MEHHATROONIKA INSTITUUT

Mehhatroonikasüsteemide õppetool

MHK70LT

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AUTOMATED PRODUCTION LINE FOR LAMINATING PLASTIC BOARDS

Automaatne plastiklaudade lamineerimisliin

The author applies for
the academic degree
Master of Science in Engineering

Tallinn
2016

AUTHOR'S DECLARATION

I declare that I have written this graduation thesis independently.

These materials have not been submitted for any academic degree.

All the works of other authors used in this thesis have been referenced.

The thesis was completed under .... supervision

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Author

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The thesis complies with the requirements for graduation theses.

“.......”....................2016.

Supervisor

.... signature

Accepted for defence.

.... chairman of the defence committee

“.......” ....2016.

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TUT Department of Mechatronics

Chair of Mechatronics Systems

MSc THESIS TASK

2016 spring semester

Student: Ingmar Roosileht 132228 (name, student code)

Study programme: MAHM02/09 – Mechatronics

Speciality: Mechatronics

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THESIS TOPIC:

(in Estonian) Automaatne plastiklaudade lamineerimisliin

(in English) Automated production line for laminating plastic boards

Assignments to be completed and the schedule for their completion:

No.	Description of the assignment	Completion date
1.	**Design of the production line, including selection and calculations of all used components; FEM calculations; CAD models**	**03.04**
2.	**Selection of automation technology; electrical and pneumatic diagrams; production drawings; BOM lists**	**17.04**
3.	**PLC programming; HMI design**	**02.05**
4.	**Project summary; production line specifications and requirements; preliminary manufacturing cost**	**16.05**

Engineering and economic problems to be solved: Design of fully-automated production/palletizing line serving an existing lamination machine – including unstacking and restacking the boards on pallets, moving and queuing the pallets, flipping the boards, feeding the lamination machine and cutting the laminate. The design must be low maintenance and serviceable. The simplicity and the costs of manufacturing must be taken into account

Additional comments and requirements: The production line must be adjustable for many different board sizes

Language of the thesis: English

Deadline for submission of the application for defence 16.05.16

Deadline for submission of the thesis 20.05.16

Student Ingmar Roosileht /signature/ ……….. date 23.02.16

Supervisor Priit Põdra /signature/ ………. date 24.02.16

Confidentiality requirements and other corporate terms and conditions shall be set out on the reverse side.

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FOREWORD

The topic of this MSc thesis was chosen thanks to my employer Aramet OÜ, who is developing and building a production line for a company producing engineered plastic timber. The supervisor of this thesis was associate professor, Priit Põdra. In the course of designing this project, I also got a lot of guidance and feedback from my colleagues.

1. INTRODUCTION

The following thesis describes a designing process of a production line that will be used by a company producing plastic construction materials. I am working as an engineer and project manager for an Estonian engineering company called Aramet OÜ, specialized in machine design. Our company is responsible for the whole process – developing, building and setting up the production line for our client. [1]

Our client is an Estonian based company with a main objective of producing plastic construction materials by recycling mixed plastic packaging waste. The production line will be set up in the company's production facilities situated in central Estonia, Mäo. The production line will be used in the production process of client's Elegro branded products – engineered timber made of recycled plastic waste – called plastic boards in this thesis. Described boards are covered by a wear proof decoration – laminate to resemble real wood – the boards are laminated. [2]

The lamination machine and technology already exists in the company, but at the moment the machine is operated manually with high labor costs. Overall approach on automating the production was given in the initial task by the client's company – it is interested in the solution to drastically cut labor costs – moving from six operators to two – one machine operator and one worker operating the forklift, with an intent to automate the whole factory in the future. Solving that problem requires to design and document a fully-automated production/palletizing line serving an existing lamination machine – this engineering project will be discussed is this work, actual manufacturing and setup is not in scope of this thesis.

An input to the production line is a pallet stacked with bare plastic boards to be laminated and in the other end now laminated boards are stacked again on pallets. During the whole process, the production line has to queue the input and output pallets and move the empty ones. The boards are lifted row by row on the series on conveyors separating the boards and feeding the laminating machine, after the lamination the laminate has to be cut at the precise positions, the boards flipped – so the other side could be laminated afterwards. Then the boards are combined again and lifted on the output pallets. The production line must be adjustable for many different board sizes, all with 3-meter length.

For a specialty task like this, there are no existing solutions in the market, so the production line has to be designed from scratch as a made-to-measure solution. Smaller parts of the machine are of course designed to be as close as possible to industry standard to use proven solutions and guarantee easy maintenance.

The result of this engineering project described in my thesis is full production drawings and specifications of described production line from which it could be manufactured, and implemented into production with no major setbacks, whilst following requirements are also taken into account: design must be low maintenance and serviceable, the simplicity and the costs of manufacturing must be taken into account.

The result of my thesis would be an accurate description of the whole design process of this project – resulting in practical guidelines or at least my approach on how similar tasks are solved in the industry.

The following software was used throughout the design of this production line and writing the thesis: computer-aided design and engineering software Solid Edge and SolidWorks, and several engineering software tools from component manufacturers.

In this thesis, at first, a problem together with initial constraints and requirements is clearly defined. After an analysis, overall design concept of the entire production line is set, and the design is divided into functional parts, all of which are given their own name. Those production line's sub-assemblies are then described and analyzed one by one, the order of describing the separate machine parts coincides with the sequence the plastic boards are moved through the production line. Each one of those parts of the production line has its unique task and principle of operation, and a number of engineering problems that are solved in sequence. Finally, an automation and control of this production line is discussed, and in appendices three examples of production drawings are displayed.

2. THE PROBLEM DEFINITION

As described in the introduction the main problem that needs to be solved during this project is to automate the lamination process of plastic boards, which is at the moment done semi-automatically. Solving that problem requires a design of automated production/palletizing line serving an existing lamination machine, that must need no more than two workers to operate. Solving this problem includes a number of subtasks.

A successful result to this engineering project will be full production drawings and specifications of described production line from which the line could be manufactured, and implemented into production with no major setbacks. An overall approach and more precise problem definition on automating the production was given by the client's company. In cooperation with the client, more detailed sub-assignments were developed and a general design concept was specified.

The production line is intended to laminate plastic boards with about 3,1-meter length The boards are a bit longer than the final 3-meter product – that is because the edges of the boards need to be cleanly cut, which is done later in the production process after they have had some time to cure. In case of some board types, both sides need to be laminated. Client's experiments have shown, that it cannot be done at the same time or shortly after, as the boards need some time to cure to guarantee the lamination's quality.

An input to the machine is a pallet stacked with bare plastic boards to be laminated. A full pallet is prepared earlier in the production process and has specified conditions, it is lifted in the input loading area of the production line by a forklift operator. An output is a pallet stacked identically but one side of the boards is covered with laminate. Also, in case of double-sided lamination, the boards on the output pallet need to be in a turned over position. Finally, a pallet is lifted off the production line to a storage area by a forklift operator. For double-sided lamination, the pallet is run through the production line twice.

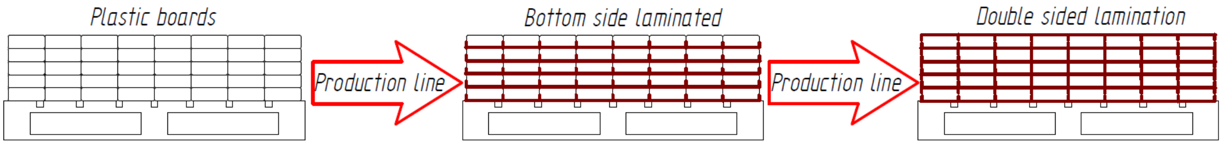


Figure 2.1 Double sided lamination process

Working concept like this implies several tasks the production line must perform also considering requirements of an existing Lamination machine:

- queueing the input and output pallets and transfer the empty ones from input to the output – necessary so the operation will not be interrupted until the forklift operator loads a new pallet
- depalletizing the boards
- separating the stack into individual boards that are sequentially fed to Lamination machine
- boards must be fed into Lamination machine with specified gap between them
- cutting the laminate between the boards to separate them
- flipping the boards over, optionally must be able to turn it off
- collecting the individual boards, and palletizing them
- operational with different board shapes and sizes

An important task of the production line is that it must be suitable for processing many different board sizes. Due to that, the most of guides, mechanisms and sensor positions need to be adjustable. The adjustment to set up the production line for a different board is made manually as changing the board type is not done often, and it also requires comprehensive setup of Lamination machine. Of course, adjusting the machines is made as convenient as it is reasonable. Another important factor has to be considered – boards lengths and their positioning on a pallet varies quite much – the production line must take that into account.

2.1 Lamination machine

In the middle of this production line sits Lamination machine – it is responsible for covering the boards with laminate decoration. The machine already exists in the company and is provided by a German company called Friz. As the plastic boards to be laminated have quite different properties than the machine is specified for, it was modified by the company. As the precise lamination process is a company’s secret, it is not discussed in current thesis. The Lamination machine used is capable for maximum production speed of 20 m/min or 0,33 m/s. The machine leaves a continuous layer of laminate, that needs to be cut afterwards so the boards can be separated again. Similar machine is shown in the Figure 2.2.

Figure 2.2 Lamination machine

2.2 Boards and pallets

An important assignment, that makes the production line's design a lot more complicated is that boards with very different sizes and shapes need to be laminated, also their length and positioning on pallets varies considerably.

As the size of the boards varies, their number on the pallets changes significantly. Depending on the board, the number of layers and boards in one layer changes, the stack of boards has some requirements: the overall maximum mass and stack height cannot be exceeded and the stack must not be over the edge of the pallet. Stacking the boards is shown for one case in Figure 2.4, input constraints in Table 2.1. Some different boards are displayed in Figure 2.3 , note that some of them have a tongue-groove side facing – it makes the board separation task mode difficult. Both sides need to be laminated in case of some boards.

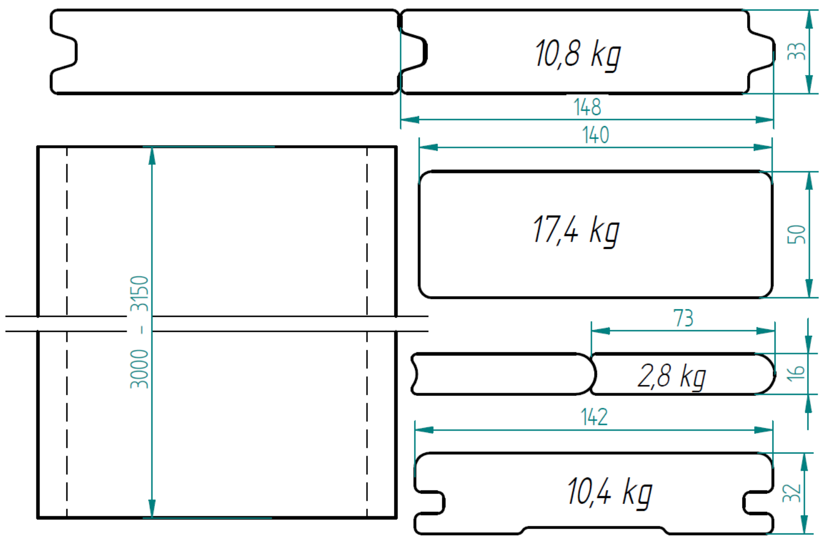


Figure 2.3 Different boards to be laminated

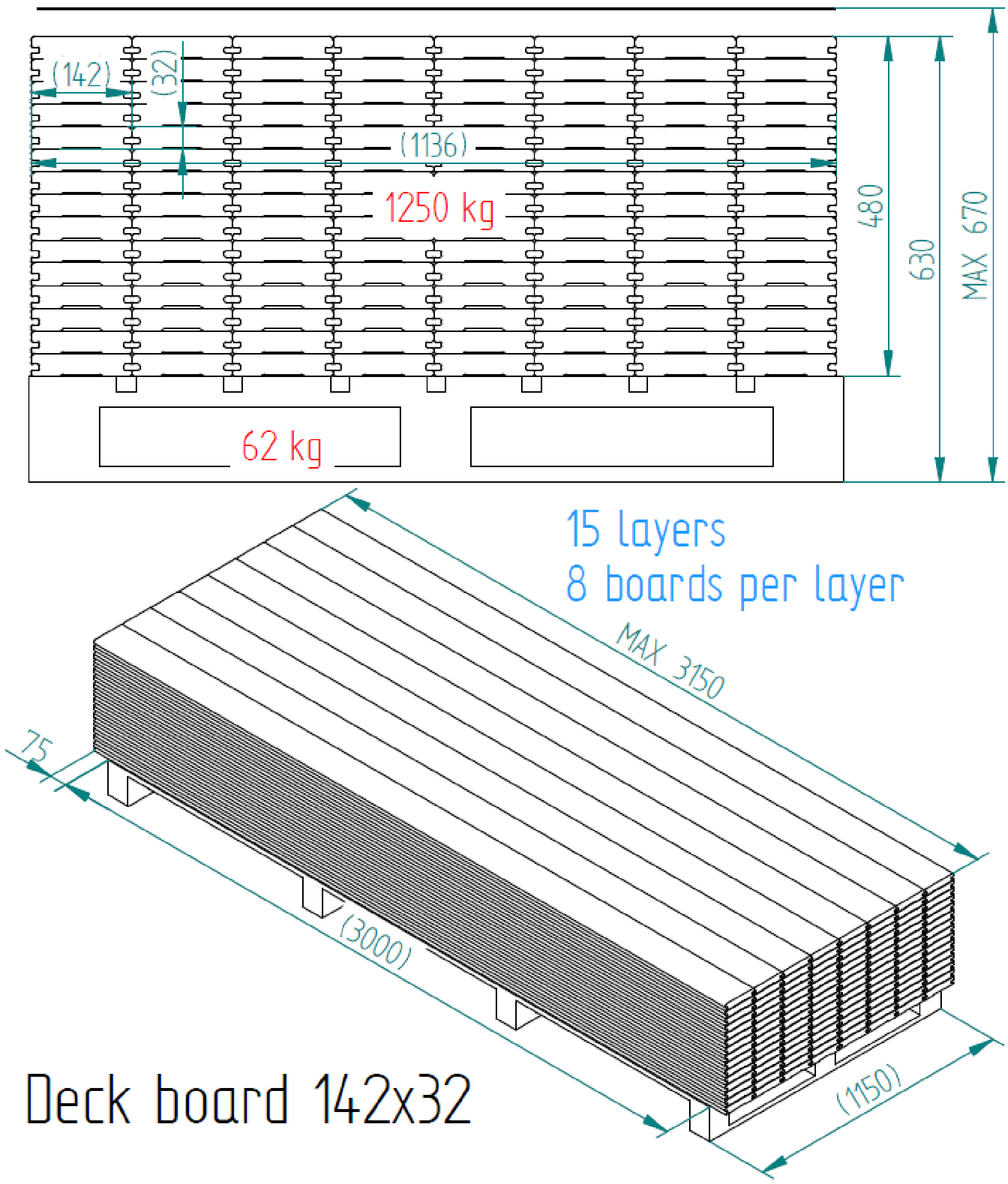


Figure 2.4 Stacking on pallets

Table 2.1 Input constraints

Production line's input parameters		
Board's maximum dimensions	[mm]	160 x 60; length 3150
Board's minimum dimensions	[mm]	65 x 15; length 3000
The highest stack height with pallet	[mm]	670
Maximum single board mass	[kg]	18
Minimum single board mass	[kg]	2,5
Maximum single layer mass	[kg]	144
Maximum mass of a full pallet	[kg]	1350

3. OVERALL DESIGN CONCEPT

As the initial problem states, an automated production line needs to be designed with an input of a pallet stacked with bare plastic boards and with an output of a pallet with identical but laminated stack of boards. That problem implies several sub-tasks, described in the last chapter. To solve them, the production line is divided into separate parts, each one with their own function. For each of those functional parts, an analysis was carried out to find the most economical, efficient and the least complicated way of satisfying its function.

- Queueing the input and output pallets – a conveyor that can fit two pallets, with a separate loading and lifting area is best suited for this task. To save floor space, the pallet is moved along its shorter side, it also means the movement is shorter, not as fast and due to design of the pallet, it is supported better that way. Two almost identical conveyors can be used, one at the input side, the other at output.
- Transfer the empty pallets from input to the output – comparatively light pallet is moved along its longer side on a conveyor. Two conveyors separated from the middle must be used, otherwise Lamination machine's operator will not have an access to the machine.
- Depalletizing the boards into individual boards that are sequentially fed to Lamination machine – can be done in two ways. The first option would be lifting the boards individually one by one off the stack, using a robot or robotized gantry to do that. That method has several problems – firstly, the whole lifting cycle must be done in only 9 seconds (calculated later), that includes the case when the pallet runs out of boards. It also requires a lifting method with a very large reach. Secondly, as many different board sizes are laminated, and the boards and pallets itself are not positioned accurately, a complicated machine vision system would be necessary.

  The second method, and the one used in this project is lifting the boards off the stack layer by layer so a queue of boards is formed. The layer is then separated and the boards can be fed individually. The same method can be used in the output side; a stack is formed layer by layer.
- A method described above requires – some type of gantry to lift the whole layer and a conveyor running along the boards shorter width to place the layer.
- Separating the layer into individual boards – as some boards have a tongue-groove side facing, which means they are overlapping each other, the easiest method would

be using a gravity to performing this task – separator is mounted in an inclined position, and the boards slide on it.

- Boards must be fed into Lamination machine with specified gap between them – requires a separate conveyor moving the boards along its length, the conveyor must have adjustable rollers to position the board.
- Receiving the boards after lamination, cutting the laminate between the boards – requires a conveyor after Lamination machine, with a cutting machine.
- Flipping the boards over – can be done on a similar, gravity assisted manner as in case of separating the boards.
- Collecting the individual boards, and palletizing them – it can be done using almost identical production line sub-assemblies as in the input side – board layer conveyor and a gantry.

To perform the tasks necessary for those functional parts, a production line is divided into separate sub-assemblies, their overall layout and naming is described in the next chapter. Individual definitions and tasks of them are described in detail in paragraph 4.

3.1 Division into subassemblies and layout

The production line's sub-assembly names and quantities is shown in the Table 3.1, the overall layout in Figure 3.1. The final design in Figure 4.47.

Table 3.1 Division into sub-assemblies

Production line for laminating plastic boards	
Production line part name	**Quantity**
Lamination machine	1
Input-Output conveyor	2
Board layer gantry	2
Board layer conveyor	2
Boards separator	1
Board feeder	1
Board receiver	1
Boards gatherer	1
Pallet conveyor	2

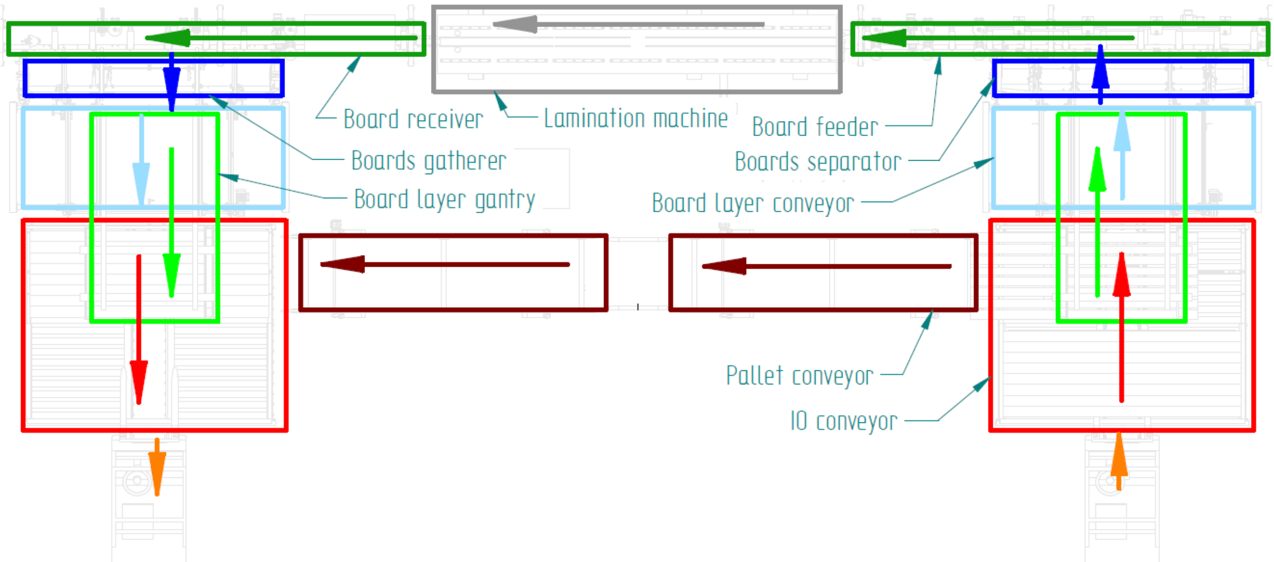


Figure 3.1 Overall layout of the production line

3.2 Overall cycle of the production line

The maximum speed of the production line is restricted by and dependent on Lamination machine. It is the maximum speed of lamination – 0,33 m/s that has to be taken into account – the conveyor speeds can be easily reduced, if the boards are not laminated at full speed. Since the lamination speed is measured along the length of the boards, the time for laminating one board is always the same – it is independent of the board type:

$$t_b = \frac{s_b}{v} = \frac{3\ \mathrm{m}}{0{,}33\ \mathrm{m/s}} = 9\ \mathrm{seconds} \tag{3.1}$$

where t_b – one board's lamination time,

s_b – minimum board length,

v – speed of lamination

All the sub-assemblies of this production line derive their cycle times from this time, and it is also affected by the board's movement direction (sideways or lengthways) and if the whole board stack, one layer or individual boards are moved.

4. DESIGN OF THE PRODUCTION LINE

In this chapter, the design process of the production line for laminating plastic boards is discussed, including developing the design concept, selection and calculations of most of the components, cycle time and dynamic calculations, structural strength calculations; CAD model development and more.

As the entire design process of the whole production line would never fit in scope of this thesis, some parts of it are described in less detail and repeating engineering problems and similar solutions are left out altogether. Also, the automatic control part of the production line is not described in great detail as it is developed in cooperation and later finalized by a specialized automation engineers.

Designing an entire production line is a very intensive task, it will be divided into smaller tasks and problems - each one of those will be solved in the end. The approach to address the whole task goes as following: at first the preliminary draft of the whole design is devised and agreed between all the parties, then it is taken into more detail considering the individual engineering problems. After that the individual parts of the machine are solved, calculated and CAD modelled in succession. Then the whole design is finalized, checked and agreed with the client. The next step will be a final selection of automation components, making electrical and pneumatic diagrams and all the production drawings together with overall production line specifications, and preliminary cost calculations. The final step for the engineering project is preparing a complete program flowchart of the machine – controlling program is based on that – discussed under paragraph 6. After the engineering project is done, there is an another step – programming the controllers and the operator's control panel (HMI – human-machine interface). That task is ordered separately by the client and executed in cooperation with automation engineering company. The manufacturing and setup of the production line is not in the scope of current thesis.

As discussed above, the production line is divided into separate parts, each one with their own function. This chapter will be divided into subdivisions based on the same logic the actual production line is separated into described subassemblies. The order of describing the separate machine parts coincides with the sequence the plastic boards are moved through the production line, from the input to the output.

Each one of those parts of the production line has its unique task and principle of operation, and a number of engineering problems that need to be solved for it to operate. In the beginning of each sub-division the overall description and design concept of that production line part is given. It includes the principle of operation that was devised and possibly some alternatives to it, all the necessary initial data and cycle time calculations. As in the actual designing process, after formulating that overall design concept, the next step is to go into more detail – it arises many engineering problems that need to be answered. In reality, the first draft keeps constantly evolving throughout the problem solving process and in the end the whole gets finalized.

Described engineering problems are separated under clauses (divisions of the subdivision). Of course, different production line parts have several similarities and share a number of engineering tasks – therefore each of these problems is only described once. This is generally done in a sequence explained above unless it is more informative to do it later in the process.

When an engineering problem involves selection of some standard component, it often seems as only one company is considered as a supplier of that. While depending on the situation, alternatives are also examined, it is generally preferred to have a one main supplier of certain standard components. This is due to several reasons:

- Experience and know-how about that component – trusted solution
- Same supplier for all the similar components
- Customer discounts
- Availability, nearby reseller (preferably in Estonia)

4.1 Input-Output conveyor

The first and the last part of this production line is called Input-Output conveyor (IO conveyor from now on). The same assembly is used with minor configuration differences as an input and output as due to the nature of this production line, the input and output sides are almost identical.

The IO conveyors main task is having a queue of one pallet before the boards can be lifted by the next stage. That is necessary for the constant running of the production line, otherwise the operation will be interrupted until the forklift operator loads a new pallet. The secondary task is to hand over an empty pallet to the Pallet conveyor. Those two tasks consist of two separate movements – a full pallet weighting over 1,3 tons must be moved along its shorter edge and after that, an empty pallet weighting 62 kg is moved along its long side. (See Figure 4.3).

Due to the weight of the pallet that needs to be moved, two types of conveyors would meet the load requirements – chain conveyor and roller conveyor. When the shape of the pallet is also considered, choice was made – a roller conveyor is best suited for this application, offering the best support for the pallet and also avoiding sliding friction. [3]

For the second movement, a common way to transfer the conveyed units between different conveyors is to use a chain transfer system – chains between the rollers that are lifted up to transfer the item off the roller conveyor, see Figure 4.1. In this project, a simpler alternative to it was chosen. [3]

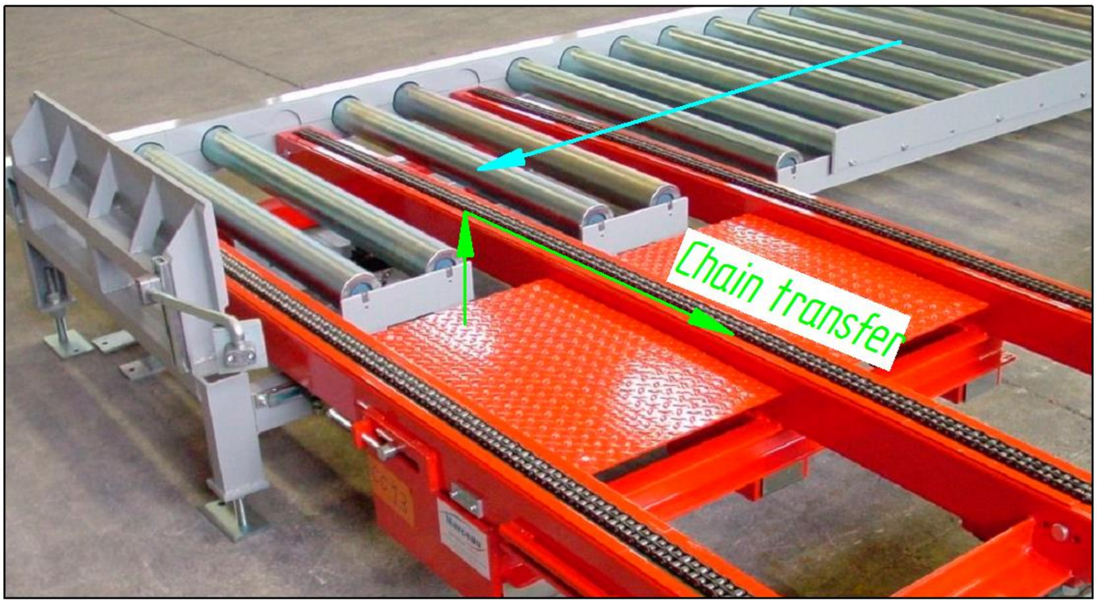


Figure 4.1 Chain transfer system

The following design concept for the IO conveyor was devised and is described next. It will have a roller conveyor to move the full pallets which will be driven by an electric motor. That conveyor moves the pallet away from the loading area to the position where its boards are lifted off layer by layer. After the pallet is empty, the second movement is done by a pneumatic cylinder, sliding the pallet along the rollers and guide rails on the Pallet conveyor where its chains teeth catch the pallet's leading edge and tow it off the IO conveyor. In case of the conveyor on the output side, the pallet transferring action is opposite – the pneumatic cylinder pulls the empty pallet on the rollers. Two photoelectric sensors detect if the pallet has been placed on the loading area, one detects if the pallet has reached the lifting area. One additional photoelectric sensor detects if the last layer on the pallet has been lifted so the pallet is empty.

The loading area, where a forklift operator places a pallet has some requirements. It has to have some positioning room at the sides – 50 mm each side with rugged guides to allow some contact. The rollers and their belts have to be protected from forklift's possible hits. A full length tube at the front protects the first rollers and helps unloading the pallet from the forklift.

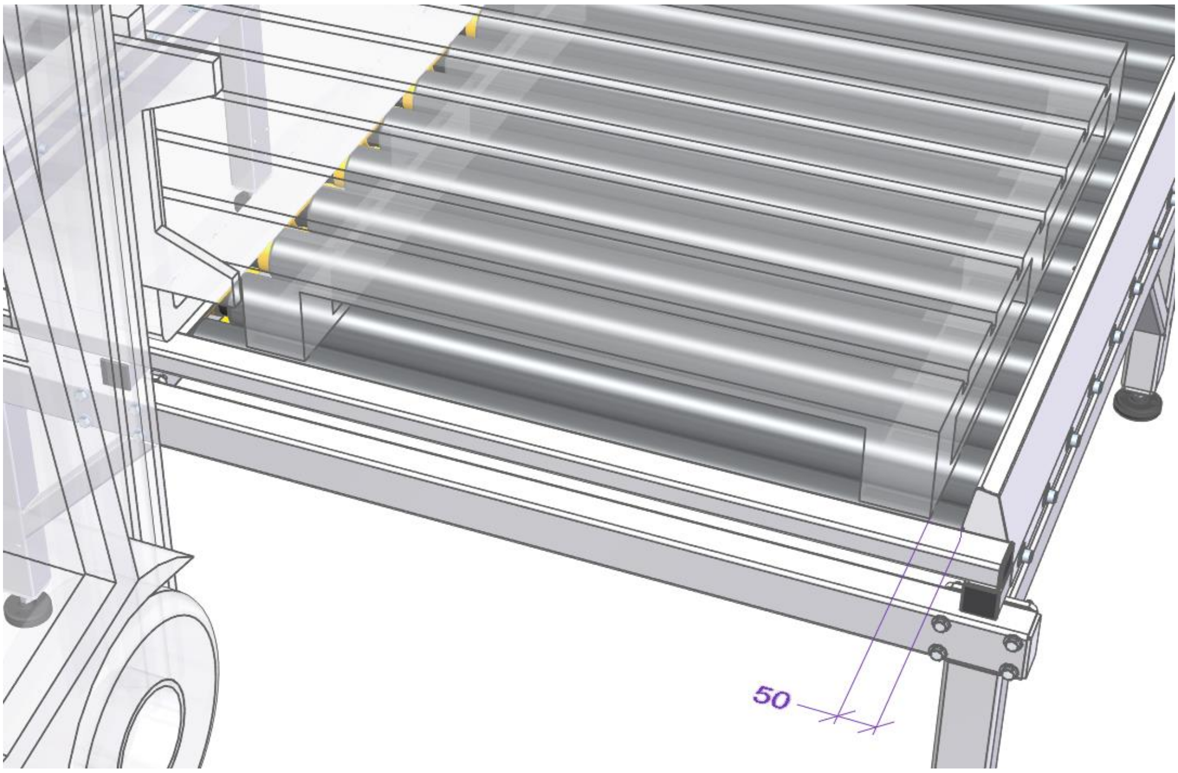


Figure 4.2 IO conveyor's loading area

The cycle time of the IO conveyor is dependent on the speed of the lamination machine, as described in Chapter 3.2. By cycle time, the time it takes to do one complete pallet change is meant (see Figure 4.3). As the next stage after the IO conveyor states lifting the boards off the pallet layer by layer, it is the time of laminating one board layer that determines the cycle time of the IO conveyor. The worst case scenario is realized when the widest boards are processed – one layer consists of 8 boards. The time for laminating one board is 9 seconds. Therefore, the whole cycle of the IO conveyor must take less than $8\text{ pc} \cdot 9\text{ s} = 72$ seconds. Some safety margin was added as required speeds are low enough already – the cycle time was set to 47 seconds. In the case of the output side conveyor, the cycle times are the same and movements opposite.

Next, an Excel spreadsheet was prepared where the cycle is separated into individual movements – thus movement times can be chosen and average velocities of the individual movements are calculated. Times are set so that the mean velocity of the heavier load is longer – less powerful drive can be used and strain on the components is reduced. (See Table 4.1) Since in this case the movements are relatively slow, acceleration and deceleration times are not considered at this stage, but when the individual movement dynamics are calculated. In case of faster movements and therefore significant accelerations, it is a good idea to take them into account as the movements can then be optimized.

Table 4.1 IO conveyors cycle calculations

Movement name	No.	Mass	Stroke	Mean velocity	Movement time
		[kg]	[m]	[m/s]	[s]
Pushing an empty pallet by a pneumatic cylinder	1	62	0,5	0,2	2,5
The Pallet conveyor removes the empty pallet	2	62	2,9	0,2	14,5
Roller conveyor moves the full pallet	3	1312	1,4	0,047	30
				Total movement time	**47**

The IO conveyors cycle is illustrated in Figure 4.3:

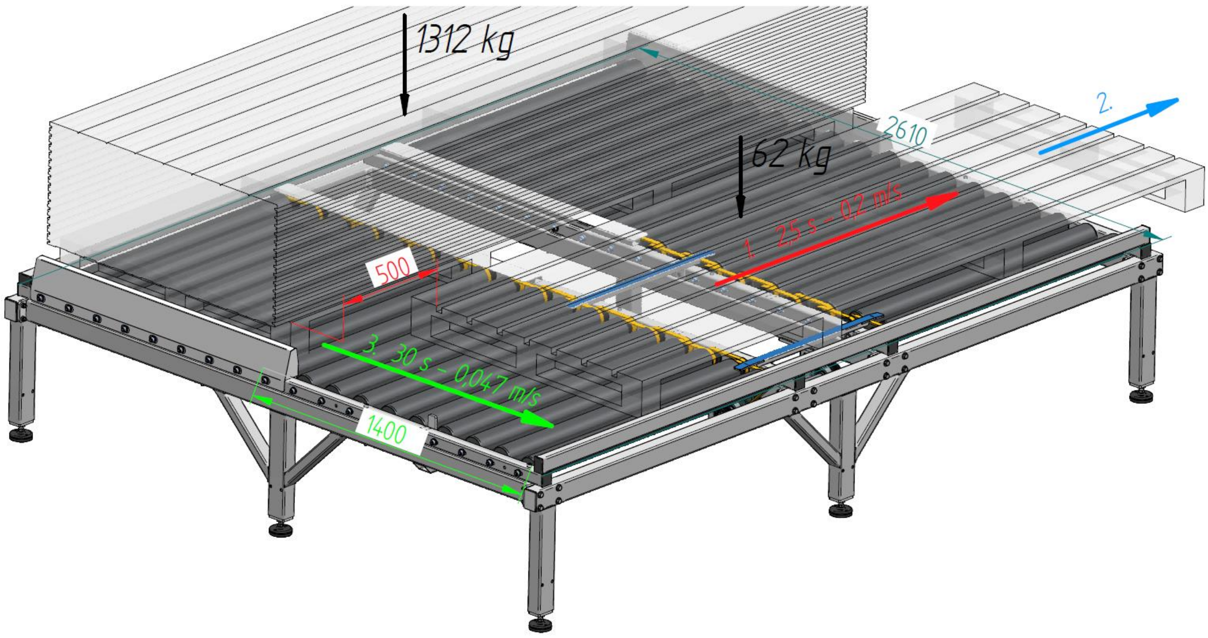


Figure 4.3 IO conveyor's movements

4.1.1 Drive selection

The IO conveyor’s rollers will be driven by an electric motor – more specifically by a three-phase AC squirrel cage induction motor. It is by far the most widely used industrial drive, being rugged, reliable and economical.

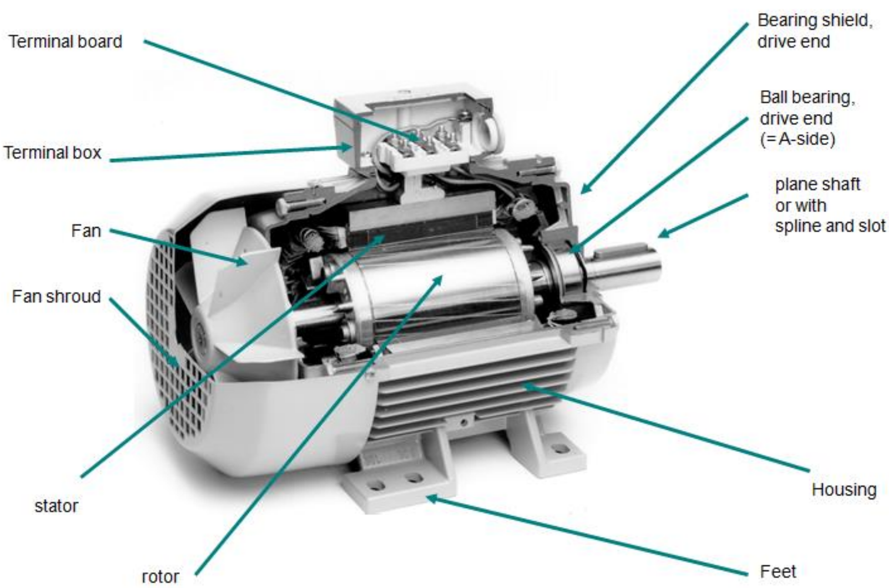


Figure 4.4 AC induction motor construction [4]

The induction motor derives its name from currents flowing in the rotating part of it – a rotor, that are induced by alternating currents flowing in the stationary part – a stator. The combined electromagnetic effects of the stator and rotor currents produce the force to create rotation. The most common type of rotor resembles a cage consisting of aluminum or copper conducting bars connected by short-circuiting end rings – hence the nickname squirrel cage for induction motors. [5] [6]

The fastest theoretical speed such a motor can spin is called synchronous speed – then the rotor spins at the same rate as the motor's internal rotating magnetic field. In practice, the rotor always rotates slower than the magnetic field – an AC induction motor is an asynchronous motor. The speed difference between the rotor and magnetic field is called slip, it allows the induction of rotor current to flow, and production of torque to drive attached load while overcoming internal losses [5] [6]

The synchronous speed of a motor is determined by the number of poles in the stator and the frequency of the power supply: [6]

$$n_s = \frac{120 \cdot f}{p} \tag{4.1}$$

where n_s – synchronous speed,

f – frequency,

p – the number of poles.

Since driving the roller conveyor is a low speed-high torque application, AC motor is used together with speed reducing gearbox.

Drive calculations

Considering the cycle times (Table 4.1), all the necessary data required for gearmotor selection can be calculated. Selecting a motor is common and recurring task, for example this production line uses 7 different gearmotors. An Excel spreadsheet has been prepared for quick calculations of the motor parameters. It is also quite common for the initial data to change, for example the mass being driven – using an Excel spreadsheet keeps the motor parameters automatically updated. Distance-time and speed-time graphs are also displayed to aid evaluating the required movement.

When required force and torque is calculated, certain safety margin is introduced. At this stage of the design, it is mostly required so the uncertainties determining the initial conditions can be taken into account. Otherwise, any inaccuracies in the calculations could result in an overloaded drive or even an inoperable system. It naturally leads to some over-dimensioning of the motor but at this stage it is not safe trying to avoid that. After the first production line has been built, the forces can be measured more accurately and some of the components including gearmotors can be optimized. Moreover, it turns out that over-dimensioning a motor by about 1,5 times normally increases its efficiency – as datasheet from a motor supplier clearly shows, motors rated over 0,5 kW operate most efficiently when the load is about 75 % of the rated. (See Table 4.2) It only agrees with constant operation of the motor, frequent starting and braking cycles reduce the efficiency because of the increased rotor mass. [7]

Table 4.2 SEW-Eurodrive DR.. Series IE1 4 and 6-pole motors

Motor type	Number of poles	Rated power	Rated speed	Rated torque	Efficiency at 50% power	Efficiency at 75% power	Efficiency at 100% power
		[kW]	[rpm]	[Nm]	[%]	[%]	[%]
DR63S4	4	0,12	1380	0,83	55.6	61.9	63.8
DRS71S4	4	0,18	1380	1,25	59,1	65,3	66,6
DRS71M4	4	0,55	1360	3,85	69,1	71,9	70,6
DRS80M4	4	1,1	1410	7,4	77,7	78,6	77,0
DRS90L4	4	2,2	1400	15	82,9	83,1	81,1
DRS80S6	6	0,55	915	5,7	64,1	68,2	67,9
DRS90L6	6	1,1	930	11,3	77,5	76,3	75,0

An Excel spreadsheet prepared for motor parameter calculations is shown in Table 4.3 and motion graph in Figure 4.5.

Table 4.3 IO conveyor's drive calculations

Static inputs				*Motion inputs*			
Moving mass	Coef. of friction	Roller diameter	Safety factor	*Stroke*	*Time*	*Acceleration*	Speed reserve
m [kg]	***μ***	***d [mm]***	***[x]***	***d_s [mm]***	***t_{tot} [s]***	***a [m/s2]***	***[x]***
1312	0,1	89	1,4	1400	30,00	0,025	1,1

Force outputs			
Dynamic force	Frictional force	Combined force	Force with reserve
$F_{dün}$ [N]	***$F_{müü}$ [N]***	***F_x [N]***	***F [N]***
33	1286	**1319**	**1847**

Acceleration		Steady-state speed		Deceleration		Linear speed	
t_a	***d_a***	***t_v***	***d_v***	***t_d***	***d_d***	***v_{mean}***	***v_{max}***
[s]	***[mm]***	***[s]***	***[mm]***	***[s]***	***[mm]***	***[m/s]***	***[m/s]***
2,000	**50,00**	**26,000**	**1300,00**	**2,000**	**50,00**	**0,047**	**0,050**

Gearmotor parameters		
Torque with reserve	Rot. Freq.	Power
M [Nm]	***ω [rpm]***	***P [W]***
82,2	**11,8**	**102**

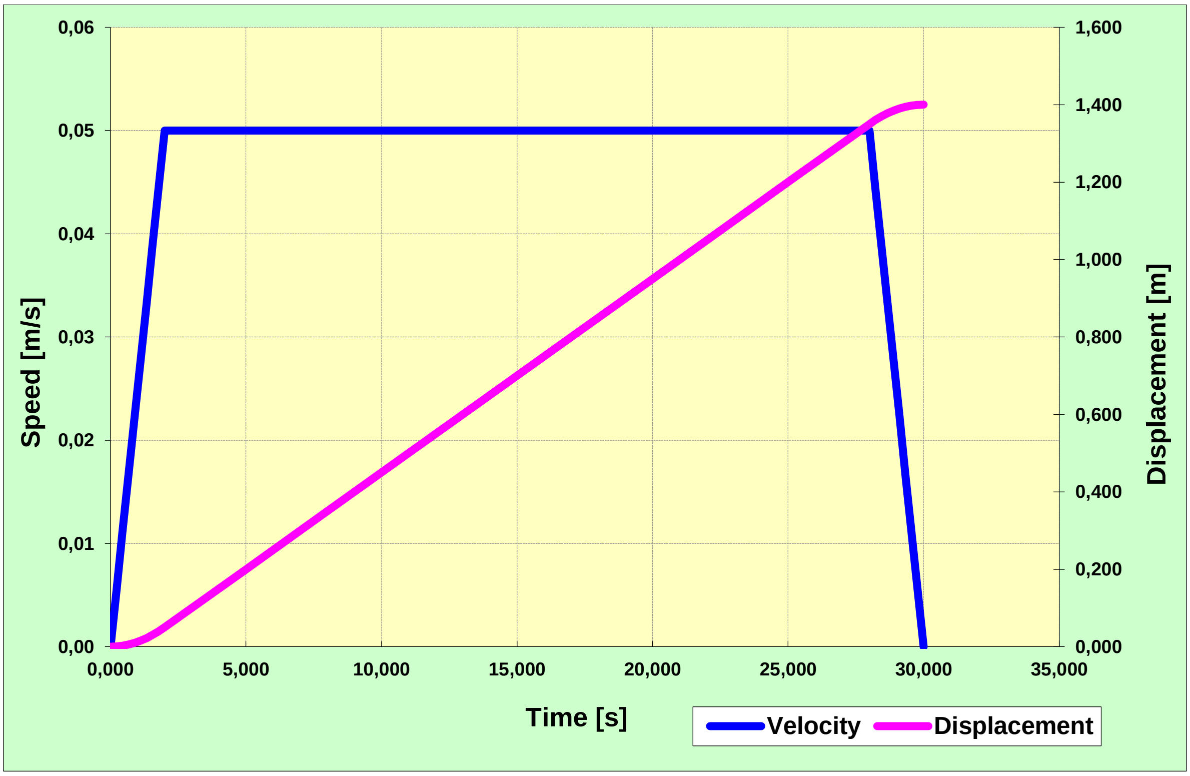


Figure 4.5 Distance-time and speed-time graph of IO conveyor

Selection of the motor

As explained in chapter 4, it is a good idea to have one main supplier of certain components. The motor supplier of choice is a German manufacturing company called SEW-Eurodrive – they are one of the market leaders in the drive technology and have a certified reseller in Estonia. SEW-Eurodrive offers fully assembled gearbox-motor combinations – gearmotors. Their modular system enables to select a correct drive for any application, and together with their comprehensive selection and configuration tool it is made quite simple. [8]

There are several selection criteria that have to be taken into account when choosing a gearmotor, some of these include:

- *The output torque and speed*. The torque and speed required for this application were calculated above
- *Gear unit type, output shaft*. For this application, considering the geometry of the mechanical design, it would be ideal to have a right-angle gearmotor mounted directly on the shaft (the gearbox has a hollow shaft) and to distribute the load more evenly, through shaft mounting will be used together with a torque arm to constrain the rotation. SEW offers five standard gear unit series using different gearing principles, number of stages, ratios and torque outputs, see Figure 4.6. [9] [10]

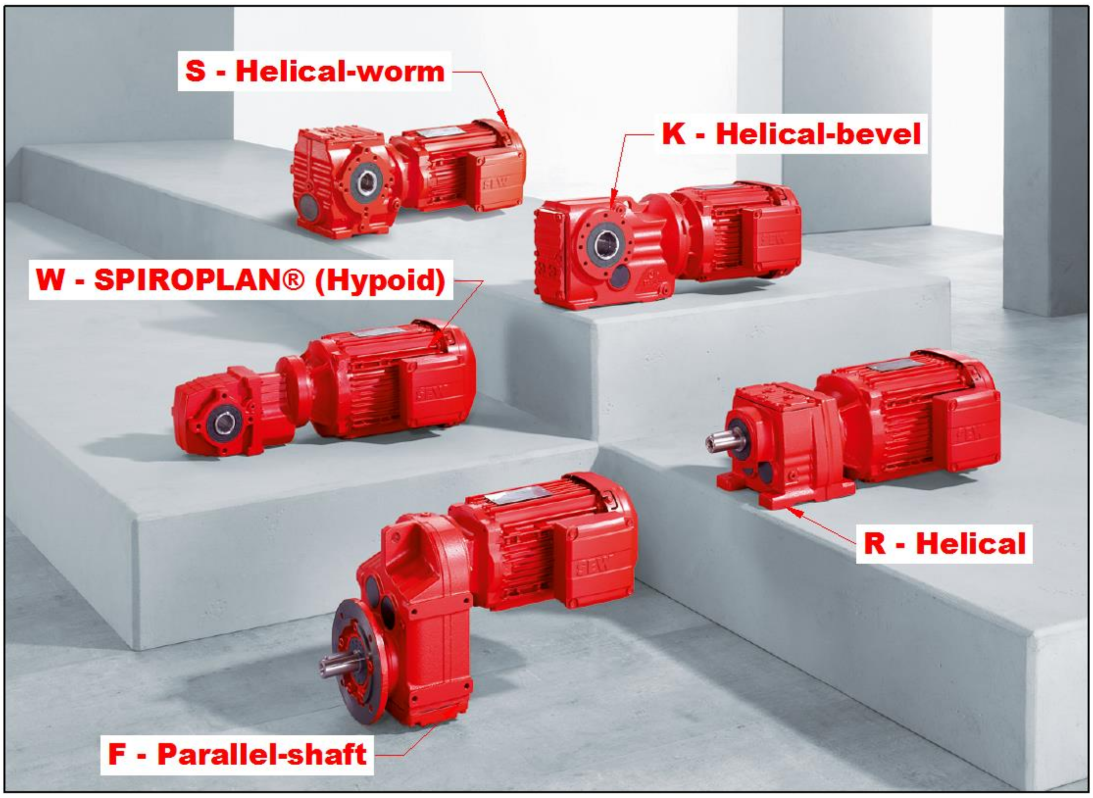


Figure 4.6 SEW gearmotors

The main factors of making a choice are usually geometry of the design and gear unit efficiency, the price is also considered but the cost of those gear units is usually quite close so it is not worth to use suboptimal geometry or reduced efficiency. Some gear unit types are also not suited for certain torque-speed combinations – SEW's selection tool reveals the best choices.

In current application, right-angle gearmotor was needed, so three gear unit types would suit: Types K, S and W. Next, the efficiency was considered: K type helical-bevel gear unit is more than 96% efficient as the other two gear unit types – type S helical-worm and type W hypoid produce a high proportion of sliding friction which leads to higher gearing losses. The efficiency of W type gear unit is around 90% and type S is even more inefficient. So the first choice would be type K gearmotor. [9] [10]

- *Motor type.* For the motor, SEW's DR series motor will used. By motor, an electric AC three-phase 50 Hz squirrel cage induction motor is meant. SEW offers 2, 4 and 6-pole motors up to 225 kW power, with many different configurations and efficiency classes. The standard IEC 60034-30 specifies energy-efficiency classes for motors dividing them into three classes: IE1 (standard), IE2 (high) and IE3 (premium efficiency). The efficiency is defined for a rated output range from 0.75 to 375 kW. With some exceptions, the IE3 class is mandatory in EU for all new motors since 1 January 2015 (7.5–375 kW) and from 1 January 2017 (0.75–375 kW). The use of energy efficient motors is also dependent on the operating mode of the motor, being especially suitable for applications with high number of daily operating hours and few starting and braking operations. [7] [11]

  Calculations show, that about 0,12 kW motor will be used – the required motor power is too low to be regulated under the standard described above. As seen from the SEW-Eurodrive catalog – efficiencies are not differentiated in so low power application. [7]

  A 4-pole DR series motor is selected for current application, being the most common motor produced it is the most economical. A 6-pole motor offers greater torque at lower speeds but it is not needed, also SEW datasheet shows that 6-pole motors are less efficient when motors with same power output are compared. (See Table 4.2) [7]

- *Frequency inverter controlled motor?* Higher thermal class and overload protection device is recommended for invertor operation. Thermal class F and PTC thermistors selected. [7]
- *Mechanical brake needed?* Motors with integrated brakes are often used for safety concerns or other design requirements. SEW motors come with optional integrated DC-operated electromagnetic disk brake that is released electrically and applied using spring force. The brake is applied when the voltage supply is interrupted. The brake can also be released mechanically if equipped with a manual brake release enabled by a hand lever. The brake is controlled by a brake control that is installed in either the motor terminal box or the control cabinet. [7]

  A mechanical brake is used in this application. It is necessary that when the conveyor has reached the end of the movement and while one pallet is being unloaded by the next stage, the rollers would remain locked to avoid any movement during that process. In the same time, a new pallet is being placed on the conveyor by the forklift operator and during that process it is very likely that the rollers would move. The strength of the mechanical brake is required to be such that it allows for sliding the pallet without the rollers being moved – so force calculations from above can be followed. The holding torque of the brake on the output shaft of the gearbox must be about 90 Nm. Necessary brake torque of the gearmotor can be calculated:

$$Braking\ torque = \frac{Output\ torque}{Overall\ gear\ ratio} = \frac{82{,}2\ \text{Nm}}{106{,}38} = 0{,}77\ \text{Nm} \qquad (4.2)$$

  Manual brake release option is also selected – it is necessary to free the rollers for example during the maintenance.
- *Operating mode of the motor*. The IEC 60034-1 motor standard uses eight duty cycle modes to describe how the motor is loaded according to duration, chronological sequence and thermal conditions. Duty types S1, S2 and S3 are shown in Table 4.4 and in Figure 4.7, where ϑ – motor temperature and P – motor load. [7] [12]

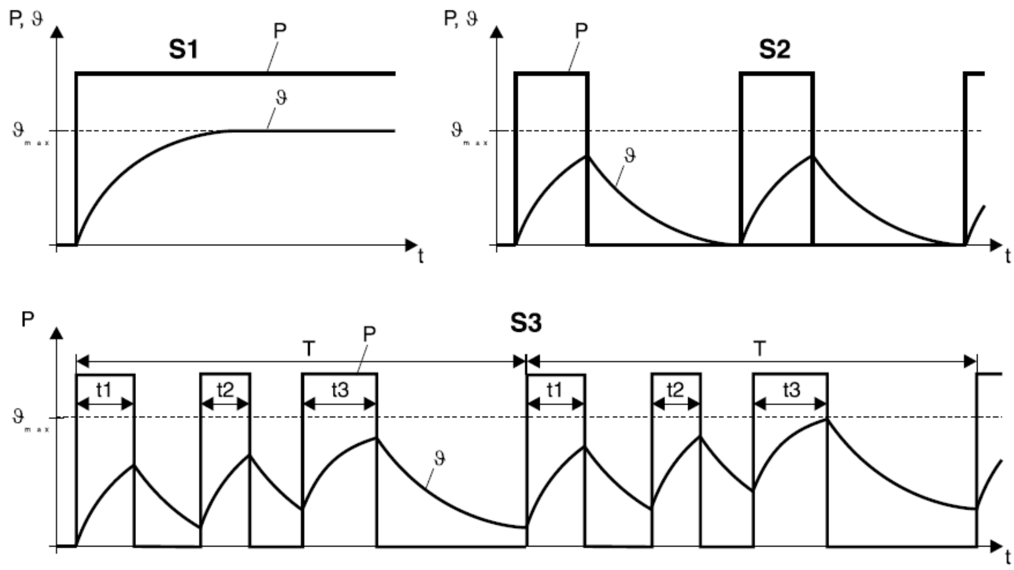


Figure 4.7 Duty cycles S1, S2 and S3

Table 4.4 Motor duty cycle modes

Mode	Mode name	Operating mode description
S1	Continuous duty	The motor works at a constant load for enough time to reach temperature equilibrium.
S2	Short-time duty	The motor works at a constant load, but not long enough to reach temperature equilibrium. The rest periods are long enough for the motor to reach ambient temperature.
S3	Intermittent periodic duty	Sequential, identical run and rest cycles with constant load. Temperature equilibrium is never reached. Starting current has little effect on temperature rise.

Unless specified differently, SEW motor rating refers to duty type S1. When motor is operated in less demanding modes, like S2 or S3, the motor can be loaded beyond the rated power. Power increasing factor can be found in the supplier's documentation. In this application, the motor is operated in S2 duty mode, but as the motor power is rather low already, it is not downgraded. [7] [12]

- *Service factor of the gearbox*. Additional safety factor for SEW gear units, that takes into account when gearmotor encounters high mass moment of inertia or frequent starting. In required force calculations safety factor was added, while it was to cover uncertainties in the initial condition calculations, it is very likely that some safety margin is already introduced – so no additional safety factor is needed, but an ideal gearbox/motor combination dictated by the configuration tool might have a service factor values over 1 anyway. [9] [10]

- *Efficiency of the motor and gear unit*. Already discussed and considered separately under motor and gearbox selection.
- *Permitted forces on the gearbox shaft.* Known as overhung load, the exact geometry of the forces is given in the gearmotors manual. In current application the forces are well below manufacturer's specifications.

The selection of a correct gearmotor is done via SEW-Eurodrive's online product configurator tool called DriveConfigurator. The parameters discussed above are entered and desired gearmotor is selected, lastly, all the necessary CAD data and documentation is provided by the tool. [13]

To start off, many of the parameters discussed above are inserted into the selection tool, after which a list with suitable choices is displayed and a selection is made.

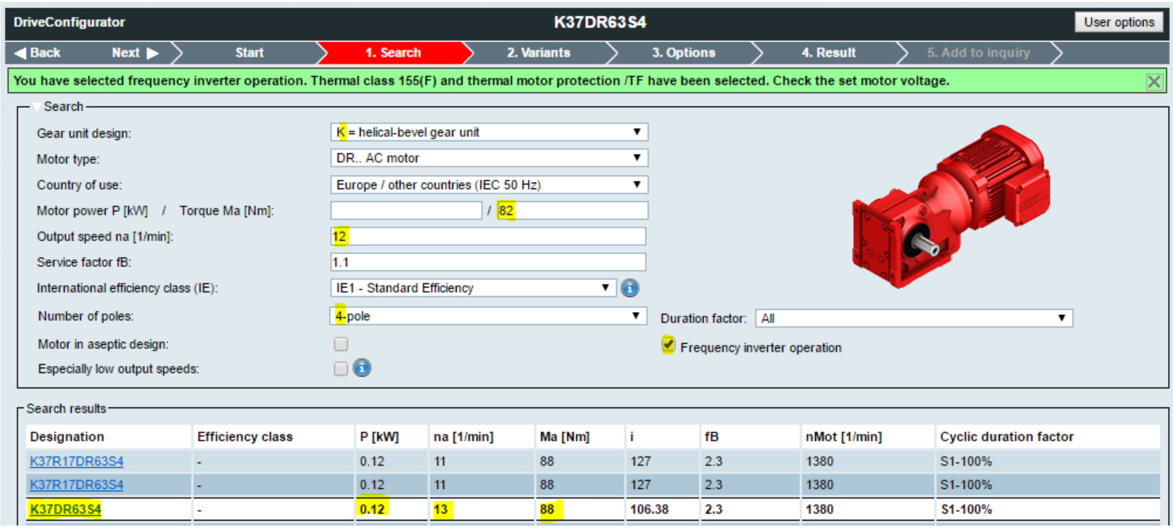


Figure 4.8 DriveConfigurator - Initial parameters and gearmotor selection

Next, a number of gearbox parameters are indicated. Mounting position of the gearmotor is required to specify so the gearbox is supplied with a correct lubricant quantity. (Figure 4.9)

After that, some additional parameters are specified, including necessary surface protection, the use of an encoder and also if a mechanical brake is needed. The braking torque necessary is 0,77 Nm, the next largest brake is chosen – 0,8 Nm. (See equation 4.2) (Figure 4.10)

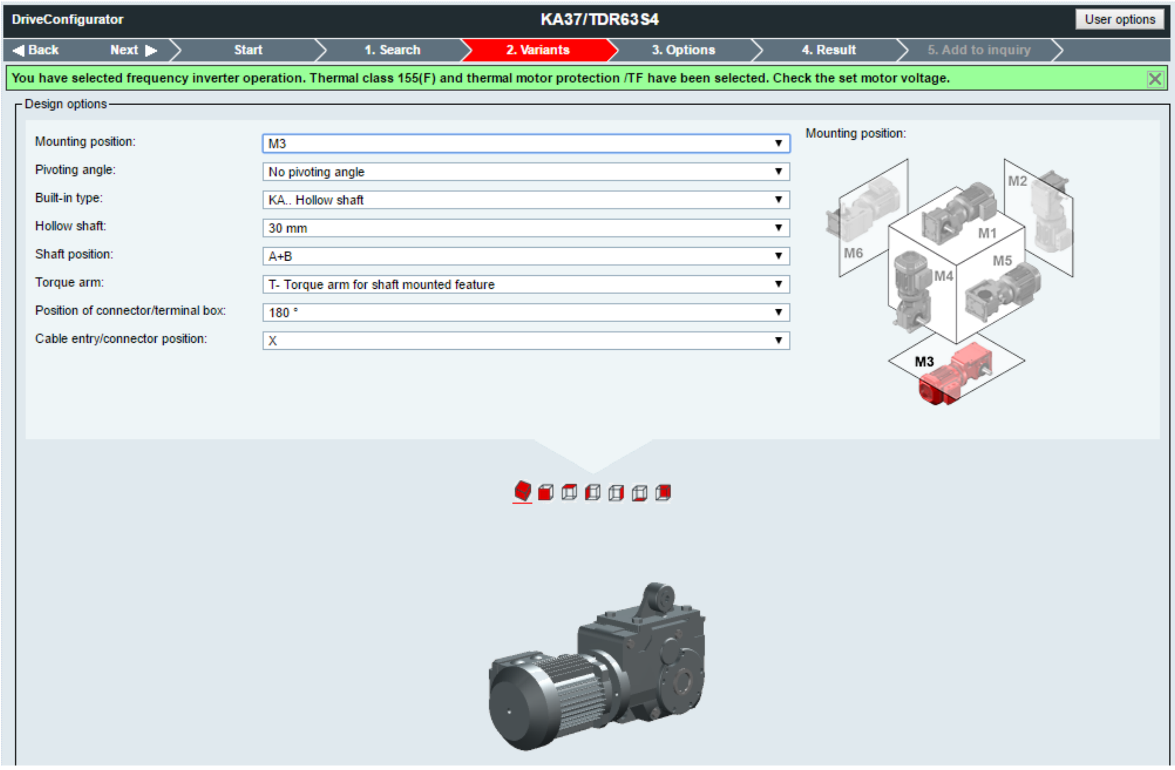


Figure 4.9 DriveConfigurator - Gearbox options

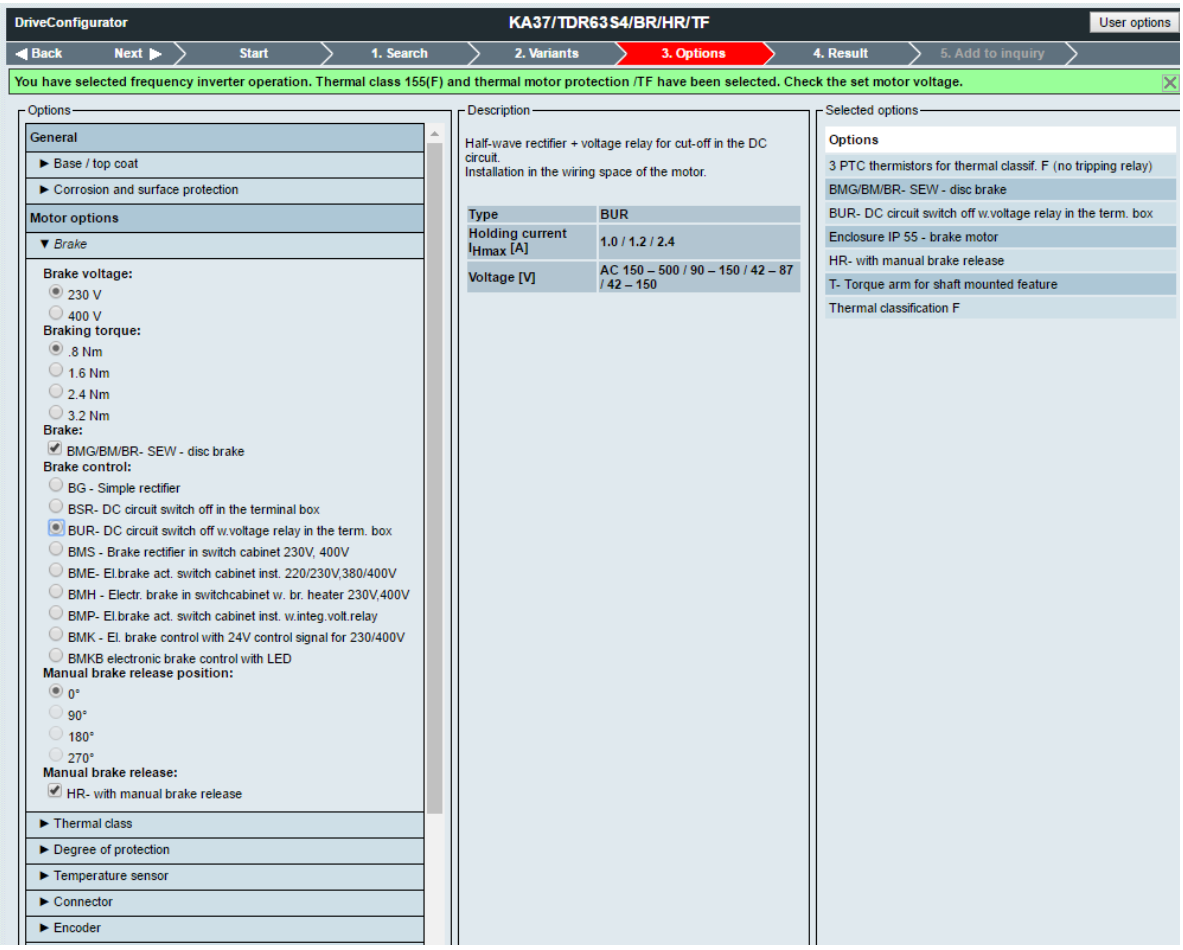
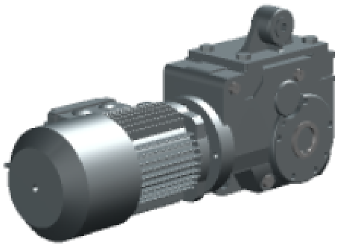


Figure 4.10 DriveConfigurator - Additional options

Lastly, the finalized selection is displayed together with CAD data and all the documentation. Technical datasheet of the motor is displayed in the Figure 4.11.

AC gearmotor

KA37/TDR63S4/BR/HR/TF



Rated motor speed	[1/min] : 1380
Output speed	[1/min] : 13
Overall gear ratio	: 106.38
Output torque	[Nm] : 88
Service factor SEW-FB	: 2.30
Mounting position	: M3AB
Base / top coat	: 7031 Blue Grey (20070310)
Position of connector/terminal box	[°] : 180
Cable entry/connector position	: X
Hollow shaft	[mm] : 30
Permitted output overhung load with n=1400	[N] : 7000
Lubricant quantity 1st gear unit	[Liter] : 1
Motor power	[kW] : 0.12
Duration factor	: S1-100%
Efficiency (50/75/100% Pn)	[%] : 55.6 / 61.9 / 63.8
CE mark	: Yes
Motor voltage	[V] : 230/400
Wiring diagram	: DT13
Frequency	[Hz] : 50
Rated current	[A] : 0.68 / 0.39
Cos Phi	: 0.69
Thermal class	: F
Motor protection type	: IP55
Net weight	[Kg] : 17.8
Braking torque	[Nm] : 0.8
Brake voltage	[V] : 230

Additional feature and Options:
3 PTC thermistors for thermal classif. F (no tripping relay)
BMG/BM/BR- SEW - disc brake
BUR- DC circuit switch off w.voltage relay in the term. box
Enclosure IP 55 - brake motor
HR- with manual brake release
T- Torque arm for shaft mounted feature
Thermal classification F

Figure 4.11 Technical datasheet of the selected gearmotor

4.1.2 Roller arrangement and selection

As described above, a roller conveyor was chosen to transport full pallets. Although, rollers that support and move the load can be designed and fabricated from scratch, conveyor rollers are a standard component and it is always more cost-effective and safer to buy them from specialized supplier. Our conveyor roller supplier of choice is The Interroll Group, being one of the world's leading manufacturers of products for internal logistics, specialized in conveyor technology. [14]

Roller selection

First important parameter of a roller conveyor is a distance between the rollers, called the roller pitch. To ensure that the pallet to be transported is conveyed smoothly, the roller pitch has to be set so that at least three conveyor rollers lie under the pallet at all times, but minimizing the roller pitch is recommended. In this case, the roller pitch depends on the shape of the pallets used – see chapter 2.2. When looked from the side, the pallet has 3 load-bearing columns joint with thin wooden board, so the roller distance is chosen so that the whole mass of the pallet is never supported only by pallet's thin sections. The pitch is also dependent on how the rollers will be driven – the length of the chains or belts used. [15]

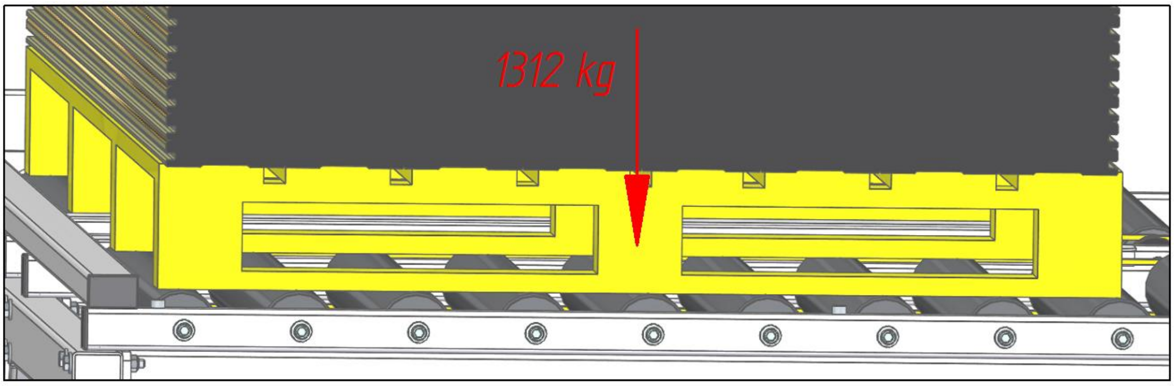


Figure 4.12 Supporting rollers

As seen from Figure 4.12, the weight of the pallet is supported by 9 roller pairs at one time, but since the pallet's load is supported only by its upright columns, it can be approximated that the load is carried by 3 pairs of rollers – six rollers. Thus, the load capacity of a single roller can be calculated, weight of a full pallet is 1312 kg (see paragraph 2.2):

$$Load\ capacity = \frac{Pallet's\ mass \cdot g}{Number\ of\ rollers} = \frac{1312\ \text{kg} \cdot 9{,}8\ \text{m/s}^2}{6} = 2143\ \text{N} \tag{4.3}$$

where g – acceleration of gravity.

From that, roller series 3600 (See Table 4.5) with installation length of 1300 mm was selected from Interroll's product lineup – it is applicable for loads up to 3500 N (2850 N at selected length), further calculations are unnecessary, integrated ball bearings and other components of the roller are designed to withstand the rated load. [15]

Table 4.5 Conveyor roller series 3600

Interroll Heavy-duty Conveyor Roller Series 3600	
General technical data	
Max. load capacity	3500 N
Max. load capacity at 1400 mm installation length	2850 N
Max. conveyor speed 0.50 m/s	0,50 m/s
Temperature range 0 to +40 °C	0 to +40 °C
Materials	
Drive head	fiberglass-reinforced polyamide
Tube	Steel, zinc-plated
Ball bearing	Steel 6204 2RZ, 6205 2RZ

Driving the rollers

Because selected rollers are rated for heavy loads, also relatively high torque needs to be transferred, two mediums of power transmission are available: chain drive and toothed belt drive. While chains are tried and trusted method for driving conveyor rollers and are characterized by their robustness and durability, they need regular maintenance, must be lubricated regularly and are relatively loud in operation. In contrast the toothed belt is maintenance-free and runs very quietly – no lubrication and retensioning is required. However, the initial setup of the roller pitch distances must to be precise, otherwise the service life will be dramatically reduced. In high torque applications, the toothed belt is also very efficient – so toothed belt rollers are selected, more specifically Interroll 3.6AX.J90.S38 – 1238, corresponding to 1300 mm installation length. The roller's drive heads have a HTD 8M profile with 25 teeth, for belts 20 mm wide. [15] [16]

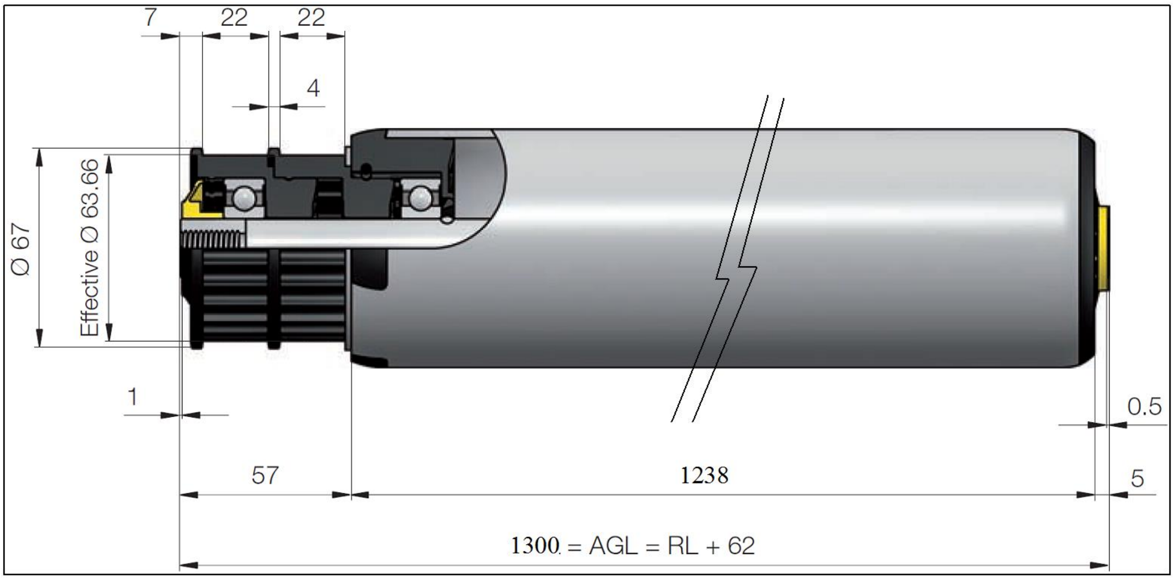


Figure 4.13 IO conveyor's rollers

In principle, there are two possible types of power transmission:

• Tangential: one belt running along the side of the conveyor

• Roller-to-roller: multiple belts running from Roller to roller

The toothed belt should only be used tangentially for relatively low levels of power and even then special guides are needed to press the belt securely onto the drive heads. It is obvious that in case of roller-to-roller configuration much higher torque can be transferred and due to that, toothed belts are primarily used in roller-to-roller drives, so it was selected for this application. In order to keep toothed belt forces and backlash as low as possible, the drive is recommended to be positioned in the middle of the conveyor length. But as in this case, the conveyor is relatively short and only one pallet is moved at the time, it is not essential. [15]

Selected rollers, belts and roller arrangement preferred is shown in the Figure 4.14.

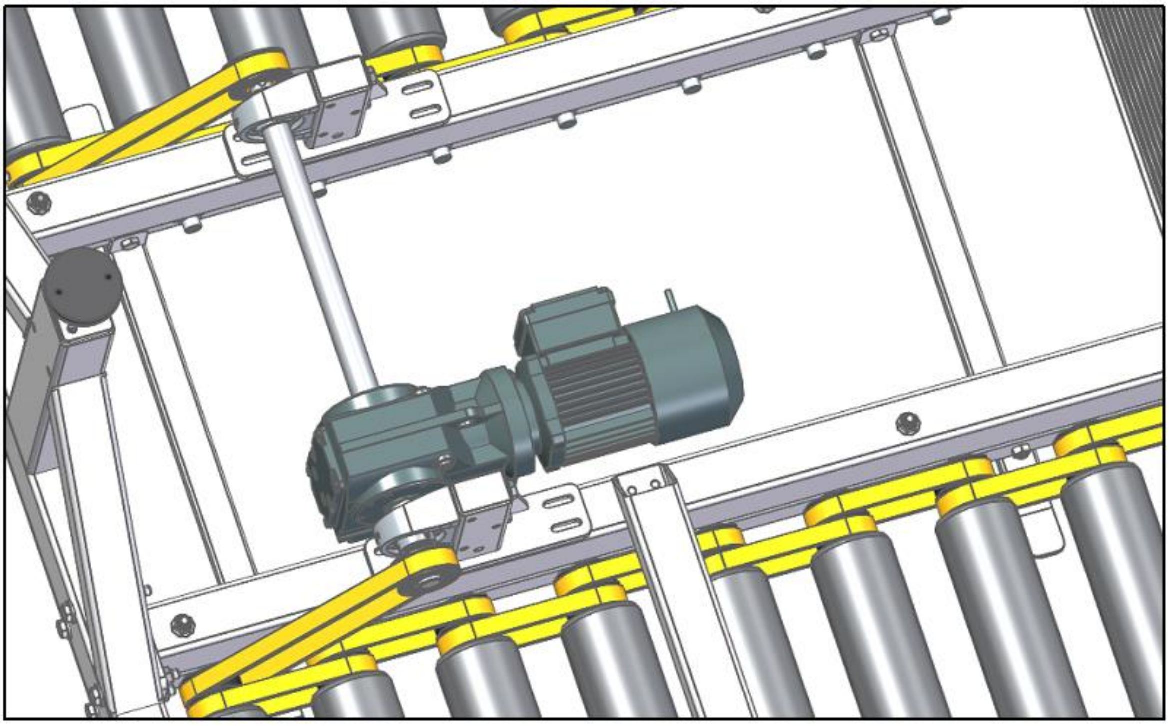


Figure 4.14 IO conveyors roller arrangement

4.1.3 Toothed belt selection

As discussed above, toothed belt (also called synchronous belt) drive was selected. The selected rollers use a HTD 8M profile with 25 teeth – pitch diameter 63,66 mm, belt width 20 mm. 8M describes the pitch length – 8 mm, see Figure 4.15.

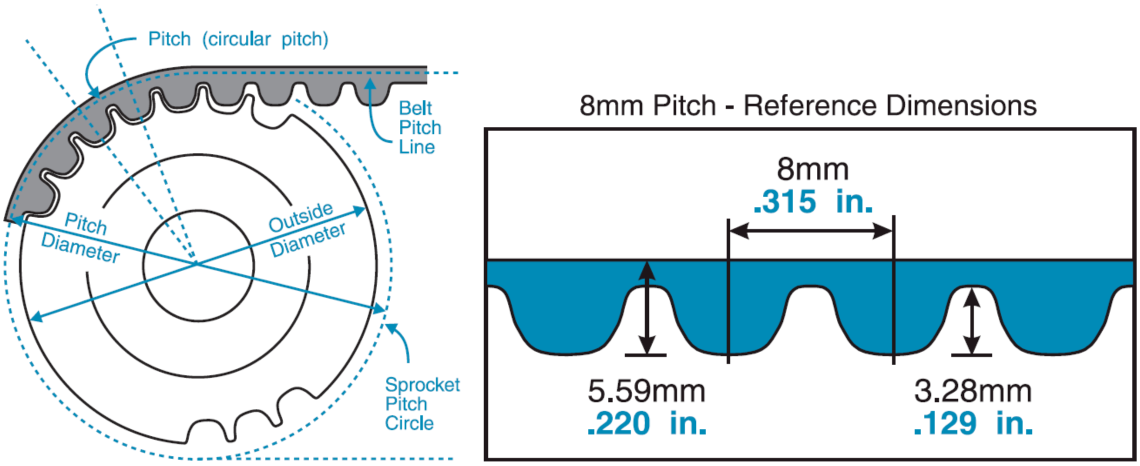


Figure 4.15 HTD belt dimensions

To dimension the toothed belt, torque that needs to be transferred by one belt is calculated. From Table 4.3 we get a necessary torque, instead of using 1,4 times safety factor, as in motor calculations, it is reduced to 1,2 – some initial data inaccuracies are still covered, also an additional safety factor is later added in belt calculations anyway. Total torque M = 70,4 Nm. As seen in the Figure 4.14, the load is divided between two sets of belts – so torque transmitted by one belt $M_b = \frac{M}{2} = \frac{70{,}4}{2} \approx 35$ Nm

Selected rollers use a belt with a 20 mm width and there is no way to increase this dimension – at that width, regular HTD belts are not strong enough, as checking some of the belt producer's manuals reveals. [17] Luckily, our synchronous belt supplier of choice – The Gates corporation has a solution. They offer a HTD type belt series called PowerGrip GT3, having twice the load carrying capacity of its predecessor HTD. They also state, that the belt suitable to be used on existing HTD sprockets. [16] [18]

While procedure for dimensioning the belt is usually described very precisely in the belt manufacturer's design manuals – it is more convenient to use Gates's own dimensioning software called Design Flex Pro. It offers a step-by-step drive calculation procedure for both V- and synchronous belts. [19]

Required information is inserted into the software – center distance of the pulleys: 140 mm; pulley sizes: 25 teeth; required torque 35 Nm; rotational speed 12 rpm and desired belt series. Drive service factor of 1,5 was selected according to supplier's recommendations. See Figure 4.16. [19]

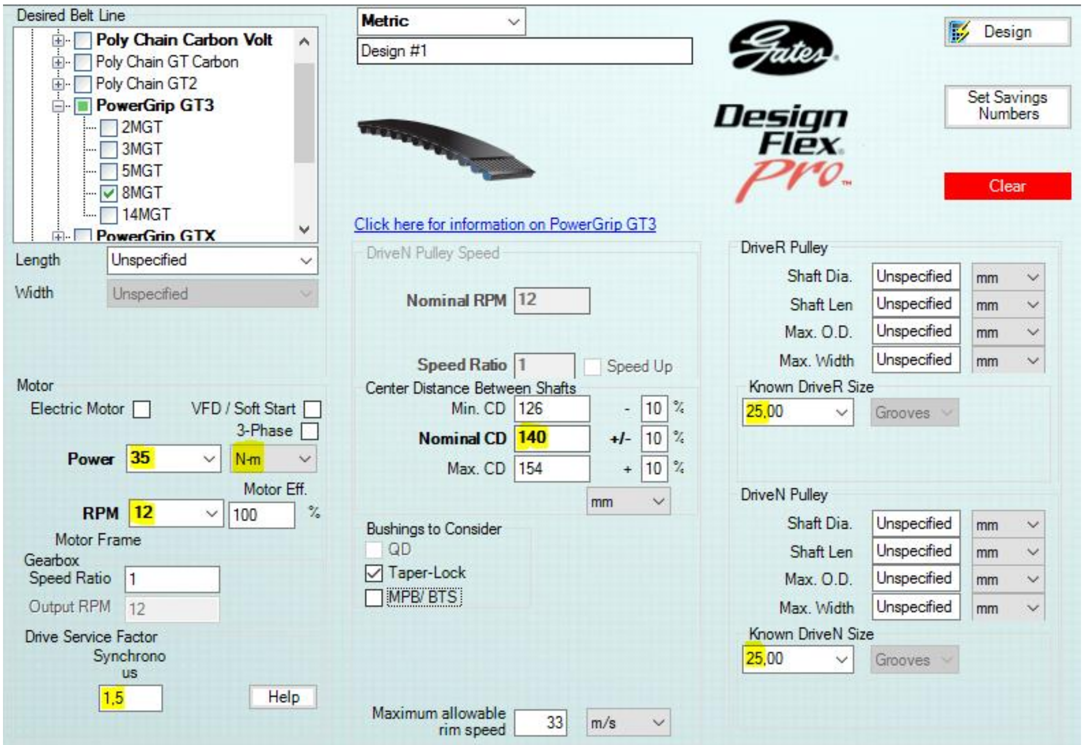
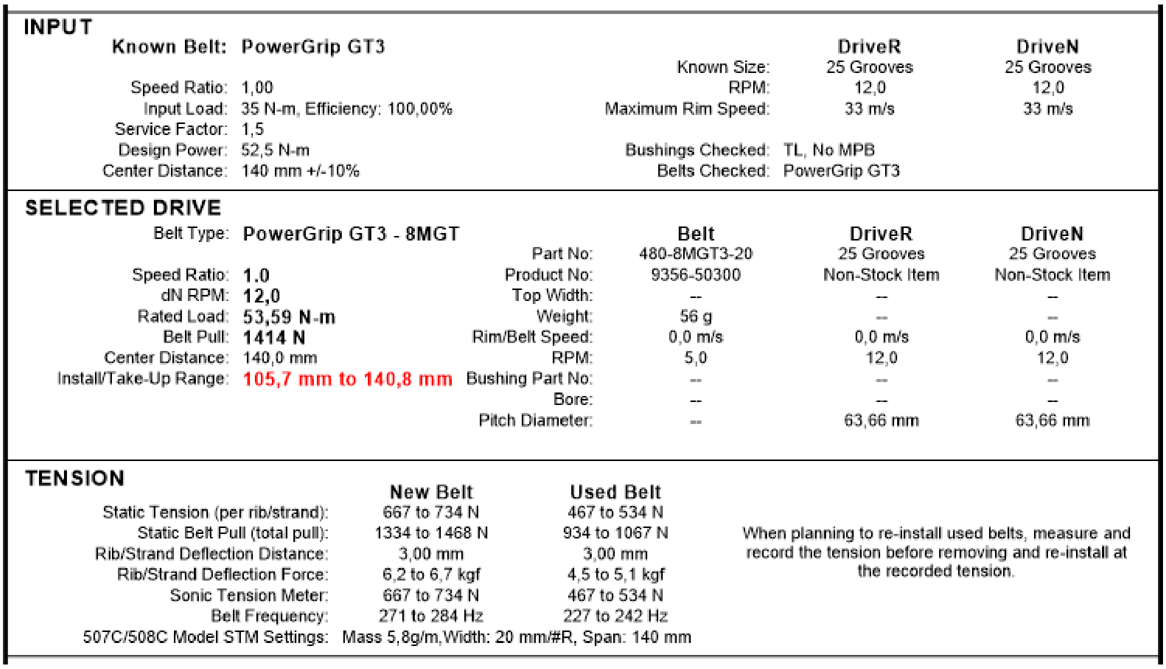


Figure 4.16 Design Flex Pro - initial data

A correct belt is displayed, together with take-up range and tensioning instructions, see Figure 4.17. 20mm wide belt just meets the rated load criteria. 480mm long belt is used – 480-8MGT3-20.



INPUT

				DriveR	DriveN
Known Belt:	PowerGrip GT3	Known Size:		25 Grooves	25 Grooves
Speed Ratio:	1,00	RPM:		12,0	12,0
Input Load:	35 N-m, Efficiency: 100,00%	Maximum Rim Speed:		33 m/s	33 m/s
Service Factor:	1,5				
Design Power:	52,5 N-m	Bushings Checked:	TL, No MPB		
Center Distance:	140 mm +/-10%	Belts Checked:	PowerGrip GT3		

SELECTED DRIVE

			Belt	DriveR	DriveN
Belt Type:	PowerGrip GT3 - 8MGT	Part No:	480-8MGT3-20	25 Grooves	25 Grooves
Speed Ratio:	1.0	Product No:	9356-50300	Non-Stock Item	Non-Stock Item
dN RPM:	12,0	Top Width:	--	--	--
Rated Load:	53,59 N-m	Weight:	56 g	--	--
Belt Pull:	1414 N	Rim/Belt Speed:	0,0 m/s	0,0 m/s	0,0 m/s
Center Distance:	140,0 mm	RPM:	5,0	12,0	12,0
Install/Take-Up Range:	105,7 mm to 140,8 mm	Bushing Part No:	--	--	--
		Bore:	--	--	--
		Pitch Diameter:	--	63,66 mm	63,66 mm

TENSION

	New Belt	Used Belt
Static Tension (per rib/strand):	667 to 734 N	467 to 534 N
Static Belt Pull (total pull):	1334 to 1468 N	934 to 1067 N
Rib/Strand Deflection Distance:	3,00 mm	3,00 mm
Rib/Strand Deflection Force:	6,2 to 6,7 kgf	4,5 to 5,1 kgf
Sonic Tension Meter:	667 to 734 N	467 to 534 N
Belt Frequency:	271 to 284 Hz	227 to 242 Hz
507C/508C Model STM Settings:	Mass 5,8g/m,Width: 20 mm/#R, Span: 140 mm	

When planning to re-install used belts, measure and record the tension before removing and re-install at the recorded tension.

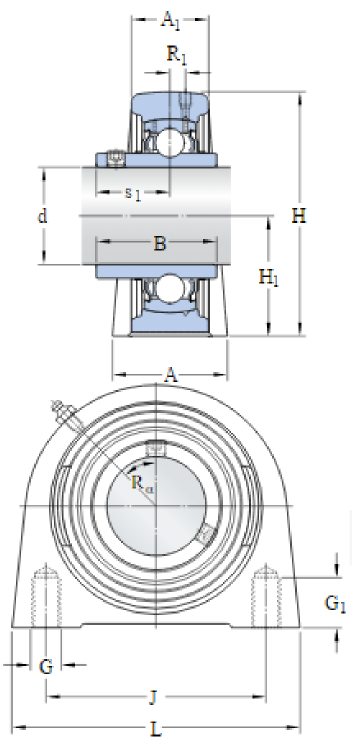
Figure 4.17 Design Flex Pro - the result

To transfer the power from driving shaft to first roller, separate sprocket is needed. Gates PowerGrip GT sprocket with 24 teeth is used – P24-8MGT-20, as 25 tooth sprocket like used on the conveyor roller is not a standard item, also small speed reduction will apply. The appropriate part can be selected and CAD models downloaded from Gates web catalog. The sprocket is mounted on the shaft by a taper-lock bushing, bushing number is found from the catalog – 1108. 25mm bore version of it is selected. [20].

4.1.4 Driving shaft bearings

The roller conveyor's driving shaft has to be mounted on bearings which will support the gearmotors weight and belt's pulling forces. The bearing design geometry can be seen in the Figure 4.14 – the bearings need to allow some misalignment of the shaft.

Our bearing supplier is SKF – the biggest bearing and seals manufacturing company in the world, founded in Sweden. For this application, the best solution is to use SKF's ready-to-mount bearing units which enable initial errors of alignment to be compensated (up to 5°) – Y-bearing units. It consists of a housing, bearing and seal that is preassembled and greased at the factory. Y-bearings, also referred as insert bearings, have convex sphered outside diameter and inner ring with a certain locking device enabling quick and easy mounting onto the shaft. The shaft requires a bearing with inner diameter of 30 mm. A bearing unit SYF 30 TF is selected, it uses a bearing YAR 206-2F and is shown in Figure 4.18. [21]



d	30	mm
A	40	mm
A_1	25	mm
B	38.1	mm
H	82	mm
H_1	42.9	mm
J	76.2	mm
L	98	mm
s_1	22.2	mm
G	M10	
G_1	15	mm
Basic dynamic load rating		
C	19.5	kN
Basic static load rating		
C_0	11.2	kN

Figure 4.18 SKF SYF 30 TF

With SKF's tool – Bearing calculator, bearing loads and its expected life can easily be calculated. The calculation was done for the selected bearing, with a radial load of $F_r =$ 2 kN (belt's pull and motor weight with reserve) and axial load of $F_a = 0{,}2$ kN [22]

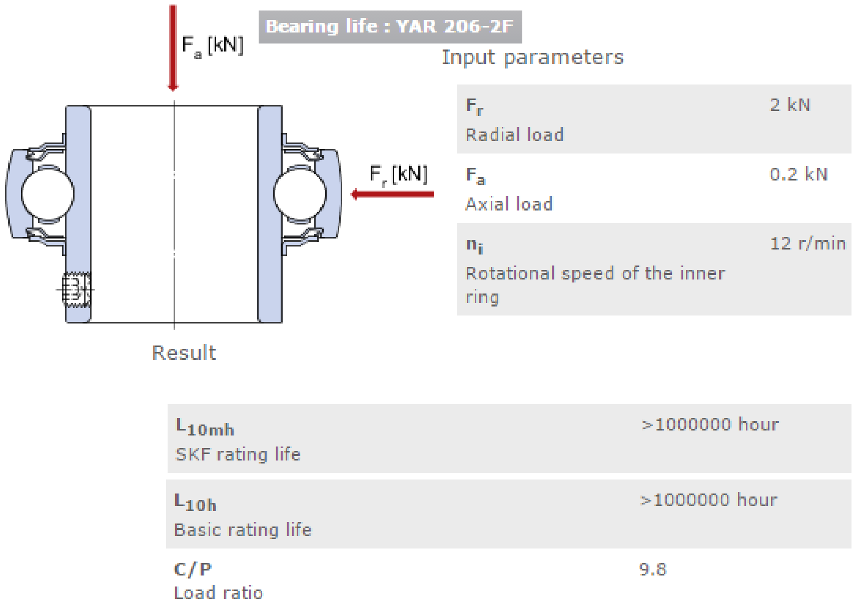


Figure 4.19 SKF Bearing calculator - YAR 206-2F

As seen from the results, selected bearings can easily take the load required, with unlimited life rating.

4.1.5 Pushing/pulling pneumatic cylinder

IO conveyors other main task is to move an empty pallet, in case of the input side conveyor it pushes the empty pallet 500 mm-s until the Pallet conveyor takes over. The output side conveyor does the opposite – the cylinder has a tooth, that grabs the empty pallet and pulls it to a position. A rodless pneumatic cylinder is used as it is easier to implement in this situation. The problem could also be solved using a regular cylinder, but would need a separate linear bearing to be used.

To start with, the force required to move an empty pallet is calculated. As the cylinder must slide the pallet off the IO conveyor, it must overcome a force by friction between the pallet and the rollers, also some dynamic force to accelerate the pallet. The mass of the empty pallet is m = 62 kg; the coefficient of friction is set to μ = 0,3 to compensate for sliding over the edges of rollers and connecting guides. A following formula is used to find out the frictional force:

$$F_f = \mu \cdot m \cdot g = 0{,}3 \ \cdot 62 \text{ kg } \cdot 9{,}8 \, \text{m/s}^2 = 182{,}3 \text{ N} \tag{4.4}$$

where g – acceleration of gravity,

F_f – frictional force.

Next, the dynamic force is calculated, acceleration of the pallet is estimated $a = 2 \ m/s^2$:

$$F_d = m \cdot a = 62 \text{ kg } \cdot 2 \ m/s^2 = 124 \text{ N} \tag{4.5}$$

where F_d – dynamic force

Total required cylinder's theoretical force is calculated, a factor of safety of 2 times is recommended for high friction applications [23].

$$F_t = \eta \ \cdot (F_f + F_d) = 2 \ \cdot (182{,}3 \text{ N} + 124 \text{ N}) \approx 613 \text{ N} \tag{4.6}$$

where F_t – cylinders theoretical force,

η – factor of safety.

Appropriate cylinder's piston diameter of rodless cylinder is found using the following formula, the air pressure used $p = 6 \text{ bar} \approx 0{,}6 \text{ MPa}$ (gauge pressure). [23]

$$D = \sqrt{\frac{4 \cdot F_t}{\pi \cdot p}} = \sqrt{\frac{4 \cdot 613 \text{ N}}{3{,}14 \cdot 0{,}6 \text{ MPa}}} = 36 \text{ mm} \tag{4.7}$$

where p – gauge pressure,

D – piston diameter.

The next bigger standard cylinder is selected – with 40 mm piston diameter. Alternatively, a correct size cylinder can just be selected from manufacturer's catalog, where theoretical forces are already calculated.

The supplier of our pneumatic components is a German company Festo. Festo's products can be accessed either from their online product catalog or more conveniently from downloadable product catalog software, that also features a number of engineering tools. From Festo's catalog, a selection is made – a rodless pneumatic cylinder with mechanical coupling from DGC series, 500 mm stroke: DGC-K-40-500-PPV-A-GK. Important values from datasheet are brought out in the Table 4.6. [24] [25] [26]

Table 4.6 Festo's rodless pneumatic cylinder DGC datasheet

Linear drive DGC-K-40-500-PPV-A-GK		
General technical data		
Stroke		500 mm
Piston diameter		40 mm
Cushioning		PPV: Pneumatic cushioning adjustable at both ends
Position detection		Proximity sensor slot
Operating pressure		2 ... 8 bar
Ambient temperature		-10 ... 60 °C
Theoretical force at 6 bar	$F_{t\,40}$	754 N
Maximum allowed moment	M_y	60 Nm

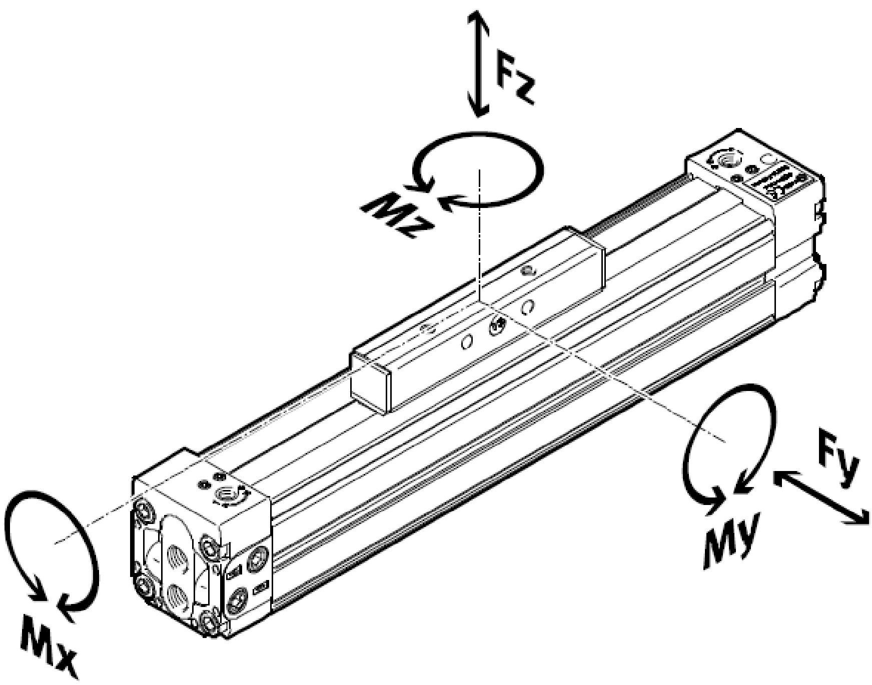


Figure 4.20 Festo DGC-K pneumatic cylinder

An additional parameter has to be checked – if the forces acting on the piston guide are acceptable for the cylinder selected. A value from datasheet – maximum moment M_y is important and gets calculated as it refers to the main axis around which the force from the pallet acts. The acting force's maximum distance from the cylinder's y-axis (See Figure 4.20) is calculated – to find out the furthest distance the cylinder can be mounted:

$$s_y = \frac{M_y}{F_t} = \frac{60\ \text{Nm}}{613\ \text{N}} = 0{,}098\ \text{m} = 98\ \text{mm} \tag{4.8}$$

where F_t – force by a pallet.

Cylinder will be mounted closer than that, 85 mm from a pallet (See Figure 4.21), any closer, and the cylinder would interfere with the rollers.

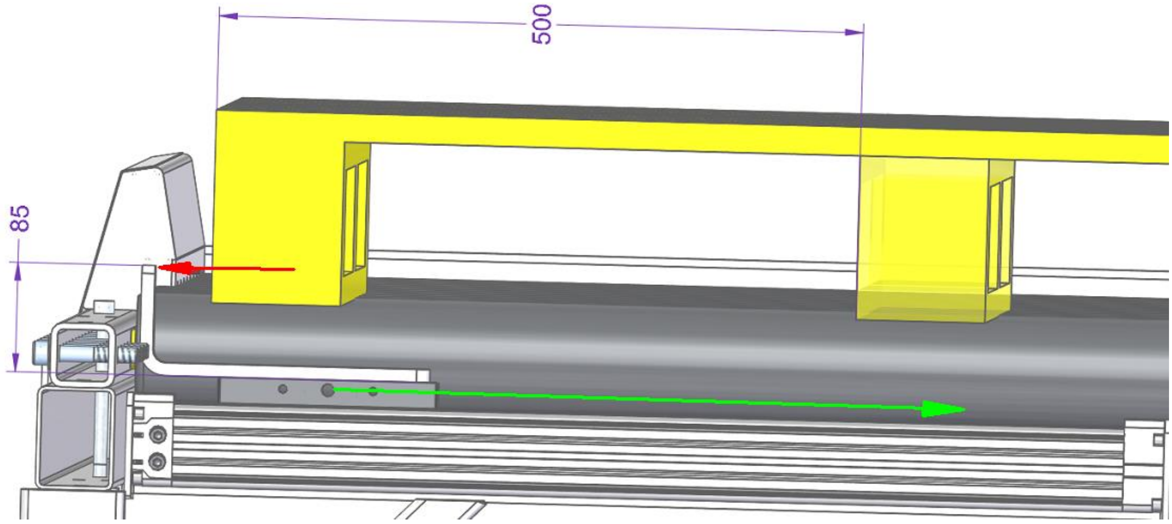


Figure 4.21 IO conveyor's pushing cylinder

Cylinder is actuated at low speed – 0,2 m/s – therefore dynamics of the cylinder is not a concern – an example of a pneumatic cylinder simulations is described in paragraph 4.5.2

4.1.6 Mechanical design

When mechanical design is addressed within this thesis, the whole mechanical, self-fabricated part is meant – everything that needs to be manufactured according to the production drawings made.

While all the parts and welded assemblies are fabricated by subcontractors, it is essential to have knowledge about how the actual manufacturing process is done. When designing a part, it is almost always considered how that part will be manufactured. Only then, can the design be optimized and the precision and dimensional tolerances taken into account. For all the individual parts, welded subassemblies and assemblies, production drawings are made, some examples are presented in appendixes of this thesis.

Mechanical design approach

Almost all of the structures of this project are made of steel, as it is preferred approach in this type of industrial environment where rugged and structurally solid design is favored. Competing method is using a structural framing made of aluminium extrusions, but that would only be viable choice for some individual frames of this production line, as the most of them have to bear heavy loads or tolerate impacts. Traditional shaped aluminum profiles are also susceptible to accumulation of dirt and debris.

Mostly, a steel grades equivalent to S355(K2) are used in this project – that is a structural steel with minimum yield strength of 355 MPa. The material comes in the shape of rectangular steel tubes or steel sheets except for parts manufactured by turning and milling. For this kind of project, where material usage does not need to be very optimized (explained later in this paragraph), S355 grade steel offers the best strength to cost ratio. [27]

For most of the mechanical design is this project, high precision and tight dimensional tolerances can be avoided. A large portion of the structures are fabricated by welding, and as accuracy is not required to be very high, for individual parts a most economical way is to fabricate them from structural steel tubes or sheet metal. CNC milled or turned precision components are better to be avoided where it is not necessary.

The parts made of structural steel tubes are manufactured either by a laser tube cutting machine or cut with a saw and the holes drilled. The preferred method depends on which is more economical and sensible taking the complexity of the required part into account – sometimes it is cost-effective to have a large number of parts made of same dimensioned tube manufactured by laser cutting, especially if the parts require a lot of precisely placed holes. While it is not generally needed to differentiate between those two fabrication methods during the part’s design, there are some things to consider about laser cut steel tubes: the method removes many constraints on the part design’s complexity; it requires a different approach to be used within the CAD software used; parts are manufactured according to the generated flat pattern file that is fed directly into laser tube cutter’s CAM software – this helps to avoid errors resulting from mistakes in production drawings or from fabricator’s side and correct parts are received with greater confidence.

All the sheet metal parts are in this project are fabricated by a laser cutting process and if needed, the final shape is produced by press brake bending process. While such fabrication method will not give very high precision, it is relatively economical. The process starts with flat pieces being manufactured according to the CAD generated flat pattern file. If the part design requires bends, the step is made according to production drawings. As the bending process is heavily dependent on the material, tooling used and machine operator, it is the greatest source of inaccuracies and errors in the parts – it has to be considered during the design process.

One design method is often used in this project – a number of identical parts and subassemblies are used through the entire production line, keeping the part count as low as possible. In addition to that, most of parts and subassemblies that cannot be made identical are designed to be similar, use the same general solutions. As a result, it significantly reduces the complexity of the whole design. An example of this can be seen in the Figure 4.22.

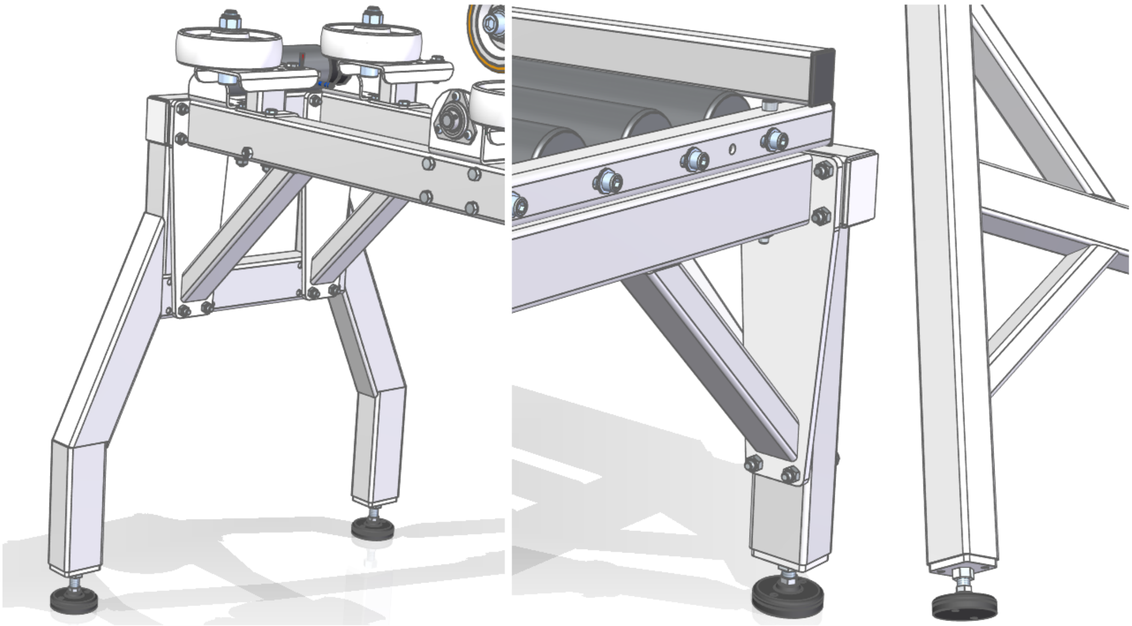


Figure 4.22 An example of similar design and identical parts

Finally, approaching the material size selection for parts – a small selection of different materials sizes greatly reduces complexity of manufacturing, thus reducing the cost. By material sizes, steel sheets or rectangular tubes with different dimensions is meant in this thesis. All the rectangular tube and steel sheet material sizes used thorough this production line are brought out in the Table 4.7, as seen, the list is short for a project this size.

Table 4.7 Material selection of the production line

Rectangular tube profile dimensions:	Equivalent grade
40x20x2 *mm*	S355K2
40x40x3 *mm*	S355K2
50x50x4 *mm*	S355K2
60x40x3 *mm*	S355K2
80x60x3 *mm*	S355K2
100x60x3 *mm*	S355K2
Sheet metal thickness:	**Equivalent grade**
1,2 *mm*	DC01
3 *mm*	S355K2
5 *mm*	S355K2
10 *mm*	S355K2

CAD design method

The entire CAD (Computer Aided Design) part of this project was made with Solid Edge ST8 software. A general approaches taken in CAD software are explained briefly next – similar methods are probably not only Solid Edge software specific, and can be implemented elsewhere.

The first approach taken is that the real world is almost exactly reflected in CAD – the configuration how large assemblies are divided into smaller sub-assemblies which in turn consist of individual parts mimics the actual manufacturing process of the design. Such structured and hierarchical approach makes individual elements of the design less complicated and increases its readability.

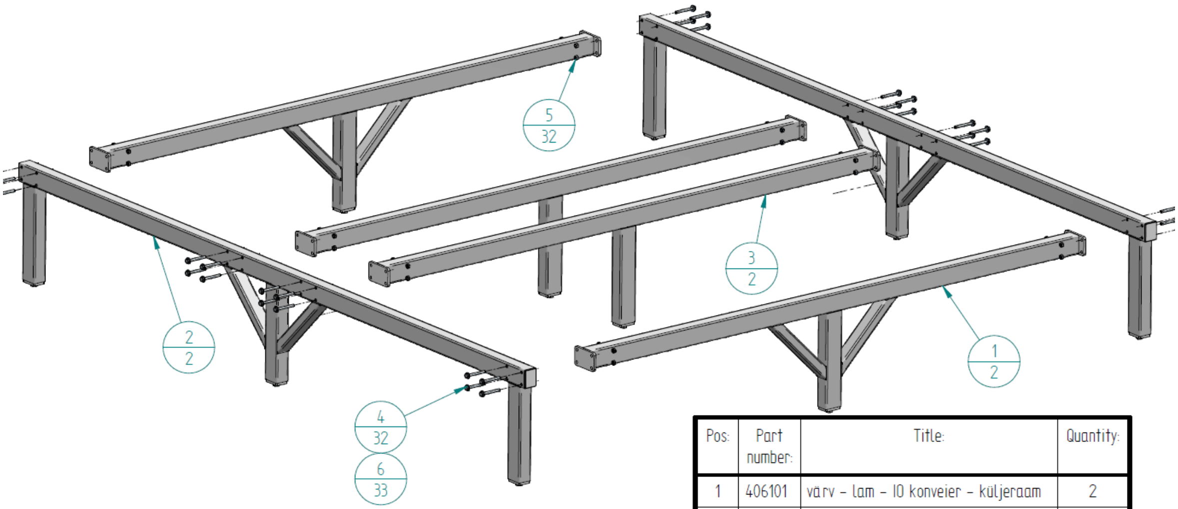
Having well prepared and organized CAD models results in significant benefits – during the design process the assemblies are changed multiple times and sufficiently automated CAD assembly saves engineering time in each case. So while it takes more effort at initial modelling phase, the time is saved multiple times later.

Many more time-saving methods for CAD must be followed in order to stay competitive and meet the deadlines, some of them include: using all the software's capabilities to speed up the modelling (CAD models using patterns, links, mirrors, etc.), prearranged material library, automatic length measuring and flat pattern generation macros, vast standard components and solutions library.

Frame design

The frame design approach taken when designing IO conveyor and in fact on all the other frames of this production line is addressed next:

- The frame consists of welded subassemblies bolted together.
- Each separate subassembly is kept flat along one dimension to aid the fabrication and transport.
- Frames are made as symmetrical as possible, subassemblies are used multiple times.



Pos:	Part number:	Title:	Quantity:
1	406101	värv – lam – IO konveier – küljeraam	2
2	406102	värv – lam – IO konveier – otsaraam	2
3	406103	värv – lam – IO konveier – vaheraam	2
4	591000	Polt M10x90 osakeere	32
5	592007	Mutter M10 kontra	32
6	593018	Seib M10x25	33

Figure 4.23 IO conveyors frame design

As seen in the Figure 4.23, three different welded subassemblies are bolted together and the frame is symmetrical along both axis when viewed from above. The weight is supported by ten vertical legs.

Structural analysis

All the structural analysis in this project was done with a software implementing the finite element method (FEM). More precisely, an integrated finite element analysis (FEA) tool built into Solid Edge environment was used. Alternatively, some structural calculations displayed in this thesis were done with a similar tool built into Solidworks CAD software.

There are many dedicated and more sophisticated structural analysis software available, for example Ansys. While those could give a more accurate results when used correctly and generally have more features, the software built into a CAD system is usually good enough for this kind of application – in addition being more convenient and user friendly. Other aspect needs to be addressed – the cost of purchasing a dedicated FEA software like Ansys is about ten times more than that of a built in system.

It has to be taken into consideration that this is a very low quantity product, so it does not make sense to have its mechanical design very optimized from mass reduction standpoint. Firstly, small material savings and the money saved from that is not worth the extra engineering time spent optimizing the design, secondly, a rigid and structurally strong design is preferred in this case anyway.

Despite that, for most of the design in this project, structural analysis was made at some stage of its development except for the similar parts or where it is obvious that the structure is strong enough. Usually several structural strength simulations are made during the design process to make correct engineering decisions, for example choosing the optimal material thickness. As making a structural analysis is made convenient these days, taking a matter of minutes to complete, it actually saves time to do some calculations on the go, also it results in a more optimized design. The other, and in some cases an outdated approach, would be finalizing the design and then making comprehensive calculations at the end (or worse, having a coworker or other company do them), only to find out that everything has to be redesigned.

IO conveyor frame’s structural analysis is discussed briefly next. The frame must be strong enough to carry two fully loaded pallets (1,3 tons each) and possibly some additional load from the forklift and from Pallet layer lifter, so loads on the frame are estimated as following: 40000 N vertically towards the ground, 1000 N horizontally along two perpendicular directions. As seen from the figure, frame’s maximum deflection under full load is 0,5 mm, and maximum stress is around 60 MPa, the design could be optimized further, but it is not reasonable for the reasons discussed above.

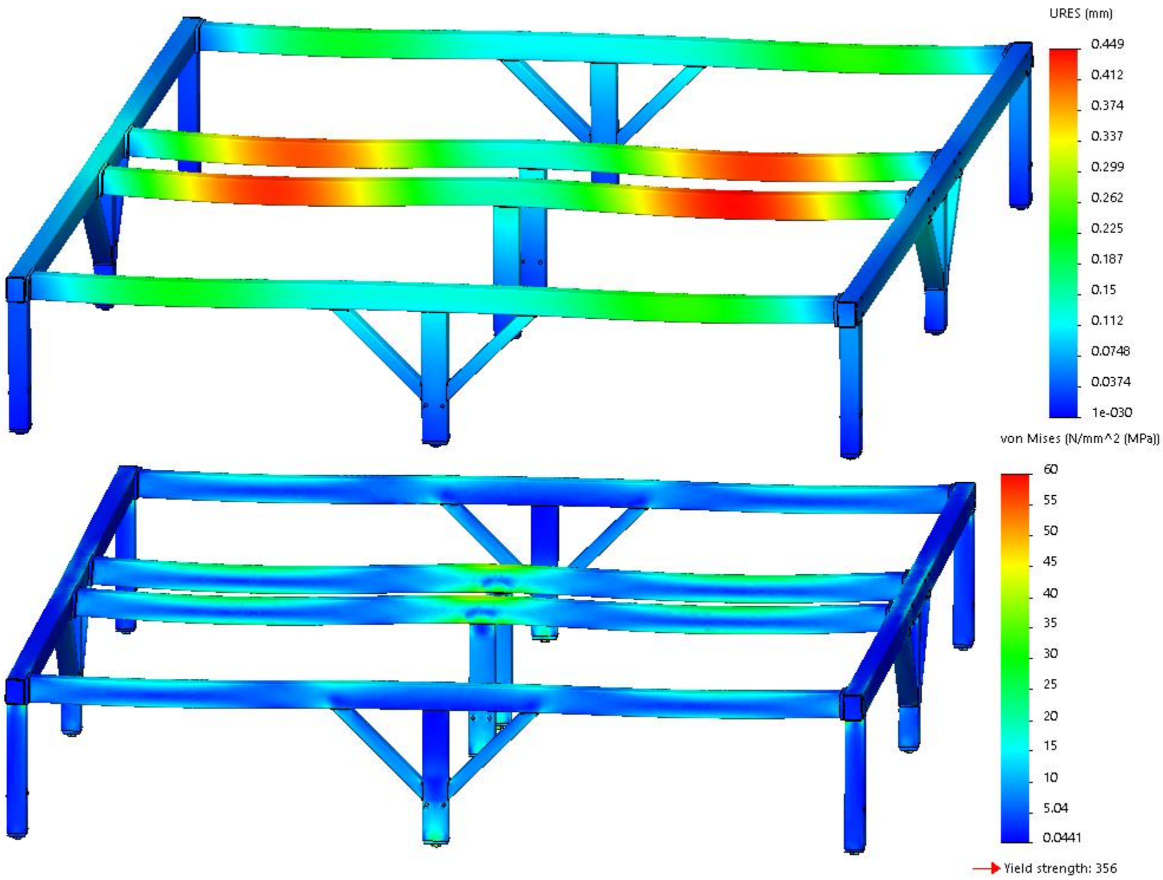


Figure 4.24 IO conveyor frame's structural analysis

Final design

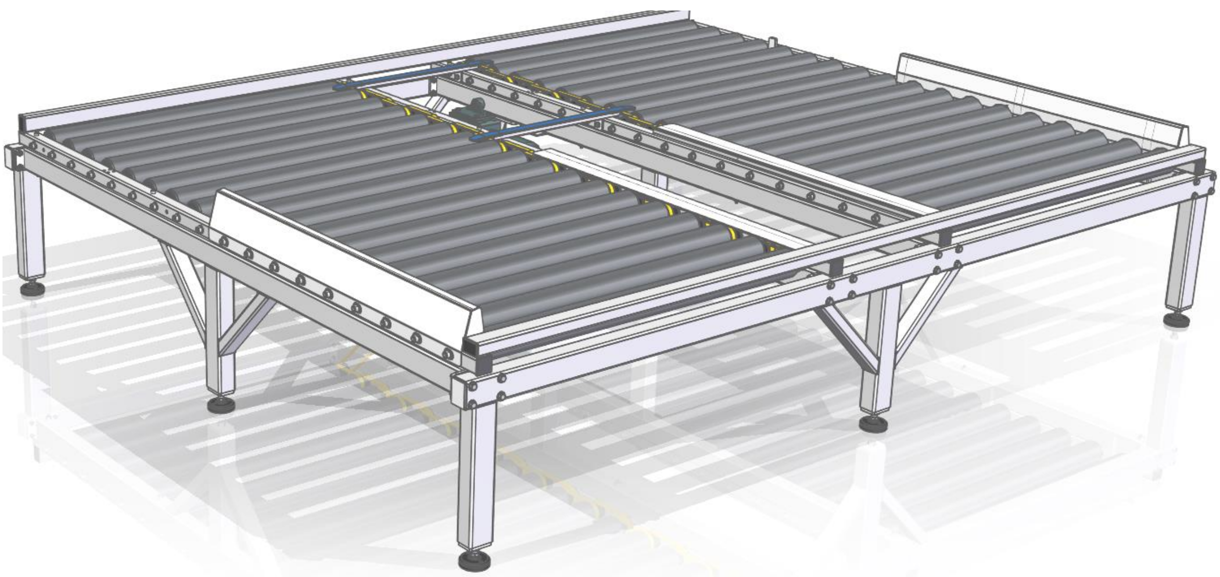


Figure 4.25 IO conveyor

4.2 Board layer gantry

The next stage of this production line is called Board layer gantry. Two similar Board layer gantries are used, one on the input and another in output side of the production line. The next stage, or the stage before as in case of output side – Board layer conveyor is mounted to the Board layer gantries, but at different heights depending on the gantry in question. Also, the Board layer conveyor used on the output side has some configurational differences, it is discussed in the next chapter and in overall design concept in chapter 3. As the scope of this thesis is limited, the Board layer gantry part of the production line is not described in great depth.

The main task of Board layer gantry's is to lift the whole layer of boards off the full pallet positioned on IO conveyor and place it on the Board layer conveyor, or in the other direction for the output side gantry. Board layer gantry includes two other subassemblies, that have their own name in this project, but are discussed under this one subdivision:

- **Board layer lifter** is the part of Board layer gantry that is responsible for grabbing the whole top layer of boards from the stack on the pallet and releasing the boards when needed. It must be capable of lifting the boards equally well independent of the board type laminated. The layer consists of 8 to 15 boards depending on the board width and weighs up to 139 kg as in case of the thickest board laminated. The board layer assembly itself moves on linear bearings and is moved by a next stage – Board layer mover.
- **Board layer mover** is a part of the production line responsible for lifting and lowering the Board layer lifter and is itself moved horizontally along its linear bearings by Board layer gantry.

For stable lifting, the board layer must be gripped from minimum two places. To verify if it is suitable, the board's deflection needs to be calculated. It is the worst in case of the thinnest boards (71x16 mm) being lifted, and must be small enough to guarantee a safe transfer to and from the Board layer conveyor. A maximum figure under 10 *mm* is estimated to be acceptable. The calculation is displayed in Figure 4.26, and the maximum displacement is 8,7 mm-s witch is acceptable, also the optimal gripping positions were found out.

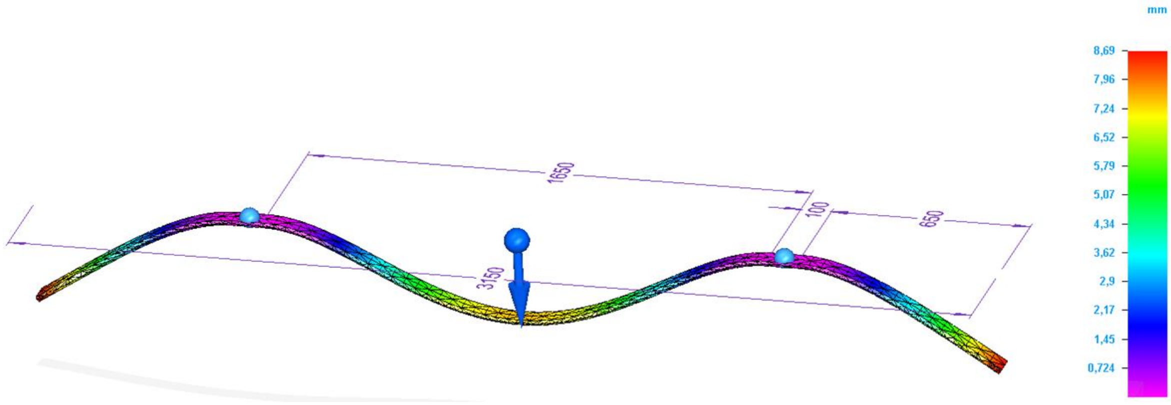


Figure 4.26 Board's deflection, lifting from two positions

A component ideally suited for lifting irregular layers of items is called vacuum area gripper, more details in Paragraph 4.2.1. Due to their shape, those grippers are often mounted on springs called height compensators, a same solution is used in this project. It also means that the vertical movement is not required to be very precise. [28]

As an actuator responsible for lifting and lowering the Board layer lifter, two alternatives were considered. One option would be using an electric motor together with a chain, toothed belt, screw or rack and pinion system. A much less complicated solution would use a pneumatic cylinder instead – but positioning accuracy of such system is much smaller. As in the current application high positioning accuracy is not necessary, a pneumatic cylinder is used for gantry's vertical movement.

The overall design concept of the Board layer gantry is described next briefly. The gantry with all of its sub-assemblies is supported by a Board layer gantry's frame. Board layer conveyor is also mounted to this frame.

Board layer mover assembly is positioned horizontally using an open ended toothed belt (also called a long-length synchronous belt) in an arrangement to translate rotational movement of a gearmotor to a linear movement. The whole assembly is supported by a linear guide system.

Board layer lifter is mounted to a Board layer mover and supported by linear guides, the assembly moves vertically and is positioned by a pneumatic cylinder. Mid-position stopping of the pneumatic cylinder is realized by using a specific pneumatic circuit diagram, furthermore, to save energy the cylinder is operated with a two-pressure setup – the pressure is reduced on the downwards stroke where the gravity does all the work. This reduces the amount of compressed air used, thus saving energy. The circuit diagram is displayed in paragraph 5.4.

Board layer lifter has two vacuum area grippers mounted on height compensators, the grippers need to lift a complete layer of boards off the stack of boards, weighting up to 144 kg. The positioning of Board layer lifter is done by sensors mounted to height compensators – the lifter is lowered slowly by a cylinder and is stopped when all the sensors detect the collision with either board stack or Board layer conveyor. Position accuracy is unimportant due to the height compensators.

The cycle time of the Board layer gantry is dependent on the exact same factors than that of a IO conveyor, see Chapter 4.1. The same amount of safety margin is used in this case also – the cycle time was set to 47 seconds, and times of the individual movements set accordingly (see Table 4.8). In case of the output side gantry, the cycle is somewhat different caused by dissimilar mounting heights of the Board layer conveyor. As the movement times are calculated for the worst case scenario, which is same for both of the gantries, the cycle times are still equal.

Table 4.8 Board layer gantry's cycle

Movement name	**Stroke**	**Mean velocity**	**Movement time**
	[m]	[m/s]	[s]
Board layer lifter down	0,6	0,06	10
Grabbing with vacuum	-		1
Board layer lifter up	0,6	0,10	6
Board layer mover travels above Board layer conv.	1,45	0,11	13
Board layer lifter down	0,1	0,06	1,7
Releasing the vacuum	-		1
Board layer lifter up	0,1	0,10	1
Board layer mover travels above IO conveyor	1,45	0,11	13
		Total movement time	**46,7**

4.2.1 Vacuum area grippers

A system capable of unstacking and stacking the boards was needed for this production line (or in other words palletizing-depalletizing). Only viable solution to this problem would be using a vacuum to grip the boards. Every other method that can be thought of, for example sliding or mechanically gripping the boards, would be unreasonably difficult to implement, especially as this assignment requires boards with vast size and weight differences to be lifted.

An ideal solution for current application would be using a vacuum area gripping system – widely applied solution in similar situations, for example in woodworking industry. It is a specialized product for gripping workpieces with an undefined pick-up position, irregular stacking patterns and varying workpiece dimensions. The surface of the items can be rough and porous and gaps between individual items are easily handled.

For the supplier of the gripping system, a German company Schmalz was selected and their FXP product series. It is necessary to lift a layer of boards weighting maximum 144 kg, that means 72 kg or 706 N force for one area gripper. Taking some dynamic loads and reserve into account, one gripper should have a gripping force of about 1400 N. Also considering a length of the layer to be lifted, a following product was selected: FXP-SVK 1234 3R18 O20. It offers a built in ejector type vacuum generation – only compressed air needs to be supplied, eliminating the need for external vacuum generation. The gripper will be mounted with flexible height compensators (50 mm stroke). This and the gripper selected is shown in Figure 4.27. [28] [29]

Type	Number of suction cells	Air consumption [l/min]	Max. suction flow [l/min]	Max. degree of evacuation [%]	Suction force [N]	Weight [kg]
FXP-SVK 1234 3R18	198	875	2,940	55	1,650	5.7

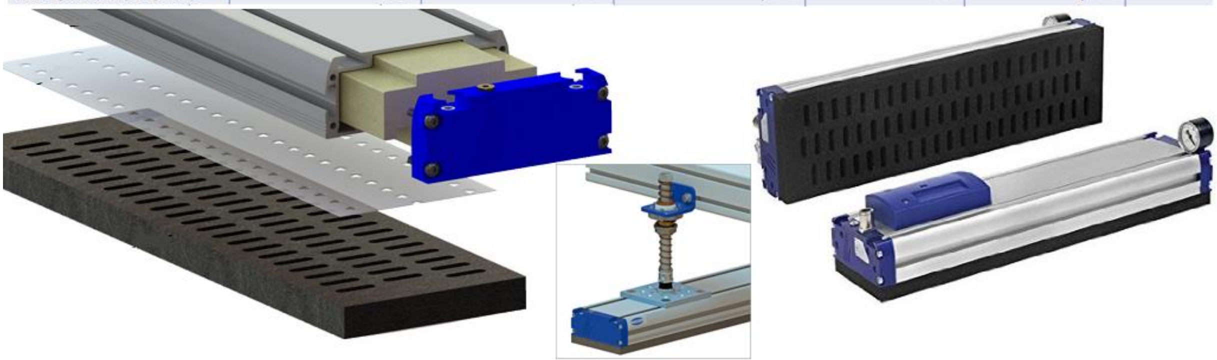


Figure 4.27 Schmalz vacuum area grippers

4.3 Board layer conveyor

Two similar Board layer conveyors will be used, one attached to the Board layer gantry at the input and another at the output side of this production line. The same base assembly is used at both sides, but as the output side conveyor has a different task, it has several add-ons.

The Board layer conveyors task at the input side is to feed the Boards separator after the boards have been placed on it by the Board layer gantry. At the output side, the Board layer conveyor is responsible for receiving the boards one by one from Boards gatherer, stopping and gathering them to one complete layer, for the next stage to pick the layer up.

To transport the boards sideways, two conveyor types would suit that application – chain or belt conveyor. As it is much easier to implement, a chain conveyor running on plastic support rails was chosen, see Figure 4.28. [3]

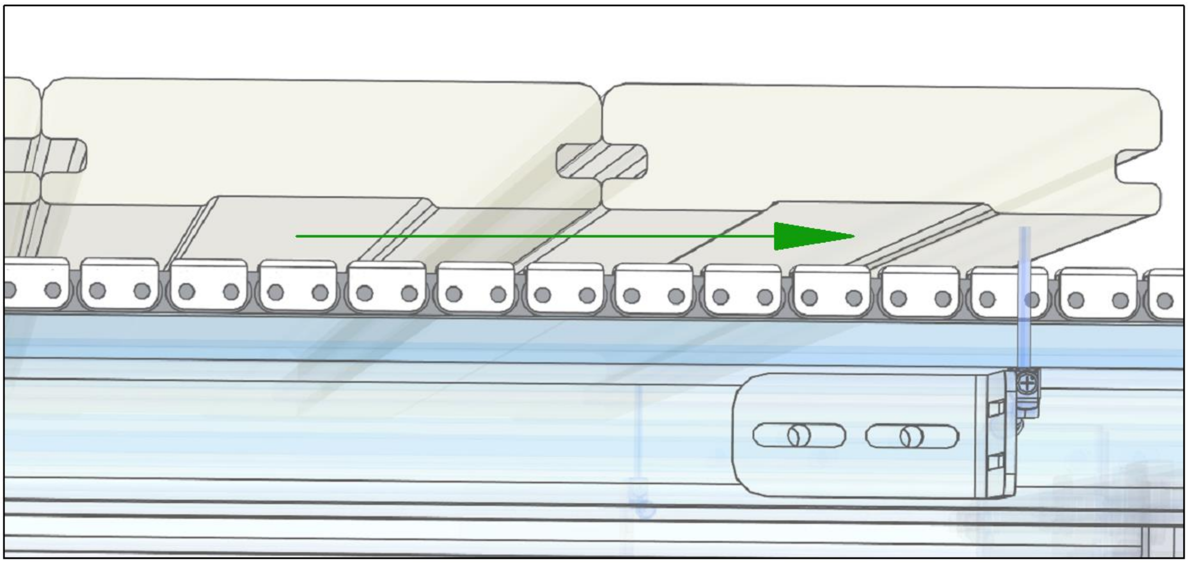


Figure 4.28 Chain conveyor

At least two chains are needed to carry the boards, but in case of the thinnest boards (71x16 mm), the deflection of the board would be too much to guarantee a safe transfer between Board layer conveyor and Boards separator and gatherer. An optimal number of supports was calculated to be four, chain locations were selected according to the positions where the Board layer lifter's vacuum area grippers would press. Chain positions are indicated in the Figure 4.29, the maximum displacement of the thinnest board is 4 *mm*, which is acceptable.

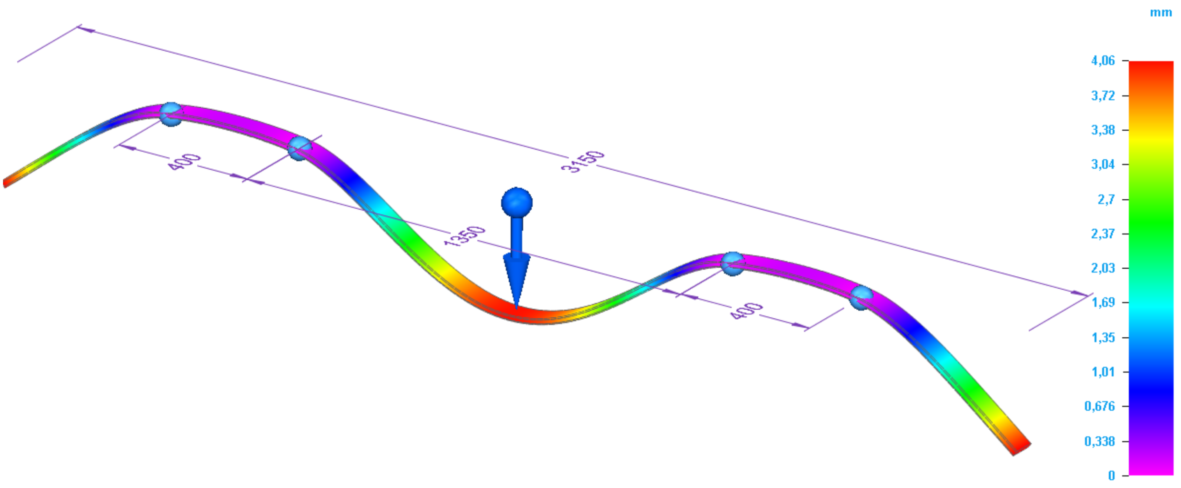


Figure 4.29 Optimal support positions

The overall design concept was devised and is described next. The conveyor in the input side has a quite straightforward principle of operation – 4 chains are driven by an electric motor with gear reducer, more specifically by SEW-Eurodrive's gearmotor KA19/TDR63S4/TF (as seen from the part number – it uses the same electric motor than IO conveyor, the gearbox is different). The gearmotor is mounted directly on the driving shaft, which is supported by four bearing units. The chains run on 4 sprockets in total, one driving and 3 driven sprockets with integrated ball bearings. As the board's surface must be handled with care, special POM plastic clips are mounted on chains, also maintenance free chains are used, to avoid boards getting in contact with chain's lubrication.

The input side Board layer conveyor is controlled by 3 photoelectric sensors fixed to its frame, with a main task to detect if the board layer has been placed and is moving along with the conveyor correctly. During the laminating cycle, the Board layer separator's sensors indicate when new boards are needed to be passed forward.

The output side Board layer conveyor has somewhat different operation and due to that it has an additional board stopper-gatherer mechanism, using two pneumatic actuators working together with the conveyor chain to stop, gather and compact the boards to a layer – the principle of operation is shown in the Figure 4.30. First, the moving board is stopped, then the stopper bracket is lowered and chains move the new board past the bracket (during which the distance between the boards is roughly measured by a photoelectric sensor) and lastly the bracket is lifted again, and the conveyor chain moves in reverse direction (for the time measured) until the gap between the boards is closed. By measuring the gap, excessive sliding of the boards is avoided to protect their surface.

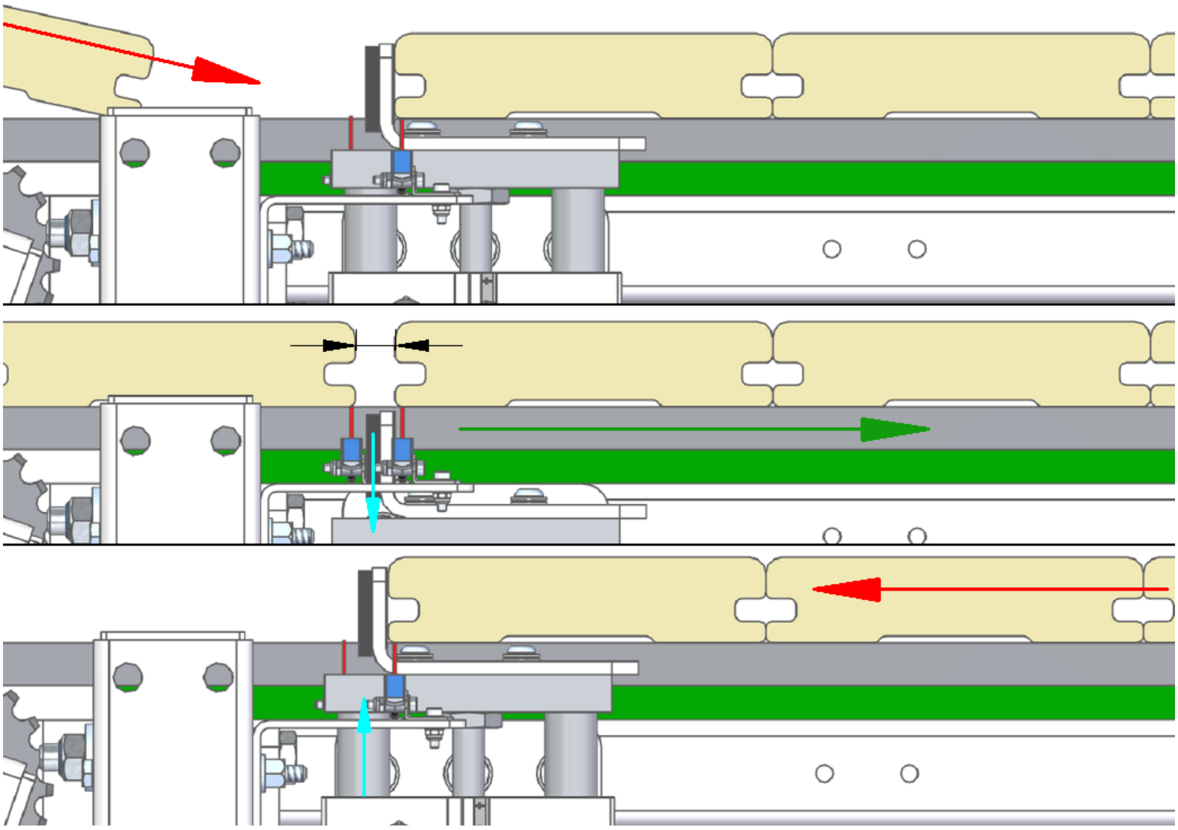


Figure 4.30 Stopper-gatherer mechanism

The output side conveyor is controlled by 5 photoelectric sensors due to a different principle operation.

There is only one movement to be considered in case of Board layer conveyor in the input side – the motion of the conveyor's chains. While the Board layer conveyors in the input and output sides have quite different tasks, the required conveyor maximum speed is about the same. The top speed for the conveyor must be at least as high as it takes to feed the lamination machine – that is moving the board along its width (140 mm) in 9 seconds. However, as there is also distances for the boards to cover and the output side conveyor needs to accelerate and stop the boards, the top steed is calculated as following: $6 \cdot 140\ \mathrm{mm} / 9\ \mathrm{s} = 93\ \mathrm{mm/s} \approx 0{,}093\ \mathrm{m/s}$. With some reserve, a chain movement speed of 0,1 m/s is chosen. The conveyor in the output side has an additional board stopper-gatherer mechanism, using two pneumatic actuators. The speed of those cylinders is not needed to be calculated, it will be adjusted on site during the production line's initial setup.

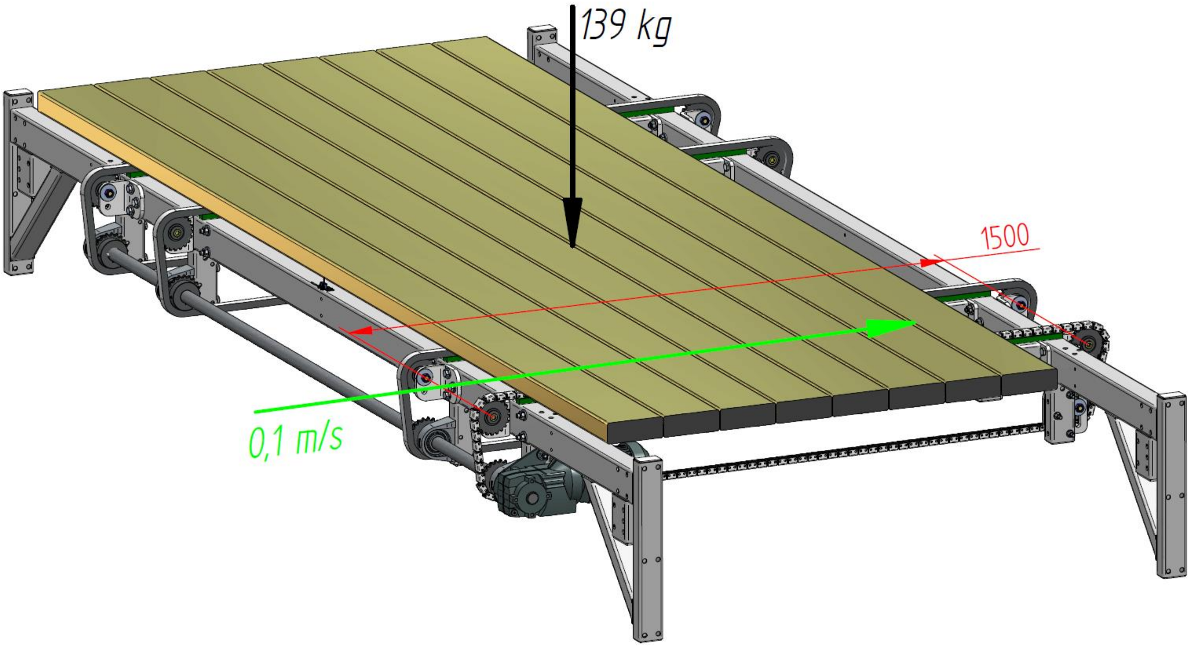


Figure 4.31 Board layer conveyor's input side movements

4.3.1 Chain conveyor

To transport the layer of boards, a roller chain conveyor was selected, it is a trusted, easily implemented, and economical method that is widely used in conveying systems. [30]

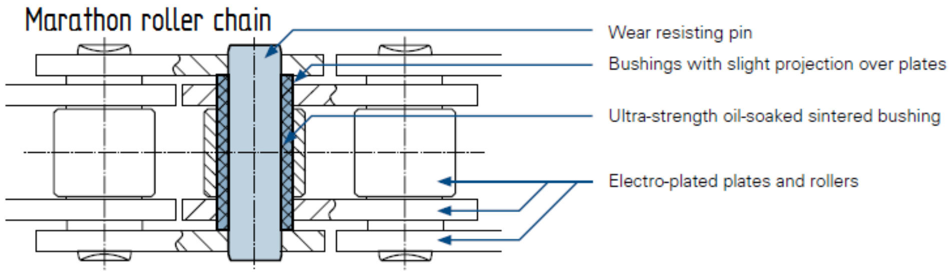
In current application, transported boards have a delicate surface that needs to must be protected against damages caused by the chain during the conveying process. Moreover, Chain conveyor in the output side requires some sliding of the boards on the chain. For this project, the roller chain supplier is German company Wippermann and they offer a viable solution: plastic clips made of POM that are suitable for mounting on roller chains (type series GL), and they will prevent the direct contact between the chain and the items to be transported while also enlarge the contact surface. [31]

As discussed earlier, maintenance free chains are used that need no relubrication, to avoid boards getting dirty, also a long life cycle is ensured. A Wippermann’s Marathon type GL series chain is chosen – they have a porous, oil-soaked sintered bushing, which is combined with a specially-coated pin to form a self-lubricating chain joint. Exact chain size chosen: 08 B-1-GL – 462 GL MA, see the datasheet in Figure 4.32. [32]

Chain according to ISO 606	Pitch		Inner width	Inner link width	Outer plate width	Roller Ø	Pin Ø	Plate height	Projection over connecting link	Breaking load	Weight	Connecting links
	p		b_1 min.	b_2 max.	b_3 min.	d_1 max.	d_2 max.	g max.	k max.	F_B min.	q ≈	
No.	mm	inch	mm	mm	mm	mm	mm	mm	mm	kN	kg/m	No.
462 GL MA	12,700	½	7,75	11,30	11,43	8,51	4,45	11,5	3,9	18,6	0,78	4,7,11,12

Figure 4.32 Roller chain selected

The smallest chain valid for plastic clips was selected, the load rating is way over what is required (0,7 *kN*). The plastic clips used and Marathon chain's design is shown in the Figure 4.33.



POM-clips

Chain	ISO	Plate height g	b_c	b_{min}	h_c	max. vertical load per clip
No.	No.	mm	mm	mm	mm	kg
462 GL	08 B-1	11,5	19,7	22,0	9,3	70

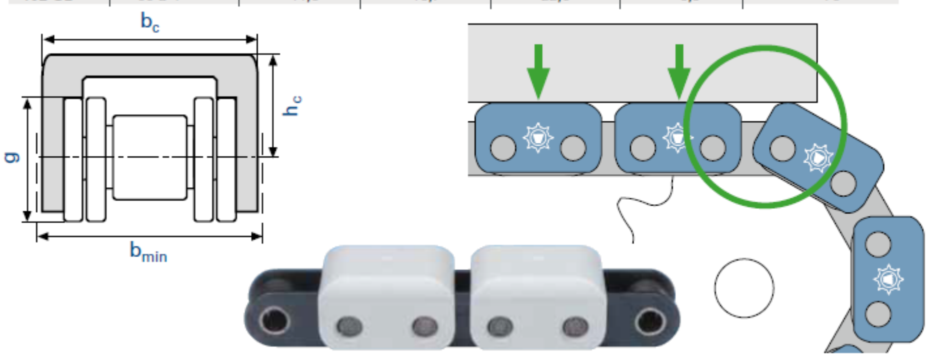


Figure 4.33 Marathon chain's design and POM-clips

4.3.2 Final design

The design of Board layer conveyor in the output side is shown with some of the key elements highlighted in Figure 4.34.

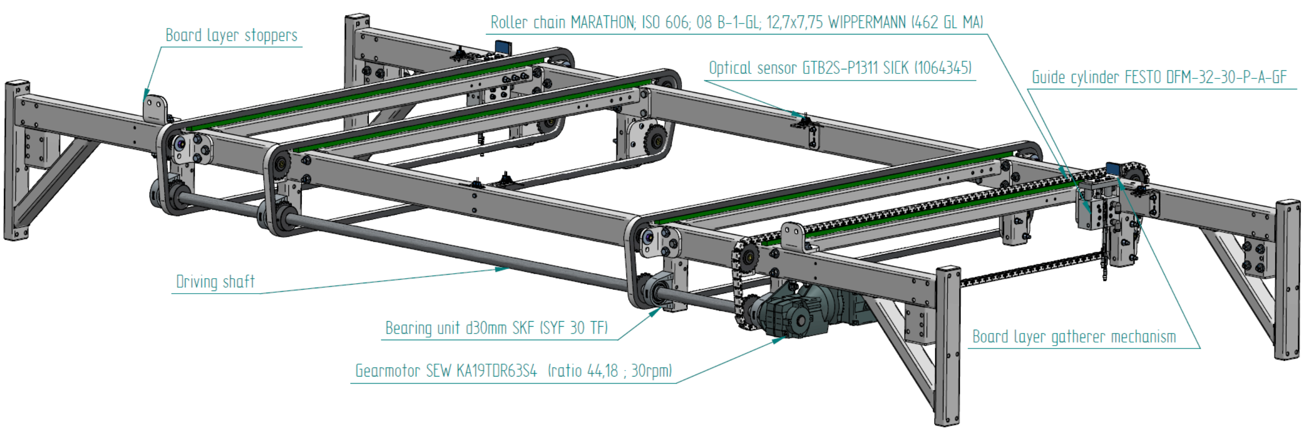


Figure 4.34 Board layer conveyor's design

4.4 Boards separator

The production line's stage after input Board layer conveyor is called Boards separator.

Its main assignment is to separate the complete layer of boards and feed the individual boards to the next stage at precisely triggered times. It has to take into account, that some of the boards have a tongue-groove side facing, which means they are overlapping each other, so separation can only be made in linear direction along the board's width.

An analysis of Boards separator will not fit in scope of the thesis, so the design is only described shortly. It operates on the following principle:

- It is mounted at 20° angle, so boards are gravity moved and sliding on plastic guides along the Boards separator.
- 3 board queue of boards is kept at all times on the assembly, if only two boards are left, photoelectric sensors trigger the Board layer conveyor to feed in new ones.
- The first board is stopped by a stopping mechanism mounted on pneumatic cylinders and has shock absorbers to smoothly stop the heavy boards.
- The stoppers are lowered to release the first board at times triggered by Board feeder.
- The second board is held on by pneumatic cylinders above the boards, mounted on a height adjustable assemblies. Positioning guide above the boards is also mounted on that assembly.
- Two other pairs of photoelectric sensors are used, controlling the presence of the first and second boards.

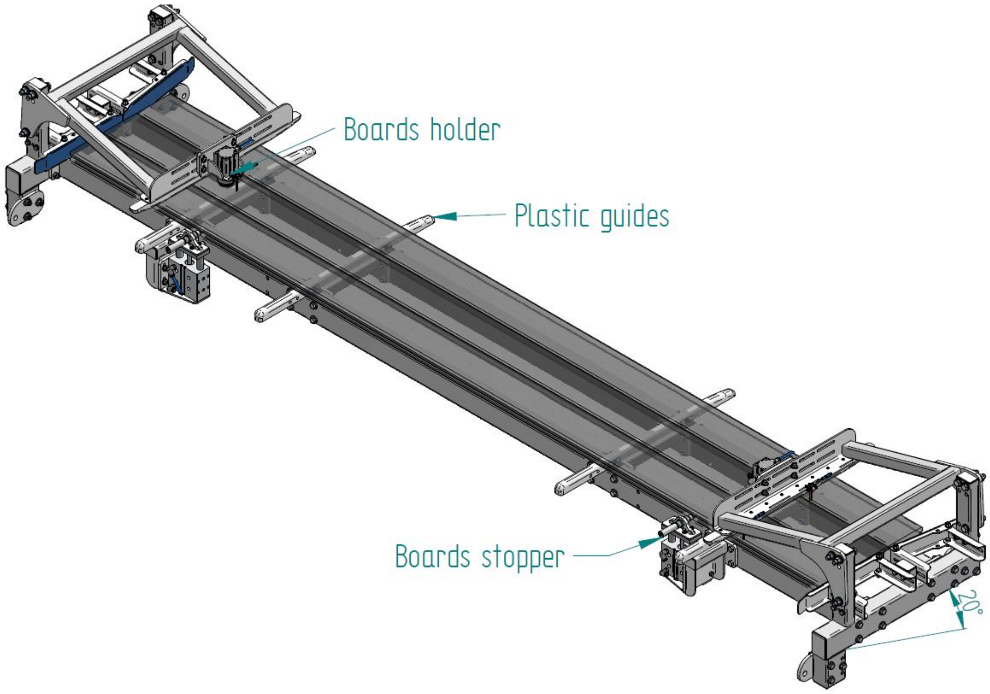


Figure 4.35 Boards separator final design

4.5 Board feeder and receiver

The next stage of the production line is called Board feeder, and because it is quite similar in its design, a stage after the Lamination machine named the Board receiver is also discussed in this chapter.

Board feeder's purpose is to receive and stop the board dropped by Boards separator, accelerate it towards Lamination machine, and then feed the boards to the machine. It includes a sub-assembly called Board distance adjuster, that sets a specified distance between the consecutive boards before they are inserted into Lamination machine.

Board receiver is responsible for receiving the board from Lamination machine, keeping the distance set earlier, then cutting the laminate between boards to separate them. After the boards have been separated, Board distance adjuster accelerates the free board, so that it can be stopped and pushed off the conveyor by two pneumatic cylinders.

Because the board is moving sideways after it is released to Board feeder, its initial position needs to be corrected as it has to be fed precisely between Lamination machine's guide rollers. For that reason, a roller conveyor is selected to move the board as it allows lateral sliding so it can be positioned sideways. It is a good idea to choose the same roller and toothed belt's type as used in IO conveyor - it means of course that the load requirement is over-dimensioned, but as the price of lower grade rollers is not a lot less, the similar solution is used.

The roller spacing was based on the maximum deflection of the thinnest board – to guarantee board's smooth movement, bending up to 3 mm can be tolerated. Another determining factor for the roller spacing was the positions of Boards separator's plastic guides. A roller pitch of 500 mm is selected, the maximum displacement is 2,9 mm, see Figure 4.36.

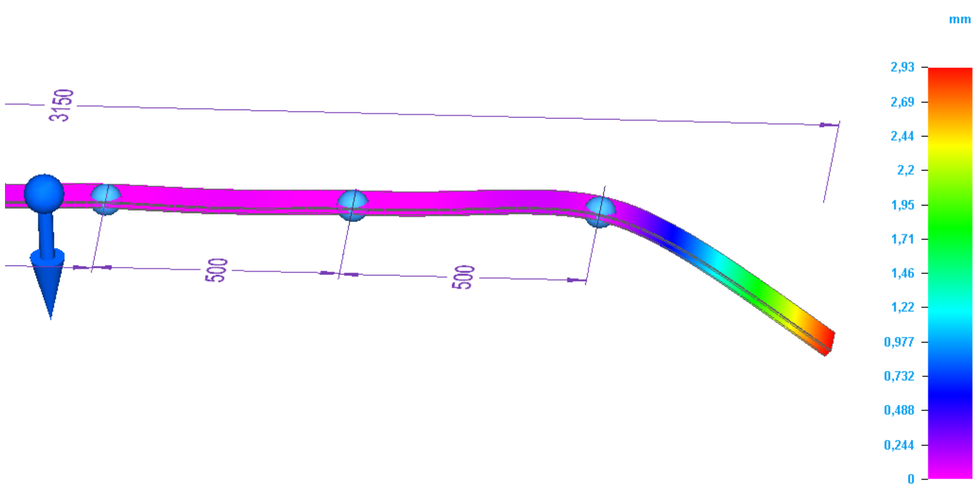


Figure 4.36 Roller spacing calculation

The overall design concept of Board feeder and principle of operation is discussed next. Board release by Board separator is triggered by a photoelectric sensor registering when the last board is cleared the way. As the board is dropped and is accelerated by gravity, it impacts the receiving side rollers with quite a high energy, for that reason the motion was simulated by software and the optimal stopping and rebound roller configuration is shown in Figure 4.37. Also, all the rollers on the side need to be adjustable for different board sizes.

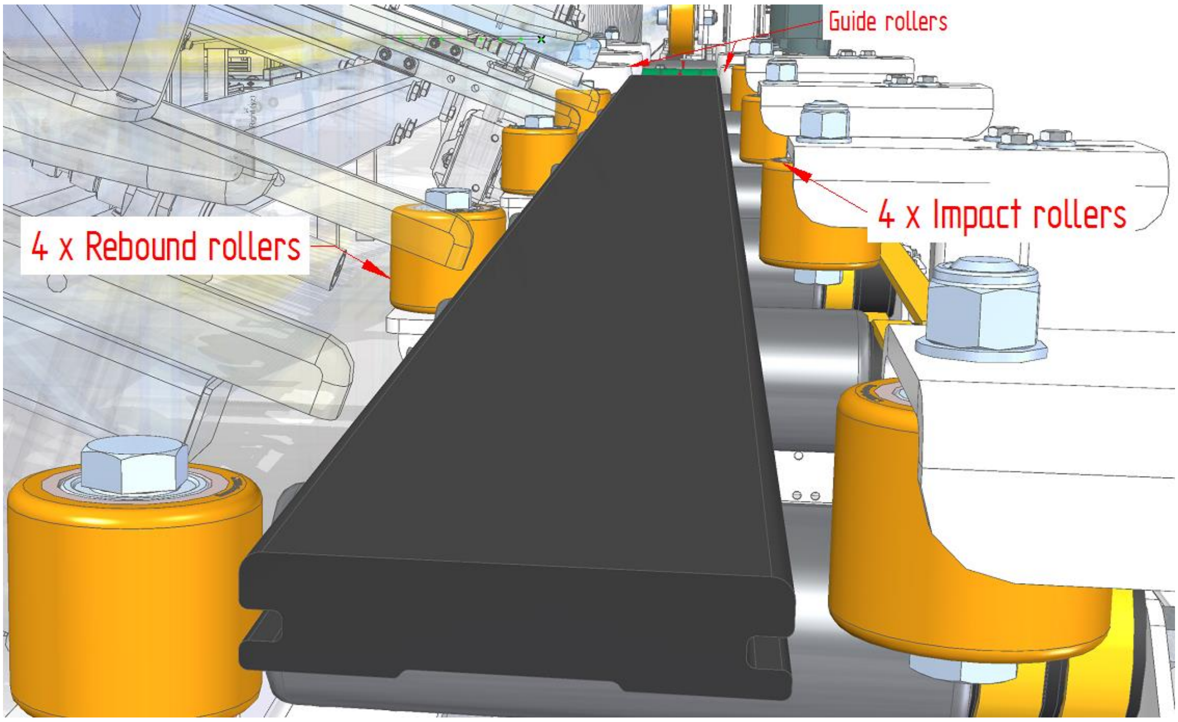


Figure 4.37 Side roller configuration

The board falls on the rollers which are turned faster than the linear speed of lamination – a new board starts to accelerate and eventually caches up with the previous board. After that, Board distance adjuster together with two photoelectric sensors sets the specified distance (normally $15 \pm 5\ mm$) between two successive boards – it is essential so the Laminate cutter can operate. The first sensor measures the distance between two boards, checking if the board has caught up, then Board distance adjuster's rollers slow down the last board shortly for specified amount giving the required distance between the boards, and then continue turning in synchronization with Lamination machine. A bit further, a second sensor measures the gap between the boards, and if it does not meet specifications, an adjustment is done.

Board receiver collects the boards after Lamination machine, Board's laminate cutter separates the boards, and right after the laminate has been cut, the board ahead is accelerated by another identical Board distance adjuster. The distance between boards is necessary to safely stop and push the first board out of the way, which is done by two pneumatic cylinders (see paragraph 4.5.2). The design of Board distance adjuster is discussed in more detail under separate paragraphs. The design of and Board's laminate cutter is not described in this thesis due to scope limitations.

The maximum speed necessary for Board feeder's conveyor was simulated by Solidworks software, as it depends on too many factors to quickly calculate. The simulation results are shown in Figure 4.38, linear speed of 0,52 m/s giving a roller rotational frequency of 130 rpm was needed with some reserve – final value 0,54 m/s or 135 rpm was used. The results show, that the board catches up with the previous board 2,2 seconds and 0,75 meters after release – enough room for the operation of Board distance adjuster.

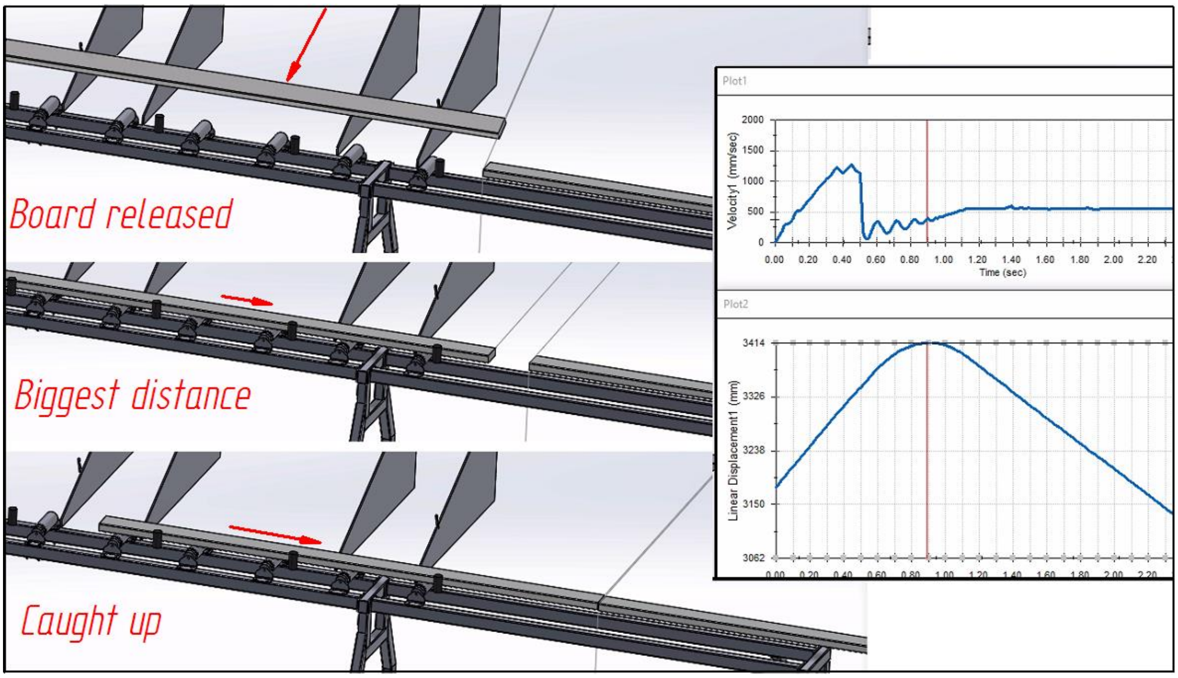


Figure 4.38 Board feeder's conveyor simulation

The motion of Board's distance adjuster is described separately in chapter 4.5.1. The motion a pneumatic cylinder used to push the boards onto Boards gatherer is simulated and shown in chapter 4.5.2.

4.5.1 Board distance adjuster

As described above, Board distance adjusted creates a specified gab between two consecutive boards. It is achieved by squeezing the board between grippy polyurethane rollers and controlling the speed of bottom rollers by a gearmotor. The pressure from a top roller is adjustable and produced by a tension spring, the top roller assembly itself glides on linear slide bearings. The design with key components highlighted shown in Figure 4.39:

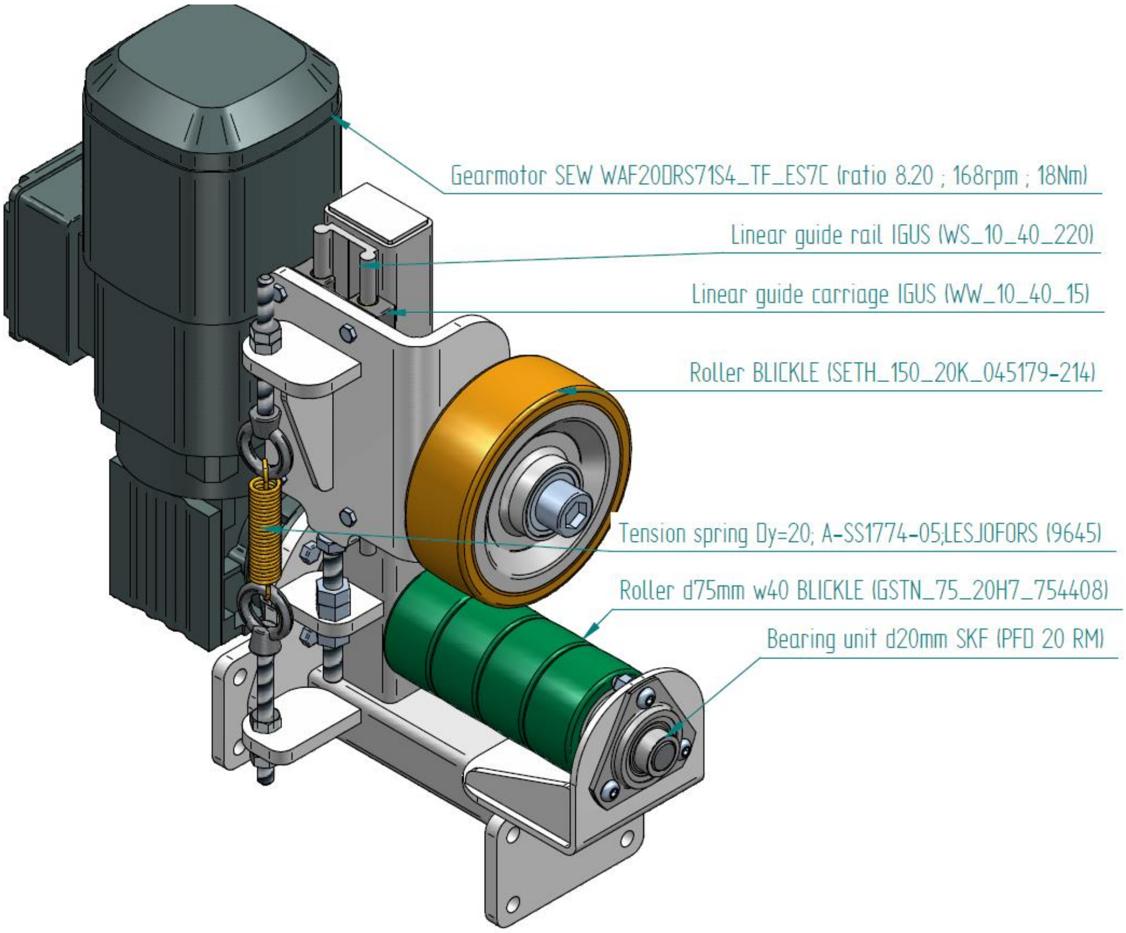


Figure 4.39 Board distance adjuster

The maximum speed necessary for Board distance adjuster was simulated by Solidworks software, as it takes less time than to calculate it manually. While the assembly is used twice, it is the Board receiver’s adjuster that needs to have a highest speed and acceleration figures to result in a safe gap between the boards. Simulation showed that a maximum linear velocity of 0,65 m/s and acceleration of 3 m/s^2 is needed, see Figure 4.40.

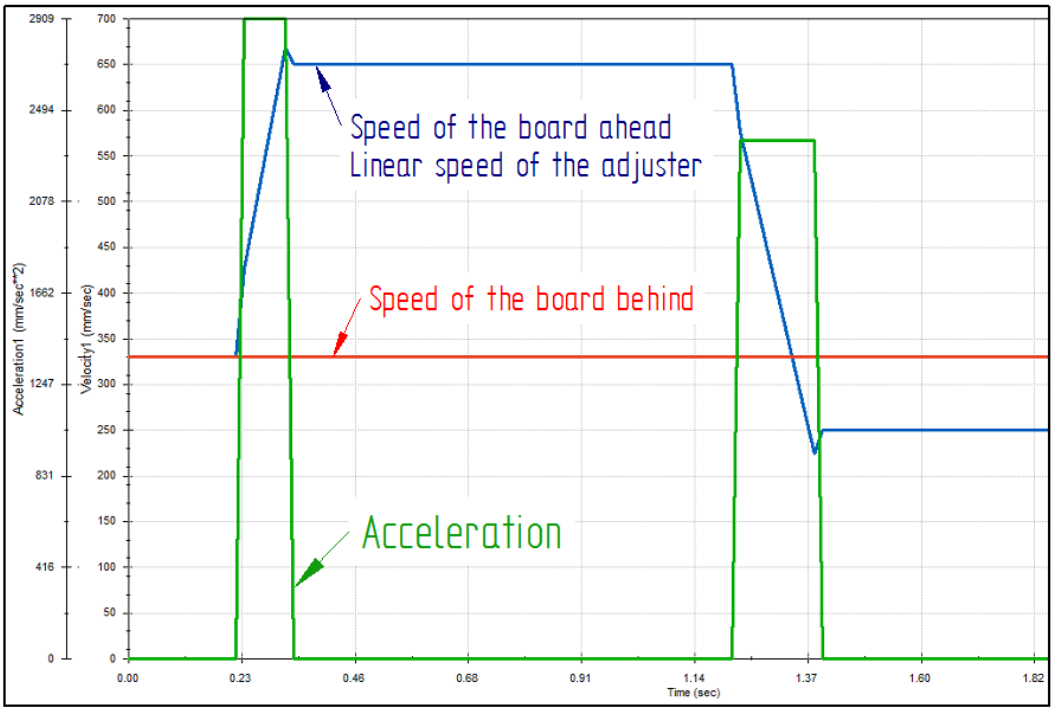


Figure 4.40 Board distance adjuster's dynamic simulation

4.5.2 Pushing pneumatic cylinders

As shown in paragraph 4.5.4, two pneumatic cylinders are used to push the boards to Boards gatherer. Festo's standard cylinder with 32 mm piston and 200 mm stroke is used: DSBC-32-200-PPSA-N3. To demonstrate if the selected cylinder is suitable for this application, Festo's online pneumatic simulation tool was used. System parameters for one cylinder were calculated – moving mass 9 kg and desired positioning time 0,8 seconds. Appropriate valve and tubing sizes are also suggested by the tool, see Figure 4.41 [33]

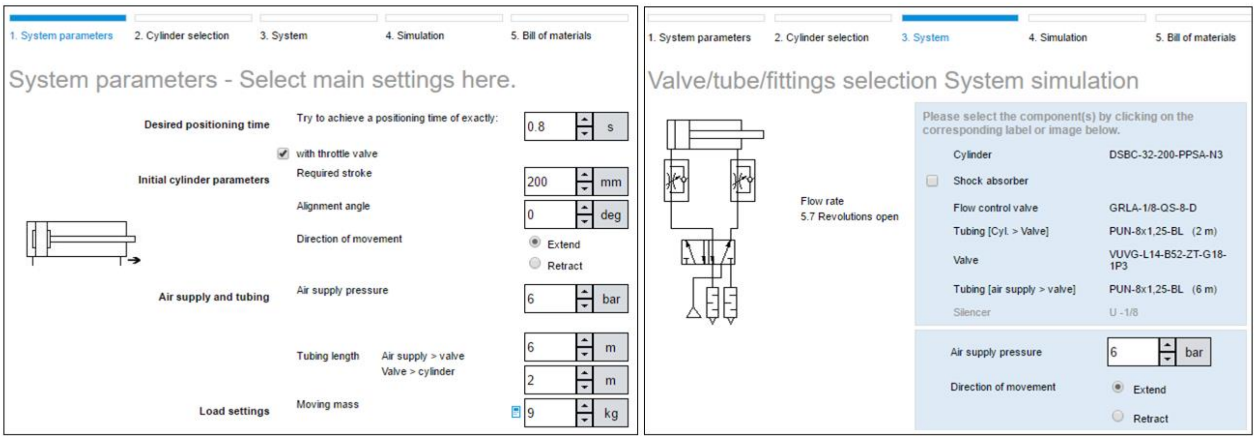


Figure 4.41 Festo simulation tool's parameters

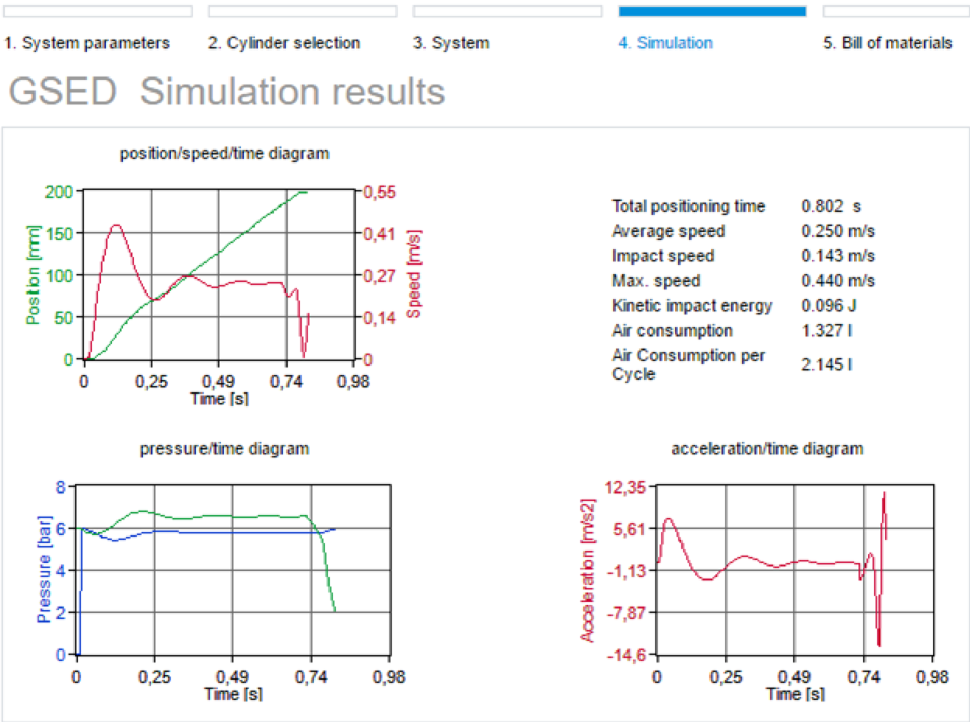


Figure 4.42 Festo simulation tool's results

The results are shown in Figure 4.42. Even throttle valve settings to control the actuation speed can be simulated. The actual setting will be adjusted on site during the production line's initial setup. It has to be taken into account, that in this case, the simulation results at the stroke's end do not match the reality, because the load is not fixed to the cylinder and is not decelerated.

4.5.3 Photoelectric sensors

Throughout the entire production line, the presence or in most cases the edges of the boards need to be detected and preferably with quite high precision (in a few millimeters range). A sensor type capable of performing this task is called a photoelectric sensor, it uses a light beam generated by LED or laser to detect a presence of an object and are widely used in industrial applications. There are three main types of photoelectric sensors: through beam, retro-reflective, and proximity-sensing sensors. [34]

- Through-beam sensors are composed of two devices: a sender and a receiver, physically separate from one another. When the beam is broken, an object is detected.
- With a retro-reflective sensor, transmitter and receiver are at the same location and the emitted light is returned by a reflector and is evaluated by the device.
- In case of a proximity sensor, the light from the sensor is reflected back from the object and it is detected when the receiver sees the transmitted light's reflection. This is the type of sensor selected for the project –it is the easiest to implement with only

single installing position needed. In many applications within this production line, the other two sensor types cannot even be used – for example Board layer conveyor, where the side edge needs to be detected but the boards are lifted up. [35]

For the sensor supplier, a German company SICK is chosen. From the three technologies Sick offers for photoelectric proximity sensors, background suppression method is used – signals from behind the set sensing range are suppressed, and anything closer to the sensor is detected. It is ideal for the applications within this production line, where black colored boards need to be detected and immunity for ambient light and background machine parts is necessary. Sick's online catalog helps to select a suitable sensor with its filtration tools. [36]

The application requires board edges to be detected with position tolerances – after an analysis of Sick's product range, a following product families are used: W2S-2 and G2S, both are very compact and have identical housings. Depending on the object distance and required detection accuracy, three different photoelectric sensors are used in this project – a sensor responsible for board distance measurement used in Board feeder is described further – WTB2S-2P3275. It features a line-shaped very narrow light spot, allowing precise board's edge detection. A datasheet is shown in Figure 4.43, some characteristics in Figure 4.44.

FEATURES	
Sensor/detection principle	Photoelectric proximity sensor, Background suppression
Dimensions (W x H x D)	7.7 mm x 21.8 mm x 13.5 mm
Sensing range	10 mm ... 70 mm [1)]
Type of light	Visible red light
Light source	PinPoint LED [2)]
Light spot size (distance)	2.2 mm x 9 mm (45 mm)
Wave length	640 nm
Adjustment	Cable
Special features	Line-shaped light spot
MECHANICS/ELECTRONICS	
Supply voltage	10 V DC ... 30 V DC [1)]
Output type	PNP
Response time	< 0.5 ms [4)]
Connection type	Cable with M8 male connector, 4-pin, 200 mm [6)]
Cable diameter	Ø 3 mm
Enclosure rating	IP 67

Figure 4.43 SICK WTB2S-2P3275 sensor datasheet

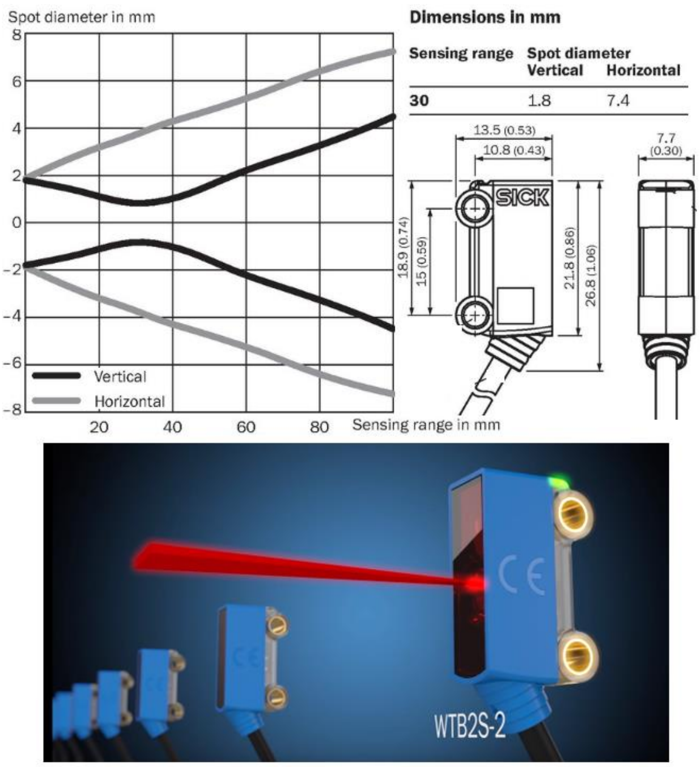


Figure 4.44 SICK's WTB2S-2 sensor

4.5.4 Final design

The design of Board receiver in the output side is shown with some of the key elements highlighted in Figure 4.45.The Laminate cutter assembly is not shown in details.

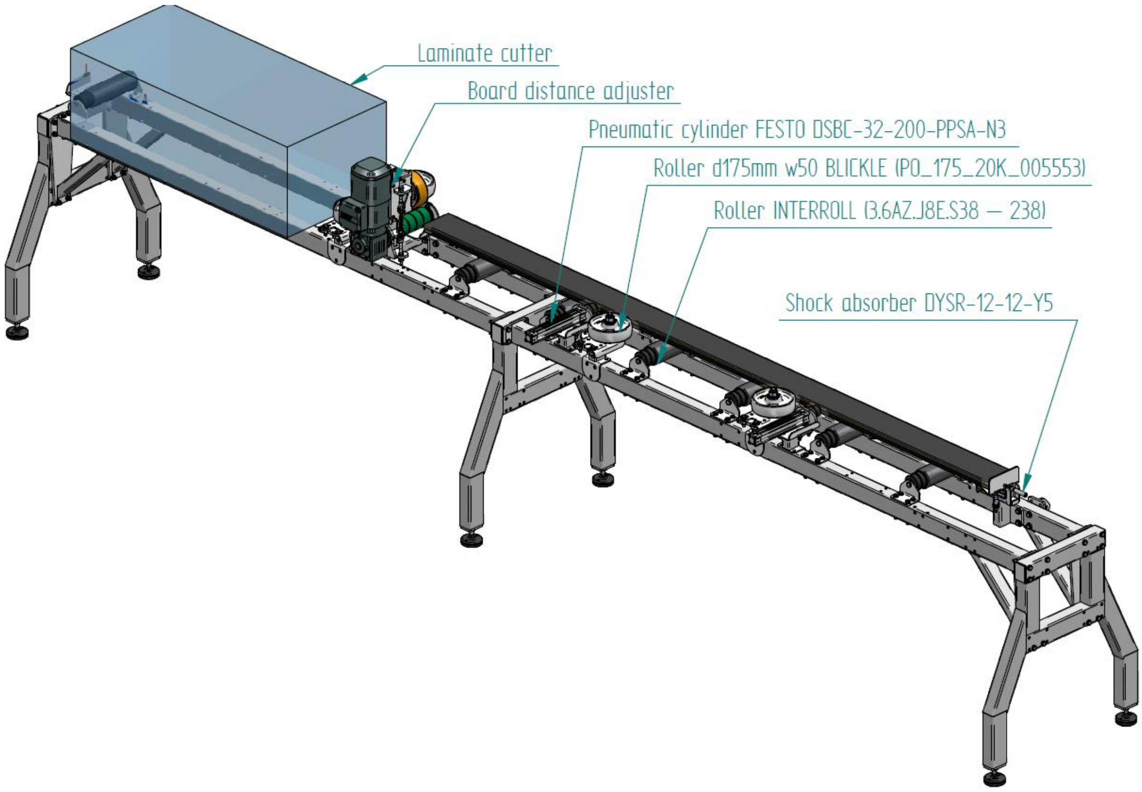


Figure 4.45 Board receiver

4.6 Boards gatherer

The next stage of this production line was named Boards gatherer. It is quite similar to the Boards separator from frame design and mounting aspects. It feeds the next stage – Board layer conveyor – described in Chapter 4.3.

Its main task is to gather the boards from Board receiver, stop the boards and release them for the Board layer conveyor, where the board layer is actually gathered. Boards gatherer also has a board flipping mechanism, required for reasons described earlier in the thesis.

An analysis of Boards gatherer will not fit in scope of the thesis, so the design is only described shortly.:

- It is also mounted at 20° angle, so boards are gravity moved and sliding on plastic guides
- Board flipping mechanism consists of two pair of fingers – both actuated by pneumatic cylinders. The first pair of them stops the board and then turns it over, the second pair of fingers then receives the flipped board and it is then lowered on the guides in a controlled manner. The flipping action can be turned off when required.
- Finally, the board reaches a stopping mechanism mounted on pneumatic cylinders. After the stopping, board is released on the next conveyor

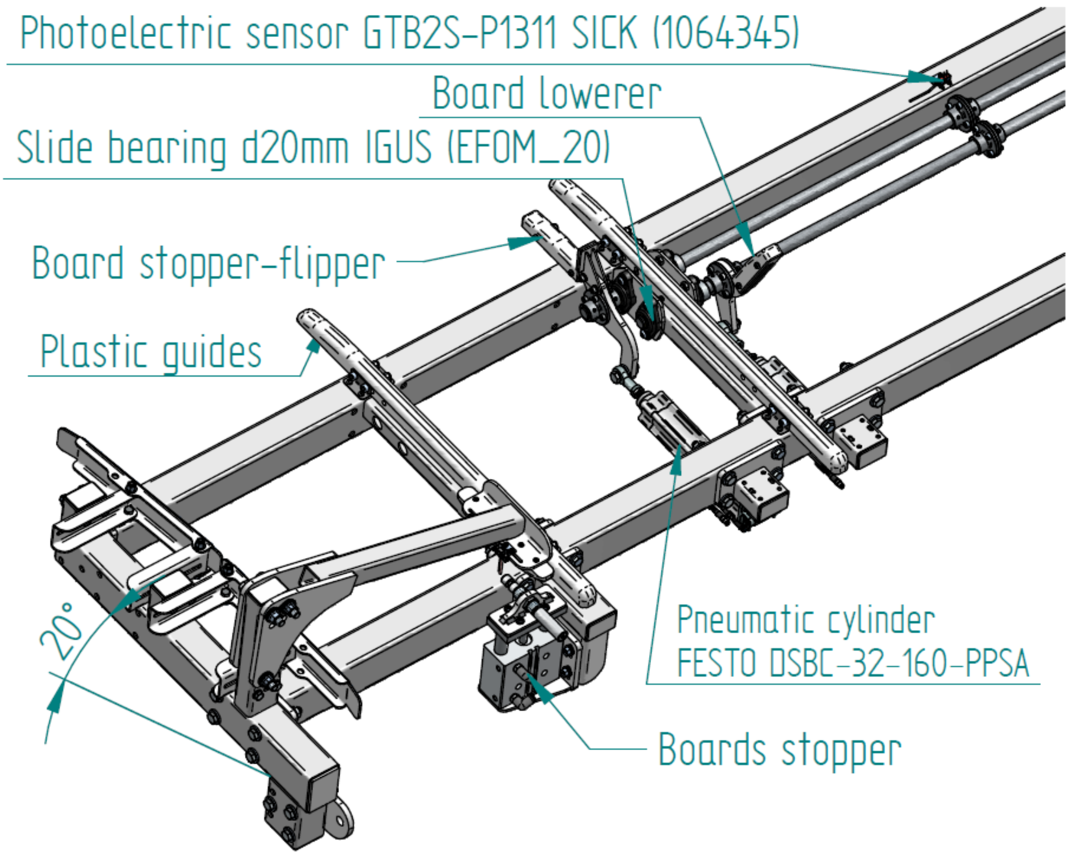


Figure 4.46 Board gatherer final design

4.7 Pallet conveyor

A final part of this production line to be discussed is called Pallet conveyor.

Pallet conveyors task is to transport empty pallets between IO conveyors, from input to the output side. Moving of the empty pallet is separated from the middle to provide an access to Lamination machine for the operator, also it simplifies the production, assembly and setup to have two smaller conveyors instead of one long. Therefore, two Pallet conveyors are used and are connected in the middle with movable guide rails that can be opened by the operator.

The empty pallets will be moved by a chain conveyor with pusher dogs (or teeth) that grab the edge of the pallet and tow it off the input IO conveyor and in the other end push the pallet on the output IO conveyor. The chain is driven by a gearmotor.

A design of Pallet conveyor is not discussed in any more depth in this thesis, as all the engineering problems raised by this part are already described earlier in this work.

4.8 Final design of the production line

Final design with subassemblies highlighted is displayed in Figure 4.47

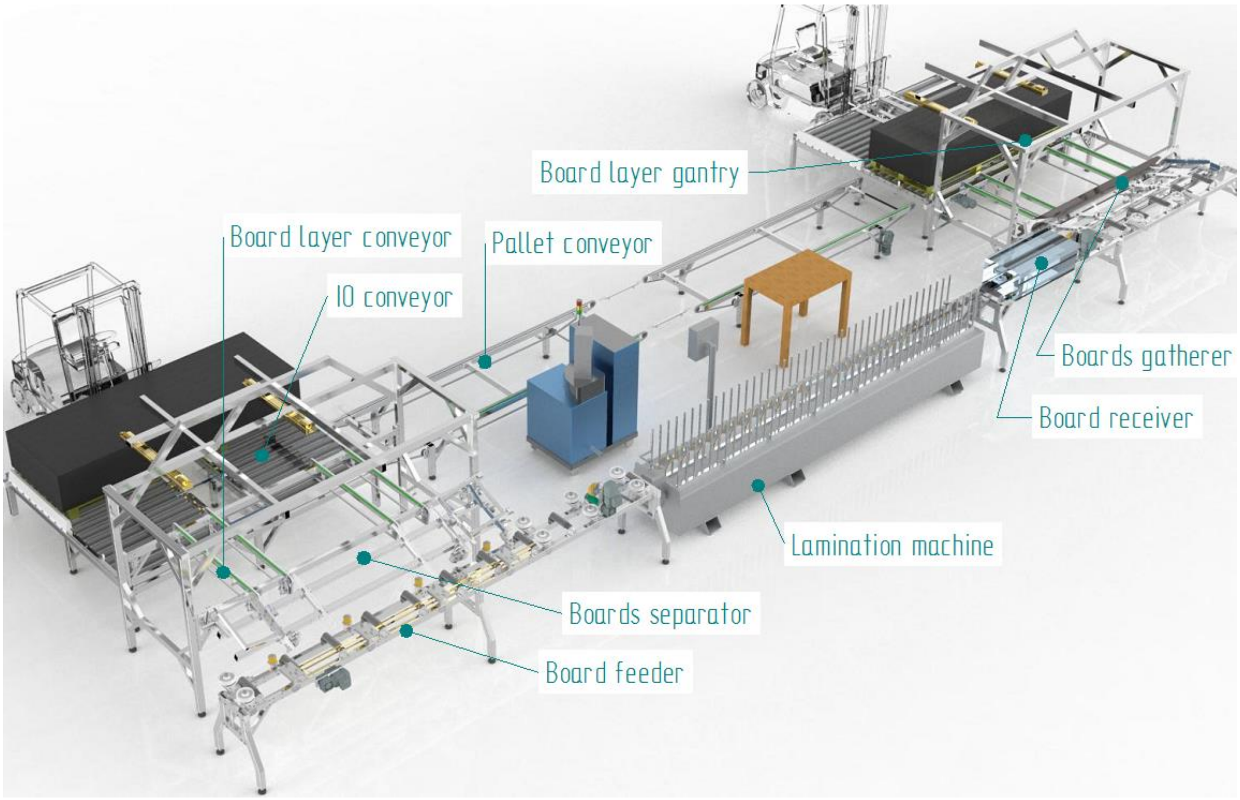


Figure 4.47 Final design of the production line

5. AUTOMATION TECHNOLOGY

The selection of automation components, except ones already described above, is discussed in this paragraph.

5.1 Main PLC

The industrial automation control system of this production line will be from Siemens, as it is preferred by the automation engineering company responsible for programming and configuring the system – a specialized brand-specific software is used for that.

From Siemens product lineup, a SIMATIC ET 200SP system will be used to control the product line – it is a multifunctional, modular system, different expansion modules can be integrated into the ET 200SP system using an internal backplane connection – modules are stacked next to each other to form a required configuration. It is in its nature a distributed control system. Due to their compact design, distributed controllers are particularly suitable for production line machinery – they can be mounted in a control cabinet directly on the machine. If several production lines are built in the future, connection between them and to a production line's central control cabinet is realized via PROFINET (standard for industrial networking in automation). [37]

For the main PLC, an SIMATIC ET 200SP module with integrated CPU is selected: CPU 1512SP-1PN. The functionality of the controller corresponds to that of a standalone SIMATIC PLC – it can be used in the ET 200SP distributed I/O system as a central system without a higher-level controller. The controller is shown in Figure 5.1. [37]

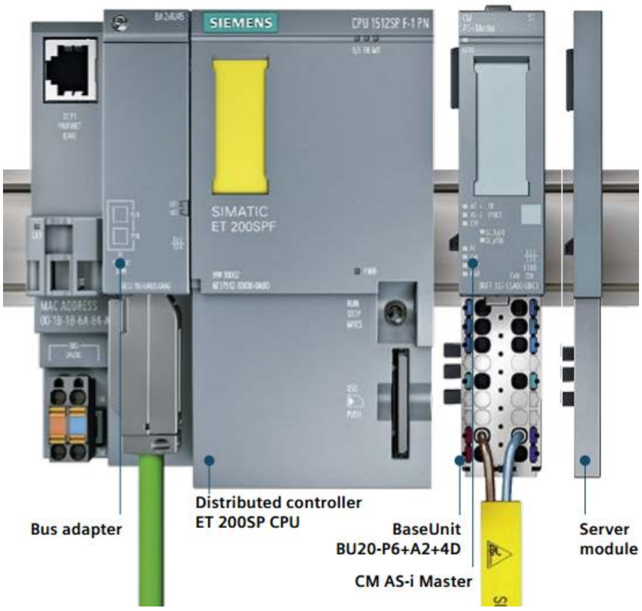


Figure 5.1 ET 200SP CPU with AS-i Master station

5.2 Distributed I/O

As described briefly above, distributed control approach is taken in this project – rather than having one central controller in one location and all the sensors and actuators connected directly to it, control elements are distributed throughout the system.

For sensor and actuator level of the control network, an industrial networking solution called AS-Interface (AS-i) – the actuator-sensor interface is used. It represents simple, standardized and manufacturer-independent network system, it enables the transmission of process- and machine-level digital and analog signals in real-time. Furthermore, it also acts as a universal communication interface between sensors of all kind, emergency-stop pushbuttons and actuators. [38] [39]

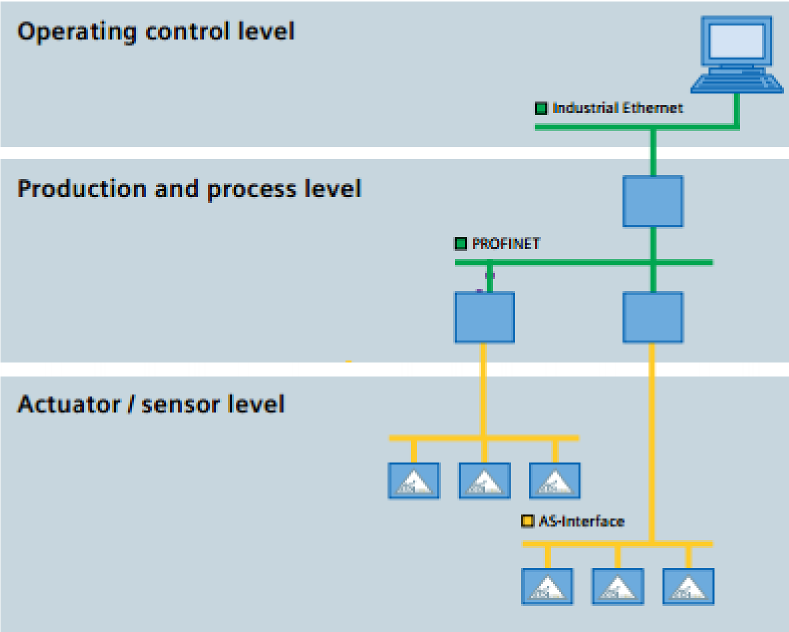


Figure 5.2 Common network topology

An AS-i network consists of a master, a power supply unit and up to 62 stations, the so-called slaves. In this project, slave controllers will be distributed throughout the product line and all the sensors and pneumatic valves connect to those slave controllers. There are no restrictions in terms of structure or network topology in the AS-I network. All the controllers are connected by only one two-pole characteristic yellow AS-i cable that is routed throughout the system and connected to the control's AS-i master. It both ensures the sensors' and actuators' data transmission and energy supply. An additional black cable can be used for a supplementary 24 V supply of powerful actuators. The slaves are docked directly onto the cable on the basis of the innovative insulation piercing method. [38]

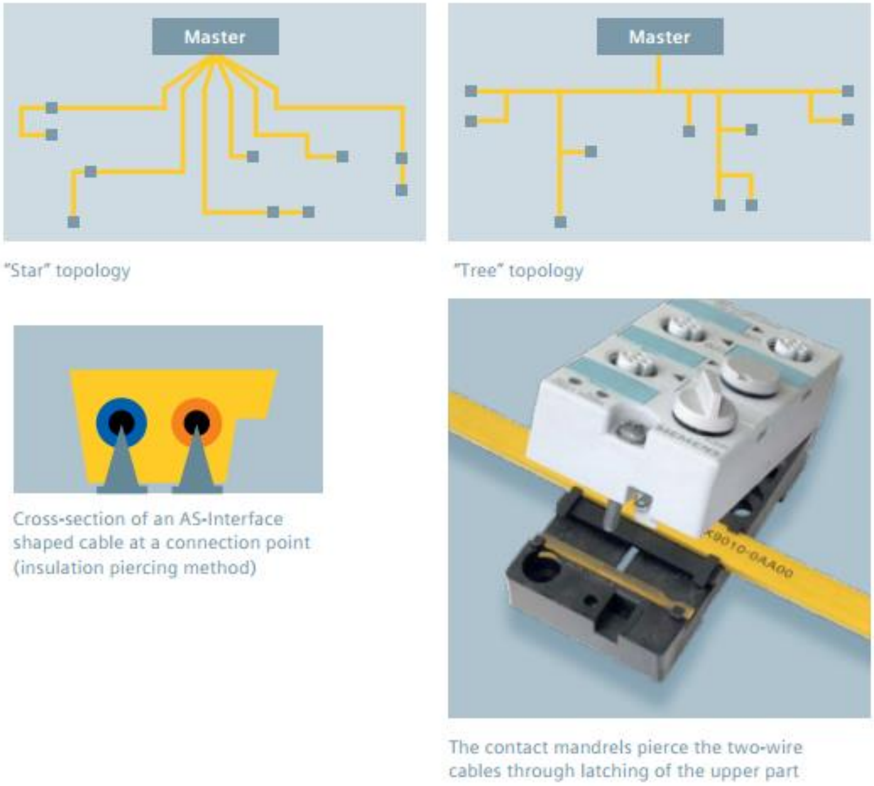


Figure 5.3 AS-i's different topologies and connecting the modules

As discussed above, our production line will have several I/O modules distributed throughout, and the sensors plug directly into those. Some different I/O modules available are shown in Figure 5.4. [38]

Figure 5.4 AS-i I/O modules and master

An overall idea of production line's network topology is shown with an optional second machine and a master controller is shown in Figure 5.5. [38]

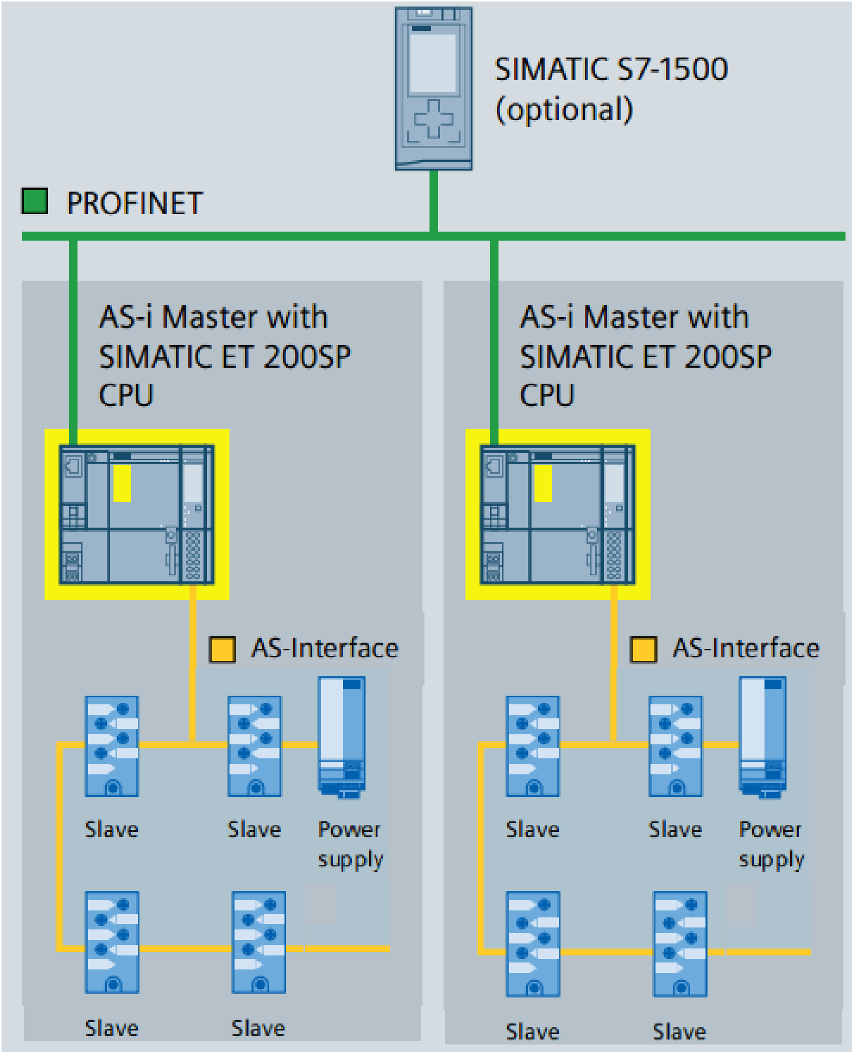


Figure 5.5 Production line's network topology with an optional second machine

5.3 Human machine interface

A Human machine interface or HMI is a piece of equipment that can be used to control and monitor the machine by operator. For this production line, HMI is implemented as relatively large, touch sensitive LCD screen. The supplier of such HMI panel will not be Siemens but Swedish company called Beijer – offering an economical yet very capable solution.

A 15,4" HMI panel was chosen from Beijer's product selection: iX T15B. A datasheet together with photos is displayed in Figure 5.6: [40]

Mechanical	
Mechanical size	410 x 286 x 83 mm
Touch type	Resistive type
Weight	3.6 kg
Housing material	Powder coated aluminum
Power	
Input voltage	+24 VDC (18 - 32 VDC)
Power consumtion	24 W
Display	
Size diagonal	15.0 inch
Resolution	1280 X 800 pixels
Backlight	LED backlight
Display type	TFT LCD
Environmental	
Operating temperature	-10 to + 50 °C
Sealing front	IP65
Sealing back	IP20

Figure 5.6 Beijer HMI iX T15B

5.4 Pneumatic diagram

For all the pneumatic control part of the production line, pneumatic diagrams are devised. Only Board layer gantry lifting cylinder's pneumatic diagram is shown in the scope of this thesis. The cylinder needs to be stopped in the middle of its stroke – mid-position stopping is realized by using a mid-position 5/3 directional valve, furthermore, to save energy the cylinder is operated with a two-pressure setup – the pressure is reduced on the downwards stroke where the gravity does all the work. This reduces the amount of compressed air used, thus saving energy. Displayed pneumatic diagram has a drawback – component leakages prevent permanent stoppage of the cylinder. If testing shows that the cylinder in not able to hold its position long enough, more comprehensive diagram is used to compensate for leakages. Initial diagram is shown next in Figure 5.7. [41]

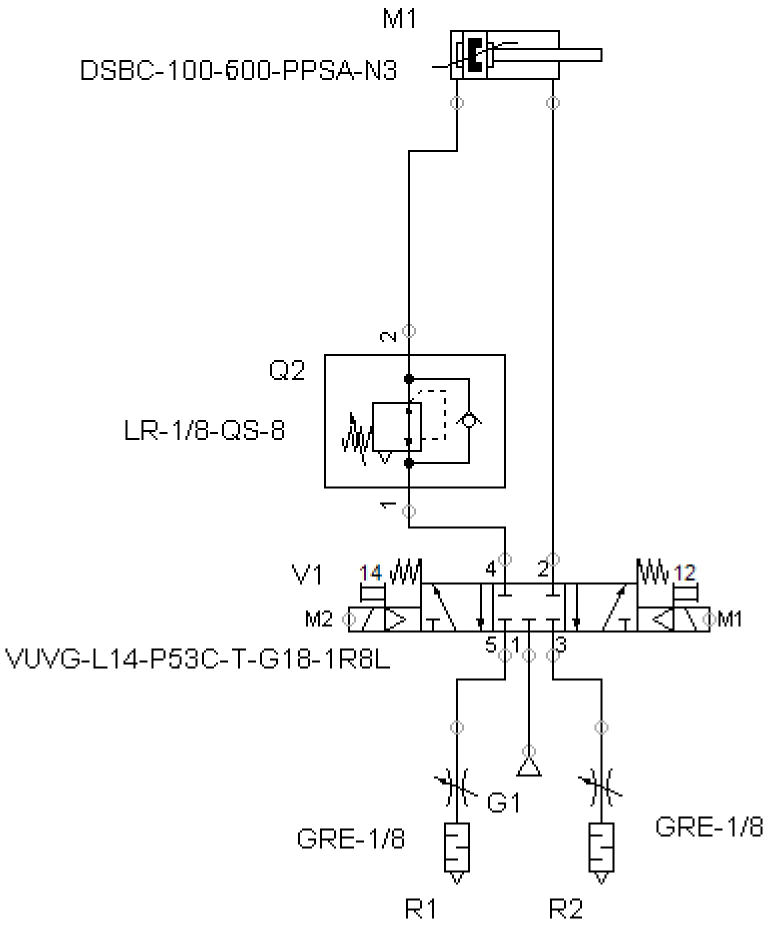


Figure 5.7 Pneumatic diagram of Board layer gantry

6. CONTROL OF THE PRODUCTION LINE

After the engineering project is finished, and usually when the machine has been built, device and network configuration together with configuration and programming of the controllers and design of HMI is next. This step is executed in cooperation with an automation engineering company – it requires specialized software. For SIMATIC controllers, that is an automation engineering framework software called TIA Portal, by Siemens, or more precisely – SIMATIC STEP 7. [42]

6.1 Process flowchart

Complete process flowchart of the machine needs to be designed – representing accurately an algorithm and workflow that describe an operation and processes of the production line. On the basis of this flowchart, controlling program is made. As in case of production line's design, process flowchart is divided into separate diagrams based on the functional parts of the production line.

Process flowchart of Board layer conveyor at the output side is displayed in this thesis, see Figure 6.1 and Figure 6.2

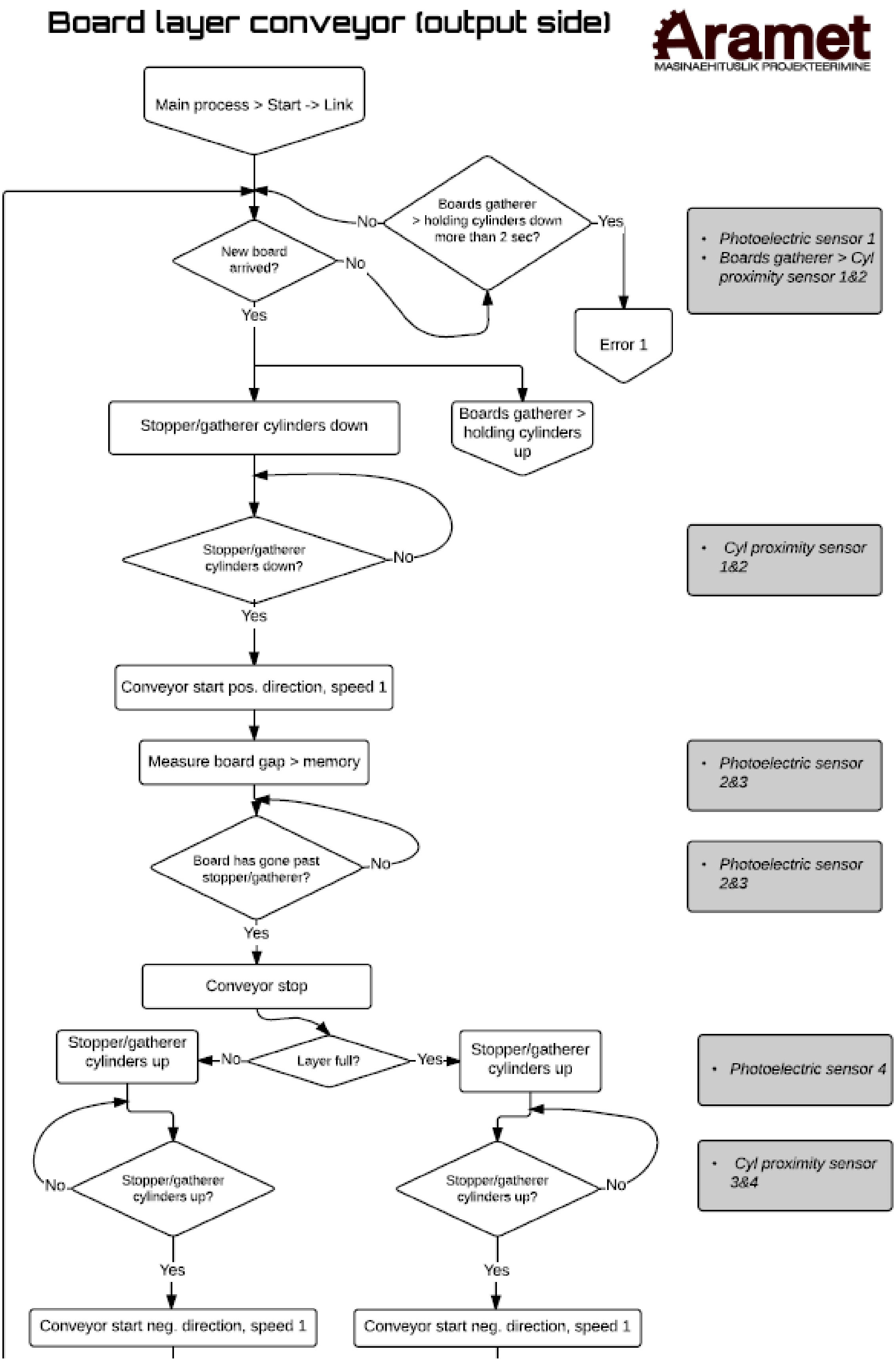


Figure 6.1 Process flowchart, Board layer conveyor, page 1

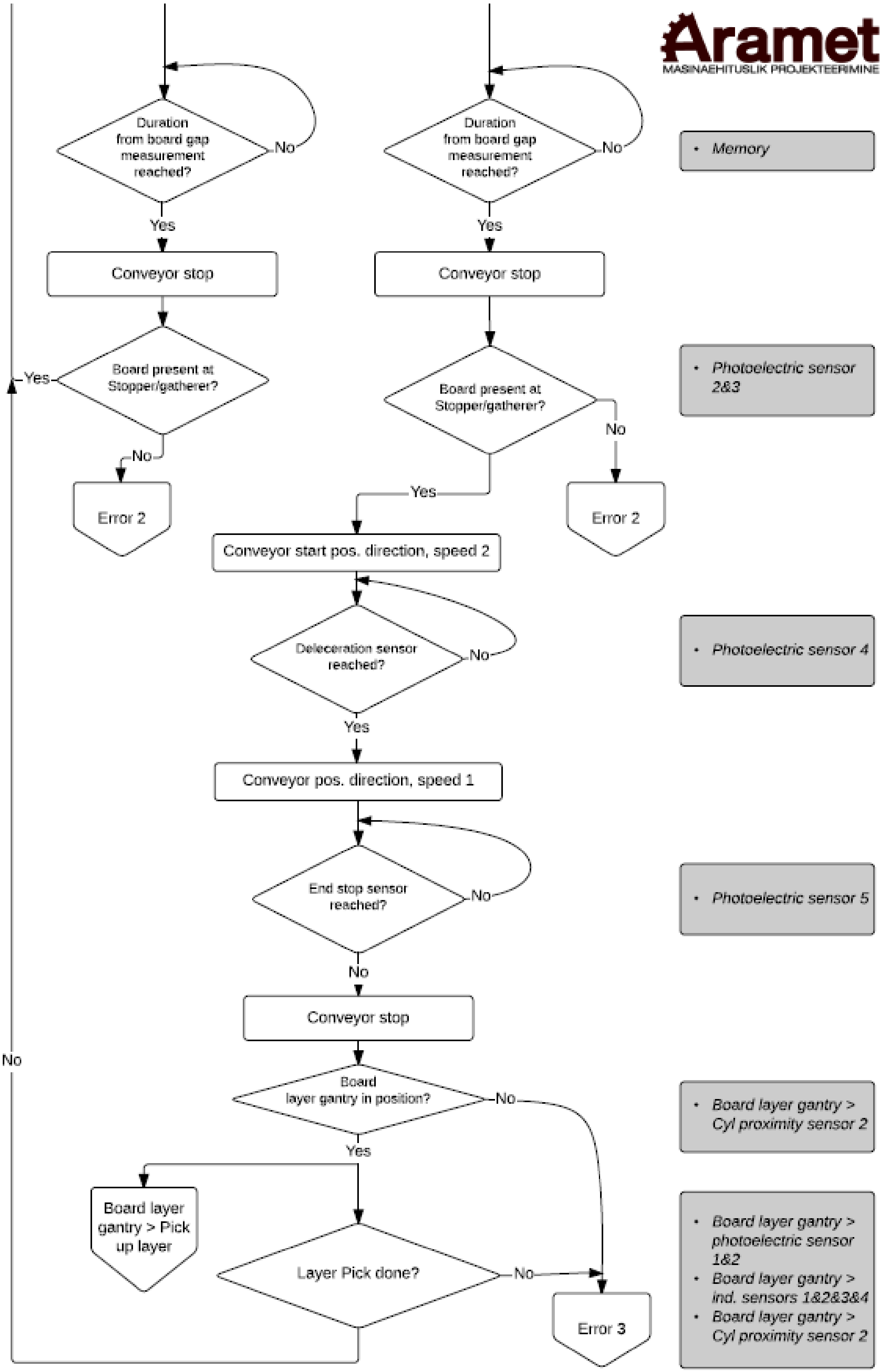


Figure 6.2 Process flowchart, Board layer conveyor, page 2

7. SUMMARY

During this MSc thesis, almost whole design process of this project – production line for laminating plastic boards was described and analyzed. To start off, distinct engineering task and initial conditions were defined – which was divided into smaller tasks the production line must perform. To solve them, the production line is divided into separate parts, each one with their own function. For each of those functional parts, an analysis was carried out to find the most economical, efficient and the least complicated way of satisfying its function.

Those production line's sub-assemblies were then described and analyzed one by one, in a logical order. First, a machine part responsible for queueing the input and output pallets was discussed and realized in a form of a roller conveyor. From that, a part lifting the boards off the stack on the pallet layer by layer or forming a stack as in case of at output side was described. The problem was solved using a 2-axis gantry with vacuum area grippers to lift the boards. The board layer is placed on a chain conveyor to feed the next stage – boards are separated by a gravity operated mechanism. The individual boards are then fed into Lamination machine with specified gap between them – it required to design a separate conveyor moving the boards along its length, with a board gap adjusting system. Receiving the boards after lamination and cutting the laminate between the boards was discussed next – it required a conveyor after Lamination machine, with a cutting mechanism and an identical gap adjuster system as described above. After that, it is necessary to flip the boards over – it was solved in a gravity assisted manner as in case of separating the boards. The next stage is responsible for gathering the individual boards to a layer again. It was realized by identical Board layer conveyor as described above, but with some configuration differences. From that to the end, the same assemblies are used as at input side. One more machine part was discussed finally, the one responsible for transferring the empty pallets from input to the output.

From each of those production line parts, a number of engineering problems emerged and were solved in succession. Finally, an automation and control of this production line was discussed, and in appendices three examples of production drawings are displayed.

As the result of this project, thoroughly analyzed design together with CAD models, production drawings, diagrams and specifications is almost finished, and will be finalized in a few weeks. From the design of this project, a comprehensive description and analysis of the whole design process was completed, describing my approach on how similar tasks are solved in the industry.

I evaluate the final outcome of this project and thesis to be positive, as on the one hand, an engineering project will be finished with more thorough analysis than usual, and also, wide-ranged and descriptive know-how was documented, to be used as a guide in the future projects.

In the near future, the production line’s design together with production drawings and other documentation will be finalized and after that, a first prototype will be built, and changes made into the design from lessons learned. After that, a number of identical production lines are planned to be built.

8. KOKKUVÕTE

Käesoleva magistritöö käigus kirjeldati ja analüüsiti peaaegu tervet plastiklaudade lamineerimisliini projekteerimise protsessi. Alustuseks defineeriti nõutud ülesanne ja algtingimused – ülesanne jagati omakorda väiksemateks osadeks mida tootmisliin peab täitma. Nende lahendamiseks jagati tootmisliin mitmeteks funktsionaalseteks osadeks, igaühel oma otstarve. Kõik need osad läbisid põhjaliku analüüsi, et leida kõige ökonoomsem, efektiivsem ja vähem keerukam lahendus.

Järgmiseks kirjeldati ja analüüsiti ükshaaval tootmisliini alamkooste, tehes seda loogilises järjekorras. Esiteks kirjeldati masina osa, mille ülesanne on tekitada järjekord masina sisendi ja väljundi kaubaalustele, see lahendati rullkonveieri abil. Järgmiseks kirjeldati masina osa, mis tõstab alusel olevalt kuhjalt kiht-kihi haaval laudu maha või virnastab neid tagasi alusele, nagu peab toimima tootmisliini väljundi puhul. See probleem lahendati kaheteljelise kraana abil, mis tõstab lauakihi kasutades vaakumhaaratseid. Lauakiht asetatakse kettkonveierile, mis söödab laudu järgmisele liini tasemele – gravitatsiooni abil töötavale laudade eraldamise mehhanismile. Nüüd söödetakse üksikud lauad lamineerimismasinasse konveieri abil, tekitades nende vahele eelnevalt määratud vahe – seda tehakse vastava laudade vahe reguleerimise süsteemiga. Peale lamineerimismasinat võtab lauad vastu järjekordne konveier, mis sisaldab lisaks ka laudade laminaadi lõikamise seadet ja identset laudade vahe reguleerijat nagu ülal kirjeldatud. Järgmiseks on vaja lauad ümber keerata – see on lahendatud samuti gravitatsiooni abiga. Järgmine tase kogub üksikud lauad jälle ühte kompaktsesse kihti – kasutades selleks sarnast lauakihi kettkonveierit nagu ülal kirjeldatud, kuid mõningate erinevustega. Sellest tasemest kuni tootmisliini väljundini kasutatakse samu kooste nagu sisendis. Viimane masina osa mida kirjeldatakse on tühjade kaubaaluste konveier, mis liigutab neid sisendist väljundisse.

Iga selline tootmisliini osa tõstatas hulga inseneriülesandeid, mis lõpuks kõik lahendati. Kõige lõpuks arutati selle tootmisliini automaatika ja juhtimise osa, ning lisades on välja toodud kolm tootmisjooniste näidet.

Selle projekti tulemusena valmib põhjalikult analüüsitud tootmisliini lahendus, mis sisaldab nii CAD mudeleid, tootmisjooniseid, skeeme kui ka spetsifikatsioone – projekt on lõpusirgel ja valmib paari nädala pärast. Tootmisliini ehitusest tehti ammendav kirjeldus ja analüüs, mis sisaldab kogu projekteerimise protsessi, kirjeldades minu lähenemist, kuidas sellised ülesanded tööstuses lahendatakse.

Ma hindan projekti ja lõputöö tulemust positiivseks, kuna ühest küljest valmis inseneriprojekt tavapärastest põhjalikuma analüüsiga, ja teisest küljest dokumenteeriti kogu teadmiste pagas, et seda kasutada tuleviku projektides.

Lähitulevikus tootmisliini projekteerimine lõpetatakse koos tootmisjooniste ja kogu dokumentatsiooniga ning peale seda valmistatakse esimene prototüüp, projekti tehakse sellest saadud õppetundide najal muudatused. Tulevikus on samasuguseid tootmisliine plaanis ehitada mitu.

REFERENCES

[1] "Aramet OÜ Website," in *(aramet.ee)*, (20.05.2016) (Webpage).

[2] "ELEGRO plastic boards," in *(https://elegro.eu/)*, (20.05.2016) (Webpage).

[3] P. Mitchel, Tool and Manufacturing Engineers Handbook: Material and Part Handling in Manufacturing, 1998 (Book).

[4] "AC Induction Motor Mechanical Construction," in *(http://www.shreeelectronics.in/?p=300)*, (4.05.2016) (Image).

[5] "What's the Difference Between AC Induction, Permanent Magnet, and Servomotor Technologies?," in *(http://machinedesign.com/motorsdrives/whats-difference-between-ac-induction-permanent-magnet-and-servomotor-technologies)*, (1.04.2012) (Online article).

[6] "AC Motors," in *(http://machinedesign.com/basics-design/ac-motors)*, (15.11.2012) (Online article).

[7] "SEW-Eurodrive AC Motors DR.71 - 315, DT56, DR63 Catalog," in *(http://download.sew-eurodrive.com/download/pdf/19290411.pdf)*, (01.11.2014) (Documentation from supplier).

[8] "SEW-Eurodrive's website," in *(http://www.seweurodrive.de/)*, (03.05.2016) (Webpage).

[9] "SEW-Eurodrive Gear units Catalog," in *(http://download.sew-eurodrive.com/download/pdf/17078415.pdf)*, (01.03.2012) (Documentation from supplier).

[10] "SEW-Eurodrive Gearmotors DRN.. (IE3) Catalog," in *(http://download.sew-eurodrive.com/download/pdf/21933189.pdf)*, (01.11.2015) (Documentation from supplier).

[11] "(EC) No 640/2009: implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors," in *(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0026:0034:EN:PDF)*, (22.06.2009) (Commission Regulation).

[12] "What are IEC 60034-1 electric motor duty cycles?," in *(http://www.machinebuilding.net/ta/t0379.htm)*, (06.05.16) (Online article).

[13] "DriveGate - SEW-EURODRIVE's Internet Customer Portal," in *(https://www.drivegate.biz/com/)*, (4.05.2016) (Engineering software).

[14] "Interroll Group homepage," in *(http://www.interroll.com/)*, (05.05.2016) (Webpage).

[15] "Interroll Conveyor Rollers Catalog," in *(http://www.interroll.fi/fileadmin//user_upload/Downloads__PDF_/Rollers/Rollers_RD_Controls_Catalog_2015_EN.pdf)*, (4.05.2016) (Documentation from supplier).

[16] "Gates Powergrip® GT3 Drive Design Manual," in *(https://www.gates.com/~/media/files/gates/industrial/power-transmission/manuals/powergripdrivedesignmanual_17195_2014.pdf)*, (3.05.2016) (Documentation from supplier).

[17] "Mädler - timing belt drives catalog," in *(http://smarthost.maedler.de/news/1109/Beltdrives.pdf)*, (08.05.16) (Documentation from supplier).

[18] "Gates PowerGrip GT3 Belts," in *(https://www.gates.com/products/industrial/industrial-belts/synchronous-belts/powergrip-gt3-belts)*, (08.05.2016) (Webpage).

[19] "Gates' Design Flex Pro industrial drive design software," in *(http://ww2.gates.com/europe/designflex/index.cfm?location_id=3433&go=SearchEuropePopular)*, (8.05.16) (Engineering software).

[20] "Gates online catalog - PartView™ System," in *(http://partview.gates.com/catalog3/d/gates.pt/)*, (6.05.16) (Catalog from supplier).

[21] "SKF Y-bearing units," in *(http://www.skf.com/group/products/bearings-units-housings/bearing-units/ball-bearing-units/index.html)*, (16.05.2016) (Documentation from supplier).

[22] "SKF Bearing Calculator," in *(http://webtools.skf.com/BearingCalc/)*, (16.05.2016) (Engineering software).

[23] R. Uulma, Festo Didactic – Pneumaatika alused, Eesti, 1996 (Book).

[24] "Festo - Linear drives DGC-K," in *(https://www.festo.com/cat/en-gb_gb/data/doc_ENGB/PDF/EN/DGC-K_EN.PDF)*, (8.05.2016) (Documentation from supplier).

[25] "Festo's website," in *(https://www.festo.com/cms/et_ee/index.htm)*, (08.05.2016) (Webpage).

[26] "Festo Product catalogue," in *(https://www.festo.com/cms/en-lb_lb/52177.htm)*, (09.05.2016) (Engineering software).

[27] "General guide to the EN 10027 steel name and numbering systems.," in *(http://www.roymech.co.uk/Useful_Tables/Matter/Steel_Europe.html)*, (10.05.2016) (Online article).

[28] "Schamalz's website," in *(http://www.schmalz.com/)*, (17.05.2016) (Webpage).

[29] "Vacuum gripping systems," in *(http://us.schmalz.com/imperia/md/content/aktuelles/produkte/vg/01_vg_area_and_layer_gripping_systems_suction_spiders_en.pdf)*, (17.05.2016) (Catalog).

[30] T. C. Co., "The Complete Guide to Chain," in *(http://chain-guide.com/)*, (12.05.2016) (e-book).

[31] "Wippermann's website," in *(http://www.wippermann.com/)*, (17.05.2016) (Webpage).

[32] "Wippermann main catalogue," in *(http://www.wippermann.com/data-live-wippermann/docs/dokumente/en/produkt-kataloge/main-catalogue-wippermann-cat-2015-en.pdf)*, (17.05.2016) (Documentaion from supplier).

[33] "Festo's Pneumatic simulation tool GSED," in *(https://www.festo.com/cat/en-gb_ww/xDKI.asp)*, (17.05.2016) (Engineering software).

[34] "Fundamentals of Photoelectric Sensors," in *(http://www.automation.com/library/articles-white-papers/sensors-sensing-technologies/fundamentals-of-photoelectric-sensors)*, (17.05.2016) (Online article).

[35] "SICK Photoelectric sensors catalog," in *(https://www.sick.com/media/dox/4/64/564/Product_catalog_Photoelectric_sensors_en_IM0061564.PDF)*, (17.05.2016) (Documentation from supplier).

[36] "Sick Photoelectric sensors," in *(https://www.sick.com/fi/en/product-portfolio/photoelectric-sensors/photoelectric-sensors/c/g172752xp2)*, (17.05.2016) (Online catalog).

[37] "Siemens distributed controller based on SIMATIC ET 200," in *(http://w3.siemens.com/mcms/programmable-logic-controller/en/distributed-controller/system-overview/Pages/Default.aspx)*, (19.05.2016) (Catalog).

[38] "AS-i Interface - the clever standard," in *(http://w3app.siemens.com/mcms/infocenter/dokumentencenter/ce/Documentsu20Brochures/e20001-a1030-p305-v2-7600.pdf)*, (19.05.2016) (Documentation from supplier).

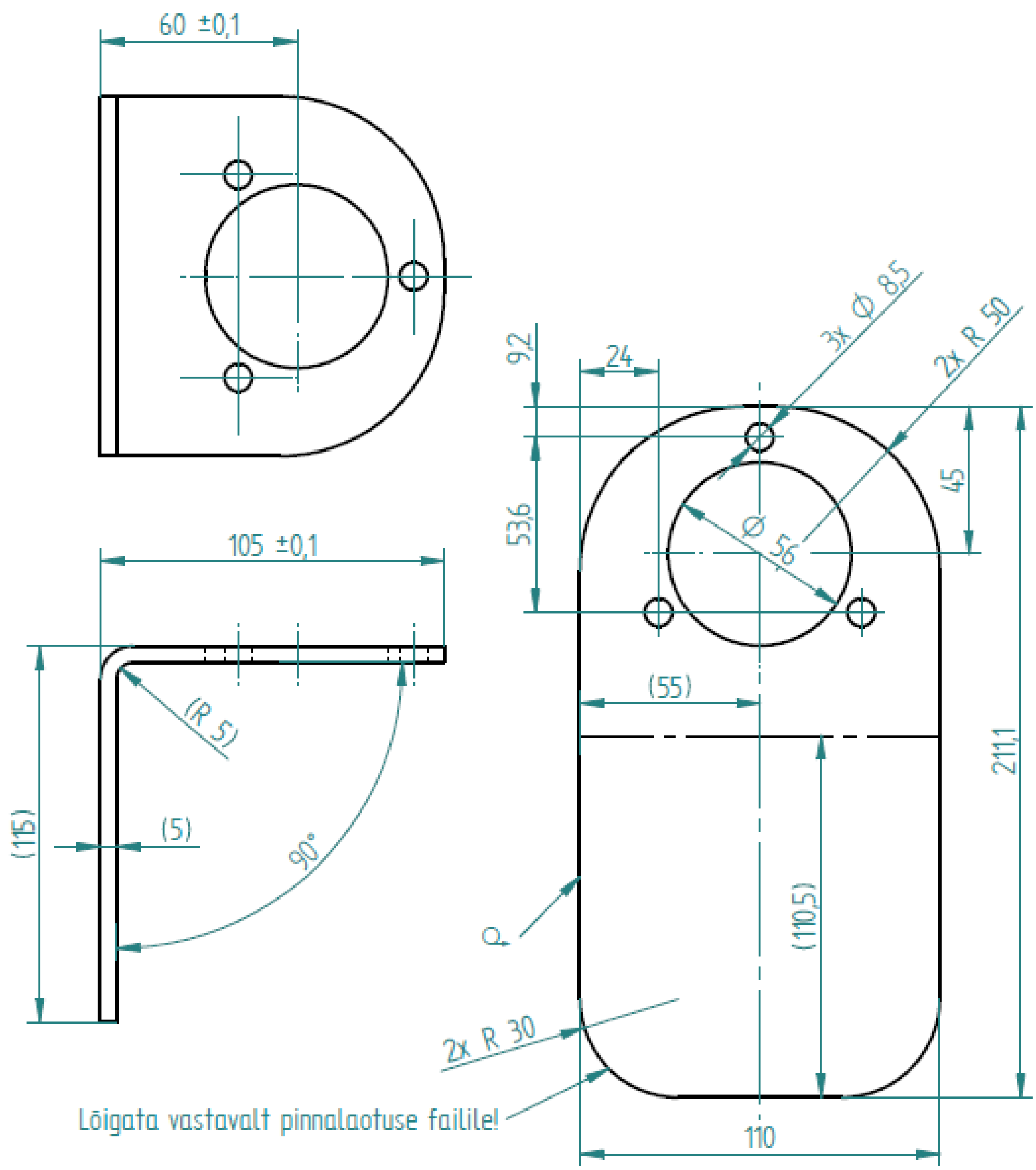
[39] "Siemens AS-i Master in the SIMATIC ET 200SP," in *(https://w3app.siemens.com/mcms/infocenter/dokumentencenter/ce/Documentsu20Brochures/e20001-a1080-p305-v3-7600.pdf)*, (19.05.2016) (Documentation from supplier).

[40] "Beijer iX T15B HMI," in *(http://www.beijerelectronics.com/en/products/ix-hmi-solution/iX___HMI___Industrial/iX___T15B)*, (19.05.2016)(Catalog).

[41] "Cylinder actuation," in *(https://www.festo.com/wiki/en/Cylinder_actuation)*, (19.05.2016) (Online article).

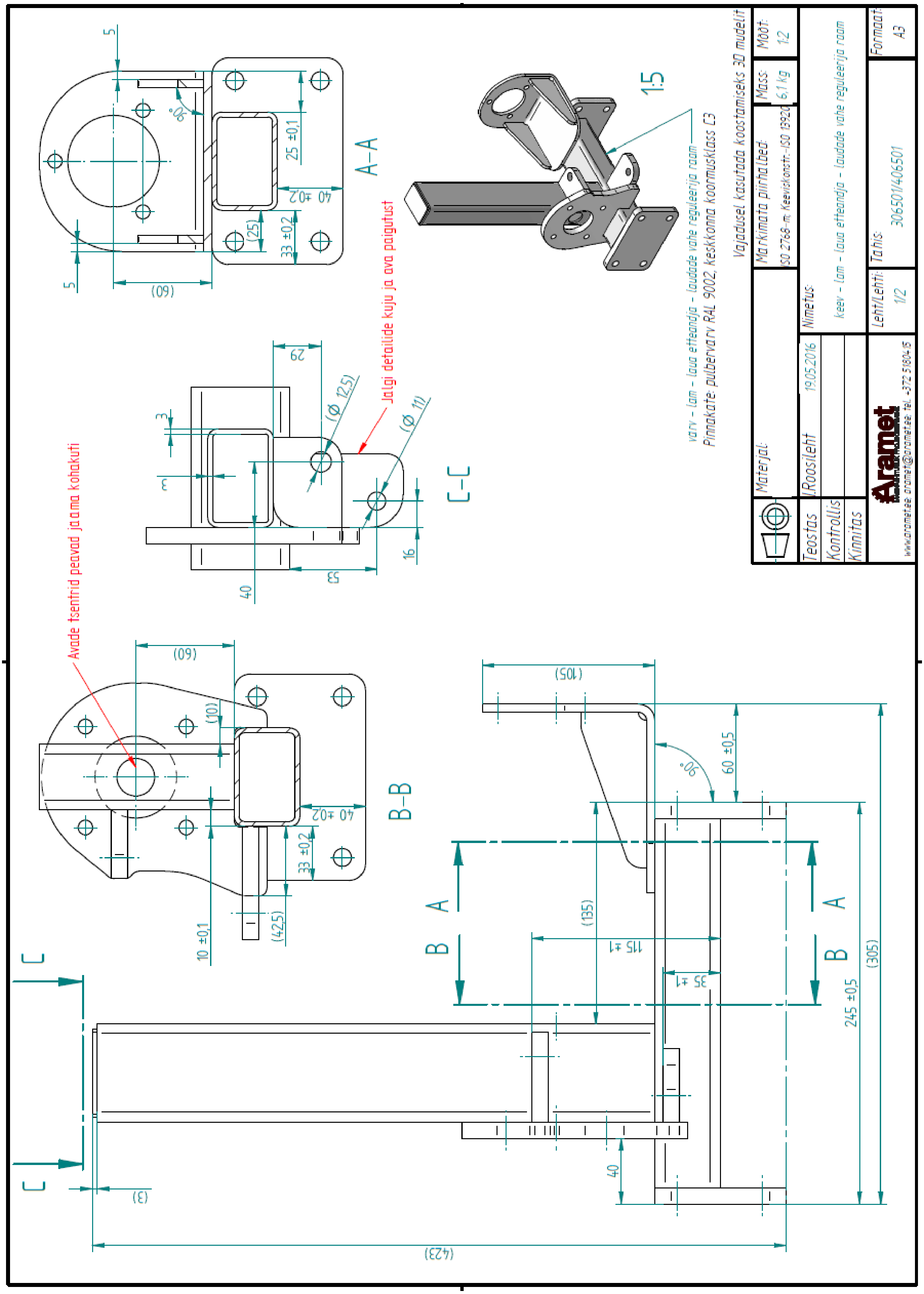
[42] "Siemens TIA Portal Engineering Framework," in *(https://www.industry.siemens.com/topics/global/en/tia-portal/Pages/default.aspx)*, (19.05.2016) (Documentation from supplier).

APPENDIX 1 – EXAMPLE PART DRAWING

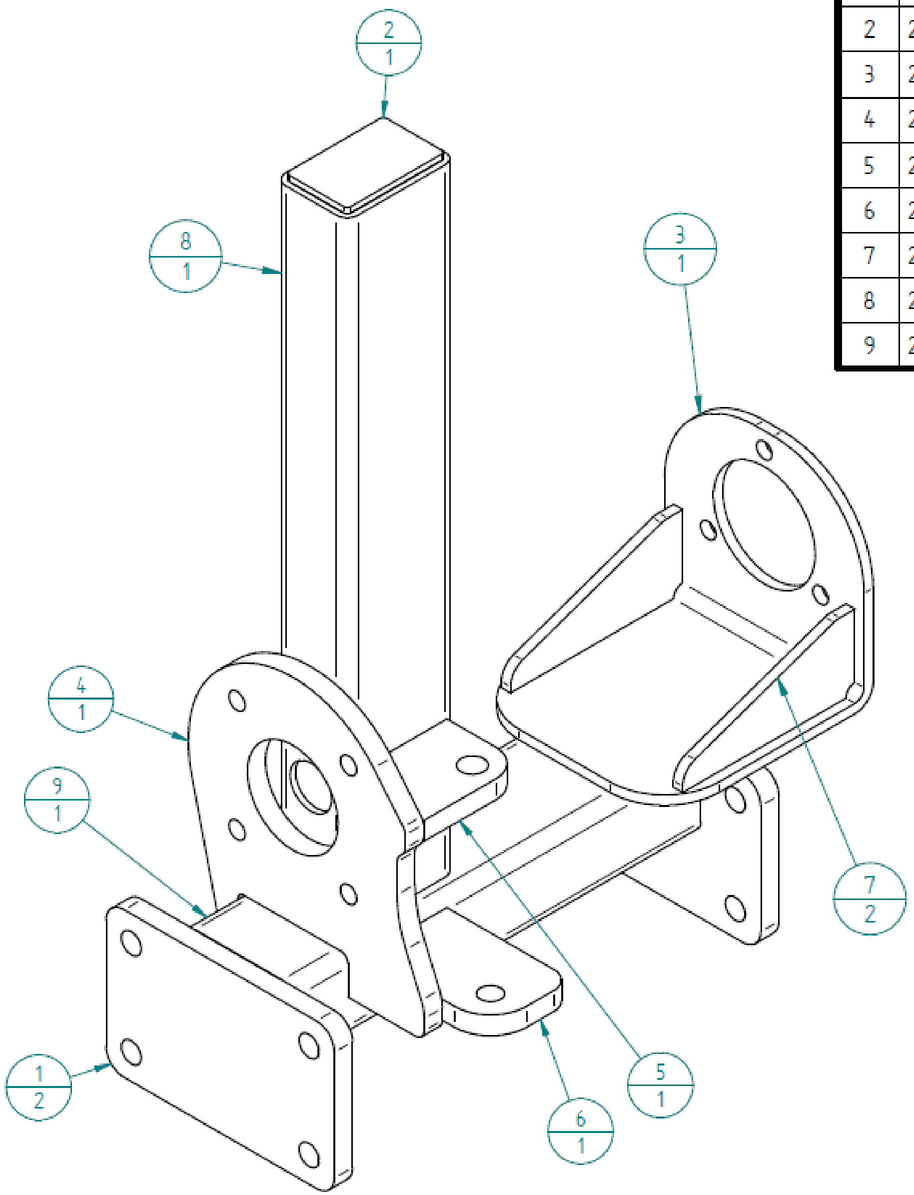


	Materjal: Must terasleht 5,0mm S355; 110x211	Märkimata piirhälbed: ISO 2768-m; Keeviskonstr.-ISO 13920	Mass: 0,7 kg	Mõõt: 1:2
Teostas	I.Roosileht 19.05.2016	Nimetus: leht – lam – laua etteandja – laudade vahe reguleerija laagri kinnitus		
Kontrollis				
Kinnitas				
Aramet www.aramet.ee; aramet@aramet.ee; tel. +372 5180415	Leht/Lehti: 1	Tähis: 206501		Formaat: A4

APPENDIX 2 – EXAMPLE WELDED ASSEMBLY DRAWING

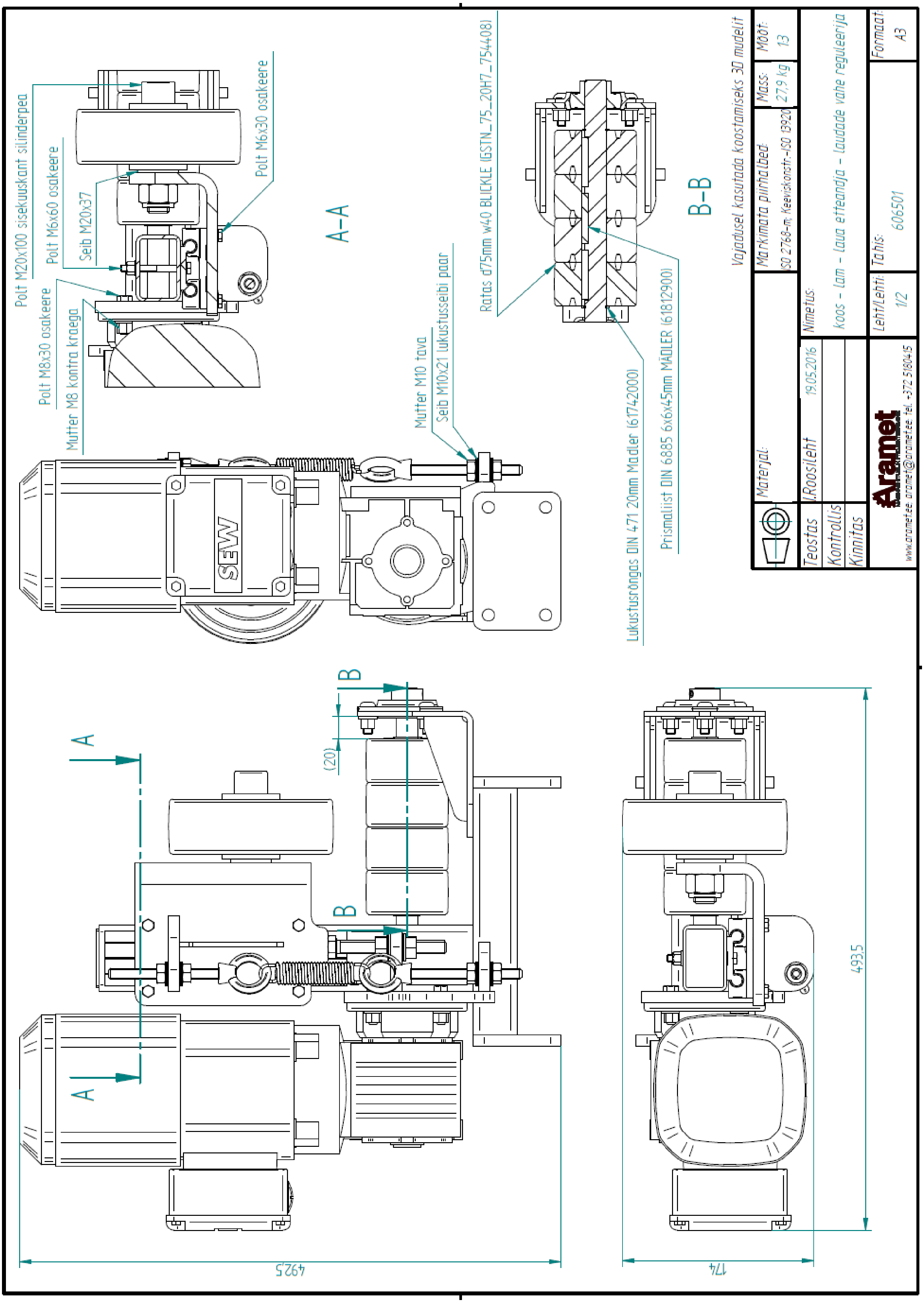


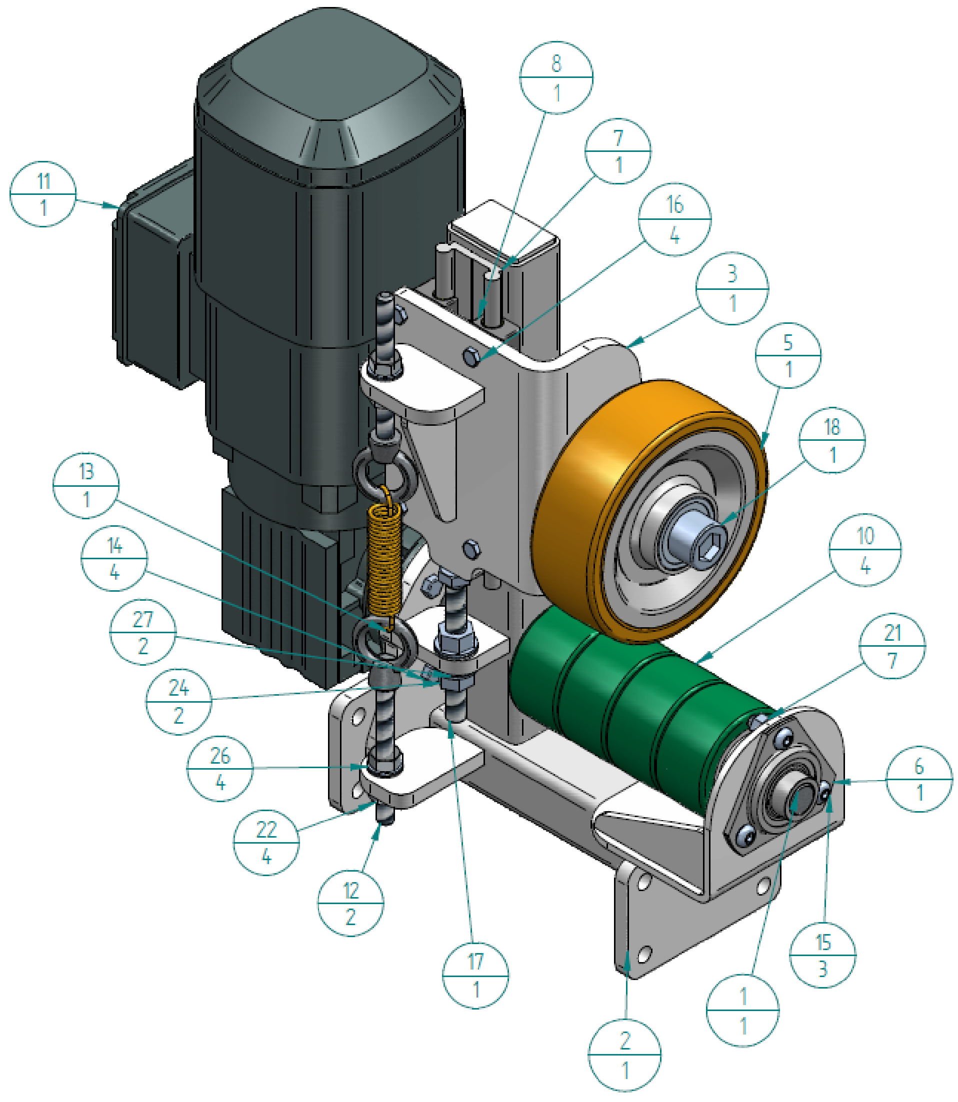
Pos:	Detaili kood:	Nimetus:	Materjal/Markused:	Arv:
1	206101	leht – lam – IO konveier – vaheraami kinnitusplaat	Must terasleht 10mm S355 ; 80x126	2
2	206201	leht – lam – lauakihi kraana – 60x40 otsaplaat	Must terasleht 3,0mm S355 ; 34x54	1
3	206501	leht – lam – laua etteandja – laudade vahe reguleerija laagri kinnitus	Must terasleht 5,0mm S355; 110x211	1
4	206502	leht – lam – laua etteandja – laudade vahe reguleerija mootori kinnitus	Must terasleht 10mm S355 ; 130x138	1
5	206503	leht – lam – laua etteandja – laudade vahe reguleerija piiraja kinnitus	Must terasleht 10mm S355 ; 42x55	1
6	206505	leht – lam – laua etteandja – laudade vahe reguleerija vedru kinnitus	Must terasleht 10mm S355 ; 45x69	1
7	206506	leht – lam – laua etteandja – tagasipõrke rulliku kinnituse tugevdusribi	Must terasleht 5,0mm S355; 40x95	2
8	206507	tala – lam – laua etteandja – laudade vahe reguleerija püsttoru	Nelikanttoru 60x40x3,0 S355 ; L-340	1
9	206508	tala – lam – laua etteandja – risttala	Nelikanttoru 60x40x3,0 S355 ; L-225	1



	Materjal:		Märkimata piirhälbed: ISO 2768-m; Keeviskonstr.-ISO 13920	Mass: 6,1 kg	Mõõt: 1:2
Teostas	I.Roosileht	19.05.2016	Nimetus: keev – lam – laua etteandja – laudade vahe reguleerija raam		
Kontrollis					
Kinnitas					
Aramet www.aramet.ee; aramet@aramet.ee; tel. +372 5180415		Leht/Lehti: 2/2	Tähis: 306501/406501		Formaat: A3

APPENDIX 3 – EXAMPLE ASSEMBLY DRAWING





Pos:	Detaili kood:	Nimetus:	Materjal/Märkused:	Arv:
1	206509	täis - lam - laudade etteandja - laudade vahe reguleerija võll	Täismaterjal must ümar 20mm S355; L-400	1
2	406501	värv - lam - laua etteandja - laudade vahe reguleerija raam		1
3	406502	värv - lam - laua etteandja - laudade vahe reguleerija rulliku kinnitus		1
4	503013	Lukustusrõngas DIN 471 20mm Mädler (61742000)		2
5	504613	Rullik SETH BLICKLE (150_20K_045179-214)		1
6	506001	Laagripukk d20mm SKF (PFD 20 RM)		1
7	506002	Lineaarjuhik IGUS (WS_10_40_220)		1
8	506003	Lineaarjuhiku kelk IGUS (WW_10_40_15)		1
9	506004	Prismaliist DIN 6885 6x6x45mm MÄDLER (61812900)		3
10	506005	Ratas d75mm w40 BLICKLE (GSTN_75_20H7_754408)		4
11	506006	Reduktormootor SEW WAF20DRS71S4_TF_ES7C	(ratio 8.20 ; 168rpm ; 18Nm)	1
12	506007	Silmuspolt M10x100 täiskeere, silmuse traat 8mm		2
13	506008	Tõmbevedru A-SS1774-05; LESJOFORS (9645)	Dy=20; L1=146.4mm	1
14	551091	Polt M8x30 osakeere	DIN 931 Würth'i kood: 0053 8 30	4
15	591067	Polt M8x25 sisekuuskant ümarpea	ISO 7380 Würth'i kood: 0060 018 25	3
16	591101	Polt M6x30 osakeere	DIN 931 Würth'i kood: 0053 6 30	4
17	591102	Polt M12x100 täiskeere	DIN 933 Würth'i kood: 0057 12 100	1
18	591103	Polt M20x100 sisekuuskant silinderpea	DIN 912 Würth'i kood: 0084 20 100	1
19	591104	Polt M6x60 osakeere	DIN 931 Würth'i kood: 0053 6 60	2
20*	592003	Mutter M6 kontra kraega	DIN 6926 Würth'i kood: 0379 100 06	2
21	592005	Mutter M8 kontra kraega	DIN 6926 Würth'i kood: 0379 100 08	7
22	592008	Mutter M10 tava	DIN 934 Würth'i kood: 0317-10	4
23*	592016	Mutter M20 kontra	DIN 985 Würth'i kood: 0368 20	1
24	592101	Mutter M12 tava	DIN 934 Würth'i kood: 0317-12	2
25	593021	Seib M20x37	DIN 125 Würth'i kood: 0407 20	1
26	593102	Seib M10x21 lukustusseibi paar	DIN 25201 Würthi kood: 0401 770 010	4
27	593103	Seib M12x25,4 lukustusseibi paar	DIN 25201 Würthi kood: 0401 770 012	2

Materjal:		Märkimata piirhälbed: ISO 2768-m; Keeviskonstr.-ISO 13920	Mass: 27,9 kg	Mõõt: 13
Teostas	I.Roosileht 19.05.2016	Nimetus: koos - lam - laua etteandja - laudade vahe reguleerija		
Kontrollis				
Kinnitas				
Aramet www.aramet.ee; aramet@aramet.ee; tel. +372 5180415	Leht/Lehti: 2/2	Tähis: 606501		Formaat: A3