

Tallinn University of Technology
Department of Mechatronics
Chair of Mechanosystem Components

MHE70LT

Kunnar Loi

Automatic firewood processor
Master's Thesis

Author applying for
master's sciences of technical
academic degrees

Tallinn
2016

AUTHOR'S DECLARATION

I hereby declare that this thesis is the result of my independent work.

On the basis of materials not previously applied for an academic degree.

All materials used in the work of other authors are provided with corresponding references.

The work was completed guidance

“.....”201...a.

The author

..... signature

The work meets the requirements for a master's work.

“.....”201...a.

Supervisor

..... signature

Permit to defense

..... curriculum defense superior

“.....”201... a.

..... signature

MASTER'S THESIS SHEET OF TASK'S

Year 2016, semester 4

Student: Kunnar Loi, MAHM 143861 (name, cod)
Curricula: MAHM 02/13
Speciality: Mechatronics
Supervisor: Professor, Priit Põdra (position, name)
Advisers: (name, position, phone)

MASTER'S THESIS TOPIC:

(in English) Automatic firewood processor

(in Estonian) Automaatne halumasin

Thesis tasks to be completed and the timetable:

Nr	Description of tasks	Timetable
1.	Searching for literature and material related to the topic. Searching for similar solutions and products.	01.03.2016
2.	Divide the machine into smaller modules or mechanisms, analyze and propose a solution for each module.	20.03.2016
3.	Compose the final machine from sub modules.	02.04.2016
4.	Build the first prototype and assess its capabilities.	01.05.2016
5.	Finalize the thesis.	19.05.2016

Solved engineering and economic problems:

Developing a prototype for automatic firewood processor. During the development the machine is divided into smaller modules. Each module is analyzed and suitable solution is proposed.

Additional comments and requirements:

Language: English

Application is filed not later than: 16.05.2016

Deadline for submitting the theses: 20.05.2016

Student: Kunnar Loi /signature/ date

Supervisor: Priit Põdra /signature/ date.....

Contents

EESSÖNA.....	6
FOREWORD	7
INTRODUCTION	8
1. SCOPE OF THE PROJECT AND THESIS	10
2. FUNCTIONALITY OF THE FIREWOOD PROCESSOR	14
3. AVAILABLE FIREWOOD PROCESSORS IN THE MARKET	18
3.1 Hakki Pilke firewood processors	18
3.2 Japa firewood processors	23
3.3 Palax firewood machines.....	28
3.4 Pezzolato firewood machinery	30
3.5 Pinosa firewood machinery	31
3.6 Sami Autochopper	32
4. FIREWOOD PROCESSOR MECHANISMS	33
4.1 Log magazine	34
4.2 Log feeder conveyor	39
4.3 Log clamp.....	43
4.4 Log cutter mechanism	47
4.5 Log splitting mechanism	48
5. CONTROLLING OF THE MACHINE.....	56
6. CONTROLLING EQUIPMENT OF EACH MECHANISM.....	62
6.1 Log magazine	62
6.2 Log feeder conveyor	62
6.3 Log clamp.....	63
6.4 Log cutter mechanism	65
6.5 Log splitting mechanism	66
6.6 Log extractor conveyor.....	68

7. RISK ANALYSIS.....	70
7.1 Hazards posed by firewood machine mechanisms	72
7.2 Operator safety equipment.....	74
8. ESTIMATED BUILD COST	76
9. FUTURE DEVELOPMENTS AND IMPROVEMENTS	80
SUMMARY	82
KOKKUVÕTE	84
REFERENCES	86
APPENDICES	89
Appendix 1.....	90
Appendix 2.....	91
Appendix 3.....	92
Appendix 4.....	93
Appendix 5.....	94
Appendix 6.....	95
Appendix 7.....	96
Appendix 8.....	97
Appendix 9.....	98
Appendix 10.....	99
Appendix 11.....	100
Appendix 12.....	101
Appendix 13.....	102
Appendix 14.....	103
Appendix 15.....	104
Appendix 16.....	105
Appendix 17.....	106
Appendix 18.....	107

Appendix 19.....	108
Appendix 20.....	109
Appendix 21.....	110
Appendix 22.....	111
Appendix 23.....	112

EESSÕNA

Käesoleva töö eesmärgiks on luua uus ja innovatiivne halumasina kontseptsioon küttepuude tootmiseks. Tänapäeval on saadaval valik erinevaid halumasinaid, kuid autori vajadustele vastavat terviklahendust ei leidu. Valmiv seadeldis peaks olema paigaldatud haagisele, millest lähtuvalt on võimalik halumasinat kasutada mobiilse üksusena, võimaldades töödelda küttepuid vastavalt toormaterjali asukohale. Lahenduse omapäraks oleks ka automaatne toimimine, mis võimaldaks ühtlasi vähendada operaatori töökoormust.

Töö raames käsitletakse olemasolevaid halumasinaid, võrreldakse nende mehhanisme ning valitakse sobilik lahendus valmiva halumasina jaoks. Peamiste automaatsete mehhanismidena näeb autor: puu magasin, etteande konveierit, fiksaatorit, lõikurit ja tükeldajat. Töös uuritakse halumasina võimalikke ohuallikaid ja teostatakse riskianalüüs. Lõpufaasis selgitatakse välja ka seadme hinnanguline maksumus.

FOREWORD

The graduation thesis topic was selected and proposed by the author himself. Author has experiences with producing firewood and takes the firewood production sort of as a hobby. Author seeks for new and innovative solutions how to produce firewood more easily and efficiently which results in writing this thesis. Hereby author is thankful for the acceptance of this topic by the *defence committee* and for the opportunity of writing this graduation thesis. Author is thankful to his supervisor who helped to prepare this thesis and provided guidance throughout the process.

INTRODUCTION

This topic is related to firewood processing equipment and was proposed by author himself. Author is working in firewood production field and is continuing to do that. As the time passes, new and innovative machinery should be used to increase productivity and decrease the physical workload of employee. Seeking for appropriate solution for mobile automatic firewood processor is the aim of this thesis. Author has more than five years working experience with firewood processor Hakki Pilkke 60 Oh and has observed other firewood processors as well, but none of the current solutions provide the satisfactory result. Not all of the firewood processors perform the same, therefore some machines require more operator's physical effort than other machines. Some firewood processor production rate (cubic meters per hour) is different compared to other models.

The target object would be improved firewood processor designed for mobility and would provide automated processes. Author is looking for firewood processor that is mobile, works automatically and decreases the operator's workload. Operating the firewood machine manually or via joystick is not required due to the automation, which allows allocating operator's work tasks as well. Author has done some research, compared several firewood processors, their mechanisms, advantages and disadvantages and has developed a new design. The new design is suitable for mobile firewood machine only, but for factory or other stationary firewood production line, the hydraulic log deck, sorting mechanism and transfer mechanism are more suitable solutions.

During the process author compares available firewood processors, their pros and cons, evaluates their mechanisms and assesses their capabilities. The available firewood machines in the market are taken as source and therefore most of the references are referring to websites of firewood machines. At the final stage the operating logic is proposed and controlling equipment needed is pointed out for each mechanism in order to provide the innovative automated capability of the firewood machine. In the end, risk analysis is performed to point out the hazards and risks involved working with the machine and personal safety equipment is recommended for the operator to wear while operating the machine.

Author used Solidworks 2011 software to create the suitable 3D model of the firewood processor in order to provide the extra illustration for the final solution. Most of the

explanatory materials like pictures of different firewood machinery or some special mechanisms with different solutions (log conveyors, log sorting and transfer units, etc.) are shown in appendices.

1. SCOPE OF THE PROJECT AND THESIS

The prospective project is to build a suitable mobile firewood processor. The scope of the project is a bit bigger than this master thesis can cover, therefore the thesis focuses only on some main parts of the automatic firewood processor. The main automated mechanisms of the firewood machine are: log magazine, log feeder conveyor, log clamp, cutter blade, splitting ram and adjustable splitting wedges. These mechanisms will provide the automated operations to turn three meter (in length) logs into small, ready for fireplace, logs. These mechanisms form the unit that works automatically. The scope of topic and the automated mechanisms are shown in Figure 1.1 for clearance.

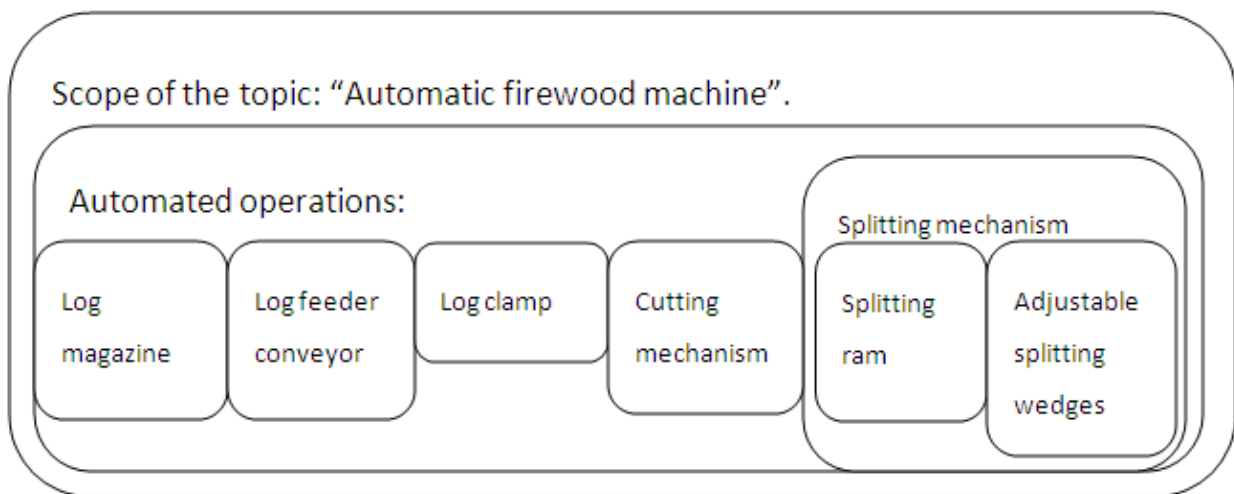


Figure 1.1. Automated operations of the firewood machine

The scope of the project can be seen in Figure 1.2. The project consists of a car trailer with gross weight up to 3500 kg, a log crane, a log extractor conveyor and two similar sets of automated operations that are covered in this thesis. The car trailer provides the mobility of the firewood machine and therefore provides the opportunity to process firewood wherever the raw wood is located. The log crane is needed to lift the logs into the firewood machine. The crane is operated manually. The logs are sorted during the lift based on their diameter. Smaller diameter logs (e.g. 8-15 cm) go to one side and the bigger ones (e.g. 15-30 cm) to the other side. One side splits logs into two or four pieces and the other side into six or eighth pieces (the splitting grids can be changed according to need). In this way the logs are separated into equal sizes based on their diameter.

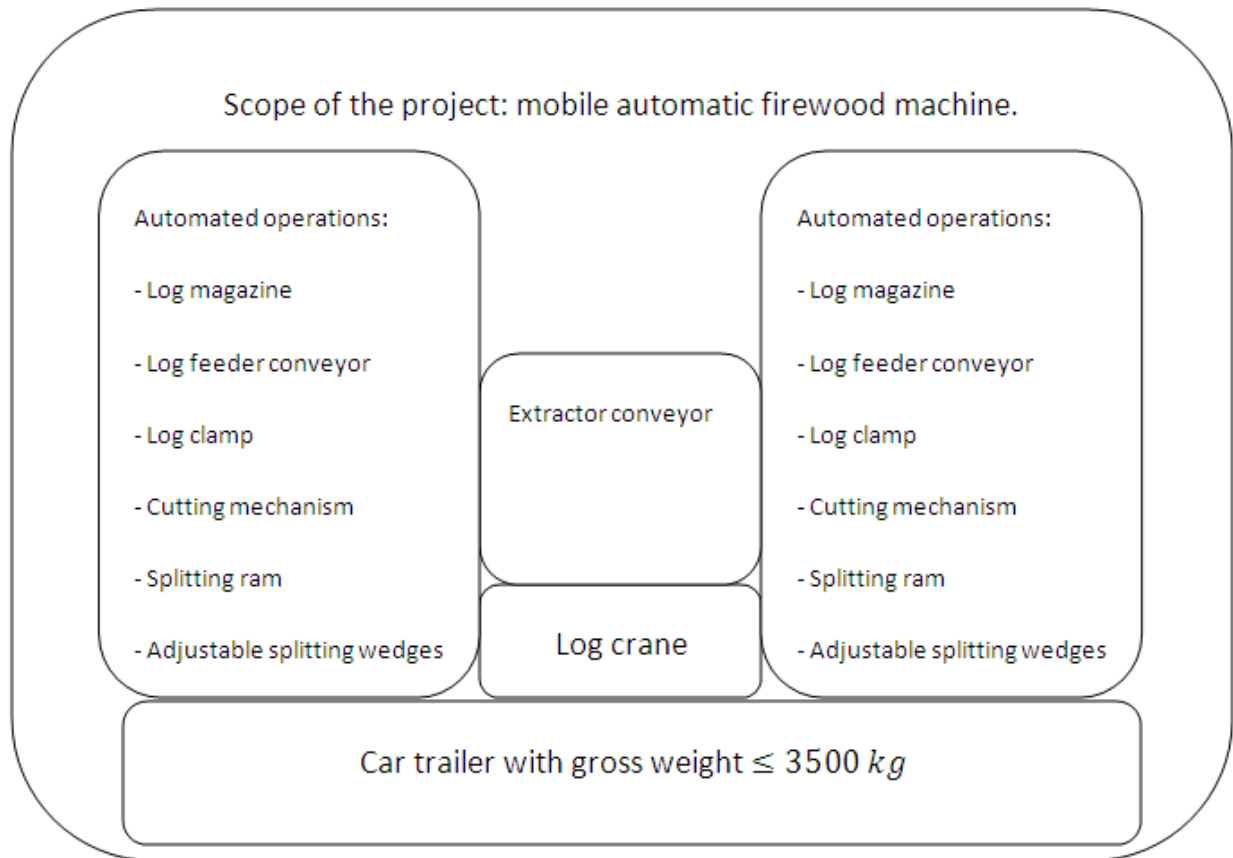


Figure 1.2. Scope of the project and master thesis

The final project consists of two operating lines. Each line contains log magazine, log feeder conveyor, log clamp, cutter, splitter and adjustable splitting wedges. The machine has one log crane and extractor conveyor. And all these components are mounted onto a car trailer. The illustration of the prospective project is shown in Appendix 23 and Figure 1.3 (conveyor not included).

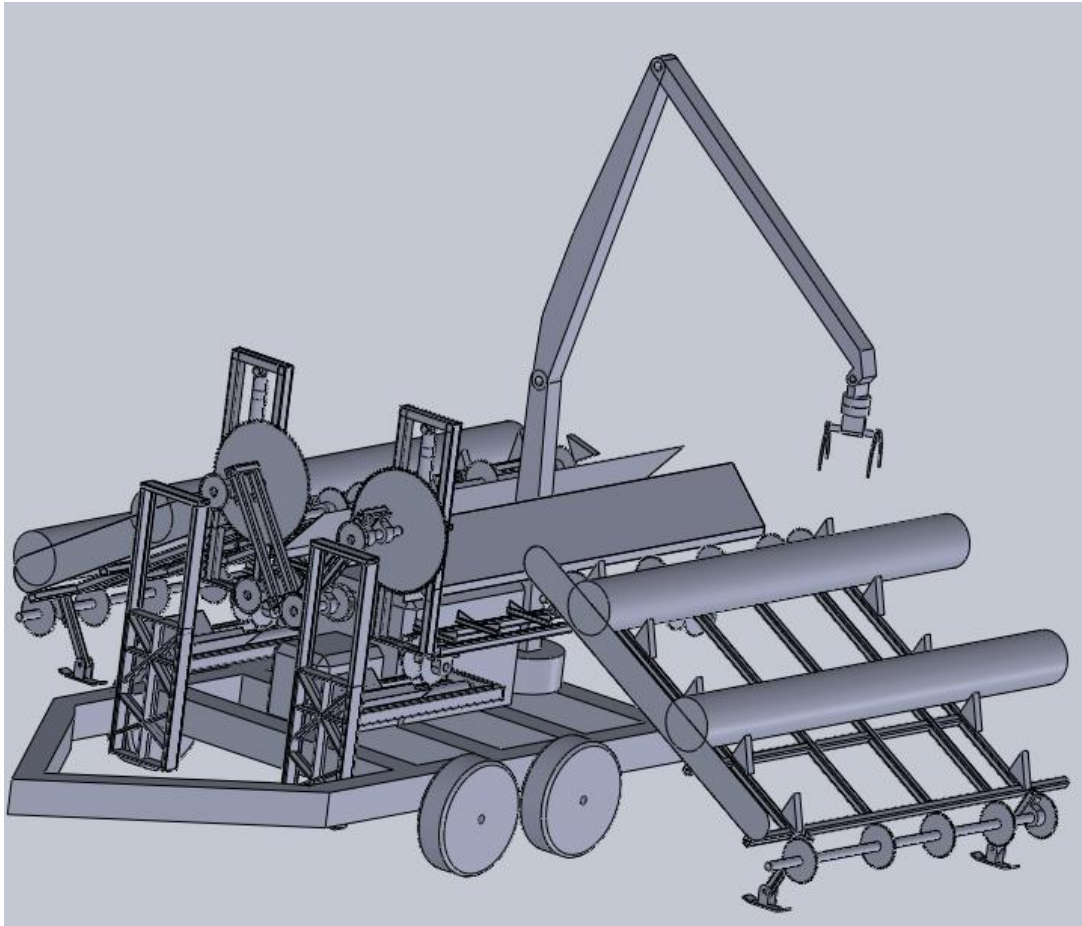


Figure 1.3. Mobile firewood processor

The development of this firewood machine and implementing the machine in the near future has several benefits. Automated processes provide ability to ease operator work load and redirect operators work tasks. The new machine has greater production rate compared to firewood machine Hakki Pilke 60 Oh used at the moment. The mobility of the firewood machine allows the machine to be used to provide firewood processing service. Implementation of this project has also economical impact.

With the new mobile firewood processor a new firewood production supply chain can be established. The new approach eliminates unnecessary processes and simplifies the supply chain. For example currently the wood has to be first loaded at the logging site, then transported to processing location, unloaded for processing and then again loaded on the truck for final delivery.

With the new approach, the firewood supply chain is simplified by deleting two unnecessary loadings. The mobile firewood machine is hooked to a truck and towed directly to the wood pile. Logs are lifted into firewood machine, processed and firewood is stacked onto truck. Loaded truck takes the firewood directly to customer.

Let us imagine a situation where log feeding, cutting and splitting processes are done automatically and therefore manual operating is not required anymore. It would give an opportunity for the operator to manage movement of the log crane to assure that logs are loaded onto log table or magazine in time. If all the mechanisms would require manual control then more than one operator would be needed. Someone has to manipulate the log crane. So the automation of the processes allows to ease up operators workload and to redirect work tasks.

With the prospective mobile firewood processor the crane operating process will not be automated at this point due to technical difficulties. That is why the operator's work task would be loading the logs into the machine.

It took at least four men to process firewood with buzz saw at the old times: one man who provided logs, one man for pushing logs forward, one man for cutting and one man for removing the blocks after the cut [44]. Nowadays it takes only one man to operate firewood machine and the automatically operated firewood processor decreases operator workload even more.

2. FUNCTIONALITY OF THE FIREWOOD PROCESSOR

The firewood processor is a machine that transforms longer and bigger logs into shorter and smaller ones, see Figure 2.1. In the first phase the log has to get inside the machine. It can be lifted by some lifting mechanism, log crane or physically. Second phase would be moving the log to the cutting position. Third phase would be cutting the log into predetermined length. Then the cut pillet is split into pieces. And the final fifth phase would be the extraction of the wood pieces.

Smaller logs are treated as final products. The size of final smaller logs are determined by customer or buyer. The final smaller logs should fit into households fireplaces, stoves or ovens. The usual length of firewood in Estonia is 30, 40 or 50 cm. The firewood processor can be considered as a machine that creates value to firewood. And the process of turning bigger logs into smaller ones can be considered therefore as value adding process.

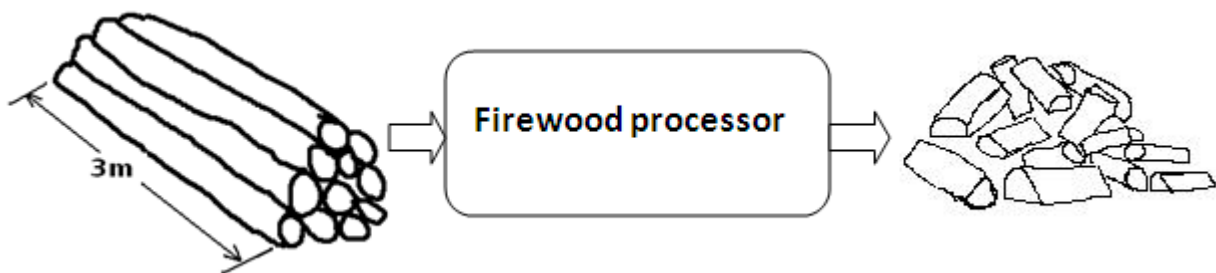


Figure 2.1 Firewood processor function

The processes of the firewood machine under development are (see Figure 2.2.):

- Log is fed from magazine to feeder conveyor,
- Log is fed to the cutting process,
- Log is cross cut into shorter blocks,
- Block is split into pieces,
- Pieces are extracted from the machine.

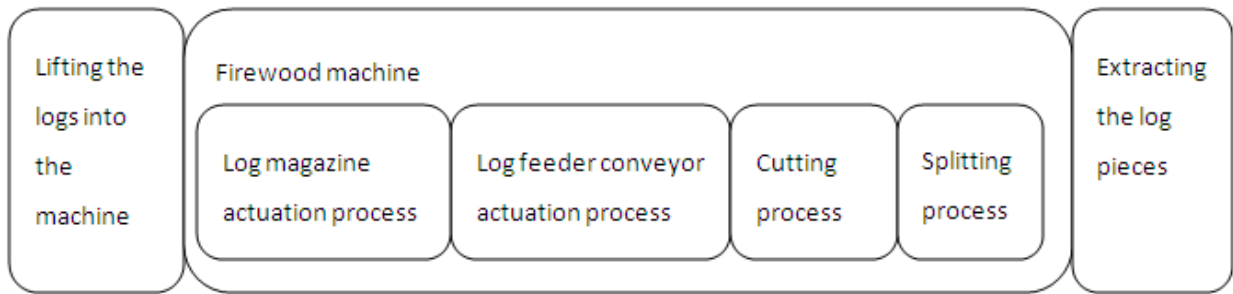


Figure 2.2. Processes inside firewood machine

Firewood processors are used to produce larger quantities of firewood. The machine can be used commercially or rented. Firewood processors can also be used to provide firewood processing service. Some automated firewood machines are also available in the market. Those firewood machines and as well this newly designed machine have similar inputs and outputs. Function structure diagram has been created to illustrate the firewood machine inputs and outputs. The function diagram can be seen in Figure 2.3.

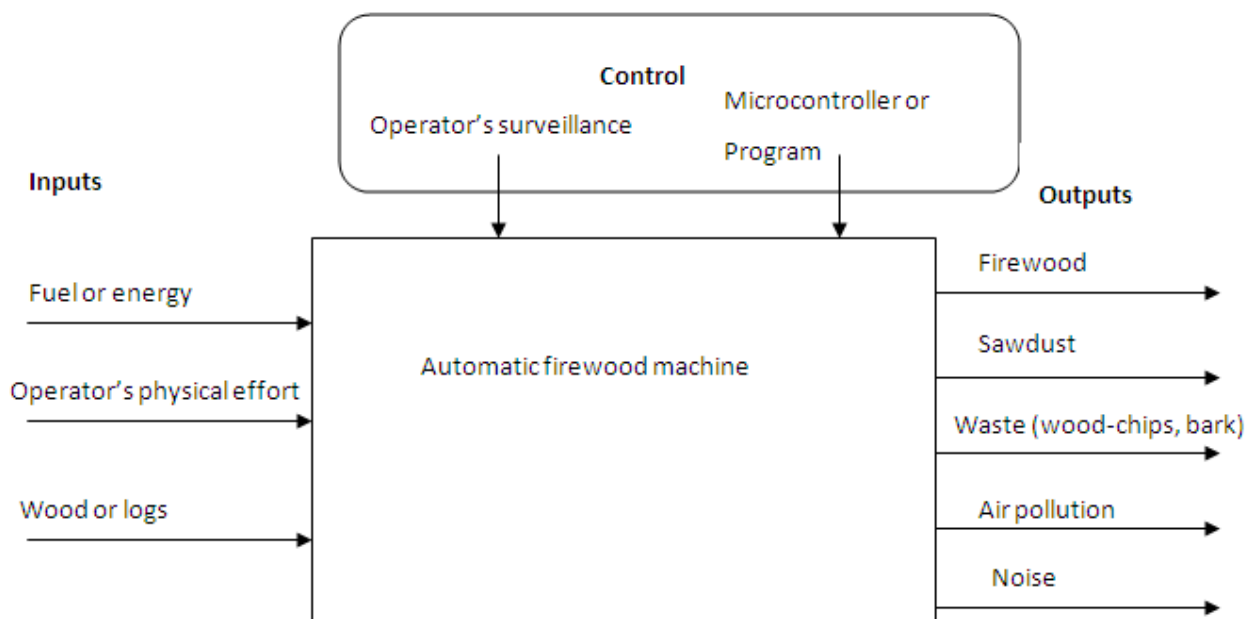


Figure 2.3. Firewood machine function diagram

Firewood machine requires fuel or energy to power the machine, some operator's effort and logs or timber as inputs. Outcome of the machine would be firewood, sawdust, waste (wood-chips and bark), noise and air pollution.

There are several steps or ways to process firewood. Process begins from a log pile. A pile consists of timber, longer and bigger logs, that are delimbed and cut into appropriate length, generally three meters in length. Then the logs are cut into shorter ones, for example 40 cm in length. And finally the shorter logs are split into smaller pieces. Smaller pieces of wood are ready for delivery or stacked for drying.

The cutting process can be established by using hand saw, chain saw, circular saw or guillotine. The logs are cut crosswise. Hand saw and chain saw are light weight tools that can be easily brought to the log or log pile. When it comes to firewood processors or splitters, then the logs have to be transferred to the machines.

The splitting process turns logs into even sized pieces suitable for household fireplace. The logs are split lengthwise. Based on the diameter of the log, the logs are split into two, four, six or eight pieces. In some cases logs are split into more than eight pieces. Those logs are usually bigger in diameter.

The splitting process can be carried out by:

- axes, wedges and hammer;
- splitting machine;
- firewood processor.

The first method is the most common one used for processing small amounts of firewood. Working with hand tools like splitting axes and wedges requires manpower, needs great amount of physical strength and therefore consumes a lot of energy.

The second method reduces the operators labor or workload. These splitting machines are more expensive compared to the first method. The splitting machines are often shared or rented. The splitting machines are available in different models and configurations. They are generally powered either by petrol, diesel or electricity. They come in different prices. The most common splitting machines have a hydraulic cylinder that pushes the log against splitting head. Those machines can work either horizontally or vertically.

Another splitting method would be using splitting machine with rotating coniform-shape tool. The splitting process carried out by coniform-shape tool forces the wooden log to go apart or

separate by the shape of coniform tool. The splitting tool causes the beginning of the crack and its intrusion along the wood tissue. At the same time the splitting process is complicated since the anisotropy of timber material, directive timber fibers in a log, since the timber heterogeneity of early wood and latewood, since the different dimensions and shapes of the billet and also due to the shape of the splitting tool [42]. All these factors influence the starting and performing the crack along the log which finally will result in splitting the log. This coniform tool forces the log to go apart, but it takes several actions to split the log into several pieces. Therefore this method is not suitable for the automatic splitting operation needed for the firewood processor currently in development.

The smaller splitting machines can split logs up to 30 cm in length. Medium size splitting machines are capable to split logs up to one meter in length, while the larger ones can split even longer logs. The splitting machines with hydraulic cylinders can be equipped with a single splitting blade or with several blades, forcing the log to split into several pieces with one stroke. This hydraulically actuated splitting mechanism, which has variations of splitting blades, is suitable for the firewood processor currently in development.

Firewood processors are used for processing firewood as third method. These machines are far more expensive than the other methods mentioned before. Firewood processor is a machine where the cutting and splitting machines are combined together. These machines first cut the wood into suitable length and then the cut wooden block is split into pieces. Some machines even have the extractor or a conveyor to carry the pieces of wood away, so they would not disturb the machines operation. Firewood processors have a greater productivity and therefore they are used commercially to produce bigger quantities of firewood.

The firewood machines are commonly processing longer and bigger logs. The bigger logs are usually three meters in length and in various diameter. Those logs are stored in piles near roads where the logging trucks have easy access to them. The logs are transported to firewood processors or vice versa. The firewood processor currently in development is designed in a way that it can be used as mobile unit and towed directly to the wood.

3. AVAILABLE FIREWOOD PROCESSORS IN THE MARKET

With the following market research, the already available firewood processors are brought out and compared. Main processes are: loading the wood onto a table or deck, feeding the logs to the cutter, cutting process, splitting process and the extraction process. Following questions will help to understand how different firewood machines operate: How are the logs loaded into the machine? How are logs fed into the cutter? How are logs cut? How are logs split? And finally, how are logs extracted? Additional tables with the main processes are added to each firewood processor.

There are several firewood processor producers and each producer has several firewood processor models. The main and more well known firewood processors are Hakki Pilke (provided by Maaselän Kone Oy), Japa (provided by Laitilan Rautarakenne Oy), Palax and Sami Autochopper.

Author uses other similar products, as well factory or production line mechanisms to provide explanatory details.

3.1 Hakki Pilke firewood processors

3.1.1 Hakki Pilke 60 Oh

Author has more than five years working experiences with the Hakki Pilke 60 Oh firewood processor. Hakki Pilke 60 Oh can be seen in Figure 3.1. It can be powered by a tractor or by electricity. The logs have to be loaded manually onto the log table. Then the logs have to be moved forward and pushed against cutter blade. The machine has 700 mm diameter circular cutter blade with carbide tipped teeth. The saw blade is running or spinning continuously. The saw blade is stationary and therefore the logs are pushed against it. When a cut is made, the billet falls onto a trigger that starts the splitting motion. The splitting motion can be considered as automatic, since it is started by a falling log right after the cut. Sometimes the falling log does not hit the trigger or log will stand in wrong way and the splitting process is not started, therefore the machines idle time increases, operator has to do excessive work and production rate suffers. Although the machines production rate (cubic meters of firewood per hour) is lower compared to others, it has still very simple design and is easy to maintain.



Figure 3.1 Hakki Pilke 60 firewood processor. Source: www.enzinger-landtechnik.de [14]

A table is created to give a better overview of the main processes required to process firewood with Hakki Pilke 60 firewood machine (see Table 3.1). The main specifications of Hakki Pilke firewood machine are shown in Table 3.2.

Table 3.1. Hakki Pilke 60 main processes.

Activity	Operation required	Comment
Log loaded onto feeder table	Manual	Physically lifted
Log feeding motion	Manual	Physically pushed or pulled
Cutting process	Manual	Physically pushed
Splitting process	Automatic or manual	Activated by trigger or operator
Log extractor conveyor	Continuous	Belt driven

Table 3.2. Hakki Pilke 60 specifications.

Powered by	Tractor, PTO or electrically
Max log diameter [mm]	250
Max log length [mm]	600
Splitting force [t]	5
Number of splitters	1
Cutter	700 mm circular saw blade
Accessories	Hakkifeed 371 log rack

3.1.2 Hakki Pilke 25

Hakki Pilke 25 is a mobile firewood processor that can be towed behind a car. Hakki Pilke 25 can be seen in Figure 3.2. The model is powered either by tractor, 4 kw electrical motor or by 13 hp petrol engine. The logs are loaded and fed manually by the operator. The cutting process is also manual, operator has to pull down a lever that moves the cutter blade. The machine is equipped with a 33 cm chain saw blade. The splitting process is either automatic, started when the chain bar has returned back to its initial position, or controlled manually by a special lever. The extractor conveyor is operated continuously by hydraulic motor.



Figure 3.2. Hakki Pilke Hawk 25. Source: www.maaselankone.fi [15]

Table 3.3 shows the main processes required to cut firewood with the Hakki Pilke Hawk 25 firewood machine. The main specifications of the Hakki Pilke Hawk 25 firewood machine are shown in Table 3.4 for clarity.

Table 3.3. Hakki Pilke Hawk 25 main processes

Activity	Operation required	Comment
Log loaded onto feeder table	Manual	Physically lifted
Log feeding motion	Manual	Physically pushed or pulled
Cutting process	Manual	Physically pulled lever
Splitting process	Automatic	Activated by cutter or operator
Log extractor conveyor	Continuous	Hydraulic

Table 3.4. Hakki Pilke Hawk 25 specifications

Powered by	Tractor, PTO or electrically
Max log diameter [mm]	250

Max log length [mm]	400
Splitting force [t]	3,6
Number of splitters	1
Cutter	33 cm chain saw blade
Accessories	Hakkifeed 371 log rack

3.1.3 Hakki Pilke Expert 25

The Hakki Pilke Expert 25 is equipped with 33 cm chain saw bar. It has two splitting units which increases the production rate. The Expert 25 model has a log feeder unit to assist operator in the log feeding process. The Expert 25 standard model has no output for additional log handling accessories, although with special equipment and extra valves the Hakkifeed log handling accessories can be connected. The main processes required to cut firewood with Hakki Pilke Expert 25 model are presented in Table 3.5 and specifications are presented in Table 3.6.

Table 3.5. Hakki Pilke Expert 25 model main processes

Activity	Operation required	Comment
Log loaded onto feeder table	Manual	Physically lifted
Log feeding motion	Manual with assisting device	Assisted with rotating spiked roller
Cutting process	Manual	Physically lever pulled
Splitting process	Automatic	Activated by cutter or operator
Log extractor conveyor	Continuous	Belt driven

Table 3.6. Hakki Pilke Expert 25 specifications

Powered by	Tractor, PTO or electrically
Max log diameter [mm]	250
Max log length [mm]	600
Splitting force [t]	5,5
Number of splitters	2
Cutter	33 cm chain saw blade
Accessories	All Hakkifeed log rack models with special adjustments

3.1.4 Hakki Pilke 30, 37, 38, 42 and 50 models

These models provided by Hakki Pilke are all equipped with chain saw bars and machines can split up to 600 mm length logs or billets. The maximum log diameter that can be cut varies from 300 to 470 mm. These models are equipped with rubber feedig belt and therefore operators physical effort is not needed to feed the logs into the machine. The log feeding motion is carried out by a lever. Models 42 and 50 are equipped with additional roller situated at the front of feeder belt. This roller helps to guide and forward logs onto the machines log feeder from log table or from other log transfer conveyor.

The Hakki Pilke firewood processor models 30 to 50 are equipped with joystick controlled log feeding, cutting and splitting processes. The operations controlled with joystick lever are reducing operators physical work a lot. Since the log feeding, cutting and splitting processes are same for models 30 to 50 and manually controlled via joystick then there is no need to mention this in Table 3.7.

Table 3.7. Hakki Pilke models 30, 37, 38, 42 and 50 main specifications

	Model 30	Model 37	Model 38	Model 42	Model 50
Max log diameter	300	370	380	420	470
Splitting force	5,5	7	8	13,5	30
Number of splitters	2	1	1	1	1

The logs are loaded onto log feeder either physically, by hydraulic lifter or transfered from log table. There are additional optional accessories like log lifters and log tables (racks) that can be connected with specific firewood processor model. Log lifters are called Hakkilift and log racks are called Hakkifeed models. Those accessories can be seen in Appendix 16. The firewood processors and compatible accessories are shown in Table 3.8. The Hakkifeed 371 log rack can be optional accessory for any firewood processor. The other Hakkifeed models (421, 422, 471 and 472) are compatible with Hakki Pilke 50, 42 and 38 models, but with special equipment and extra valves those Hakkifeed log rack models can be fitted with rest of the firewood processor models as well, except Hakki Pilke OH 27 and Hawk 25. The Hakki Pilke OH 27 and Hawk 25 are the only models that can be fitted with one standard log rack Hakkifeed 371.

Table 3.8. Hakki Pilke models and compatible accessories

Firewood processor	Suitable accessories	
	Hakkilift models	Hakkifeed models
Hakki Pilke 30 and 37	Hakkilift 371	Hakkifeed 371
Hakki Pilke 38	Hakkilift 381	Hakkifeed 371, 421, 422, 471, 472
Hakki Pilke Easy 42	Hakkilift 421	Hakkifeed 371, 421, 422, 471, 472
Falcon	Hakkilift Falcon	Hakki feed 371
Hakki Pilke 42	Hakkilift 421	Hakkifeed 371, 421, 422, 471, 472
Hakki Pilke 50	-	Hakkifeed 371, 421, 422, 471, 472

3.2 Japa firewood processors

Japa firewood machines are manufactured by Latilan Rautarakenne Oy. Japa is providing several firewood processors, log splitters and other accessories. Log splitters are not considered as firewood machines therefore those are not evaluated in this matter. The main interest lies on chainsaw machines: Japa 235, 305, 355, 385, 435 and 485. The circular saw machines come in three versions: Japa 100 E, 100 TR and Japa 700. The smaller versions Japa 100 E and TR are not suitable for this project. They are simple in design, each process is physically operated, therefore more suitable for home usage or to produce smaller amounts of firewood.

3.2.1 Japa 235

The Japa 235 is one of the smallest mobile firewood processor. Illustration of Japa 235 firewood machine can be seen in Figure 3.3. It is powered by petrol engine. It is mobile and suitable for households or summer cottages where people like to make their own firewood.



Figure 3.3. Japa 235 firewood machine. Source: www.japa.fi [25]

The Japa 235 machine is capable of cutting logs up to 23 cm in diameter and splitting blocks up to 33 cm in length. It has 33 cm chain saw for cutting logs and the chain saw is actuated by lever. The log is lifted and forwarded manually. It has no log extractor conveyor.

Japa 235 firewood machine is not suitable for this project. The small wheels indicate that this machine can not be towed on public roads. Also this model is capable to split only logs up to 33 cm in length, but current project requires maximum log length 50 cm.

3.2.2 Japa 305

The Japa 305 model is designed and manufactured as mobile firewood machine (see Appendix 12). The machine can be towed with car or ATV to summer homes, countrysides or anywhere the raw wood is located. The advantages of this product are that it is light weight, easy in design and towable. The splitting process can be considered as automatic since it is actuated by moving the cutting lever to its initial state. The disadvantages of this product are the processes that require physical effort or manual operation. The logs are lifted and loaded manually into the machine. Then the log is physically pushed further by defined length. The cutting process is done manually by pulling a lever downwards. The Japa 305 model is similar with the Hakki Pilke Hawk 25 model described earlier (see chapter 3.1.2) and which illustration can be seen in Figure 3.2.

3.2.3 Japa 355

The Japa 355 is suitable for semi-professional level. Japa 355 model can be seen in Appendix 13. Japa 355 is also suitable for farmers who have to process bigger amount of firewood. Japa 355 is equipped with hydraulic log feeder belt that will ease the log forwarding process. The log feeder is actuated by the cutting lever. The log feeder belt can be seen in Figure 3.4. The cutting lever has two operations. The lever starts the cutting process when it is moved downwards and when the lever is moved upwards it will start the feeder conveyor. In Figure 3.4. is shown the feeder belt that is actuated by the lever which operator holds with his left arm. The same lever operates splitting process as well. When the lever is returned to its initial position after the cut, the splitting process will take place. Main specifications of Japa 355 model are shown in Table 3.9.



Figure 3.4. Japa 355 log feeder belt. Source: www.metsaomanik.ee [24]

The logs have to be loaded onto the log feeder conveyor either manually, by log lifter or by some hydraulic log deck. Log lifter, log rack or log deck can be purchased as separate accessory.

Table 3.9. Japa 355 specifications

Model	Max log diameter [cm]	Max log length [cm]	Splitting force [t]	Accessories
Japa 355	35	60	7	Log lifter 495

3.2.4 Japa 385, 435 and 485

The Japa 385, 435 and 485 models are designed for professional use. They have different optional accessories and model range. For Japa 385 firewood machine three equipment range is provided: Basic, Expert and Professional (see Table 3.10). The main specifications of the 385, 435 and 485 are shown in Table 3.11.

Table 3.10. Japa 385 equipment range

Basic	Expert	Professional
Mechanical splitting blade height adjustment	Mechanical splitting blade height adjustment	Hydraulic splitting blade height adjustment
Feeder belt and cutting with lever	Joystick operated feeder belt (forward and reverse) and cutting	Joystick operated feeder belt (forward and reverse) and cutting
Automatic splitting start when lever is pushed upwards	Automatic splitting start when saw blade goes up	Automatic splitting start when saw blade goes up
-	Separate lever for splitting action	Separate lever for splitting action
-	Output conveyor speed adjustment possibility	Output conveyor speed adjustment possibility
-	Saw blade downwards motion speed adjustment possibility	Saw blade downwards motion speed adjustment possibility
-	-	Output for hydraulics and joystick operated log table

These models all have log feeder conveyor as standard and additional log lifter, log rack or hydraulic log deck can be connected to provide comfortable and easy log handling. Log lifter, log rack and log deck help to lift or carry the log to the infeed conveyor of the firewood machine. The log lifter, log rack and log deck can be seen in Appendix 14.

Table 3.11. Japa 385, 435 and 485 specifications

Model	Japa 385	Japa 435	Japa 485
Max log diameter [cm]	38	43	48
Max log length [cm]	54	-	66
Splitting force [t]	6 or 8	-	24
Accessories	Log lifter 495	-	-

The Japa 435 firewood machine is different from others because of the new and innovative design of the splitting mechanism. The new design does not require any additional splitting knives. There is no need for two, four, six, eight or other number of splitting blades. The 435

model has stationary splitting knives and the log is pushed through the knives back and forth several times until the log is completed. The splitting knives can be seen in Appendix 15.

The Japa 485 firewood machine is equipped with cassette type splitting knives. The cassette type splitting knives can be seen in Table 4.4. With the cassette knives the splitting forces are distributed to the sides and therefore reduces the load of the center vertical post.

3.2.5 Japa 700

The Japa 700 is the biggest circular saw type firewood processor provided by Japa. It is equipped with hydraulic splitter, adjustable splitting wedges and hydraulic output conveyor that has three positions. The logs are fed manually, as well the cutting procedure is carried out manually. The splitting procedure is started when the saw table is pulled back towards operator. Japa 700 is capable to process logs that are up to 26 cm in diameter and split logs up to 58 cm in length.

3.2.6 Japa accessories

Japa provides additional accessories and equipment for firewood machines like splitting knives, cleaning drum, sawdust extractor, sacking rack, skidding grapple, log rack, log lifter and log deck. The main interest lies in the accessories that improve the output of firewood machine and makes the log handling easier. The log lifter, log rack and hydraulic log deck are accessories that help to transfer logs into the machine. Log rack, log lifter and log deck can be seen in Appendix 14. Log lifter is a device that helps to lift the log from ground up to the machine's infeed conveyor. Operator has to push, pull or roll the log onto the log lifter and then the log is raised hydraulically up to the level of feeder belt. Log lifter has infeed roller that helps to transfer log further to the infeed conveyor. Log rack is a device that holds a pile of logs on the level of machine's infeed conveyor. Logs are already lifted onto the log rack from where they are sorted and moved towards the machine. Log rack can be connected with the firewood machine, if it has hydraulic output. Hydraulic roller assists to transfer the log to the infeed conveyor. If the machine does not have hydraulic output for the log rack, then the logs are transferred manually to the infeed conveyor. Hydraulic log deck is more advanced design of log rack. Log deck has crosswise chains that are actuated hydraulically and help to move and sort logs from log pile and transfer logs to the machine's infeed conveyor. The

splitting knives set can be seen in Appendix 17. Splitting knives range vary from six to 12 section configuration.

3.3 Palax firewood machines

Palax provides firewood processors in two main categories, equipped either with circular saw or chain saw. The main interest lies in circular saw firewood machines. The two categories are presented in Table 3.12. The illustrations of the Palax circular saw and chain saw firewood processors are presented in Appendix 18. The Palax firewood machines can be ordered in many versions specified by the customer.

Table 3.12. Palax firewood machines

Circular saw	Chain saw
Palax 55T	Palax Active
Palax C900	Palax D350
Palax Combi M II	Palax KS 35
Palax Power 70	Palax KS 40
Palax Power 100	Palax KS 45 S

The Palax Combi M II and Palax Active are models that can be optionally ordered as mobile platforms. Palax 55T is a small size firewood machine suitable for processing smaller amount of wood. Palax 55T has cone splitter, which is located separately on the other side of the machine and therefore extra work is required to split the logs. There is no data regards the Palax 55T cone splitter therefore the splitting force cell in Table 3.13. is left unknown. Processing firewood with Palax 55T needs quite a lot physical effort, because the logs have to be lifted, fed into the machine, cut and split manually.

Table 3.13. Palax firewood machines and their main specifications

Firewood machine	Cutting device	Max log diameter [mm]	Cutting length [mm]	Splitting force [t]	Accessories
Palax 55T	550 mm circular saw	200	500	-	-

Palax C900	900 mm circular saw	370	-	-	Palax log deck, Palax Lifter
Palax Combi M II	700 mm circular saw	250	600	3,5 or 5,6	Palax log deck, Palax Lifter
Palax Power 70	700 mm circular saw	250	600	3 or 6	Palax Lifter, Palax Midi
Palax Power 100	1000 mm circular saw	400	550	10 or 16	Palax Lifter, Palax Midi
Palax Active	33 cm bar	270	400	4	Palax Log Deck
Palax D350	38 cm bar	350		6 or 9	Palax Log Deck
Palax KS 35	38 cm bar	350	600	3,5 or 5,6 or 8	Palax Midi, Palax Mega
Palax KS 40	40 cm bar	380	600	13	Palax Midi, Palax Mega
Palax KS 45S	50 cm bar	450	550	16	Palax Midi, Palax Mega

Palax Power 70 and 100 are more advanced circular saw firewood machines for higher production. Palax D350, KS35, KS40 and KS45 are more advanced chainsaw firewood machines for higher productivity and easier log handling. The Palax firewood machines and their main processes are presented in Table 3.14.

Table 3.14. Palax firewood machines main processes

Firewood machine	Log loaded onto feeder conveyor	Log feeding motion	Cutting motion	Splitting motion	Splitting wedge height adjustment
Palax 55T	Manually	Manual	Manual	Manual	Manual
Palax C900	-	Manual, pulling lever	Manual, pushing lever	-	Manual
Palax Combi M II	Manually or joystick operated log lifter, log table	Manual	Manual, pushing crosscut deck	Automatic, dropping log actuated	Manual

Palax Power 70	Manually or joystick operated log lifter, log table	Manual, joystick actuated feeder conveyor	Manual, joystick actuated	Manual, joystick actuated	Manual, joystick operated hydraulically moved
Palax Power 100	Manually or joystick operated log lifter, log table	Manual, joystick actuated feeder conveyor	Manual, joystick actuated	Automatic, when saw returns to initial position. Manual, lever actuated	Manual, joystick operated hydraulically moved
Palax Active	Manually, from log deck	Manual, lever actuated feeder conveyor and roller	Manual, lever actuated saw bar	Manual, lever actuated	Manual, lever actuated mechanically
Palax D350	Joystick operated manually	Joystick operated manually	Joystick operated manually	Joystick operated manually	Joystick operated manually
Palax KS 35	Lever operated manually	Lever operated manually	Lever operated manually	Automatically starts after cut.	Manually operated, mechanically or hydraulically
Palax KS 40	Lever operated manually	Lever operated manually	Lever operated manually	Lever operated manually	Manually operated, mechanically or hydraulically
Palax KS 45S	Lever operated manually	Lever operated manually	Lever operated manually	Automatically started when bar retrieves its initial position. Additional lever for manual mode.	Manually by lever on control panel

3.4 Pezzolato firewood machinery

The Pezzolato S.p.A. company produces also firewood machines among other products. They classify firewood machinery based on the wood splitter, if it is integrated into the machine or independent. Into the first class belong firewood machines which wood splitter is integrated

into the machine. Into the second class belong firewood machines which wood splitter is independent, separate from the machine. The main interest lies in the firewood machines that have integrated wood splitting mechanism which is more efficient and easier to operate. The firewood machines with independent wood splitter designate that the wood is sorted and handled manually.

The smallest Pezzolato model is TL 1000, followed by TLC 1000, TLC 1100, TLC 1200, TLC 1300, TLC 1500 and TLC 1100 Vario. Pezzolato firewood machines can be ordered as mobile version. They can be set into manual or automatic mode based on the operator's wishes. Pezzolato firewood machines are equipped with circular saw and push plate infeed mechanism. The circular saw diameter varies from 1000 mm to 1500 mm. The model names are referring to saw blade diameter. Maximum log diameter that can be cut varies from 38 cm to 60 cm, depending on the size of the cutter blade. The cutting length can be set from 20 cm to 65 cm. The splitting knives are adjusted according to the size of the log. The splitting knives are formed into a grid, which distributes the splitting forces along the grid evenly.

The TLC 1100 Vario is a special firewood machine that has innovative splitting mechanism. The splitting mechanism allows to split logs up to 45 cm in diameter. The splitting mechanism has fixed cross and four adjustable T-shape blades. The splitting mechanism adjusts the four T-shape splitting blades according to the diameter of the log and splits the log into 12 pieces. This mechanism allows to split the log into equal parts and with minimum amount of waste.

The Pezzolato company produces also custom-made firewood machines and factory setups.

3.5 Pinosa firewood machinery

Pinosa S.r.l. is a Italian based automation company that makes wide range of firewood machines. The Pinosa firewood machine can be automatic or controlled manually. Pinosa firewood machines are capable of processing logs from six meters in length and up to 600 mm in diameter. It can handle round wood, branch wood, bundle wood and sawmill waste. Pinosa firewood machines generally have circular saw blade to cut logs into length. The logs are fed to the cutter with push plate mechanism, similar to Pezzolato technology (see

Appendix 10). The push plate feeding mechanism enables to process bundle wood, like branches, small diameter roundwood and sawmill waste material more effectively.

3.6 Sami Autochopper

Reikälevy Oy is producing firewood machinery in Finland called Sami Autochopper, Sami Autosorter and Sami Autofactory. There are several models of Sami Autochopper firewood processors which can be seen in Appendix 21. The Sami Autochopper firewood processors have different work modes in order to adapt different production requirements. Work mode can be selected between manual, semi automatic, automatic, non stop or double cut mode [41]. In the automatic mode, the wood is detected on feeder conveyor, transferred to sawing and then to the splitter. The splitting wedge aligns itself automatically according to the center of the log. Sami Autochopper has special features like hydraulic log clamp, log diameter measurement capability, ability to adjust the splitting grid according to wood diameter and ability to optimize the cutting length.

Disadvantage of the Sami Autochopper is the fact that the manufacturer does not produce mobile versions of the machines. Additionally the size of log sorting mechanism is rather big. The log sorting mechanism called Sami Autosorter would be perfect solution if it is used as stationary. Since the sorting mechanism is not integrated with firewood mechanism directly then it would not be suitable for the current project. Also Sami Autochopper firewood machines are equipped with chain saws, but for the project circular saw would be more appropriate.

4. FIREWOOD PROCESSOR MECHANISMS

In this chapter the firewood processor is divided into submodules based on the processes needed to produce firewood. At first the logs have to be loaded into the magazine. This step is done by the operator and with an assistance of hydraulic log crane. The first operation of the machine would be to transport the logs from magazine onto the conveyor that moves the logs further to cutting process. Next step would be the locking of the log with log clamp followed by cutting of the log. As the log is cut, the smaller block fall into the v-shape groove where the splitting process takes place. And finally the logs are moved away by a conveyor.

The main processes of the firewood machine are:

- Moving the log storage or magazine,
- Moving the log feeder conveyor,
- Moving the log clamp,
- Moving circular saw blade,
- Moving splitting cylinder,
- Moving splitting grid height adjuster.

The following Figure 4.1 will illustrate the main components of the machine. The arrows in Figure 4.1 represent the log movement flow direction.

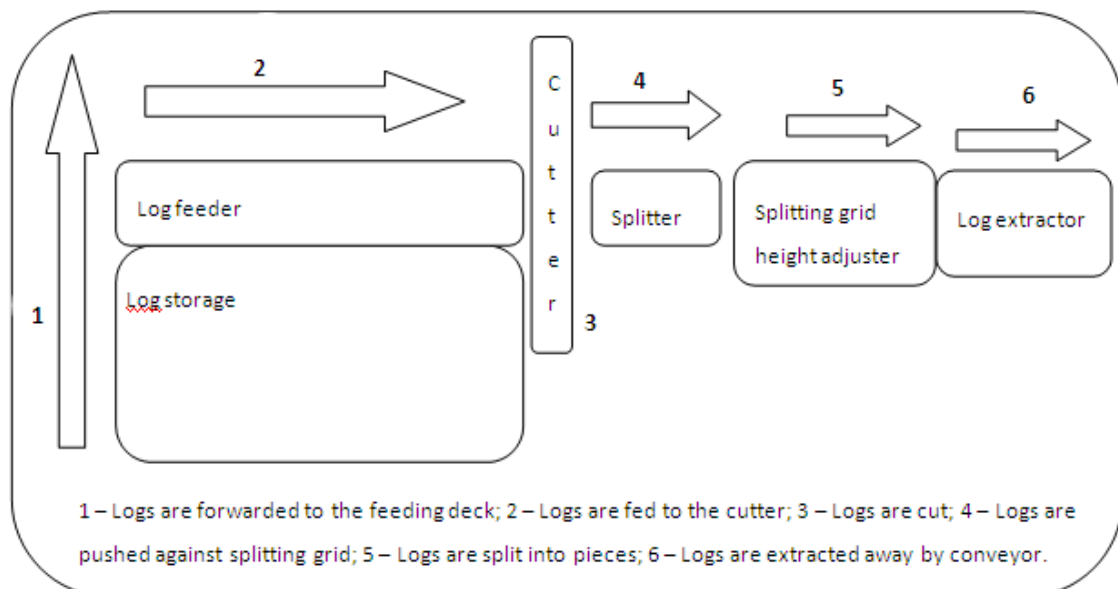


Figure 4.1. Concept of firewood processes

The current firewood machine and the project in development has mechanisms and the function of each mechanism is shown in Figure 4.2. The final complete 3D model of the firewood processor can be seen in Appenix 23.

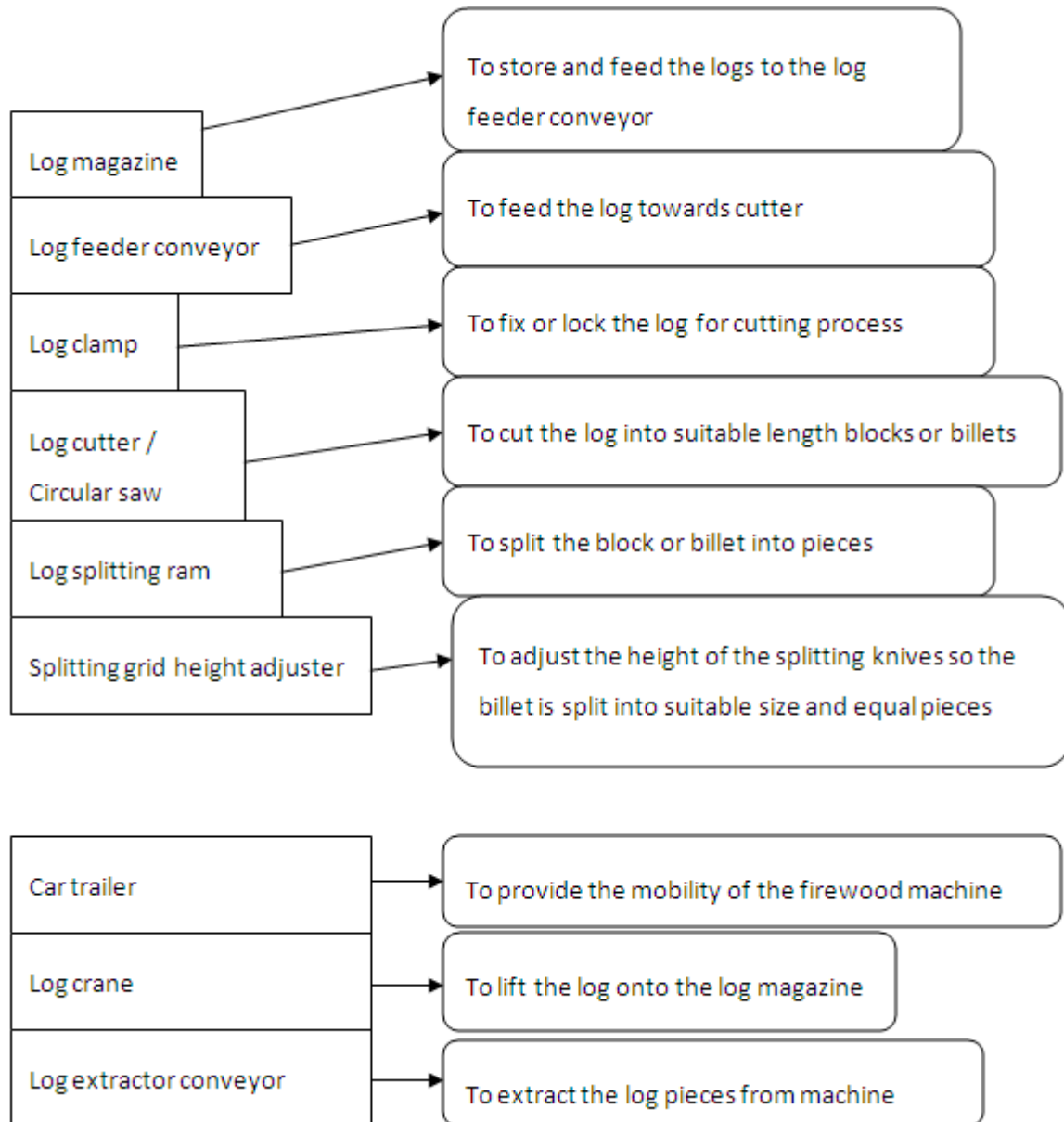


Figure 4.2. Function of each firewood mechanism

4.1 Log magazine

In this chapter the new log storage and feeding device called magazine is explained. At first some products are compared, their pros and cons are brought out and a new suitable solution is proposed.

Author has chosen a product called Sami Autochopper as one example to take into consideration. Sami Autochopper has several models (see Appendix 21), ranging from S110-EC440, S110-TC440, S110-TEC440 till S185-EC440, S185-TC440, S110-TEC440 [1]. All the model come with a log lifter, that minimizes the physical effort and provides assistance when lifting logs onto the feeding belt. The log lifter of Autochopper can be seen in Figure 4.3 [2]. The log is pushed onto the lifter, which then will lift the log vertically up to the level of feeder belt and then the log is pushed onto the feeder belt.



Figure 4.3. Hydraulic log lifter. Source: www.reikalevy.fi [2]

Author sees a downside of the log lifter, since each log has to be lifted and pushed onto the feeder belt. It would be a lot easier if the logs are ordered into queue, waiting to be rolled onto the feeder belt. With the new design the logs are lifted into queue by log crane. When the logs are ordered into queue, then the logs are rolled onto the feeder belt one log at a time by the machine automatically, which in return simplifies the process and minimizes the operators effort even more.

For example, let's consider a situation where five logs are set for processing. With the Autochopper log lifter (Figure 4.3) the operator has to push ten times in total to get the logs onto the feeder belt. But with the new log magazine design, operator only has to manipulate the log crane to lift the logs onto the magazine into queue and from there the logs are moved further onto the feeder conveyor by the machine automatically. So there is no physical effort like pushing or pulling needed at all.

Let us assume that it will take one minute to process one log. And it will take five minutes to process five logs. With Autochopper log lifter the operator has to lift and push each log onto the feeder belt after the previous log reaches the end point. This gives about one minute to rest and then operator is occupied with another log. This gives operators 50% of occupation. With the new magazine design, the logs are loaded with the log crane which allows the operator to load five logs into queue and does not have to wait for the log that is processed to reach its end point. The operator has to load new logs when the last log from the queue is processed. If it takes two minutes to lift five logs, then there will be three minutes of spare time. The crucial moment comes when the last fifth log reaches the end point. Even if the log lifting takes more time due to some reason, then there is still more time to load the magazine and therefore less chances to increase machines idle time. The goal with the new design is to minimize machines idle time between each log.

The perfect solution for logs to be loaded onto the feeder conveyor would be factory setup or wood supply line, but the equipment size is the downside of the setup. The production line consists of log loading table and log sorter. Logs are loaded onto the loading table straight from the log truck via log crane. Loading table slowly moves logs onto the log sorter. The log sorter then sorts logs in a way that only one log is passed onto the feeder belt.

Reikalevy Oy provides factory solution as an accessory. The Sami Autosorter or Autofactory is wood supply chain that consists of loading table, automatic sorter and a transfer conveyor. Logs are loaded manually onto the loading table and from that point on the process is automatic. There are similar already existing wood supply chains in the lumber industry that are capable to sort the logs.

Next are just few industrial sorting equipment mentioned.

- Comact wave feeder – works with same principle as the step feeder. The bottom log is moved upwards with each motion till the log is discharged from top onto the feeder belt [3]. Comact wave feeder can be seen in Figure 4.4.
- Step feeder – the step feeder separates the logs to load a single log into the infeed conveyor. Each stroke of the step feeder will pick up a new log at the bottom and discharge one log at the top [8]. The step feeder can be seen in Appendix 1. This is similar with the previous wave feeder.

- Rotary log singulator – this method works in the same way like the others, separating the logs while only single logs are passed onto the feeder belt. This method uses rotated blades. Rotary log separator can be seen in Appendix 3. Similar solution is used in reciprocating technology [6].
- Springer screw feeder – with this feeder the logs are moved upwards by rotating screws. During the process logs are separated and only single log can exit from the screw mechanism [7]. The top single log is executed then onto the feeder belt. This method allows also backwards motion in case of logs get bundled or jammed, while the step and wave feeder do not have the ability to do so [10]. Screw feeder can be seen in Appendix 2.



Figure 4.4. Comact wave feeder [4]

The wood supply chain and sorting equipment mentioned before, is little bit too big and heavy equipment to fit into mobile firewood processor unit. Better solution for the log sorting, loading and forwarding process would be compact mechanism integrated with the mobile firewood machine.

Since the new firewood processor has to be mobile, which means that the firewood processor equipment has to fit onto a two axle car trailer and therefore the factory type wood supply chain is not appropriate and acceptable.

The new suitable solution for the log storing, sorting and log supply for the feeder conveyor is the log magazine or log storage table. The log magazine can be seen in Figure 4.5. At the moment it is designed to hold up to five logs, but in the future the design and number of logs that are hold in magazine might be changed. Some live experiments will provide feedback if some changes in machine design are necessary.

The log magazine is a cartridge or a deck where logs are stored. The function of each log mechanism part is represented in Figure 4.6. The logs are situated crosswise compared to the support chains. Log magazine 3D model can be seen in Figure 4.5. Logs are ordered into queue, aligned by one end that is closest to the cutter. Logs from the magazine are moved onto the log feeder conveyor that takes them to the cutter. The logs from the magazine are moved onto the feeder conveyor one log at a time as soon as the log on the feeder conveyor reaches end point. In this way the logs are processed one after another and the machine idle time or time cap between logs is kept minimum.

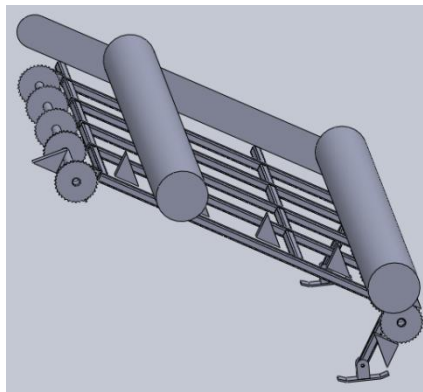


Figure 4.5. Log magazine 3D model

Author uses the term log magazine as related to firearm magazine. Based on Wikipedia, the firearm magazine is referred to as ammunition storage and feeding device [11]. Author adapted the same meaning and fitted it into log processing content, therefore the log magazine is a log storage and feeding device and the term is suitable within firewood processing content.

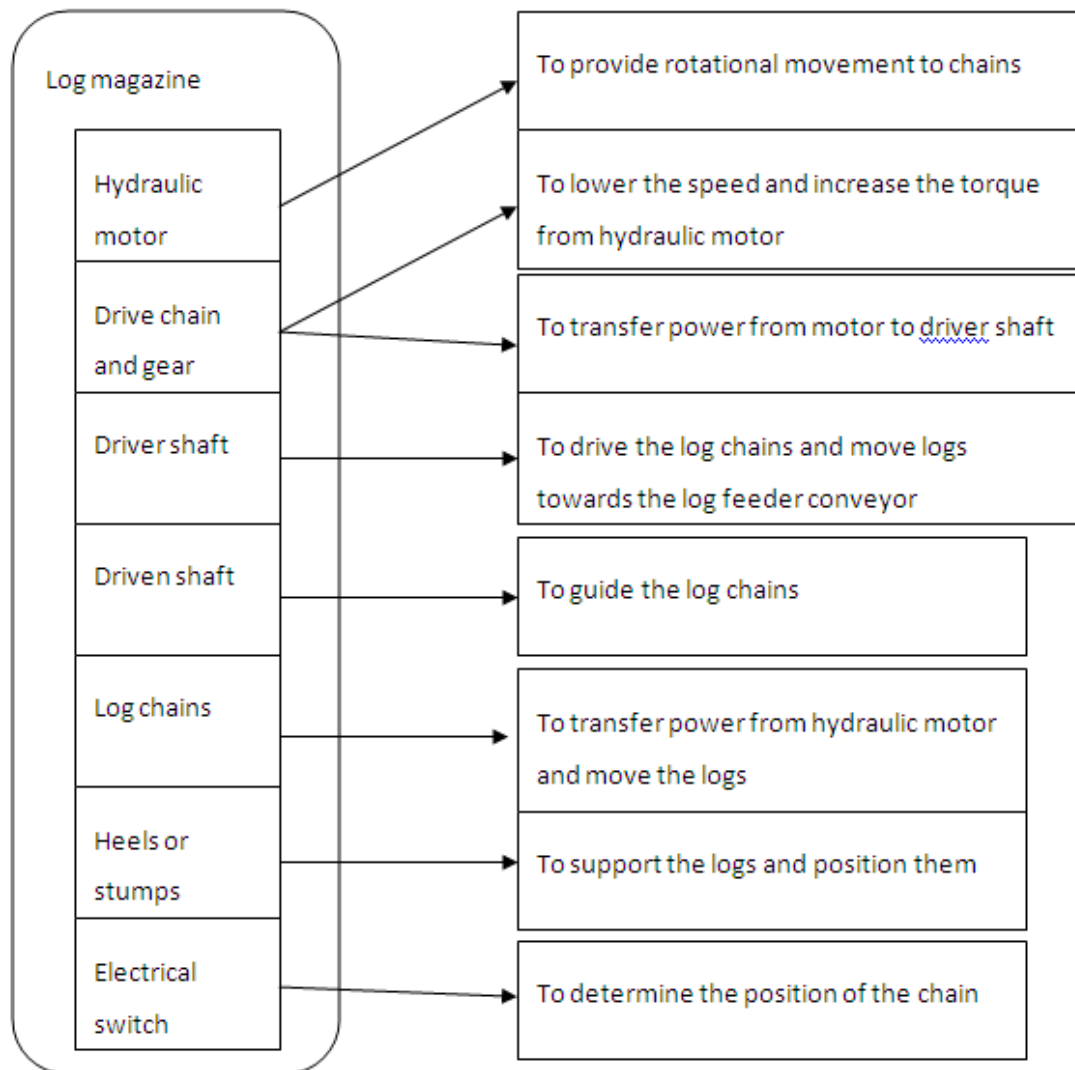


Figure 4.6. Log magazine parts and their function

4.2 Log feeder conveyor

Log feeder is a mechanism that moves a log to the cutting process. Log feeders are usually longitudinal or lengthwise with the logs. When a log is cut and cutter is returned to its initial position the conveyor feeds the log further by the length of predetermined log measurement. The feeder conveyor is operated either manually or automatically. Sami Autochopper has both, the manual and automatic modes to control the log feeder belt. Log feeder can be driven by hydraulic or electric motors. In factory production line an electric motor with gear reduction unit is most commonly used to drive the feeder conveyor. Firewood processor feeder belts or conveyors on the other hand are commonly powered by hydraulic motors. Hydraulic motor

can be controlled by hydraulic valve. There are several ways how the log feeder is designed. Most commonly used solutions are presented in Table 4.1.

Most of the firewood processor models like Japa, Palax, Hakki Pilke have the belt log feeder mechanisms. Lumber factories on the other hand are using chain driven log conveyors to move timber.

Company called Pezzolato S.p.A. is producing firewood processors and factory setups. The Pezzolato firewood factories like TLA-10 and TLA-150 have the push plate mechanism (see Appendix 10) for feeding the logs to the cutter. The Pezzolato's push plate pushes the wood forward to the cutter. When the log reaches end then the plate is raised up, moved back to its initial point and lowered down again. The push plate is suitable for bundle wood. It has bigger area to push bundle of small diameter logs forward the cutter, the cutter blade cuts more logs at one cut therefore the machine is more efficient. The downside of it is the size and complexity of the mechanism.

Author has to say that belt conveyors are most versatile and most oftenly used in industries, assembly lines and in firewood processing equipments as well. Belts can hold small particles, they are flexible and elastic therefore great for bulk material handling. They are easy to maintain. Belts are used to transmit power from one shaft or pulley to another. Belt drives where used in the early 19th century. Belt is used to carry load from one point to another. Rubber belts may have an advantage because they tend to slip rather than break. The slip may occur between pulley and belt or between belt and movable object. The weather and specially the temperature in Estonia changes a lot during the year. When the temperature drops below $-10\text{ }^{\circ}\text{C}$ then it influences the belt tension, makes it more stiffer and changes the grip characteristics from bad to worse. The snowy and freezy weather clog up metal pulleys, the metal pulley diameter grows, surface changes resulting in slip and belt tension change. The metal pulleys clog up with dirt and saw saw dust even in rainy weather. Belt conveyor tend to wear in time more quickly than other type of conveyors.

In the case of firewood processor Bilke S3, the rubber belt slip characteristic is used as an advantages to move log into the machine. The belt is powered almost constantly. The belt drives the logs into the machine. While the cut is made, the belt stops for a moment and when the cutting process has finished, the belt drives the log further by designated length. As

the log stops against the log measuring device, the belt is still moving, slipping against the log surface. This method allows to feed several logs at the same time. This method does not require any control mechanisms, since the machine works continuously and automatically due to the belt and its slip characteristics. The Bilke S3 firewood processor can be seen in Figure 4.7.



Figure 4.7. Firewood processor Bilke S3. Source: <http://www.bilke.net/en/bilke-s3-en> [21]

As for the rotating rollers, each roller needs bearings and power transfer via chains. As there are many rollers and each roller should be powered, then the chains act also as power transfer units. Chain conveyor needs only two shafts as compared to rollers, which in return minimizes parts required for the transfer unit.

Main log transfer units and conveyors are presented in Table 4.1 to provide a better overview and comparison. In table 4.1 some advantages and disadvantages of each log transfer mechanism are also presented.

Table 4.1. Overview of the log transfer mechanisms

Mechanism	Advantages	Disadvantages	Related illustration
Belt conveyor	<ul style="list-style-type: none"> - Light weight - Flexible - Backward and forward 	<ul style="list-style-type: none"> - Slipping - Tends to break or tear 	Figure 4.7

	motion		
Chain conveyor	<ul style="list-style-type: none"> - Stronger than belt - Transfers bigger forces - Backward and forward motion 	<ul style="list-style-type: none"> - More heavier than belt drive 	Appendix 4,5,6
Rotating rollers	<ul style="list-style-type: none"> - Good grip - Nothing to break - Backward and forward motion 	<ul style="list-style-type: none"> - Additional shafts needed - Additional bearings needed - Sometimes slipping 	Appendix 7
Sliding deck	<ul style="list-style-type: none"> - Multifunctional, integrated with log lifter - Actuated by splitting ram - Simple design - Backward and forward motion 	<ul style="list-style-type: none"> - Slipping - Sometimes not sufficient grip - Lips or edges are pointing at one direction 	Appendix 8
Sliding hydraulic gripper	<ul style="list-style-type: none"> - No slip - Backward and forward motion - Multifunctional as a substitute for log clamp 	<ul style="list-style-type: none"> - Heavy and big construction - Two hydraulic actuators and two control valves needed 	Appendix 11
Push plate	<ul style="list-style-type: none"> - No slip - Great for bundle wood - Only forward motion 	<ul style="list-style-type: none"> - Heavy and big construction - Two actuators and two control mechanisms needed 	Appendix 9 and 10

Although the belt log conveyors are mostly used along firewood processors, author persists in choosing chain conveyor as the most suitable solution for log feeding mechanism. In conclusion the suitable solution for the log feeder would be a chain conveyor, due to the good grip, less number of components and wear factors. The newly designed log feeder conveyor can be seen in Figure 4.8. It has two shafts and two chains. Flights are attached to the chains in order to grasp and carry the log.

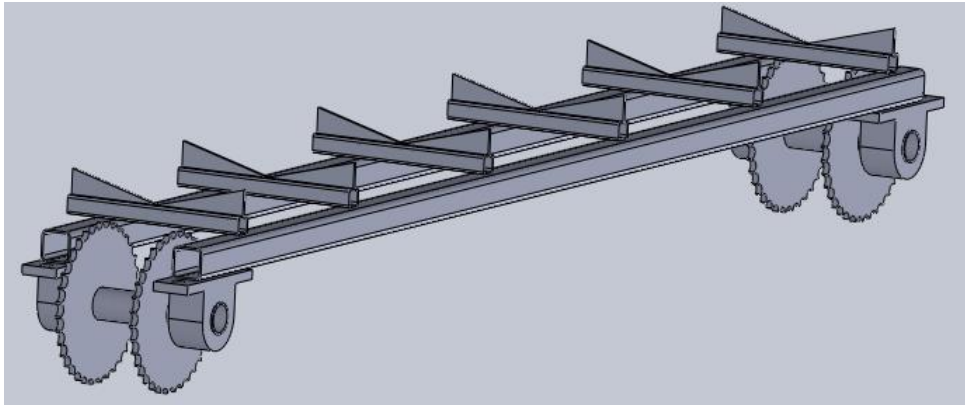


Figure 4.8. Log feeder conveyor

4.3 Log clamp





Log clamp is a mechanism that holds the log in place while the cut is made. It does not matter if it is a chainsaw or circular saw type firewood machine, the log clamp is still needed. Log clamp or log fixing mechanism is a safety feature as well. When the cut is to be made the rotating blade or chain might grab the log, the log might rotate or twist or move in some other way resulting a jammed blade or chain. As the blade rotates at high speeds and getting into contact with the log, the cutting friction designates forces that influence the log. As the log is bigger and heavier at the beginning, the cutting forces have less influence since the log mass acts as counter weight and cannot be moved so easily. As the log gets shorter and lighter at the end of the process, usually the last cut has the most influence over the log. Therefore holding the log in place plays crucial role. The forces designated by the blade or chainsaw are creating a thrust which will cause the log to move if not held properly in place.

There are several ways how to implement the log clamp or log fixing device. The available log fixing mechanism are presented in Table 4.2. The log fixing mechanisms are taken from Japa, Hakki Pilke, Palax, Sami Autochopper, Pinosa and Pezzolato firewood machines as example to show available solutions.

Table 4.2. Available solutions for log fixing mechanisms

Firewood machine	Description	Illustration

<p>Japa 355</p>	<p>Spring loaded lever with a grooved roller at the end.</p>	 <p>Japa 355 log clamp. Source: www.fuelwood.co.uk [32].</p>
<p>Hakki Pilke Easy 50</p>	<p>Hydraulically actuated log clamp with two rollers situated at the end.</p>	 <p>Hakki Pilke 50 log clamp. Source: www.maaselankone.fi [34].</p>
<p>Hakki Pilke Easy 42</p>	<p>Similar to Japa 355 model log clamp. Spring loaded lever with grooved roller at the end.</p>	 <p>Hakki Pilke Easy 42 log clamp. Source www.maaselankone.fi [33].</p>

<p>Palax KS35</p>	<p>Spring loaded lever with grooved roller at the end.</p>	 <p>Palax KS35 log clamp. Source: www.hakmet.com [31].</p>
<p>Sami Autochopper</p>	<p>Hydraulically actuated log clamp or lever.</p>	 <p>Source: www.reikalevy.fi [30].</p>
<p>Pezzolato</p>	<p>Hydraulically actuated wood locking mechanism with special toothed chain. Moves vertically up and down.</p>	 <p>Pezzolato TLC 1200 wood locking mechanism [36].</p>
<p>Pinosa 400 EPC</p>	<p>Hydraulically actuated log clamp, moves vertically up and down.</p>	 <p>Pinosa 400 EPC log clamp [35].</p>

In general Japa, Palax and Hakki Pilke firewood machines have spring loaded or mechanically operated log fixing mechanisms. The automated Sami Autochopper firewood machine uses hydraulically operated log clamp. The Pezzolato and Pinosa firewood processors are using similar log fixing mechanisms, which are hydraulically operated and are moving vertically up and down. Pezzolato uses special toothed chain for wood locking mechanism. In author's opinion this Pezzolato special wood locking mechanism is great for bundle wood but not necessary for single log. The suitable solution for this project would be a hydraulically controlled log clamp, which moves vertically up and down, similar to the Pinosa log fixing mechanism. The hydraulically operated log clamp enables to implement the automation of the log locking process more easily.

The newly designed log clamp for the project can be seen in Figure 4.9, where left illustration a) represents fully retracted position and right hand illustration b) represents fully extended stroke. The toothed bar is attached in the center in order to measure the log diameter. Hydraulic cylinder performs linear motion vertically up and down.

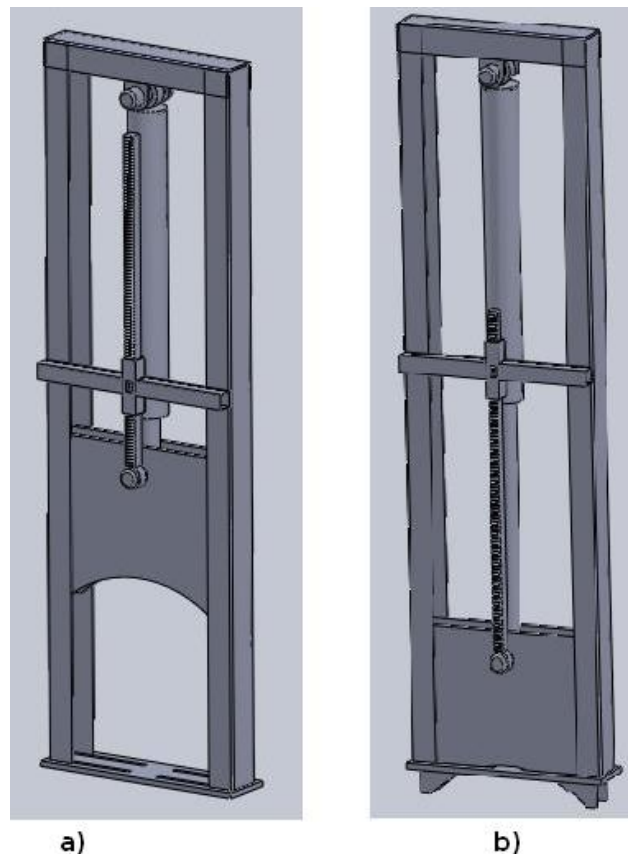


Figure 4.9. Log clamp mechanism. A) – retracted, B) – extended

4.4 Log cutter mechanism

The most suitable solution for the log cutting mechanism is a circular saw blade. Circular saw teeth are generally Tungsten or Carbide tipped, which makes it very durable and the maintenance costs are kept low. The circular saw makes a narrow kerf or gash and smooth surface compared to the chainsaw. Chainsaw equipped firewood machines are producing twice as much sawdust compared to the circular saw. Chainsaws require additional lubrication, chain oil, in order to lubricate the chain. Proper lubrication minimizes the wear and makes the chain last longer. Proper chain tension has to be granted at all times. Some firewood processors have automatic chain tensioner. Circular saws on the other hand have bearings which have to be lubricated with bearing grease in certain interval. The amount of bearing grease needed is significantly smaller than compared to the amount chain oil needed.

The cutting motion of the circular saw should be vertical. Most of the timber industry cross cut circular saws are pivot circular saws. Pinosa, Pezzolato, Multitek and Rapido Loco firewood processor are using vertically moved circular saw. Vertically up and down movable saw makes the cut while travelling downwards. In this way the saw blade is not sagged or pinched by the log. With the vertical cutting movement downwards, the cut is made from top and till the saw blade moves downwards, the log starts to gravitate (log drop by the gravity of Earth) and therefore releases or widens the kerf and minimizes the frictional forces against saw blade. With the new design the cutter blade has to situate above the log because of the splitting mechanism is situated below the log, leaving no room for cutter blade to be placed as well below the log.

Some Pinosa firewood processors are equipped with circular saws which are moving vertically upwards. This upwards moving saw blade is situated below the log, cut is started at the bottom of the log and is finished at the top. After the cut the blade goes back to its initial position. This cutter position is established since the splitting mechanism is located to the side. The vertically upwards movement of the circular saw blade can be seen in Figure 4.10.



Figure 4.10. Saw blade vertical upwards movement. Source: [37]

Final appropriate solution would be circular cutter blade, situating above the log and moving vertically up and down. The reasons for selecting circular saw blade instead of chain saw are durability, maintenance requirements and sawdust generation mentioned earlier. The newly designed cutter mechanism can be seen in Figure 4.11. A 700 mm circular saw blade is used and the power is transmitted from the drive shaft by v-belts.

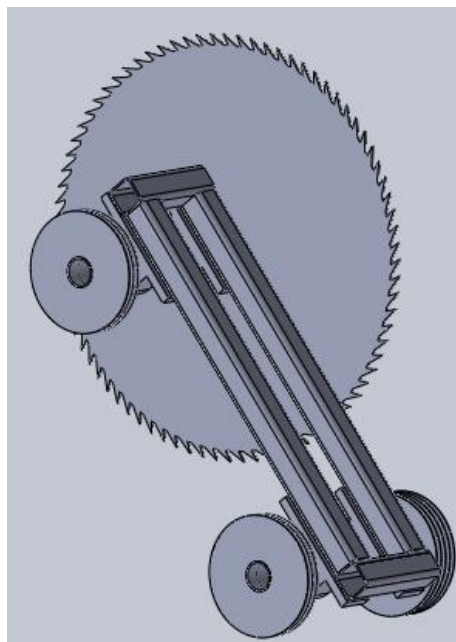


Figure 4.11. Cutter mechanism

4.5 Log splitting mechanism

The log splitting mechanism consists of two main parts: hydraulic splitting cylinder and splitting knife height adjustment mechanism. The combination of splitting cylinder and splitting grid specially designed for this project, can be seen in Figure 4.12. The log splitting

mechanism is used to make logs into smaller pieces. After the cut, the billet drops or falls into V-shape holder or chute. A hydraulic cylinder pushes the billet against splitting knives or wedges. The splitting knives or wedges are welded into grid. The splitting knife grid height is adjustable so the log can be split into two, four, six or eight pieces depending on the number of knives in the set. The height of the splitting knives grid depends on the diameter of the log.

In author's opinion, the innovative splitting mechanism mentioned in the article found in Journal of Agricultural Engineering 2014; volume XLV:228, pages 32 – 36; [43], is not necessarily applicable with the new firewood processor. The usage of splitting grids similar to Pezzolato solution seen in Appendix 19, which has multiple splitting knives set, is more suitable for this project and firewood machine. Based on the productivity model graph [43], which shows the productivity according to mean diameter and length of the input log [43], author has to agree that the productivity increases as the log diameter increases from 20 cm to 30 cm in diameter. It takes more time to process smaller diameter logs.

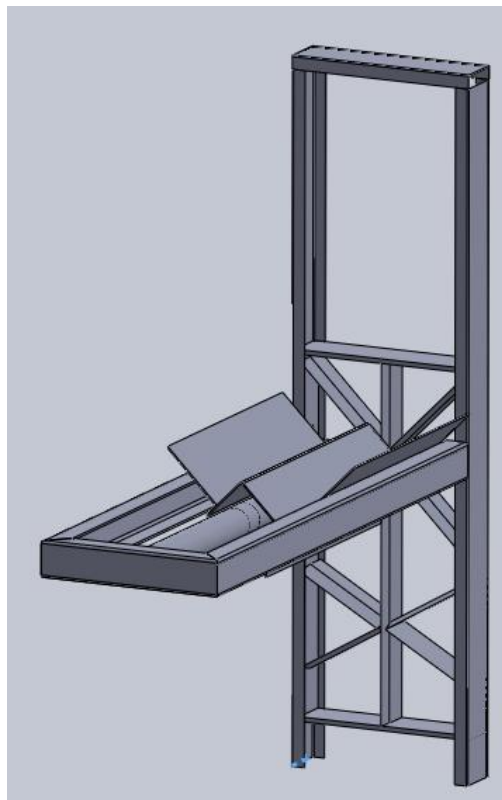


Figure 4.12. Splitting mechanism

4.5.1 Hydraulic splitting cylinder



The hydraulic splitting cylinder is mounted below the log deck, allowing the billet fall into V-shape holder right after the cut. The billet is then pushed against splitting knives which results the billet to go into pieces. The hydraulic cylinder is used as actuator to drive billet against splitting knives. Hydraulic cylinder has linear movement and a stroke about 50 cm, enough to push the billet almost through the splitting knives.

Most of the well known firewood processors available in the market are equipped with hydraulical splitting cylinder. The same concept, a hydraulic cylinder with linear push motion, is used in this project.

4.5.2 Adjustable splitting grid height mechanism




The splitting knives are set into grid. Splitting knives or wedges are used to drive the billet into pieces by lengthwise. The billet is pushed against the splitting grid by the splitting cylinder. The splitting knife can split the log into two, four, six or eight or into more parts, depending on the setup of the blades. Most of the well known firewood processors are using splitting knives with one vertical center post, as shown in Table 4.3. Those are light weight and easy to handle. Although there are cassette type splitting knives used by Japa 375 and 385 models (see Table 4.4).


Table 4.3. Splitting knives with main center post.

Splitting mechanism	Comment	Illustration
Four part	Splits wood block into four parts. Requires manual changing.	 <p>Source: www.japa.fi [28]</p>
Six part	Splits wood block into six parts. Requires manual changing.	 <p>Source: www.japa.fi [28]</p>

Pinosa and Pezzolato firewood achiness are using mostly splitting grid with multiple knives. Grid may consist of several knife setup. For example there can be four, six and eight part splitting knives mounted into single grid. The splitting grid with multiple splitting knives, allow adjusting the height of the blades without changing the splitting knife set itself.

Table 4.4. Multiple splitting knives and grids.

Splitting mechanism	Comment	Illustration
Six part	Used by Japa 375/385	 <p data-bbox="970 891 1273 922">Source: www.japa.fi [28]</p>
Eight part	Used by Japa 375/385	 <p data-bbox="970 1236 1273 1267">Source: www.japa.fi [28]</p>
Twelve part	Japa 450/455/485	 <p data-bbox="970 1585 1273 1617">Source: www.japa.fi [28]</p>

<p>Pezzolato multiple knives splitting grid</p>	<p>One grid can hold several knife sets (2, 4, 6, 8 or more). This one has two sets: a 6 and 8 knife configuration. Height is adjusted according to log diameter. Changing the knife set is not necessary as compared to single center post splitting knives.</p>	 <p>Source: http://www.pezzolato.it/en/prodotto/redline/tlc-1000-firewood-processor.</p>
---	---	---

There might be several sets of knives in one grid. As shown in Appendix 20, there are four main sets of splitting knives in one grid. Each set has either six, eight, sixteen or more knives. The desired set of knives can be adjusted with the whole grid according to the size of the log or billet to be split. Using a grid has the ability to split logs depending on the number of sets of knives without the need to change the actual splitting grid. This special splitting mechanism and grid shown in Appendix 20, has the opportunity to adjust the grid in both directions: vertically up and down, horizontally left and right. With the two directional splitting grid adjustment, the log can be split from centre, providing therefore equal size pieces. This would be a perfect solution, but it requires the exact location of the centre of the log which is hard to achieve as the logs are not symmetrical.

Japa has developed a new splitting knife design, so called perfect split and it is introduced with Japa 435 model. The perfect split knife set or mesh is shown in Appendix 15. The new design splits the billet into equal sizes.

In author's opinion, this Japa perfect split splitting technology is not the best solution for this project, since customers order firewood in different sizes. As some customers order small size firewood and other order large size firewood. This requires for example an 18 cm in diameter log to be split either in first case into six parts or in second case into two parts. As some customers prefer bigger logs for central heating stoves, but others again smaller logs for fireplaces with restricted size. Secondly the perfect split requires several strokes, back and forth in order to split the log entirely. As the log is bigger in diameter, more strokes are

needed to split the log, which results in machines hold up time. If it takes three to four strokes to process a 20 cm log with the Japa perfect split technology and compared to splitting knife that splits the log into pieces with one stroke, then the last choice would be more productive and time saving solution.

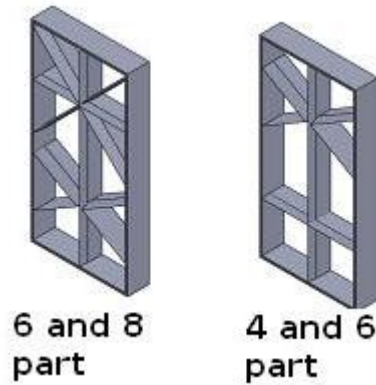


Figure 4.13. 3D models of splitting grids with different set of knives

Perfect solution for this project would be the multiple set of knives mounted into single grid and there should be several grids with different sets of knives. This multiple set of knives can be seen in Table 4.4 and in Appendix 19 and 20. The final solution would be a vertical splitting grid with two sets of knives. One grid contains a set of two, four and six part knives and the other set holds six and eight knives. There are 3D models shown in Figure 4.13 to provide an illustration of the splitting grids designed for this project. The splitting grids can be changed according to the wood pile consistence and customer needs. Additional ten or twelve part splitting grid can be manufactured.

4.5.3 Log extractor conveyor

Log extractor conveyor is used to carry the logs away from the machine. After the billets are split into pieces, the pieces are going to pile up and might jam the splitting grid. Most suitable solution would be a conveyor with two longitudinal chains, small bars that are situated crosswise and connecting the two chains together. The two chains are running on two shafts situated at the ends. The bars or flights between the chains are carrying the log pieces. The chains and bars can be seen in Figure 4.14.

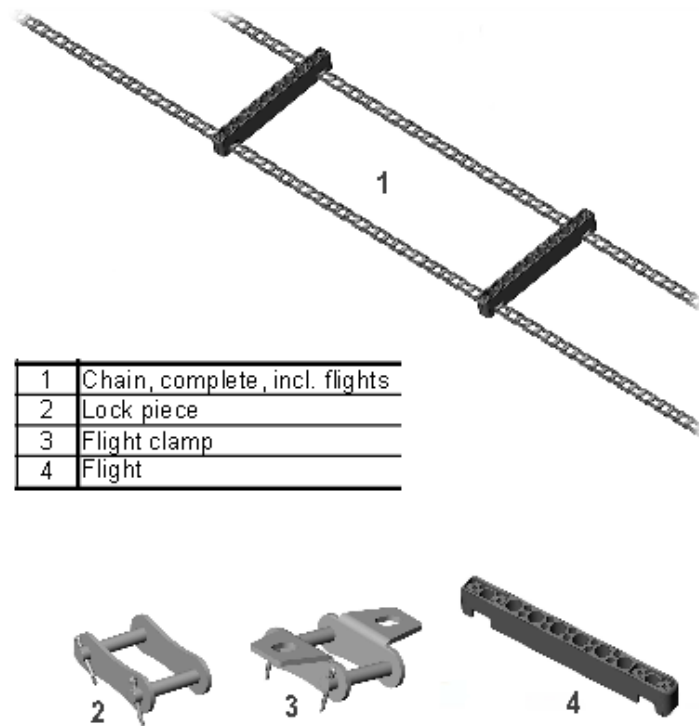


Figure 4.14. Log extractor chains and fitments [40].

Best solution would be using already finished and complete conveyor from other firewood machine available in the market. Suitable conveyor solution seems to be Palax Firewood processor KS 43 or 45 log extractor conveyor. The conveyor can be bought separately from Palax and it can be adjusted to fit with the new machine in development. In this way building process is simplified and the development time is decreased. The final solution, Palax KS 45 firewood processors log extractor conveyor, suitable for the project can be seen in Figure 4.15. With this approach the access to spare parts is guaranteed by Palax.

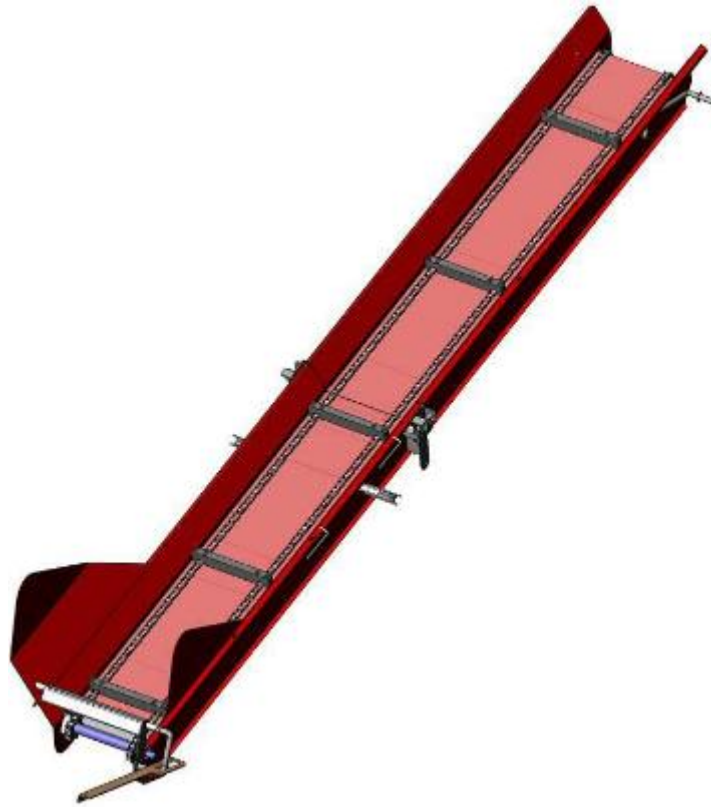


Figure 4.15. Available log extractor conveyor (Palax KS45) suitable for the project [40].

5. CONTROLLING OF THE MACHINE

A microcontroller Arduino Mega is used to control the whole automated process of the firewood machine. As mentioned before (see Chapter 1 and Figure 1.1) the firewood machine consist of six main mechanisms that have to be controlled to perform the automation of the machine. Those six mechanisms and the corresponding hydraulic actuator for each mechanism are presented in the following table, Table 5.1. The firewood machine is designed for mobile use, which determines the power source, a car engine, which in turn provides power source for microcontroller. As the alternator is producing between 12 to 14,5 volts, a voltage regulator is used to provide stable 12 volts for the microcontroller.

Table 5.1. Firewood machine mechanism and corresponding hydraulic actuator

Mechanism	Corresponding hydraulic actuator	Function
Log magazine	Motor	To drive log magazine
Log feeder conveyor	Motor	To drive the log feeder conveyor
Log clamp	Cylinder	To raise and lower the log clamp
Log cutter	Cylinder	To raise and lower the cutter blade
Log splitter	Cylinder	To push billet through the splitting knives
Splitting grid height adjuster	Cylinder	To adjust the height of splitting grid (lower or raise)

The microcontroller will control the process of each mechanism, when it is started and when it is stopped. Microcontroller sends signals to each hydraulic actuator and reads signals from sensors and switches. Input signals from switches and sensors are presented in Figure 5.1. Output signals are presented in Figure 5.2.

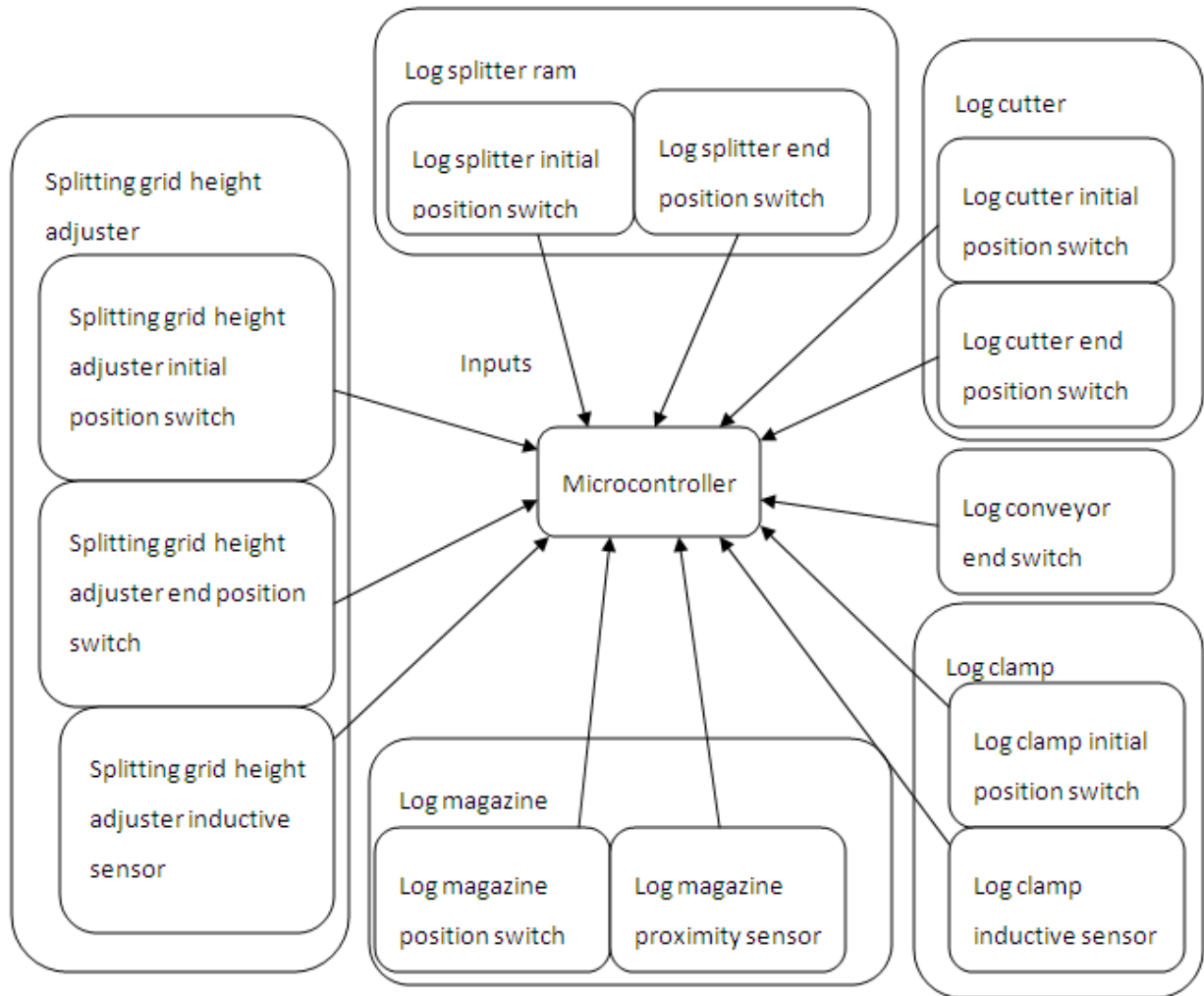


Figure 5.1. Microcontroller input signals

There are six hydraulic actuators that are controlled by microcontroller. Those six actuators are present in Table 5.1. A monoblock with six hydraulic solenoid valves or spools is needed to control those hydraulic actuators. Each valve has three positions with spring returned neutral position. The three position spool allows forward and reverse movement. The output schematics can be seen in Figure 5.2.

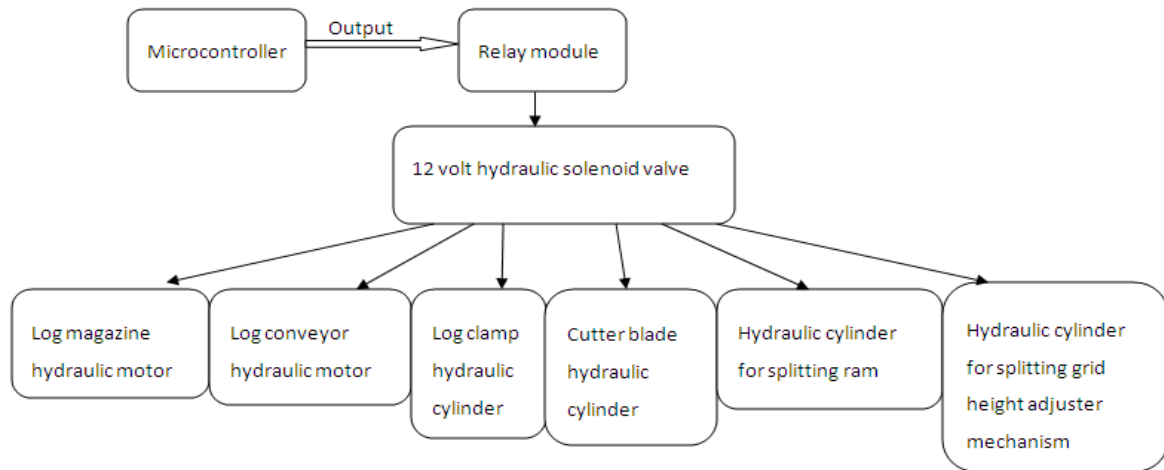


Figure 5.2. Microcontroller output signals

The machine should have two control modes. With the two mode configuration, operator is able to choose between manual and automatic mode. In automatic mode the machine runs by itself. In manual mode, each firewood machine mechanism can be controlled separately by pressing buttons manually. Manual mode is needed in case of testing purposes, logs get jammed or some other reason, to provide the opportunity for operator to control the machine. The control panel has a key switch to turn the power on and off, a twist switch to select either manual or automatic mode, manual mode button set and an emergency button to shutdown the machine in case needed. Control panel button configuration can be seen in Figure 5.3.

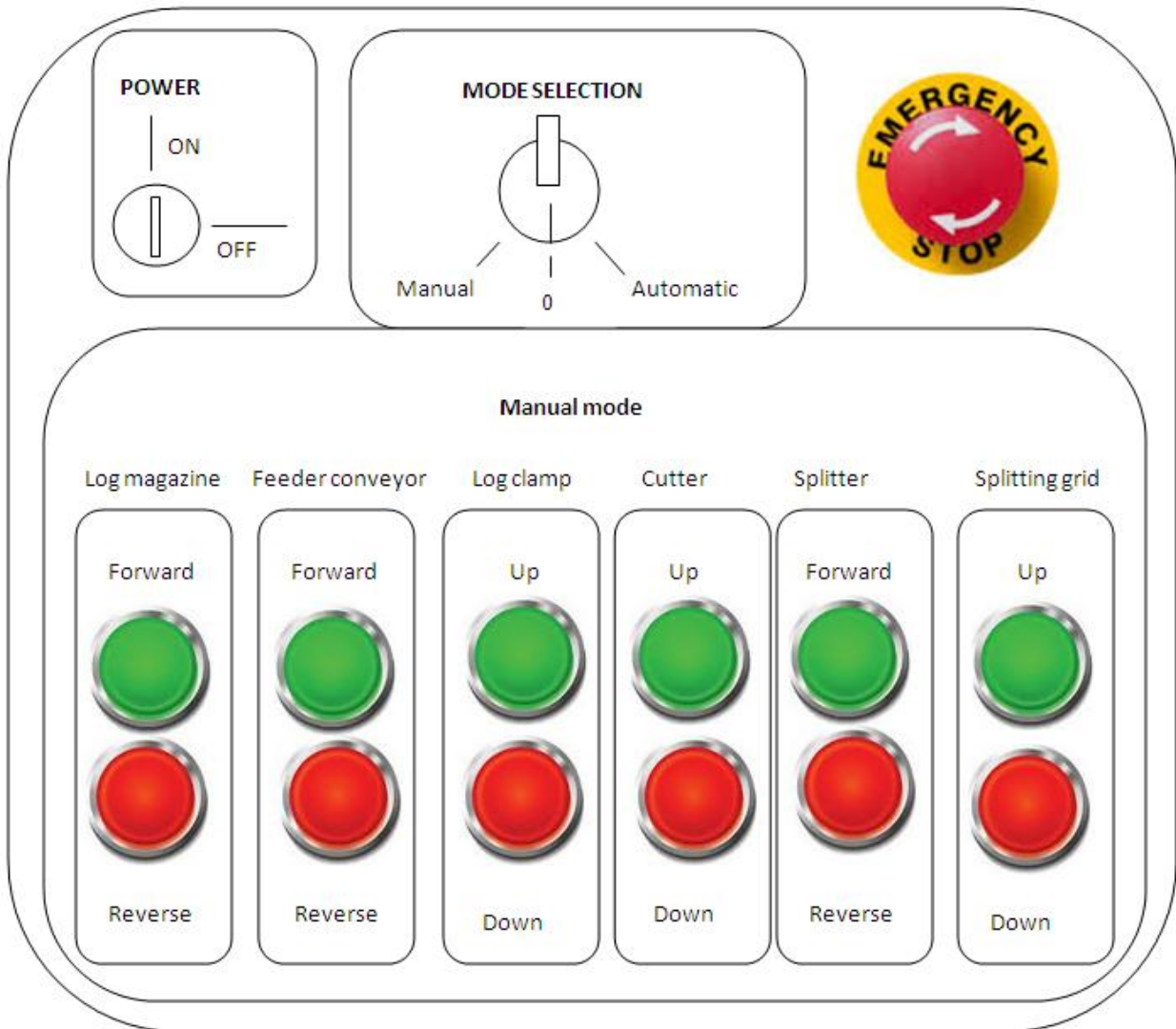


Figure 5.3. Control panel of the firewood machine

Controlling of the machine is done by the microcontroller Arduino Mega. The logical conditions how the whole firewood processor should work, is demonstrated by a flowchart which can be seen in Figure 5.4.

The process begins when the twist switch on the control panel is turned into automatic mode position. When it is in automatic mode, the first condition would be checking if the switch is turned into „0” position. If the switch is in „0” position the process is stopped. If switch is in automatic mode position, next step would be checking if there is a log on the log feeder conveyor. If there is a log on feeder conveyor, the process flow is passed to next step, if there is no log on the feeder conveyor, then the log magazine is actuated to turn one log slot. If there is a log on the feeder conveyor then log magazine is stopped and log feeder conveyor is

actuated. There is a sensor in splitting cutter to check if the new log has pushed last log block into the splitting cutter. If there is a log block in splitting cutter, then the conveyor is stopped and splitting process is started. If there is no block in cutter, then the log feeder conveyor is actuated.

The log feeder conveyor is actuated until the log length measurement switch at the end of the conveyor is hit or activated. When the switch is activated then predetermined log measurement is reached and it can be cut into block or billet, resulting the log conveyor to stop and log clamp to activate. At the same time when the log cutter is activated the reading from log clamp toothed bar is taken to determine the log diameter. Based on the log diameter the splitting grid height can be adjusted. The correct height of the splitting grid is activated when the cutter has reached its end point. When cutter has reached end point, the log cutter and after that log clamp is retracted. The next process would be acutating the log splitting ram. The conditions for splitting ram to move to its end point and back to initial state, are determined by the end and initial position switch. When the splitting ram has been retracted, then the process is started over again. The automatic mode is a loop that is started and ended by the twist switch found on the control panel.

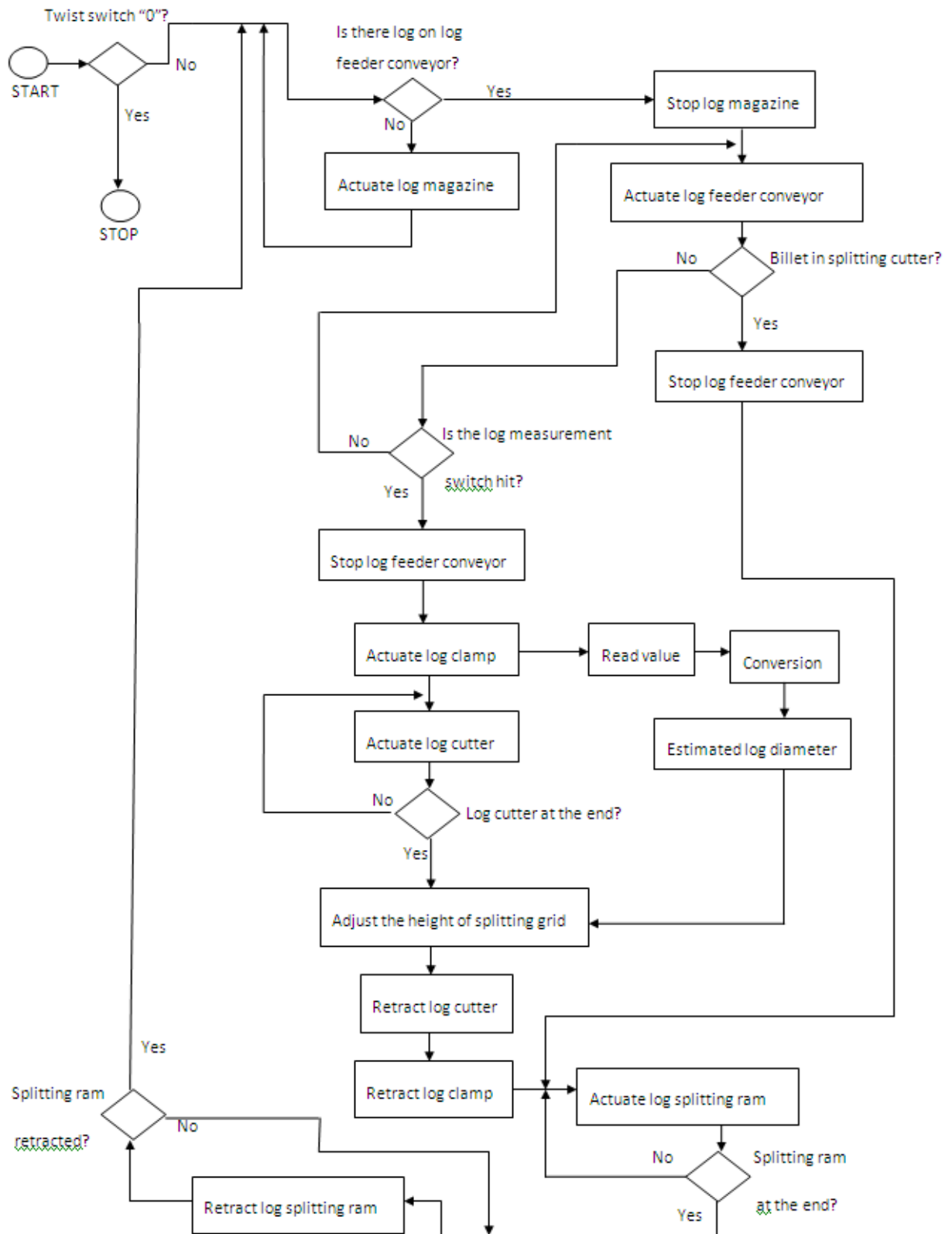


Figure 5.4. Automatic mode loop

6. CONTROLLING EQUIPMENT OF EACH MECHANISM

In this chapter the controlling equipment required and each mechanism with its specific controlling features are explained. Each mechanism has its own specific sensors or switches, which help to sense and detect the right condition to provide the automatic working capability of the whole firewood machine.

6.1 Log magazine

Log magazine has one mechanical switch to determine the position of the magazine and a proximity sensor to determine if another log is needed to be loaded onto log feeder conveyor. The mechanical switch is placed on the bottom side of the magazine. The switch is activated by the log supporter or carrier. If the switch is activated, then one log position is moved forward, which means the log is moved onto the feeder conveyor. Log magazine has hydraulic motor to drive and power the log chains. Hydraulic motor is connected to the shaft that drives the log magazine cross chain through a chain geared speed reduction mechanism. So the hydraulic motor does not drive directly, the motor drives speed reduction mechanism which finally drives the shaft of the log magazine. Log magazine has two shafts, one is driver and other is idler or driven shaft.

The proximity sensor is located on the log feeder conveyor (see Figure 6.1.). As the log being processed, reaches the end point, the proximity sensor is activated and announces that a new log can be moved from log magazine onto log feeder conveyor.

6.2 Log feeder conveyor

Log feeder conveyor transfers the log to the cutter by predetermined log length measurement. Log feeder conveyor has end switch. Log conveyor end switch can be seen in Figure 6.1. Log feeder end switch determines the length of the billet to be cut.

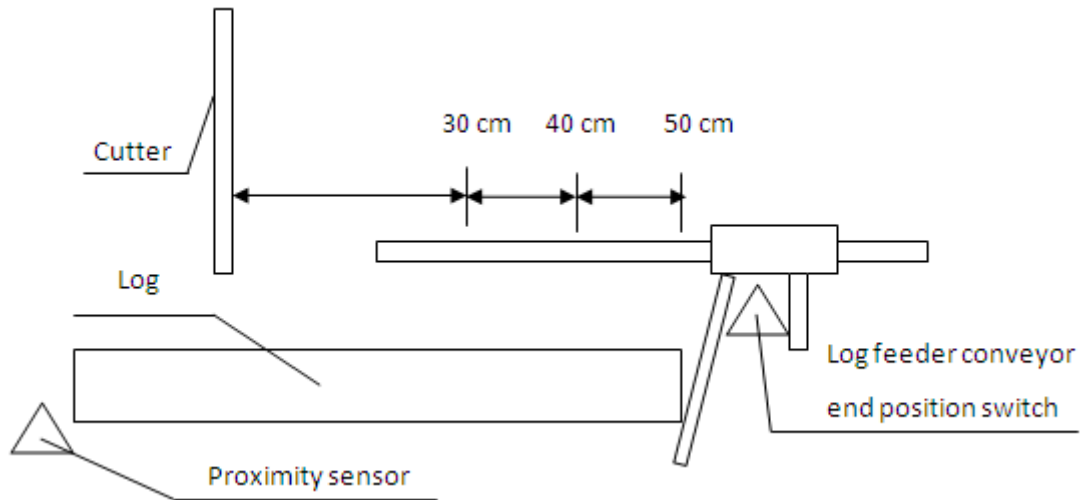


Figure 6.1. Log feeder conveyor end position switch

Log feeder conveyor is actuated until the log hits the end switch. End switch is lever actuated spring loaded mechanical device which is activated by the log. End switch can be adjusted according to the desired cutting length. The cutting length of the billet or block can be adjusted between 25 and 50 cm. Most common billet length are 30, 40 or 50 cm. The log conveyor has to travel according to the set billet length. Log conveyor has hydraulic motor to drive and power the conveyor. Hydraulic motor is connected via chains and gearing mechanism to the shaft that drives the log conveyor.

6.3 Log clamp

Log clamp has initial position switch and inductive sensor. Initial position switch determines if the log clamp is positioned in its initial position. Inductive sensor is used to measure the travelled distance of the log clamp. The log clamp is activated just before cutting operation and is kept activated until the cutter is returned to its initial position. As the log clamp is activated which means the clamp is pressurised with constant hydraulic pressure. Activated log clamp during cutting process is safety feature to ensure constant pressure to the log and no log movement during the cut. Log clamp schematics can be seen in Figure 6.2.

Log clamp plays quite a big role in the firewood machine. Log clamp has to carry two assignments. Firstly the log clamp has to hold or lock the log and secondly it provides the log diameter or log height measurement. Log diameter is used to adjust the height of the splitting grid or knives. As the log clamp is activated, it moves downwards against the log and

distance travelled is measured. A rack gear is attached to the log clamp mechanism and the teeth are counted as the log clamp travels downwards. Counted teeth number is considered equivalent to log diameter which finally results in the height of the splitting knives. The calibration of log diameter and splitting grid height adjuster can be executed by performing several tests with the prototype.

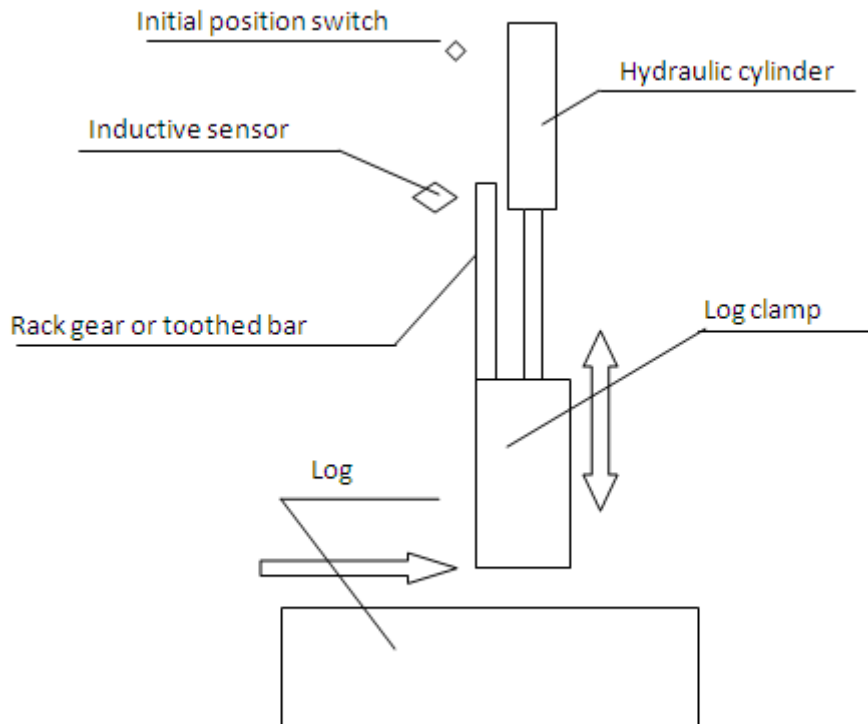


Figure 6.2. Log clamp schematics

There are several alternatives to measure the diameter of the log. First is the rack gear teeth counting technique as mentioned before. Second option would be using a laser sensor to measure the distance travelled by the log clamp. The final option would be using a sensor to measure the log height directly. A laser sensor is pointed directly at the billet in the v-shape cutter, just before it is pushed against splitting blades.

If the log clamp is moved against the log and no further movement is detected, the measurement is taken of how many teeth were counted. When the cutter blade finishes the cut, hitting the end switch, the log height measurement process is ended. The cutter end switch triggers the log splitting grid height adjuster, so the machine can set the splitting grid to proper level. The reading from log clamp is taken to measure the log height, and the log

cutter end switch activates the splitting grid height adjuster to adjust the splitting grid according to the log diameter. The splitting grid or the splitting knives center point is positioned to the center of the billet in order to split the billet into equal sizes.

The following example provides estimated conversion how the log diameter is calculated with the rack gear method. Let us assume that the log clamp maximum travel distance is 400 mm. Teeth counted for the maximum distance is 80. Log with the diameter 80 mm is equalized with 64 teeth count. When 48 teeth are counted, it would be converted into 160 mm log diameter. A conversion table is created (see Table 6.1) to illustrate the log diameter estimation with rack gear technique.

Table 6.1. Log diameter estimation table

Log clamp distance travelled [mm]	Corresponding rack gear teeth numbers	Estimated log diameter [mm]
400	80	0
320	64	80
240	48	160
200	40	200
100	20	300
50	10	350
0	0	400

In order to count the teeth of the rack gear a sensor is needed. Since the rack teeth are made of metal, the inductive NBB-V3-Z4L sensor can be used to detect each tooth that is passing the sensor.

6.4 Log cutter mechanism

The log cutter is actuated by hydraulic cylinder. Log cutter has upper initial position switch and lower end position switch. Log cutter hydraulic actuator travels the full distance, resulting the cutter blade to travel 30 cm. The basic log cutter schematics can be seen in Figure 6.3.

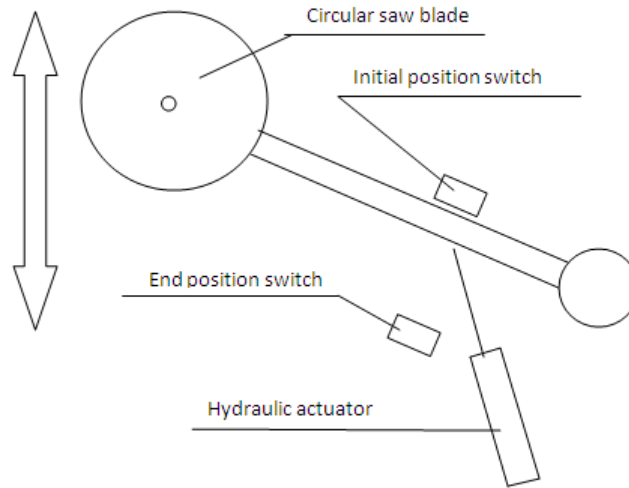


Figure 6.3. Log cutter basic schematics and switches locations

The logical condition to actuate the cutter blade is following: the log measurement switch has to be activated (the log has reached the determined cutting length), log clamp has to be activated in order to lock the log in place and splitting ram has to be in initial position. If these required steps are fulfilled, then the cutting process can be implemented.

6.5 Log splitting mechanism

Log splitting mechanism (see Figure 6.4.) in general consists of two mechanisms: log splitting cylinder or ram and splitting grid height adjuster mechanism. The designed 3D model can be seen in Figure 4.12. Log splitting cylinder is used to push the billet against and through the splitting knives in order to split the billet into smaller equal size pieces. Splitting grid height adjuster mechanism is used to adjust the splitting knives into proper height according to the diameter of the billet or log. The grid height is adjusted before the splitting process. The grid height is adjustment is carried out when the cutter hits the end position. The log splitting action takes place when cutter reaches the initial position.

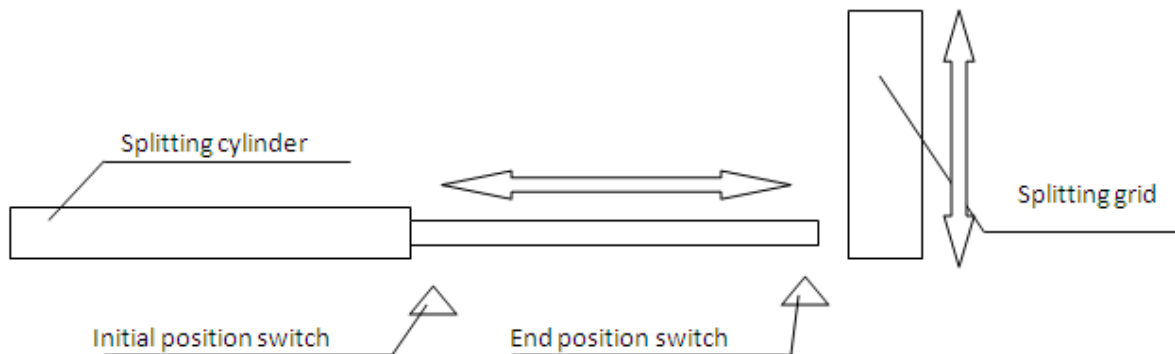


Figure 6.4. Log splitting mechanism

6.5.1 Log splitting ram

Splitting ram is activated after the cutting process has finished, cutter blade has returned to its initial position. The splitting cylinder or ram has two switches, as seen in Figure 6.4. One switch is for determining the initial position and the other for determining the end position of the ram. The log splitting ram is activated as soon as the cutter has returned to initial position. As the splitting cylinder is activated the pushing stroke is started. As the splitting cylinder reaches the end and hits end position switch, the return stroke is initiated. As the splitting ram activates initial position switch, one cycle of splitting operation is finished and ready for another one.

6.5.2 Splitting grid height adjuster

Splitting grid height adjuster has one hydraulic cylinder which is controlled by the microcontroller and it has initial position and end position switch. The splitting grid height adjuster mechanism has also rack gear or toothed bar mounted to the frame in order to position the splitting grid according to the log diameter. The splitting grid adjuster mechanism can be seen in Figure 6.5. The inductive sensor NBB-V3-Z4L is used to count the teeth of the rack bar or toothed bar, in order to position the splitting grid. The initial position and end position switches are for detecting boundaries or the limited position, most upper and most lower position the splitting grid can travel. The calibration of the splitting grid height adjuster is carried out by implementing several tests with the prototype.

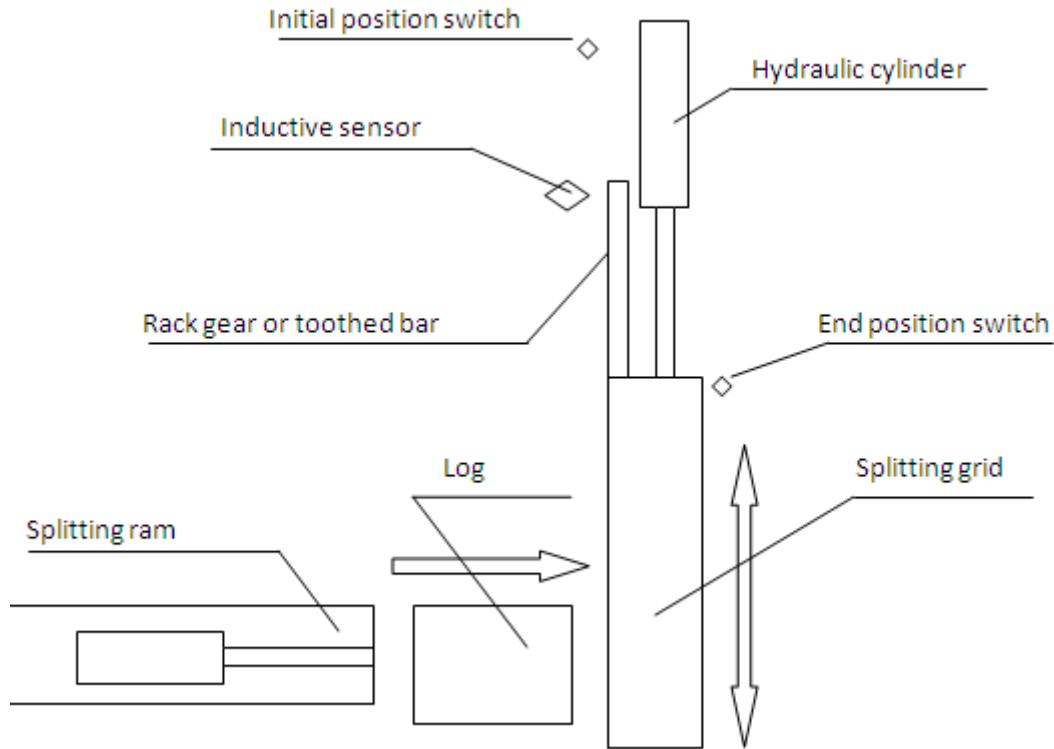


Figure 6.5. Splitting grid height adjuster

For example, if the splitting grid with two sets of knives is used then two main heights are considered. One set of knives splits into four parts and the other splits into six parts. This splitting grid can be seen in Figure 4.13. In general the splitting grid has to be raised and lowered according to log diameter. Two main splitting heights are based on the diameter of the log. Logs with diameter in between 15 to 20 cm are split into four and logs with diameter in between 20 and 25 cm are split into six pieces. The log diameter is received from log clamp mechanism as described in chapter 5.3. The conversion of log diameter to splitting grid height is similar to log clamp mechanism mentioned before, but with one exception. Logs between 20 to 25 cm are split into four and the splitting grid height is adjusted in certain level, bigger logs above 20 cm are split into six parts and the splitting grid height is adjusted in another level, by the offset of the two knife set. The offset is the difference between the two center points of four and six part knives.

6.6 Log extractor conveyor

Log extractor conveyor is started and stopped separately. Extractor conveyor runs continuously and has no relation to automation. Hydraulic three way valve controls the

conveyor. The hydraulic valve is actuated manually. Hydraulic adjustable choke valve is placed in between the log extractor conveyor hydraulic lines in order to control the speed of the conveyor.

7. RISK ANALYSIS

Risk analysis is performed in a way that the prospective machine would be safe for the operator. It is obligatory that only one operator is allowed to work and carry the necessary tasks to run the machine. Each mechanism and related risks is considered separately in the following chapters. There are several types of hazards involved with the firewood machine. The hazard classification is brought out in Table 7.1. The safe and hazardous zones around the firewood machine is brought out in Appendix 22.

Tabel 7.1. Hazards classification table

Type of hazard	Origin of the hazard
Mechanical hazards	<ul style="list-style-type: none"> - Rotating drive shafts - Chains and belts - Rotating circular saw blade - Heavy logs might fall - Moving machine elements - Angular parts
Thermal hazards	<ul style="list-style-type: none"> - Engine exhaust system - Engine cooling system
Electrical hazards	<ul style="list-style-type: none"> - short circuit
Noise hazards	<ul style="list-style-type: none"> - Rotating circular saw - Cutting the log crosswise - Engine running
Vibration hazards	<ul style="list-style-type: none"> - Engine running - Drive shafts - Belts and chains - Moving logs and billets
Substance hazards	<ul style="list-style-type: none"> - Fuel for the engine - Cooling liquid - Hydraulic oil

The classification of severity of the hazards are presented in Table 7.2. and a few „what if ...” possible hazardous situations are presented in Table 7.3.

Tabel 7.2. Severity level of the hazard

Severity level	Description	Scope of harm or damage
4	Major	Body part amputation, permanent disability or even worse death
3	Serious	Injuries requiring hospitalisation,
2	Moderate	Injuries requiring hospitalisation or lost work days
1	Minor	Injuries requiring first aid kit

The „what if ...” possible hazardous situations brought out in Table 7.3 might not take place at all, but it gives good overview of possible damages or injuries compared to the severity level of the threat listed in Table 7.2.

Table 7.3. What if ... possible hazardous situations

What if ...	Resulting condition	Severity level	Safeguards	Recommendations
Circular saw blade v-belt gets broken	Flying object, body injuries	3	Protective cover or shield	Protective cover obligatory
Circular saw blade has a fracture and shatters	Flying objects, body injuries	3 or 4	Protective cover or shield	Protective cover obligatory
Log clamp malfunction, causes log movement and resulting cutter blade shatter	Flying objects, body injuries	3 or 4	Protective cover or shield	Protective cover obligatory.
Wood chips or debris flying while logs are cut	Flying objects, eyesight injuries	2 or 3	Protective cover around saw blade and cutting area	Protective glasses or visor obligatory.
Log fall from magazine or conveyor	Moving objects, body injuries	2 or 3	Warning signs and safe distance.	Protective helmet, boots and gloves obligatory.

Hand gets pinched between belts, pulleys, chains and sprockets	Severe body injuries	4	Protective cover or shield	Pinch points warning stickers and protective cover obligatory.
Loose clothing getting entangled or caught in rotating drive shafts, sprockets, pulleys, belts or chains	Machine jam, break or overheating. Minor till severe body injuries.	1 - 4	Protective cover or shield. Correct clothing and personal safety equipment.	Warning signs of hazardous machine elements.

7.1 Hazards posed by firewood machine mechanisms

7.1.1 Log magazine

Log magazine is mechanism that holds or stores the logs and feeds them to log feeder conveyor. It is powered by hydraulic motor, which drives a gearing mechanism and the gearing mechanism drives a shaft which eventually moves the two chains that are moving the logs. The two chains are situated crosswise with the logs. In general, the log magazine has many moving parts and performs modern risk. Log magazine is actuated cyclically, so it is standing still most of the time. If the log magazine is actuated, it moves the chains about 30 cm, that's about the size of one log seat, and rolls the log onto log feeder conveyor.

Special care must be taken to the gearing mechanism. The gearing mechanism should be covered, so no debris and nobody could access the rotating sprocket wheels and chains. Gearing mechanism works as safety unit as well, since it takes the rotational speed down and multiplies the torque from hydraulic motor several times. Slow moving devices are little bit safer for humans. The two shafts (driver and driven shaft) and the two chains are performing a threat. The chains are under tension since heavy logs are situated on the chains. As the shaft rotates, damage may occur if something gets between the chain and sprocket wheel. Luckily the gearing mechanism decreases the speed of the log magazine when it is actuated. The log magazine is actuated only when the log being processed reaches end point and a new log may be rolled onto the feeder conveyor. The shafts and chains are actuated cyclically therefore threat from continuous moveable objects are lowered. If possible the cover for chain and

sprocket wheel area should be applied. Otherwise at least one meter safe zone around the log magazine should be assured while the firewood machine is activated and in action.

7.1.2 Log feeder conveyor

Log feeder is very similar to log magazine. It serves similar hazards as well. The log feeder conveyor poses mostly mechanical hazards like rotating shafts, moving chains and belts, and angular parts. Log feeder conveyor poses minor noise and vibration hazards. Log feeder runs cyclically, but more frequent than log magazine. Cycle frequent of the log feeder conveyor is determined by log clamp, log cutter and splitter duty cycle. Threat is posed by conveyor chains that are moving the log forward to cutter, and by angular parts. The gearing or gear reduction unit should be covered to minimize the risk of getting injured. The gear reduction unit reduces the rotational speed of the hydraulic motor and moves the conveyor relatively slow. Slowly moving objects are considered to be more safer. Safe zone of one meter around the log feeder conveyor should be assured while the firewood machine is running and in action.

7.1.3 Log clamp

Log clamp travels up and down to fix and lock the log while cutting. Log clamp is actuated by hydraulic cylinder. Operator has no activity related to log clamp and it has minor risk factor if treated correctly. Log clamp moves relatively slow and the travel distance is about 40 cm. Special care must be taken if processing crooked logs or logs with irregular shape, as they might flick or move when the log clamp locks the log in place and may cause a risk or threat.

7.1.4 Log cutter

Log cutter is a circular saw which rotates at very high speed and it is moved vertically up and down. Log cutter is considered as most dangerous mechanism of the firewood processor. Log cutter generates saw dust as it cuts through wood. Wood chips, debris and other small particles might fly as the blade cuts through wood. Eye protection against flying particles should be used. The circular saw blade is powered by diesel engine via drive shafts and v-belts. Drive shafts, v-belt and pulley mechanism should be covered to avoid any access to them as severe damage and injuries might occur.

7.1.5 Splitting ram

Splitting ram is hydraulic cylinder which pushes the billet through splitting wedges. Splitting ram is situated under the log feeder deck and is guarded quite well. When the splitting ram is in its fully extended stroke, the piston rod is covered with metal shield to protect the cylinder rod from falling billets or blocks as something might go wrong and damage may occur. The splitting area is guarded while the machine is in action. The guard prevents any access as severe injuries might take place when something gets between billet and splitting ram or billet and splitting wedges.

7.1.6 Splitting grid height adjuster

Splitting grid holds sets of splitting wedges or knives. Splitting grid is moved vertically up and down. Splitting grid may pose a threat by its angular edges and sharp knives. It is heavy and needs special attention when handled or serviced.

7.1.7 Log extractor conveyor

Log extractor conveyor transports the log pieces away from the machine to avoid any jam or obstruction. The extractor conveyor is powered constantly. The firewood or log pieces landing zone at the end of the conveyor should be considered as dangerous and four meter radius safe zone should be assured.

7.2 Operator safety equipment

Operator of the firewood machine has to carry safety equipment in order to work with the machine. The personal protective equipment needed is listed in Table 7.4. Operator has to carry personal protective equipment against possible threats from falling logs, flying wood chips and noise. Easy access to emergency switch should be assured. Paper towels should be provided in case of contact with chemicals like hydraulic oil, fuel, coolant or grease. A first-aid kit should be easily reachable.

Table 7.4. Personal protective equipment and related hazards to protect against

Personal protective equipment	Related hazards
Safety helmet	Moving objects, lifting logs with the crane
Eye protection (a visor or safety glasses)	Against flying wood chips, debris and dirt
Hearing protection (ear plugs or muffs)	Against noise level above 85 dB
Protective boots	Against falling objects, logs, heavy equipments
Gloves with reinforced palms and fingers	To provide good grip and safe log handling

8. ESTIMATED BUILD COST

In this chapter estimated costs to build this firewood machine are calculated. As there might be several opportunities and variations how this machine can be built, then there would be also variation in build costs. This is just one of the approaches how the machine is built and what it might cost. Some of the prices are very approximate, some parts might be exchanged during the build causing the final build cost to fluctuate even more. The labor cost for the project is calculated based on five euros per hour salary, resulting around 4800 eur per six months. The salary considered in the calculations is net salary, no taxes included. Build costs for log magazine are shown in Table 8.1, costs for log feeder conveyor are shown in Table 8.2, costs for log clamp mechanism are shown in Table 8.3. Estimated costs for log cutter are presented in Table 8.4. Splitting mechanism costs are presented in Table 8.5 and 8.6.

Table 8.1. Log magazine components

Component	Units required	Price [EUR]
Hydraulic motor OMP-400C	1	140
Chain	10	300
Gear reduction unit T281-J; 1:2.91; 8,1kW	1	132
Sprocket	4	200
Bearings UCP210	4	50
Shafts	2	200
Construction	-	40
Fasteners	-	50
Total		1112

Table 8.2. Log feeder conveyor

Component	Units required	Price [EUR]
Hydraulic motor OMP-400C	1	140
Chain	10	300
Gear reduction unit T281-J; 1:2.91; 8,1kW	1	132
Sprocket	4	200
Shafts	2	100

Bearings UCP210	4	50
Construction	-	40
Fasteners	-	50
Total		1012

Table 8.3. Log clamp components

Component	Units required	Price [EUR]
Hydraulic cylinder 70/40/400	1	257
Construction elements (sheet metal, U-shaped steel bar)	-	120
Fasteners	-	30
Toothed bar	-	50
Total		577

Table 8.4. Log cutter mechanism components

Component	Units required	Price per unit [EUR]	Price [EUR]
700 mm circular saw blade	1	179	179
Shaft	3	-	650
Pulleys	4	50	200
V-belts	6	15	90
Bearings UCP210	6	12	72
Metal parts	-	-	100
Sheet metal for safeguard	-	-	50
Fasteners	-	-	50
Total			1391

Table 8.5. Log splitter mechanism components

Component	Units required	Estimated price [EUR]
Hydraulic cylinder CN2SFB	1	140
Metal (U-shape)	-	150
Fasteners	-	40
Total		330

Table 8.6. Log splitting grid and height adjuster

Component	Units required	Estimated price [EUR]
Hydraulic cylinder CN2SFB	1	140
Metal (U-shape)	-	50
Sheet metal (knives, grid) 90x10 S235	-	100
Toothed bar	1	50
Total		340

The controlling components required for the machine are shown in Table 8.7.

Table 8.7. Controlling components

Component	Units required	Price [EUR]
Inductive sensor NBB-V3-Z4L	2	160
Proximity sensor	1	90
Switch	7	84
Microcontroller Arduino Mega	1	50
Relay	1	40
Hydraulic valve module Z50x6 12V	1	730
Hydraulic lines	-	300
Hydraulic pump	1	380
Hydraulic fluid MGE46V	100 litre	240
Total		2074

Table 8.8. Project cost

Components	Units required	Price [EUR]
Controlling	2	2308
Log splitting grid and height adjuster	2	680
Log splitter	2	660
Log cutter	2	2782
Log clamp	2	1154
Log feeder conveyor	2	2024

Log magazine	2	2224
Log extractor conveyor	1	1000
Perkins 403D-11 20 kW diesel engine	1	4400
Car trailer Respo 2700P402T205 2700 kg	1	3759
Log crane 4,7 m	1	5640
Labor cost	6 months	4800
Total		32351

The total project costs are presented in Table 8.8. The estimated costs for the project would be around approximately 35000 EUR. As mentioned earlier, the costs might fluctuate even more because of the possible upcoming changes in equipment, changes in prices, upcoming equipment delivery costs, add up of the inspection and registration costs of the car trailer and because some of the components exact prices are still unknown and therefore estimated at this point.

In conclusion, this mobile firewood processor with its automatic capabilities makes it quite unique and powerful tool to process firewood. The price range of the final firewood processor is quite high as compared to the other similar products, but the benefits of the automatic mode, log sorting and operator's work task allocation, will lower the machine idle time and increase the production rate.

9. FUTURE DEVELOPMENTS AND IMPROVEMENTS

The status of the firewood processor described in current thesis is at a very beginning stage and many improvements are to be made. The firewood machine needs some further developments in the future to improve the efficiency of the machine.

At first the log optimization process could be added. With this approach, the last remaining log is measured from back side and the excess block is cut at the front side, closest to the cutter. The result of this optimization process would be improved quality of the produced firewood, since the number of evenly cut logs are increased. Also the waste piece should be extracted by separate actuator or mechanism.

Second improvement would be creating several mappings for log block length in relation to log diameter. Those mappings could be used for setting the parameters for firewood processor to determine which output is desired. In some cases 50 cm length logs with diameter up to 20 cm should be splitted into two, logs with diameter between 20 and 30 cm should be splitted into four parts. Sometimes 50 cm length logs with diameter up to 15 cm should be split into four parts. While other cases determine that logs with 30 cm in length and diameter between 20 to 25 cm should be split into eight parts or same 30 cm length logs with diameter of 20 to 25 cm should be split into four parts. There are several oportunities how the logs are cut and into how many pieces the pillets are split depending on the customer needs. The mappings help to adjust the firewood machine settings according to the desired output.

Third improvement would be changing some current sensors or add some new sensor in order to simplify the measuring of the log diameter process and improve the accuracy of the splitting grid adjuster.

Log measurement switch mechanism can be exchanged for single sensor which measures the length of the log by lazer beam.

Most advanced improvement would be changing the log splitting process into machine vision guided process and the splitting grid adjuster to move along two axis, vertically up and down, horizontally left and right. As the log block situated in the v-shape splitting cutter might have

branch, dirt, snow, ice or some other residue that influences the center point of the log block to shift causing a mismatch or misalignment between log diameter measured and splitting grid height adjusted. If the center point of a log gets misaligned with the center point of the splitting grid then the result would be uneven sizes of pieces. The position and diameter of the log is determined with a camera and machine vision technology which enables the splitting grid to be adjusted right in the center of the log block. This method improves the quality of production as the wood is split evenly.

Another advantage of the machine vision technology would be calculating the volume of firewood produced per period of time by measuring the log diameter and number of blocks cut. This approach enables to measure the volume of the outcome, loosely fallen firewood pile. As wood stacking requires human labor, then transporting the loosely packed firewood directly to customer without stacking, would save a lot of effort. The problem of delivering loosely packed firewood is the fact that the volume can not be measured accurately and in most cases the customers are not satisfied with the result. Many customers still would like to have their firewood delivered in stacked form, so they can be convinced in right volume of firewood. With the ability to measure the quantity of firewood produced, would result in more efficient firewood production. With the ability to measure the quantity of firewood produced, will provide also the ability to compare the relation between wood volumes before and after processing them.

SUMMARY

This thesis proposes a new and innovative technology which processes firewood more efficiently, reducing the time and labor required for the production. The aim of this thesis was to develop a concept of a firewood processor specifically designed for mobile use with automated processes.

The novelty of this newly designed firewood processor is the compact design with integrated log storing and handling device called log magazine and the overall automation of the main log handling processes. Those automated mechanisms are log magazine, log feeder conveyor, log clamp, log cutter saw, log splitting ram and splitting grid height adjuster. Log lifting and sorting is executed by the operator with a assistance of a log crane. Billets are extracted from the machine by log extractor conveyor which runs continuously.

At first market research was performed, based on which some similar firewood processors were drawn out and compared. The most suitable solution for each mechanism was then selected based on the comparison. After the composition of the firewood machine, the controlling mechanism was proposed, followed by cost calculation and risk analysis.

The firewood processing machine is designed to reduce the risks of injuries for the operator. Possible risky and hazardous parts are pointed out as well as the safety requirements needed towards those hazardous machine parts and possible situations. Recommended personal safety equipment for the operator for safe and riskfree firewood production is also drawn out.

In author's opinion, the log diameter, log cutting length measurement as well as the log splitting grid height adjustment mechanism should be substituted in the future with a more accurate and compact laser sensor technology. The exact performance of the firewood machine can be evaluated after some experimental tests with future prototype.

Author is pleased with the results of this thesis. In conclusion the thesis provides basic knowledge and conceptual design of the automatic firewood machine, its mechanisms and the concept of how it processes firewood. The machine is designed for mobile use, towing the machine directly to wherever wood is located and serves to do that. Despite of high pricing, the machine should produce firewood more easily and efficiently, saves time and labor

requirements. The automation of the firewood machine allows to redirect operator's work tasks to control the log crane and to ensure wood's presence in log magazine, which in return decreases machine idle time and boosts productivity rate.

KOKKUVÕTE

Antud töö eesmärgiks oli välja töötada uus ja innovatiivne tehnoloogia küttepuude töötlemiseks, mis säästaks aega ja inime tööressursse. Töö käigus valmis halumasina kontseptsioon spetsiaalselt mõeldud töötama mobiilse üksusena ning mille põhilised protsessid on automatiseeritud. Põhilised automaatsed mehhanismid on: magasin, etteande konveier, fiksaator, lõikur ja tükeldaja. Kusjuures puude tõstmine, sorteerimine ja paigutamine magasinini jääb operaatori ülesandeks. Halud eemaldatakse masinast konveieriga.

Uudse halumasina eelis seisneb operaatori tööülesannete ümber jaotamisel puude etteandmisele, sorteerimisele ja paigutamisele magasinini. Operaatori töö ümber jaotamist võimaldab halumasina automaatne juhtimissüsteem, mille tulemusena ei ole vaja enam pidevat operaatori tähelepanu. Operaator peab tagama ainult puude olemasolu magasinis. Automaatne juhtimissüsteem võtab vastavalt vajadusele puud magasinist, söötab need ette lõike mehhanismile, hoiab puunotti kinni vastava fiksaatoriga, lõikab ja tükeldab iseseisvalt. Pakkude lõhestamine toimub spetsiaalse seadme abil, mis omab kahte lõhkumisterade kombinatsiooni (4 ja 6 või 6 ja 8 tera) ja mille kõrgus reguleeritakse automaatselt vastavalt puu diameetrile. Puu diameetri hindamine teostatakse puunoti fikseerimise mehhanismiga.

Esmalt teostati turu-uuring, kus võrreldi olemasolevaid halumasinaid, nende eeliseid ja puudusi. Võrdluse käigus valiti välja sobivaimad lahendused iga mehhanismi jaoks. Käsitleti ka masina juhtimiseks mõeldud algoritmi, mis seisnes iga mehhanismi lülitite ja andurite staatuse kontrollimises. Lisaks on töös välja toodud ka võimalikud ohuallikad ja ohtlikud mehhanismid. Peamisteks ohtlikeks kohtadeks on: pöörlevad elemendid (võllid, kardaanid) ning võimalus jääda keti ja ketirataste või rihma ja rihmarataste vahele. Lisaks pöörleb saeketas suurel kiirusel ning kokkupuutel puuga võib tekkida lenduvaid osi. Saeketta purunemisel võivad tekkida suured kahjud. Välja on toodud ka nõuded operaatori ohutusvarustusele halumasinaga töötamisel. Kõige lõpuks on töös välja toodud ka toote hinna kalkulatsioon.

Autori arvates võib tulevikus puu diameetri, paku pikkuse ja lõhestusterade kõrguse reguleerimiseks mõeldud seadmed või andurid asendada uudsemate ning täpsemate laser anduritega. Antud halumasina tootlikust saab hinnata alles prototüübi valmimisel ja selle töösse rakendamisel. Autor jääb töö tulemustega rahule, kuna valminud on halumasina

esmane kontseptsioon, millele toetudes on võimalik edaspidi ellu viia täiendusi või uuendusi. Välja töötatud halumasina mudel on loodud eeskätt töötama automaatselt ja mobiilse üksusena.

REFERENCES

Internet sites:

1. Website of Reikalevy, Autochopper models [WWW] http://www.reikalevy.fi/en/energy/log_splitters.html (22.03.2016).
2. Website of Reikalevy, Hydraulic log lifter photo, [WWW] http://www.reikalevy.fi/en/energy/log_lifter.html (22.03.2016).
3. Website of Comact, wave feeder [WWW] <http://www.comact.com/equipments/sawmill-equipment/handling-log/wave-feeder-for-logs-lwf-300> (23.03.2016).
4. Website of Youtube, Comact wave feeder video, [WWW] <https://www.youtube.com/watch?v=Yh-sJPo13Sg> (23.03.2016).
5. Website of Youtube, Rotary log singulator video [WWW] <https://www.youtube.com/watch?v=IDmUir8edRY> (23.03.2016).
6. Website of Youtube, Reciprocating feeder video [WWW] https://www.youtube.com/watch?v=QUp8ru_zJtw (23.03.2016).
7. Website of Youtube, Springer screw conveyor system video [WWW] <https://www.youtube.com/watch?v=Nm8NX6cgREE> (23.03.2016).
8. Website of USN, step feeder [WWW] <http://www.usnr.com/Pages/prod.aspx?ProductId=StepFeeder> (23.03.2016).
9. Website of Springer, Springer screw infeed unit [WWW] <http://www.springer.eu/en/log-processing-and-sorting-lines/log-sorting/screw-infeed.html> (23.03.2016).
10. Website of Youtube, Springer screw conveyor system video [WWW] <https://www.youtube.com/watch?v=Nm8NX6cgREE> (23.03.2016).
11. Website of Wikipedia, Firearm magazine term [WWW] https://en.wikipedia.org/wiki/Magazine_%28firearms%29 (23.0.2016).
12. Website of KARA [WWW] <http://kara.fi/products/conveyors-and-sawmill-lines/tukkikuljettimet> (24.03.2016).
13. Website of Lietotidarbagaldi.lv [WWW] <http://lietotidarbagaldi.lv/en/kokapstraades-iekaartas-16710/transportjory-16723/log-table--step-feeder--conveyor> (24.03.2016).
14. Website of Enzinger [WWW] <http://www.enzinger-landtechnik.de/forstmaschinen/saegespaltautomaten/> (25.03.2016).

15. Website of Maaselan Kone Oy [WWW] <https://www.maaselankone.fi/en/content/hakki-pilke-hawk-25> (25.03.2016).
16. Website of Built-Rite [WWW] <http://www.built-rite.com/> (04.04.2016).
17. Website of Yumpu [WWW] <https://www.yumpu.com/en/document/view/38474234/mastersplit-wp36-amp-wp30-farmi-forest-corporation> (04.04.2016).
18. Website of Youtube, video, [WWW] https://www.youtube.com/watch?v=fbq_3VFNHiU (05.04.2016).
19. Website of Pezzolato, link to TLA 150 video, [WWW] <https://vimeo.com/channels/1042648> (05.04.2016).
20. Website of Youtube, video [WWW] <https://www.youtube.com/watch?v=UYDrMx7cgEU> (05.04.2016).
21. Website of Bilke, [WWW] <http://www.bilke.net/en/bilke-s3-en> , (11.04.2016).
22. Website of Japa, [WWW] <https://japa.fi/en/product/japa305> (12.04.2016).
23. Website of Japa, [WWW] <https://japa.fi/en/product/japa355> (12.04.2016).
24. Website of Metsaomanik, [WWW] <http://www.metsaomanik.ee/media/Japa355-tutvustus.pdf> (12.04.2016).
25. Website of Japa, [WWW] <https://japa.fi/en/product/japa235> (14.04.2016).
26. Website of Japa, [WWW], <https://japa.fi/en/products/accessories?page=1> (14.04.2016).
27. Website of Japa, [WWW], <https://japa.fi/en/product/japa435> (14.04.2016).
28. Website of Japa, [WWW], <https://japa.fi/en/products/accessories> (19.04.2016).
29. Website of Palax, [WWW], <https://www.palax.fi/en/products> (20.04.2016).
30. Website of Reikälevy [WWW], http://www.reikälevy.fi/tiedostopankki/324/SAMI_Autochopper_esite_A4_EN_6.0_web.pdf (23.04.2016).
31. Website of Hakmet, [WWW], <http://www.hakmet.com/PalaxFirewoodProcessors.asp?Bottom=3&Info=1&PicNo=1> (23.04.2016).
32. Website of Fuelwood, [WWW], <http://www.fuelwood.co.uk/Firewood-Processors/355-Firewood-Processor.aspx> (23.04.2016).
33. Website of Maaselankone, [WWW], <https://www.maaselankone.fi/en/content/hakki-pilke-easy-42#tekniset> (23.04.2016).
34. Website of Maaselankone, [WWW], <https://www.maaselankone.fi/en/content/hakki-pilke-easy-50s#kuvat> (23.04.2016).

35. Website of Youtube, video, [WWW], <https://www.youtube.com/watch?v=UjbLZzTlbk8> (23.04.2016).
36. Website of Pezzolato, [WWW], <http://www.pezzolato.it/en/prodotto/redline/tlc-1200-firewood-processor> (24.04.2016).
37. Website of Youtube, video, [WWW], <https://www.youtube.com/watch?v=8JJBvhlafsc> (25.04.2016).
38. Website of Youtube, video of Pezzolato TLA 150, [WWW], https://www.youtube.com/watch?v=gMbf9hsb_Gg (25.04.2016).
39. Website of Youtube, video of Pezzolato TLC 1400, [WWW], <https://www.youtube.com/watch?v=23nFMq3T8B4> (25.04.2016).
40. Website of Palax, spare parts manual, [WWW], https://palax.fi/sites/default/files/Varaosakirja_KS45_3-2014_0.pdf (10.05.2016).
41. Website of Reikälevy Oy, [WWW], http://www.reikalevy.fi/en/energy/log_splitters.html (12.05.2016).

Books and articles:

42. Bodnar F., Minarik M. “Coniform-shape tool for splitting of wooden logs”, Research in Agricultural Engineering, 2015, Vol 61, No 1, pages 29-34.
43. Cavalli R., Grigolato S., Sgarbossa A., “Productivity and quality performance of an innovative firewood processor”, Journal of Agricultural Engineering, 2014, volume 228, pages 32-36.
44. H. R. Tolley, “Machinery for cutting firewood”, U.S. Dept. of Agriculture, 1919.

APPENDICES

APPENDIX 1



USNR step feeder. Source: www.usnr.com [8]



Springer infeed screw. Source: www.springer.eu [9].

APPENDIX 3



Rotary log singulator. Source: screenshot from video [5],
<https://www.youtube.com/watch?v=IDmUir8edRY>.



Figure XXX. Longitudinal log chain conveyor. Source www.kara.fi [12].

APPENDIX 5



Figure XXX. Longitudinal log chain conveyor. Source www.kara.fi [12].

APPENDIX 6



Chain conveyor. Source: <http://lietotidarbagaldi.lv> [13]



Log feeder with rotating rollers [16]

APPENDIX 8



Mastersplit WP 30 and 36 firewood processor with sliding deck log feeder [17].



Push plate log feeder [18]



Pezzolato TLA 150 push plate feeder unit [19]

APPENDIX 11



Grapple used as log feeder [20]

APPENDIX 12



Japa 305 mobile firewood machine [22].



Firewood machine Japa 355 [23].

APPENDIX 14



JAPA® 495 LOG LIFTER



JAPA 465 LOG RACK



**HYDRAULIC LOG DECK
JAPA46501**



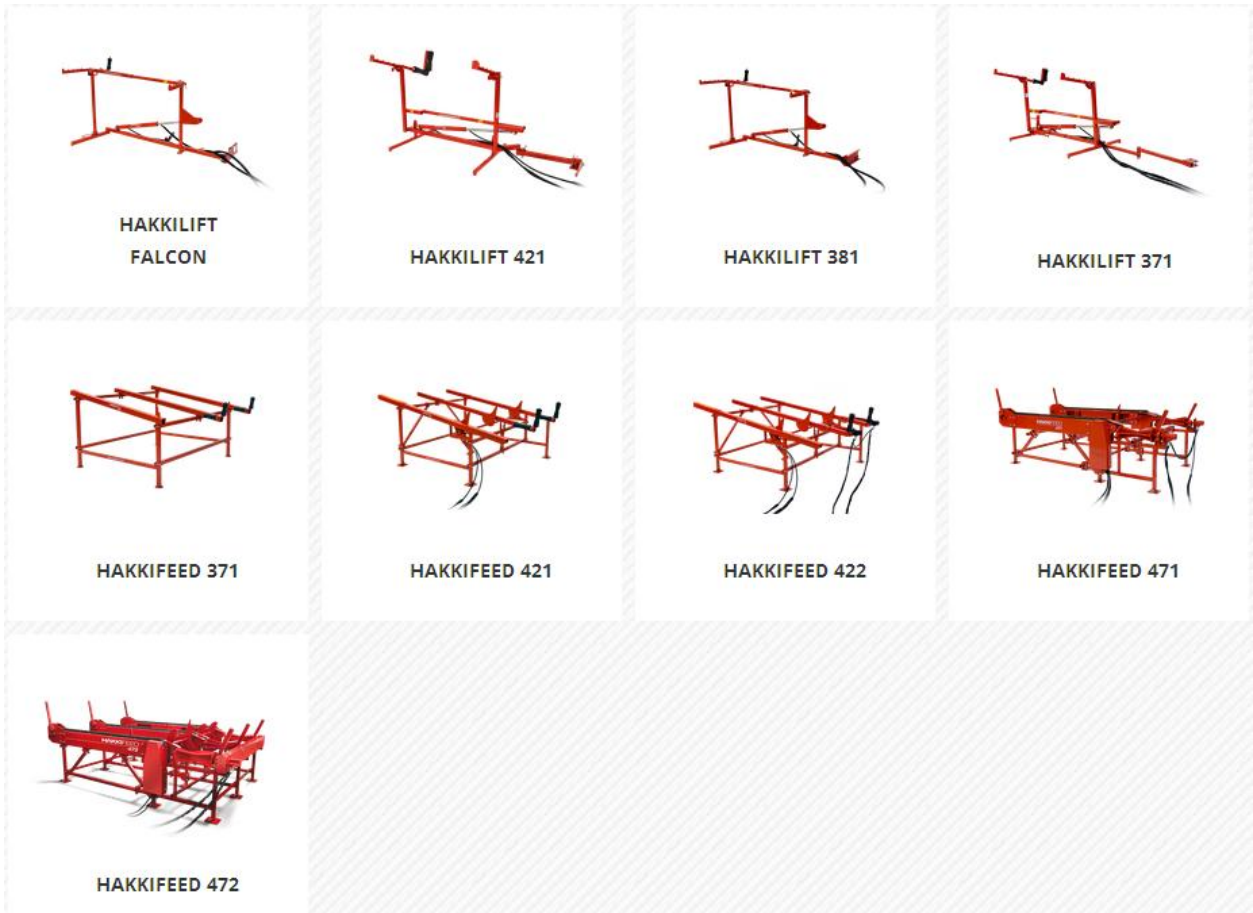
**HYDRAULIC TIMBER
DECK**

Japa firewood accessories. Source: www.japa.fi [26].



Japa 435 splitting knives mesh. Source: www.japa.fi [27]

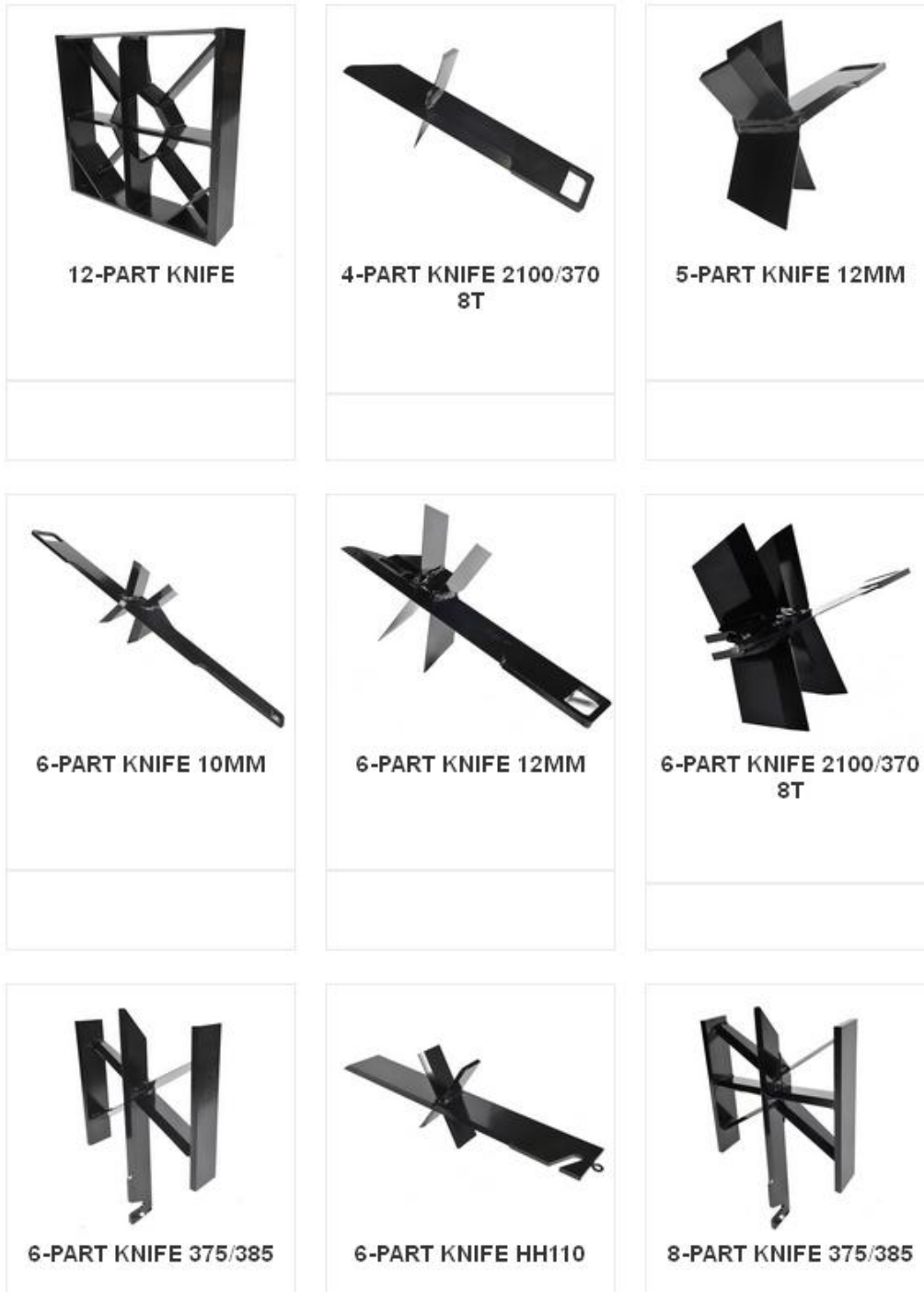
APPENDIX 16



Hakki Pilke accessories. Source: <https://www.maaselankone.fi/en/products/accessories>.

APPENDIX 17

Accessories



Japa firewood machines splitting knives set. Source: www.japa.fi [28].

Firewood processors with a circular saw

Three reasons to choose a circular saw for your firewood processor: Speed, freedom of maintenance, a small amount of sawdust generated. The Palax firewood processors with a circular saw are real powerhouses, which do not freeze in the face of challenges. The hard-metal blade cuts the log reliably and quickly. Long sharpening intervals increase the effective working time. Even the splitting blade with quick-release can be changed in a matter of seconds.



PALAX 55T

The Palax 55T is the right choice for a tough guy, who yearns for a smaller handy and easy-to-use firewood processor.



PALAX C900

The new generation Palax C900 is a firewood processor with a circular saw-blade for professional use in demanding conditions.



PALAX COMBI M II

The real bestseller of Palax is an easy-to-use, versatile and fast firewood processor.



PALAX POWER 100

The Palax Power 100 provides an uncompromising productivity and effect for the handling of large logs.




PALAX POWER 70

Uncompromising speed and efficiency with the fastest firewood processor with a circular blade on the market.


Firewood processors with a chain saw

The chain saw offers a greater cutting diameter compared with the hard-metal blade machines in the same category. The Palax chain saw machines are uncompromising and tireless powerhouses, with a taste of steel and exceptional drive. They are at the very best, when the thickness of the logs varies a great deal. To make the workman's life easier, all the chain saws are fitted with an automatic chain lubrication system and quick-release of the splitting wedge.




PALAX ACTIVE

The smallest member of the Palax chain saw range makes processing of firewood effortless and fast at a competitive price.




PALAX D350

The Palax D350 is a great choice for processing firewood, especially when the diameter of the logs, to be processed, varies a great deal.




PALAX KS 35

Easy-to-operate, easy to handle, 15" chain-saw ready to use.



PALAX KS 40

The KS 40s, which is more robust than the smaller models in the range, is the choice of seasoned professionals.



PALAX KS 45S

The Palax KS 45s brings high capacity, speed and sheer force to the professional processing of firewood.

Palax firewood processors with circular saw and chain saw [29].

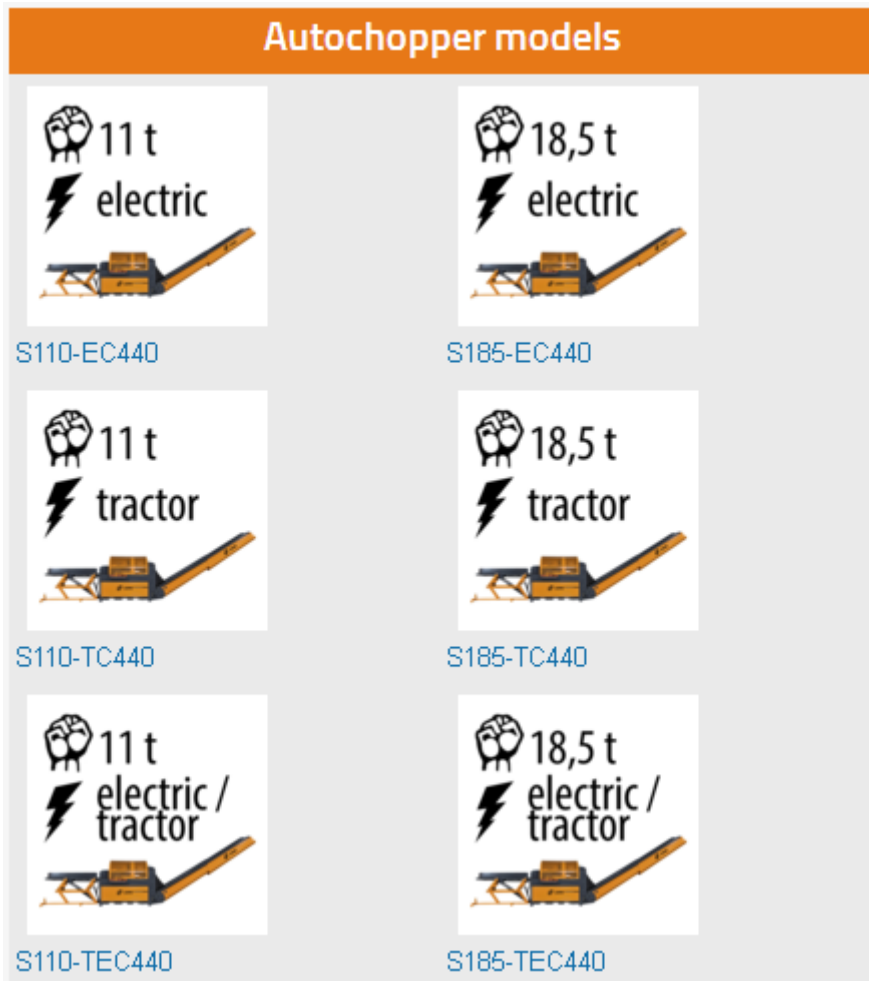


Pezzolato TLA 150 firewood processor with multiple splitting grids [38].

APPENDIX 20

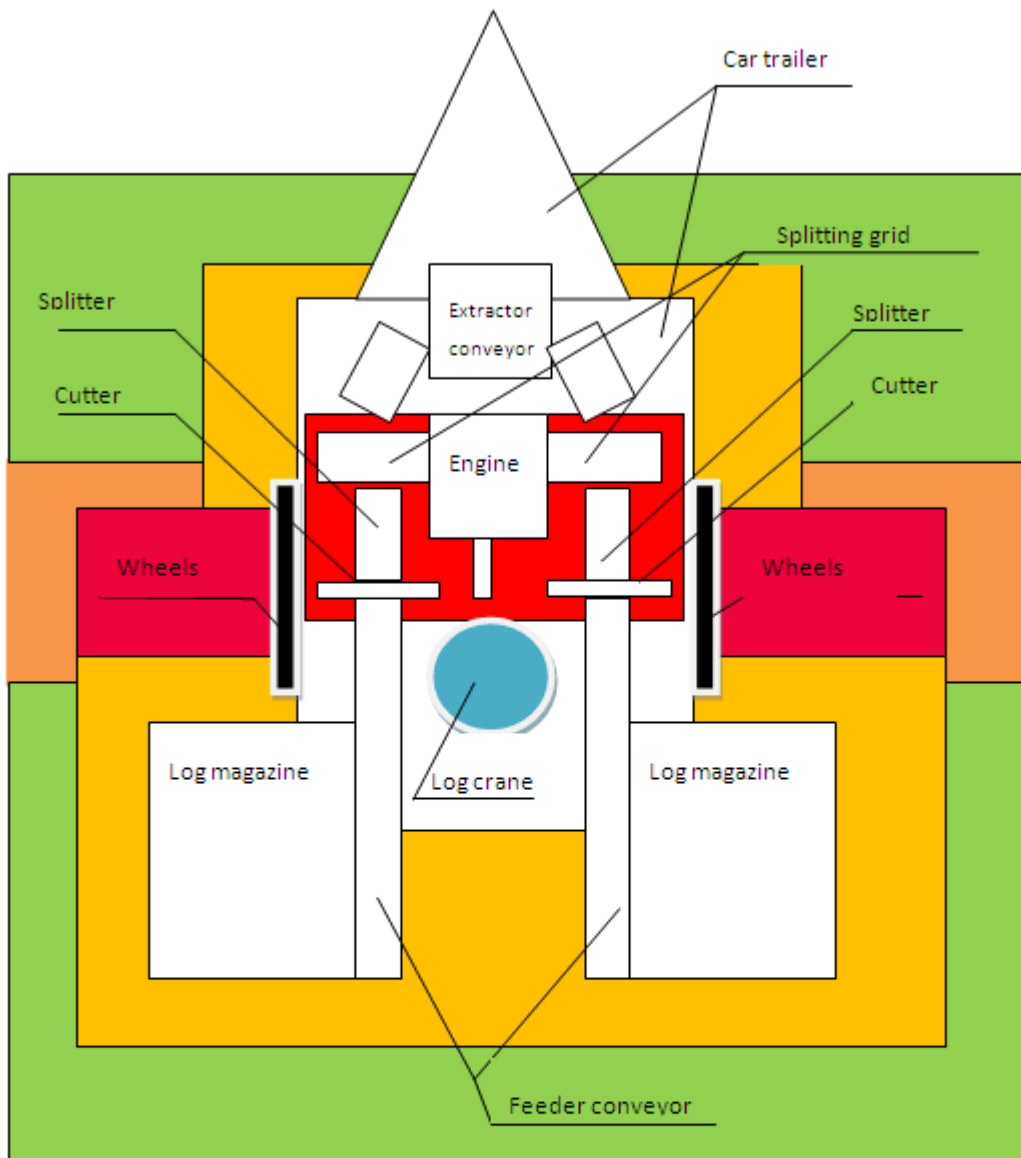







Pezzolato TLC 1400 firewood processor with horizontal multiple splitting grid. The splitting grid is movable in both directions: up and down, left and right. Source: Youtube video [39].



Sami Autochopper models [41].

APPENDIX 22



Color	Hazard level
	Safe
	Low
	Moderate
	High
	Very high

APPENDIX 23

