TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Industrial Engineering and Management

AUTOMATION PREPARATION OF SPECIMENS

KATSEKEHADE ETTEVALMISTAMISE AUTOMATISEERIMINE

MASTER THESIS

Student: Jaanus Ehrlich

Student code: 192560MARM

Supervisor: Margus Müür, lecturer

Tallinn 2023

(*On the reverse side of title page*)

AUTHOR’S DECLARATION

Hereby I declare that I have written this thesis independently.
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THESIS TASK

Student: Jaanus Ehrlich, 192560MARM
Study programme: Industrial Engineering and Management (MARM06/18)
Supervisor: Lecturer, Margus Müür, +372 6203252

Thesis topic:
(in English) Specimen Automated Preparation
(in Estonian) Katsekehade ettevalmistamise automatiseerimine

Thesis main objectives:
1. Analyse the current preparation process of weldment specimens.
2. Analyse possibilities for automation: system requirements, available solutions, new concepts and economical payback period.
3. Propose concepts and designs for fixtures and propose future research and layout ideas.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Test objects overview	09.07.2022
2.	The current process of specimens preparation	10.08.2022
3.	Possible concepts description	15.09.2022
4.	New fixtures design	16.10.2022
5.	Analyse new concepts, fixtures, layouts and payback period	18.10.2022
6.	Text Editing and Formatting	01.01.2023

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Student: Jaanus Ehrlich (signed digitally) "2" Jan 2023
/signature/
Supervisor: Margus Müür (signed digitally) "2" Jan 2023
/signature/

Head of study programme: Kristo Karjust (signed digitally) "12" Jan 2023
/signature/

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PREFACE

The thesis topic was initiated by the TalTech Metrology Laboratory, where there is a survival need for more efficient specimen preparation methods. The thesis's main purpose is to analyse and propose different possible solutions to increase the efficiency of specimen preparation.

My thanks go to the TalTech Metrology Laboratory, to Priidu Peetsalu and Mart Kolnes for allowing me to work on this topic and for the guidance and counseling.

Also, my gratitude goes to my supervisor Margus Müür for the guidance and counseling provided throughout the thesis.

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Keywords of this master thesis: automation, robotics, welding specimen, master thesis

List of abbreviations and symbols

BT	Bending stress specimen
TT	Tensile strength specimen
IW	Impact test specimen (from the thermal zone)
IH	Impact test specimen (from the centre of weldment)
MA	Macro picture and hardness test specimen
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
EDM	Electrical discharge machining
WIPS	Wireless Intuitive Probing System
KPI	Key Performance Indicators
HACS	Hermle Automation Control System
EOAT	End Of Arm Tooling

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1. INTRODUCTION

The thesis is made in cooperation with the Metrology Testing Laboratory in TalTech. The main objective of this thesis is to find and solve specimens' preparation-related bottlenecks at the site of TalTech Metrology Laboratory. After that, propose possible automated solutions to decrease bottlenecks in preparation processes. Make it possible to increase testing volume five times through a more effective automated specimens preparation solution.

The actual main issue is on the moments when the laboratory receives many specimens at once. That means the specimens preparation time is too long and it affects the laboratory efficiency, which also affects the company's efficiency and decreases laboratory trust between companies. Thesis' main purpose of this thesis is to, select and propose possible solutions to increase efficiency.

The aim of this master thesis is to analyse:

- The current situation in preparation processes and find out the bottlenecks.
- Available solutions and their possibilities for implementation.
- The authors own concepts of different possible solutions.
- Make possible future specimens growth volume by 5 times using automated solutions.
- Describe the possible workpiece fixture jigs design.
- Possible ways to decrease the payback period and increase efficiency.
- Possible solutions for automated testing.
- Possible ways how a new automated preparation system can be used in study processes.
- Possible workshop layouts.

Chapter 2 gives a general overview of how the specimens look, are produced and describes different testing methods and describes the actual specimens including current manual processing. Chapter 3 defines the system's general requirements and analyzes possible occurring risks.

Chapter 4 describes available systems that are possible to implement in this thesis concept and then describes the selected solution system parts. Chapter 5 describes the automated concept development process. Chapter 6 describes efficiency analysis between manual and robotized preparation and analysis which defines the system payback in different scenarios. Chapter 7 offers possible solutions and alternative ways to use the system in times when there are no specimens to produce.

2. SPECIMENS AND THEORETICAL OVERVIEW

2.1 Weldment types

Specimens are chosen from specially prepared specimen weldment plates. Those weldments plates are divided into different parts where every specimen has its own location from it. All the weldments types: Butt Joint, pipe and T-joint weldment specimens positions are defined in Table 1. it also describes different areas, where every area represents a different type of specimen location from the main specimen before the specimens are cut out.

Butt Joint weldment

Butt joint welding is a process in which mostly two pieces of metal are put together on the same plane and the side of each metal is found to be joined with the help of welding. This type of weld is used in the manufacturing of structures and piping systems [1]. Butt welds are found to be made in various ways in which each way serves a different purpose. There are numerous factors in terms of the shape of the groove, the layering as well as the width of the gap [1].

Tee Joint weldment

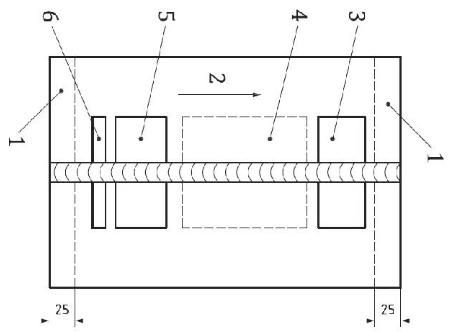
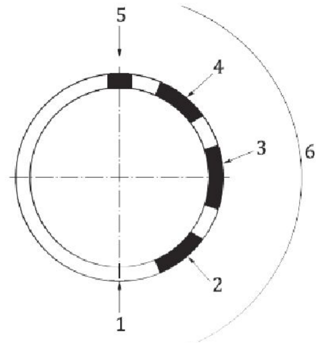
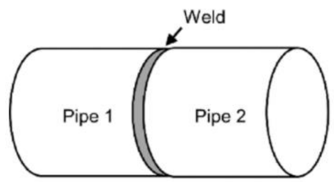
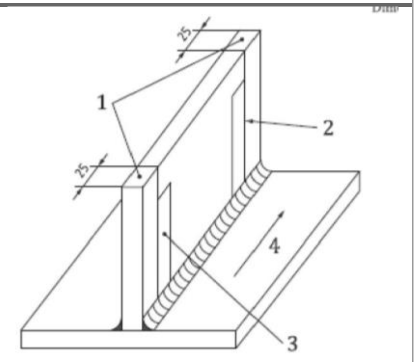
Tee welding joints are referred to as those welding joints which are mostly formed whenever two pieces can intersect at a 90° angle. This results in the edges coming together at the center of the plate or like the component in a T shape. [1].

These are types of welds that are critical and always ensure that there is an effective penetration into the roof of the weld. There are a handful of welding styles that can be used to create a tee joint [1]. The Tee Joint specimen will be separated into two main specimens.

Pipe weldment

The pipe weldment is similar to the butt joint weldment, the only difference is the shape of the main body. In Table 1 you can see a specimen from two pipe weldment connections. The pipe for specimens is divided into different parts to get exactly the needed specimens for testing.

Table 1. Specimens Billets locations before cutting

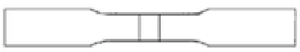
Butt Joint weldment	Pipe Weldment	T-Joint weldment
	 	
Key *1.* Discard 25mm *2.* Welding direction *3.* Area for: - 1 tensile test specimen - Bend test specimens *4.* Area for: - Impact and additional test specimens if required *5.* Area for: - 1 tensile test specimen - Bend test specimen *6.* Area for: - 1 macro test specimen - 1 hardness test specimen	*Key* *1.* End of weld *2.* Area for: - 1 tensile test specimen, 1 Bend test specimens *3.* Area for: - Impact and additional test specimens if required *4.* Area for: - 1 tensile test specimen - Bend test specimen *5.* - Start of weld; area for: - 1 macro test specimen - 1 hardness test specimen (taken from the start of weld) *6.* Weld direction	*Key* *1.* Discard 25mm *2.* Macro test specimen *3.* Macro and hardness test specimen *4.* Welding direction

2.2 Weldment specimens general dimensions and conditions

Weldment specimens are prepared based on the customers requirements in accordance with ISO 286-1 standards.

Every specimen has its own specific dimensions and tolerances, following the customers requirements and specimen's preparation standards. Specimen types and their main dimensions and milling procedures are generally described in Table 2.

Table 2. Weldments specimens description

	Dimensions	**The shape of the specimen**	**Milling procedure**
BT	Length – 300…350 mm Width – 20…40 mm Thickness – 1…10 mm		Mill down weldments from the top and bottom side
TT	Length – 300…350 mm Width – 20 or 30 mm Average milled part Width – 12,5 or 25 mm Thickness – 1…20 mm		Mill down weldments on the top and bottom sides of the plate and narrow centre.
IW and IH	Length – 55 mm Width – 5; 7,5 or 10mm (mostly 10 mm) Thickness – 10 mm		Mill into the exact dimensions from four sides
MA	Length – 20…50 mm Width – 16 mm Thickness – 1…40 mm		Mill two sides parallel

2.3 Current specimens' preparation process

Every manufacturer has its specific demands on what type of procedures or manufacturer tests are required with specimens. Some of them need only a specific test, not all the possible options. This defines the real demand and how many specimens are required yearly. Table 3 displays examples of possible testing methods.

Table 3. Batch sizes and production volume

	NR.	SPECIMEN'S	IN YEAR
The lot and Batch sizes	**1**	2xBT + 1xMA	3
	2	2xBT + 1xTT+1xMA	27
	3	1xMA + 3xIW + 3xIH	11
	4	1xTT + 1xMA + 3xIW + 3xIH	16
	5	2xBT + 1xTT + 1xMA + 3xIW + 3xIH	2
	6	2xTT + 1xMA	1
	7	4xBT + 2xTT + 1xMA	11
	8	4xBT + 2xTT + 1xMA + 3xIW + 3xIH	7
	9	4xBT + 2xTT + 1xMA + 6xIW + 6xIH	13

		BT	TT	IW / IH	MA
Production volume	Per year - x1 **(Current situation)**	162	109	186	80
	Per year - x5 **(Using automation)**	810	545	930	400

Table 3 describes the yearly demand for every procedure or manufacturing test and the possible number of required specimens when the producing demand is increased five times.

Appendix 1 indicates the general flow of occuring processes in the specimen's preparation processes and shows the processes included in the receiving of orders and reports sending.

If an order is received, it will specified which type of tests will be performed. The selected testing method and the required number of specimens are based on the customer's requirements. After that, there will be a weldments analysis and all the weldments' specimens are sent to the next preparation process. In this process, all the required specimens will be prepared for breakable tests.

Table 4 and Appendix 3 describes general processes in Tensile Strength test specimen preparation. Because there is no organized data on how many different thicknesses and material specimens are produced during the year, the S355 30mm Tensile Strength Butt Joint specimen production data is taken as a base for all analysis and all the other times are derivate from that one-part cycle times.

Table 4 describes the cycle times of the specimen's preparations. The most time consuming is the cutting process by the bandsaw. After that, the specimens are milled in a (CNC) Computer Numerical Controlled Machine. The used CNC machine is quite basic, there is no probe which enables to measure the billet automatically. Because of that the operator needs do to it manually on both sides. That takes 1/3 of all the milling time and the used cutting parameters are also quite small because of the lack of machine power.

Table 4. Tensile strenght Test body (TT) specimen preparation Times

Butt Joint Weldment (S355 – 300x350x30mm)		
Process		**Time/ min**
1.	Marking	10
2.	Set in the vise/machine setup	10
3.	A cutting (Nr. of cuts 2)	32
4.	Edges grinding	1
5.	Milling preparation 1 (setup)	12
6.	Milling 1	22
7.	Milling preparation 2 (setup)	5
8.	Milling 2	17
9.	Edges grinding 1	1
10.	Weldments grinding 2	1
11.	Marking and documenting	6
12.	Storing	1
	Total time (min):	118

Table 5 describes the current cutting times using Electrical discharge machining (EDM). Because the process takes a lot of time it is better to consider replacing the current process with CNC machining. This allows the use of higher cutting parameters and get the same result as using the EDM method.

Table 5. Impact Test Body (IW and IH) preparation Times

Butt Joint Weldment (S355 – 300x350x30mm)		
	Process	**Time/ min**
1.	Marking	10
2.	Set in the vise	5
3.	A cutting (Nr. of cuts 2)	32
4.	Edges grinding	1
5.	Wire EDM setup	30
6.	Wire EDM cutting 3 (0,5mm/min)	72
7.	Cut the V notch	2
8.	Marking and documenting	6
9.	Storing	1
	Total time (min):	159

Bandsaw cutting and milling procedures with softer materials like aluminium takes 2 times less time compared with current cycle times in Table 4. Stronger materials like Hardox 500 take 20% more time compared with tensile strength specimen processing times in Table 4.

When using the bandsaw for cutting, the feed rate depends on the type of material and the sharpness of the bandsaw blade. Because of the weldment cutting the most common issue is that the bandsaw tooth breaks off. That means an instant replacement of the bandsaw blade is required. Bandsaw replacement can take up to 10 minutes.

Another possibility is to replace bandsaw cutting with waterjet cutting. This way it is possible to cut many parts without the need to remove already cut parts during the cutting process.

3. AUTOMATION POSSIBILITIES

3.1 Task Description

The main objective of this automation possibility is to find and solve specimens' preparation-related bottlenecks in the specimen preparation process.

Propose and analyse possible automated solutions to decrease bottlenecks in preparation processes. A future solution should make it possible to increase specimens' preparation for testing five times through a more effective automated specimens preparation solution. Without increasing the number of workers involved in specimen preparation and preserving the customers satisfaction.

When the specimens are sent to the workshop, workers mark the cuttable regions on the specimens and then start cutting specimens using two or one bandsaws. After that, the billets are ready for milling. Currently, they use manual processes for milling, grinding and edge smoothing.

Manual processing setup times are much higher compared to CNC where it's possible to use an automatic probe for setup. The ideal solution is a system where the two workers can prepare specimen billets for robotized CNC tending, without wasting time on high setup times. Thanks to this, it is possible to achieve a moment where robot tended CNC milling takes place outside of work hours and workers can prepare more billets during their work hours. At the same time, it is possible to use higher speed cutting parameters and automatic probing options.

3.2 Suitability analysis for automation

The main concern of suitability analysis is to find the best solution according to the set of criteria, using a method which allows the most realistic input for each criterion.

Table 6 analyses the suitability of automation in the specimen's preparation process. Bringing out different criteria from the aspect of the product, technology, and objective view.

Table 6. Suitability criteria for CNC robot tending analysis

Product view	**Technology view**	**Objective's view**
- The specimens are produced in repeatable batches - The products have specific parameters. (not all the sides of the products need to be processed) - In some specimens, it is possible to use standard fixtures but some of them require custom fixtures - Products classify into four types	- Experience in CNC milling and fixtures - CNC milling has great importance in the specimen's preparation process - There is already a survival need to increase productivity to stay competitive in the market. - From a technological point of view, the specimens are not complicated	- To shorten the throughput time - To increase the productivity in the workplace - To increase the production volume - To shorten the lead time - To reduce the production cost - To make the work environment safer

3.3 Risk Assessment

ISO 12100-Safety of machinery defines different basic concepts such as risk assessments and risk reduction for all types of machines. The ISO 10218 –Robots and robotic devices standard is written specifically in terms of robotics and uses robotic examples for detailed safety requirements for industrial robots. Both standards provide the same function, machine, and robots safety, but since ISO 10218 is specific to robots, it is what should be used [30].

The definition of a risk assessment is the identification, evaluation, and estimation of the levels of risk involved in a situation, comparison against benchmarks or standards and the determination of an acceptable level of risk. To conform to International Standard of Organization (ISO) standards, all individual items pass through the risk assessment process from the manufacturer [2]. Table 7 describes the possible occurring risks in the automated system.

Table 7. Risks in automation and project management

No	Description of the risk
1.	Targeting the wrong products - Products billet may fall off from the gripper or the fixture
2.	Not enough work is found for the robot
3.	Wrong workplace design
4.	The required competencies are missing
5.	During the system break off the orders delivery time will be extended
6.	Wrong decisions (not following the implemented procedures)
7.	No robot maintenance skills
8.	Resupply of billets (operator places it in the wrong spot)
9.	Picking and placing
10.	Milled chips removing
11.	Tool changing

Table 8 main goal is to describe the risks and identify the probability of the risk occurring and what the importance of the risk is. The possible actions to minimize the risks are also listed in
Table 8.

Table 8. Risk assessment

Risk description	The probability of the risk occurring	Importance of Risk	Actions needed for minimizing risk
The robot stops due to an error	Middle	Middle	Establish a notification system that sends out the error message in the event of robot failure. A live video feed should be also used to get an instant idea of what has happened.
Cyber security	Middle	Middle	All of the security measures should be considered to prevent possible cyber-attacks and cell malfunctions.
Unauthorized people's attendance in the robot cell	Low	Middle	Fences around the cell to prevent any unattended actions by visitors.
No robot maintenance skills	Middle	Middle	A responsible person should be continuously trained.
The Robot is hot after working and can be dangerous for the worker	Middle	High	Sensors that show the temperature of different robot parts and warning labels that there is a risk to hot surfaces, electric shocks and pinch points.
No ability to use the robot	High	Middle	Persons who are using the robot should be well trained and know exactly what they are doing.
Resupply of billets	High	High	Resupplying billets into the storage system may cause issues by human error. Where the operator places billets in the wrong direction or wrong place. It can be prevented through the Poka-Yoke method, where it is not possible that the billet will be placed in the wrong slot or wrong direction. The slot shape is specially designed, especially for the billet. On the

Risk description	The probability of the risk occurring	Importan ce of Risk	Actions needed for minimizing risk
			bottom of the slot a picture with instructions is added. It will prevent human errors so the billet cant be placed in the wrong direction or spot.
Picking and placing	Middle	High	Failed proximity sensor or software error.
Milled chips removing	High	High	Pinch points, hitting the head, particles in the eye(manual chips cleaning), frequently moving the robot to get access to the CNC, software error (automatic chips conveyor)
Tool changing	Low	High	The system may not identify when the tool is broken (software or probe error), pinch points, hitting the head

3.4 Decision-making criteria

Before it is possible to define the requirements for the system it is mandatory to define the decision making criteria for specimen preparation processes. It ensures that the correct system parts and features for the parts are selected.

From the flexibility side, the robot system should be able to load different specimens billets into the CNC mill where an operator is not needed without making any big programming changes.

From the side of productivity, access to the CNC mill should be quick for maintenance and billets insertion into the system without stopping the cell for a long time. The storing system must be sufficient to store multiple types of billets. The system should process small batches independently out of working hours to increase efficiency.

Table 3 describes the lot and batch sizes in the year. The second part of the table defines the production volume if the production rate is increased 5 times during the period.

Specimens processes: milling, marking, and loading into a CNC mill should be integrated to increase the system efficiency and lower the payback period without investing in external equipment.

The work environment should be as safe as possible to avoid injuries and digital twins should be used for programming to avoid machine damage and long shutdowns during the programming. When the system is working, the contact with moving machine parts must be cut off. Implementing safety fences, laser fences, safety switches and double-checking systems to prevent unintentional robot cell starts. When a person is in the robot zone, starting the robot cell should be impossible.

No matter how much effort is put into improving operations, there is always a risk that something unexpected or unusual will happen that could reverse much, if not all, of the improvement effort [3].

3.5 Specimens Specificity

When placing billets in storage area, it is important to check that the billets are in the correct position to prevent grabbing errors. Billets in the storage area and when being placed on the jig should be as similar as possible. If the billets outer dimensions difference is too big then the part may fall off from the gripper or cause errors in the workpiece fixture.

Some billets may be deformed because deformations can occur in the welding process. In the robot feeding system and the CNC, it can cause many problems with positioning specimens in the jig (Figure 1). To prevent positioning errors, it is important to place details into the jig in a way that the two narrow sides of the billet will be parallel to the jig.

Heat induces thermal stress and strain, as shown in Figure 1(a). Here, only one side of the plate is heated; so, the heated region expands and creates a reaction force. This reaction makes the heated area convex as Figure 1(b) shows. After this, the heated area is cooled by air, which induces shrinkage of the expanded region and generates a contraction force like Figure 1(c) shows. Finally, due to the shrinkage, angular distortion remains as shown in Figure 1(d). The angular distortion is caused by a non-uniform temperature gradient across the plates thickness due to one-sided heating, which results in different amounts of plate expansion and shrinkage through the thickness direction at the heated local area [4].

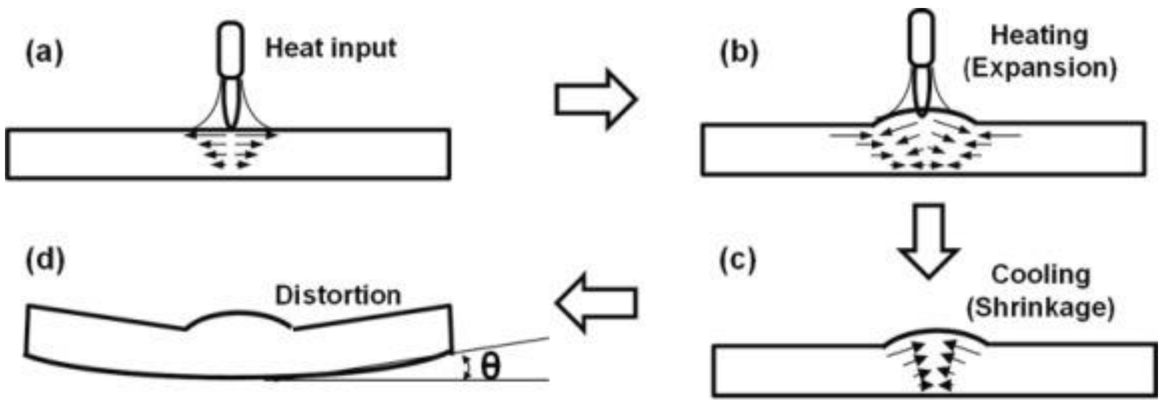


Figure 1. Welding Deformation in Butt welding [4].

During the milling process, the deformation angle has to be measured every time measured. It ensures that during the milling process the material thickness is not milled down. It is required to keep the original thickness of the material for testing. In this case, the specimen weldments must be milled down to the same thickness.

4. CONCEPTS DESCRIPTION

This topic analyses six different concept. It analyses the concepts sub-cycle times which includes production rate, equipment and personnel yearly usage and idle times. Based on this data, the decision is partly made on which concept should be taken into use to increase the efficiency and production rate in one year. At the same time increasing the efficiency of personnel and equipment use.

Table 9 shows the main input in the simulations. The usual workday length is 8 hours whereas the active work time for the workers is 7 hours without any breaks. Robot Cells considered active work time can be 20 hours per day for 5 days a week. It is considered in concepts where it’s possible to use robot feeders and storage systems. Where it’s possible to feed so many parts that the milling time occupies a 20-hour cycle or where the operator refeeds the storage system at the end of an 8-hour workday for the next 12 hours, for the robot cell to use.

New possible concepts are considering the 5 times increased yearly demand for the specimens from 537 pcs to 2689 pcs per year. Some concepts use only two different types of yearly increased specimens, milling 1740 pcs per year. It is to keep the transition to a more complex system under control.

Table 9. Source Data

Workday length:	**8**	**hours**
Real workday length without the brakes:	**7**	hours
Work Week Length:	**40**	hours
Work Year Length:	**2040**	hours
Robot Cell Workday length:	**20**	hours
Robot Cell Work Week Length:	**100**	hours
Robot Cell active work time:	**5200**	hours
1. Specimens demand in the year after a 5x increase:	**2685**	Pcs
2. Specimens demand in the year after a 5x increase:	**1740**	Pcs
3. Current specimen’s yearly demand:	**537**	Pcs

The concept uses two bandsaws simultaneously and it is affecting the production rate. That way the average production rate for the bandsaw in one cycle is two times smaller than the cycle time for a single bandsaw.

The bandsaw operator be must always with the machines during the cutting process but the Robot Cell operator needs to setup/refeed the Robot Cell after every 5 billets. If there are more prepared billets or other millable products then the operator can add more.

Figure 2. Billets manual (bandsaw cutting) preparation process layout

In Figure 2 the current layout of machines for producing the billets is shown. The right side of the layout takes part in a cutting process using the two bandsaws and after cutting there the sharp edges are deblurred by the operator. The billets cutting process doesn't change it will be the same.

In Table 10 the current cycle times are shown. It is possible to increase the future concept's efficiency it through setup times. In the current case, their operator needs to set up the mill every time the part is milled from one side and then from another side, after that he needs to measure the specimen dimensions manually because the mill is not capable of automatic probing.

Table 10. Current concept cycle times

	Current concept (min)
1.1 Marking	10
1.2 Set-up time (cutting)	10
1.3 Billets preparation time (cutting)	32
1.4 Billet edges grinding (manual)	1
2.1 Set-up time (milling)	17
2.2 Cycle time (milling)	39
2.3 Edges grinding (manual)	2
2.4 Marking and documenting	6 (manual)
2.5 Storing	1
Lead time:	116
Cutting Cycle Time:	53
Milling Cycle Time:	58

4.1 Concept 1 – External System Parts

4.1.1 Description of concept 1

The concept consists of different separate machines. For example, the robot takes the billets from the storage area and places them in the CNC mill for milling. After that, the robot picks up the specimen and places it in the marking device, where its gets the serial number marking. After that, the robot picks the billet and places it in the Coordinate Measuring Machine (CMM) for measuring. Finally, the specimen is placed in another storage area and the process starts from the beginning.

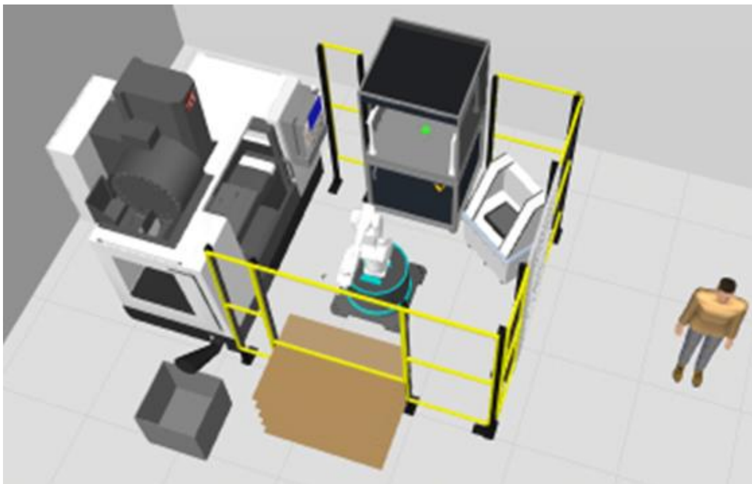


Figure 3. Concept 1 robot cell with separate system parts

Table 11 describes the system base requirements to define the needs of the system and based on this possible automation systems will be analyzed.

Table 11. General System Requirements

	Requirements	Possible Solutions
1.	3 axis, Motorized doors, Camera, Probe, Tools magazine, vise cleaner, chips conveyor	CNC mill
2.	Long enough arms to operate between work units	Robot
3.	2in1 - Grabbing and sensor unit	EOAT
4.	Safety based on the standards – it should be possible to add workpieces without interrupting the robot	Storage 1
5.	Storage unit for processed workpieces	Storage 2
6.	Laser engraving (another option is CNC)	Marking Device
7.	Laser scanner unit for milled details comparison	CMM or Laser scanner
8.	Proximity sensor	Sensors
9.	Rotating test piece in machining operations	Workpiece rotation tool

	Requirements	Possible Solutions
10	Before milling operation CenterPoint positioning	Supportive platform vs 2D vision indication
11.	Emergency switches, laser fence, physical fence	Safety

Figure 4 shows the ideal process sequence in this automated specimens preparation process. That may not be possible to achieve in real-life scenarios.

The process starts from pre-cut weldments billets. The next step is for the robot to take the specimen billet, position it and place it into the CNC. After milling from both sides, measurements are checked. After that the workpiece will be marked and the marking code will be received from the ERP system. The received code is converted to the G code and after that it is milled on the workpiece. After that, the specimen is placed in storage 2. During this process, the CNC sends out the measurement data into the ERP system and connects measurements with a working code in the ERP system.

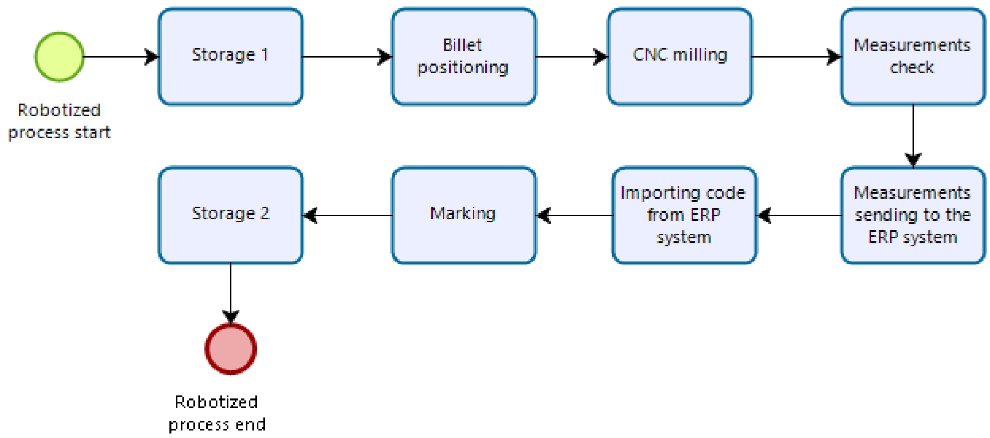


Figure 4. Automated general process sequence

4.1.2 Simulations

The simulations are analysing how the sub-parts are affecting the system sub-parts cycle times, robot reach and the system parts placement in the robot cell.

In

Table 12 the results of the simulations shown.

Table 12. Concept 1 Results from simulations

Cycle Times		
Billets cutting by bandsaw (Total):	**52**	min
Robot Cell (Total):	**36,5**	min

Cycle Times		
Robot Movements (Total):	**2**	min
Lead Time:	**90,5**	min
Final Product Production Rate		
Production Rate:	**0,93**	Pcs/h
Production Rate:	**43,0**	Pcs/week
Production Rate:	**1897,7**	Pcs/year
Equipment and Personnel Yearly usage %		
Bandsaw (2):	**63,9**	%
CNC Mill:	**48,3**	%
CMM:	**5,0**	%
Laser Marking Device:	**0,9**	%
Operator 1 (Bandsaw):	**70,0**	%
Operator 2 (Robot Cell):	**14,4**	%
Equipment and Personnel Yearly Idle Time %		
Bandsaw:	**36,1**	%
CNC:	**51,7**	%
CMM:	**95,0**	%
Laser Marking Device:	**99,1**	%
Operator 1 (Bandsaw):	**30,0**	%
Operator 2 (Robot Cell):	**85,6**	%

In this solution, the robot's idle time is shorter compared to the other solutions where the robot is used. It is mainly caused by the number of separate devices which are included in the system.

For the robot cell, the operator added 10% of occupation time to solve unexpected errors and maintenance time.

More detailed results from simulations are shown in **Error! Reference source not found.**.

4.2 Concept 2 – Hermle Robot System RS 05-2 Adapted to C250

4.2.1 Description of concept 2

This chapter describes an all in one ready-to-use solution. It includes a storing unit, an industrial robot, a CNC mill and software specially designed for those systems to keep everything simple to operate.

The solution allows the feeding of billets without stopping the robot cell. A feeding storage unit ensures safety and during the billet's insertion time into the machine, there is no need to stop the robot cell. The robot cell continues working until the system has processed all the billets.

Hermle Automation Control System (HACS) simple to program, control and it is possible to monitor all the processes independently of the robot operating station, including work plans, tools, sequence plans or operator tasks.

Figure 5 describes Hermle Robot System RS 05-2 and Table 13 describes its main parameters.

Figure 5. Hermle Robot System RS 05-2 Adapted to C250 [5].

Table 13. RS05-2 Robot System characteristics [5].

ROBOT	6-axis industrial robot
TRANSPORT WEIGHT	up to 10 kg
GRIPPER	Double gripper for ITS 50 pallets and workpieces
STORAGE MODULES	Single-die, storage module with five telescopic drawers, pallet storage or Kanban storage
ROBOT OPERATING STATION KRC	for robot setup mode with GRP software
OPERATING SOFTWARE	HACS (Hermle Automation-Control-System)
CNC	C12 5-axis CNC Vertical mill
PRICE	Starting price 320 000€
LOCAL MAINTENANCE POSSIBILITIES	Very Low (Service time and support)

4.2.2 Results from simulations

The simulations are analysing how the sub-parts are affecting the system sub-parts cycle times, robot reach and the system parts placement in the robot cell.

In Table 14 the results of the simulations are shown.

Table 14. Concept 2 Results from simulations

Cycle Times		
Billets cutting by bandsaw (Total):	**52**	min
Robot Cell (Total):	**35,5**	min
Robot Movements (Total):	**2**	min
Lead Time:	**89,5**	min
Final Product Production Rate		
Production Rate:	**0,94**	Pcs/h
Production Rate:	**42,3**	Pcs/week
Production Rate:	**1927,5**	Pcs/year
Equipment and Personnel Yearly usage %		
Bandsaw (2):	**63,9**	%
CNC Mill:	**48,3**	%
Operator 1 (Bandsaw):	**70,0**	%
Operator 2 (Robot Cell):	**12,2**	%

Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	**36,1**	%
CNC Idle Time:	**51,7**	%
Operator 1 (Bandsaw):	**30,0**	%
Operator 2 (Robot Cell):	**87,8**	%

For the robot cell the operator added 10% of occupation time to solve unexpected errors and maintenance time.

More detailed results from simulations are shown in **Error! Reference source not found.**

4.3 Concept 3 - Haas Robot Package 1

4.3.1 Description of concept 3

The second ready-to-use simple robot solution is from Haas. Figure 6 illustrates the Haas HRP- Robot package with an integrated CNC mill. This kit doesn't include a storage system, it is selected additionally and integrated with the system.

Figure 6. Haas HRP-1 Robot package [6]

Table 15 describes the Haas robot package 1 system's main characteristics.

Table 15. Haas Robot package 1 - system characteristics

ROBOT	6-axis industrial robot, FANUC LR Mate 200i
TRANSPORT WEIGHT	7kg -2,7kg (Single Gripper)=4,3kg real robot hand lifting mass 7kg -3,2kg (Dual Gripper)=3,8kg real robot hand lifting mass
GRIPPER	Single and double grippers add the possibility
STORAGE MODULES	Base stand and parts table

ROBOT OPERATING	Haas robot interface
OPERATING SOFTWARE HACS	Integrated Haas robot interface in the main interface
CNC	VF2 with all of the required additional features
PRICE	Haas robot package 68 280€ Haas VF-2 CNC mill 78 684€

Haas Robot Package controls the robot directly from the Haas control, there is no need for complex PLC connections or a 3rd-party integrator [7].

On mills, it is possible to pair the Haas Robot Package with a Haas E-vise or pneumatic vise with programmable air for fully autonomous part loading and unloading [7].

The easy-to-use robot interface is set up directly through the Haas control using the Haas Robot Interface, which guides the operator through the steps necessary to quickly program the robot's motions using the Haas Touch Remote Jog Handle [7].

The APL sequence has been expanded to allow for additional capabilities for the robot. Expanded capabilities for the robot include [7]:

- Part Flipping
- Pickup and dropoff from multiple locations (allowing for conveyor feeds, etc.)

The Robot Cell is capable of loading and Unloading from multiple locations (Main or sub-spindle, multiple vises). The cell layout is shown in the simulation software-generated layout in Figure 8 and a more detailed layout in Figure 7.

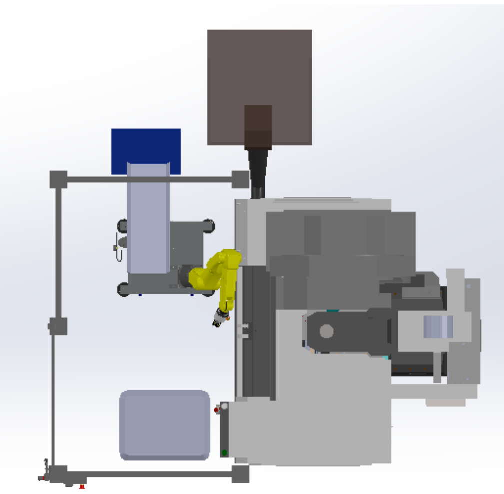


Figure 7 Customized Haas Robot Package layout

4.3.2 Results from simulations

The simulations are analysing how the sub-parts are affecting the system sub-parts cycle times, robot reach and the system parts placement in the robot cell.

In
Table 16 the results of the simulations are shown.

Table 16. Concept 3 Results from simulations

Cycle Times		
Billets cutting by bandsaw (Total):	**52**	min
Robot Cell (Total):	**35,5**	min
Robot Movements (Total):	**2**	min
Lead Time:	**89,5**	min
Final Product Production Rate		
Production Rate:	**0,94**	Pcs/h
Production Rate:	**42,3**	Pcs/week
Production Rate:	**1927,5**	Pcs/year
Equipment and Personnel Yearly usage %		
Bandsaw (2):	**63,9**	%
CNC Mill:	**48,3**	%
Operator 1 (Bandsaw):	**70,0**	%
Operator 2 (Robot Cell):	**12,2**	%
Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	**36,1**	%
CNC Idle Time:	**51,7**	%
Operator 1 (Bandsaw):	**30,0**	%
Operator 2 (Robot Cell):	**87,8**	%

For the robot cell, the operator added 10% of occupation time to solve unexpected errors and maintenance time.

More detailed results from simulations are shown in Appendix 9**.**

4.4 Concept 4 - Existing or used CNC mill implementation with a robot

4.4.1 Description of concept 4

Implementing an existing or second-hand CNC machine can be complicated and may require more effort. If older equipment is used, for example an already existing CNC mill (Avemax EH-610), then locally in Estonia for that brand, there is no service. That means machine repair is time-consuming, expensive and complicated. When the machine breaks, the work may stop for many months until the replacement parts arrive or correct repair guidelines are given or the service engineers arrive in Estonia.

Another possibility is to use second-hand CNC machines. It is important to select the brand that is represented locally in Estonia. In this case, it is possible to buy second-hand machines which are 5 years or less old with 1000 work hours. They can cost 15-30% less than new CNC milling machines. And newer second-hand CNC machines may consist of all the required features that are needed to perform all the required processes (Appendix).

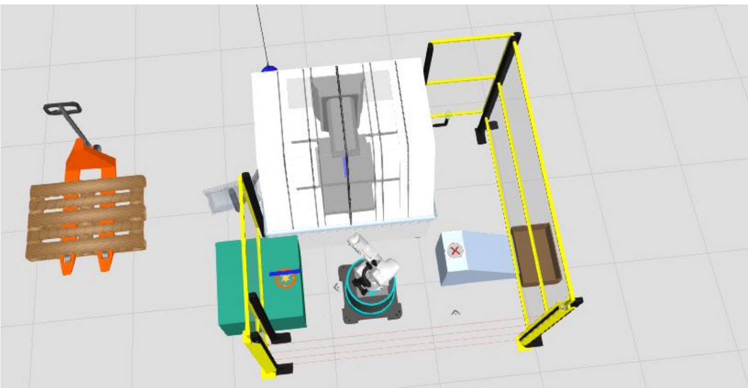


Figure 8. Layout Billets produced in RobotCell

4.4.2 Results from simulations

Table 17. Concept 4 Results from simulations

Cycle Times		
Billets cutting by bandsaw (Total):	**52**	min
Robot Cell (Total):	**37,5**	min
Robot Movements (Total):	**2**	min
Lead Time:	**91,5**	min
Final Product Production Rate		
Production Rate:	**0,92**	Pcs/h

Production Rate:	**43,7**	Pcs/week
Production Rate:	**1868,7**	Pcs/year
Equipment and Personnel Yearly usage %		
Bandsaw (2):	**63,9**	%
CNC Mill:	**48,3**	%
Operator 1 (Bandsaw):	**70,0**	%
Operator 2 (Robot Cell):	**16,6**	%
Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	**36,1**	%
CNC Idle Time:	**51,7**	%
Operator 1 (Bandsaw):	**30,0**	%
Operator 2 (Robot Cell):	**83,4**	%

For the robot cell operator, 10% of occupation time to solve unexpected errors and maintenance time was added. More detailed results from simulations are shown in Appendix 10. The concept layout is shown in Figure 8.

4.5 Concept 5 – System with multiple centres, robots and linear axis

4.5.1 Description of concept 5

The concept's main idea is to use a single robot with multiple workstations. Using this solution the robot needs an external axis to reach all the machines and to avoid unnecessary investments in additional robots. Avoiding additional robots is only necessary when the machining cycle time is longer than the robot's movements and operation between another machine. That means instead of the robot's idle time during the machine cycle times it is efficient to use the robot during the time to service other machines.

To make it possible there is a need for an external axis for the robot. That may change the need to use faster industrial robots to operate different machines. Some machines may require more reach compared with a selected COBOT.

Figure 9. One robot serves multiple stations Figure 9 shows the possibilities of using multiple machines with a single robot.

Figure 9. One robot serves multiple stations [8]

4.5.2 Results from simulations

Only one CNC mill. Table 18 explains the results from the simulations.

Table 18. Concept 5 Results from simulations

Cycle Times		
Billets cutting by bandsaw (Total):	**52**	min
Robot Cell (Total):	**40,5**	min
Robot Movements (Total):	**2**	min
Lead Time:	**94,5**	min
Final Product Production Rate		
Production Rate:	**0,88**	Pcs/h
Production Rate:	**45,7**	Pcs/week
Production Rate:	**1786,8**	Pcs/year
Equipment and Personnel Yearly usage %		
Bandsaw (2):	**63,9**	%
CNC Mill:	**48,33**	%
Robot:	**13,16**	%
Operator 1 (Bandsaw):	**70,0**	%
Operator 2 (Robot Cell):	**23,16**	%
Equipment and Personnel Yearly Idle Time %		
Bandsaw:	**36,1**	%
CNC:	**51,7**	%
Robot:	**86,4**	%
Operator 1 (Bandsaw):	**30,0**	%
Operator 2 (Robot Cell):	**76,8**	%

For the robot cell, the operator has added 10% of occupation time to solve unexpected errors and maintenance time. Simulation results show that the robot's idle time during the processing time is 86,4%. Based on this data it is possible to use the robot for another operation if there is an external axis for robot movements. More detailed results from simulations are shown in Appendix 11.

4.6 Concept 6 – Operator and CNC mill

4.6.1 Description of concept 6

A CNC mill with the operator can easily perform multiple milling tasks without any additional automatics. It is possible to perform multiple parts at a time. It ensures that there is no need for longer setup times as it is in the older CNC mills where the probe is not included and setup and measurement checks are done manually.

4.6.2 Results from simulations

Simulations show the equipment located in the room and how the other things are connected.

Table 19. Concept 6 Results from simulations

Cycle Times		
Billets cutting by bandsaw (Total):	**52**	min
CNC Milling (Total):	**33**	min
Lead Time:	**85**	min
Final Product Production Rate		
Production Rate:	**1,02**	Pcs/h
Production Rate:	**34,4**	Pcs/week
Production Rate:	**1851**	Pcs/year
Equipment and Personnel Yearly usage %		
Bandsaw (2):	**63,9**	%
CNC Mill:	**52,6**	%
Operator 1 (Bandsaw):	**63,9**	%
Operator 2 (CNC mill):	**19,6**	%
Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	**36,1**	%
CNC Idle Time:	**47,4**	%
Operator 1 (Bandsaw):	**36,1**	%
Operator 2 (CNC mill):	**80,4**	%

More detailed results from simulations are shown in Appendix 12.

It is possible to mill at least three parts with a single interruption by the operator. Based on this information, it is the most optimal way to process billets. Because the milling machine setup time is short and compared with robot tending there are fewer problems with it. With robot tending the setup requires always the robot setup and milling machine setup. It is time-consuming and unnecessary because there are not so many billets of the same material and thickness at the time. Setting up the robot and milling machine can be impractical because of this.

5. FINAL SELECTION

Table 20 describes different conceptions and brings out their advantages and disadvantages. The main goal of the table is to help to select the best possible option for automated specimen preparation. The system's main options, features and possibilities are described

5.1 Concepts Comparison

Table 20. Different conceptions comparison

	Advantages	**Disadvantages**
Concept 1	**Separate system parts**	
	- Easy to maintain, more space (not integrated) - It is easier to program (integrated systems programming with external software can be more complex)	- requires more investments (273 000€) - occupies more space - requires external control software - Very highly trained personnel
Concept 2	**Hermle Robot System RS 05-2 Adapted to C250**	
	- Ready to use package - Easy to program - All system parts and features from one place - User-friendly interface	- Starting price 320 000€ - low local service time - Robot usage for some other external automated processes is not possible because of the robot's reach.
Concept 3	**Haas Robot Package 1**	
	- Local service availability - Ready to use package - Easy to program (one type at a time) - Transparency (all the instructions and tips are available for everyone) - User-friendly interface	- Multiple types of billets inserted into the system is difficult to program - Limited robot reach (only for one work centre
Concept 4	**Existing or second-hand CNC mill implementation with a robot**	
	- No need for new investments in robots and CNC mills - It is possible to test if the automatisation is possible in real-life scenarios - Utilizing already available, not used, equipment	- Equipment is with some issues - No local maintenance availability and spare parts (Avemax EH-610) - Multiple parts inserted into the system make the programming more complex
Concept 5 (Figure 9)	**The system with multiple centres, robots and linear axis**	
	- Billet cutting, preparation and testing in the same system - It is possible to fully automate billets preparation and after that testing - Robot is more occupied during the processes	- Requires larger investment - If any issues, all the processes will be interrupted - Complex to program - Many variables - During processing the dimensional differences may cause issues
Concept 6	**Operator and CNC mill**	
	- Easier to maintain - Machine breakdowns are more easily controllable	- Requires operator attention after every few hours

	Advantages	Disadvantages
	- Takes less time to program compared to a solution, where the robot is included. - It is possible to mill multiple parts at the same time without stopping the machine.	

In Table 20 there is a concepts comparison description. Service availability in Estonia is analysed with different conceptions in Estonia. The higher the grade the faster the service. The functionality is rated as the system's main capability to perform required processes.

The highest grade was the most functionality. In the table, the highest grade for functionality is in concept 5 where multiple workstations are used with a single robot, where the robot uses a linear axis.

The highest grade for the safest system is in concepts 2 and 5. The price grading analyses the total cost of the concept, the higher the grade the lower amount of investments needed.

Based on the scoring in Table 21, the best solution for an automated feeding system is the Haas VF2-YT Vertical milling machine with Haas Robot package 1 and storing system from ProFeeder Compact.

The selected system consists of all the required features to perform the required processes with the specimens. Haas robot interface is user-friendly and easy to program. In the milling centre, it is possible to use the probing system and user-defined macros to measure the weldment billet for machining. Marking in the work centre is possible using the engraving option and serial number sequence. It is possible to send the serial number and measurements into the ERP system.

After processing, the robot moves all of the parts in one container using a small ramp. It saves some time instead of placing the billet back in the same storage space. For safety, the robot cell is surrounded by a safety fence. It makes sure that the operator or some other people don't get into the robot's working area.

Because ordering and order arrival takes two years. It is better to start testing the tending and milling processes on already existing equipment. This way it is possible to test how the new jigs, the robot picking, and everything else is performing. When the new system arrives it makes the system implementation process faster.

Based on the need to increase efficiency the best option is to start implementing concept 6 as the scoring results are showing. In the future, it is possible to add an automated solution based on concept 3.

5.2 Concepts Rating and Selection

Table 21. Concepts rating

	1 Concept	2 Concept	3 Concept	4 Concept	5 Concept	6 Concept
Service availability	4	3	5	2	5	5
Functionality	2	3	4	2	5	5
Safety	5	5	4	3	5	4
Price	2	1	4	5	1	5
Total Score:	13	12	17	12	16	**19**

The safety analysis is conducted for concept 6, it analyses how well the operator or other third parties from the area of the robot zone are protected (Table 22).

5.3 Safety Analysis for Human Aspect in Selected Concept

Table 22. Safety analyses for the human aspect in selected concept 6

Risk description	The probability of the risk occurring	Importance of Risk	Actions needed for minimizing risk
Pinch points	Middle	Middle	Eliminate pinch points
Flying particles	Middle	High	Use safety glasses
Sharp edges	High	low	Use gloves
Slippery floor	high	High	Keep the work area clean
Falling Objects	High	High	Protective work boots

In Table 22 the general possible safety aspects for the human factor which may occur in concept 6 are described. To prevent mentioned risks, there should be eliminated pinch points, and the operator and all personnel should wear safety glasses. Operators should wear gloves to prevent injuries from sharp edges. The operator should apply a daily cleaning routine to keep the work area and machine clean. Operators and everyone else in the work zone should wear protective work boots to avoid injuries from falling objects.

6. MORE DETAILED CONCEPTS DESCRIPTION

6.1 CNC mill selection

When selecting a CNC mill, the most important aspect is the availability of local Estonian based services. The second aspect is transparency, that all the supportive materials are easily accessible. The third requirement is the correct size of the worktable, worktable size shouldn't be smaller than 900x400 mm. Forth requirement is an automatic probing option, it is important to keep the setup times shorter and it is one important base feature which makes automated milling possible. The fifth aspect is quality and price. The best ratio between speed, quality and price.

Table 23. CNC mills comparison

	DMG Mori	**Haas**	**Doosan**
	Japan	USA	South-Korea
Model	CMX 800V	VF-2YT	SVM4100
Worktable	1100 x 560mm	914 x 457mm	919 x 409mm
Control & software	Options: -Siemens - Heidenham - MAPPS Fanuc The Robo2Go-APP Celos app	The Haas Control	FANUC Oi-Plus iHMI
Tool Storage Capacity	20	20	30
Maintenance service time (In Estonia)	Good	Good	Good
Intuitive Probing System	yes	yes	yes
Price	144 000€ (used 5y.)	78 684€	85 000€
Transparency	High	Very High	High

Based on Table 23, the best option for a CNC mill is Haas VF-2YT, shown in Figure 10. Selection is made because of the quick service time in Estonia and their free access to different supportive guides and case studies.

Figure 10. Haas VF-2YT

This CNC Mill includes the following features and additional features to perform all the needed machining operations (Appendix 1). Haas offers the option of using their robot package, which allows using a simple operator-friendly Haas Robot Interface.

The robot (Figure 6) can be set up directly through the the Haas Robot Interface, which guides the operator through the steps necessary to quickly program the robot's motions using the Haas Touch Remote Jog Handle [9].

A basic part management table can be created by setting up a grid pattern template of equally spaced rows and columns. The robot APL grippers can be configured for various part shapes – such as round, hex, and square bars – and adjusted or modified to the best fit [9].

The robot APL operates in the background during normal machining operations, returning parts to the storage table and retrieving new raw pieces, while parts are being machined. The result is near-continuous unattended machining [9].

6.2 Workpiece marking and measuring system

Keeping the system user friendly is a priority. For that reason, it is better to operate an independent marking system which is not directly controlled by a milling centre. It allows to receive and send feedback back to the ERP system more easily.

For example, in Haas milling centres they use a DPRINT function to send formatted text to the serial port. It is not possible to receive codes from ERP systems without using external software. The only option without using external software is to use G47 code to engrave sequential serial numbers.

This solution doesn’t allow for receiving or transmitting serial numbers from the ERP system. For measurements measuring there are more options. The DPRINT function to measure the specimen automatically and send the data to the ERP system (Figure 11). One of the possible ways is a two-way connection with Putty.org software which is free and uses TCP ports to receive and transmit the serial numbers in the ERP system. Another possible choice is Predator software but it isn’t free.

Code	Output
N1 #1= 1.5436 ;	
N2 DPRNT[X#1[44]*Z#1[03]*T#1[40]] ;	X1.5436 Z 1.544 T 1
N3 DPRNT[***MEASURED*INSIDE*DIAMETER***] ;	MEASURED INSIDE DIAMETER
N4 DPRNT[] ;	(no text, only a carriage return)
N5 #1=123.456789 ;	
N6 DPRNT[X-#1[35]] ;	X-123.45679 ;

Figure 11. DPRINT example [10]

The negative side of taking into use the external devices or software is the external investment. On the other hand, it is not necessary because the Haas milling centre allows using an integrated solution which is already in the system, included by default. The real question is how well the robot cell operator is trained so that they will be able to set up the robot cell without any external help and at the same time keep it working without any problems.

Specimen's shapes during the bandsaw cutting are similar, it is possible to use 3D printed templates to mark the cuttable region. They are specially designed to eliminate the need to use a ruler for measuring and marking the positions for bandsaw cutting. It may help to save some time.

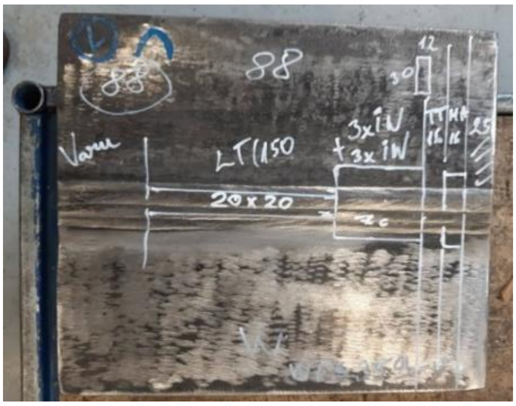


Figure 12. Manually marked cuttable Butt Joint Weld specimen positions

The compact desktop laser workstation from Trotec is used for the serial number marking on metals and other materials (Figure 13). When using external software, it is possible to receive and transmit serial numbers from an ERP system. One of these softwares is Predator software (**Error! Reference source not found.**).

Figure 13. Trotec SpeedMarker 300 Compact Desktop Laser marker [11].

Trotec Speedmarker has an easily accessible working area it has an optional pass-through mechanism, Max workpiece size 300 x 300 mm x 250, F160 marking field 120 x 120 mm, F254 marking field 190 x 190 mm, mechanical or software-controlled Z-axis, SpeedMark laser software, laser safety class 2. The system price starts from 10 000 €.

6.3 Billets fixing in the CNC

6.3.1 GripMatic Self-centering vise

GripMatic self-centring vise works hydraulically and pneumatically. The jaws are interchangeable and modular, which allows the use of custom jaws. The vise minimal clamping force is 4N and maximum of 43 000N. Vise minimal stroke is 58mm and maximum 124mm (Figure 14).

Figure 14. GripMatic Self-Centering vise [12]

6.3.2 Haas 150mm Air Vise

Haas is offering another type of pneumatically operating vise (Figure 15). 150 mm Air Vise Figure 15; self-centring pneumatic vise with 150 mm jaws. The jaws are made of hardened steel, with a 45° dovetail and serrations. Each vise also includes the necessary hardware (studs, nuts, and T-nuts, as needed) for mounting the vise to the table it also includes the fittings and hoses needed to connect the vise to an air supply [13].

Figure 15. Haas 150mm Air vise [13]

Using this vise requires the Air Vise Ready Provision (UMCs), or Programmable Air (VFs, DTs, DMs).

6.3.3 Custom made workpiece fixture for an automated solution

The custom solution is shown in Figure 16 and the general drawing is in Graphical material 2 and Figure 17. In Graphical material 3 there are conceptional designs to show the possible solutions of the automatically controllable workpiece fixtures.

Solution 1 in Figure 16 helps to fix the billet in the jig using pneumatic clamps and special rotating supports that change their position based on the angle of the weldment specimen. The fixture allows to mill the welds on the top from the sides of the specimen.

After the first step it is needed to place the billet in an external flipping station, because there isnt any space to rotate it in the CNC mill. The CNC milling centre can mill off the welds from another side. The fixture and probing possibility ensures that the thickness of the material is not damaged during the milling process, it is important to ensure it for testing.

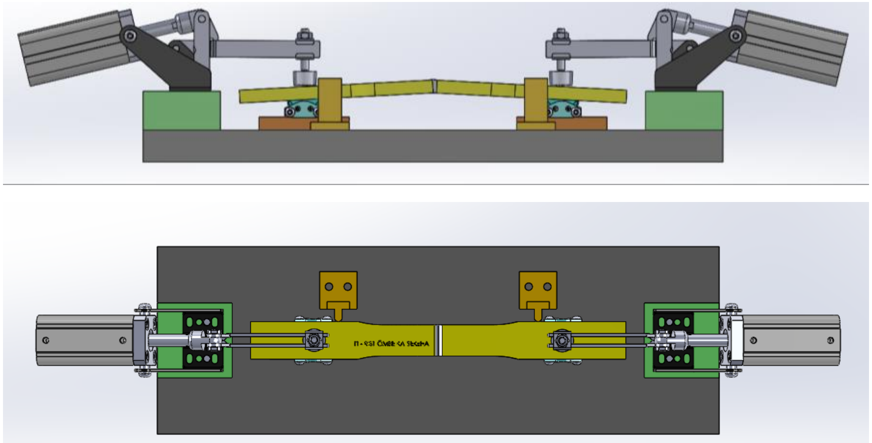


Figure 16. Custom Jig 1 conceptual idea (Graphical material 2)

Figure 17 shows a possible scnario for when the machine probing cant measure and change the machine coordinates, whichwas caused by the welding deformation.

If for some reason the first custom jig is not working, then it is possible to fix the billet in the jig using another placement. Figure 17 shows the solution where it is possible to mill the sides using linear movements only. In this case, the specimens positioning in the jig by the robot is important. If The billet is longer or shorter it may mill the parts that are important to keep.

Another way is to use external software and sensors for placing the component into the jig. The sensors need to detect the weldment location during the work by robot when it places the billet into the jig. The location of the weldment is also the endpoint of milling, where the sensor gives the command to the CNC mill to stop if the mill has reached the sensor area.

Another way to solve the problem is to place the billet into the jig that is then used as the stopper. In this case, it is important to avoid misplacing and possible collisions with the jig. That means the length of the billet must be as accurate as possible.

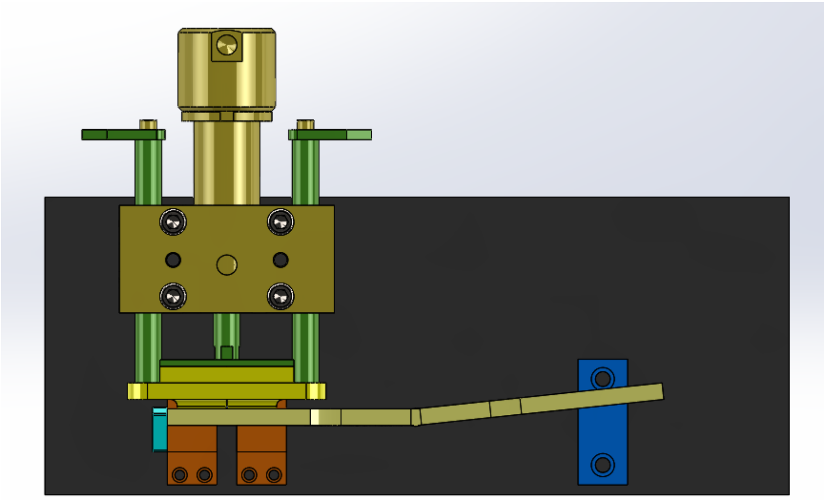


Figure 17. Custom Jig 2 conceptual idea (Graphical material 3)

6.3.4 Hydro Pneumatic Booster Cylinder

The Hydro Pneumatic Booster Cylinder shown in Figure 18 is a space-saving option in the CNC mill for workpiece fixing. It helps to save space in the milling centre, when the custom jigs need to use higher fixing forces. That means the pneumatic cylinder size is too large and it can occupy too much space. With the hydro-pneumatic booster cylinder it is possible to use smaller hydro cylinders which will save up some extra space in the CNC work area.

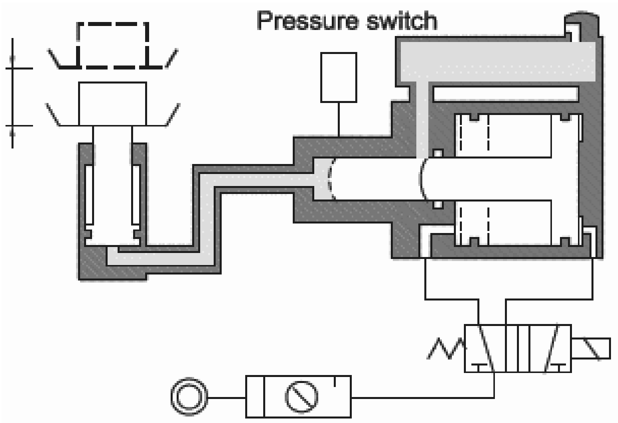


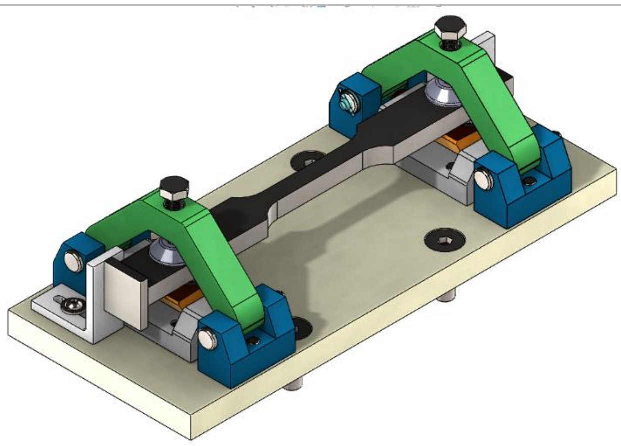
Figure 18. Hydro Pneumatic Booster Cylinder [14]

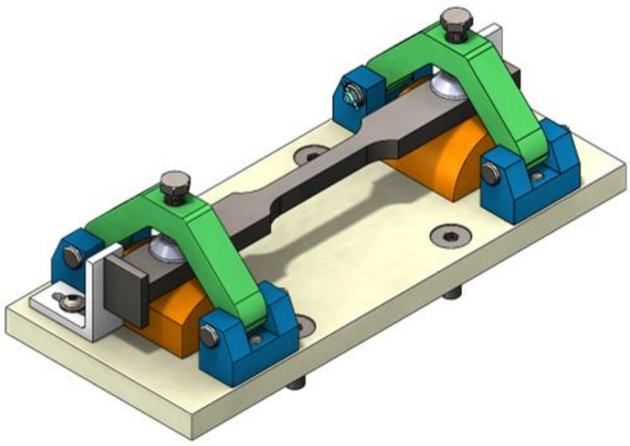
6.3.1 Workpiece fixture for an operator-based CNC mill

Custom-made fixtures are easier to use, and they make fixing much faster. Custom fixtures provide enough accuracy, and they are more compact which allows for more billets in the work area.

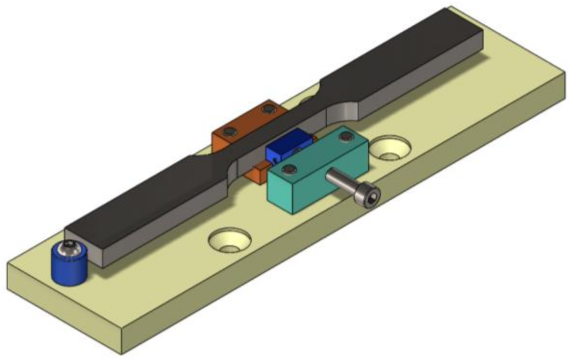
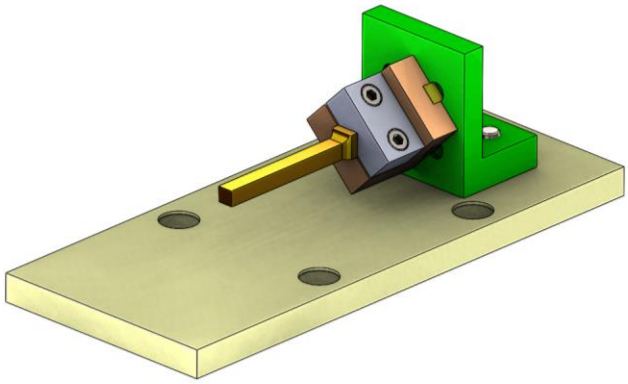
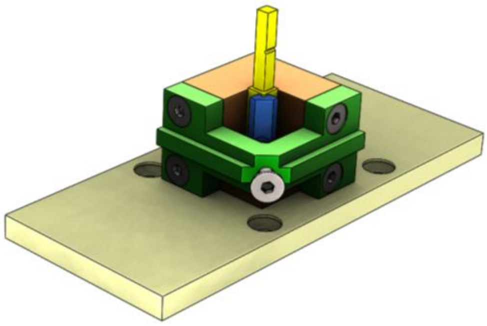
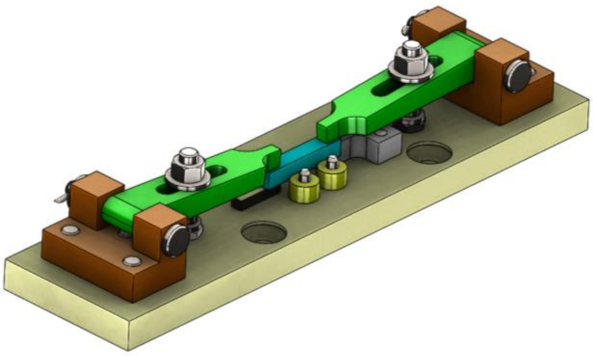
Table 24 shows custom-made fixtures concepts and their comparison based on the functional advantages and disadvantages.

Table 24. Fixtures description

<table>
<tr><td>1. Impact and tensile strength specimen fixture.</td><td rowspan="2"></td></tr>
<tr><td><u>Advantages:</u>
- Supporting blocks are self-adjusting
- Adjustable limiters enable the use of multiple sizes of billets

<u>Disadvantages:</u>
- Complex design</td></tr>
<tr><td>2. Impact and tensile strength specimen fixture.</td><td rowspan="2"></td></tr>
<tr><td><u>Advantages:</u>
- Supporting blocks are self-adjusting
- Adjustable limiters enable the use of multiple sizes of billets

<u>Disadvantages:</u>
- Fixing marks on the specimens</td></tr>
</table>

3. Impact strength specimen fixture.	
Advantages: - Simple design - Easy to use Disadvantages: - It is possible to use standard vices and modify only its jaws, that way they will match	
4. Impact strength specimen fixture.	
Advantages: - It is easier to flip the side of the specimen - Easier to use Disadvantages: - Fixture parts milling requires more accuracy - The end of the billet should be supported to prevent bending - The length cutting requires additional operation	
5. Impact strength specimen fixture.	
Advantages: - No need for another placement Disadvantages: - Requires long milling tools which are more expensive - Cutting the specimen at the correct length requires another blade-type tool or cutting using a belt saw	
6. Impact strength specimen fixture.	
Advantages: - The billet length is pre-cut - Simple to fix - Easy to use Disadvantages: - Specimens require two placements - Every placement requires the use of limiters to preserve the parallelism.	

The first fixture is for the impact and tensile strength specimen. The fixture uses movable supportive blocks which are moving in positions based on the weldment specimen angle. It enables the bottom side supportive area to be greater. It ensures that there will not be any marks caused by the bottom supportive base. The side limiters are movable if needed, incase the billet is thinner which ensures the part is always in the centre of the fixture. From the top, the billet is locked in place using movable handles. The side of the handle is locked by a bolt and the other side is fixed by the stud which enables it to open and close quickly. On top of that, there is a special locking bolt which adds pressure on the top of the billet and locks it in position.

The second fixture is a simplified solution from the first one. The bottom movable support is removed and replaced by a solid rounded support. It still works the same way as the first solution, but the risk is that using the billets from softer materials than the bottom support can cause marks on the material.

The third fixture is a vise like a fixture for the impact strength specimen. The specimen is processed in the first or the second fixture. After that, the specimen is placed in the third fixture where specimen cutting is performed. After this process, the required length of the specimen is achieved.

The fourth fixture is meant for the impact strength specimen. In this fixture the billet is milled from both sides and after that, the fixture bolt is loosened and the billet holder is rotated 180 degrees. It enables one to mill an other side and there is no need for an external fixture. After that, the required length is kept and the part is milled in length.

The fifth fixture is meant for the milling impact strength specimen. The billet is fixed in the fixture corner. The milling process is performed in a single cycle. That means the milling tool should be long enough to perform this operation. After milling, the billet is cut off using a blade milling tool.

The sixth fixture is for the impact strength specimen. In this fixture, the billet is cut to the correct length before starting the milling process. The billet is placed in the fixture using the limiters to ensure that the part is fixed in the correct position. After the top supportive fixtures are tightened, the side limiters are removed to allow space for milling. After the first milling process, the top supports are loosened and the specimen billet is rotated in the fixture and the limiters are added. The next step is to fix the top supports and remove the limiters for the second milling procedure.

In Table 25 the previously described fixtures are rated and based on that the best fixture solutions for the operator-based milling process in the CNC are selected. The possibility to select two fixtures for two different specimens is analysed in the table. The usability, fixing speed, fixture accuracy and functionality is rated there.

Table 25. Concepts rating

	Conc.1		**Conc. 2**		**Conc.3**	**Conc.4**	**Conc.5**	**Conc.6**
Is possible to use impact (IT)/tensile strength (TS) tests	IT	TS	IT	TS	IT	IT	IT	IT
Fixing speed	3	3	3	3	5	4	5	4
Accuracy	4	4	4	4	3	4	4	5
Functionality	4	4	5	5	4	5	4	5
Total Score:	11	11	12	**12**	12	13	13	**14**

Table 25 results show that the custom fixtures concept 2 and concept 6 are the best choices. For tensile strength, the best option is concept 2 and for Impact strength its concept 6. The concept uses a simple fixing method. The two supporting arches over the billet are removable. From one side its stud is fixed with the stopper ring. Another side is fixed the same way only without the stopper ring. That makes the stud removal before and after specimen removal quicker. After that, the two bolts will be fastened to ensure no movement occurs during the milling process.

Concept 2 compared to concept 1 is easier to build. Using the second concept makes the fixture easier and foolproof.

Concept 6 for the impact strength specimen fixture is the best choice mainly because of its simplicity. The billet length is cut before milling, because of that there is no need to cut the specimen after the milling.

Specimen milling in the fixture is done in two placements. On the first placement, two sides are milled down. That means the two sides will be parallel and highly accurate. The second placement takes place in the same way, the milled side is supported which makes the accuracy higher.

7. ECONOMICAL ANALYSIS

7.1 Critical success factors and key performance indicators

Key Performance Indicators (KPI) help to define the organization and measure the progress toward the organization's goals [15].

If a KPI is to be valuable, there must be a way to accurately define and measure it. A KPI can be general or connected to the processes. Choosing the right KPI-s is important because that helps to understand what is important to the organization and they always stay the same, year by year, to measure real and accurate performance. The selected KPI-s that should be monitored in the future to track processes are shown in Table 26. The monitoring of KPIs help to analyse all the mentioned indicators in the table and through that implement changes in processes to avoid future errors.

Table 26. Classifications

KPI-s connected to the customers	**KPI-s connected to the production**	**KPI-s of the supply chain**
- speed of delivery (customer satisfaction) - Quality (correct testing results) - Capacity (on higher capacities more profit if the processes are efficient and optimized) - Price (More automation means the total processing cost is lower) - Flexibility (different types of specimens produced means more customers and more capacity) - customer satisfaction (determines the capacity)	- Overall equipment efficiency (total processing cost is slower - Quality (higher quality, less waste, more efficiency) - Cycle time (determines the real processing cost) - Total throughput time (optimizing it can reduce the time) - Rejection rate (more control systems to prevent waste-producing) - Manufacturing costs (determines the cost for the client and also the rate of profit) - Costs of poor quality (increases utilization period, which means it decreases the total production rate in an hour)	- Speed of delivery (customers don't need to delay their manufacturing if the speed of delivery is quicker) - Delivery accuracy (Customers can plan their production more accurately if they know that the results received take always the same time) -Capacity (higher capacity, more efficient and problem-free system) - Flexibility (take different specimens, thicknesses and the type of materials and change the machines easily so that time is not lost for programming or program changes)

7.2 Efficiency and Feasibility analysis

The efficiency analysis evaluates the designed or installed solution based on the best competencies. The main task of the feasibility analysis is to ascertain whether automation in a company is practical or not.

This topic analyses the current situation based on the yearly demand and faculty production capacity. The currently used concept in the production of specimens is compared with new selected concept 6.

1) Forming the billet preparation cycle time (Bandsaw)

$$\mathrm{t_{co}} = \mathrm{t_{suo}} + \mathrm{t_{mo}} + \mathrm{t_{po}} + \mathrm{t_{mao}} + \mathrm{t_{gr}} = 7+32+8+3+3 = 53 \text{ (min)} \tag{5.1}$$

where

t_{co}	- Operation cycle time – manual billets preparation
t_{suo}	- set-up time
t_{mo}	- machining time (cutting in bandsaw)
t_{po}	- positioning time
t_{mao}	- marking time
t_{gr}	- edges grinding

2) Forming the semi-automatic NC mill work-cycle time

The cycle time analyses and determines the rate at which the NC mill works to complete the task. Based on this data it is possible to analyze the efficiency.

$$t_c = t_{su} + t_m + t_p + t_o + t_{ma} + t_{me} = 17+39 + 2 + 6 = 64 \text{ (min)} \tag{5.2}$$

where

t_c	- operation cycle time
t_{su}	- set-up time
t_m	- machining time (NC milling)
t_p	- Edges and weldment grinding after milling (a manual process)
t_{ma}	- Marking and documenting specimens (a manual process)

3) Billets prepared in a week with a bandsaw (operator)

$\mathrm{PC} = \mathrm{n}\ \mathrm{S}\ H_m\ \mathrm{R} = 2 \times 5 \times 7 \times 1{,}13 = 87{,}5 \approx 79$ (pcs/week)

(5.3)

Where

PC	- the number of units produce in the time interval (week)
H_m	- H(work time) – L(lunch brake) + S(smaller brakes)
n	- the number of bandsaws in the facility
S	- number of workdays per period (days/week)
H	- a certain number of hours per shift (8hr/shift)
R	- hourly production rate of each machine (output units/hr)

4) Specimens preparation with a semi-automatic NC milling machine

$\mathrm{PR} = H_R\ \mathrm{n}\ \mathrm{S}\ H_m\ \mathrm{R} = 1 \times 1 \times 5 \times 7 \times 1{,}06 \approx 37$ (pcs/week) (5.4)

Where

PR	- the number of units produce in the time interval (pcs/week)
H_R	- the number of NC mills in facility
n	- the number of operators at the NC mills (1 worker and 1 NC vertical mill)
S	- number of shifts per period (shift/week)
H_m	- H(work time) – L(lunch brake) + S(smaller brakes)
R	- hourly production rate of each machine (output units/hr)

5) Machines utilization rate

Utilization rate refers to the amount of output of a production facility relative to its capacity. A production machine operates 40 hr/week (1 shift, 5 days) at full capacity.

$\mathrm{U} = \mathrm{Q} / \mathrm{PC}$ (5.5)

Where

U	- utilization of a facility
Q	- actual quantity produced by the facility during a given period (pcs/week)
PC	- (R $\times H_m \times$ S) production capacity for the same period (real capacity)

Billets prepared with a bandsaw (operator)

Calculation finding the facility utilization rate

U1	- ?
Q1	- 537 (pcs) / 51(week)=10 (pcs/week)
PC1	- (R1 x H_m x S) = 1,13 x 7 x 5 x 2 = 78 (pcs/week)

$$U1 = Q1 / PC1 = 10 / 78 = 0{,}128\ (12{,}8\ \%)$$

Billets processing in the NC (Operator tending)

U2	- ?
Q2	- 537 (pcs) / 51(week)=10 (pcs/week)
PC2	- (R2 x H_m x S) = 0,93 x 7 x 5 = 32 (pcs/week)

$$U2 = Q2 / PC2 = 10 / 32 = 0{,}31\ (31\ \%)$$

Based on the previous calculations of the current concept utilization rate, where bandsaws are used 12,8% of the time in the year and NC milling machine 31% per year. It is not possible to increase production capacity five times, without replacing the old NC mills with the concept 6 solution.

Calculations indicate that increasing the cutting by five times is possible if two bandsaws are used because the weekly bandsaw utilization rate is 12,8% in the facility.

Table 27. Efficiency analysis

	Current concept (min)	**Concept 6 (min)**
Cutting Cycle Time:	53	52
Milling Cycle Time:	58	33
Lead time:	116	85
Efficiency increase (cutting):	-	**1,9 %**
Efficiency increase (milling):	-	**44 %**
Efficiency increase (lead time):	-	**26,8 %**

In comparison Table 27 the analysis result showed that the most time-consuming process is the specimens billets cutting. Speeding the process up without changing cutting technology is not a real option. It is possible if Water Jet cutting is used. Replacing Bandsaw cutting with the waterjet cutting method increases the price of the billets processing. It is more efficient to keep the same bandsaw-cutting method.

As a second part, it was found that the current CNC bench set-up time for each specimen was 1/3 of the total milling lead time. Because the bench does not have the probing ability to measure the part automatically. If a new CNC mill based on concept 6 is used, then it is possible to avoid the high setup times and increase the processing efficiency and quality.

Based on the results, concept 6 will help to increase milling efficiency by 44% and it increases the total specimens preparation lead time efficiency by 26,8%.

7.3 Payback and cost-effectiveness calculation

In the operator-based workplace, there is one operator who works 8 hours a shift and a CNC that operates 8 hours per day, five days a week. The work cell break-even point is in the third year in ideal conditions. This is indicated in Table 29. In Table 28 the investments for the new machine and yearly expenses are brought out.

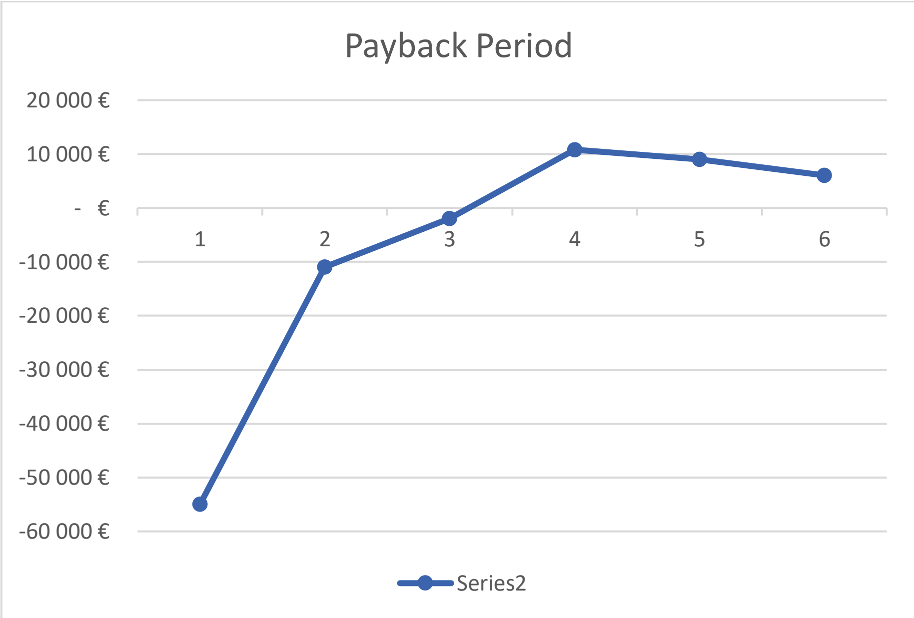
Table 28. Milling expenses with the automation

One time Expenses	**Cost (EUR)**
Haas VF-2 Vertical CNC mill	78 684
Needed tools (tool holders, fixtures)	9 000
First-time setup (machining base programs)	3 000
Value together	90 684 ≈ 91 000
Yearly Expenses	**Cash outflows (EUR)**
Coolant fluid	700
Milling tools	3 200
Operator salary	22 000
Maintenance	3 000
Electricity (0,3 €/kWh)	26 000
Value together	54 900 ≈ 55 000
Yearly Income	**Cash Inflows (EUR)**
Cash inflow is based on the milling time 26min x total number of parts x hourly rate (60€/h)	69 810
Value together	69 810

Table 29. Payback period calculation table

Year	Cash Inflows	Cash Outflows	Net Cash Flow
1	- €	55 000 €	- 55 000 €
2	45 000 €	56 000 €	- 11 000 €
3	55 000 €	57 000 €	- 2 000 €
4	69 810 €	59 000 €	10 810 €
5	72 000 €	63 000 €	9 000 €
6	76 000 €	70 000 €	6 000 €

Year	Cash Inflows	Cash Outflows	Net Cash Flow
Break-Even Point		3	
Last Negative Cash Flow		-€ 2 000,00	
Cash Flow (In) in the Next Year		€ 69 810,00	
Fraction Year Value		0,029	
Payback Period (Years)		**3,029**	
Payback Period (Months)		36,344	



If the operator-based work cell processes only specimens, then the work centre capacity is used 52,6% of the available time in 8-hour-day cycles and the operator is used 19,6%. That means there is available idle time of 47,4%. It is possible to use it for other orders to use the work centre more efficiently and through that decrease the total time of the payback period.

Management can use the break-even results in two ways. Initially, they can decide to abandon the project if forecasts show that below break-even values are likely to occur. Management can prepare for a worst-case scenario involving the investigated variables being realized during the project's life. This action could be to suspend production, to try to make production more efficient or to adjust the unit selling price. [16]

It is important to consider that the break-even values may not be accurate. If the points are calculated then it is important to consider the point recalculation at the chosen point in time. It is mostly because the sales price and expenses in real-time when they are happening may be different. The forecasts of the rate of cash inflows and outflows are mostly unpredictable, and a lot depends on the situation of the economy. The demand for the products can differ during the period of production and also the expenses to keep the production rate up may increase for a longer period which makes it necessary to increase the rate of customers. In the long term, it mayinfluence the customer to change the company that tests their weldments. It means that the cash inflows decrease and there may be unfilled gaps in production. That may change the break-even points and extends the real outcomes of profitability.

8. FUTURE DEVELOPMENTS

1) One way to increase the system efficiency is to design a custom storage system or select something similar from another application and modify it so that it is possible to use it for a storage system. It may help decrease the total cost of the storage system from 45 000€ to 5 000€.

2) To speed up the new system implementation it is possible to make the preparations before the machine's arrival. Prepare the milling programs and design the custom fixtures.

3) Find the possible standard components to produce and decrease payback time, when there are not enough specimens to produce during idle times in the robot cell.

4) In the future, the specimens bandsaw replacement with a Waterjet to increase productivity should be considered. Possible system availability to work independently for more hours outside of working hours should also be analysed.

5) Another possible way is to automate testing, for example using a similar system as the Figure 18, or the same solution.

Figure 19. RoboTest R robotic testing system (Polar) for metals [17].

RoboTest R has many ranges of applications in the field of automatic testing. The system is used for the following fully automatic tests: tensile tests on metal specimens, pendulum impact tests, hardness tests and roughness Tests.

8.1 Billets positioning

It is important to make sure that the gripper has grabbed the part equally from both sides, so it's fixed as accurately as possible. The first step is to use a special angular supportive table which helps to position the Centerpoint and achieve a better grabbing point (Figure 20).

Figure 20. Angular Positioning table [18]

It ensures that the part is parallel after grabbing from the storage area and helps to reorient it. In the next step, when the part is picked up from the angular positioning table and placed in the CNC fixture, it decreases the risk that the part could fall off the fixture because of too large, misaligned grabbing points.

8.2 Part Flipping Station

One example that Haas offers is a Part Flipping Station (Figure 21). It is possible to add it to the Haas Robot Package-2 as an additional feature. The part-flipping station is a heavy-duty pedestal that mounts to the floor. Providing a convenient location for the robot arm to place parts and then regrip (flip) to machine the other side [19]:

Figure 21. Part Flipping Station [19]

Part flipping is one possible solution to change the part sides during the milling process. It may not be the best solution if there are the movements that the robotic hands need to perform before the part is flipped. If the CNC mill worktable is large enough it is better to place it into the machine. It will save some time during the flipping process.

The first question is whether there is a real need for the external flipping jig. If the CNC mill uses pneumatically, hydraulically or electromechanically controllable vises/fixtures it is possible to flip the part there. It saves the work area space and increases the efficiency because there is no need for external robot moves and additional investments.

8.3 Possible accessories for the robot

To make the robot system smarter it needs to use more sensors. One option is to use a vacuum gripper instead of a sensor, when the vacuum gripper grabs to the part then the vacuum sensor understands it. Through that, it is possible to know when there is close enough contact. It will enable the detection of the distance between the object from the vacuum head tip. It makes pick and place operations easier, and it ensures that the end-effector will grip the workpiece from the correct distance.

Machine vision makes the object's location easier to detect and enables the detection of the location of the billet. If the billet is misaligned for some reason, the machine vision understands it and aligns the gripper so it will be able to pick the product up without causing any errors.

When using machine vision, the material reflection may confuse the camera view because of. Because of that it may be necessary to paint or cover the billets storing area and cnc milling work area. That means the camera should be able to tell the difference between the billet and surrounding equipment. The billets storing area and CNC milling area should be painted or at least covered to prevent errors caused by reflective surfaces. If resolution of the detection camera is good enough, the reflective surfaces may not be an issue.

For robot cell simulations and programming, it is possible to use Digital twin solutions, for example, RoboDK. There is a custom programming option to easily test and edit programs. Digital twin solutions help to test and edit the custom programs. It helps to program the system using all the sensors that the equipment consists of. Programming should be done in that software to prevent and to avoid equipment unintentional damage.

8.4 Storage system options

The topic's main idea is to describe four types of storage systems from the market solutions for billets storage.

Storage systems are major system parts to manage automated, processed and unprocessed billet storing. Their function remains always the same but their semi-functions can differ. On the market, there are simple table-type and shelf-type units. Where the most complex ones are with an external robot or mechanism.

8.4.1 ProFeeder Compact

ProFeeder Compact (Figure 26) is equipped with compact dimensions and is easily movable around the production facility [20].

Figure 22. Storage system – ProFeeder Compact [21].

The Profeeder Compact has the following features [20]: Mechanical locking system or Air locking system; Footprint dimension. L610*W860*H1084mm; Holds up to 10 trays; GD wheels to transport parts (can be mounted optionally); Optional Docking station; Optional EasyPedestal for Robot Arm and controller compartment; Air locking is running Modbus; The trays can be customized depending on the requirements.

8.4.2 MRC Flextray

MRC Flextray (Figure 23) is using its docking station with an integrated machine interface. The pallets are then loaded with the billets and fed into the robotic cell. The small KUKA robot opens the relevant drawer, removes the parts and places them in the clamping fixture. Once they have been machined, the robot places the parts back on the pallet or another storage area. The parts are accessible for inspection and various parameters can be monitored to ensure process reliability without having to interrupt the automation. [22].

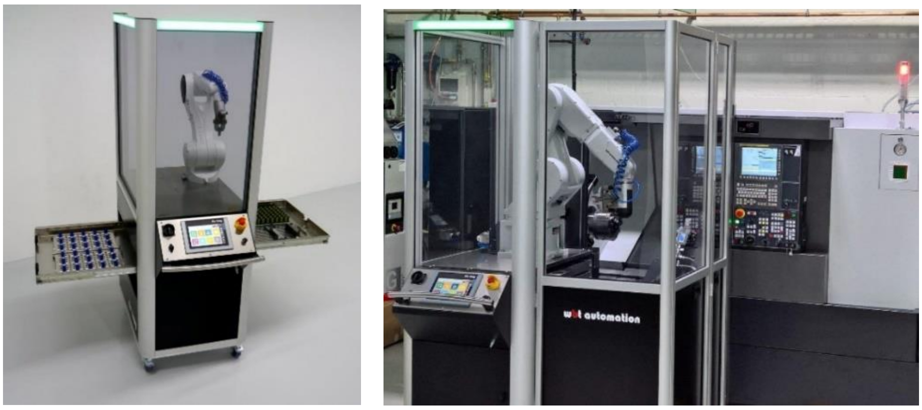


Figure 23. MRC Flextray [23].

The robotic cell can process up to four drawers, each with two component-specific pallets. It is thus also highly suitable for small and medium batch sizes. Individual expansions can be easily tailored to specific customer requirements [22].

8.4.3 BILA IQ Metal System

BILA IQ Metal System (Figure 24) is a compact and moveable cell that can be easily moved using a pallet jack or a truck. The system can be placed in between several CNC machines and can be set for production in 20-30 minutes [24].

The combination of parametric programming and block teaching (operator programming) makes it possible to quickly change items (5-10 min) while at the same time allowing the operator to do new programming and to use the cell with other machines [24].

Figure 24. BILA IQ Metal system [18].

8.4.4 Aramet storage robot

Aramet storage robot (Figure 25) the products for storage are placed in the loading area of the storage system by an autonomous robot. The products are stored in metal boxes, which are kept on shelves. The system is using 3-axis servo system and after recieving the command the billet is brought into the loading area.

Figure 25. Aramet Storage robot [25].

The storage robot is a complete set of devices that can operate independently, including all the necessary controllers and other automation devices. The warehouse system keeps track of which shelf the desired order is stored in and brings the correct box to the loading area. Storage robots can also keep track of vacant and occupied shelf space. The logic of placing empty and order-filled boxes on the shelf can be changed, in addition, the storage system automatically performs an inventory when a person has entered the storage area. The shelf boxes are equipped with an RFID chip and ESL screens.

8.5 Storage system selection

In the previous chapter, the most commonly used storage systems in robot cell design is described. This part will help to select the best option by rating the: price, compactness, simplicity and functionality to identify every system's weak and strong sides. Storing system comparison is performed in Table 30.

Table 30. Storing Systems Comparison

	Storing System Model	**Profeeder Compact (Without robot)**	**MRC Flextray (With robot)**	**IQ Metal system (Without robot)**	**Aramet Storage Robot**
1.	Work process description	Mechanical air locking system for drawers (Modbus)	Four trays storage system with a robot	The parametric programming and block teaching programming	3 axis servo system allows to call out specific drawer.
2.	Price	Average (20800 – 45000€)	Average without robot	Low	Very high
3.	Compactness	Very compact It is possible to add more units on top of each one or next to	A very compact Robot and storage system is connected	Billets are placed in only one layer	In storing units there are many levels for storing
4.	Simplicity	Storing space is limited but it is possible to use larger units or stack many units	Storage space is limited, because of the robot's reach	Billets are placed in customized slots	A lot of mechanics and sensors)
5.	Functionality	It is possible to add custom slots into the units	Functional on smaller parts but not in this case study	Very simple and functional design	In this case study, it is unnecessary and too complex
6.	Safety	No robot contact with a human when adding billets. Shelf-system	Robot contact with a human is not possible, Billets adding through the shelf	When more billets are added, the system must be paused	Closed system
7.	Storage space	10 trays L610xW860x H1084mm	4 trays	2 trays	36 storage boxes Boxes are equipped with RFID chips and ESL screens

Table 31 compares previously described storage unit systems and helps to define the best solution using the scoring method, where the highest score is the best option.

Table 31. Storing systems rating

	Storing System Model	Profeeder Compact (Without robot)	MRC Flextray (With robot)	IQ Metal system (Without robot)	Aramet Storage Robot
1	Compactness	5	5	2	4
2.	Simplicity	5	4	5	2
3.	Functionality	5	4	4	3
4.	Safety	5	5	1	5
5.	Storage size	5	4	3	5
6.	Price	2	3	3	1
	Total score:	**27**	25	18	20

Based on the results from the comparisons rating as shown in Table 31, the best option is the ProFeeder Compact type shelf-system. It doesn't mean that exactly this type of model must be selected but based on comparison it fits the requirements to use many different types of billets at the same time in the same system. The selected model doesn't compromise functionality and safety. It is possible to insert new billets without being in the robot work zone.

The storage system is expensive compared with other equipment (20 000 – 45 000€ per storage system). A more cost-effective option is to develop a custom storage drawer system with similar functionality. It helps to bring down the price and enables to define the exact custom parameters for each drawer based on the billet dimensions.

Storage systems are major system parts to manage automated, processed and unprocessed billets storing. Storage systems can differ in their semi functions but their main function always remains the same.

On the market, there are simple table type and shelf type units, where the most complex ones are using automated separate positioning, where an external robot or mechanism is bringing billets to the front of the tooling robot and after that transports those back in their positions those types of solutions are more complex which makes their cost higher.

The topic's main propose is to analyse and select the best options from the market solutions for weldment storage before milling.

ProFeeder Compact (Figure 26) is a one-of-a-kind machine that is equipped with compact dimensions and is easily movable around the production facility. ProFeeder Compact takes less space in the factory and supports mass production [20].
The Profeeder Compact has the following features [20]:

- Mechanical locking system or Air locking system;
- Footprint dimension. L610*W860*H1084mm;
- Holds up to 10 trays;
- GD wheels to transport parts (can be mounted optionally);
- Optional Docking station;
- Optional EasyPedestal for Robot Arm and controller compartment;
- Air locking is running Modbus;
- The trays can be customized depending on the requirements.

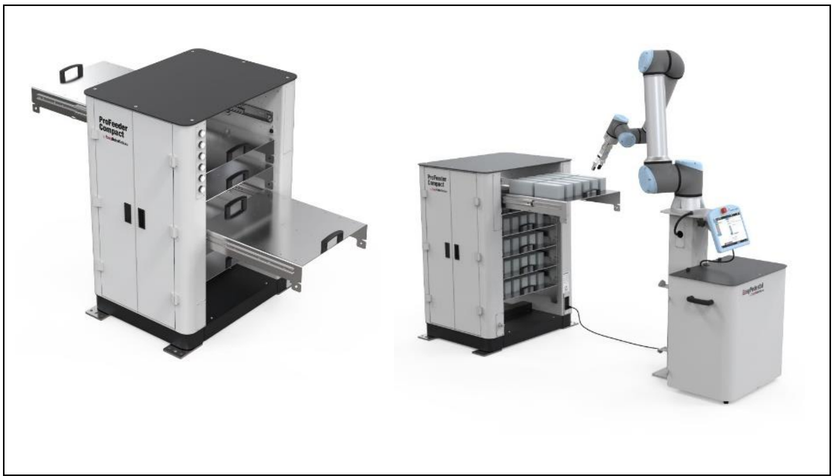


Figure 26. Storage system – ProFeeder Compact [21].

8.1 Robot selection process

This topic will be describe different scenarios for when the robot selection depends on the type of task.

It should be clear if the robot serves only one machine or if it has to move between different machines and perform multiple tasks. The third question is about already existing robots, maybe some of the robots in the industry are not fully occupied and it is possible to implement those into the new manufacturing processes. It helps to increase the efficiency and reduce the system payback period.

It is well known that industrial robots are more complex to program and their price may be higher, compared with COBOTS. Based on this for basic tasks it is cheaper and more reasonable to choose a COBOT instead of industrial robot. For complex tasks you should use industrial robots, because they have higher have higher work capacity and higher robot movement speeds.

Robot selection starts by defining the type of work that the robot should be able to perform. The next step is to define the criteria of the task that the robot must be able to perform. After that, when the important criteria are defined, it is important to go over the needed characteristic for the robot (Table 32).

Table 32. Needed characteristics of the robot

Robot payload	4kg (billet max weight 1.2kg).When using a robot with an insufficient payload, the task performing is not possible. (robot tool weight should be considered)
Robot reach	900-1500mm The robot must be able to pick up the part from the storage drawer and then place it in the jig of the CNC milling machine
Speed, acceleration	500 mm/s
Positioning accuracy	+/- 0.1 mm
Integration with other devices	A robot should be connectable to a different device: marking device, CMM, CNC mill, etc.
Accuracy of movements	It is important to pick the billets up and then place them in the jig, positioning accuracy doesn't need to be very high.
Maintenance	Maintenance required, support and service should be quick.

If the criteria and characteristics of the robot are defined then there will be a comparison between different types of robots that stay into the defined criteria and characteristics (Table 33).

Table 33. Comparison of suitable robots

	RETHINK (SAWYER)	**MABI (SPEEDY10)**	**FANUC (CR-35IA)**	**UNIV. ROBOTS (UR10)**	**DOBOT (CR10)**
REACH (MM)	1260 mm	1384,5 mm	1813 mm	1300 mm	1525 mm
PAYLOAD (KG)	4 kg	10 kg	35 kg	10 kg	10 kg
NO OF CONTROLLED AXES	7 axes	6 axes	6 axes	6 axes	6 axes
MOVEMENTS SPEED (M/S)	1,5 m/s	1 m/s	1,5 m/s	1 m/sec	4 m/s
REPEATABILITY (MM) (ISO 9283)	+/- 0,1 mm	+/- 0,1mm	+/- 0,03 mm	+/- 0,1 mm	+/- 0,03 mm
PRICE	**26 000€**	47 000€	35 000 €	35 000 €	24 000€

Based on the comparison of the suitable robots, the robot is selected based on the needed characteristics and then by price. Based on the comparison, the best choice is the Rethink Sawyer cobot. It has the required reach, payload and speed.

In larger organizations it is necessary to overcheck, if there are robots already bought which are not used efficiently. It may be possible to use those robots for tasks they are more suited for.

As an example, there is access to an already existing and not often used Omron COBOT (Omron TM5-900), that has a part detection camera and robot operation software. Using that changes the need to buy another robot. Through this, it is possible to test billets grabbing and placing in real-life scenarios. To see how the gripper should be designed or if the standard gripper is enough to perform the needed billet movements.

In cases where the robot must operate multiple machines, it can do so through an external linear axis. However, it is necessary to consider investing in industrial robots. Their payload capacity is higher and most importantly the robot's reach is larger. It ensures that there is more free reach which allows the use of higher speeds and different equipment. If the robots reach is insufficient then it may cause unexpected problems.

One of the industrial robots examples is FANUC ARC Mate 100iD/8L. The robot's main parameters are 2032 mm reach and a load capacity of 8 kg **(**Appendix 6). It occupies a small area and can be installed upside down or angle mounted for even more flexibility. The long-arm robot comes with a fully integrated hose pack and cable management system. For easy and reliable routing of sensor or camera cables, air pipes and other utilities, services are routed through the robot’s hollow arm, wrist and body [26].

8.2 End of arm tooling selection for the robot

The robot's task is to pick billets from the storage area and then place those into the jig of the CNC milling machine. The gripper then takes the part out, rotates it and places it back in the jig. When it is done then the part is removed from the milling machine and placed into the storage area or if needed in a CMM or the marking device.

For the end of arm tooling (EOAT) selection, it is important to define the types of objects and their parameters, it is important to perform successful picking and placing operations.

A robots gripper should be able to lift all types of specimens. Selection is based on the specimen billet dimensions. Specimen minimal width is 4 mm and the maximum is 32 mm. Based on this data the selected type of gripper should be something, that can pick objects in the previously mentioned 4 and 32 mm range.

The next step is to describe the requirements of the type of object (Table 34)

Table 34. Requirements for the robot picking and placing

REQUIREMENT	PARAMETER	EXPLANATION
Positioning accuracy	+/- 0,1mm	Accuracy is necessary to place components in the jig
EOAT nature	Quick change is useful but not very necessary	The product types are the same, there is no need for a different type of end-effector
Speed the movements of EOAT	Speed is necessary to consider	The range of motion is wide, and the robot can move quite fast. Most of the time will be spent on the detection of the components and positioning the jig location and after that placing it there.
Acceleration	Average	If the billet is picked up, then it is possible to accelerate at maximum speed back to the new component detection. The COBOT safe speeds are overwritten (more than 250mm/s)
Safety	No specific conditions	COBOT functions as a cobot are turned off, safety is ensured by restricting the work area with fences which means it is also possible to use industrial robots.

After defining the requirements, an analysis is conducted which helps to evaluate different gripper types and then select the best option for the gripper (Table 35).

Table 35. Gripper selection I / Type of grippers

Parameters	2-fingers	3-Fingers	Multiple fingers	Vacuum	Magnetizing
Gripping force	5	5	5	2	2
Part indexing	5	4	4	5	5
Repeatability	4	4	3	4	4
Endurance	4	4	3	2	4
Compactness	4	3	1	5	4
ESTIMATION	**22**	20	16	18	19

The evaluation score estimates that the best option is to select 2 finger gripper. The next step is to evaluate which type of gripper driver should be selected. Considering the gripping force, endurance, setting complexity, system compactness, ease of maintenance and the price (Table 36).

Table 36. Gripper selection II / Gripper drive

Criteria	Pneumatics	Hydraulics	Electro-mechanics	Electro-Magnet (Magnetic materials)
Gripping force	3	5	4	4
Endurance	3	3	5	4
Setting complexity	3	3	4	3
System compactness	3	2	5	5
Ease of maintenance	3	2	5	2
Price	5	3	4	3
ESTIMATION	20	18	**27**	21

Based on the evaluation score, the best option is to select the electro mechanically working gripper. The next step is to analyse possible grippers (Table 37).

Table 37. Parametric Comparison of grippers

Criteria	OnRobot RG2	Robotiq 2F-85	Schunk PG70
Maximum gripping force (N)	40 N	230N	200N
Range movement of the gripper elements (mm)	110 mm	85 mm	140mm
The speed of movement of the gripper elements (mm/s)	55 mm/s	150 mm/s	82 mm/s
***Price**	3600 €	4600 €	2800 €

The next step is to select some of the grippers from the market that fit the required task performing criteria. After that, another grippers evaluation to select the best choice is performed (Table 38).

Table 38. Gripper selection matrix

	Universal robots RG2	Robotiq 2F-85	Schunk PG70
Technical support	4	4	4
Spare parts available	5	5	3
Gripping time	3	5	4
Price	3	2	3
RESULTS	15	**16**	14

Based on the evaluation score the best choice is the Robotiq 2F-85 gripper (Figure 27).

Figure 27. ROBOTIQ Grippers [27]

On the ROBOTQ grippers, it is possible to replace the gripper plates with custom ones to achieve a stronger gripping effect.

SUMMARY

The first chapter of the Master’s thesis introduces the processes of preparing the specimens in the TalTech Metrology Laboratory. Analysis was conducted regarding the current state of test specimen preparation. The author measured the time taken to prepare the test specimens in the workshop and monitor the various performed processes.

In the following chapters, the possibility for automation was analyzed. The risks associated with automation were assessed and the basic requirements of the system were defined. After that, analysis of the various system components was conducted to find a suitable solution. Different solutions from separate system parts were analysed, as well as the complete solutions available on the market to produce automated products.

The author also came up with possible concepts for jigs so that the welded specimens could be mounted in the CNC mill as efficiently as possible by the robot and another type of jigs for operator-based CNC mills. The specificity of the test specimens was considered, which was a variable angle due to the thermal effect caused by weldment.

After that, various possible concepts of how the system could be created were described. It was later evaluated which of the solution is the most suitable. As a result of the research, it turned out that the most suitable automated solution would consist of the Haas VF-2YT milling machine and the accompanying Haas robot set, with a safety package. When selecting a storage system, it turned out that the most suitable storage system solution is a ready-made solution created by Profeeder Compact. Based on the research the chosen option for automation is to only select Haas VF-2YT mill. Which enables to mill multiple specimens in mill using operator to feed the machine. Results are showing that the new selected CNC mill is more efficient.

The author also suggested a possible educational testing solution. The proposed solution is to use an existing CNC machine and robot to test the system in real life. In this process, the suitability of the jigs can be tested. It enables to use of robot tending in study processes to see how well is the process programmable even if it is not used in the real specimens preparation process.

The results of the analysis show that with the new solution, the processing efficiency will increase by 44%. The main efficiency gains come from the shorter set-up time and the use of higher milling speeds in the milling centre.

The break-even point calculation showed that the expected payback period for the new solution alone is 3 years for the production of test specimens. Increasing the workload of making use of the concept machine's idle times, it is possible to manufacture other standard components, and then the payback period decreases.

As a continuation of this master's thesis, it is possible to continue with the implementation of the solutions proposed by the author and the development of various system parts. Before acquiring the real solution and afterwards accelerating the implementation of the real solution.

KOKKUVÕTE

Magistritöö esimestes peatükkides tutvustati TalTech Metoroloogia katselaboris läbiviidavate purustavate katsekehade ettevalmistamist, katsetuste läbiviimiseks, millele järgnes katsekehade valmistamise hetkeseisundi analüüs. Selleks mõõtis töö autor töökojas toimuvate katsekehade valmistamisele kulunud aegu ja jälgis erinevaid läbiviidavaid protsesse.

Järgnevates peatükkides analüüsiti automatiseerimise võimalikust, hinnati automatiseerimisega kaasnevaid riske ja defineeriti süsteemi põhinõudeid. Peale seda toimus erinevate automatiseerimiseks vajalike süsteemiosade analüüs parima lahenduse leidmiseks.

Automatiseeritud töödeldavate katsekehade valmistamiseks, analüüsiti nii erinevatest eraldiseisvatest süsteemiosadest kokkupandavaid lahendusi kui ka turul olemasolevaid terviklahendusi.

Autori poolt käidi välja ka võimalikud rakiste kontseptsioonid, keeviskatsekehade rakistamiseks roboti poolt kui ka operaatori abil kinnitatavad rakised. Seejures võeti arvesse katsekehade eripära, milleks oli keevisõmbluse poolt tekitatud termomõju tõttu muutuv nurk.

Peale seda kirjeldati erinevaid võimalike kontseptsioone, kuidas saaks efektiivsemat osaliselt või tervenisti automatiseeritud süsteemi luua ja hiljem hinnati, milline lahendus sobiks kõige paremini. Uurismustöö tulemusel selgus, et kõige paremini sobiv lahendus koosneks freespingist Haas VF-2YT ja sinna juurde kuuluvast Haasi robotikomplektist, koos turvalahendusega. Laosüsteemi valikul selgus, et kõige sobivam laosüsteemi lahendus on Profeeder Compacti poolt loodud valmislahendus.

Töö autor tõi välja ka võimaluse kasutada automatiseeritud lahendust õppetöös. Õppetöös on võimalik kasutada robotit ja CNC pinki, et praktiseerida programmeerimist ja näha seeläbi eluliselt kui keeruline see olla võib. Kasutades olemasolevaid seadmeid on võimalik testida robotlahendusele vajalike rakiseid ilma terviksüsteemi olemasolu.

Analüüsitulemustest selgus, et uue lahenduse kasutuselevõtmisega kasvab töötlusefektiivsus 44%. Peamine efektiivsuse kasv tuleb lühemast seadistamisele kuluvast ajast ja suurematest võimalikest lõikeparameetrite kasutamise võimalikusest.

Tasuvusarvutusest selgus, et uue lahenduse kasutuselevõtmisel on eeldatav tasuvusaeg katsekehade valmistamisel 3 aastat. Kui süsteemi ooteaegadel, mil puuduvad katsekehad valmistatakse midagi mud siis süsteemitasuvusaeg on veelgi kiirem.

Magistritöö leiab välja suurema tootlikusega lahenduse katsekehade tootmiseks ning uued võimalikud rakised katsekehatoorikute töötlemiseks CNC pingis. Käesoleva magistritöö jätkuna on võimalik jätkata autoripoolt väljapakutud lahenduste elluviimisega ja erinevate süsteemiosade arendamisega, enne pärislahenduse hankimist ja mis kiirendab hiljem pärislahenduse töösse rakendamist.

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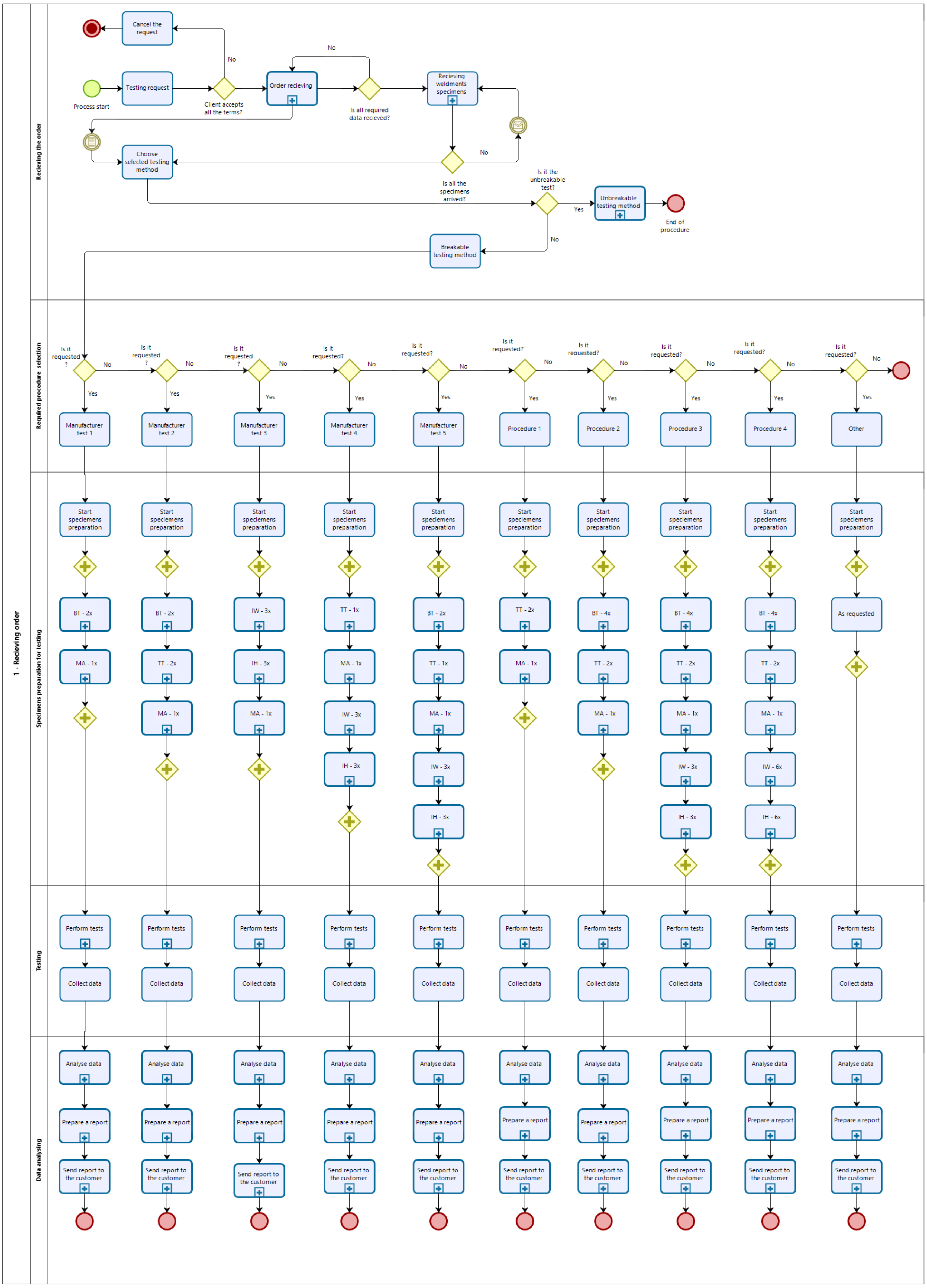
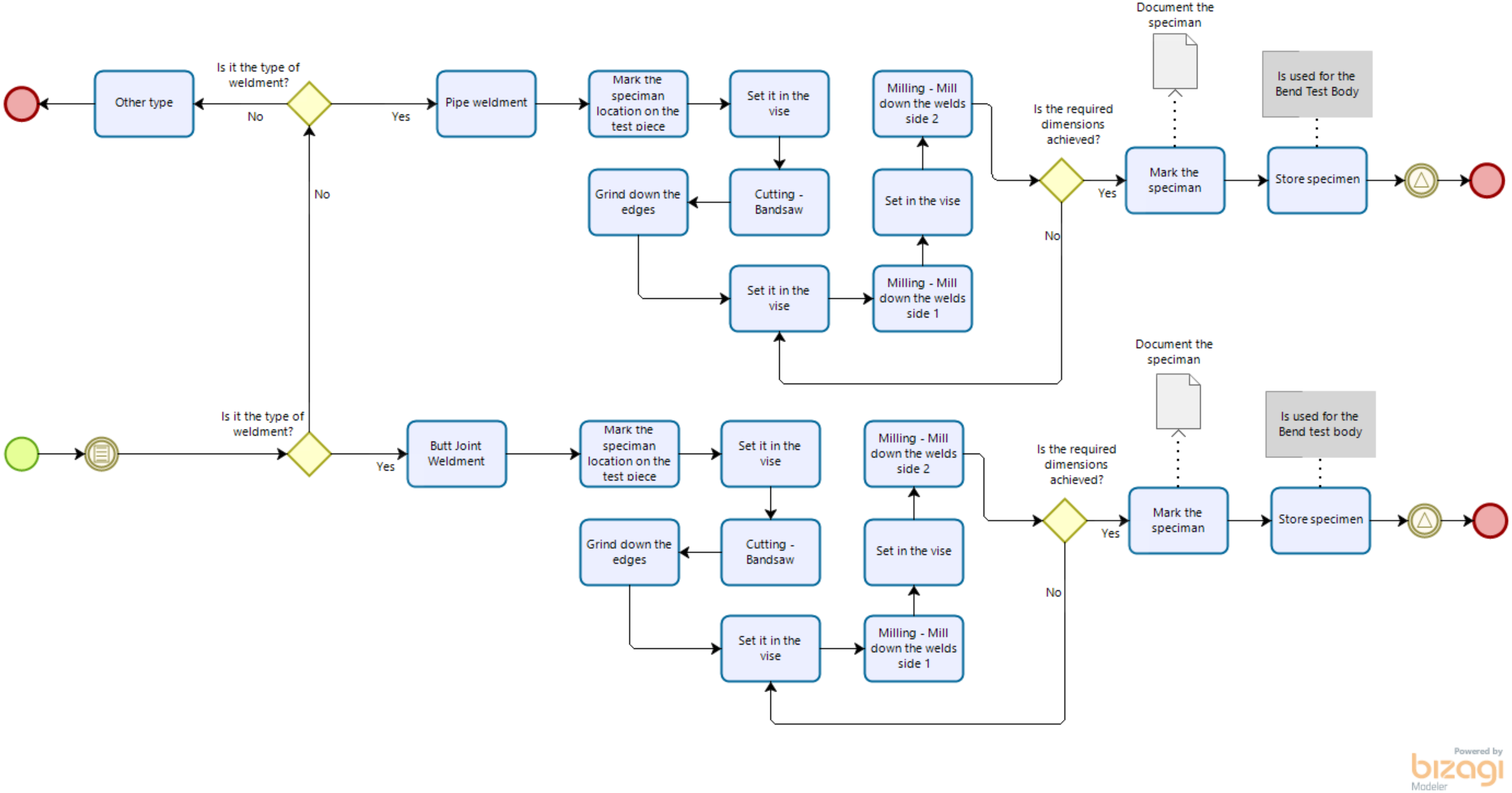
APPENDICES

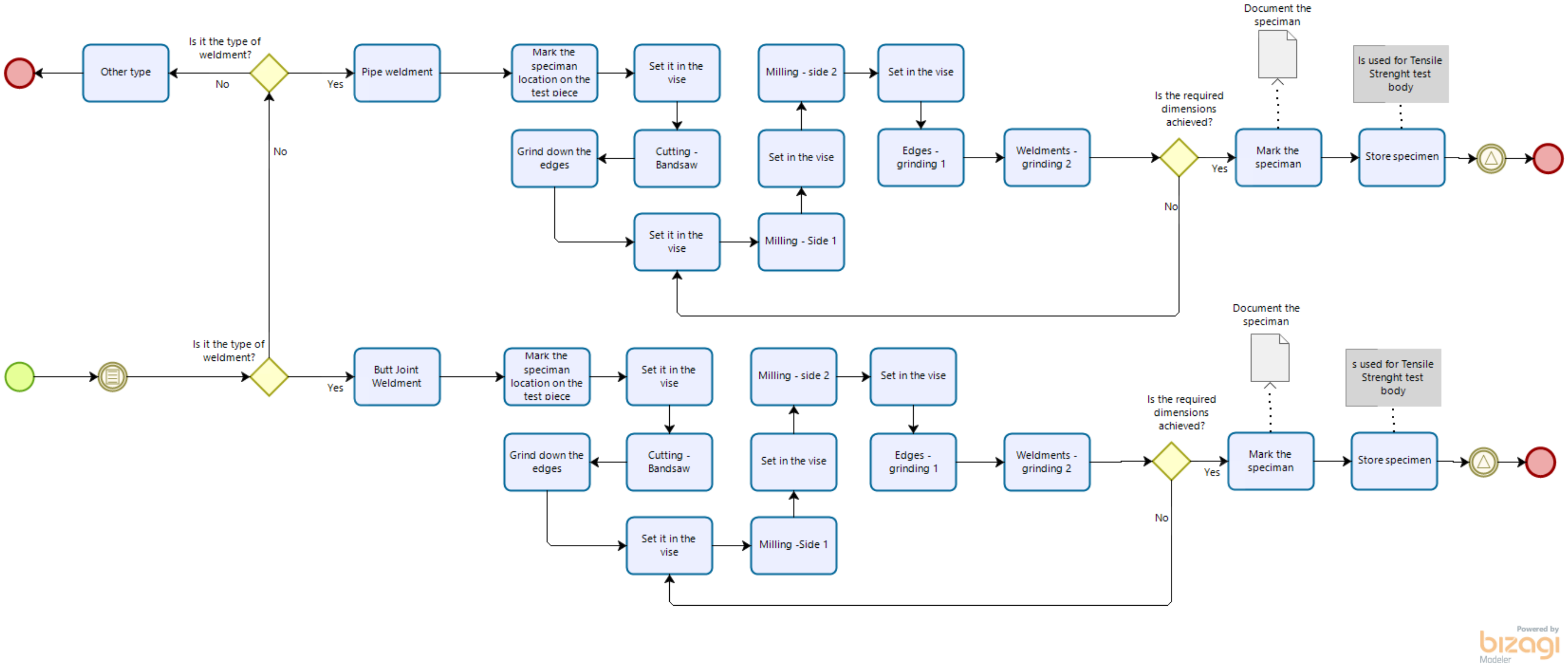
Appendix 1: General Process



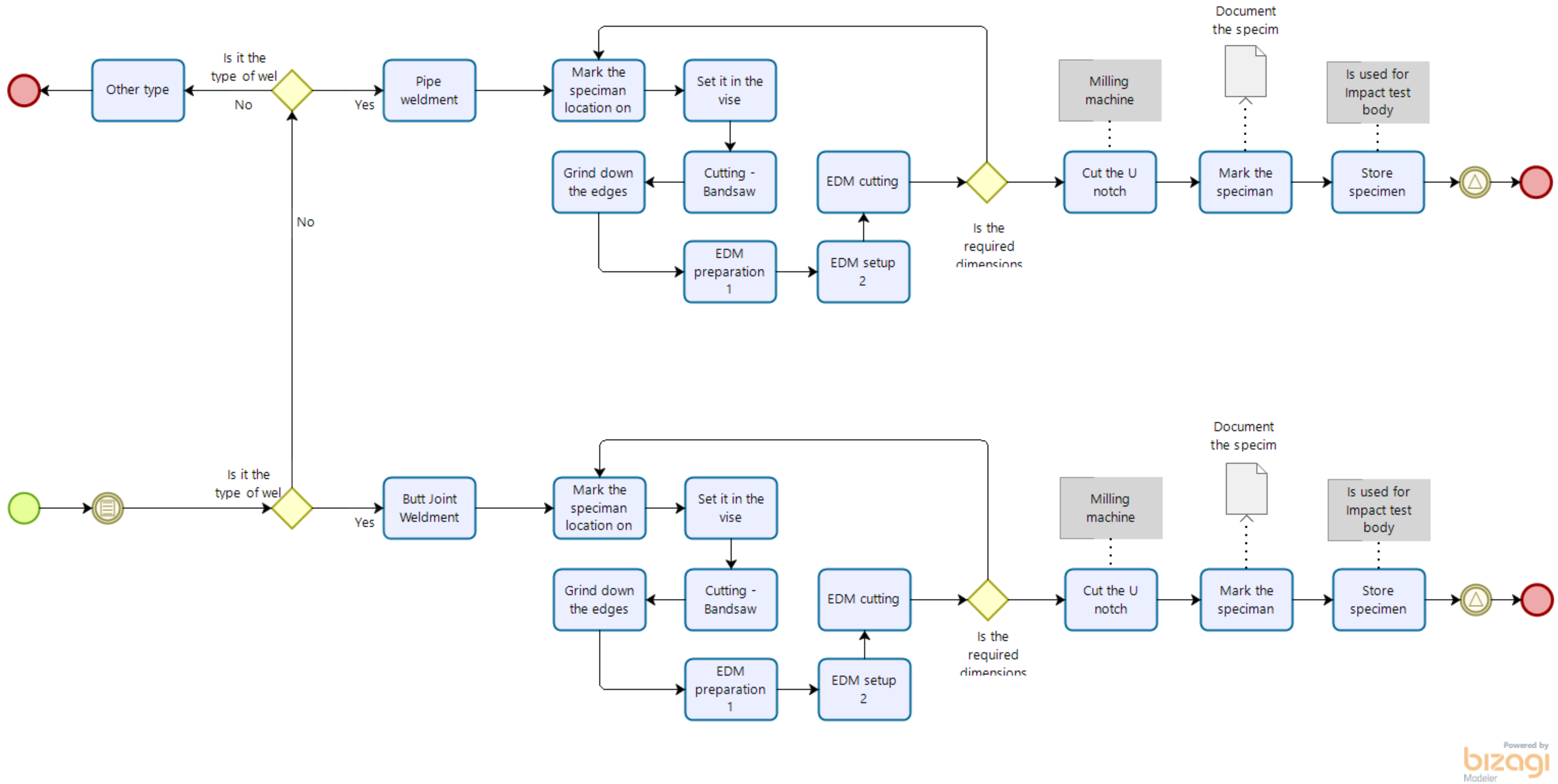
Appendix 2: Bend Test body (BT) preparation process



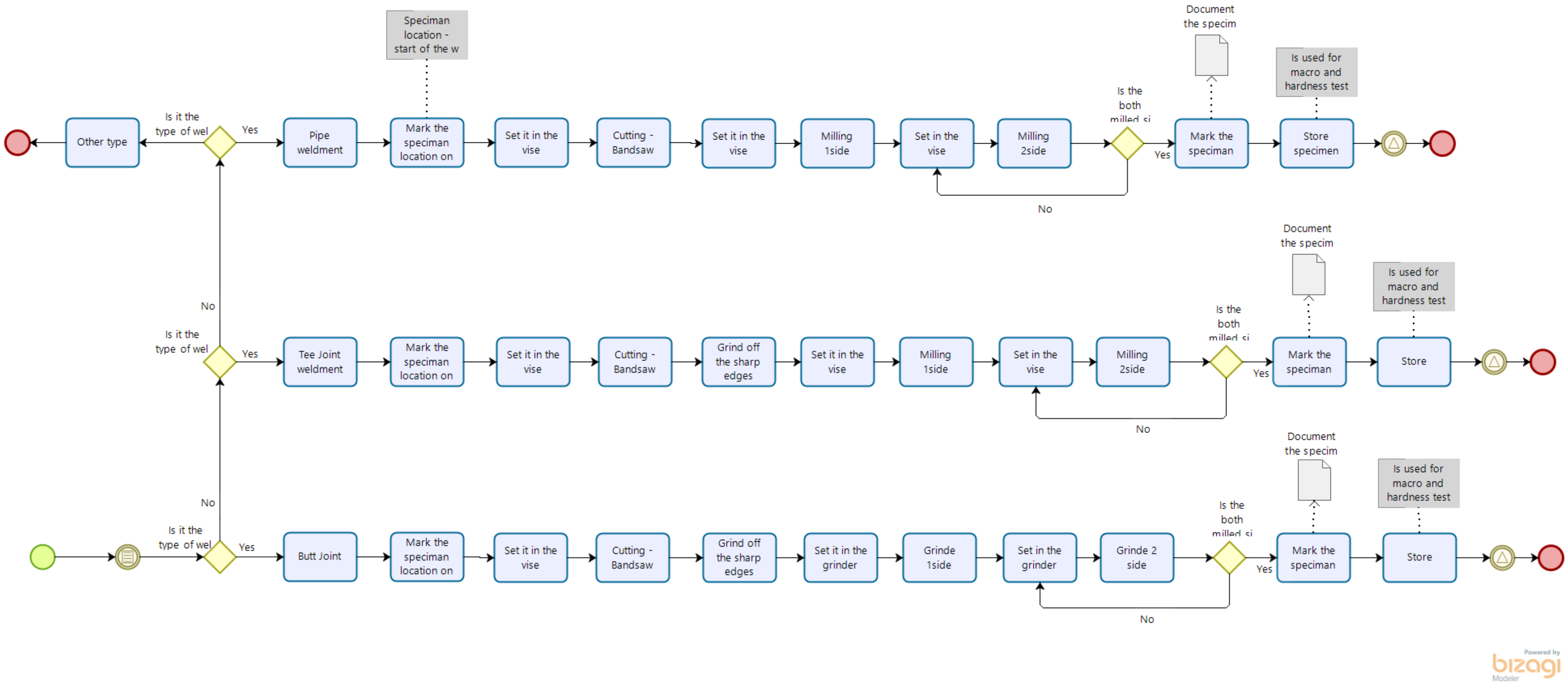
Appendix 3: Tensile Strenght Test Body (TT) preparation



Appendix 4: IW and IH Impact Test Body preparation



Appendix 5: Macro Test piece preparation cycle times on Pipe, Tee Joint and Butt Joint



Appendix 6: Haas VF-2 standard features and additional feature

FEATURES	SHORT DESCRIPTION	PRICE
CNC MILL		
HAAS VF-2		49 995€
STANDARD FEATURES IN VF-2		
SPINDLE:		
8100-RPM SPINDLE	30 hp (22.4kW) vector drive, inline direct-drive; provides a good combination of low-speed torque and high rpm for all-purpose machining work.	
TOOL CHANGER:		
20-POCKET CAROUSEL TOOL CHANGER	20-Station Automatic Tool Changer; this carousel-style tool changer is an economical choice for cost-conscious shops.	
CHIP & COOLANT MANAGEMENT		
WINDOW AIR BLAST	Haas Window Blast; airgun-activated feature for clearing coolant from the machine's window during machining.	
55-GALLON COOLANT TANK	55-Gallon (208 liter) Coolant Tank with 1 hp (0.75 kW) pump; flows 12 gpm @ 30 psi (45 L/min @ 2 bar) @ 60 Hz, and features a multi-section labyrinth design that prevents chips from reaching the coolant pump.	
VARIABLE FLOW COOLANT	Variable Flow Coolant Pump, allows control of the flood coolant flow and pressure via M-code P values.	
THE HAAS CONTROL		
CONTROL TOUCH SCREEN	Touch Screen interface for the Haas control; allows screen navigation, data entry, and other control functions on-screen, without using the keypad.	
MEDIA DISPLAY M-CODE; M130	Media Display M-Code; M130 is used within an NC program to call up media files (images, videos, PDF files) from memory and display them on the control screen as the program runs. NextGen Control only.	
HAASCONNECT: REMOTE MONITORING	HaasConnect: Remote monitoring of your Haas machine. Requires the machine to be connected to the Internet.	
EARLY POWER-FAILURE DETECTION MODULE	Early Power-Failure Detection Module; senses a power failure or severe drop in incoming line voltage and quickly brings all axis motion to a safe and controlled stop.	
ETHERNET INTERFACE	Ethernet Interface; allows you to easily transfer files to and from the machine over a local wired network.	
WIFI CONNECTION FOR THE HAAS CONTROL	WiFi Connection for the Haas Control; provides wireless connectivity between the Haas control and a local area network.	
SAFE RUN	Safe Run; a software feature in the Haas control that reduces the chances of significant machine damage during a machine crash.	
HAASDROP	HaasDrop Wireless File Transfer is a fast and convenient method for sending images, videos, and even program files from a mobile device directly to the Next-Generation Control on a Haas CNC machine. Available for Android and iOS devices.	
RIGID TAPPING	Rigid Tapping; synchronized tapping, with built-in tap cycles and up to 8X retract speed.	
STANDARD PROGRAM MEMORY, 1 GB	Standard Program Memory; 1 GB of onboard memory for program storage and backup.	
WARRANTY		

1-YEAR STANDARD WARRANTY	1-Year Standard Warranty. Haas products carry a full 1-year warranty on the entire machine, including the control – that’s 365 days x 24 hours.	
ADDITIONAL FEATURES		
ADDITIONAL AXIS		
4TH-AXIS DRIVE AND WIRING	Fully integrated to the Haas Control; Reduces setups, increases accuracy, and increases throughput; Allows simple plug-n-play installation of a Haas rotary table or indexer	2595 €
PROBING		
WIRELESS INTUITIVE PROBING SYSTEM	Wireless Intuitive Probing System; Renishaw. Includes the Haas Visual Programming System, macros, spindle orientation, and coordinate rotation and scaling.	4759 €
PROBE RISER BLOCK	Probe Riser Block; provides additional height for the tool probe when using extended clearance options, tall fixtures, or rotary tables.	395 €
CHIP & COOLANT MANAGEMENT		
AUTOMATIC AIR GUN	Automatic Air Gun; provides a constant air blast to clear chips during dry machining.	1195 €
CHIP AUGER	Chip Auger; automatically removes chips from the machine, while compressing them and wringing out the coolant.	3095 €
THE HAAS CONTROL		
CNC CONTROL CABINET COOLER	CNC Control Cabinet Cooler; reduces the internal temperature of the control cabinet to boost reliability and increase component life No external power required.	1695 €
64 GB EXPANDED MEMORY	64 GB Expanded Memory; allows you to store large programs and media files on the machine, eliminating the need for an external storage device.	1895 €
8 SPARE M FUNCTIONS	8 Spare M Functions; provides 8 additional M-code relays for activating other devices.	1495 €
PRODUCT OPTION		
HIGH-INTENSITY LIGHTING, 24V	High-Intensity Lighting; externally mounted LED lights that turn on/off automatically with the machine doors, or manually via switch.	895 €
WIFI CAMERA	WiFi Camera; fully enclosed camera that mounts inside the machine enclosure, allowing remote viewing of machining operations via WiFi.	595 €
PROGRAMMABLE AIR	Programmable Air; m-code activated air supply that allows users to operate pneumatic devices on their machine, directly from the Haas control	995 €
AUTO DOOR FOR MILLS	Auto Door for Mills; opens and closes the machine doors automatically via M-code, or manually via a switch.	1795 €
WORKHOLDING		
***150 MM AIR VISE**	150 mm Air Vise; self-centering pneumatic vise with 150 mm jaws. Includes one set of hardened-steel jaws, with 45° dovetail and serrations. Requires the Air Vise Ready option (UMCs), or Programmable Air	3095 € (not included in total price)
5" HAAS PROGRAMMABLE ELECTRIC VISE	5" (127 mm) self-centering, programmable electric vise is fully integrated with the Haas control, NOTE: Requires the E-Vise Ready option.	3000 €
WARRANTY		
1-YEAR EXTENDED WARRANTY	1-Year Extended Warranty (includes 1-year standard warranty); adds another full year to your warranty, parts and labor.	1895 €
	CNC Mill Additional Options:	28 689€
	CNC Mill and Additional Options Total Price:	78 684€

ROBOT PACKAGE OPTION FOR HAAS		67 995€
THE HAAS CONTROL		
ROBOT	6-axis	
REMOTE E-STOP	E-Stop Button allows you to instantly stop all robot and machine motion in the event of an emergency. Mounts to the safety guard fencing of the Haas Robot Package.	
SAFETY GUARD FENCING	Safety Guard Fencing for the Haas Robot Packages.	
SINGLE GRIPPER	Single Gripper for Haas Robot Package-1	
ROBOT-2 INSTALLATION KIT, ST-20 TO ST-35	Includes all necessary items to install a Haas Robot Package.	
CUSTOM OPTION		
PART FLIPPING STATION	Place and regrip parts for flipping	295€
	Robot Total Price:	68 290€
	Robot and CNC mill Total Price:	151 664€

Appendix 7: Haas VF-2YT parameters

VF-2YT		
TRAVELS	**S.A.E.**	**METRIC**
X Axis	30 "	762 mm
Y Axis	20 "	508 mm
Z Axis	20 "	508 mm
Spindle Nose to Table (~ max)	24 "	610 mm
Spindle Nose to Table (~ min)	4 "	102 mm
TABLE	**S.A.E.**	**METRIC**
Length	36 "	914 mm
Width	18 "	457 mm
T-Slot Width	5/8 "	16 mm
T-Slot Center Distance	4.92 "	125 mm
Number of Std T-Slots	3	3
Max Weight on Table (evenly distributed)	3000 lb	1361 kg
SPINDLE	**S.A.E.**	**METRIC**
Max Rating	30 hp	22.4 kW
Max Speed	8100 rpm	8100 rpm
Max Torque	90 ft-lb @ 2000 rpm	122 Nm @ 2000 rpm
Drive System	Inline Direct-Drive	Inline Direct-Drive
Max Torque w/opt Gearbox	250 ft-lb @ 450 rpm	339 Nm @ 450 rpm
Taper	BT or CT 40	BT or CT 40
Bearing Lubrication	Air/Oil Injection	Air/Oil Injection
Cooling	Liquid Cooled	Liquid Cooled
FEEDRATES	**S.A.E.**	**METRIC**
Rapids on X	1000 in/min	25.4 m/min
Rapids on Y	1000 in/min	25.4 m/min
Rapids on Z	1000 in/min	25.4 m/min
Max Cutting	650 in/min	16.5 m/min
AXIS MOTORS	**S.A.E.**	**METRIC**

VF-2YT		
Max Thrust X	2550 lb	11343 N
Max Thrust Y	2550 lb	11343 N
Max Thrust Z	4200 lb	18683 N
TOOL CHANGER	**S.A.E.**	**METRIC**
Type	Carousel (SMTC Optional)	Carousel (SMTC Optional)
Capacity	20	20
Max Tool Diameter (full)	3.5 "	89 mm
Max Tool Weight	12 lb	5.4 kg
Tool-to-Tool (avg)	4.2 sec	4.2 sec
Chip-to-Chip (avg)	4.5 sec	4.5 sec
GENERALS	**S.A.E.**	**METRIC**
Air Required	4 scfm, 100 psi	113 L/min, 6.9 bar
Coolant Capacity	55 gal	208 L

Appendix 8: Hydro Pneumatic Booster Cylinder Datasheet [28]

BOOSTERS SERIES MHB

STRÁNSKÝ A PETRŽÍK

Boosters series MHB are used for generating of high pressure of hydraulic oil by air with common pressure. They are designed to save energy, time, space and money in wide variety of applications. These abilities and benefits of power cylinders make them ideal component in many applications, you can use them for such operation as marking, forming, punching riveting, shearing, stearing, straightening, and so on.

For more information, please visit our web page on www.sappv.cz .

Working pressure	0,2 to 0,7 MPa
Temp. range	+5°C to +60°C
Working medium	modified compressed air
Installation	horizontal

Type	078	110	250
Intensified pressure ratio	7,8	11	25
Max. oil pressure at air pressure 0,7 MPa [MPa]	5,3	7,6	17,2
Max. discharged oil volume at high pressure [ml]	50	120	120
Recommended oil	hydraulic petroleum oil ISO 68		

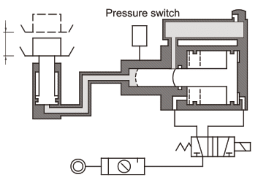
Order codes

P MHBD 110

Booster	
MHBS	single pressure 
MHBD	double pressure 

Type	
078	ratio 7,8x
110	ratio 11x
250	ratio 25x

Operating principle
of single pressure booster MHBS



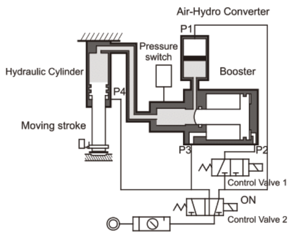
Booster can be used for short stroke hydraulic cylinders, for which is volume discharged by booster sufficient. In this case, any 5/2 valve can be used for control of booster and hydraulic cylinder, which copy the movement of booster.

Notice
- booster must be levelled
- booster must be placed higher than hydraulic cylinder
- frequency of use should be 6 times/min or lower

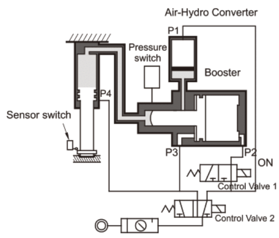
For more information, please visit our web page on www.sappv.cz .

Operating principle
of double pressure booster MHBD

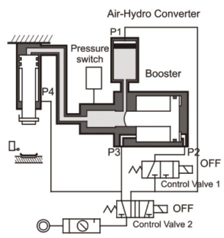
This type of booster is used for applications, where the auxiliary stroke with low force and working short stroke with big force is needed. Working stroke then conform to the oil volume, which is discharged by booster. Auxiliary stroke depends on volume of external air-hydro converter (which isn't in the supply).



Quick traverse
When the air is charged from the port P1, the oil in the tank will forward the hydraulic cylinder quickly. The pressure is the same as the air pressure, but the inflow of oil is large in volume.



Intensified feeding
When the air is charged from the port P2, a ram will advance. the highly pressured fluid will come in to the hydraulic cylinder which will be forwarded by large thrust.



Swift release
When the air is send into port P4 and P3. the hydraulic cylinder is swiftly reversed. and at the same time the ram goes back.

Appendix 6: ARC MateiD/8L

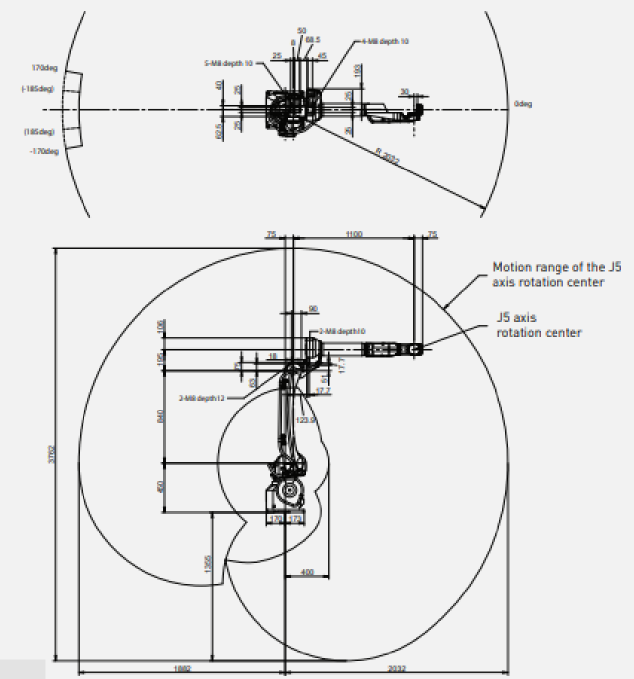
ARC Mate 100*i*D/8L

Max. load capacity at wrist: **8 kg**

Max. reach: **2032 mm**

Controlled axes	Repeatability (mm)	Mechanical weight (kg)	Motion range (°)						Maximum speed (°/s)						J4 Moment/ Inertia (Nm/kgm2)	J5 Moment/ Inertia (Nm/kgm2)	J6 Moment/ Inertia (Nm/kgm2)
			J1	J2	J3	J4	J5	J6	J1	J2	J3	J4	J5	J6			
6	± 0.03*	180	340 (370)	235	455	380	360	900	210	210	220	430	450	720	16.1/0.63	16.1/0.63	5.9/0.061

Working range



Motion range may be restricted according to the mounting angle!

Robot	**ARC Mate 100*i*D/8L**
Robot footprint [mm]	343 x 343
Mounting position Floor	•
Mounting position Upside down	•
Mounting position Angle	•
Controller	**R-30*i*B Plus**
Open air cabinet	-
Mate cabinet	o
A-cabinet	•
B-cabinet	o
*i*Pendant Touch	•
Electrical connections	
Voltage 50/60Hz 3phase [V]	380-575
Voltage 50/60Hz 1phase [V]	-
Average power consumption [kW]	1
Integrated services	
Integrated signals on upper arm In/Out	1/1
Integrated air supply	1
Environment	
Acoustic noise level [dB]	57.4
Ambient temperature [° C]	0-45
Protection	
Body standard/optional	IP54
Wrist & J3 arm standard/optional	IP67

Appendix 7: Detailed results from simulations

Cycle Times		
Cutting in Bandsaw (2 Saws = 2 Billets):	**32**	min
Setup Time:	**19**	min
Edges Grinding (1 Grinder):	**1**	min
Operator 1 (Bandsaw):	**52**	min
Operator 2 (Storing/setup Robot Cell (x5):	**2**	min
1. Robot Cell Setup Time:	**2**	min
1.1 Robot Movements:	**0,5**	min
2. CNC Milling in the Robot Cell:	**29**	min
2.1. Robot Movements:	**0,5**	min
3. Measuring in the CMM:	**3**	min
3.1 Robot Movements:	**0,5**	min
4. Laser Marking:	**1**	min
4.1 Robot Movements:	**0,5**	min
(Billets cutting Cycle Time) Total:	**52**	min
(Robot Cell Cycle time)Total:	**36,5**	min
(Robot Movements Cycle Time)Total:	**2**	min
Lead Time:	**90,5**	min

Production Rate		
Final Product Production Rate:	**0,93**	Pcs/h
Final Product Production Rate:	**43,0**	Pcs/week
Final Product Production Rate:	**1897,674**	Pcs/year

Equipment and Personnel Yearly usage %		
Bandsaw (2):	**63,9**	%
CNC Mill:	**48,3**	%
CMM:	**5,0**	%
Laser Marking Device:	**0,9**	%
Operator 1 (Bandsaw):	**70,0**	%
Operator 2 (Robot Cell):	**14,4**	%

Equipment and Personnel Yearly Idle Time %		
Bandsaw:	**36,1**	%
CNC:	**51,7**	%
CMM:	**95,0**	%
Laser Marking Device:	**99,1**	%
Operator 1 (Bandsaw):	**30,0**	%
Operator 2 (Robot Cell):	**85,6**	%

Appendix 8: Concept 2 Detailed results from simulations

Cycle Times		
Cutting in Bandsaw (2 Saws = 2 Billets):	32	min
Setup Time:	19	min
Edges Grinding (1 Grinder):	1	min
Operator 1 (Bandsaw):	52	min
Operator 2 (Storing/setup Robot Cell (x10):	1	min
1. Robot Cell Setup Time:	1	min
1.1 Robot Movements:	0,5	min
2. CNC Milling:	29	min
2.1. Robot Movements:	0,5	min
3. Measuring in the CNC mill:	3	min
3.1 Robot Movements:	0,5	min
4. Serial Number Engraving:	1	min
4.1 Robot Movements:	0,5	min
(Billets cutting Cycle Time) Total:	52	min
(Robot Cell Cycle time)Total:	35,5	min
(Robot Movements Cycle Time)Total:	2	min
Lead Time:	89,5	min

Production Rate		
Final Product Production Rate:	0,94	Pcs/h
Final Product Production Rate:	42,3	Pcs/week
Final Product Production Rate:	1927,559	Pcs/year

Equipment and Personnel Yearly usage %		
Bandsaw (2):	63,9	%
CNC Mill:	48,3	%
Operator 1 (Bandsaw):	70,0	%
Operator 2 (Robot Cell):	12,2	%

Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	36,1	%
CNC Idle Time:	51,7	%
Operator 1 (Bandsaw):	30,0	%
Operator 2 (Robot Cell):	87,8	%

Appendix 9: Concept 3 Detailed results from simulations

Cycle Times		
Cutting in Bandsaw (2 Saws = 2 Billets):	32	min
Setup Time:	19	min
Edges Grinding (1 Grinder):	1	min
Operator 1 (Bandsaw):	52	min
Operator 2 (Storing/setup Robot Cell (x10):	1	min
1. Robot Cell Setup Time:	1	min
1.1 Robot Movements:	0,5	min
2. CNC Milling:	29	min
2.1. Robot Movements:	0,5	min
3. Measuring in the CNC mill:	3	min
3.1 Robot Movements:	0,5	min
4. Serial Number Engraving:	1	min
4.1 Robot Movements:	0,5	min
(Billets cutting Cycle Time) Total:	52	min
(Robot Cell Cycle time)Total:	35,5	min
(Robot Movements Cycle Time)Total:	2	min
Lead Time:	89,5	min

Production Rate		
Final Product Production Rate:	0,94	Pcs/h
Final Product Production Rate:	42,3	Pcs/week
Final Product Production Rate:	1927,559	Pcs/year

Equipment and Personnel Yearly usage %		
Bandsaw (2):	63,9	%
CNC Mill:	48,3	%
Operator 1 (Bandsaw):	70,0	%
Operator 2 (Robot Cell):	12,2	%

Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	36,1	%
CNC Idle Time:	51,7	%
Operator 1 (Bandsaw):	30,0	%
Operator 2 (Robot Cell):	87,8	%

Appendix 10: Concept 4 Detailed results from simulations

Cycle Times		
Cutting in Bandsaw (2 Saws = 2 Billets):	32	min
Setup Time:	19	min
Edges Grinding (1 Grinder):	1	min
Operator 1 (Bandsaw):	52	min
Operator 2 (Storing/setup Robot Cell (x10):	3	min
1. Robot Cell Setup Time:	3	min
1.1 Robot Movements:	0,5	min
2. CNC Milling:	29	min
2.1. Robot Movements:	0,5	min
3. Measuring in the CNC mill:	3	min
3.1 Robot Movements:	0,5	min
4. Serial Number Engraving:	1	min
4.1 Robot Movements:	0,5	min
(Billets cutting Cycle Time) Total:	52	min
(Robot Cell Cycle time)Total:	37,5	min
(Robot Movements Cycle Time)Total:	2	min
Lead Time:	91,5	min

Production Rate		
Final Product Production Rate:	0,92	Pcs/h
Final Product Production Rate:	43,7	Pcs/week
Final Product Production Rate:	1868,702	Pcs/year

Equipment and Personnel Yearly usage %		
Bandsaw (2):	63,9	%
CNC Mill:	48,3	%
Operator 1 (Bandsaw):	70,0	%
Operator 2 (Robot Cell):	16,6	%

Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	36,1	%
CNC Idle Time:	51,7	%
Operator 1 (Bandsaw):	30,0	%
Operator 2 (Robot Cell):	83,4	%

Appendix 11: Concept 5 Detailed results from simulations

Cycle Times		
Cutting in Bandsaw (2 Saws = 2 Billets):	32	min
Setup Time:	19	min
Edges Grinding (1 Grinder):	1	min
Operator 1 (Bandsaw):	52	min
Edges Grinding (1 Grinder):	1	min
Operator 2 (Storing/setup Robot Cell (x10):	6	min
1. Robot Cell Setup Time:	6	min
1.1 Robot Movements:	0,5	min
2. CNC Milling:	29	min
2.1. Robot Movements:	0,5	min
3. Measuring in the CNC mill:	3	min
3.1 Robot Movements:	0,5	min
4. Serial Number Engraving:	1	min
4.1 Robot Movements:	0,5	min
(Billets cutting Cycle Time) Total:	52	min
(Robot Cell Cycle time)Total:	40,5	min
(Robot Movements Cycle Time)Total:	2	min
Lead Time:	94,5	min

Production Rate		
Final Product Production Rate:	0,88	Pcs/h
Final Product Production Rate:	45,7	Pcs/week
Final Product Production Rate:	1786,861	Pcs/year

Equipment and Personnel Yearly usage %		
Bandsaw (2):	63,9	%
CNC Mill:	48,33	%
Operator 1 (Bandsaw):	70,0	%
Operator 2 (Robot Cell):	23,16	%

Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	36,1	%
CNC Idle Time:	51,7	%
Operator 1 (Bandsaw):	30,0	%
Operator 2 (Robot Cell):	76,8	%

Appendix 12: Concept 6 Detailed results from simulations

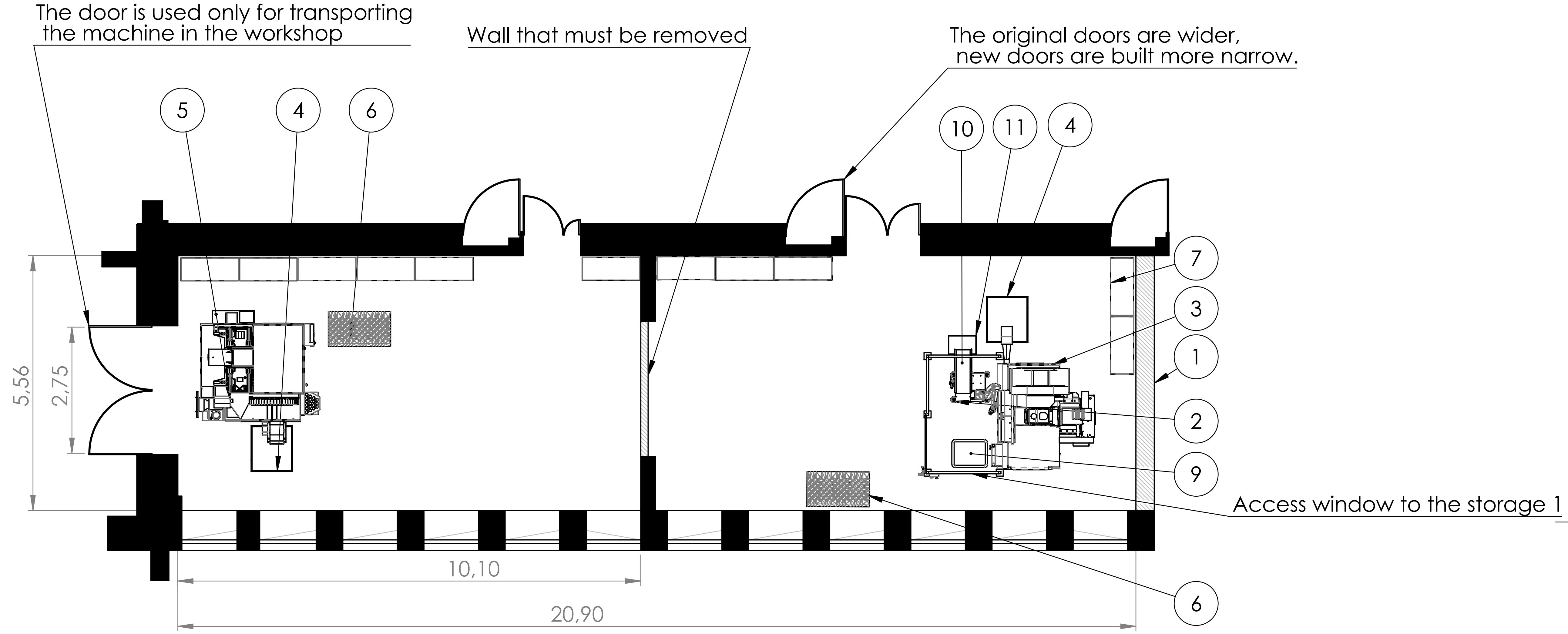
Cycle Times		
Cutting in Bandsaw (2 Saws = 2 Billets):	32	min
Setup Time:	19	min
Edges Grinding (1 Grinder):	1	min
Operator 1 (Bandsaw x2):	52	min
Operator 2 (Storing/setup CNC Mill:	6	min
2. CNC Milling:	29	min
3. Measuring in the CNC mill:	3	min
4. Serial Number Engraving:	1	min
(Billets cutting) Total:	52	min
(CNC Milling Process)Total:	33	min
Lead Time:	85	min

Production Rate		
Final Product Production Rate:	1,02	Pcs/h
Final Product Production Rate:	34,4	Pcs/week
Final Product Production Rate:	1851	Pcs/year

Equipment and Personnel Yearly usage %		
Bandsaw (2):	63,9	%
CNC Mill:	52,6	%
Operator 1 (Bandsaw):	63,9	%
Operator 2 (Robot Cell):	19,6	%

Equipment and Personnel Yearly Idle Time %		
Bandsaw Idle Time:	36,1	%
CNC Idle Time:	47,4	%
Operator 1 (Bandsaw):	36,1	%
Operator 2 (Robot Cell):	80,4	%

GRAPHICAL MATERIALS



ITEM NO.	PART NUMBER	DESCRIPTION	Quantity
1	New_layout	Two separate connected rooms	1
2	HRP1	Haas Robot Package and fence	1
3	VF-2YT_2SSYT	Haas Vertical mill	1
4	Chip container		2
5	UMC-500	Haas Vertical 5 axes mill	1
6	Workshop Bench	Table with the hand tools	2
7	Storage Shelf		11
9	Profeeder compact	Storage 1 - Billets feeder	1
10	Storage 2 - ramp	Specimens transporting unit	1
11	Storage 2 - Box	Processed specimens	1

1. The plan on the drawing are one seqment of the main floor. Other rooms on the floor have not indicated.
2. The wall between the room is necessary to remove to connect the two rooms and get access to move machines.
3. Around the machines is left some space for access

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J. Ehrlich		5.4.2022
CHK'D			
APPV'D			
MFG			
Q.A			

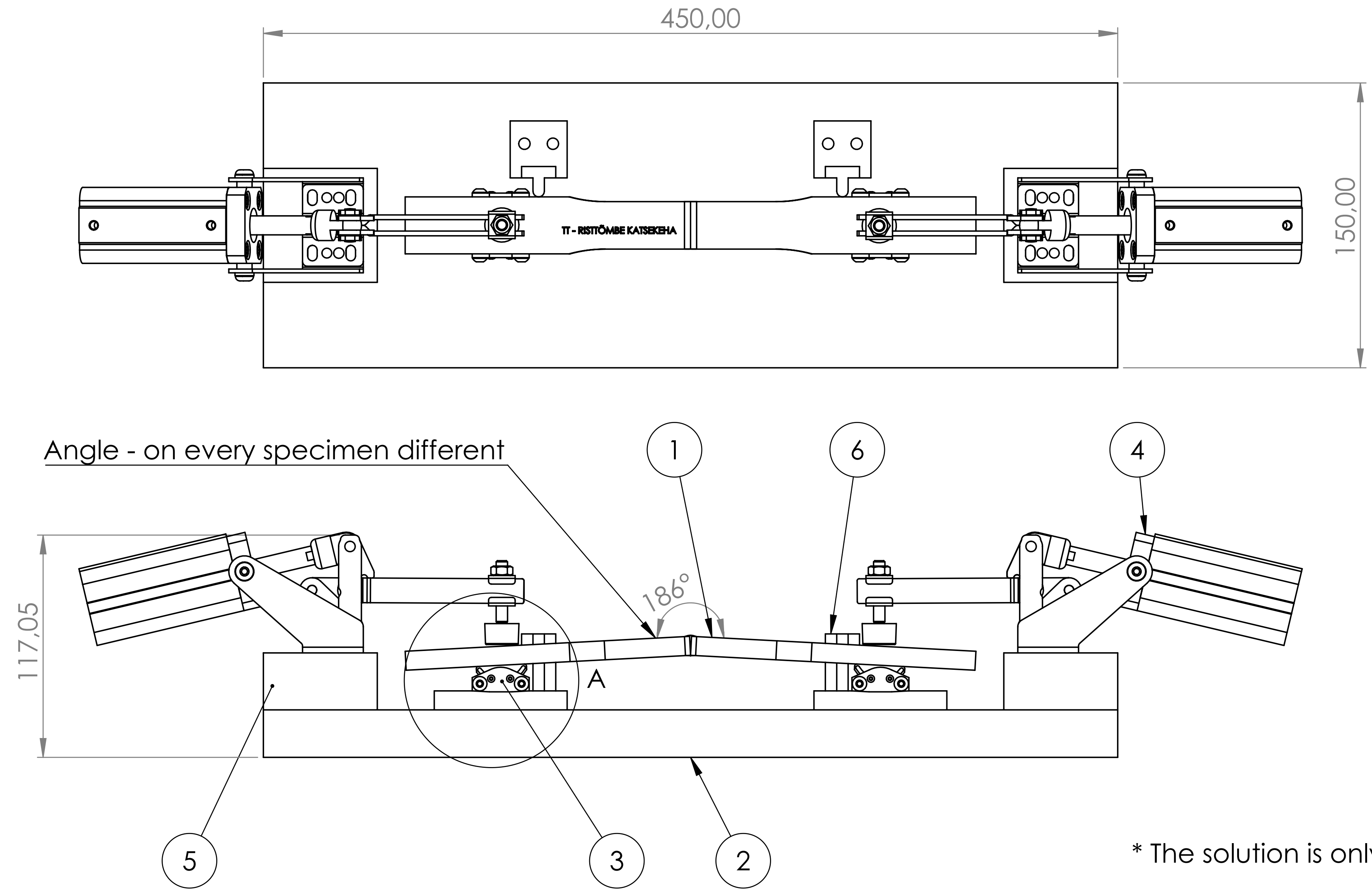
MATERIAL:
WEIGHT:

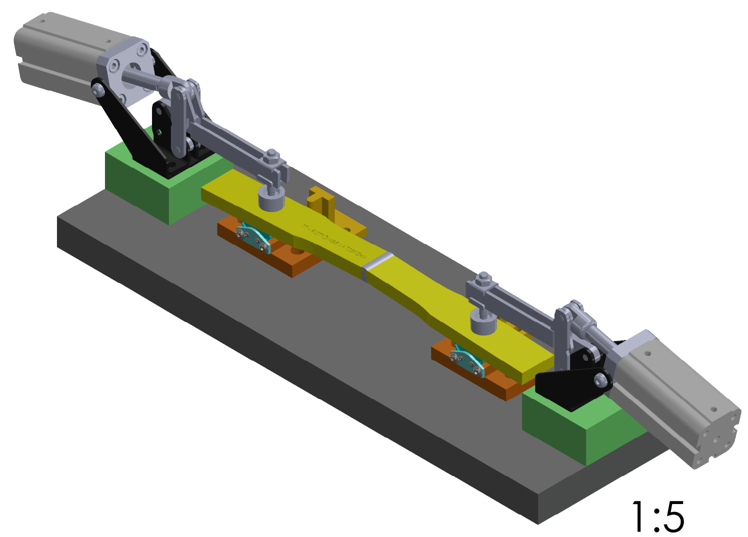
TITLE: Workshop new layout

DWG NO. New_layout

A3

SCALE: 1:100
SHEET 1 OF 1





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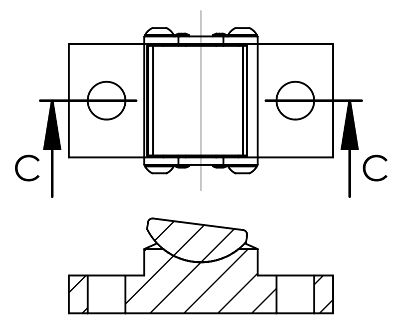
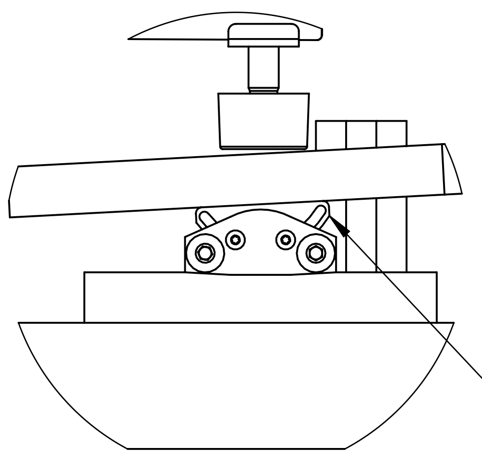


SECTION C-C
SCALE 1 : 2



DETAIL A
SCALE 2 : 3

* The solution is only conceptional idea.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TT Specimen	Fixed Specimen	1
2	Base Plate		1
3	Movable support^RakisTT1		2
4	Pneumatic Clamp		2
5	Support		2
6	Support 2		2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		04.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
GENERAL DRAWING - CONCEPTION 1
CUSTOM JIG

MATERIAL:

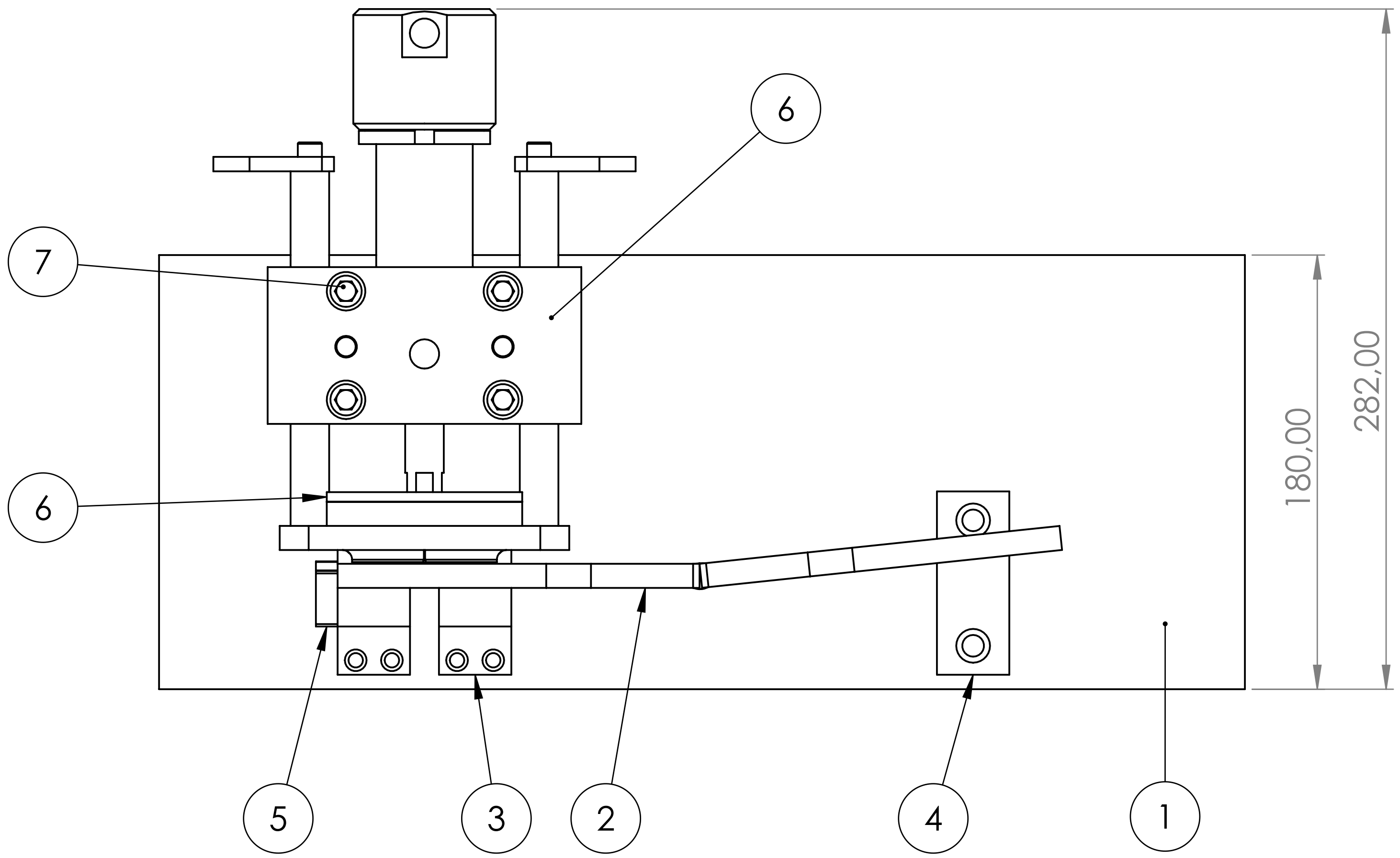
DWG NO.
RakisTT1

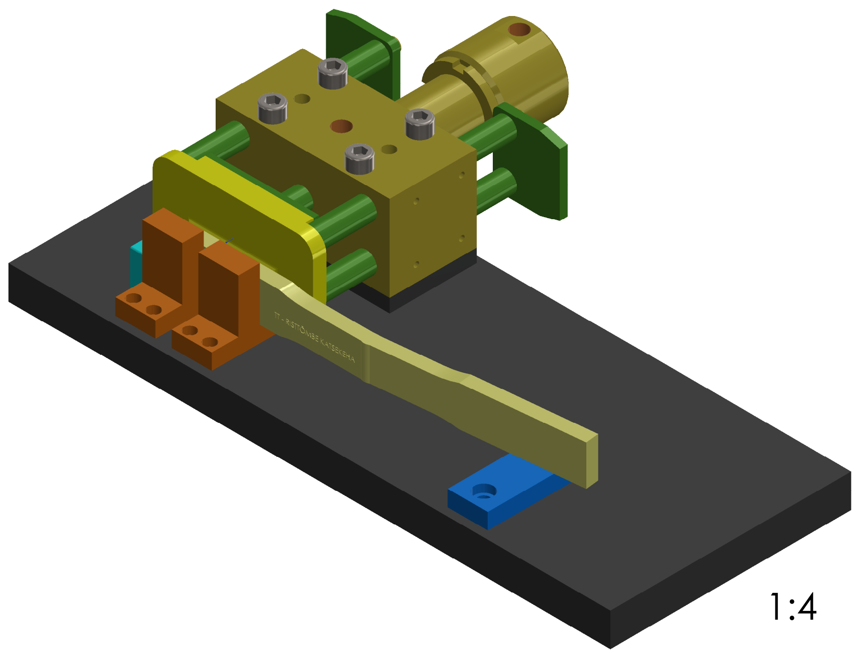
A3

WEIGHT:

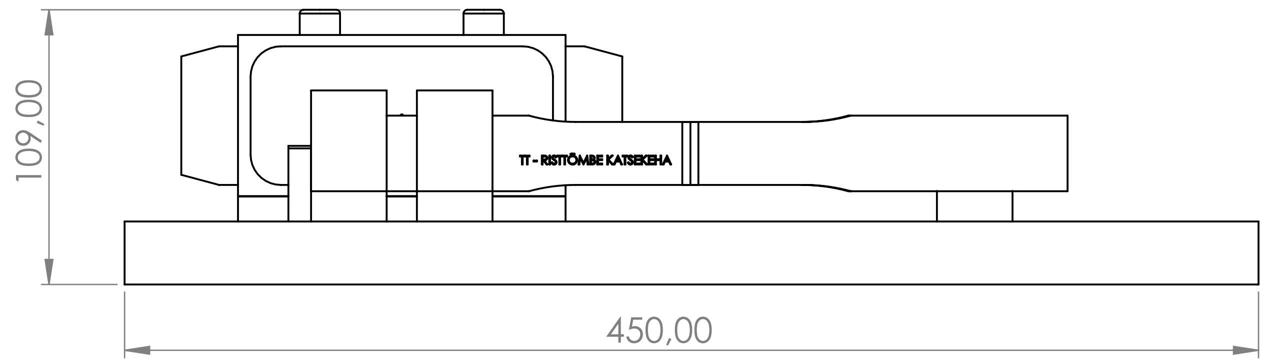
SCALE:1:5

SHEET 1 OF 1





1:4



Hydraulic piston presses the specimen against the support 2

* The solution is only conceptional idea.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base Plate		1
2	TT Katsekeha		1
3	Support		2
4	Support 2		1
5	Limiter	Helps to position specimen	1
6	Hydraulic piston^Rakis2		1
7	ISO 4762 M10 x 20 - 20N		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.EHRLICH		05.22
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

GENERAL DRAWING - CONCEPTION 2
CUSTOM JIG

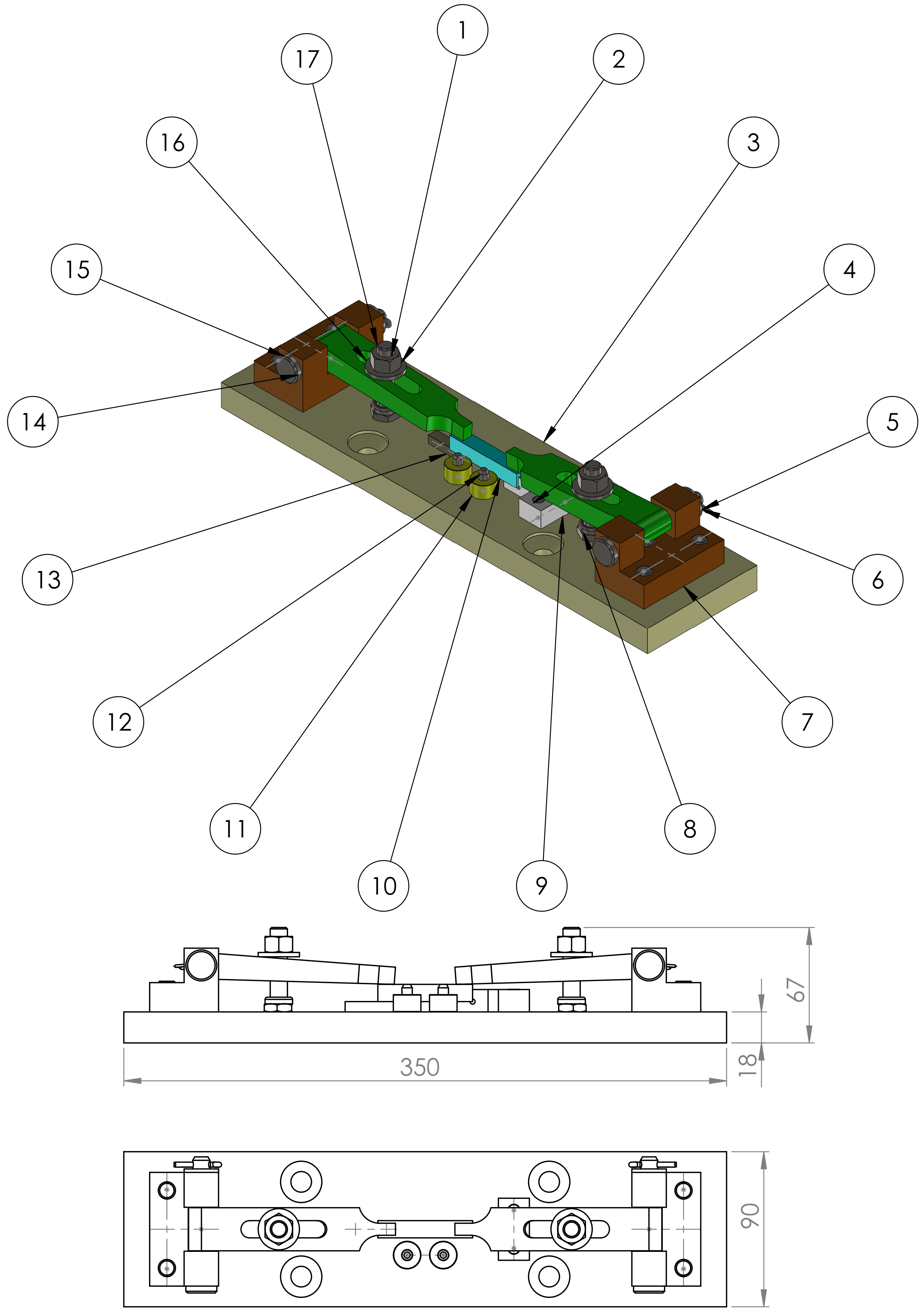
DWG NO.

Rakis2

A3

SCALE:1:5

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ISO - 8674 - M10 x 1.0 - D - N		2
2	Liigendtugi		2
3	Kinnitus ehk alusplaat		1
4	ISO 10642 - M8 x 30 - 30N		4
5	ISO 10673-11-S		2
6	ISO 1234-3.2x18-C		2
7	Alustugi 3		2
8	ISO 10511-M10-N		2
9	Alustugi 1		1
10	Katsekeha		1
11	Distantspuks		2
12	ISO 2340 - A - 6 x 26 - St		2
13	Alustugi 2		1
14	ISO 2341 - B - 10 x 75 x 3.2 - St		2
15	ISO 10642 - M10 x 35 - 35N		6
16	ISO 10673-11-N		2
17	ISO 4014 - M10 x 60 x 60-N		2
18	Copy of Part2^Rakis5_Rakis2 - Rev B		1
19	ISO 10642 - M5 x 20 - 20N		2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

KOOSTEJOONIS - Rakis 5

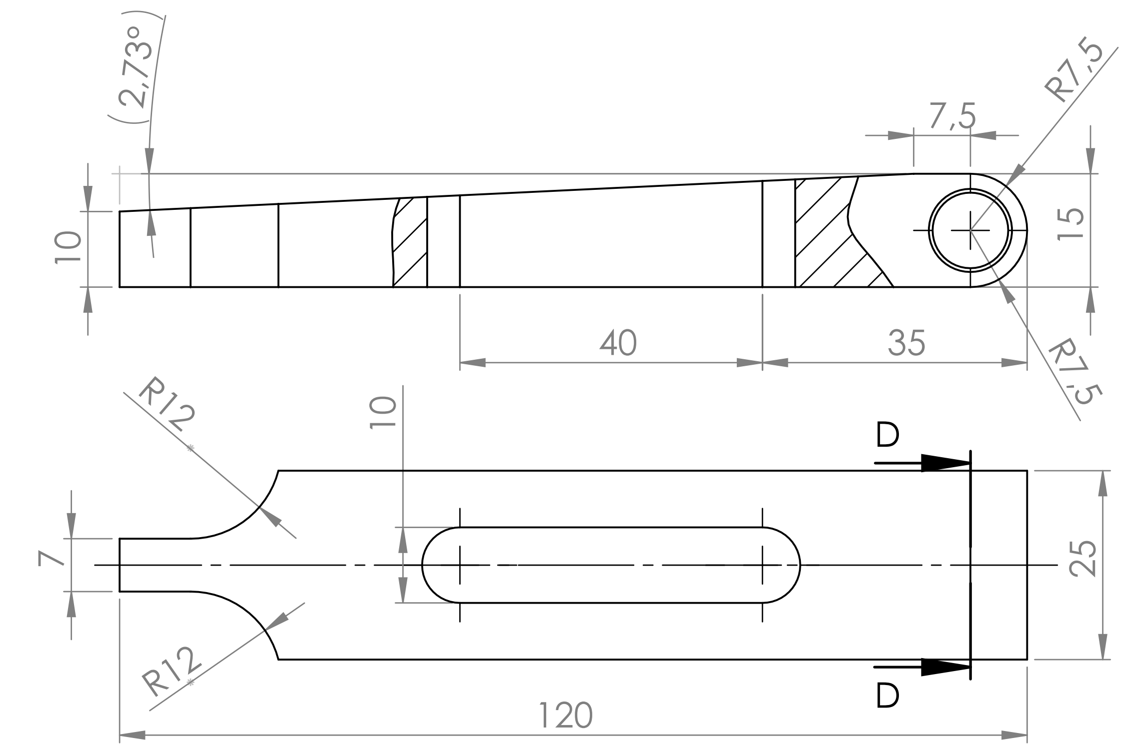
DWG NO.

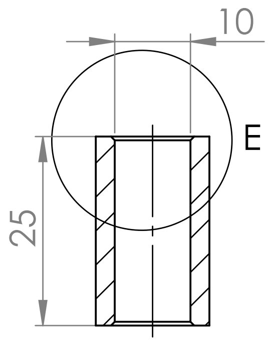
Rakis 5 - Rev B

A3

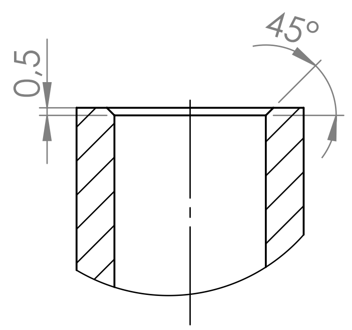
SCALE:1:5

SHEET 1 OF 1

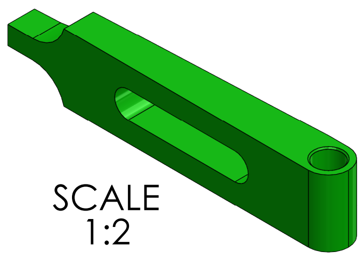




D-D
SCALE 1 : 1

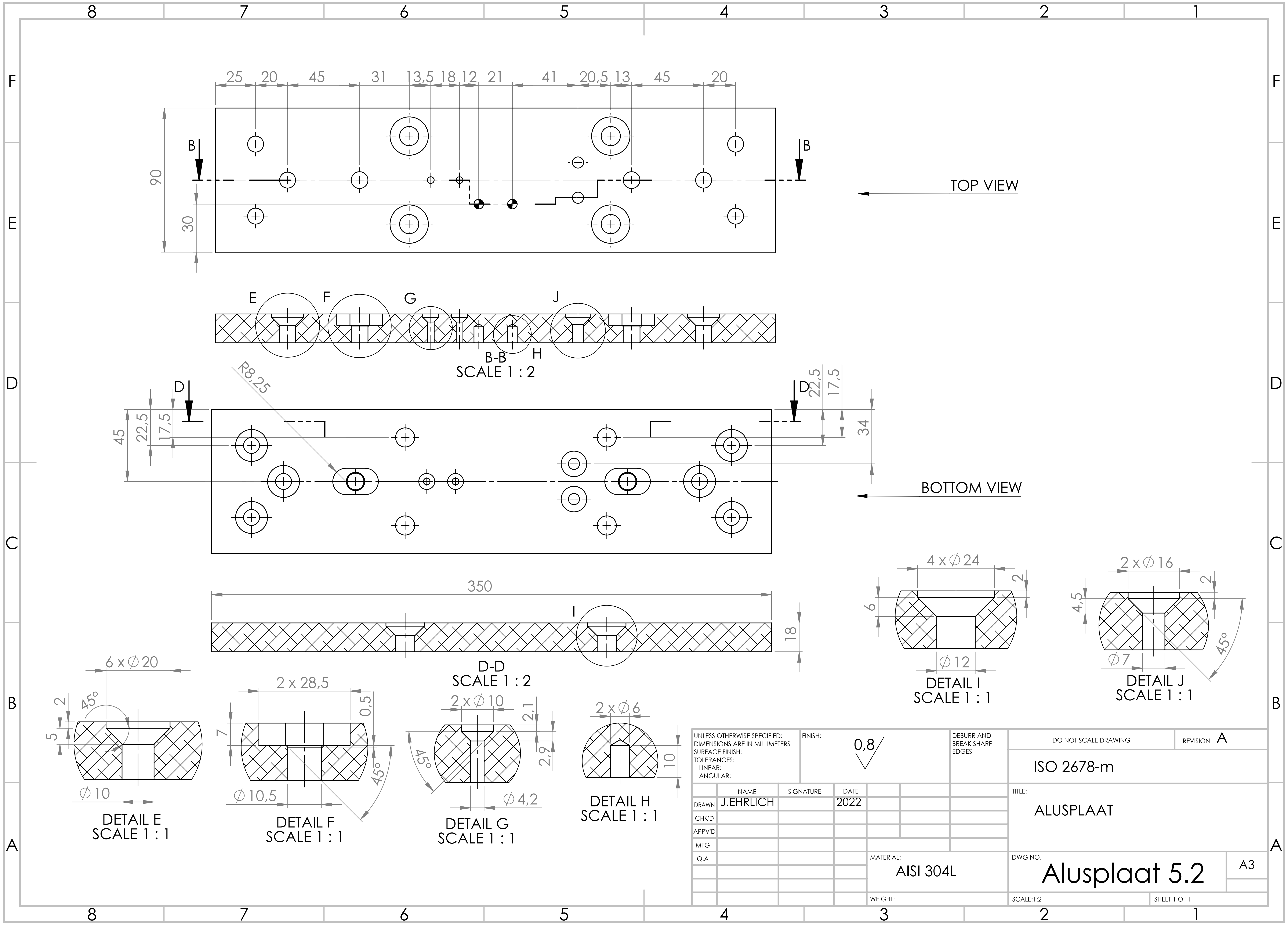


DETAIL E
SCALE 2 : 1

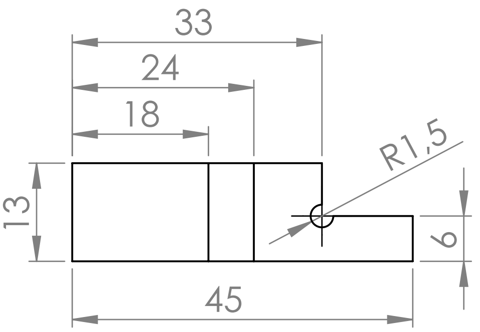


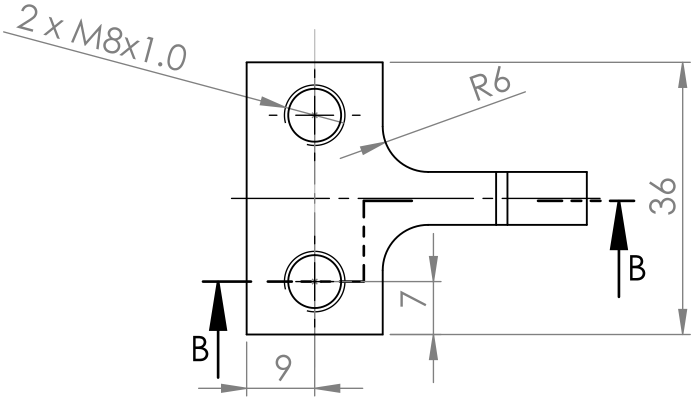
SCALE
1:2

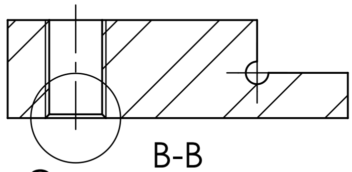
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A	
			ISO 2678-m		
NAME	SIGNATURE	DATE	TITLE:		
DRAWN J.EHRLICH		2022	LIIGENDTUGI		
CHK'D					
APPV'D					
MFG					
Q.A		MATERIAL: AISI 304L	DWG NO. Liigendtugi	A4	
		WEIGHT:	SCALE:1:1	SHEET 1 OF 1	



TOP VIEW
B-B
SCALE 1 : 2
BOTTOM VIEW
R8,25
350
18
D-D
SCALE 1 : 2
DETAIL E
SCALE 1 : 1
6 x ∅20
∅10
45°
DETAIL F
SCALE 1 : 1
2 x 28,5
∅10,5
45°
DETAIL G
SCALE 1 : 1
2 x ∅10
∅4,2
45°
DETAIL H
SCALE 1 : 1
2 x ∅6
DETAIL I
SCALE 1 : 1
4 x ∅24
∅12
DETAIL J
SCALE 1 : 1
2 x ∅16
∅7
45°
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
0,8
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION A
ISO 2678-m
NAME
SIGNATURE
DATE
DRAWN J.EHRLICH 2022
CHK'D
APPV'D
MFG
Q.A
TITLE:
ALUSPLAAT
MATERIAL:
AISI 304L
DWG NO.
Alusplaat 5.2
A3
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

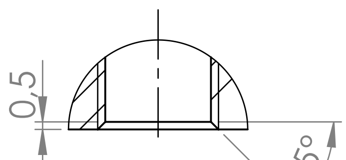




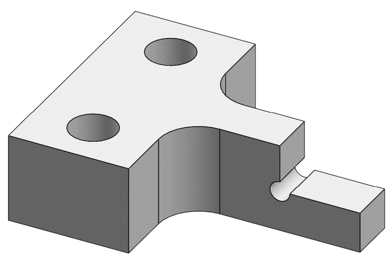


C

B-B



DETAIL C
SCALE 2 : 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
			ISO 2678-m	

	NAME	SIGNATURE	DATE		
DRAWN	J.EHRLICH		2022		
CHK'D					
APPV'D					
MFG					
Q.A					

TITLE: ALUSTUGI 1

MATERIAL: AISI 304L

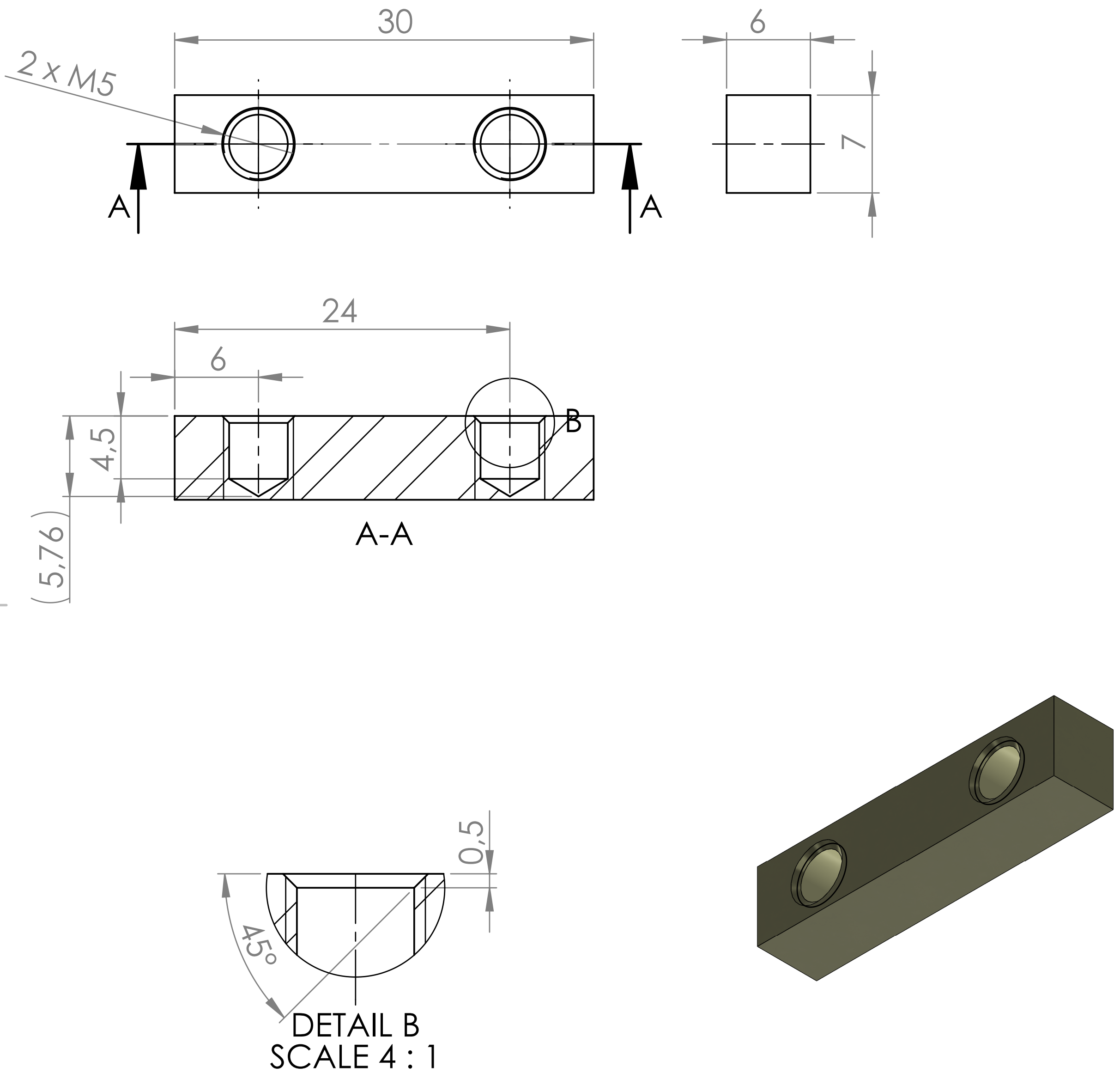
DWG NO. Alustugi 1

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: 0,8

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.EHRLICH		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: ALUSTUGI 2

MATERIAL: AISI 304L

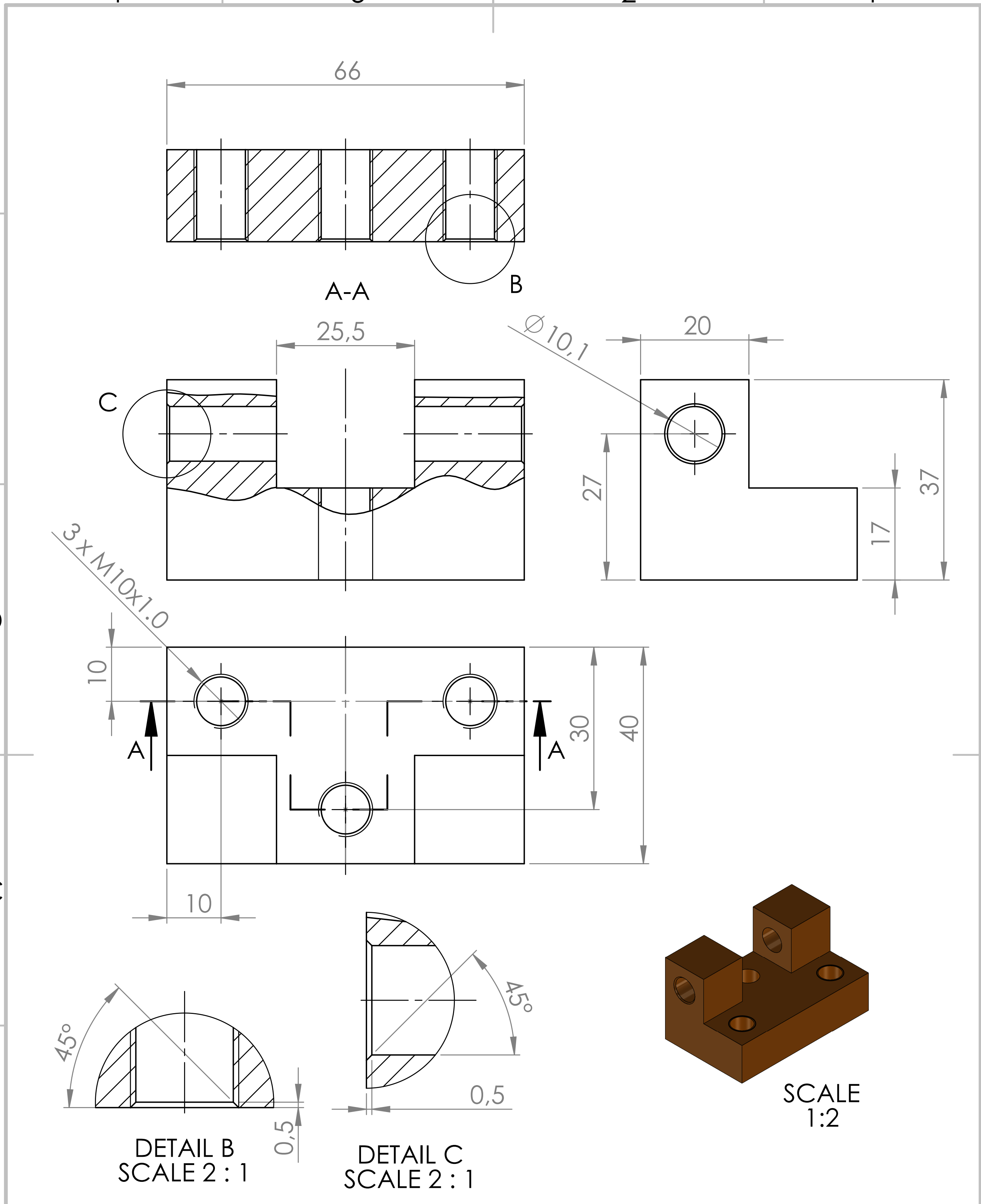
DWG NO. Alustugi 2

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING — REVISION A ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.EHRLICH		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: ALUSTUGI 3

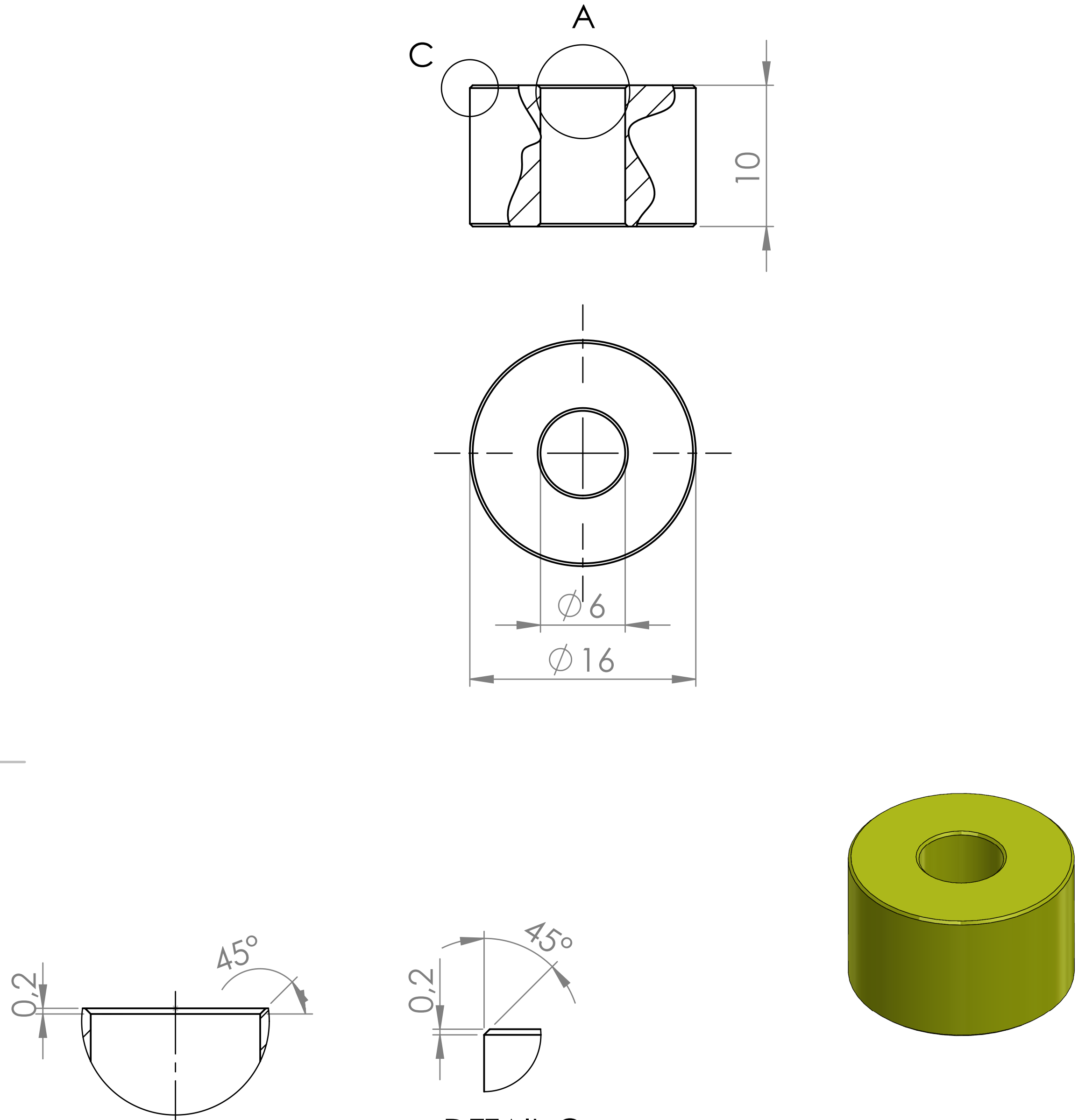
MATERIAL: AISI 304L

DWG NO. Alustugi 3 — A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1

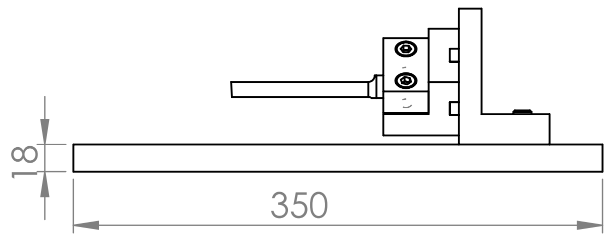


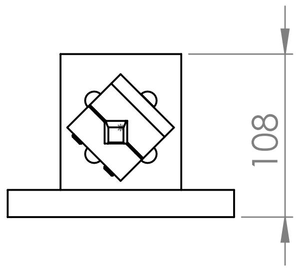
DETAIL A
SCALE 4 : 1

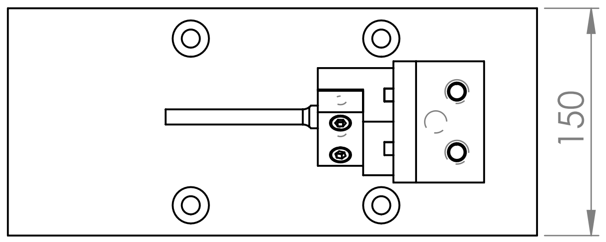
DETAIL C
SCALE 4 : 1

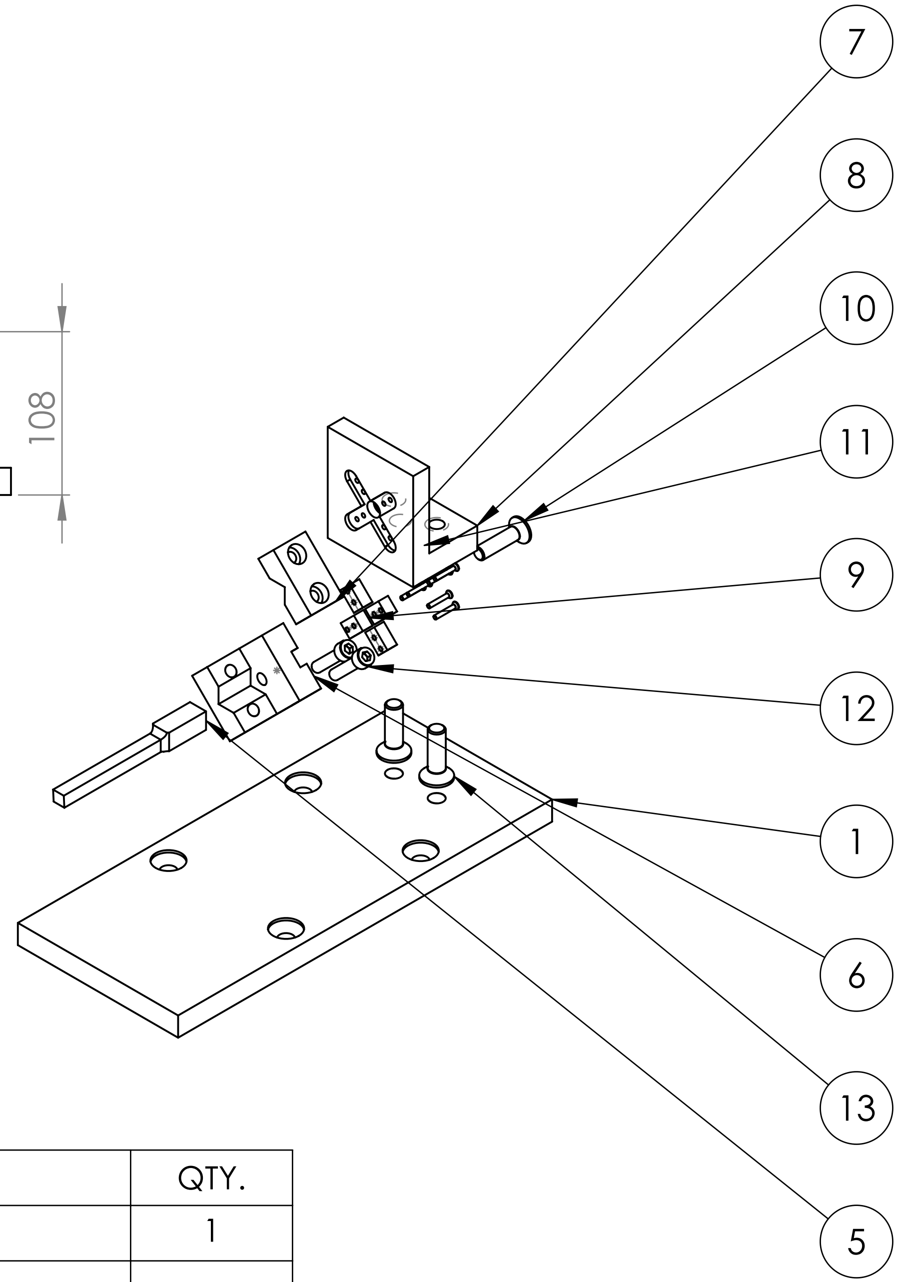
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
			ISO 2678-m	

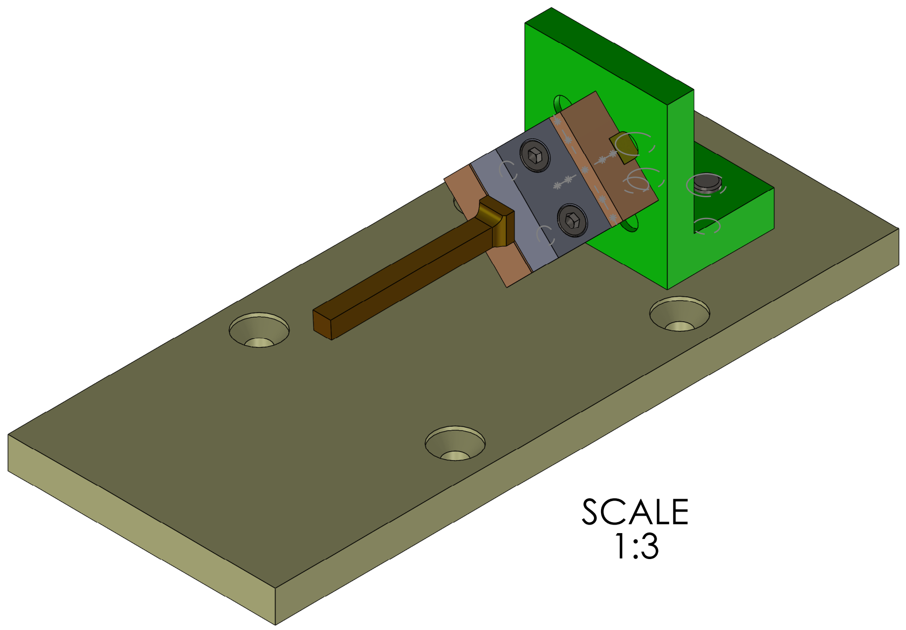
	NAME	SIGNATURE	DATE	
DRAWN	J.EHRLICH		2022	TITLE: DISTANTSPUKS
CHK'D				
APPV'D				
MFG				
Q.A			MATERIAL: AISI 304L	DWG NO. Distantspuks A4
			WEIGHT:	SCALE:2:1 SHEET 1 OF 1











SCALE
1:3

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Kinnitus ehk alusplaat		1
2	Copy of Katsekeha2_toorik1		1
3	Copy of Katsekeha2_toorik2		1
4	Copy of Katsekeha2_toorik3		1
5	Ümar_Katsekeha2_toorik2		1
6	Part5		1
7	Part6		1
8	Part4		1
9	Part 5		1
10	ISO 10642 - M10 x 40 - 40N		1
11	ISO 10642 - M3 x 20 - 20N		8
12	ISO 4762 M8 x 35 - 35N		2
13	ISO 10642 - M12 x 40 - 40N		2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.EHRLICH		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

RAKIS 2 - KOOSTEJOONIS

MATERIAL:

WEIGHT:

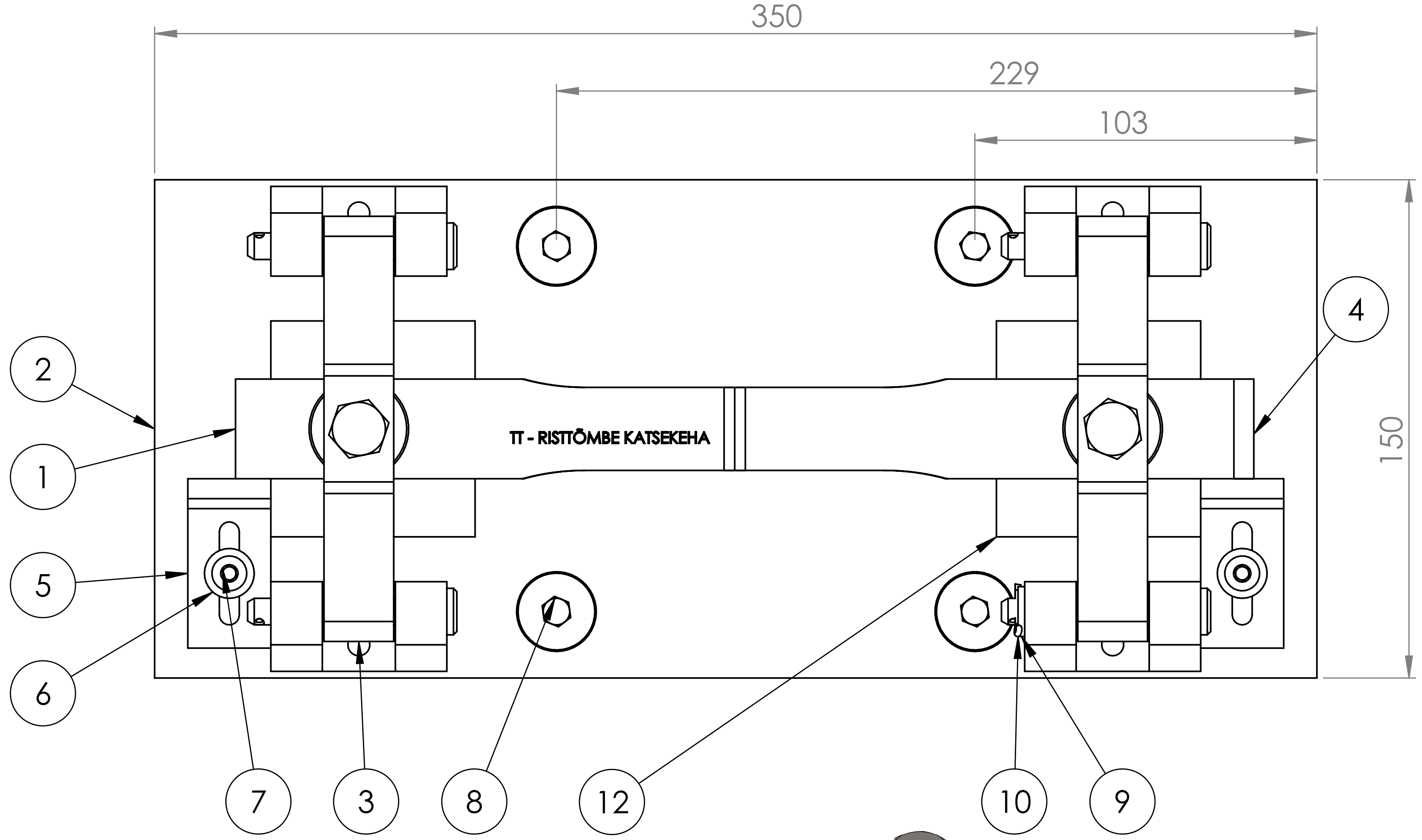
DWG NO.

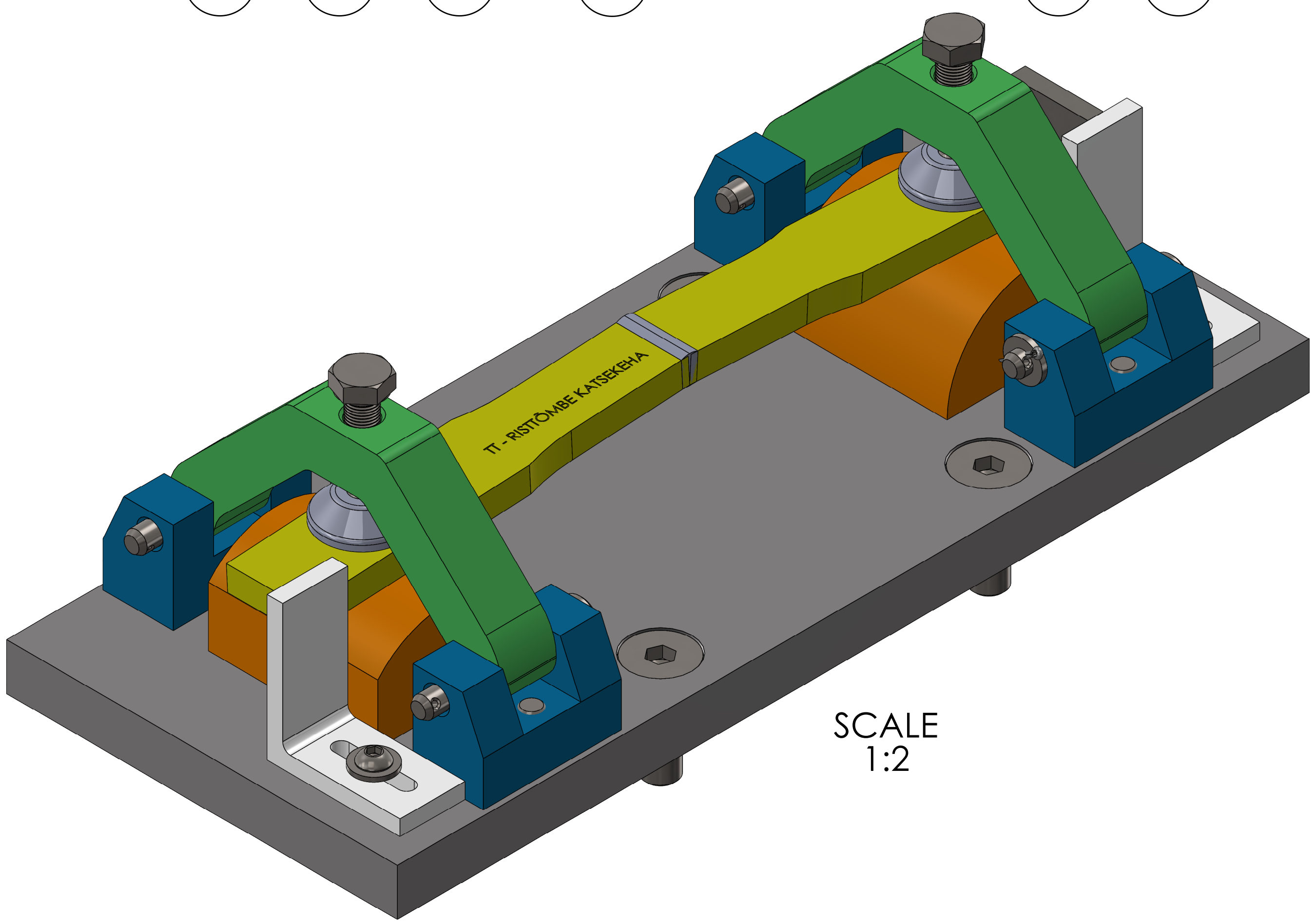
Rakis2

A3

SCALE:1:3

SHEET 1 OF 1





SCALE
1:2

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TT Specimen	Fixed Specimen	1
2	Kinnitus ehk alusplaat		1
3	Tugi2		2
4	Piiraja1		1
5	Piiraja2		1
6	ISO 10673-7.4-S		1
7	ISO 7380 - M6 x 20 - 20N		1
8	ISO 10642 - M12 x 40 - 40N		4
9	ISO 8738 - 8		1
10	WUERTH_047092_12_split_pin_2x12_Blank_12_		1
11	Pinguti2		2
12	Alustugi v2^Rakis2_Rakis2 - Rev C		2
13	ISO 10642 - M8 x 30 - 30N		8

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J. Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

Koostejoonis

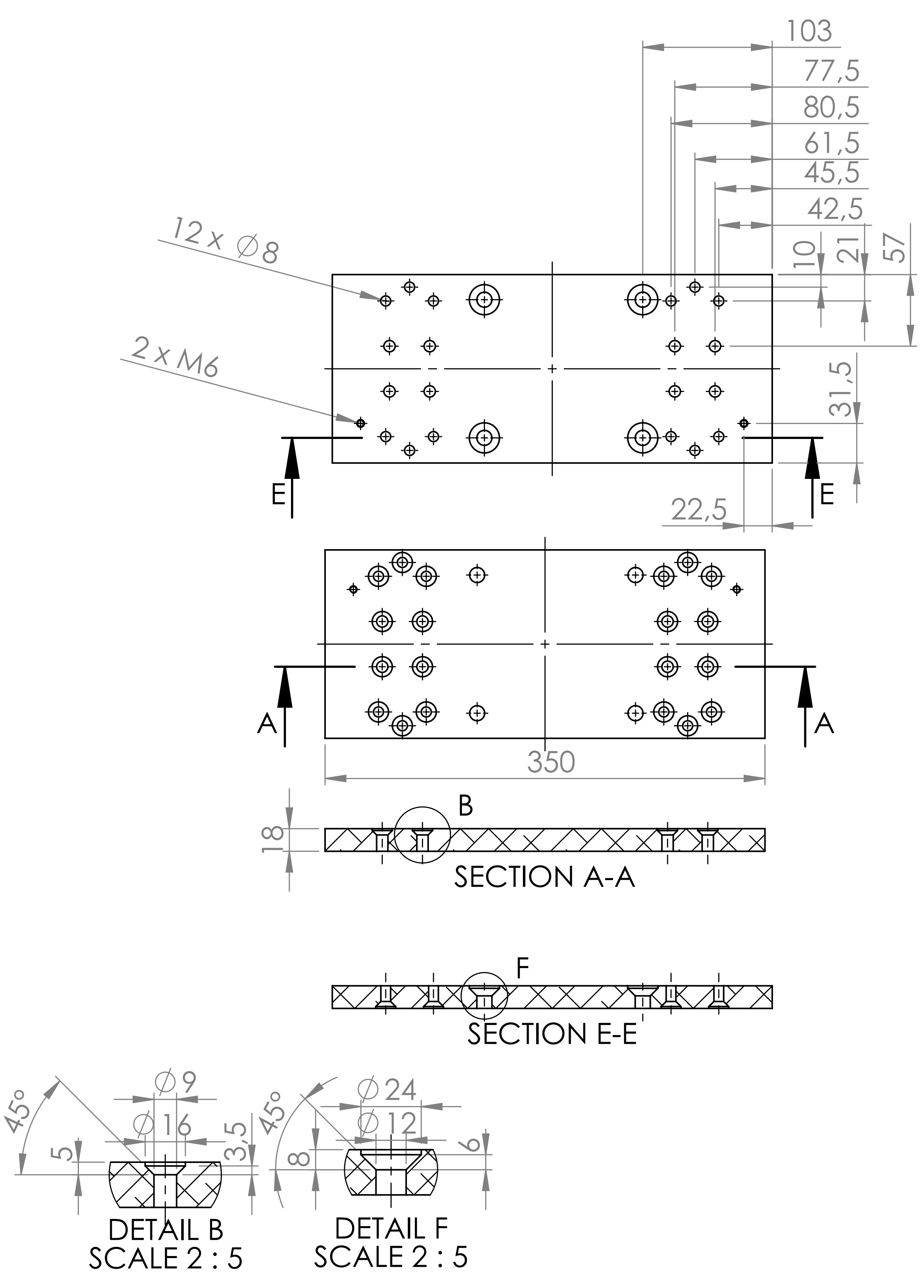
DWG NO.

Rakis2^Rakis2 - Rev C

A3

SCALE:1:5

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
			ISO 2687-m	

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Kinnitus ehk alusplaat

MATERIAL:

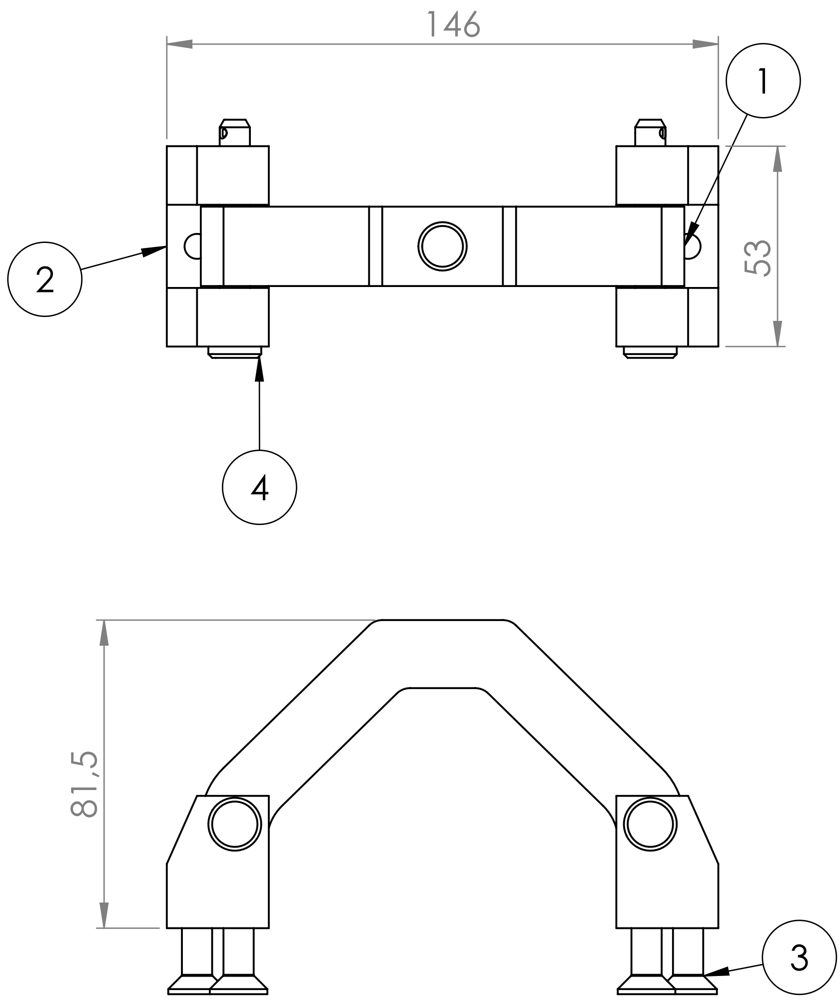
DWG NO. Kinnitusplaat

A4

WEIGHT:

SCALE:1:5

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tugi		1
2	Ühendusklots		2
3	ISO 10642 - M8 x 35 - 35N		6
4	ISO 2341 - B - 8 x 60 x 2 - St		2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Toe koost

MATERIAL:

WEIGHT:

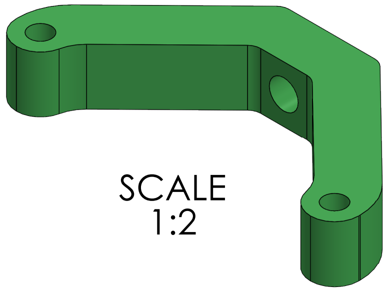
DWG NO.

Tugi2

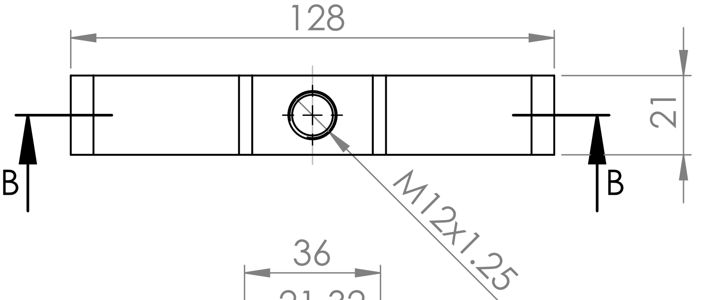
A4

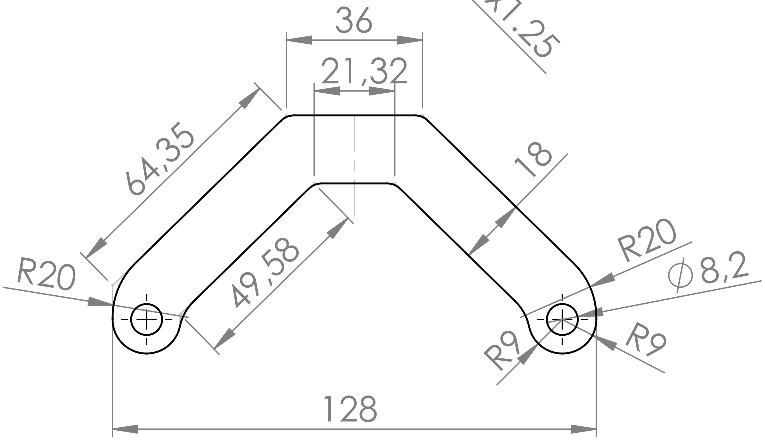
SCALE:1:2

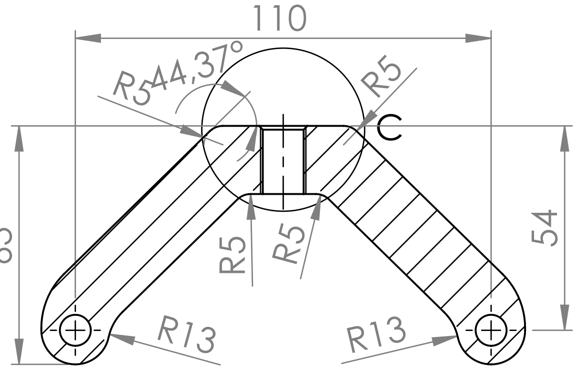
SHEET 1 OF 1



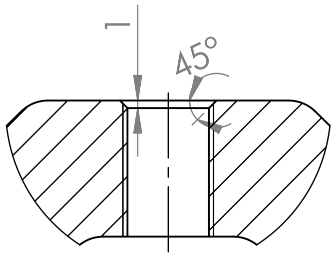
SCALE 1:2







SECTION B-B



DETAIL C
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: 0,8

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Kinnitustugi

MATERIAL: AISI 304L

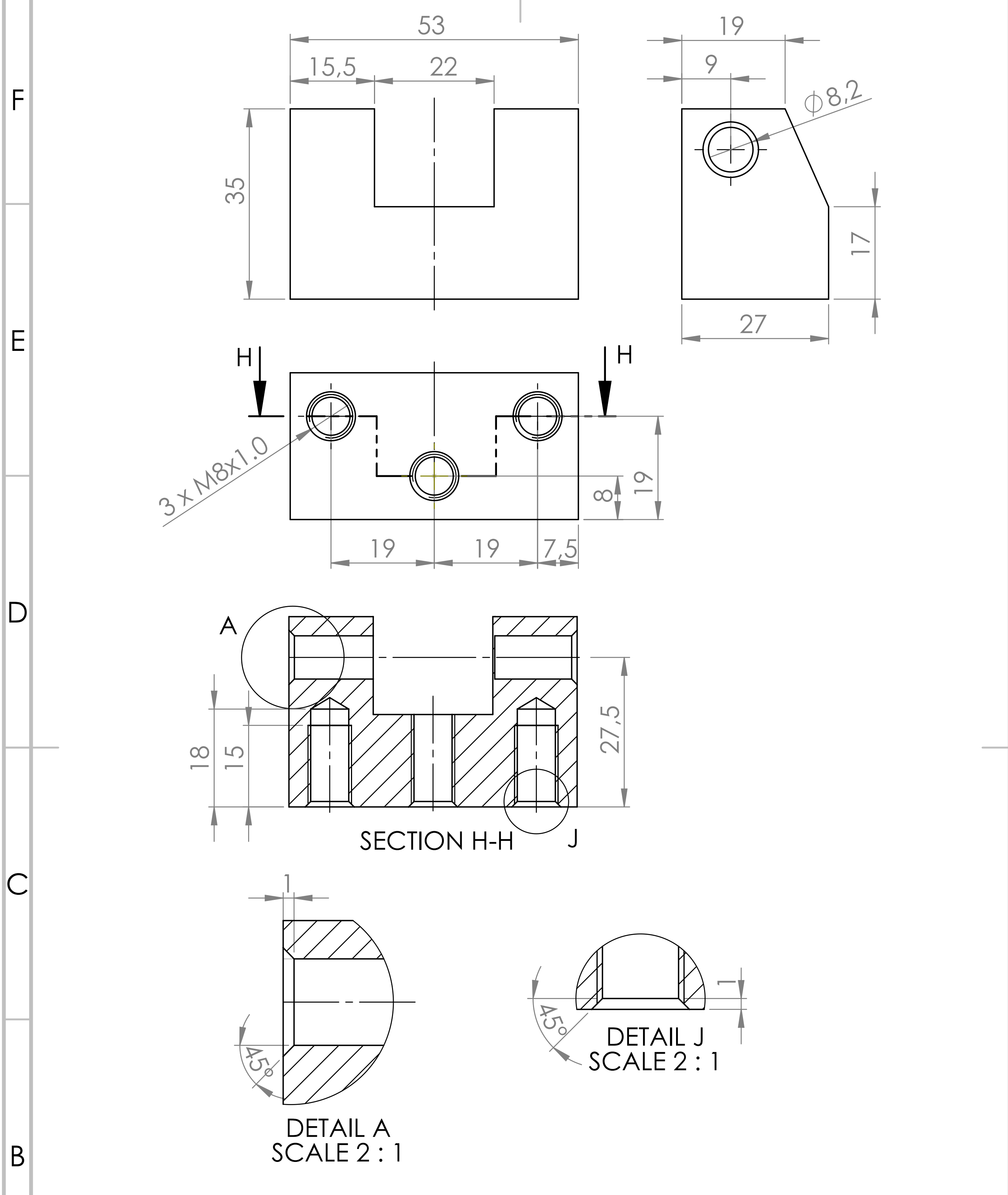
DWG NO. Tugi

A4

WEIGHT:

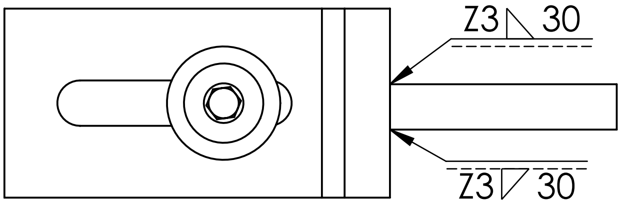
SCALE:1:2

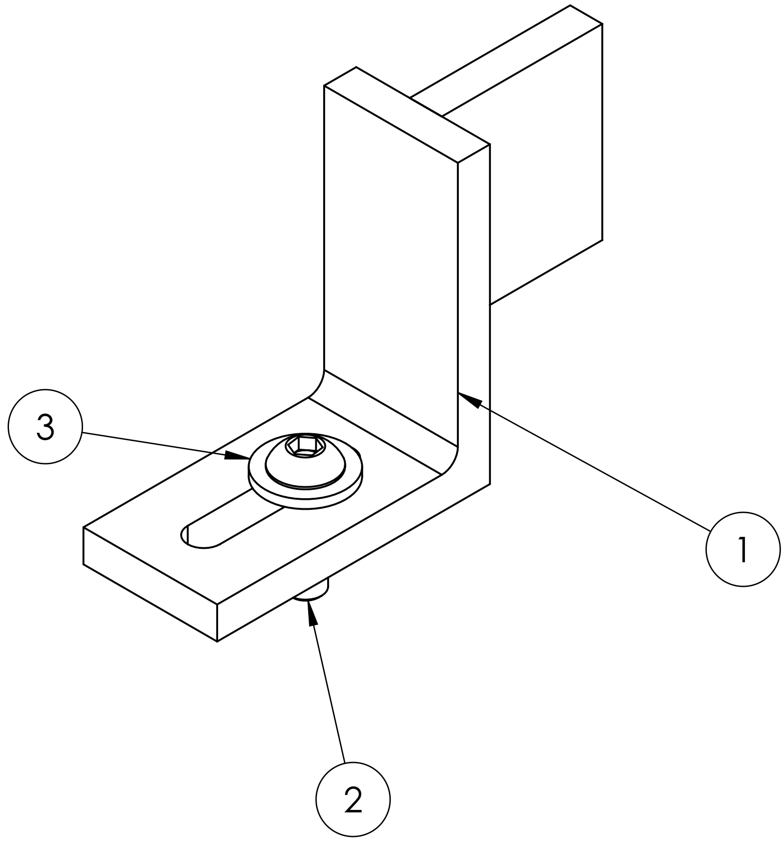
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A	
			ISO 2678-m		

	NAME	SIGNATURE	DATE		TITLE:
DRAWN	J.Ehrlich		2022		Toekoostu ühendusklots
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL: AISI 304L	DWG NO. Ühendusklots — A4
				WEIGHT:	SCALE:1:1 — SHEET 1 OF 1





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Lisatugi2		1
2	ISO 7380 - M6 x 20 - 20N		1
3	ISO 10673-7.4-S		1
4	Keevistugi^Piiraja1		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Piiraja kooste ja keevisjoonis

MATERIAL:

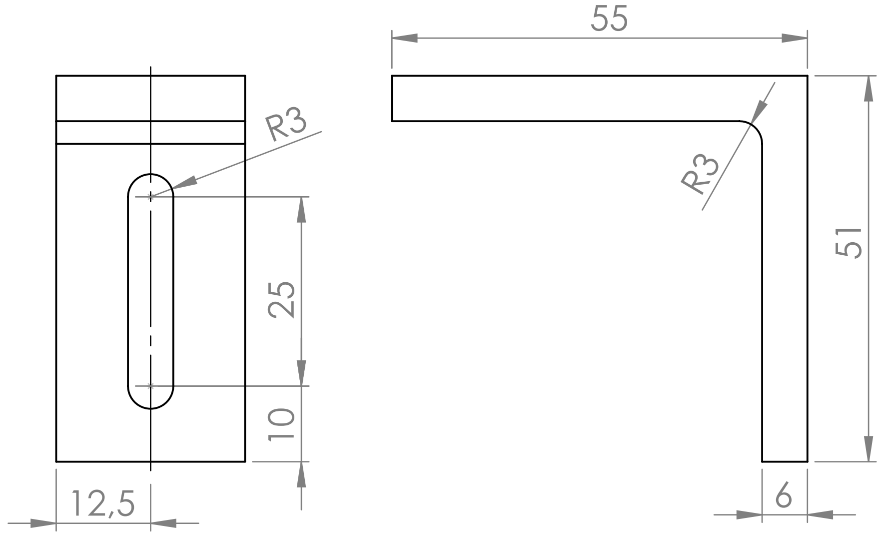
WEIGHT:

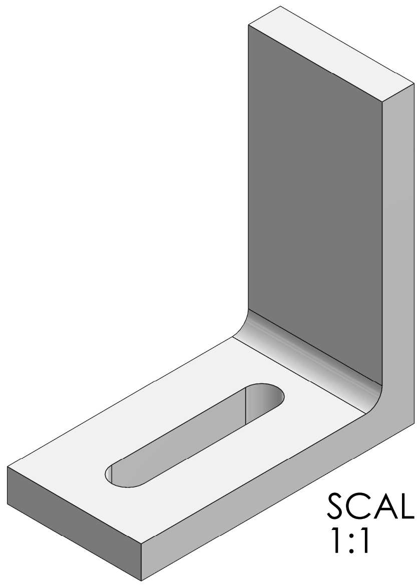
DWG NO. Piiraja1

A4

SCALE:1:1

SHEET 1 OF 1





SCALE 1:1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING — REVISION A — ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Piiraja 2

MATERIAL: AISI 304L

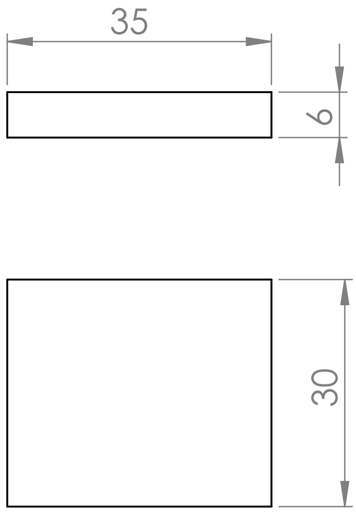
DWG NO. Piiraja2

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: 0,8

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Tugiplaadi väike plaat

MATERIAL:

AISI 304L

DWG NO.

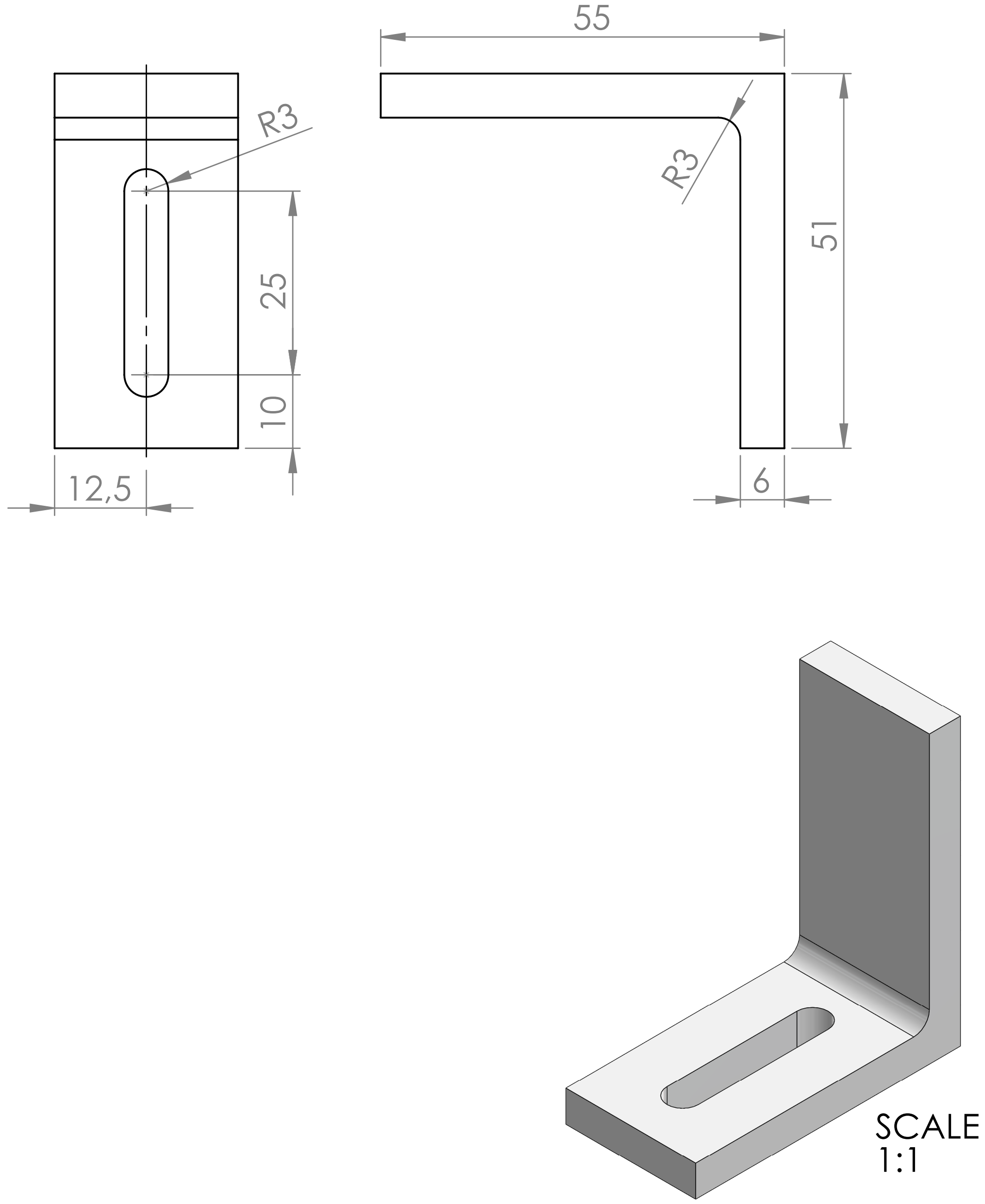
Assem2

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
			ISO 2678-m	

	NAME	SIGNATURE	DATE
DRAWN	Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Piiraja 2

MATERIAL: AISI 304L

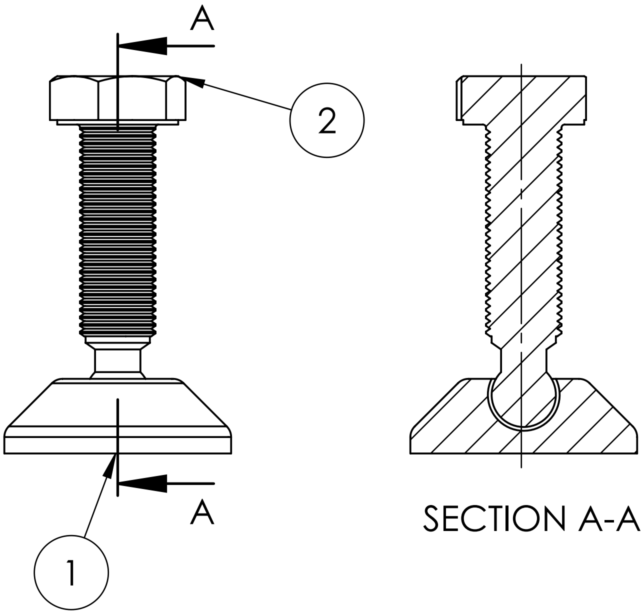
DWG NO. Piiraja2

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Ümar ots2		1
2	ISO 8676 - M10x1.0 x 35-N		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

Pinguti koostejoonis

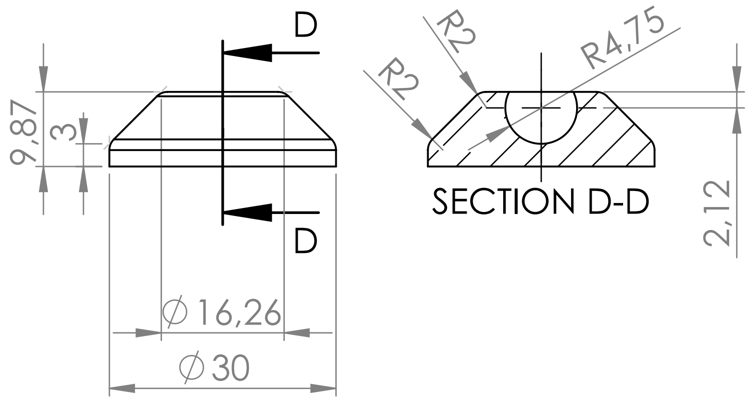
DWG NO.

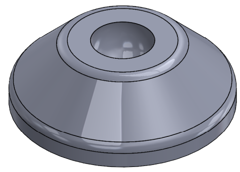
Pinguti2

A4

SCALE:1:1

SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: 0,8

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Ümar ots2

MATERIAL: AISI 304L

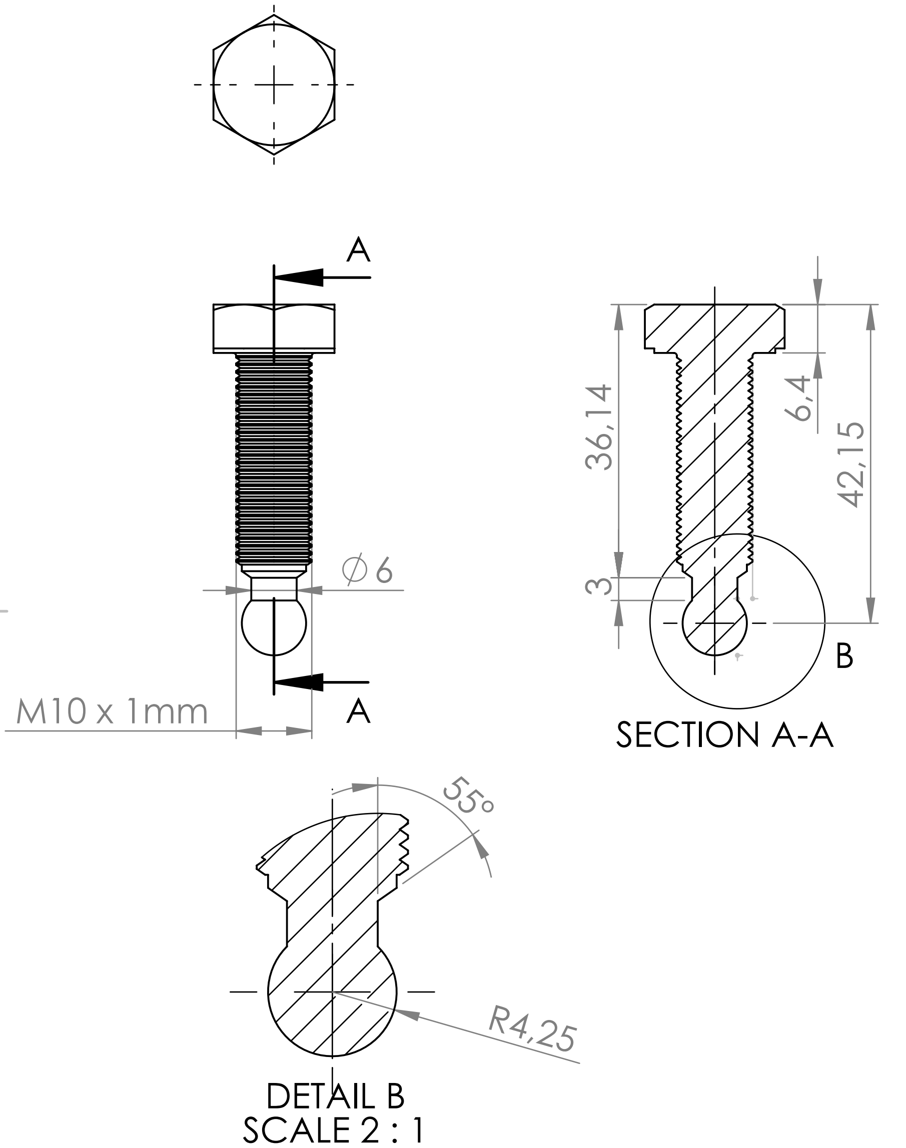
DWG NO. Ümar ots2

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



Toorik: ISO8676 - M10 x 1,0 - 40mm

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: 0,8

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Pingutuspolt

MATERIAL: AISI 304L

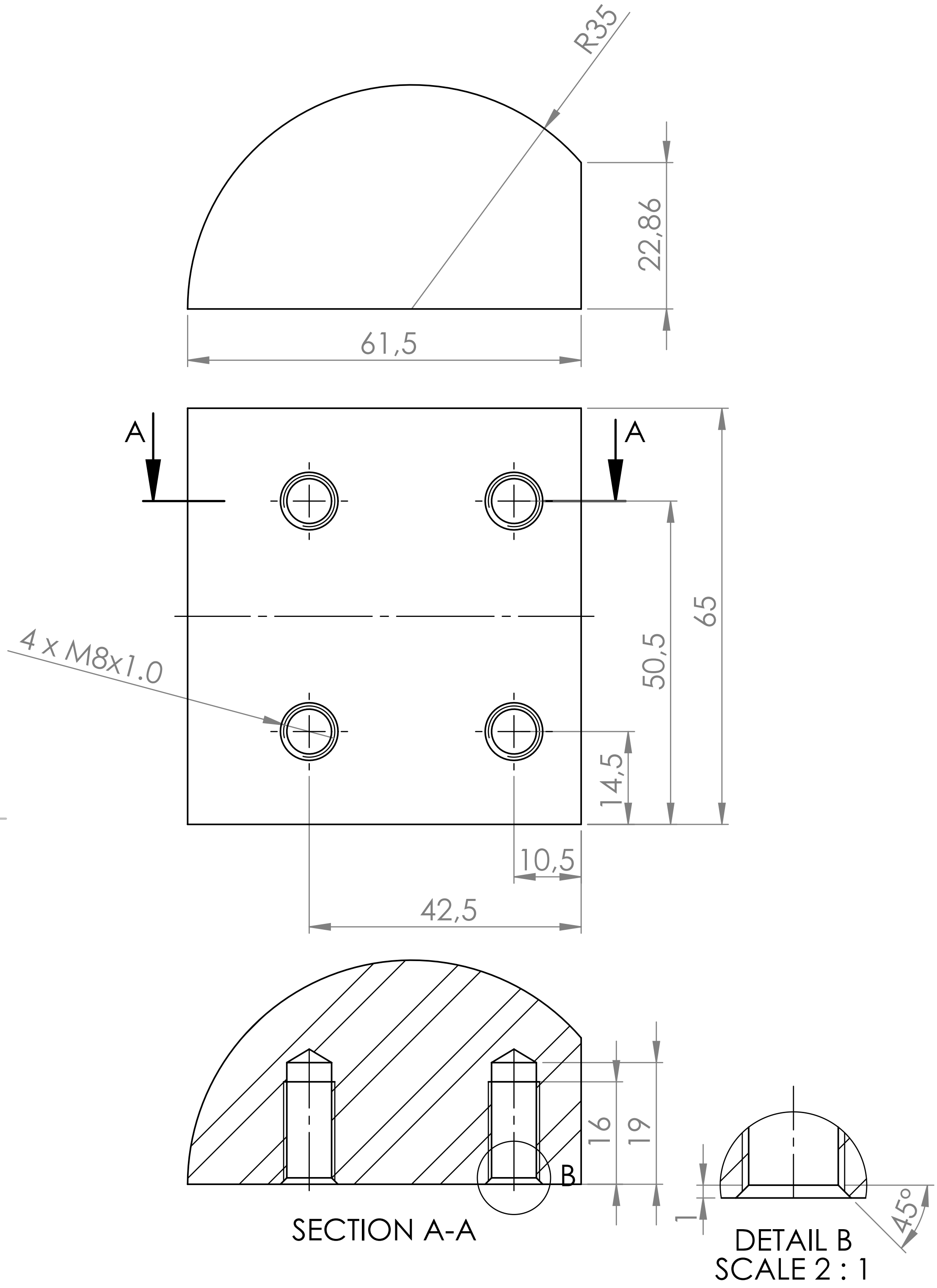
DWG NO. Hex screw_muudetud

A4

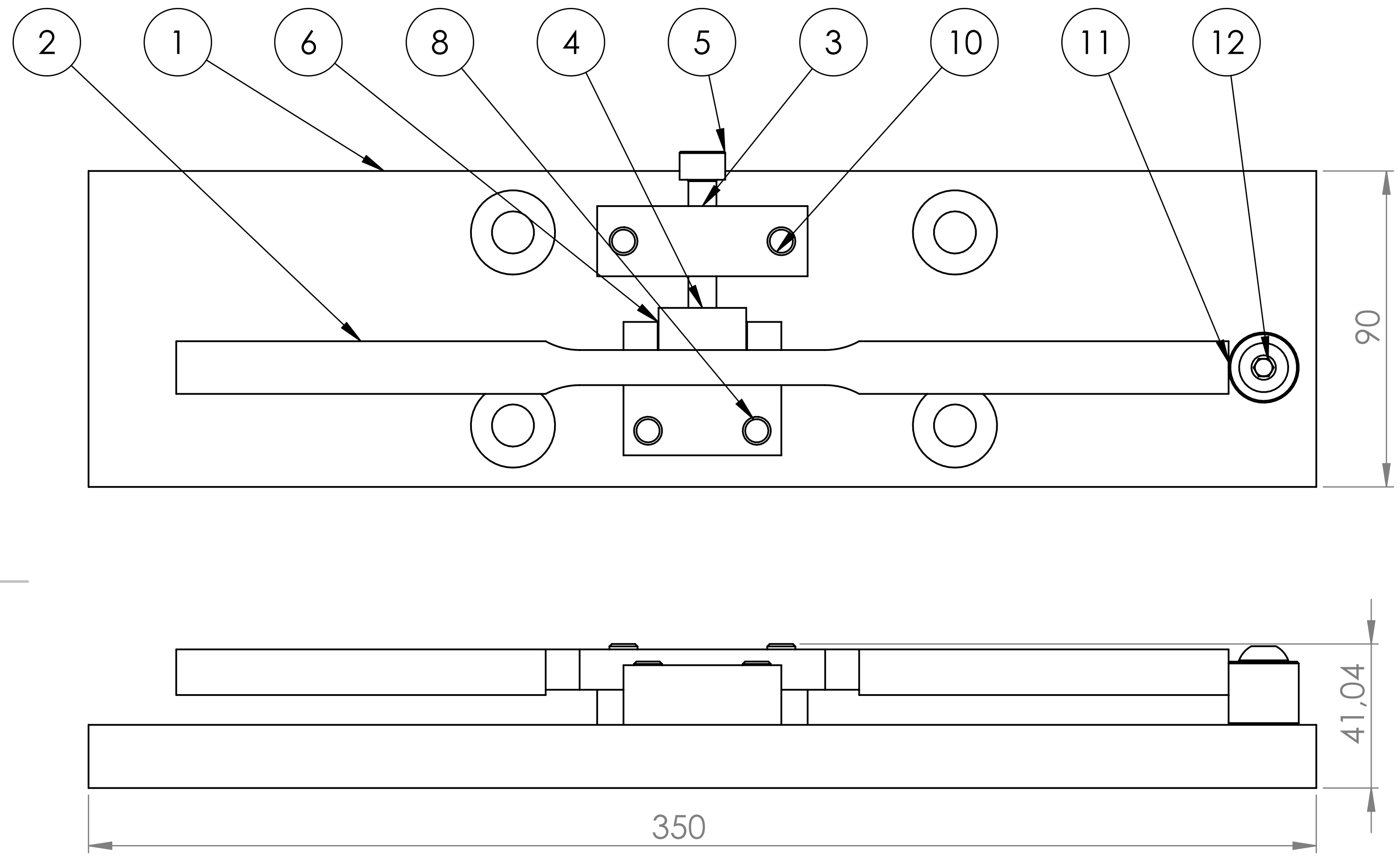
WEIGHT:

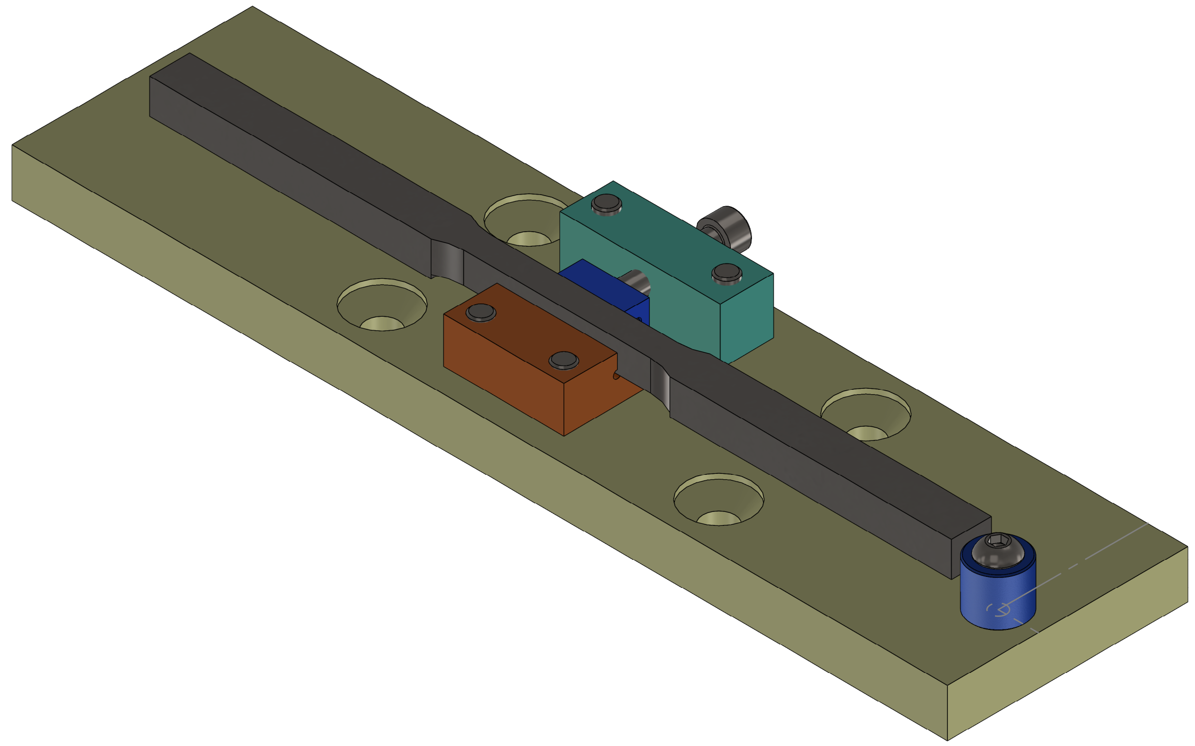
SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
			ISO 2687-m		
NAME	SIGNATURE	DATE	TITLE:		
DRAWN J.Ehrlich		2022	Tugi2		
CHK'D					
APPV'D					
MFG					
Q.A		MATERIAL: AISI 304L	DWG NO. Alustugi V2		A4
		WEIGHT:	SCALE:1:1	SHEET 1 OF 1	





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Kinnitus ehk alusplaat		1
2	Paindeekeha23		1
3	Alustugi 4.2		1
4	Tugi 4.3		1
5	ISO 4762 M8 x 60 - 28N	Poldi kuju on muudetud	1
6	Alustugi 4.1		1
7	ISO 7435 - M3 x 8-N		1
8	ISO 10642 - M8 x 35 - 35N		2
9	ISO 10642 - M8 x 20 - 20N		1
10	ISO 10642 - M8 x 40 - 40N		2
11	Distantspuks D20		1
12	ISO 7380 - M8 x 35 - 35N		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.EHRLICH		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: RAKIS 4 -KOOSTEJOONIS

MATERIAL: AISI 304L

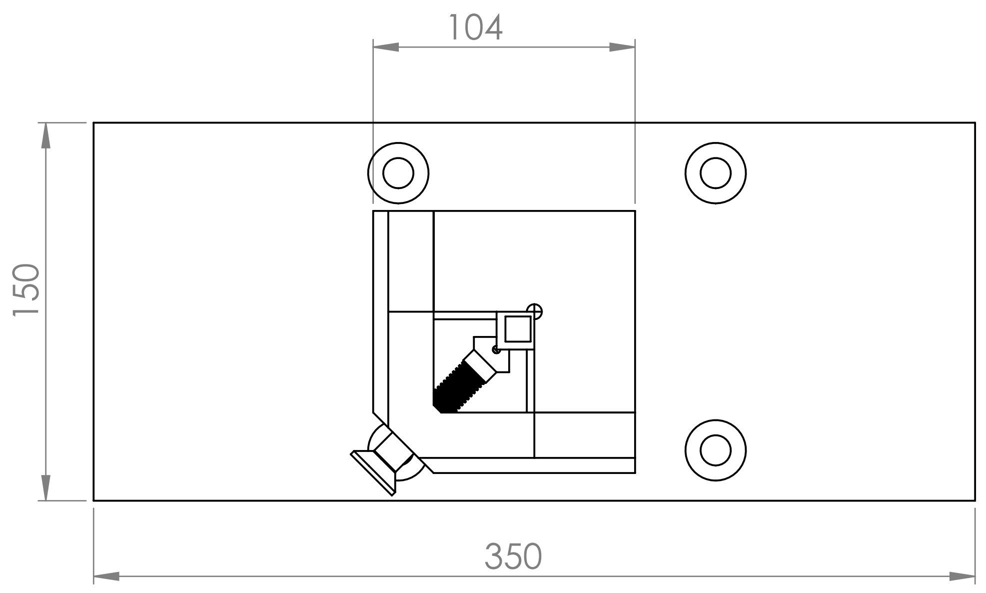
DWG NO. Rakis 4

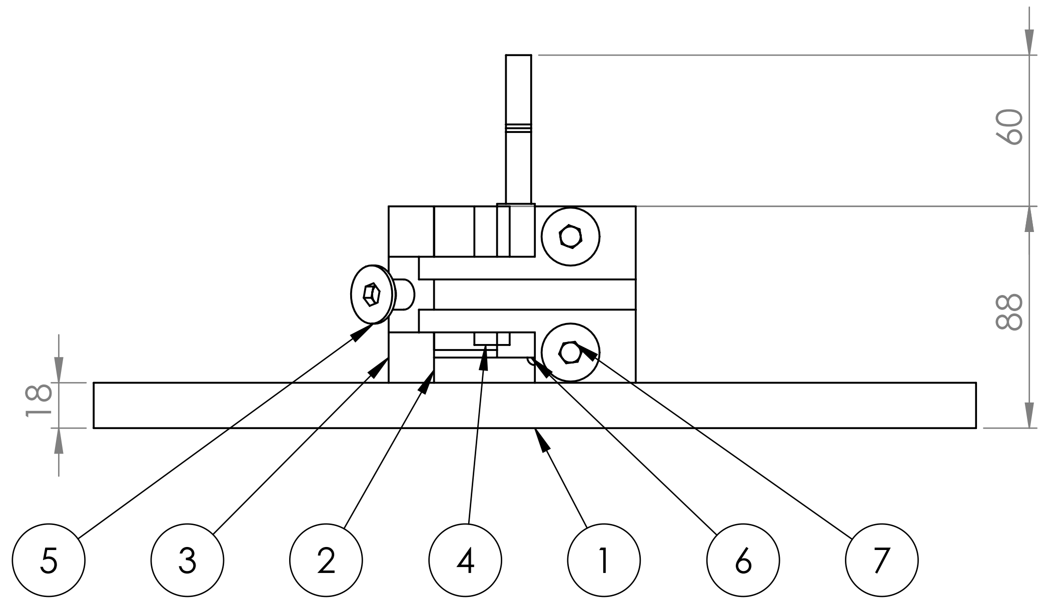
A3

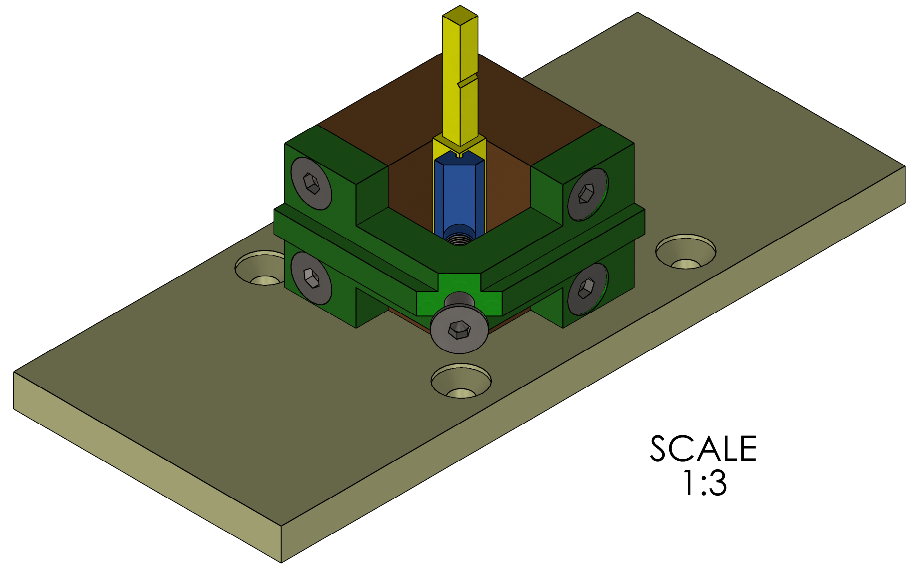
WEIGHT:

SCALE:1:2

SHEET 1 OF 1







SCALE
1:3

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Kinnitus ehk alusplaat		1
2	Põhitugi		1
3	Külgtugi		1
4	Liikuv tugi		1
5	ISO 10642 - M12 x 70 - 36N	Muudetud otsakuju	1
6	Katsekeha 3rakis		1
7	ISO 10642 - M12 x 30 - 30N		7

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.EHRLICH		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

RAKIS 3 - KOOSTEJOONIS

MATERIAL:

DWG NO.

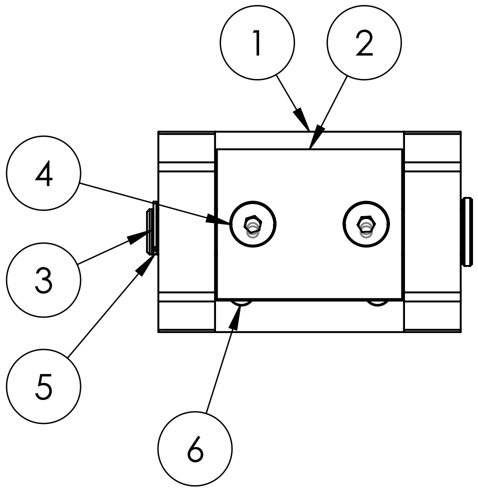
Rakis 3

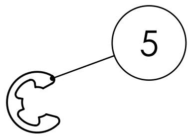
A3

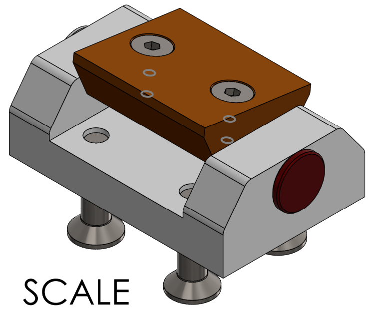
WEIGHT:

SCALE:1:3

SHEET 1 OF 1







SCALE
1:2

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Alus		1
2	Tugi 3		1
3	Võll		1
4	ISO 10642 - M6 x 20 - 20N		2
5	NETW08	Kinnitusrõngas	1
6	ISO 10642 - M8 x 30 - 30N		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

Liikuv tugi

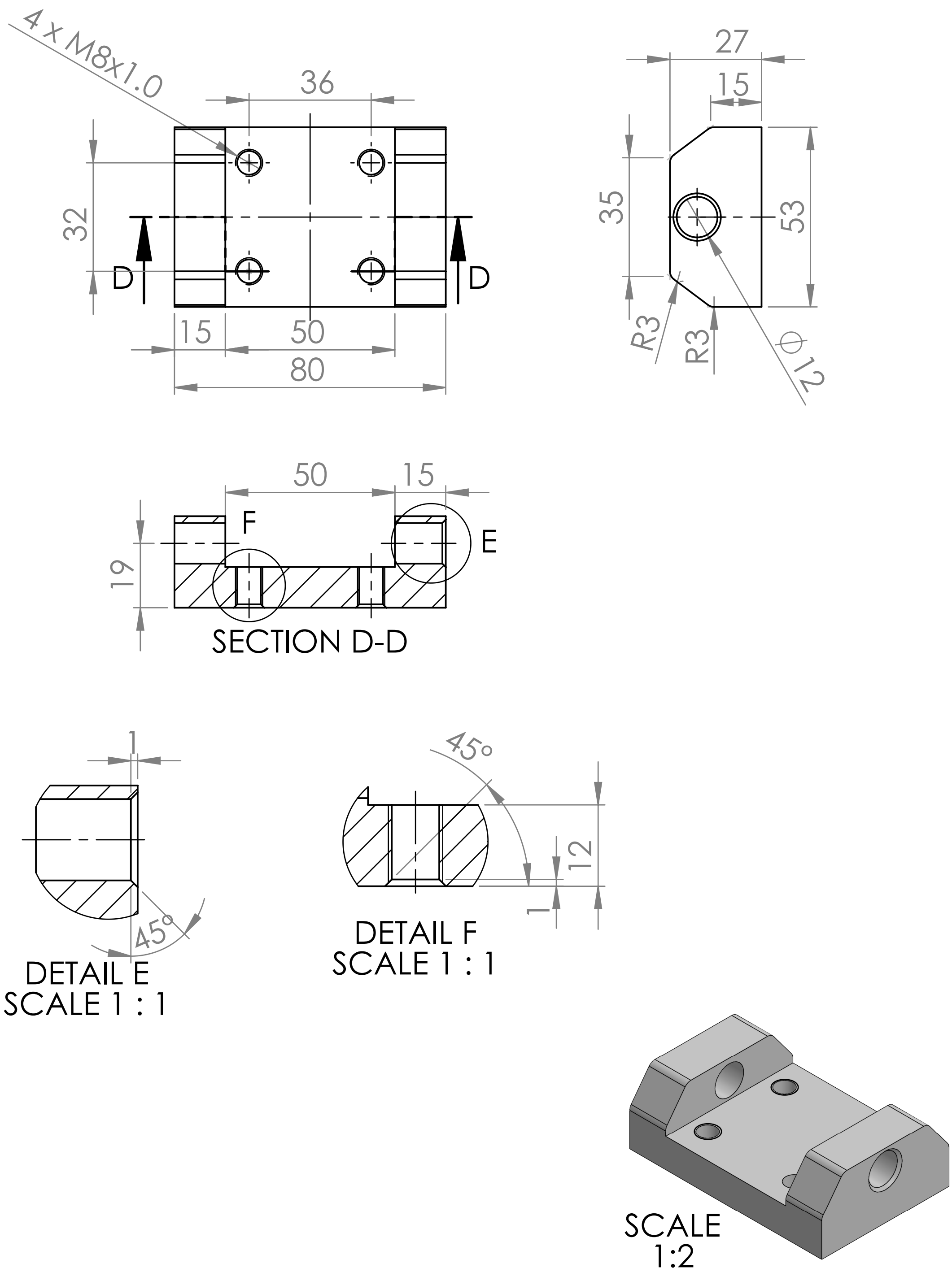
DWG NO.

Liikuv tugi

A4

SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: 0,8

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Liikuvatoe kinnitusalus

MATERIAL: AISI 304L

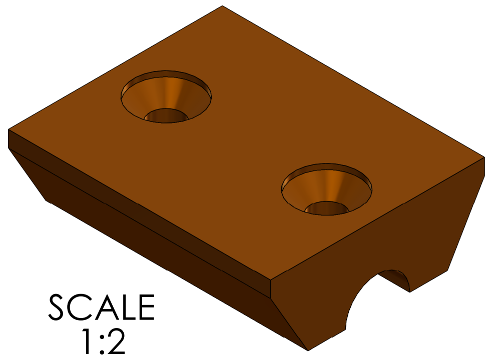
DWG NO. Alus

A4

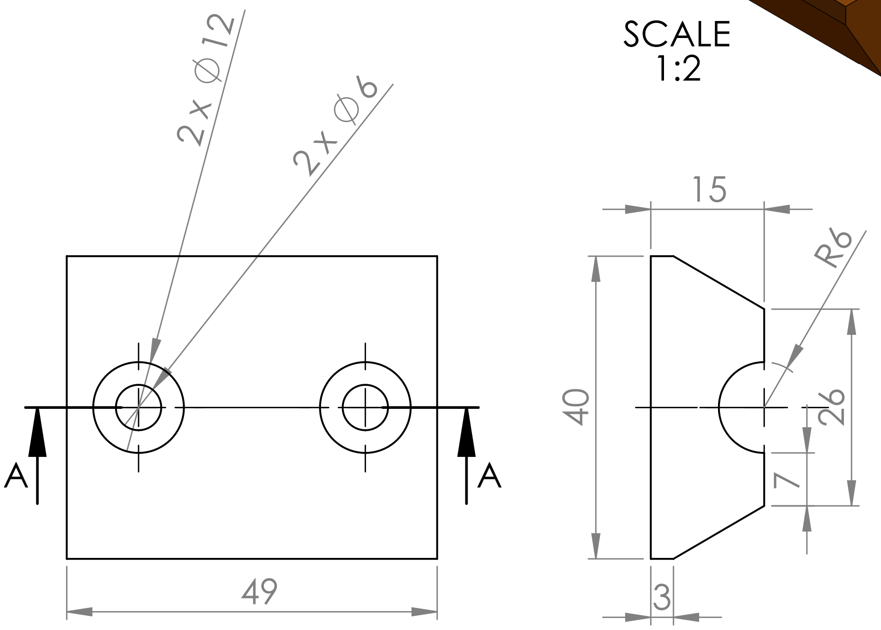
WEIGHT:

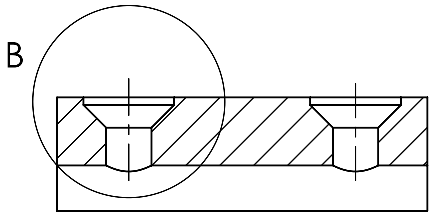
SCALE:1:2

SHEET 1 OF 1

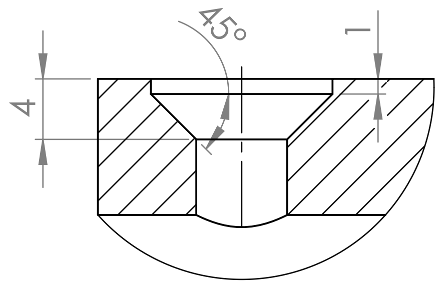


SCALE
1:2





SECTION A-A



DETAIL B
SCALE 2 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING REVISION A ISO 2678-m

	NAME	SIGNATURE	DATE
DRAWN	J.Ehrlich		2022
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Tugi 3

MATERIAL: AISI 304L

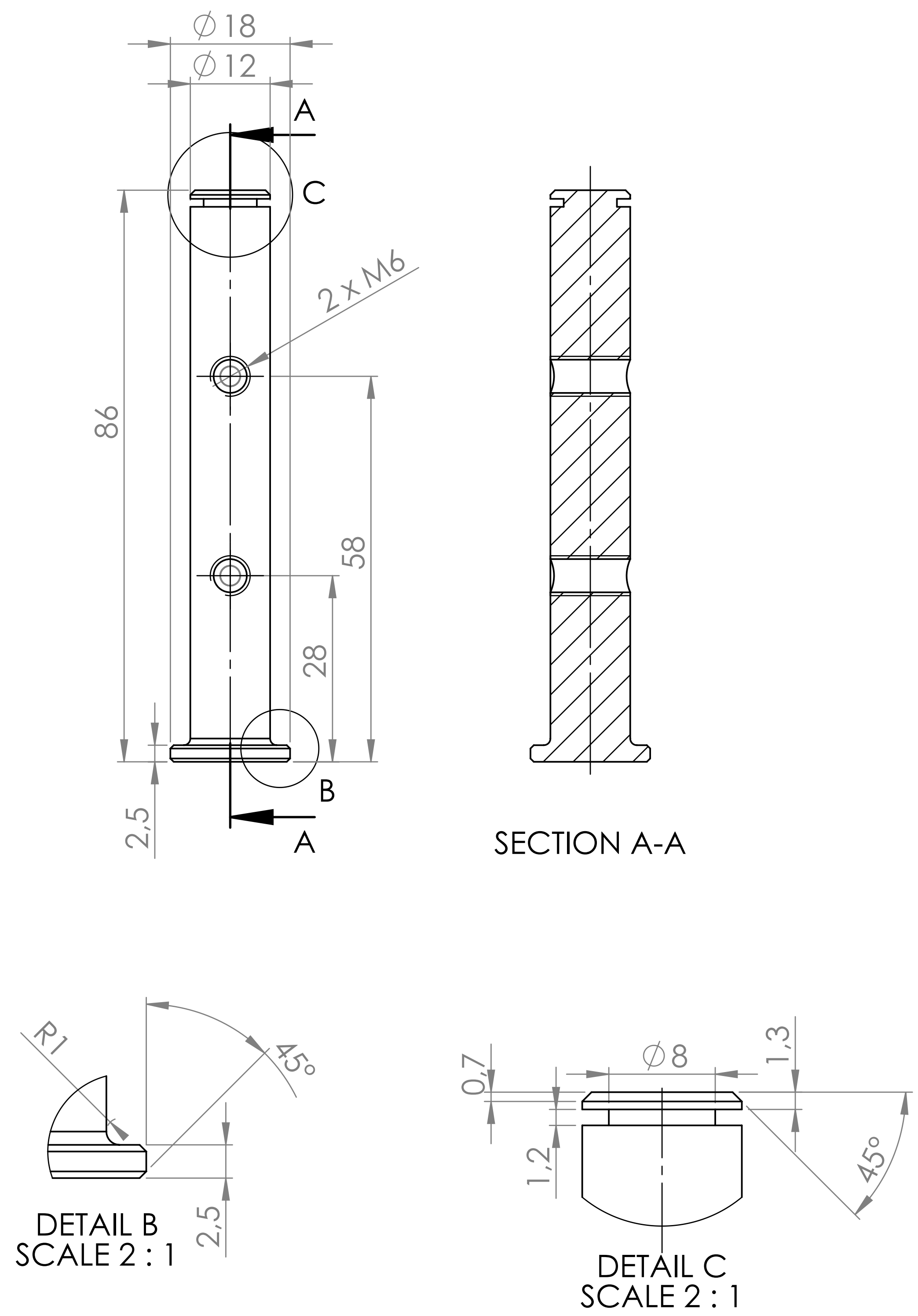
DWG NO. Tugi 3

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: 0,8	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
			ISO 2678-m	

	NAME	SIGNATURE	DATE	
DRAWN	J.Ehrlich		2022	
CHK'D				
APPV'D				
MFG				
Q.A				

TITLE: Liikuv alustoe kinnitusdetail

MATERIAL: AISI 304L

DWG NO. Võll

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1