analyse is done for different components. The wheel solution provides the chance to implement the solution for already-made equipment. The suitable profile and components are selected during this phase.

Finally, economic calculations are done and the cost price is calculated for one set of the rotators – one driver unit and one idler unit.

8 Kokkuvõte

Käesoleva töö eesmärk on pakkuda parandusettepanekuid olemasolevale mahuti pööramise seadmele. Teema on esilekerkinud tulenevalt ettevõtte Estanc AS vajadusest uute pööritajate järgi. Ettevõte on viimase paari aasta jooksul kiiresti arenenud ning kasvanud on vajadus uute seadmete järele. Antud töös on keskendutud tehnilise lahenduse väljatöötamisele olemasolevale probleemile läbi insenertehnilise vaatenurga. Sellest hoolimata on D&E õppekaval omandatud meetodid ja töövahendid andnud teadmised fikseerida, kirjeldada ja lahendada probleemi struktureeritud viisil.

Esimene osa tööst on fokusseeritud mahuti tootmisprotsessist ning ettevõttest ülevaate andmisele. Tootmisprotsess on jagatud osadeks ning erinevaid etappe on uuritud, et omandada täielikku ülevaadet tootmisest. Üldjoontes on protsess jagatud neljaks erinevaks etapiks – Detailide ettevalmistus, milles materjal on lõigatud mõõtu, kestad on valtsitud ning servade faasimine on tehtud; Koostamise-keevitamise etapp on mahuti tootmisprotsessi tuum, milles kestad on koostatud ning ühendused on keevitatud; Toote kontrolli etapis on oluline avastada igasugune erinevus toote nõutud kvaliteedi ning tegelikkuse vahel; Viimane etapp on pinnatöötlus, milles mahuti puhastatakse, vajadusel värvitakse, pakitakse ja toote toimetamine kliendile.

Põhjalikumalt on vaatluse alla võetud koostamise-keevitamise etapp. Selgus, et enne kui kest tõstetakse pööritajate peale ja on võimalik koostama hakata, peab mitu erinevat ettevalmistavat sammu tegema. Kahe või enama pööritaja vahel peab olema tagatud paralleelsus, nagu ka nende omavaheline kaugus. Väiksemgi vastuolu võib viia olukorrani, milles kest pööritajate pealt maha keerab. Sildkraana abiga, mis on ajakulukas meetod, on pööritajad paika seatud. Pööritaja paika seadmisel kasutatakse lisaks ka kangimeetodit, mis kahjustab seadet. Üks kitsaskohtadest on seadme sõltuvus sildkraana kättesaadavuseset, selle hõivatus võib viia tootmisseisakuni. Samuti on täheldatud, et silindrilistele kestadele tekivad mõlgid koostamise-keevitamise etapis. See puudutab rohkem õhukeseseinalisi ja suurema läbimõõduga kestasid, kuna kitsam rull vajutab mõlgi kestapinnale.

Järgnevas osas on vaatluse alla võetud turul olemasolevad tooted ning analüüsitud nende võimekust. Tootjate poolt pakutud seadmete majanduslikud ja tehnilised aspektid näitavad, et ollakse võimetud pakkuma efektiivset lahendust antud probleemile. Edasiarendamisele minevate komponentide nõuete kirjeldus on genereeritud.

Teine pool tööst on fokusseeritud sobivate lahenduste leidmisele. Morfoloogilise maatriksi abiga on genereeritud ning analüüsitud kolme lahendust. Ajutiselt ratastel ning sõltumatu rulliraamid on valitud lahenduseks, millega edasi töötatakse. Ratta süsteemi on uuritud ning tehtud on tugevusarvutused erinevatele komponentidele. Ajutiselt ratastel töötavat lahendust on võimalik ülekanda ka olemasolevatele pööritajatele. Selle etapi tulemusel on sobivad profiilid ning komponendid valitud.

Viimases osas on teostatud majanduslikud arvutused. Toote omahind on arvutatud ühe paari pööritajate jaoks – üks vedav seade ja üks veetav seade.

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