LAB University of Applied Sciences
Lappeenranta
Mechanical Engineering and Production Technology

Pekko Jalkanen

Design of a log barking machine

Bachelor’s thesis 2020

Abstract

Pekko Jalkanen
Design of a log barking machine, 41 pages, 5 appendices
LAB University of Applied Sciences
Lappeenranta
Mechanical Engineering and Production Technology
Bachelor´s Thesis 2020
Instructor: Mr Seppo Toivanen, Principal lecturer

The objective of this bachelor's thesis was to design a log barking machine based on a circular saw used by a tractor. The thesis was done for a sole trader called HKJ Energia in order to improve the profitability of small logs. The machine would utilize the power take-off from a tractor and automatically rotate and do the barking for the entire log. The result should look like it was done by hand.

The design was done by SolidWorks 3D modelling software. Most of the measurements were taken from the existing circular saw at the company, which would be modified into the barking machine. The goal was to make the design mainly from existing parts so that the design would be as cost effective as possible.

The result of this thesis was a design for a log barking machine. The needed aspects in building the machine were considered and the next step would be to build the prototype based on the design.

Keywords: design, product development, log barking

Table of contents

1 Introduction

The goal of this bachelor's thesis is to design a carving machine for a sole trader called HKJ Energia. The machine will be used to take the bark off from the beam sized logs. These kinds of machines already exist in the market, but the goal is to make it cheaper by utilizing the frame of a circular saw. The machine should be simple and built mostly from existing materials. The goal of the design is to be as economical as possible. The thesis focuses on designing the machine so that it can be built later.

HKJ Energia focuses to forest management and has a wide field of services in the industry. The barking machine is one way of expanding and strengthening the business. With the carving of the logs they can be sold for a better price and for different purposes. Now the barking would have to be done by hand and since it is a slow process it is not profitable.

This bachelor's thesis starts with the theory of the barking and the product development processes. After the theoretical part, the design and structure of the machine are analysed. In the design stage, the requirements list is created and the operational demands, including safety aspects are listed. The requirements list is followed during the entire process as closely as possible to match the wishes and demands of the customer. The structure of the machine is designed with SolidWorks 3D modelling software. In the end the solutions and the conclusion of the machine design process are considered.

The goal of the log barking machine product development process is to utilize a circular saw so that it works as the basis of the machine. The circular saw has a similar structure and it is thought to be easy to modify into the desired log barking machine. A frame needs to be designed around the saw where all the needed new parts could be attached.

2 Carving

Carving is a method of barking logs whilst leaving a nice-looking outcome on the tree trunk. Carving is done parallel to the fibres of the tree trunk which makes the result look better than barking any other way. The desired purpose for the carving machine is to improve the price of a beam log which is not thick enough to be made into sawn good or sold as log but still good, for example, for small shelters, warehouses or saunas. The price and usage possibilities for the beams are greater when they are being carved instead of sold as pulpwood. The goal of the log barking machine is to have the same looking outcome that a hand tool have.

During the carving, the bark is taken off from the surface of the logs. Manninen (1989, 16-17) divides the biological structure of a tree’s cross-sectional area into six layers: pith, heartwood, sapwood, cambium, phloem and rhytidome (Figure 1). Rhytidome is the outermost layer and also known as the bark. Cambium and phloem layers can be considered as the inner bark.

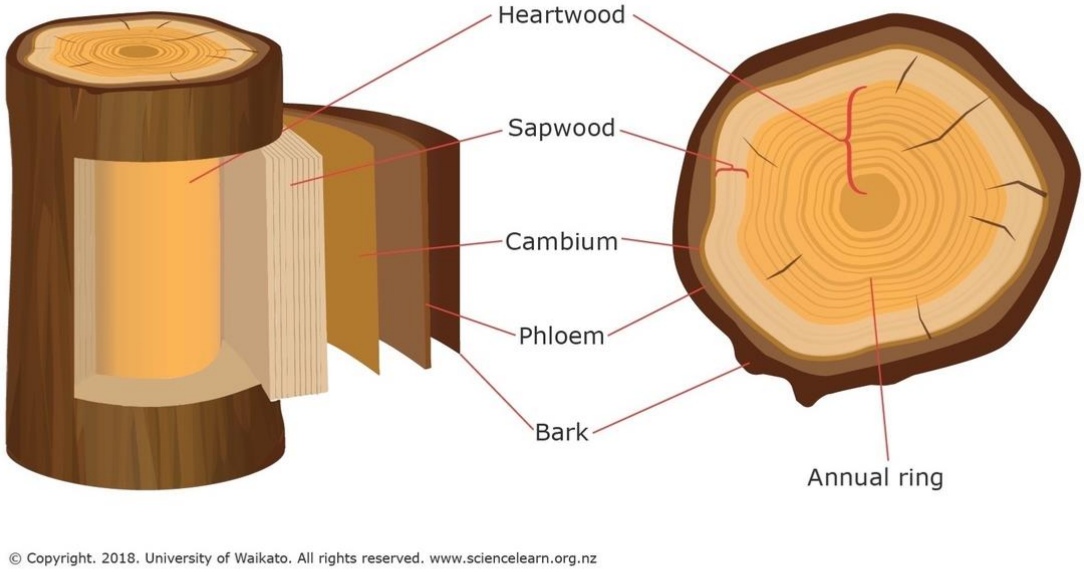


Figure 1. The layers in a tree trunk. (https://www.sciencelearn.org.nz/images/)

Carving of the logs is traditionally done by hand. Bark spuds or drawknife are the most common hand tools for barking. Bark spuds can be used to take off the larger pieces of the rhytidome and the drawknife takes off the cambium and phloem layers leaving the trunk clean (Kärkkäinen 2003). The carving of the logs is a physical task and requires a lot of work to clean the trunks. It is also time consuming and that is why it is not usually worth doing to smaller logs.

In some situations, the bark might get tightly stuck to the trunk and it will be difficult to get the bark off. The bark is easier to remove if the carving is done soon after the tree has been cut down since especially for a spruce trunk the bark gets easily stuck when dry. That is why some electrical hand tools are made to ease the carving. One example is a barking disk attached to an angle grinder or chainsaw (Hiltunen 2017, 16.)

3 Product development process

A successful product development process is one of the most fundamental requirements for a thriving company. The main idea behind the product development process is to develop a new or improved product. The process can consist of various steps including the idea of a new product, sketching, detailed planning and optimizing and improving the production procedure (Figure 2). The product development plan can be divided into four phases: starting, sketching, refinement and finishing. (Jokinen 1991, 9.)

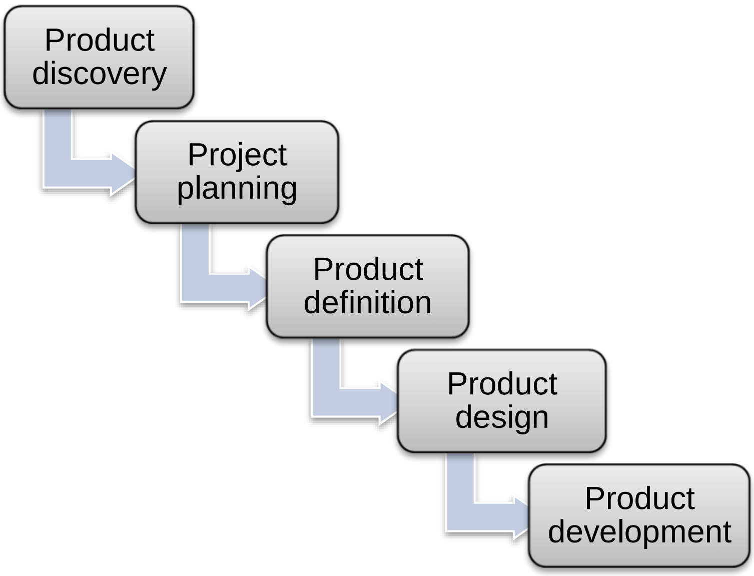


Figure 2. The mechanical design process. (Ullman 2010, 82.)

3.1 Starting

The product development process starts by specifying the desired needs for the machine in the list of requirements as well as the idea of the execution possibilities. The execution properties are important since without them the process cannot start. From project propositions the most suitable one is chosen to be taken into consideration in the sketching. For the success of the company, it is important to focus on the correct and important projects. The development costs, possible revenue and safety issues should be carefully assessed before the final implementation of the product development process. (Jokinen 1991. 14-18.)

During the development process there might be situations which have an affect on the result. For example, in the later stages of the design, the forces affecting the frame might lead to adjustments in the frame structure or material. These changes might result in the final product seeming different than it was during the planning. Unexpected events can be negative or positive and the entire process should be flexible enough to adapt for these changing situations. Even though the coincidences during the product development might produce effective ideas, the process should be well organized and not based on these occasions. (Jokinen 1991, 19.)

According to Jokinen (1991, 20), in order to discover ideas for the product development, explicit information needs to be gathered outside and within the company. The information from outside the company can include for example the market analyses, customers' needs, the product analyses of the competitors as well as the development projections of the technology. The needed information from within the company can include, for instance, the available personnel in the production and their knowledge, available facilities, production capacity and the existing production equipment, possible issues with patents and licenses and the financial possibilities of the company. All these together build the resources for the company's actions.

An improvement idea for a product or a process leads to the development proposition. This proposition should include the description, technical demands, schedule, the available improvement contribution and the financial demands. The company's administration makes the final decision concerning the development and if it is accepted, the sketching phase starts. (Jokinen 1991, 21)

3.2 Sketching

In the sketching phase the alternative choices for the product in development are evaluated. The sketching of a new product starts with analysing the task. The demands and wishes of the development should be decided in the early stages of the project. Sketching includes the main functions and also divides it into subfunctions of the machine. The goal of the sketching is to consider the best possible solutions for the machines functions and then combine the most suitable ones to be taken into further planning. During this phase, the drawings of the machine do not need to be precise, clarifying sketches are acceptable. (Jokinen 1991.)

The main function of the machine consist of multiple different subfunctions. All the alternative choices are evaluated on the basis of the demand criteria. By connecting the best possible options from each of the subfunctions the working principle of the machine should achieve the best possible outcome. The solutions used in the selected main function are evaluated and eliminated before building the final sketch propositions. One of the propositions is then chosen to be used as the final sketch in the development phase. (Jokinen 1991, 22-23.)

Analysis should be done carefully during the beginning of the development project since the development decision does not necessarily include all the information needed in the sketching. During the analysis it is important to try to find a solution to the problem that the development project is trying to solve. Also, the hopes, expectations and limits for the project should be considered.

The development project should not be too precisely instructed at the start since that might affect the problem solving. If the boundaries for the machine development are too strict then innovative ideas might be missed. Most of the required conditions should be figured out during the analysing phase. The required terms should show what kind of properties the final solution needs to have or fulfil and what it should not have. (Jokinen 1991, 24.)

The proposed ideas for the development project should be evaluated on a wide scale with various points of view. Critical thinking in the idea assessment is important since it is difficult to know if all the aspects have been considered. In the end the bad options are eliminated and only the best ones remain. The best ideas then form the solution of how the project is continued.

The sketching phase ends in the evaluation and selection of the most suitable option, which is then designed in detail. During this phase the machine is evaluated according to its operational demands, functions, structure and safety. Different options are compared in a chart to see what is the most beneficial to be used in the end. A weighted point table is done at the end of the sketching from the presented ideas for the machine.

3.3 Development

One of the options from sketching phase is used in the further development of the machine. The structure is evaluated more carefully in order to make a specific drawing of the model. If any problems occur with the model at this point, it is easier to make changes to the structure or to the design. If unsolvable obstacles occur during development, other options should be taken into consideration.

The goal of the development phase is to design the product in such detail that there is no chance of misunderstanding in the finishing phase. The selected sketch from the sketching phase is refined in order to be built or manufactured as a final product. During the sketching, precise drawings were not yet drawn, and the development phase starts by making the selected structure drawings to scale. (Jokinen 1991, 92.)

The sketched design is evaluated by its financial and technical properties. The evaluation will show the possible weaknesses of the design which can be fixed before the finishing phase of the process. If weaknesses occur, the elimination happen by introducing new possible ideas for that function and designing those parts again. The modified and improved structure is then evaluated again and if it is approved, the development phase can continue to optimizing the details. After the structure is analysed by its reliability it will be approved into the finishing phase. (Jokinen 1991, 92-98.)

3.4 Finishing

The last step on the product development process is finishing. All the drawings and instructions needed to build and operate the machine are done during this phase. The manufacturing methods and raw materials should be decided according to the requirements. After everything is in order the building of the machine can begin with a prototype or a test specimen. The prototype can be used as a way of figuring out the financial and technical properties. (Jokinen 1991, 99-102.)

The first stage in the finishing is to finalize the details and drawings of the machine. The manufacturing methods for the needed parts are chosen if they are not available beforehand. Also, the part lists, assembly figures and all the instructions are checked and finished. The last steps are to design, manufacture and test the prototype which in the best case will lead to the production of the machine. (Jokinen 1991, 99-100.)

The use of modern computer aided design programs makes the finishing part much easier. The documentations, details and drawings are easier to finish with the help of 3D modelling software. The details and measurements are also easy to adjust and measure later on the basis of the designed model.

4 Design of the log barking machine

The machine is first designed on paper by hand in order to get an impression of the structure. After the idea is clear the machine is built with SolidWorks 3D modelling software. With the software, the prototype can be modified before the actual manufacturing of the machine. The structure of the machine is easier to comprehend when it is done with modelling software and that also improves the co-operation with the designer, customer and manufacturer.

There are several advantages of 3D computer aided design (CAD) in the product development process. One of the biggest is that it makes the design process much faster. It also reduces the mistakes in the design which results in less delays in the production and manufacturing. The changes in the design are much easier to control with the help of the software and it also makes it possible to use the data already created. Also, the visualisation of the machine is much easier with the software. (Laakko, Sukuvaara, Borgman, Simolin, Björkstrand, Konkola, Tuomi, Kaikonen 1998, 33.)

The reduction of design mistakes is one of the many advantages of the 3D modelling. The software is carefully specified, and it does not allow the user to build impossible shapes or structures. The drawings are also automatically updated if changes are made into the original model. The entire product development process is more proficient, less time consuming and better meets the customers needs. (Laakko et al. 1998, 32-34.)

At the start of the product development process, it is important to recognize, understand and clarify the demands and limitations for the new product. The machine design demands should at least deal with manufacturing, maintenance, assembly and costs of the process. It is necessary to understand the difference between wishes and demands. The demands need to be taken into consideration and the wishes are additional benefits for the design. If they can be observed, it is positive, but the design should not focus on those. List of requirements should be done with the customer in order to set the demands and wishes for the project.

The list of requirements confirm that the machine works the way it was designed. Some of the demands must be fulfilled and are considered as the minimum requirements for the design. For example, the safe operation of the machine is a minimum technical requirement and it needs to be closely monitored.

4.1 List of requirements

The design process of the log barking machine starts with and follows the list of requirements. During the design process there might be some changes and adjustments to the list. In the following table 1 is the list of requirements, which was created with the customer in order to recognize the demands and wishes of the project.

Demand Wish	Requirements
	1. Geometry
W	Length = 1000 - 2000 mm
D	Width = max. 1700 mm
W	Height = 800 - 1600 mm
D	Operational height = 800 - 1000 mm
D	Connection to a three-point hitch in a tractor
D	Side supports for logs
	2. Operation
D	The length of the log = 1500 - 6700 mm
D	The diameter of the log = 100 - 150 mm
W	Fast operation
D	Adjustable weight for the log
D	Ensure the position of the log
D	Automatically do the barking of the log
W	Time to make operative < 1 min.
	3. Forces
D	Weight of the log = min. 150 kg
W	Weight of the log 200 - 300 kg
	4. Power
D	Powered by a tractor
D	Moved by a tractor
	5. Material
W	Exploit existing materials
W	Rust protection
D	Frame built from steel
D	Temperature range = -20 - +30 °C
D	Circular saw for the base of the machine
W	Casing from thin metal plate
D	Bearings with high rating life
	6. Assembly

D	Welded joints for the frame
D	Bolts for the casing
W	Adjusting the machine mainly without tools
W	Small number of total parts
	7. Safety
D	Safe to operate the machine
D	Safety bars
D	Casing for the blades
D	Safe removal of created waste
	8. Maintenance
W	High maintenance interval
W	Ease of maintenance

Table 1. List of requirements

The desired size for which the machine is being designed is a beam wood with a diameter between 100 mm and 150 mm. Usually the beam wood refers to the thickness of the canopy in a tree and can be called a light log. If the diameter in a canopy is less than 150 mm it is not counted as a log anymore and the price drops down (Kaihlanen 2016). When the diameter is less than 100 mm there is no financial benefit for the carving, and they are sold as pulpwood (Figure 3).

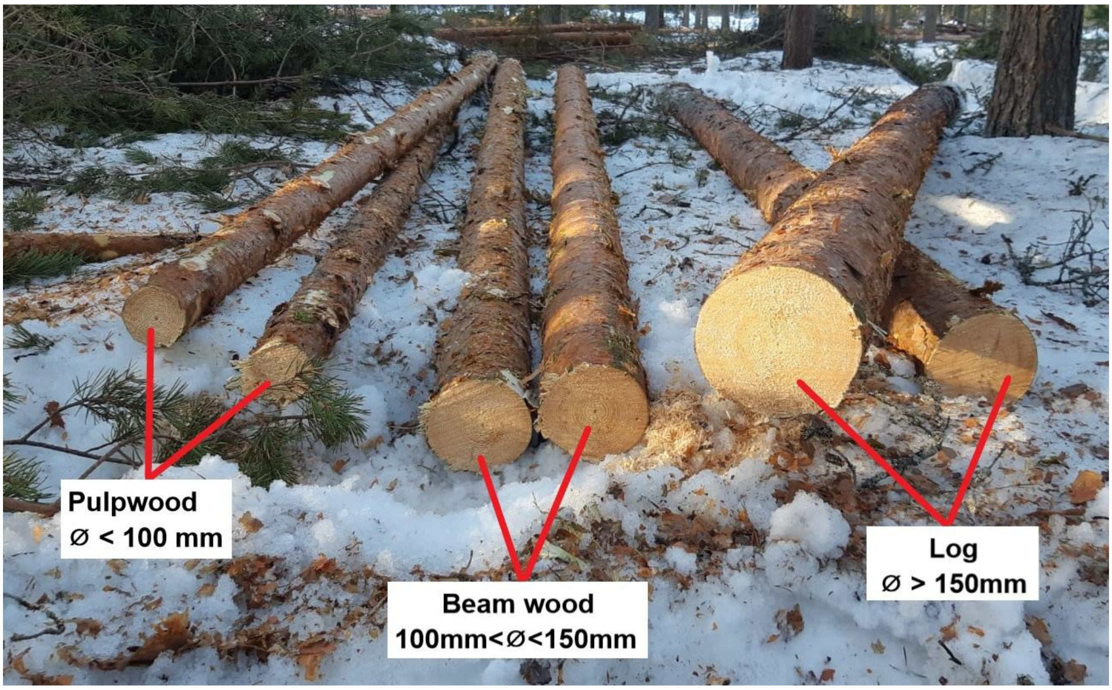


Figure 3. Log sizes.

The maximum diameter for the beam woods used in the machine is estimated to be a little bit over 150 mm since that is the minimum diameter for a log. With small adjustments it might be possible to do the carving for a slightly bigger logs. It is estimated, that the same operational principle does not work well without changes if the logs get too heavy. It could be designed for larger logs as well, but the sawn goods made from them already have good enough quality-price ratio.

There is no need to limit the length of the log since there needs to be supports on each side of the machine so that they support the log before and after the barking. The only limiting factor is the weight of the log since they need to be lifted into the machine by hand.

Figure 4. Circular saw used for the log barking machine.

One demand for the machine structure is that it needs to be as economical as possible. That is why the frame of the machine is modified from a circular saw (Figure 4), which is already available at the company. The frame needs small alterations, but it is thought to be rather simple to modify into shape since the operating principle is almost the same.

4.2 Barking plate

The design of the machine is constructed on the basis of a circular saw frame and the blades that resemble an angle grinder barking wheel (Figure 5) but built on a larger scale. The saw blade of the circular saw is changed to on occasion designed barking plate which should function on the same bearings as well since the force towards the bearing is not increasing (Energiansäästö Oy). The diameter of the plate is designed to be slightly smaller since there is no need for it to be too big. The diameter for the barking plate will be 500 mm whereas the common size for the saw plate is between 500 mm – 700 mm. The casing for the plate needs to be built again anyway so the smaller size does not cause a problem.

Figure 5. Angle grinder with attached barking wheel. (https://www.uittokalusto.fi)

For safety reasons the barking plate should be bought instead of manufactured personally, which was the goal in the beginning. It is rotating at high speeds and there is no margin for errors during usage. If the blades, or even small pieces of them would come loose while it is being used or malfunction in any other way, it could be extremely dangerous for people next to the machine.

The barking plate consist of four tempered and sharpened barking blades which can also be sharpened again. The thickness of the plate is 15 mm and according to the manufacturer it should fit to the bearing of the circular saw (Energiansäästö Oy). The advantage of buying the barking plate straight from the retailer ensures that the barking plate works properly and without need for huge adjustments.

The blades are attached so that when the bark comes off it is driven through a hole to the backside of the plate. From there, the waste is immediately blown out through a tube. The rotational movement of the plate and the wings on the back side throw away the bark and keep the machine clean. The blades are distributed equally on the radius around the plate and located closer to the circumference. During operation, the plate is rotating clockwise in relation to the power take-off from the tractor which causes the barking direction also to be from left to right.

4.3 Subfunctions

The main function of the machine is to do the barking for the log. The barking needs to be done with blades on some level since the desired quality for the end results requires it. That is why the barking plate does not cause a problem in design since there are not many options for that. The blade carving method resembles the exact same result that hand tools previously achieved. The adjustment of the blades on the other hand is thought to be more challenging.

In order to achieve the most suitable structure, the product development process evaluates the machine design by dividing its operational demands into subfunctions. The subfunctions are compared in the following table 2, and the most suitable ones were chosen to be used in the further design process. For each subfunction, the best option is written in bold and together they form the most suitable combination for the machine.

Subfunction	Subfunction options		
Log positioning	Sloped table	**Threaded rod**	Springs
Log stabilization force	Constant	**Adjustable**	
Frame material	**Steel (S355)**	Wood	Stainless steel
Frame profile	50x50x4 RHS	**60x100x4 RHS**	60x120x4 RHS
Power	**Tractor PTO**	Tractor hydraulics	Electricity
Side supports	Fixed	**Adjustable**	
Waste removal	Up and behind	**To the side**	

Drivetrain	Axel	Belt	**Both**
Safety bars	Up	Down	**Both**

Table 2. Subfunctions

4.4 Evaluation of subfunctions

For the secure positioning of the log, a threaded rod will be attached to the middle of the barking plate. It was considered to be the simplest yet effective way to keep the log against the barking plate. It does not force the log against the blades too heavily and allows the log to move a little bit more freely. The rod would be supported by bearing from the end.

It was also thought that the design needs an external force to keep the log against the blades in addition to the threaded rod. The most suitable option for that was an adjustable force, which could be changed according to the size of the logs.

The machine needs to be safe, so the structure needs to be robust and stiff. The best option for the frame in this case was steel (s355) since it has the best properties to be used under heavy loads and it is easy to customise. The best estimated frame profile would be a 60x100x4mm rectangular hollow section pipe.

In this product development process, most of the problems for subfunctions are solved since the machine is designed to be operated by a tractor. It will provide the power for the machine, control the speed and move the machine. The cardan shaft used from the tractors power take-off will be connected to the machine through belt transmission.

The best solution for the side supports was thought to be adjustable supports. They should be adjusted so that the log always stays horizontal. That ensures that the barking is not affected by uneven grounds. Also, the safe operation of the machine was a demand in the list of requirements and that is why safety bars on upper and lower part of the machine were thought to be necessary. The safety bars should be designed so that the machine operator does not accidentally reach the barking plate during operation.

4.5 Weighted point table

The machine properties are evaluated in the weighted point table on how important they are in the result. The criteria are weighted between each other so that the combined result is one. After the weighing has been done, all the features in each option are evaluated by points on how they fit to the requirements. The scale for the points is from 0 to 4, with the former being a fail and the latter being ideal. The weighed points are calculated by multiplying the weight value of the criteria with the points. The option with the most points is then taken into further development. (Jokinen 1991, 80-83.)

In table 3, the three different solutions for the machine design were evaluated with weighted points table. Option number one had the most points and weighted points as well. This indicates that the first option would be the most suitable one for the design. Even though it got most points, the sum for the points does not always show the best solution if the bad results are not observed with necessary consideration (Jokinen 1991, 81).

Criteria	Weight	Option 1			Option 2			Option 3		
		Feature	Points	Weighted points	Feature	Points	Weighted points	Feature	Points	Weighted points
Manufacturing	0,15	Easy	4	0,6	Difficult	2	0,3	Average	3	0,45
Assembly	0,15	Average	2	0,3	Difficult	2	0,3	Easy	3	0,45
Safety	0,10	Good	2	0,2	Good	2	0,2	Good	2	0,2
Maintenance	0,15	Small	3	0,45	Average	2	0,3	Small	3	0,45
Cost	0,35	2000	4	1,4	7000	1	0,35	4000	3	1,05
Number of parts	0,10	Small	3	0,3	Great	1	0,1	Small	2	0,2
Total	1		18	3,25		10	1,55		16	2,8

Table 3. Weighted point table.

The criteria chosen for the weighted point table were considered the most important ones in order to design a simple yet working machine. Manufacturing, assembly and maintenance of the machine should be as simple as possible and easy to put into practise, which is why they got the weighted value of 0,15 each. The safety and number of parts were almost as important and consist mostly from demands in the list of requirements, which is why they were valued at 0,10 each. In this design process the cost was the biggest and the most important factor, since the machine should be as cheap as possible. That is why its weighted value was 0,35.

In the machine design two basic structures were considered as the design of the machine. Option number one was a machine with a rotating plate on only one side with blades attached to it, the same way there is only one saw plate in circular saw. It would use the same functionality in the barking as in the angle grinders barking wheel, but on a larger scale. Option number two had rotating roller blades assembled in a circular pattern and the log going through it. The option number three was just slightly modified from the first option.

Option number one has the great advantage for being the cheapest one to manufacture. The third option was almost as good, but the downside was the two times higher cost evaluation. Option number three had the same working principle but the logs would be at a 90 degrees angle in comparison to the first one. The third option would have also probably been wider than the tractor connected to it, so it would have been difficult to transport on public roads. The second option scored least points since it was the most difficult and expensive one to manufacture. It can be left out from future considerations for the machine design.

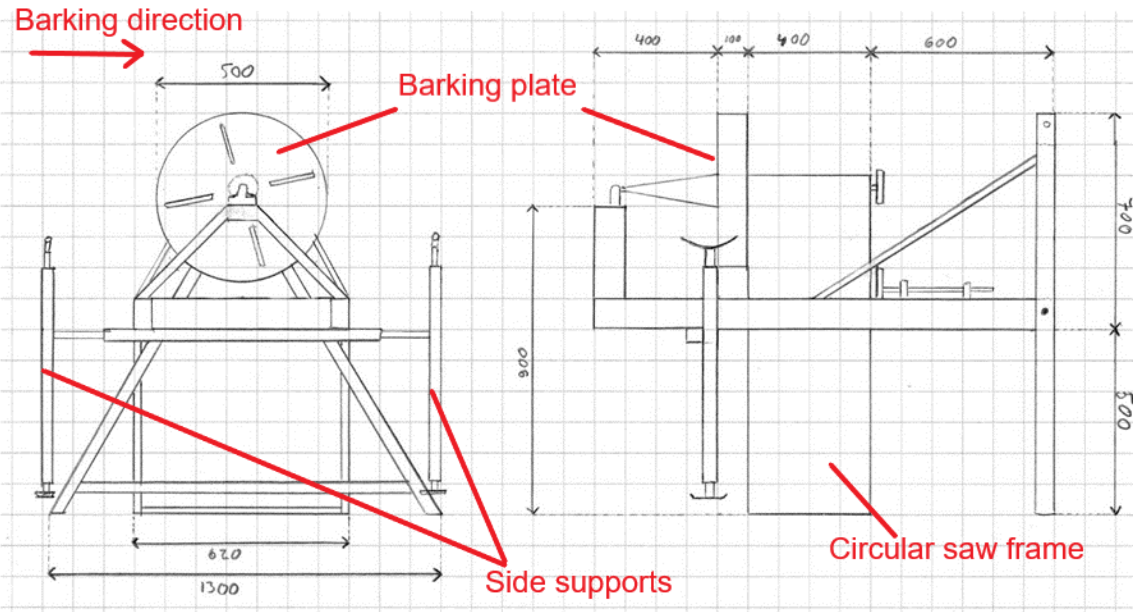


Figure 6. Option number 1.

In the figure 6 is the option number 1 and the first sketched drawing of the machine with the desired measurements. The working principle is to automatically rotate and move the log from left to right while taking off the bark. The blades which cut off the bark and rotate on a plate should cause the log to turn and move automatically. This process could be adjusted by changing the speed of the blades and the force which the log is pressed against the blades.

4.6 Power source

The power source for the machine is going to be a tractor which is also going to be used in transportation. The machine will be designed so that it is connected to the three-point hitch in the back of a tractor. The hydraulic cylinders attached to the hitch arms will then be used to lift or tilt the machine. When the machine is safely connected to the tractor it is easy to move and easy to power up. The power take-off from tractor will be used in order to rotate the barking plate. The cardan shaft is connected to the power take-off which will then power the machine (Figure 7).

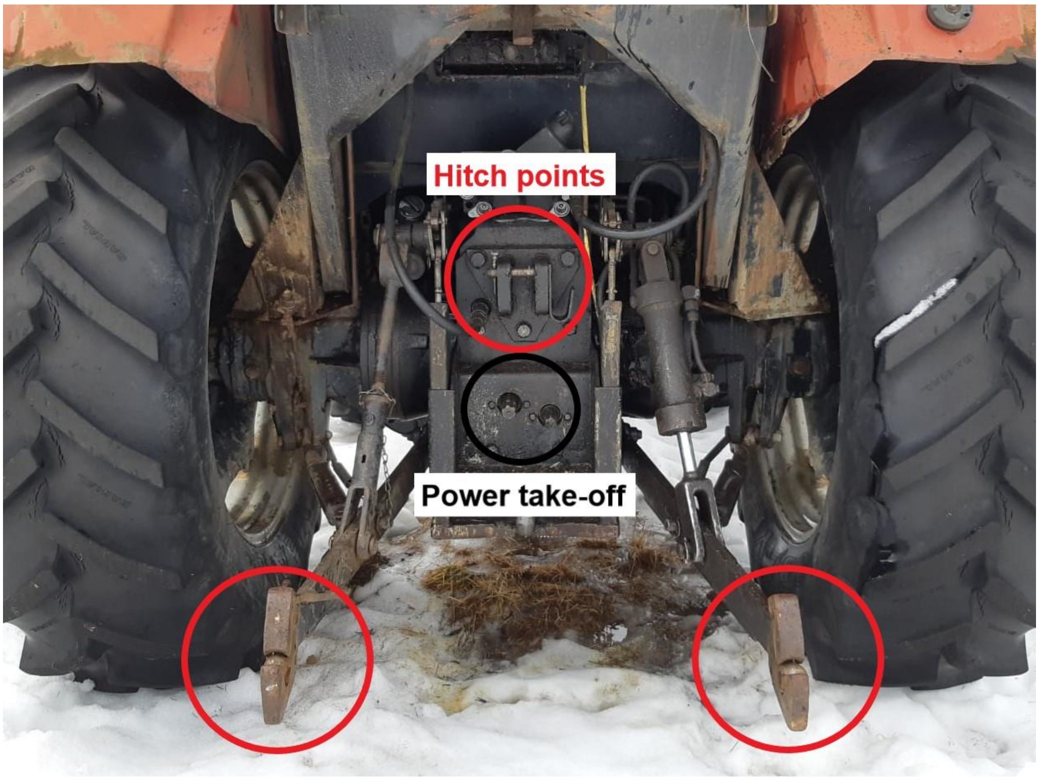


Figure 7. Three-point hitch and power take-off in a tractor.

The cardan shaft which transmits the power to the machine will be similar as what is used in a circular saw powered by a tractor. There are no large forces to the axel in the machine, so a smaller axel works well. One suitable option would be 1 3/8 inches thick axel suitable for small machines run by a tractor (ikh.fi).

The most common rotation speeds from a tractor PTO's are 540 and 1000 rounds per minute (rpm). These speeds are often adjusted so that they fit to the maximum torque from the tractor's engine (Vesterinen 2018). An efficient ratio between the rpm of the tractor output and the machine is estimated to be 1:2, which makes the speed of the barking plate around 500 rpm when the higher output is used. This ratio is automatically achieved by the belt transmission from the cardan shaft when the belt pulleys diameters are 100 mm and 200 mm. The final operating speed is adjusted by changing the tractor engines rpm.

4.7 Safety

Safety in the machine design needs to be considered and it is one of the minimum requirements in the process. Even though this machine is designed for personal use only, the safety aspects are still part of the product development. The design is aiming to be as safe as possible and fulfil the requirements set in the Finnish legislation on occupational safety and the safety of machinery.

The dangers of a machine should be examined before the machine is taken into use. The moving parts, machine properties and structural hazards should be carefully assessed beforehand. If any risks occur, they should be immediately repaired. The risks should be eliminated, if possible, by changing the design or structure and if that is not effective the needed protective covers should be installed. If the risks cannot be excluded, the last option is to use warnings, instructions and training on how to use the machine safely. (Occupational Safety 2017)

In this machine it is impossible to completely remove the safety hazards caused by the blades which then requires protective covers to be used in the machine. The Finnish Occupational Safety and Health Act lists the following requirements for covers (Finlex 2008):

- structure is strong
- does not cause additional danger

- is not easy to remove or made inoperative
- located far enough from the danger zone
- does not unnecessarily restrict the visibility to the working area.

These are the aspects that are taken into consideration when designing the covers for the machine. The biggest concern is to hide the barking blades so that there is no risk for accident but maintains easy operation of the machine. An extra safety gear is recommended during the usage of the machine since all the dangers and downsides cannot be completely excluded. The barking plate rotates fast and it might cause small pieces of wood or bark to fly from the machine and cause a danger. That is why safety glasses should be used when standing near the machine to protect eyes. Operating the machine might make rather loud noise together with the tractor, so a pair of earmuffs are also recommended to protect hearing.

5 Structure

The machine design had some limitations which had to be taken into consideration during the process so that the machine would fulfil the customers' needs. One of the biggest requirements for the machine design was to be as cheap as possible to manufacture. It should exploit the circular saw as widely as possible in order to reduce the costs. The following requirements were the ones that had the biggest affect on the structure of the machine:

- The diameter of the barked log approx. 100 mm – 150 mm.
- The length of the log 3100 mm – 6700 mm.
- The minimum supporting weight around 150 kg.
- Powered by tractor.
- Moved by tractor.
- Utilize the circular saw frame.

5.1 3D model

In the following figure 8 is the 3D model of the machine. It was designed with SolidWorks modelling software and it should include all the needed aspects for building the machine. The measurements can be found in the attachments at the end of the thesis.

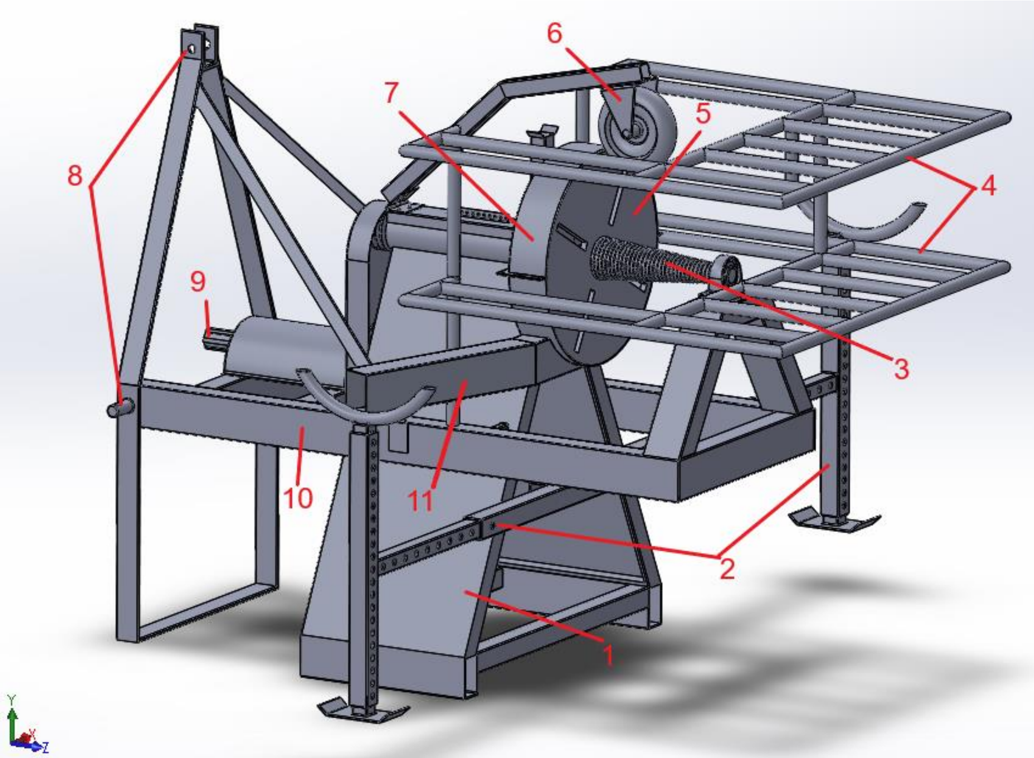


Figure 8. 3D model.

The log barking machine can be divided into the following parts:

1) An old circular saw is the basis of the machine. The circular saw is welded onto the frame.
2) Supports for logs are welded on both sides below the frame of the machine. The supports are built from steel bars and their length and height can be adjusted depending on the ground and the length of the logs.
3) A threaded rod should be connected to the middle of the barking plate so that the threads are pushing towards the plate when it rotates. This makes sure that the log is all the time pushed against the blades.
4) Safety bars are welded from steel pipe and they also guide the logs on to the threaded rod. The safety bars ensure that the logs do not get in touch with the blades in wrong position.

5) The barking plate with 4 blades. The plate rotates clockwise and thus the movement of the logs is from left to right.
6) An adjustable weight is on top of the machine, which pushes the log down slightly. A wheel is pressing towards the log to ensure that the weight does not affect the turning of the logs during barking. The weight can be adjusted by springs in order to stabilize the movement of the logs.
7) A casing is built into the back side of the barking plate. The casing is welded and bent from thin metal sheet which can then be bolted into the frame. The casing should be removable in case the bark gets jammed behind the plate.
8) The three-point connection of the machine to the tractor is gotten straight from the circular saw. It needs to be turned 90 degrees and then welded to the new frame.
9) The power take-off (PTO) from tractor is connected to the axel in the machine, which will then rotate the barking plate via belt transmission.
10) The frame is constructed mainly from the 60x100x4 mm RHS pipe. The frame is built around the circular saw so that all the additional parts can be added to the machine.
11) The waste removal pipe. Air flow created by the rotating barking plate should push the waste out from inside the casing.

There are three similar bearing units used in the model of the machine. One is at the end of the threaded rod supporting the axel which is connected to the barking plate. Two other units are under the cover supporting the power take-off axel (9) from the tractor. Also, the belt pulleys which transmit the force to the machine are under the cover to keep them clean and safe.

The width of the frame is also considered during the design process. The machine might be transported on public roads and it will be easier if the basic width is not too wide. It is important that during the transportation the supports for the logs can be pushed out of the way in order to make the overall span smaller. According to tractor manufacturer John Deere, their most popular small tractors are the 5M series. The width for those start from 1723 mm depending on the chosen tires and that can be considered the limit for the design in order to make the machine more practical.

5.2 Part list

The manufacturing of the machine consist of pre-owned parts and purchased raw materials and parts. The following table 4 is an estimation made from the costs of the project according to the 3D model and other requirements. The list does not take into consideration the money needed during the manufacturing, for example the working hours and the welding equipment. Most of the prices were gotten from ikh.fi website which has a wide catalogue of needed materials.

Part	Quantity (pcs.)	Price (Eur)
Ball bearing block unit, UCP 206 (laaker-inetti.com)	3	32,55
50X50X4X2000 RHS pipe (ikh.fi)	2	42,00
40X40X4X2000 RHS pipe (ikh.fi)	2	32,50
60X100X4X2000 RHS pipe (ikh.fi)	2	69,90
Belt pulley A100/2/1610 (ikh.fi)	1	22,00
Belt pulley A200/2/2517 (ikh.fi)	1	71,00
Trapezoidal belt (ikh.fi)	1	17,50
5X50X2000 steel bar (ikh.fi)	1	8,60
30X1,5X2000 pipe (ikh.fi)	9	9,90
Barking plate (Energiansäästö OY)	1	1600,00
Cardan shaft B101 1.3/8-6 (ikh.fi)	1	83,00
	Total	**2277,65**

Table 4. Part list.

The cost estimation for the machine in the weighted point table (Table 3) was thought to be 2000 euros. According to this calculation the total amount of

2277,65 euros does not exceed that too badly. The total price might vary to one way or another during the manufacturing. For example, if the parts can be purchased for tax free price, the sum would be less than the estimated but there might also be additional expenses during the project.

5.3 Calculations

The weight of the logs varies depending on the species of the wood and the moisture inside the log. The density of a tree reduces when moving towards the canopy, but the maximum weight is still calculated with the maximum density. The most common trees in construction are spruce and pine (Puuinfo).

The density of spruce varies between 300 – 640 kg/m^3 and pine between 300 – 860 kg/m^3 (Isomäki, Koponen, Nummela, Suomi-Lindberg 2002, 19). The length of the log can vary between 3100 – 6700 mm depending on the thickness of the canopy (Varis 2017, 42). When the maximum diameter is 150 mm, the volume (V) and the mass (m) of the log can be calculated with following formulas 1 and 2 (Valtanen 2013).

$$V = \pi R^2 h \quad (1)$$

$$V_{max} = \pi * 0{,}075\ m^2 * 6{,}70\ m \approx 0{,}12\ m^3$$

When the maximum volume of the log is calculated, the maximum mass is calculated by multiplying the volume with the highest density. This is the minimum weight the frame of the machine needs to carry.

$$\rho = \frac{m}{V} \rightarrow m = \rho * V \quad (2)$$

$$m_{max} = 860 \frac{kg}{m^3} * 0{,}12\ m^3 \approx 103\ kg$$

At one point of the barking, the entire weight of the log might be affecting on the bearing at the end of the threaded rod. When calculating the bearing rating life, the estimated weight of the log can be doubled just to be certain that the bearing is long-lasting. The bearing rating life at 90% reliability can be calculated with the following formulas, when the desired bearing type UC206 is used (skf.com).

$$L_{10} = \left(\frac{C}{P}\right)^{p} \quad (3)$$

L_{10} is the basic rating life in millions of revolutions. The basic dynamic load rating value C is gotten from the SKF catalogue. P is the equivalent dynamic bearing load and p is the exponent of the life equation. In this case the weight affecting the bearing is 2 kN. Since ball bearings are used, the p value is 3.

$$L_{10} = \left(\frac{19.5\ kN}{2\ kN}\right)^{3} = 926{,}9$$

The bearing operating hours L_{10h} is calculated with the following formula. The n value is the revolutions per minute that the machine would be running, which in this case is maximum of 1000 rpm.

$$L_{10h} = \left(\frac{10^6}{60n}\right) L_{10} \quad (4)$$

$$L_{10h} = \left(\frac{10^6}{60*1000}\right) * 926{,}9 \approx 15\ 500\ h$$

According to these calculations the operating hours for the desired bearing would be over 15 000 hours, which is thought to be adequate in this kind of machinery. The American Roller Bearing Company estimates, that when the operation of the machine is intermittent and the reliability is important, 12 000 hours of bearing life is recommended. The bearing is also easy to replace if it breaks down so this bearing will be used in the machine.

In this machine, the biggest force affects in the support bars of the frame during the transportation of the machine. To find out the stress, the estimated weight of the machine is calculated and then the forces are calculated in a free body diagram (FBD). The weight and forces are calculated with values from Lujuusoppi textbook (Karhunen, Lassila, Pyy, Ranta, Räsänen, Saikkonen, Suosara 1992). The weights are multiplied with 9,81 m/s^2 to have the results in newtons. The weight of the circular saw is approximately 150 kg (1471 N).

The frame is constructed from the 60x100x4 mm RHS pipe and it is needed 4600 mm. The cross-sectional area for that pipe is 1175 mm^{2} and density of steel is approximately 7850 kg/m^{3}. This force can be thought affecting in the middle of the machine.

$$1175\ mm^2 * 4600\ mm \approx 5{,}405\ * 10^{-3} m^3$$

$$5{,}405\ * 10^{-3} m^3 * 7850 \frac{kg}{m^3} = 42{,}4\ kg \approx 416\ N$$

The safety bars are built from 30x1,5 mm pipe with the cross-sectional area of 134,3 mm^{2} and the total length is around 17 000 mm. This force is affecting at the end of the frame.

$$134{,}4\ mm^2 * 17\ 000\ mm\ \approx 2{,}2848\ * 10^{-3}\ m^3$$

$$2{,}2848\ * 10^{-3}\ m^3 *\ 7850 \frac{kg}{m^3} = 17{,}9\ kg\ \approx 176\ N$$

The supports for logs are built from 50x50x4 mm RHS pipe which is needed 1300 mm and from 40x40x4 mm RHS pipe which is needed 3180 mm. The cross-sectional areas are 695 mm^{2} and 535 mm^{2}.

$$695\ mm^2 * 1300\ mm\ \approx 0{,}9035 * 10^{-3} m^3$$

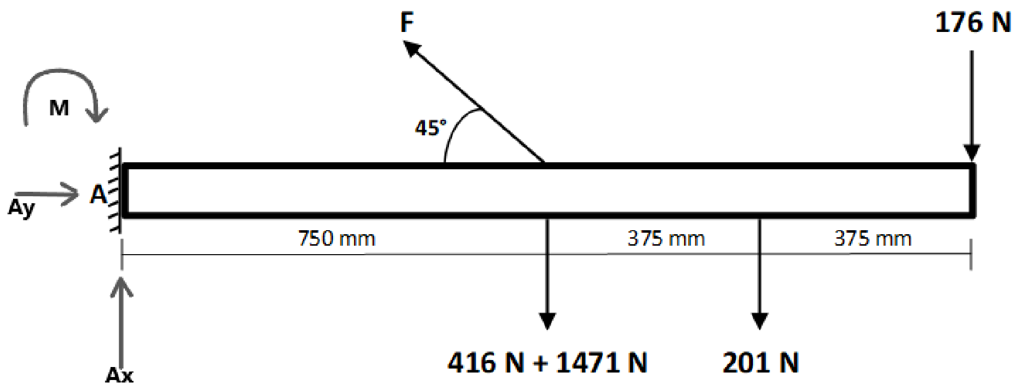
$$0{,}9035 * 10^{-3} m^3 *\ 7850 \frac{kg}{m^3}\ = 7{,}1\ kg\ \approx 70\ N$$

$$535\ mm^2 * 3180\ mm\ \approx 1{,}7013 * 10^{-3}\ m^3$$

$$1{,}7013 * 10^{-3}\ m^3 *\ 7850 \frac{kg}{m^3}\ = 13{,}4\ kg\ \approx 131\ N$$

$$70\ N +\ 131\ N = 201\ N$$

The free body diagram of the frame is used to find the stress in the bars. The F value is solved by calculating the moment around point A. There are two steel bars supporting the weight so the total force is divided by two at the end.



$$\sum M_A = 0 \qquad (5)$$

$$M_A = 0{,}75\ m * F * \sin 45° - 0{,}75\ m * 1887\ N - 1{,}125\ m * 201\ N - 1{,}5\ m * 176\ N = 0$$

$$F_{total} = \frac{0{,}75\ m*1887\ N + 1{,}125\ m*201\ N + 1{,}5\ m*176\ N}{0{,}75\ m*\sin 45°} \approx 3590\ N$$

$$F = \frac{3590\ N}{2} \approx 1800\ N$$

The stress (σ) in the supporting bars is calculated with the following formula (6). N is the force affecting the bar and A is the cross-sectional area. The profile used is 5x50 mm steel bar.

$$\sigma = \frac{N}{A} \qquad (6)$$

$$\sigma = \frac{1800\ N}{0{,}005*0{,}05\ m^2} = 7{,}2\ MPa$$

As the stress in the bar is much less than the yield strength in steel (355 MPa), the following Hooke's law (7) can be used. The young's modulus (E) for steel is 210 GPa.

$$\varepsilon = \frac{\sigma}{E} \qquad (7)$$

$$\varepsilon = \frac{7{,}2*10^6\ Pa}{210*10^9\ Pa} = 3{,}43 * 10^{-5}$$

The length transformation is calculated with the formula 8. The length of the supporting bar (L) is 1100 mm.

$$\Delta L = \varepsilon L \qquad (8)$$

$$\Delta L = 3{,}43 * 10^{-5} * 1100\, mm = 0{,}038\, mm$$

The bars are welded onto the frame with normal fillet weld. The shear stress in the weld shows how well it will hold the force affecting the weld. The thickness of the weld (a) is thought to be 3 mm and the length of the weld (L) 40 mm. The force (F), which applies to each of the bars is 1800 N.

$$\tau = \frac{F}{2*a*L} \qquad (9)$$

$$\tau = \frac{1800\, N}{2*3mm*40mm} = 7{,}5\, MPa$$

The shear stress is fairly small so the structure is thought to be strong also in the welded part of the machine.

The maximum bending at the right end of the frame is calculated with the formula 10. In the formula, F is the resulting force at the end, L is the length to the supporting legs, E is the young's modulus and I is the moment of inertia of the frame profile.

$$\delta = \frac{FL}{3EI} \qquad (10)$$

$$\delta = \frac{276{,}5\, N*750mm}{3*210\,000\, N/mm^2*1{,}6*10^6 mm^4} = 2{,}06 * 10^{-7} mm = 0{,}2\, \mu mm$$

Since the transformation is extremely small, it can be assumed that the structural material and profile is strong and adequate for the frame.

5.4 Assembly

The structural material was chosen to be steel S355 so that the frame is robust, stiff and easy to modify. The steel works well since the assembly is done mostly by welding. The welding might cause some reformations in the structure and those should be taken into consideration in the measurements. The frame should be assembled by short welds first in order to get the correct measurements.

The frame, the circular saw basis and the side supports for logs are all welded together. The side supports have multiple holes in the RHS pipes and are constructed so that they move inside each other. The suitable position is then locked in by pins. The same way they will be adjusted both horizontal and vertical direction. The safety bars are also welded together but they are then connected into the frame by bolts so that they can be removed if neccesary.

There are two structures made from sheet metals, the body of the barking plate casing and the cover for the bearings and belt pulleys. They are both bent and welded in form and then connected to the machine by bolts so that they are easy to remove, if maintenance is needed for the barking blades or the bearings.

When all the welds are done, the machine should be painted in order to avoid rust formation in any parts of the machine. The machine is designed to be operative in basically every environment, and that might make it vulnerable for rust.

5.5 Quality control

The quality of the carving is adjusted mainly by changing the speed of the plate. This is done by simply increasing or decreasing the rpm from the tractor. It is difficult to say beforehand what would be the optimum speed and that must be tested in practise. Depending on how tightly the bark has dried onto the log or what species of tree is being barked the speed might differ a lot. According to the barking plate manufacturer the maximum speed would be around 700 rpm.

One option is to adjust the weight pushing the log towards the barking blades. The weight is created by springs and there are multiple points for them to be attached depending on the force required. It is important that the adjustment is simple and fast since the weight might have bigger effect on different logs. If bark is left on the tree trunk the weight can be slightly increased and vice versa. The function of the weight is to keep the log against the blades and the goal is not to push it too much since it would increase the wear and tear in the blades. Most of the adjustments should be done by changing the speed only.

The blades are attached to the barking plate so that it is possible to adjust them as well. Still, they should be carefully fixed to one position and moved only if necessary. It is important that the blades are always on the same level in comparison to each other and their level should be carefully measured after any adjustments. If the blades are not at the exact same position, the barking quality will suffer and also wear on the blades. After the proper position for the blades has been found they should not be moved.

The threaded rod in the middle of the barking plate is also having an effect in the result. It is difficult to predict how much affect it does have, and it also might change depending on the species and condition of the barked log. If the threads are too sharp, it might be pushing the log to the blades too hard and if they are too smooth, they do not affect at all. This needs to be tested during the prototype phase of the process.

6 Conclusion

The goal of the bachelor’s thesis was to design a log barking machine which would be used with a tractor and what would be improving the profitability of a small logs. The goal was to make the design as cost efficient as possible and to ease the workload of barking logs whilst make the process much faster. The result should handle all the aspects needed for building the machine.

During the design process it was thought that the barking plate would be built from scratch at the company. After doing some research on the machine and on the plate, it was clear that for safety reasons the plate should be purchased instead of manufactured on your own. A company called Energiansäästö Oy has the desired plate in store and it would cost 1600 euros. Without that, the calculated cost of the machine (2277,65 e) would have been much less than the estimate done in the early phases of the project (2000 e).

According to the calculations, the forces affecting the machine are rather small. This indicates that, for example, the steel bars of the frame could have been from slightly smaller profile which again would be cheaper. On the other hand there should be no affect on how large logs are being barked.

It has been difficult to comprehend the entire design so that the result would be as flawless as possible. There have been several alterations in the design during the process and the next task would be to build a prototype of the machine. During the manufacturing of the prototype the weaknesses can be seen and if possible, they should be fixed. If the mistakes or faults in the design cannot be corrected anymore, they could be fixed in the further designs. It is difficult to understand, predict and know beforehand the behaviour of the logs as well as the quality of the barking without a little trial and error.

Figures

Tables

Formulas

$$V = \pi R^2 h \qquad (1)$$

$$\rho = \frac{m}{V} \rightarrow m = \rho * V \qquad (2)$$

$$L_{10} = \left(\frac{C}{P}\right)^p \qquad (3)$$

$$L_{10h} = \left(\frac{10^6}{60n}\right) L_{10} \qquad (4)$$

$$\sum M_A = 0 \qquad (5)$$

$$\sigma = \frac{N}{A} \qquad (6)$$

$$\varepsilon = \frac{\sigma}{E} \qquad (7)$$

$$\Delta L = \varepsilon L \qquad (8)$$

$$\tau = \frac{F}{2 * a * L} \qquad (9)$$

$$\delta = \frac{FL}{3EI} \qquad (10)$$

List of references

Finlex 2008. Valtioneuvoston asetus työvälineiden turvallisesta käytöstä ja tarkastamisesta. http://www.finlex.fi/fi/laki/ajantasa/2008/20080403. Read 6.3.2019

Hiltunen, J. 2017. Uudistunut perinteinen hirrenveisto. Helsinki: Rakennustieto.

https://www.amroll.com/bearing-selection-load-life.html. Read 17.3.2020

https://www.laakerinetti.com/ucp206-pystylaakeriyksikko-valurauta-ruuvilukitus-asahi-p-4818.html. Read 10.12.2019

https://skf.com. Bearing rating life. Read 12.12.2019.

https://www.uittokalusto.fi/kuorinta-kalle-e3732.html. Figure 2. Read 27.3.2019

https://johndeeredistributor.fi/Maatalous/Tuotteet/Traktorit/5M-sarja2. Read 10.4.2019

Energiansäästö Oy. http://www.energian.net/energiansaasto_oy/index.html. Read 2.4.2019

Science Learning Hub – Pokapū Akoranga Pūtaiao, University of Waikato, https://www.sciencelearn.org.nz/images/3588-structure-of-a-woody-stem. Figure 1. Read: 18.3.2019

IKH verkkokauppa. https://www.ikh.fi. Read 12.3.2019

Jokinen, T. 1991. Tuotekehitys. Helsinki: Otatieto.

Kaihlanen 2016. Sahurit: Pienten tukkien sahaus täysin kannattamatonta. https://www.maaseuduntulevaisuus.fi/mets%C3%A4/sahurit-pienten-tukkien-sahaus-t%C3%A4ysin-kannattamatonta-1.136236. Read 27.2.2019

Karhunen, J., Lassila, V., Pyy, S., Ranta, A., Räsänen, S., Saikkonen, M., Suosara, E. 1992. Lujuusoppi. Helsinki: Oy Yliopistokustannus/Otatieto.

Kärkkäinen, M. 2003. Puutieteen perusteet. Hämeenlinna: Kustannusosakeyhtiö Metsälehti.

Laakko, T., Sukuvaara, A., Borgman, J., Simolin, T., Björkstrand, R., Konkola, M., Tuomi, J. & Kaikonen, H. 1998. Tuotteen 3D-CAD-suunnittelu. Porvoo: WSOY.

Manninen, J. 1989. Puu ja puutuotteet rakennustarvikkeina. Mänttä: Mäntän Kirjapaino.

Puuinfo. Lujuusteknisiä ominaisuuksia. https://www.puuinfo.fi/puutieto/puu-materiaalina/lujuusteknisi%C3%A4-ominaisuuksia. Read 8.3.2019

Isomäki, O., Koponen, Nummela & Suomi-Lindberg. Puutuoteteollisuus 2. Raaka-aineet ja aihiot. Helsinki: Edita Prima Oy.

Tyosuojelu 2017. Machinery and tools. https://www.tyosuojelu.fi/tyoolot/koneet-ja-tyovalineet. Read 6.3.2019

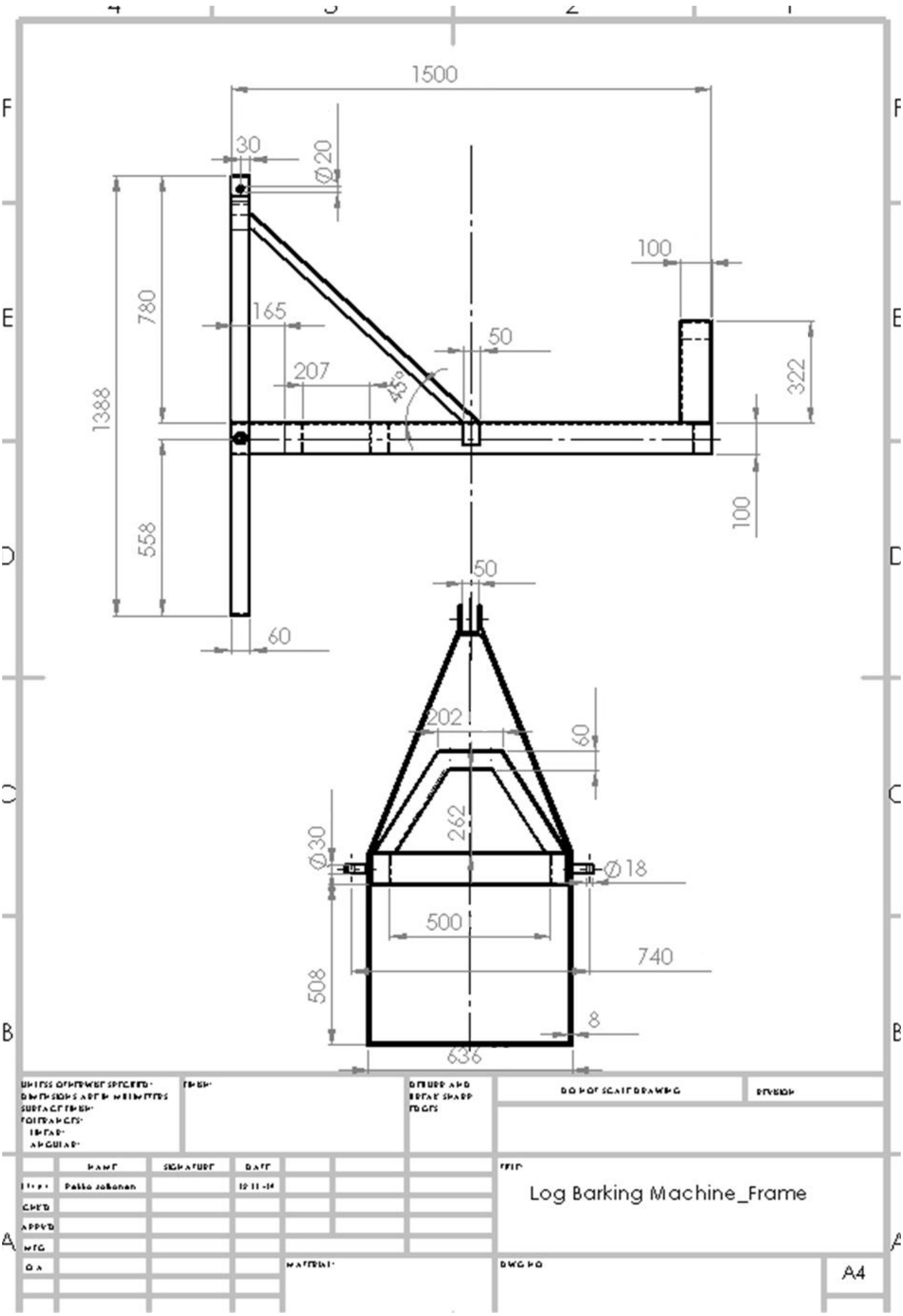
Ullman, D. 2010. The Mechanical Design Process. New York: McGraw-Hill.

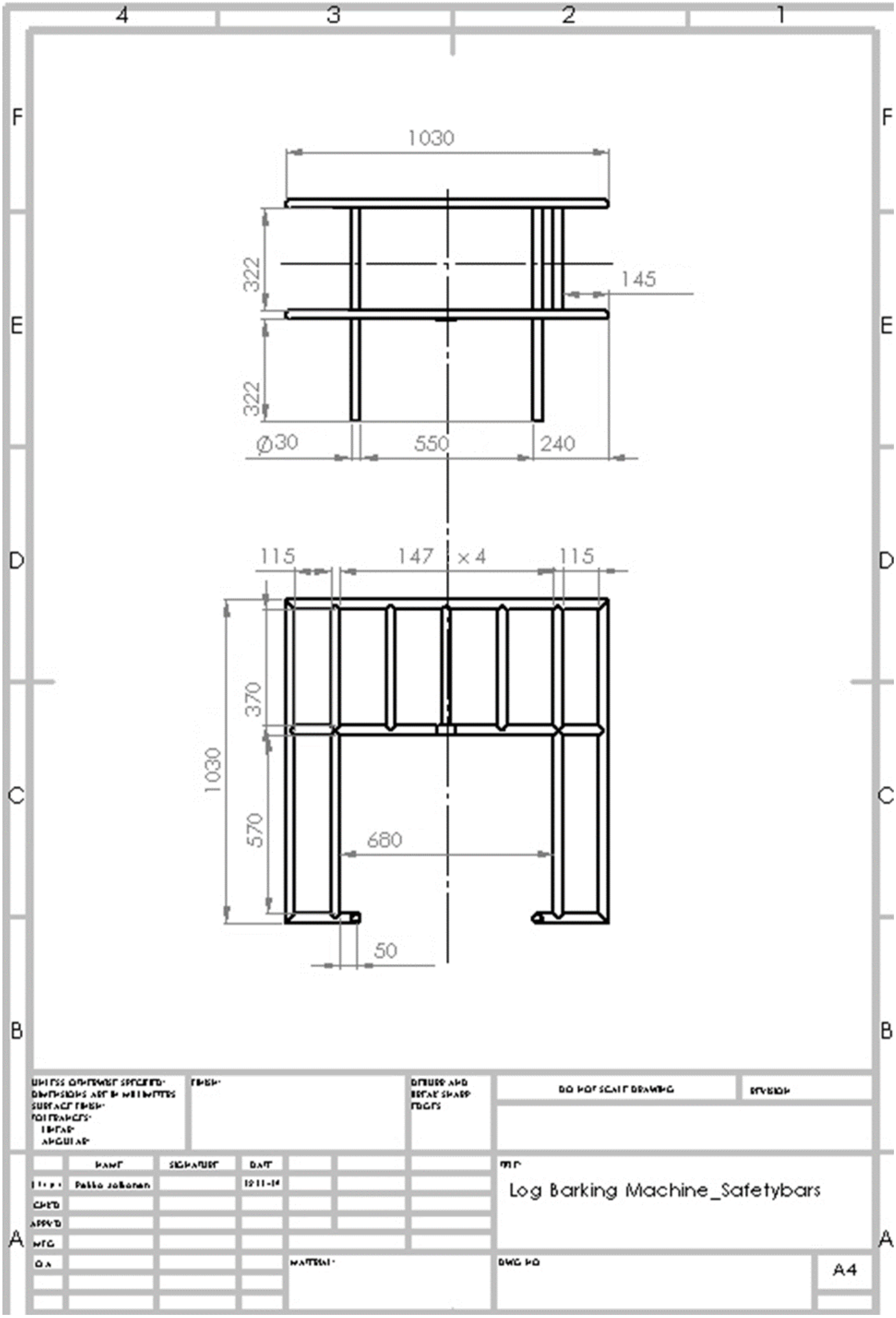
Valtanen, E. 2013. Matemaattisia kaavoja ja taulukoita. Jyväskylä: Genesis-Kirjat Oy.

Varis, R. 2017. Sahateollisuus. Kustannuspalvelut Kirjakaari Oy

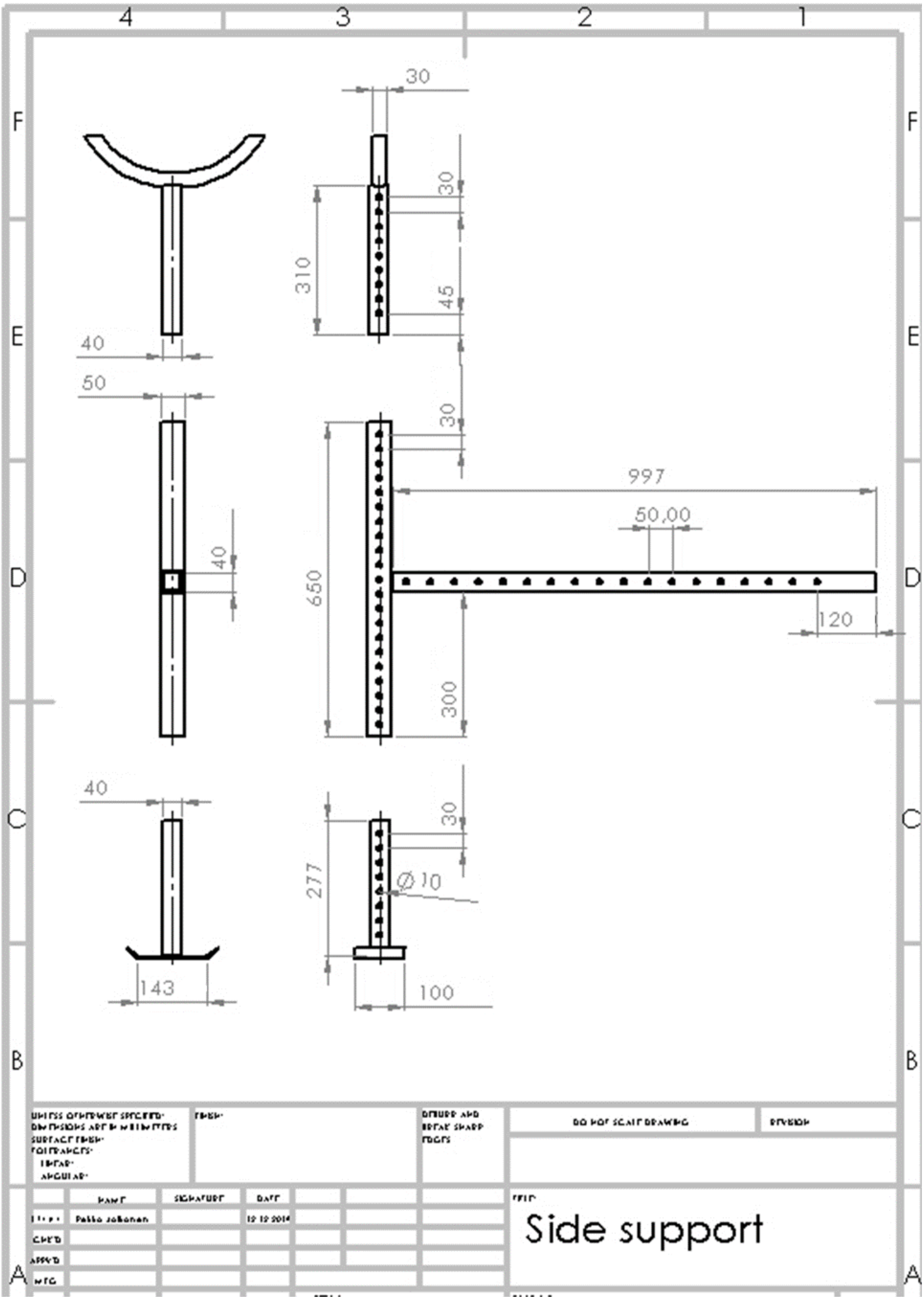
Vesterinen, T. 2018. Voimaa kulmittainkin – Nivelakselit. KV 03/2018. https://www.koneviesti.fi/artikkelit/artikkeli-1.225019. Read 12.3.2019

Attachments

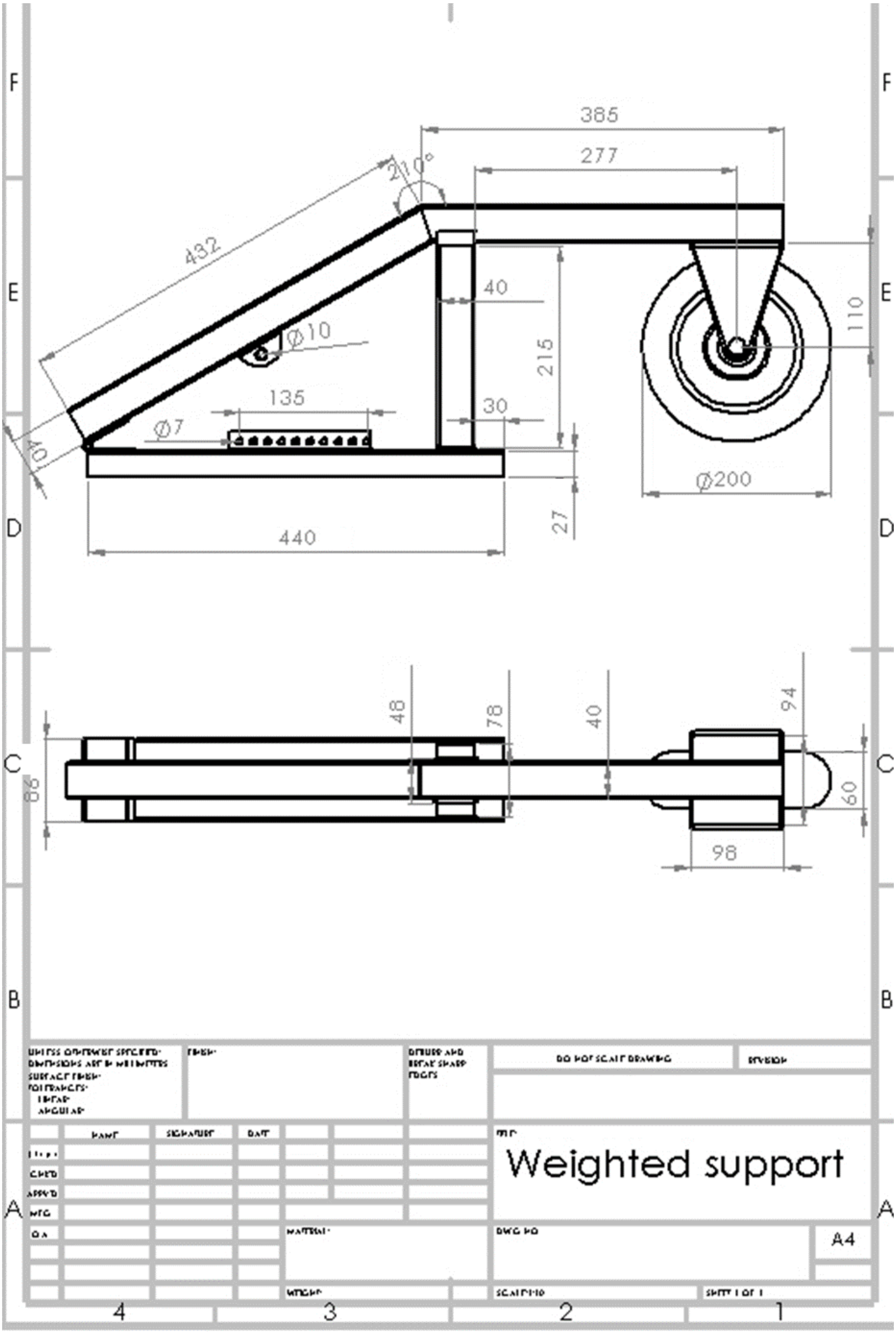


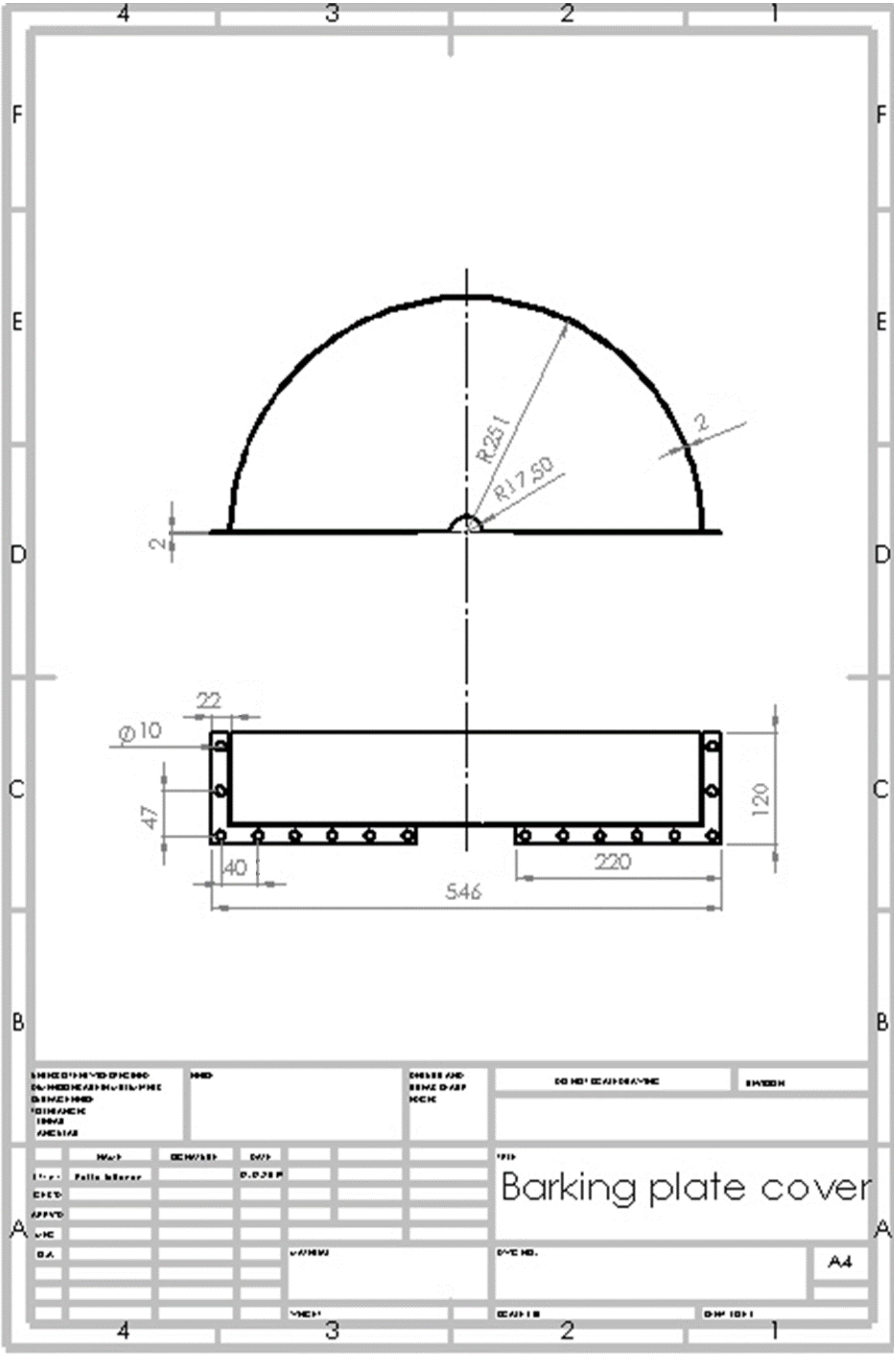


1030
322
322
145
Ø30
550
240
115
147
× 4
115
370
1030
570
680
50
DO NOT SCALE DRAWING
Log Barking Machine_Safetybars
A4



30
30
310
45
40
50
30
997
50,00
40
650
120
300
40
30
277
∅10
143
100
Side support


385
277
210°
432
40
Ø10
215
110
135
30
Ø7
40
Ø200
27
440
48
78
40
94
88
60
98
Weighted support
A4
F
E
D
C
B
A
4
3
2
1


R251
R17.50
2
22
Ø10
47
40
220
546
120
Barking plate cover
A4