# DESIGN WORKSTATION FOR A COLLABORATIVE ROBOT IN TAPPING PROCESS

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Mechanical Engineering and Production Technology Abstract
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Collaborative robots (cobots) can be used to improve the tasks that are currently done manually. This thesis aims to design a workstation for a collaborative robot application in the tapping process for Prolaser Oy. The workstation is evaluated for practicality.

For the purpose of writing this thesis, literature review was conducted along with correspondence with the commissioner. Information on the required dimensions was gathered through available standards. Creo software was used to model parts needed for the prototype. A simulation was done to demonstrate the assembly of all components by Visual Component software. Robot programs were made for testing phase after a setup with the prototype had been built.

The outcome shows cobot application can provide a more efficient alternative to the current manual method of tapping. However, this is only the case for mass production application. In conclusion, this thesis has potential to be deployed in an industrial manufacturing process to improve the productivity, as well as the quality of the tapping task.

Keywords Cobot, collaborative robot, workstation design, tapping application
Pages 36 pages and appendices 17 pages

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## Appendices

# 1 Background

This thesis is commissioned by Prolaser Oy to study collaborative robot tapping application and design a workstation for it. The thesis also includes the jig's design for sample products, which is required to be reliable and have a fast-fixturing system working during process.

## 1.1 ProLaser Oy

Prolaser Oy is a company of SVL Group, which is the largest waterjet and laser cutting company in Finland. They offer laser and water cutting services as subcontracting. With advantages in modern facilities and machinery, their products of laser cutting are enhanced. (SVL Group, n.d.).

## 1.2 Problems

The tapping process in Prolaser Oy is currently being done manually with a pneumatic tapping arm, as seen from Figure 1.

Figure 1. The current worktable for tapping process.

After the raw material has been laser cut into slabs, there is a worker who unloads them into a container. During this cutting process, the metal slabs also have holes cut into them. Another worker takes the slabs from the container for tapping. The slabs are put on a working table where the tapping arm is installed. On this table, there are locators to maintain the material in a designated position. After that, the worker uses the pneumatic tool to tap into the already made holes. With the current process, there are some aspects that can be improved upon. This method requires at least two people, one for the unloading process and one for tapping. By introducing a collaborative robot to the process, it can help reduce labour cost and risk of workplace accidents. Additionally, it also offers more consistent quality and productivity.

# 2 Objectives

Based on the meeting with a representative from Prolaser Oy, we have agreed on some aspects which both parties are concerned about. Basically, applying a collaborative robot to a repetitive manual process does not only relieve people from heavy workload, but also reduces the risk of errors as well as increases the quality and productivity of the task. In order for the technology to be utilized effectively, a working space with all the the necessary equipment should be available. The objective of this thesis is to design a workstation that is can accommodate all the equipment in one unit for the tapping process.

## 2.1 Requirements and questions

The outputs of this thesis, which are expected from Prolaser Oy, are mostly focused on the productivity of the application of the collaborative robot in the tapping process. The designs of the jigs and the worktable are required to satisfy the quick loading and unloading tasks. By saving time in this procedure, it helps to decrease significantly the time consumption in the production. Some of the main criteria that needs to be considered in this case includes fast and accurate positioning for the slabs, multiple parts loaded for a jig, and easy disposal for tapping chips. On the side of the collaborative robot, the accuracy and durability in an industrial workplace is also concerned. The productivity of the work is evaluated based on how many parts can be finished in a certain amount of time. This includes the whole process from loading slabs to the jigs to unloading completed products after being tapped for the next steps.

## 2.2 Scope

According to the main objectives, a number of tasks can be roughly planned. Firstly, the drawings of the sample products are requested from Prolaser Oy. With those drawings, jig designs can be made and sent back for commenting and modifying. After the designs are proceeded with, a worktable is designed to fit in a limited area. Then, the progress continues with making a simulation to demonstrate the designs and how the workstation appears when all the components are connected. Next, the real components are produced by

Prolaser Oy for programming and testing with the cobot. The results from the testing are gathered at the end of the process. For analyzing and assessing the application, the use of outcomes from the testing is essential. During the progress, if errors occur, their cause should be investigated and reported carefully in the final thesis report.

Based on the requirements, this thesis is conducted to test and analyse the efficiency and limitation of applying a collaborative robot to the tapping process. The robot, tools and equipment which are used in this thesis are the following:

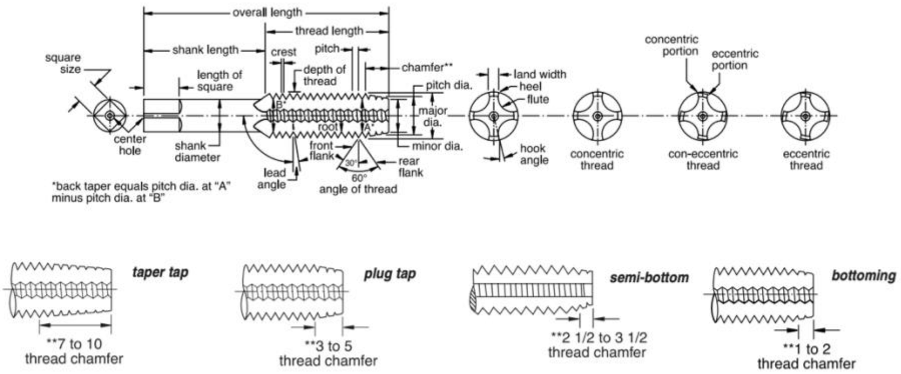
- Collaborative robot Universal Robot UR5e (see Appendix 10)
- Pneumatic motor Ober SP6R – 8731255 (see Appendix 13)
- Tapping spindle SPV Spintec GS-8E – 36470 (see Appendix 11)
- Tap holder SPV Spintec TK-8 M4 – 29852 (see Appendix 12)
- Tap holder SPV Spintec TK-8 M6 – 29874 (see Appendix 12)
- Tap holder SPV Spintec TK-8 M8 – 29887 (see Appendix 12)
- Tap tool Dormer M4 E001 6H 2RT0845658 (see Appendix 14)
- Tap tool DC N320V-4 M6 6H HSSE (see Appendix 15)
- Tap tool DC N320-4 M8 6H HSSE (see Appendix 15)
- Safety sensors system sBot Speed SICK sensor (see Appendix 16)
- Hose pipes, filter, regulator and lubricator for compressed air system

# 3 Fundamental knowledge

## 3.1 Tapping process

Tapping is one of the most important and common manufacturing methods. Depending on the requirements of strength and reliability of the threaded hole, the suitable taps can be selected. Tapping can be executed manually or automatically. There are three basic types of taps which are: taper, plug, and bottoming. All of these tap types is similar in thread form and size, but differences between them are in the chamfered parts at the tap point. In details, the numbers of tapered thread at the tap point vary from 1 to 2 for the bottoming taps, from 3 to 5 for the plug taps, and from 7 to 10 for the tapered taps. Additionally, the semi-bottoming tap is updated recently from 2.5 to 3.5 to fulfill the gap between plug taps and botoming taps. (Chapman, 2004, p. 591). As seen in Figure 2, tap nomenclatures are presented.

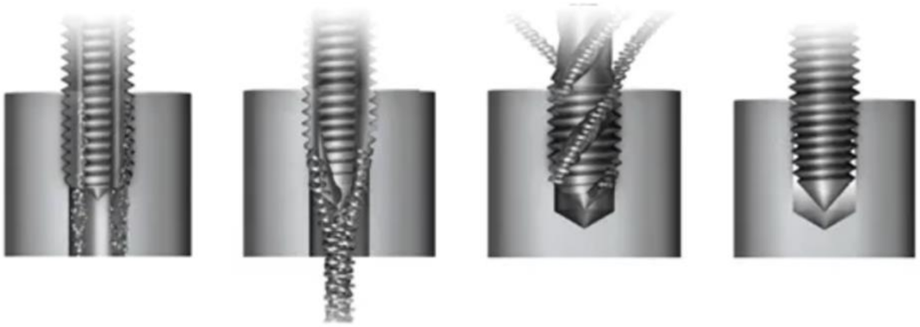
Figure 2. Tap terminology. (Chapman, 2004, p. 593)



There are two principle methods to creating taps, which are cutting taps, and forming taps. Generally, cutting taps produce internal threads by cutting the material from the drill hole until the desired thread depth is achieved, then reversing the tool to back it out of the hole. In another way, forming taps create threads by deforming the material around the hole walls in the shape of willing threads. While the cutting taps can be used for almost all sorts of materials, the forming taps only work well in ductile materials such as aluminum, soft steel and non-ferrous materials. In addition, forming taps require considerably higher torque than cutting taps. Moreover, based on the working functions, there are no chips produced by forming taps. Conversely, the chips from cutting taps are expulsed in two ways depending on the type of tapping operations, which are through-hole tapping and blind-hole tapping. The selection of taps is made based on clearly understanding the tapping operation which will be performed.

For more information, the term through-hole tapping is used to refer to the process of cutting internal threads the whole length of a hole that has previously been drilled completely through a workpiece. On the other hand, the term blind-hole tapping, or sometimes called controlled-depth tapping, is used to mention the process of cutting internal threads to a specified depth. This type of tapping operation is done in a hole that has been drilled into a workpiece but not completely through. It requires an accurate mechanism on the machine to control the depth of thread in this kind of tapping operation. Without the considerations to the precision of the machine, it can ram the tap into the bottom of the hole and cause tool failure or undesired thread. In opposite, through-hole tapping does not need accurate depth control. According to the type of hole being threaded, tap selection is influenced. It is affected by the way that chips are pushed out from the hole. Through-hole tapping requires the tap tool to push the chips out to the other side. The blind-hole tapping needs the chips to be pulled up and removed out to the same way that the tap coming in. (Kennametal, n.d.)

Figure 3. Different types of tap and chips generated. (Sandvik Coromant, n.d.)



As seen from Figure 3, types of tap are classified depending on chips expulsion. There are four principle types of tap from left to right: straight fluted tap, spiral pointed tap, spiral fluted tap, and thread forming tap. (Chapman, 2004, pp. 594—598).

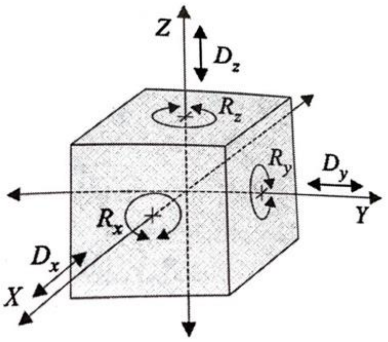
## 3.2 Jigs and fixtures

The main purpose of making jigs and fixtures in a manufacturing process is to produce identical components. Jigs and fixtures are typical tool-guiding and work-holding devices designed particularly for mass production. A setup action for every workpiece is not needed when working with them. Therefore, they facilitate production and ensure the quality of the products. Designing jigs and fixtures is dependent on the manufacturing method and the tools available in the operation. The use of jigs and fixtures brings out various benefits. Some significant advantages are growth in production, minimalizing changeability in the dimensions of the products, leading to stable quality of mass-produced items, decreasing manufacturing cost, making identical parts and with high precision, reducing inspection requirement and cost of quality control, as well as presumable decreasing manufacturing defects. Working with jigs and fixtures, every workpiece is appoximately set up to the same position in the manufacturing process, meaning that a predetermined tolerance is ensured to be applied for all parts produced. (Okpala & Okechukwu, 2015).

A jig is used to define a workholding device, which locates and holds a workpiece in a stable position. It aims to keep the products from slippage and vibration during manufacturing process. A fixture is also a workholding device, and has a similar purpose in use as a jig. However, the difference between a jig and a fixture is that, while a jig is used to guide the manufacturing tool, a fixture does not provide any guidance to the production tool. Both jigs and fixtures are required to be produced in the highest accuracy as well as be designed for quickly mounting and disassemblying the workpiece by operators or robots. (Benhabib, 2003, p. 363).

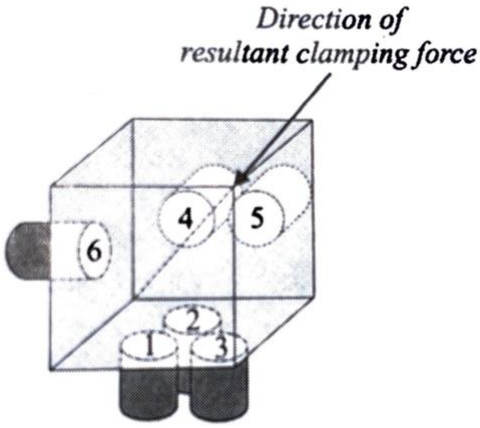
A solid body without any contraints has six degree-of-freedoms (DoF). Those are three degrees in translational movement along x, y, z directions ($D_x$, $D_y$, $D_z$) and three degrees in rotational movement along x-axis, y-axis, z-axis ($R_x$, $R_y$, $R_z$). The axes are addressed at the center of mass of the part. The demonstration of the six DoF is shown in Figure 4.

Figure 4. Mobility of a solid body. (Benhabib, 2003, p. 365)



To eliminate totally the mobility of a part for machining processes, the “3-2-1 principle” is commonly applied. Kinematic constraint of a workpiece is defined only when a fixturing system satisfies the “3-2-1 principle”. The explanation of the “3-2-1 principle” is presented below with Figure 5.

Figure 5. The “3-2-1 principle”. (Benhabib, 2003, p. 365)



This principle constrains vertical (z-axis) translation movement and rotation along the two other axes by establishing three-point contacts on the largest surface area of the workpiece. This is called “3” as it stabilizes the part by constraining three DoF motion. Locators making two-point contacts with the part upon the second largest surface area prevent translation movement in x- or y-axis and rotation along z-axis. “2” in “3-2-1 principle” is named so for the constraint on two DoF motion. Likewise, one-point contact with the other surface area contrains one DoF motion, translational movement in the remaining axis. (Syam, 2021).

## 3.3 Collaborative robot

“Three laws of robotics” were initially introduced by Isaac Asimov in 1942. The first law expresses that “A robot may not injure a human being or, through inaction, allow a human being to come to harm”. The second law states that “A robot must obey the orders given it by human beings except where such orders would conflict with the First Law”. The third law says that “A robot must protect its own existence as long as such protection does not conflict with the First or Second Law”. (Asimov, 1950, p. 40). According to those principle rules, an industrial robot is always deployed with various safety components for preventing risks to human beings. Although industrial robots are normally strong, fast, and accurate, there are still applications that need collaborative operation between the robots and people. To meet this demand, collaborative robots (cobots) are constructed to have properties that allow them to work safely along with human. With cobots, possibilities such as flexibility, productivity, and fenceless production cell, are expected to be developed.

The global market size of collaborative robots (cobots) in 2020 was valued at USD 590,5 million and is anticipated to reach USD 1990,2 billion by 2030 with a compound annual growth rate of over 12% in the period of time from 2021 to 2030. (GlobeNewswire, 2022).

Cobots are typically small in size with less payload than industrial robots. However, they are expected to execute a more diverse set of tasks than that of industrial robots. One of the most important reasons is that cobots are easier to program. (Kilda et al., 2018, p. 1). Due to a fewer number of objects needed in the workspace, deploying a cobot production cell is quicker and simpler than doing the same task with an industrial robot.

Depending on the application the robot cell is conducting and how the shared working space is arranged, the type of collaborative operation is determined. Table 1 gives an overview of four principle techniques which can be involved in collaborative operation.

Table 1. Types of collaborative operations. (Mihelj et al., 2019, p. 177)

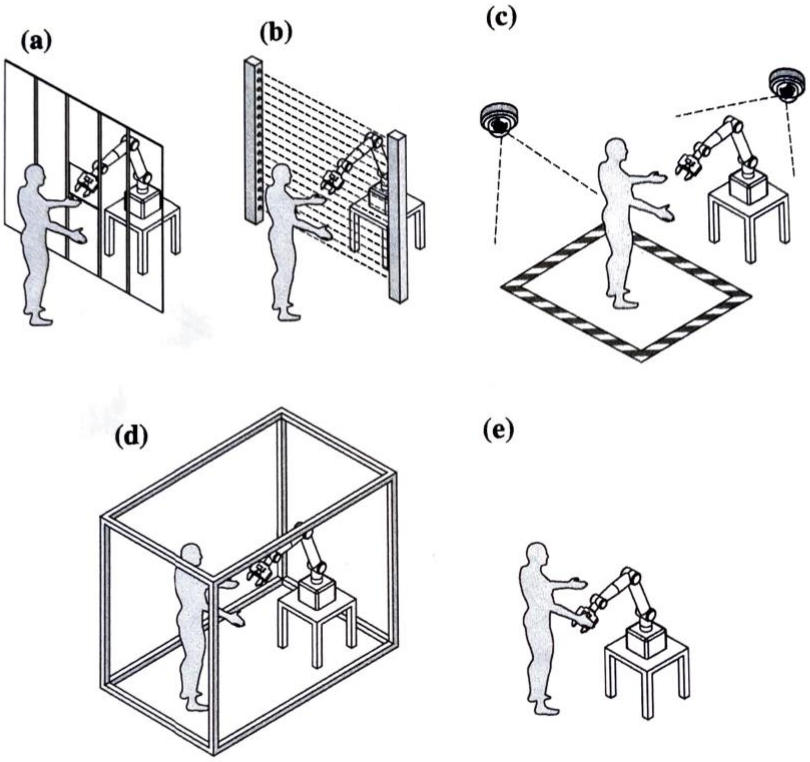
| | Speed | Torques | Operator controls | Technique |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Safety-rated monitored stop | Zero while operator is is collaborative workspace | Gravity and load compensation only | None while operator is in collaborative workspace | No motion in the presence of the operator |
| Hand guiding | Safety-rated monitored speed | As by direct operator input | Emergency stop, enabling device, motion input | Motion only by direct operator input |
| Speed and separation monitoring | Safety-rated monitored speed | As required to maintain min. separation distance and to execute the application | None while operator is in collaborative workspace | Prevented contact beween the robot system and the operator |
| Power and force limiting | Max. determined speed to limit impact forces | Max. determined torque to limit static forces | As required by application | Robot cannot impart excessive force (by design or control) |

The division of collaborative robot’s applications is categorized into five concepts, as shown in Figure 6 below. The applications of hand-over window are used for loading, unloading, testing, benching, cleaning, and service missions. The robot executes tasks within a safeguarded area, which is surrounded by fixed or sensitive guards. Working in this space, the robot has no limitation in automatic mode. Operator interacts with the robot through a window, at which point the robot decreases its moving speed. The robot does not work outside the window. The applications of interface window cover automatic stacking/de-stacking, guided assembling, guided filling/un-filling, testing, benching, cleaning, and service tasks. When the robot is coming close to the window, its speed is reduced. An interface window is placed between the operator and the robot. At this window, the robot stops and can be manually moved by operator outside the safeguard space. It is required a hold-to-run control for the operator to guide robot movement. The applications of collaborative workspace are used for common assembling, common handling, testing benching, cleaning, and service tasks. A common collaborative working area is where the robot works. Its speed is declined and/or stopped when an operator interrupts the shared workspace. Using one or more sensors to detect a person entering the working area is required. With this sensors system, the robot can work safely beside a human by stopping when the prohibited area is accessed and restarting automatically after clearance.

The applications of inspection focus on inspection and parameter tuning tasks such as welding application. It needs a workspace surrounded by fixed or sensitive guards. In this area, a person-detection system or an enabling device is attached. When an operator enters the shared working space, the robot moves slower in a smaller area. To avoid misuse, additional measures are necessary. The applications of hand-guided robot can be used in hand-guided assembling, painting, and other similar missions. A hold-to-run control is equipped onto the robot. The robot is guided by the operator using hand-guiding device along a path in a specific workspace. In this application, the robot moves with reduced speed. Based on hazards of the task, the area of shared working space is limited. (ISO 10218:2011, 2011, pp. 65—66)

Figure 6. Conceptual applications of collaborative robots: (a) hand-over window, (b) interface window, (c) collaborative workspace, (d) inspection, and (e) hand-guided robot. (Mihelj et al., 2019, p. 186)



## 3.4 Cobots in tapping process current status

There is an application of cobot with tapping process introduced in the market currently. The application in question requires a cobot working along with a flexible tapping arm. The tapping station is a combination of a Forge station, a Universal robot UR10, and a FlexArm A-32 tapping arm. Additionally, the cobot controls an end-effector containing two parts. An air-powered magnetic gripper is used to grab and position the slabs to the working place, where the cobot is connected to the FlexArm tapping arm. This means that, the cobot carries two different roles, which are loading and unloading the workpiece to the tapping position on the worktable, as well as maneuvering the tapping arm to execute the tapping action. There is also a station installed with a sensor system to distinguish the two kinds of products mixed in the stack. Last but not least, the self-developed programming software makes this design of workstation significantly different from other designs of cobot tapping application. This can be seen in the video *Tap Your Parts with a Cobot - Automated Tapping with a Forge Station and FlexArm A-32* (READY Robotics, 2020).

With this application, the advantage of using a tapping cobot comes from its ability to load and unload the products as well as doing the tapping process by using the tapping arm. However, the speed of the process needs to be considered. Basically, the deployed cobot here is just for replacing the apperance of an operator. There simply is no collaborative action between the human and the robot. So, the role of the cobot in this application design can be applied to an industrial robot with more efficiency in practice.

## 3.5 Risk evaluation

There are four levels of collaboration in working with robots as presented by Aaltonen et al. (2018, p. 95):

- No coexistence: physical separation.

- Coexistence: human works in (partially or completely) shared space with the robot with no shared goals.

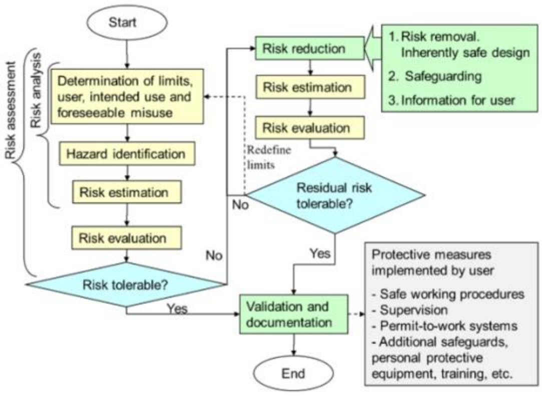
- Cooperation: human and robot work towards a shared in (partially or completely) shared space.

- Collaboration: human and robot work simultaneously on a shared object in shared space. Physical contact is allowed, possibility for hand-guiding.

According to the level of collaboration, the safety level is defined. The risk for an operator is not highly considered when there is no coexistence. However, with the three other collaboration levels, it is more difficult to analyze the difference of the hazard.

The collaborative robot's safety design progress is an application of the safety design process for machinery, as shown in Figure 7. Following this process, first the risk assessment is analyzed to examine parts of the machine, where the safety measures need to be applied to. Generally, assessing the risk is a must for recognizing risks. By identifying risks, a comparison between the risks and hazard list of ISO 10218-2 is made. After that, the risk estimation phase can be done according to the standard where it is demonstrated in. However, if the risk is not similar to any from the standard, the above process needs to be completed and detailed carefully. When the risk is identified and evaluated, the selection of safety measures can be applied. Arguments are required for proving the solution, which is not included in the standard. To reduce risk, there are three steps to follow. Eliminating risk by utilizing an inherently safe design is the first step. Using safeguarding to the design is done second. And the last step is informing the operator about the risks. The inherently safe design relates to choosing and deploying the smallest collaborative robots, which cannot hurt people.

Figure 7. Safety design process according to ISO 12100:2010. (Malm et al., 2019, p. 5)



# 4 Solutions

Based on the requirement from Prolaser Oy, the area for the workstation is limited between 600 mm in width and 800 mm in length. Additionally, the design of the workstation for the collaborative robot can be in similar form to that of a welding table. After receiving the drawing of samples, which are required for the thesis, the jigs are designed based on some main criteria: reliability, the loading and unloading speed of the fixturing system. When the jigs have been modelled, the simulation is started with the 3D model of the working table, the right type model of the robot and the jigs as well as the right tool. After this, the simulation is sent to Prolaser Oy for commenting on what needs to be improved or modified before making the real jigs from the 3D design. It does not take a long time to produce the jigs. Right after receiving the jigs and samples from Prolaser Oy, the testing phase is executed to get the result in a real situation for analysing and giving conclusion. In the testing phase, a simple set up with aluminium extrusion, similar to the designed workstation for the robot, is made and the compressed air system needs to be ready. In addition, before the testing can be run, the collaborative robot is required to be programmed. The collaborative robot programming must be completely safe, as well as easy for understanding and modifying, because the system might be run by an operator without robotics expertise in the future.

## 4.1 Jig and tool holder designs

According to the drawings of the slabs requested from Prolaser Oy, the idea for the jigs is generated to solve the fundamental requirements, which are suitability for two different sizes or designs of sample products, reliability, and fast loading and unloading for fixturing process. Based on this, the jigs are designed into 3 separate parts named ‘bottom’, ‘middle’ and ‘top’. The ‘bottom’ part is located, as per its name, at the bottom, where it comes in contact with the working table. The objective of this part is to make a plane for the products to stay in the jigs during the assembly and tapping processes. The ‘middle’ part is created with the aim of positioning the products into the right location in the jigs and also keep them from moving or rotating during the tapping process. Similarly, while the ‘bottom’ part acts as a base for the products when the tap tool starts cutting, the ‘top’ part plays the role of holding the parts in place when the tap tool moves out. Moreover, there is an extra part in the designs of the jigs for people to handle it during assembly and fixturing process more conveniently. The prototype of the jigs are produced as seen from Figure 8 and Figure 9.

Figure 8. The jigs design for first sample product. (bottom, middle, top)

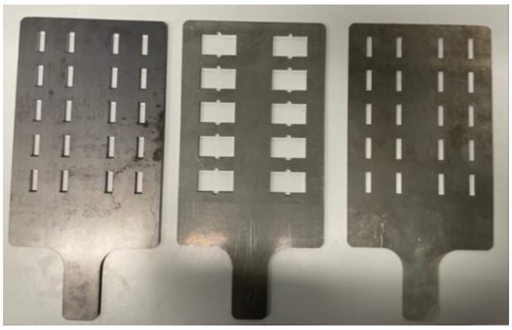
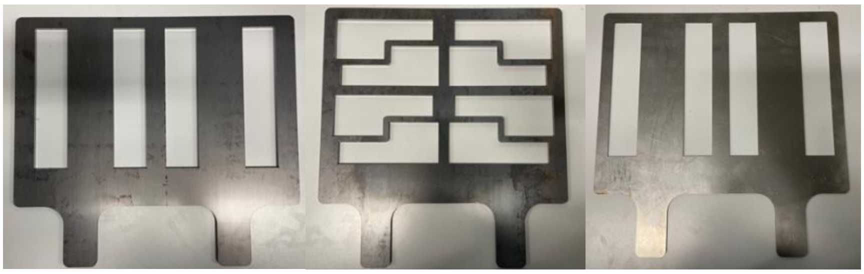


Figure 9. The jigs design for second sample product. (bottom, middle, top)

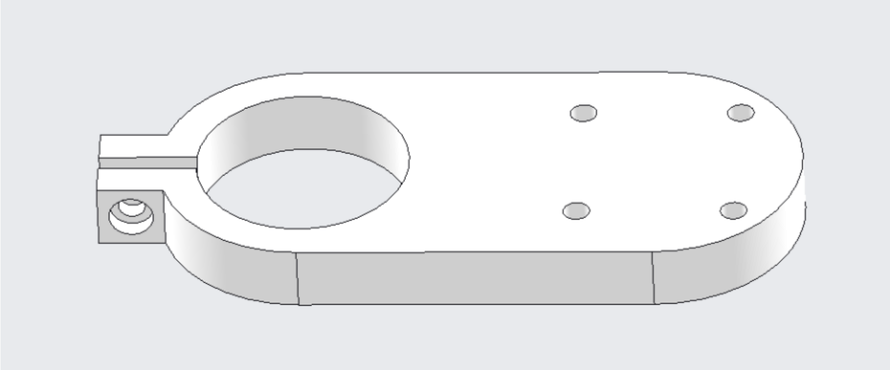


The process of assembling the jigs and inserting the slabs into the designed slots can be divided into 4 steps. Firstly, the bottom part is placed at the assembly location. After that, the middle part is put on top of the bottom one for inserting the slabs into the slots. Before completing the jig assembly process by locking C-clamp pliers, the top part is placed on top the middle one while the slabs are in the right positions. When the C-clamp pliers are locked, the jig is ready for the tapping process, as shown in Figure 10.

Figure 10. Setup of the jig for tapping process.

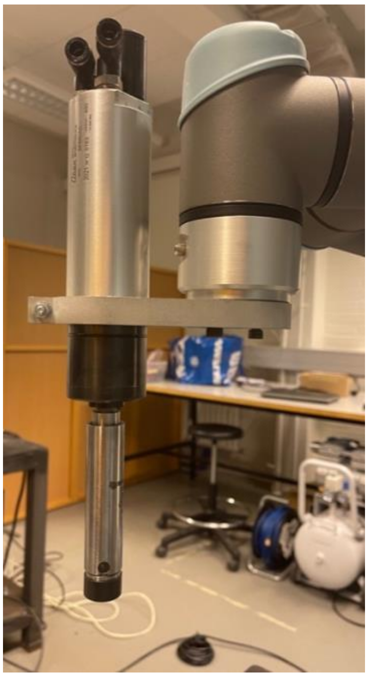
To attach the pneumatic motor Ober to the end flange of UR5e robot, the tool holder is considered to have a simple design to produce. However, it is still required to satisfy the geometry of the devices which can be found in manufacture's manual documents. For more details, the end flange of the collaborative robot has four screws for connecting the tool effector and the pneumatic motor has a round part for attaching a tool holder. The design of the tool holder can be seen as Figure 11.

Figure 11. Tool holder design.



The total weight of tool setup in this case is about 2178 grams, which is suitable for the handling capability of the UR5e collaborative robot. The setup of the motor to the cobot is shown in Figure 12.

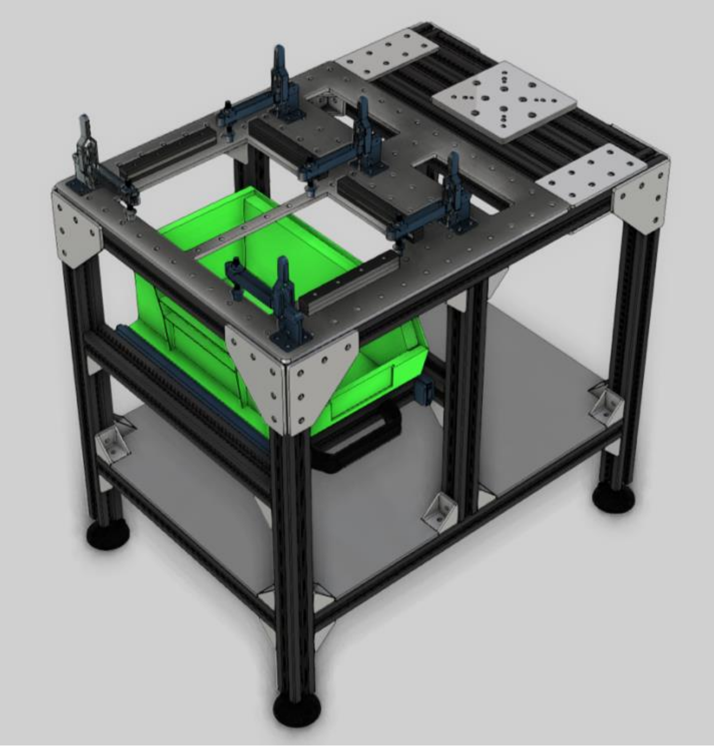
Figure 12. Setup of pneumatic tool with the cobot.



## 4.2 Worktable design

Worktable is where the robot is installed for the tapping process to be done. The idea for designing the worktable is that it must be stable and easy for assembly. The reason is to avoid vibration during the work process. Beside that, the ease of assembly can increase the possibility of changing or extending the design of the working area in the future according to the demand of the production. With those considerations, the worktable is designed in a structure of aluminium extrusion profiles. On top of the table, there is a plate for mounting the collaborative robot, and there is also an area for placing the jigs in the tapping process. To fix the jigs to the worktable, there are some clamps which can be quickly locked and unlocked during the work progress. The clamps are easy to set up based on the design of the jigs for different products. Under the location of the jigs, there is a drawer slide with a box which helps to easily remove the chips falling down after being taped from the slabs. Moreover, the space under the collaborative robot is reserved for the robot's control box. With this design of the worktable, the safety sensor system can be installed at the two legs of the table to create a safety area for detecting the movement around it. The worktable design can be seen as Figure 13.

Figure 13. Design of worktable.



## 4.3 Simulation

Creating a simulation has advantages in speeding up the design phase for a robot cell. In particular, in this thesis, the simulation can help in predicting the performance of the collaborative robot. It is possible to optimise the movements of the collaborative robot by analysing the result of the simulation. Besides that, in case there are some changes in the design before production, it is easy and fast to update those to the simulation for checking errors. These benefits of making a simulation can significantly reduce the time consumption of designing a robot cell as well as eliminate the risk when deploying the robot at a work site.

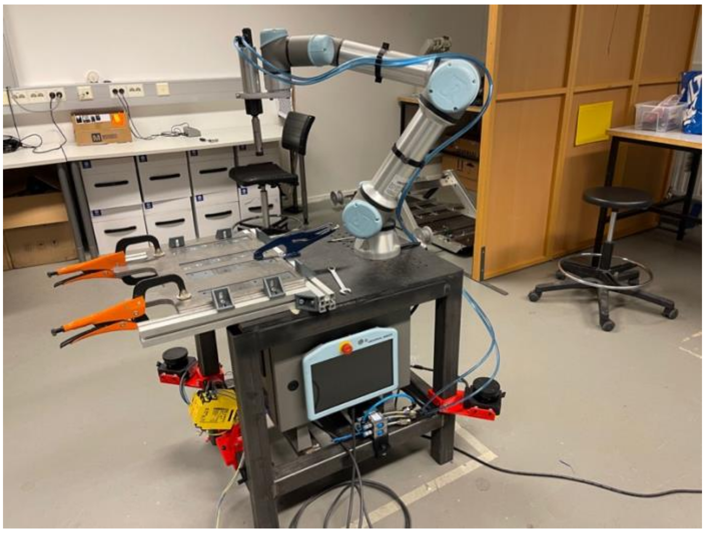
The simulation for this thesis can be seen via following link:
https://kaltura.hamk.fi/media/Simulation_layout/0_a5p4besb

Visual Component 4.3 is the simulation software used to simulate the tapping process for the UR5e robot. The general progress can be described briefly in a number of separated steps. Above all, understanding objectives of the thesis and its requirements is one of the most important things to begin with. In the next step, planning the robot cell design for cobot application in tapping manufacturing method helps the working flow to run smoothly. After this, the selection for equipment, which is available in the software library, is made. In this case, a model of UR5e robot is ready to use. However, for specific components such as worktable and clamps system or the jigs and required products, it needs to be customized and imported to the software. When all the necessary components for the simulation are prepared in the software, they are firstly needed to be assembled into the right positions according to the robot cell design. The programming for the virtual robot to execute the task can demonstrate all the movements of robot in working process. In case there is impact between the robot and the environment around it, the simulation needs to be modified and updated. Finally, the simulation can be exported to share to others for commenting and preparing to manufacture real components with the following steps.

## 4.4 Setup cobot, tools and equipment

With the purpose of programming the cobot and testing the main function, the setup is comprised of available resources in the HAMK Robotics Lab. As seen in Figure 14, the locations of the cobot and the jig are similar to those in the mentioned simulation. The pneumatic motor is attached to the robot with the use of the tool holder. For the pneumatic motor to function, it needs an air compressor system. The compressed air travels from the main system to the motor through hose pipes. Before reaching the motor, the air first goes through a filter to remove any unwanted components. After that, it continues to a regulator, which controls the exact level of pressure to avoid overloading the motor. A lubricator then supplies a small amount of lubricant to the motor for the duration of the operation. There is a valve that controls the air flow coming out from the lubricator. This is followed by another valve to direct the air into one of the two inlets of the motor. Each inlet corresponds to a rotation of the motor. The two valves are controlled by the I/O signals sent from the control box of the cobot. The signal of the valve which controls the air flow right after the lubricator is connected to the port named ‘Configurable Output 5’. While the other valve’s signal is contacted to the port named ‘Configurable Output 4’. In addition, the safety sensor system is also connected to the same control box. The setup of the jigs as seen from Figure 10 is placed onto the working table and secured by a clamp. Only when the setup is completed will the next step be taken.

Figure 14. The setup for cobot programming and testing.



## 4.5 Robot programming

To begin with, some notes which need to be focused on before programming robot are that the programs of the robot should be simple to understand and easy to modify. It is because the robot operator, who mainly works with the robot in future, may not have expertise in robotics and programming.

In the program for the first sample products, there is only one size of the tapping needed to be done. However, in each slab, there are three positions for tapping. With that information, the idea of programming is to apply the ‘palletizing program’ which is already made as a template in the ‘program’ tab. ‘Palletizing program’ allows the robot to perform picking-and-placing parts between areas, but in this situation, it is programmed to do the tapping actions for multiple items.

In the beginning of the program, there is a ‘BeforeStart’ section. The commands in it will be executed before the main section of program. ‘Assignment’ command is used for assigning the specified variable with the value which is entered or confirmed by the robot operator. The first command with the message: ’Jig ready? M4 tool ready?’ will activate a pop-up window to ask the operator to confirm if the right jig and tool is attached to the right position as well as to the robot. After that, the ‘If’ command is executed depending on the signal or the value of variable. In this case, the program only continues when the answer of previous ‘assignment’ command is ‘True’. It means that the operator confirms the readiness of the jig and the tool for tapping process. Inside the ‘if’ command, there are two ‘set’ commands, which are used for closing the valve controlling the compressed air flow to the pneumatic motor. The other ‘assignment’ commands in the same level of this part are for counting and activating when the safety sensors are triggered. After every signal is ready to run the main program, the robot is programmed to move to the ‘home’ position by a ‘moveJ’ command. The ‘moveJ’ command stands for moveJoint which controls the robot to reach a position in the fastest path. This command is used to move the robot quickly to a given destination for reducing the time of the robot movement.

‘Robot Program’ section is the main program for the tapping process. Firstly, a folder named ‘M4 tapping’ is created to help in tracing back and easier in modifying in case there are some changes in the program. Inside this folder, a ‘moveJ’ command for controlling the robot to go back to ‘home’ position is made. The reason why to put a similar command in the beginning of ‘Robot Program’ section compared to in the last of ‘BeforeStart’ section is that the commands in the ‘BeforeStart’ section run only once when the program is started. Conversely, the commands in the ‘Robot Program’ can be looped during the working time.

The jig for the first sample products has 10 slots corresponding to 10 slabs to be tapped in a sequence. Based on how many products needs to be tapped, a ‘loop’ command is created to loop the actions with the same number of times. Inside the ‘loop’ command, a ‘palletizing’ template command is added. As mentioned above, this template command is used for applying the same actions of a robot to multiple products. The ‘palletizing’ template command required operator to add some parameters for full setup. When the ‘Pallet_1’ command is selected, in the ‘Pallet Properties’, a parameter of ‘Object Height’ needs to be confirmed. For this case, the thickness of the sample products can be used to fill in. Next, it needs to define the pattern of parts in a sequence, or in the jig in this situation. According to the arrangement of the products in the jig, the type of pattern is chosen in ‘grid’. After the selection of ‘grid’ type for pattern definition, the ‘Grid_Pattern_1’ is automatically created. However, it is still required for the operator to setup two variables, which are ‘Rows’ and ‘Columns’. This step is for determining the number of products in each direction in the grid pattern. To finish the programming for defining ‘Patterns’, the positions of four corners of the grid pattern needs to be set. The order of these four destinations are arranged in counterclockwise direction. Only when all of these four positions are set up, the definition of ‘Patterns’ is completed. The process is now continued with ‘Layers’ section, which is still belonged in the ‘palettizing’ command. In this section, it will first ask for how many layers in the sequence and require defining also the pattern for each layer.

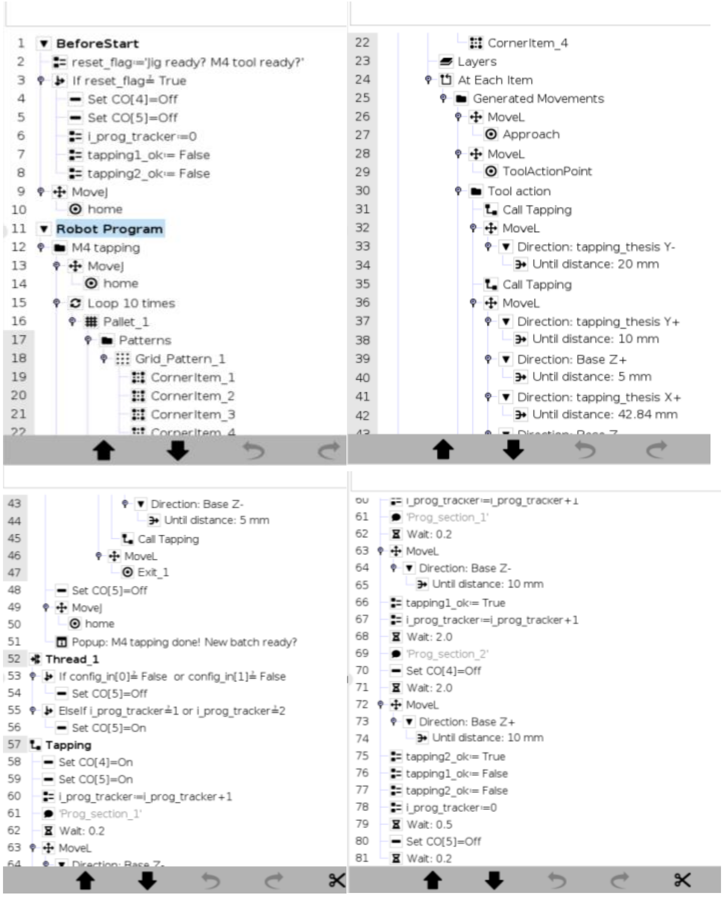
Because there is only one layer of jig in this case, it is simple to add the grid pattern, which is already defined above, directly to this part. When the setup of ‘Layer’ section is ready, the program continues with ‘At Each Item’ section. In this step, the actions of the robot, which will be copied to every product, is programmed. By selecting the ‘At Each Item’ command, there is a wizard to proceed. This wizard needs six steps to be finished. Following the instructions of the wizard, in the first step, the programming asks to move robot to the destination of the ‘CornerItem_1’, which is set before. Then, it moves to the next step to define an ‘Approach’ position. Again, the wizard continues moving back to the ‘CornerItem_1’. After that, it is required to set an ‘Exit’ position. When every step in the wizard is defined, the process of this is complete. The program automatically generates a sequence of movements for the robot as a folder named ‘Generated Movements’. There are three main movements of the robot inside this folder. The ‘Approach’, the ‘ToolActionPoint’ and the ‘Exit’ are the positions corresponding to these movements. Between the movements of the robot from the ‘ToolActionPoint’ to the ‘Exit’, there is another folder named ‘Tool action’. The explanation for the robot’s action in this ‘Generated Movements’ folder can be described in this way. Before the robot moves to ‘ToolActionPoint’ position to execute the tasks in ‘Tool action’, it travels to the ‘Approach’ destination first to keep the item’s orientation and direction regardless of the other item’s orientation. The purpose of the ‘Exit’ position, where the robot moves to after finishing all the tasks in ‘Tool action’, is also similar to that idea of the ‘Approach’ position. As mentioned before, the ‘Tool action’ folder contains the main tasks for the robot to execute in each product. In this folder, there is a subprogram named ‘Call Tapping’ which is programmed to do the tapping action. When this subprogram fully runs, it means that there is one tap completed and the robot is back to its position away from the slabs. The details about actions in this subprogram will be demonstrated later on. Coming back to the ‘Tool action’ folder, when the robot reaches to the first ‘ToolActionPoint’, the actions in this folder are activated. The robot does the first tap, then moves to the direction of Y- an amount distance of 20 millimetres for executing the second tap. Finishing the second tap, the robot continues moving as direction Y+ for 10 millimetres, then up to direction Z+ for 5 millimetres, next to direction X+ for 42.84 millimetres, and down to direction Z- for 5 millimetres. At this position, the robot does the last tap to complete the whole tapping process for the first product. This sequence is looped for 10 times corresponding to 10 slabs in the jig. When every tap is finished, the ‘set’ command is created to shutdown motor and the robot moves to the ‘home’ position. A popup with message ‘M4 tapping done! New batch ready?’ is created to inform operator to replace the jig with a new one to continue the tapping process with the next batch.

When the subprogram ‘Call Tapping’ is called by the main program, it runs all the commands inside it before the main one is being continued. In the beginning of the ‘Tapping’ program, two ‘set’ commands, which are ‘Configurable Output 4’ and ‘Configurable Output 5’, are placed to activate the pneumatic motor. An ‘assignment’ command, after that, is put to separate the subprogram to be controlled with a safety purpose. The variable ‘i_prog_tracker’ is assigned with new value by adding 1 unit. After this command, this variable has the new value of ‘1’. There is a ‘comment’ command for noting ‘Prog_section_1’, which helps the operator in the programming process. To continue, a ‘wait’ command of 0.2 second is added before a ‘moveL’ to direction of Z- for 10 millimetres starts to do the tapping action. Another variable ‘tapping1_ok’ is assigned with value of ‘True’ to confirm that the tap tool has reached the end destination of the tap hole. Next, the variable ‘i_prog_tracker’ is added 1 more unit to have new value of ‘2’. Again a ‘comment’ command is placed to note operator about ‘Prog_section_2’. Then, a ‘set’ command for switching the ‘Configurable Output 4’ to ‘Off’ value is inserted. After this command, the rotation of the pneumatic motor is changed oppositely. By doing this, the tap tool begins going out from the tap hole. The robot is also controlled with a ‘moveL’ command to move up in direction of Z+ for 10 millimetres. Before a ‘set’ command, for setting the ‘Configurable Output 5’ to be ‘Off’ value, is added to stop the pneumatic motor, some ‘assignment’ commands are used to set all variables in this subprogram back to the origin values. The subprogram is completed with a ‘wait’ command of 0.2 second at the end.

To work along with the safety sensor system, a ‘thread’ program is added. This ‘thread’ program is run parallelly along with the main program. By receiving the I/O signals from the safety sensor system, the robot can control the state of the pneumatic motor to be ‘on’ or ‘off’ to avoid dangerous situations. Inside this ‘thread’ program, an ‘if’ condition command is added to check the state of sensor input in case it meets the requirement. The value of safety sensor is sent to the robot control box as signals ‘config_in[0]’ and ‘config_in[1]’ when it detects any violation to the safety area, meaning that if the condition that any value within those two signals is ‘False’, the ‘Configurable Output 5’ signal which controls the working status of the pneumatic motor will be set to ‘Off’ value. Simultaneously, the movement of robot is stopped. To be more specific, the pneumatic motor is only activated in the subprogram. It means that if the safety area is violated when the robot is not doing the tapping process, the robot just stops its movement without considering to the status of the pneumatic motor. However, when the robot is executing the tapping process and the safety area is violated, not only the robot needs to be stopped but also the pneumatic motor is required to be deactivated. This is the reason why it needs a separation, which is made in the subprogram. By tracking the part of program which is running at the moment the robot is stopped by the safety sensor, the robot and motor can continue the sequence from that steps without requiring a full restart from the beginning. This is the explanation for the 'ElseIf' condition in the 'thread' program. It checks the condition whether value of variable 'i_prog_tracker' is equal to '1' or '2', to switch the signal 'Configurable Output 5' to be 'On'.

The program for the cobot with the jig for the first sample products is fully presented, as seen in Figure 15. After this programming task, the testing phase is executed first without the tap tool attached for checking any errors and modifying to optimise the movement of the cobot.

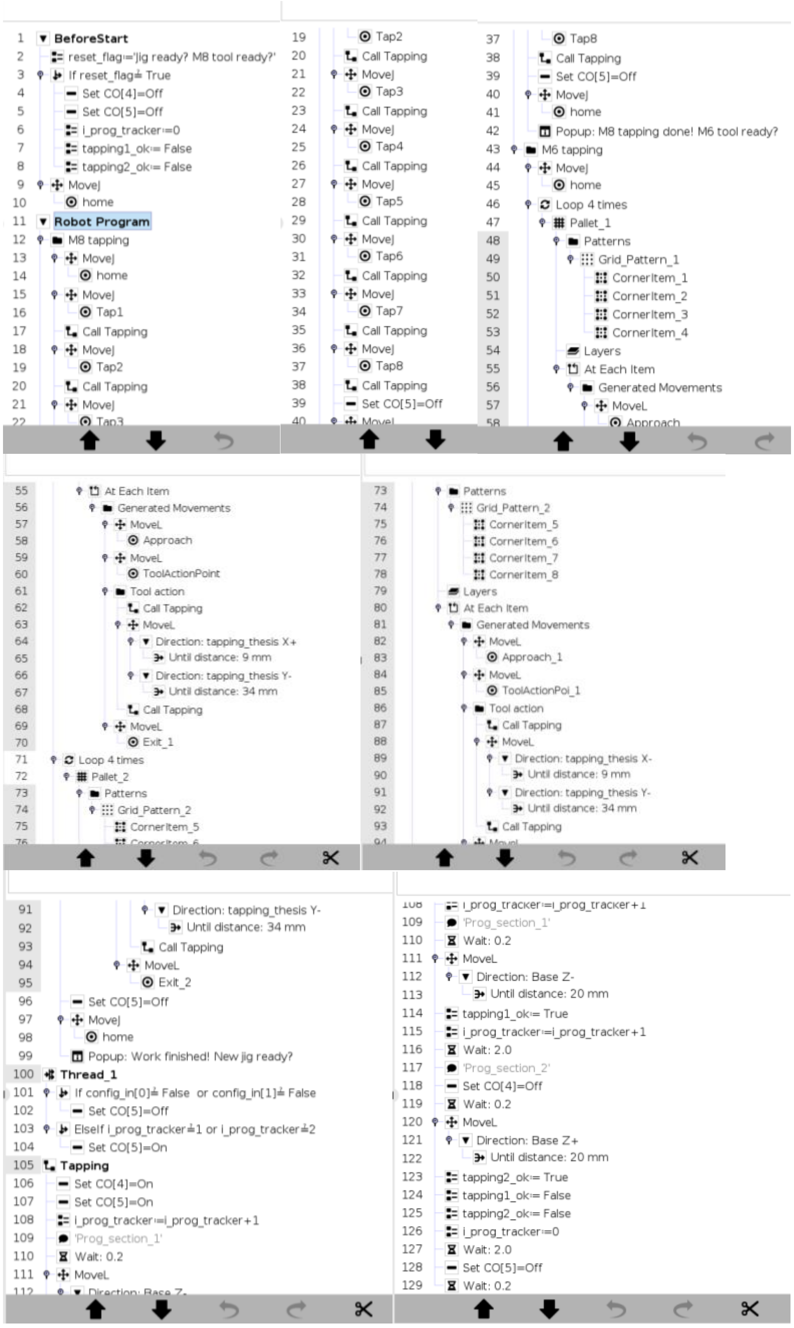
Figure 15. The cobot's program for the first sample products.



```
▼ BeforeStart
    reset_flag≔'Jig ready? M4 tool ready?'
    If reset_flag≟ True
        Set CO[4]=Off
        Set CO[5]=Off
        i_prog_tracker≔0
        tapping1_ok≔ False
        tapping2_ok≔ False
    MoveJ
        home
▼ Robot Program
    M4 tapping
        MoveJ
            home
        Loop 10 times
            Pallet_1
                Patterns
                    Grid_Pattern_1
                        CornerItem_1
                        CornerItem_2
                        CornerItem_3
                        CornerItem_4
                Layers
                At Each Item
                    Generated Movements
                        MoveL
                            Approach
                        MoveL
                            ToolActionPoint
                        Tool action
                            Call Tapping
                            MoveL
                                ▼ Direction: tapping_thesis Y-
                                    Until distance: 20 mm
                            Call Tapping
                            MoveL
                                ▼ Direction: tapping_thesis Y+
                                    Until distance: 10 mm
                                ▼ Direction: Base Z+
                                    Until distance: 5 mm
                                ▼ Direction: tapping_thesis X+
                                    Until distance: 42.84 mm
                                ▼ Direction: Base Z-
                                    Until distance: 5 mm
                            Call Tapping
                        MoveL
                            Exit_1
        Set CO[5]=Off
        MoveJ
            home
        Popup: M4 tapping done! New batch ready?
Thread_1
    If config_in[0]≟ False  or config_in[1]≟ False
        Set CO[5]=Off
    ElseIf i_prog_tracker≟1 or i_prog_tracker≟2
        Set CO[5]=On
Tapping
    Set CO[4]=On
    Set CO[5]=On
    i_prog_tracker≔i_prog_tracker+1
    'Prog_section_1'
    Wait: 0.2
    MoveL
        ▼ Direction: Base Z-
            Until distance: 10 mm
    tapping1_ok≔ True
    i_prog_tracker≔i_prog_tracker+1
    Wait: 2.0
    'Prog_section_2'
    Set CO[4]=Off
    Wait: 2.0
    MoveL
        ▼ Direction: Base Z+
            Until distance: 10 mm
    tapping2_ok≔ True
    tapping1_ok≔ False
    tapping2_ok≔ False
    i_prog_tracker≔0
    Wait: 0.5
    Set CO[5]=Off
    Wait: 0.2
```

Basically, the program for the jig with the second sample products is similar to the program for the jig with the first sample products. The main consideration is that there are two different sizes of tapping required for one product in this application. Those are two tapping holes for M6 and one tapping hole for M8 in each product. In general, the idea for this program is similar to the previous one, where the robot moves to the tapping hole position and does the tapping by a subprogram ‘Tapping’ activated. The full program of cobot for the second sample product can be seen in Figure 16.

Figure 16. The cobot’s program for the second sample products.



```
BeforeStart
  reset_flag≔'Jig ready? M8 tool ready?'
  If reset_flag≟ True
    Set CO[4]=Off
    Set CO[5]=Off
    i_prog_tracker≔0
    tapping1_ok≔ False
    tapping2_ok≔ False
  MoveJ
    home
Robot Program
  M8 tapping
    MoveJ
      home
    MoveJ
      Tap1
    Call Tapping
    MoveJ
      Tap2
    Call Tapping
    MoveJ
      Tap3
    Call Tapping
    MoveJ
      Tap4
    Call Tapping
    MoveJ
      Tap5
    Call Tapping
    MoveJ
      Tap6
    Call Tapping
    MoveJ
      Tap7
    Call Tapping
    MoveJ
      Tap8
    Call Tapping
    Set CO[5]=Off
    MoveJ
      home
    Popup: M8 tapping done! M6 tool ready?
  M6 tapping
    MoveJ
      home
    Loop 4 times
      Pallet_1
        Patterns
          Grid_Pattern_1
            CornerItem_1
            CornerItem_2
            CornerItem_3
            CornerItem_4
        Layers
        At Each Item
          Generated Movements
            MoveL
              Approach
            MoveL
              ToolActionPoint
            Tool action
              Call Tapping
              MoveL
                Direction: tapping_thesis X+
                  Until distance: 9 mm
                Direction: tapping_thesis Y-
                  Until distance: 34 mm
              Call Tapping
            MoveL
              Exit_1
    Loop 4 times
      Pallet_2
        Patterns
          Grid_Pattern_2
            CornerItem_5
            CornerItem_6
            CornerItem_7
            CornerItem_8
        Layers
        At Each Item
          Generated Movements
            MoveL
              Approach_1
            MoveL
              ToolActionPoi_1
            Tool action
              Call Tapping
              MoveL
                Direction: tapping_thesis X-
                  Until distance: 9 mm
                Direction: tapping_thesis Y-
                  Until distance: 34 mm
              Call Tapping
            MoveL
              Exit_2
    Set CO[5]=Off
    MoveJ
      home
    Popup: Work finished! New jig ready?
Thread_1
  If config_in[0]≟ False  or config_in[1]≟ False
    Set CO[5]=Off
  ElseIf i_prog_tracker≟1 or i_prog_tracker≟2
    Set CO[5]=On
Tapping
  Set CO[4]=On
  Set CO[5]=On
  i_prog_tracker≔i_prog_tracker+1
  'Prog_section_1'
  Wait: 0.2
  MoveL
    Direction: Base Z-
      Until distance: 20 mm
  tapping1_ok≔ True
  i_prog_tracker≔i_prog_tracker+1
  Wait: 2.0
  'Prog_section_2'
  Set CO[4]=Off
  Wait: 0.2
  MoveL
    Direction: Base Z+
      Until distance: 20 mm
  tapping2_ok≔ True
  tapping1_ok≔ False
  tapping2_ok≔ False
  i_prog_tracker≔0
  Wait: 2.0
  Set CO[5]=Off
  Wait: 0.2
```

To begin with, the ‘BeforeStart’ section in this program for the second sample products is similar to the previous one. In addition, based on the main idea as described above, the subprogram ‘Tapping’ and the ‘Thread’ program also are remained the same. So that, it does not need to repeat those parts of program again. With the main program, because there are only 8 positions for M8 tappings, and those positions is not located in any simple pattern, it is easier as well as faster for programming those positions as separating ‘waypoints’. For more details, the robot moves to those positions and starts tapping, then continues to the next tapping positions. After finishing all the tappings with the M8 tap tool, the robot goes back to the ‘home’ position and a popup window will show up with message ‘M8 tapping done! M6 tool ready?’. Seeing this message, the operator needs to change the tap tool to the M6 size manually, then confirm the popup window.

The program now starts to activate the tapping process for the M6 tap holes. There are a total of 16 tap holes with the M6 size, and each set of two is for one product. In this situation, the method of programming can be used as the similar method within the previous program for the M4 tapping size. However, the left side and the right side of the jig are not the same but symmetrical. Therefore, in practice, there are two ‘palletizing’ commands which are made. Although there are two parts of program created to execute this tapping process, the ideas and parameters are still similar to each other. When the program runs all commands to complete the tapping process with the M6 tap tool, the ‘set’ command for switch ‘off’ the ‘Configurable Output 5’ is added. Next, the robot changes its position to the ‘home’ waypoint. A popup window with the message ‘Work finished! New jig ready?’ is shown to inform the operator about the status of the tapping process which is completed, and to ask to change to a new jig to continue the work progress. In addition, while the operator changes a new jig to the worktable, they also need to remember to put the tap tool of M8 size for restarting the process. By doing that, the tapping process can be continued with the next batch of products.

## 4.6 Safety features

The safety sensors system, which is applied in this setup, is sBot Speed – URe safety system from SICK sensor manufacturer.  Generally, this safety system creates two levels of protective fields to eliminate mechanical hazards caused by the movements of the robot. A model of this safety system is demonstrated in Figure 17. For example, when a person approaches the working area of the robot, the protective fields are interrupted and signals are sent to the robot. Receiving these signals from the sensors, the robot can reduce its speed if the outer safety area is interrupted, or it can completely stop in case the inner safety area is triggered. Furthermore, when the protective fields are clear, the robot can automatically continue its sequence from the positions where it reduced speed or it stopped. The software structure and logic for configuration with automatic reset and automatic restart are respectively shown in Figure 18 and 19. For installation, components in this system includes:

- Flexi Soft safety controller (FX3-CPU0 main module, 2*FX3-XTIO expansion module, FX3-MPL0 system plug)
- 2*nanoScan3 Pro I/O safety laser scanners, 2*Ethernet system plugs
- Reset push button, restart push button, indicators

Figure 17. Model of safety system. (Sick AG, 2020, p. 11)

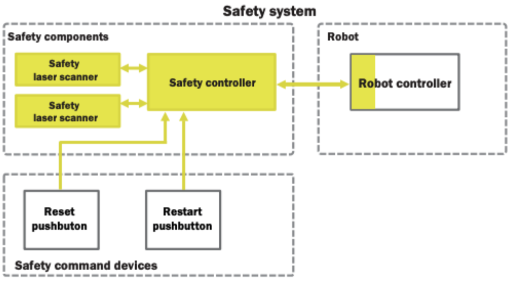


Figure 18. Software structure for configuration with automatic reset and automatic restart. (Sick AG, 2020, p. 34)

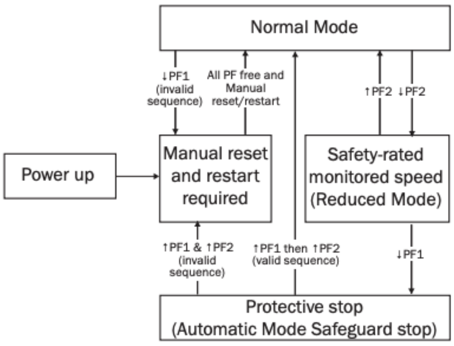


Figure 19. Software logic for configuration with automatic reset and automatic restart. (Sick AG, 2020, p. 35)

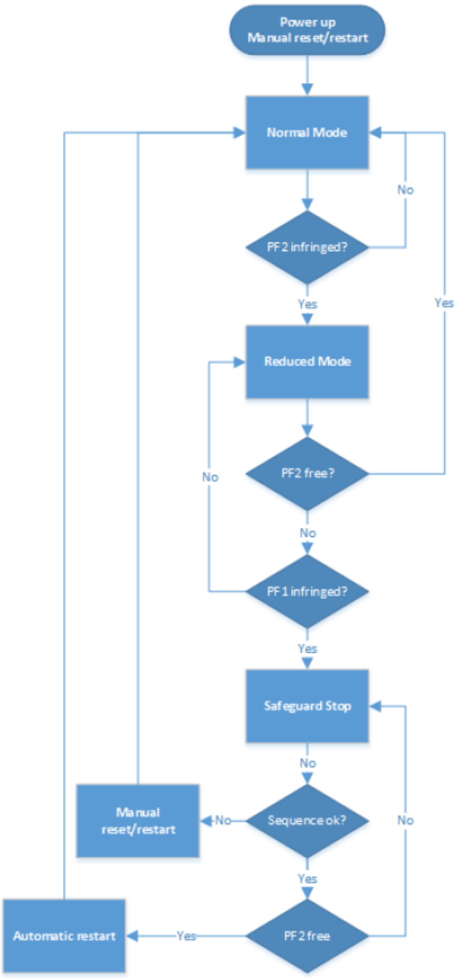
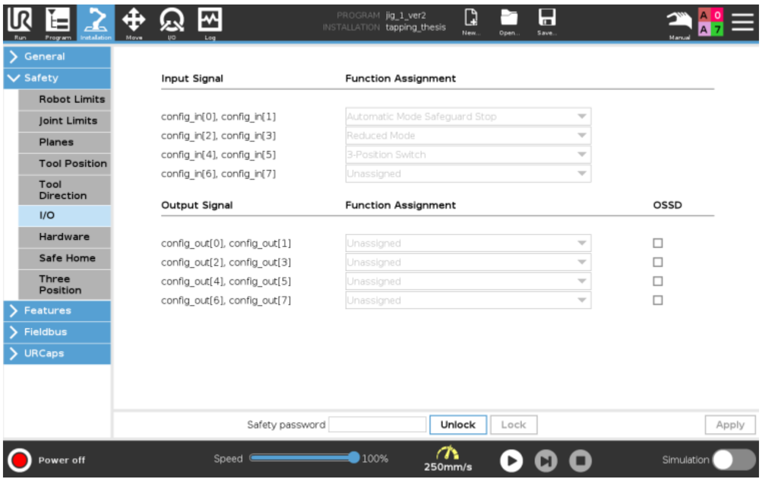


Figure 20 shows the I/O installation setup for safety feature when connecting the sensor system to the cobot.

Figure 20. Safety feature installation in cobot programs.



PROGRAM jig_1_ver2
INSTALLATION tapping_thesis

| Input Signal | Function Assignment |
|---|---|
| config_in[0], config_in[1] | Automatic Mode Safeguard Stop |
| config_in[2], config_in[3] | Reduced Mode |
| config_in[4], config_in[5] | 3-Position Switch |
| config_in[6], config_in[7] | Unassigned |

| Output Signal | Function Assignment | OSSD |
|---|---|---|
| config_out[0], config_out[1] | Unassigned | ☐ |
| config_out[2], config_out[3] | Unassigned | ☐ |
| config_out[4], config_out[5] | Unassigned | ☐ |
| config_out[6], config_out[7] | Unassigned | ☐ |

Safety password

Speed 100%

# 5 Testing and results

The testing phase is conducted right after the programmings for the cobot are completed. The purpose of this phase is to measure the time it takes for each step. The process includes assemblying slabs to the jigs, running the tapping programs, and unloading the finished products. Moreover, the quality of the tappings, which are done by the cobot, is also significantly considered. By using these collected results, the analysis of this cobot tapping process is more coherent and empirical.

## 5.1 Testing

To prepare for the testing phase, the setup of the tapping process needs to be readied. In detail, all the components are required to be connected as mentioned in section 4.4 and the program of cobot is created as described in section 4.5. After setting up the worktable, the compressed air is connected to the motor to get ready to start. Firstly, the cobot is turned on. Then, the signals, which control the valves for deciding rotations of the pneumatic motor are checked carefully to prevent any errors. After that, the sensors of the safety system are also activated to diagnose problems which may occur. When all of these steps are completed, the programs for tapping process are started. However, in the first run, the tap is not yet connected to the pneumatic motor. The reason for this extended step is to do a final check of the whole program to avoid all the unwanted problems which can come from the cobot programs or the assemble progresses. Having completed all steps, the tap tool can be attached to the pneumatic motor to run the tapping process.

## 5.2 Results

The amount of time for the whole tapping process is gathered from the real testing results. It includes the time for loading the products to the jigs, executing the tapping process by the cobot, and removing the finished parts out of the jigs after completing the process. Additionally, the accuracy of the threads is also a point of consideration.

After conducting the testing phase, the recorded videos for each part of process are uploaded to the HAMK's online video platform as known as HAMK Kaltura. The links to those videos are listed as:

- Tapping process for the first sample products: https://kaltura.hamk.fi/media/Cobot tapping thesis - Tapping process for 1st sample products/0_q9si1470
- Tapping process for the second sample products: https://kaltura.hamk.fi/media/Cobot tapping thesis - Tapping process for 2nd sample products/0_5xzsbxbh
- Assembly sample products to jigs: https://kaltura.hamk.fi/media/Cobot tapping thesis - Assembly sample products to jigs/0_cj0g0s1d
- Safety sensor system demonstration: https://kaltura.hamk.fi/media/Cobot tapping thesis - Safety system demonstration/0_r68j58hu

According to the videos, the results of the testing can be briefly concluded as Table 2.

Table 2. Time consumption in tapping process as separated steps.

| | Descriptions | Time |
|---|---|---|
| Tapping process of the first sample product | The number of taps conducted is 30 in M4. | 6 mins 11 seconds |
| Tapping process of the second sample product | The number of taps conducted is 8 in M8 and 16 in M6. | 6 mins 25 seconds |
| Assembly products to the first jig | There are 10 products in a jig. | 32 seconds |
| Assembly products to the second jig | There are 8 products in a jig. | 51 seconds |

## 5.3 Errors

During the programming and testing phases, some errors occured. The problems are mostly from the lack of experience, which can be improved by gaining more knowledge.

The pneumatic motor is broken once and needs to be sent for a maintenance service during these periods. There is a small air compressor in the robotics lab. It is used to run the motor in the programming phase which does not require compressed air to run at full capacity. The programming is then followed by the testing period. This period needs a stable capacity of compressed air to do the tapping in both pressure as well as volume aspects. As a result, the pneumatic motor is required to be connected to a compressed air system which can meet the requirements for the tapping process. However, the compressed air pipelines leading to the testing area are not regularly used. Without any notice about this, the pneumatic motor is directly connected to the pipelines. Having not been used in a long time, the pipes are contaminated with dust and water. When the pneumatic motor is connected to the system by hoses, all the dust and water are transported into the motor and cause congestion between the vanes and the cylinder of the motor. The motor is immediately stopped. Unless maintenance is done to remove all the dust and water from the motor, it can not work normally. Furthermore, the remaining water in the pneumatic motor also causes rust, which can be harmful to the motor. The mainternance work is not simple to execute without specialized tools. Therefore, the motor is sent to a maintenance service for this task and it takes almost a month for it to return. To avoid this problem, it should be noted that the compressed air before connecting to the motor is required to go through a compact of devices which include filter, regulator, and lubricator. This is highly recommended for working with any pneumatic motor. By running through those devices, the dust and water are eliminated at the filter, the regulator is used to control the exact pressure of the air going to the motor, and the lubricator supplies a small amount of lubricant oil to the motor. After having been repaired, the motor is connected to the compressed air system through a set of above devices and it works normally.

A limitation from the design of the jigs is realized when assembly the slabs into slots. As seen from Figure 21, there is a small part of extra material remained at the edge from laser cutting process. To solve this issue, a slight modification can be made to the jigs. Extra space can be added to the jig to accommodate the extra material on the slabs. Doing so can not only prevent collision but also make it convenient to unload the finished product after tapping operation. Furthermore, this can also be applied to the second sample product jig.

Figure 21. Extra material on the slabs (right) and after removal (left).

In the testing phase, there is a mistake in the selection of tapping tools with the M4 tap size. A straight flute tap is used for the tapping process. Because of the mechanical characteristic of this type of tapping, the chips which are generated during the process are stuck in the tap hole instead of being expulsed out of the hole. This is why the tapping process can not be done where the tap tool is not able to cut the material. After analyzing the problem, a decision in changing the tap tool is created. A new tap tool is a type of spiral point tap. With this type of tap, the chips fall out from the bottom side of the tap hole. The tapping process is executed well after the replacement of the tool. Furthermore, to increase the quality and productivity of tap performance, as well as extend the durability of the tool, adding suitable lubricant oil fluid to the tap tools is required. Besides that, applying the lubricants in tapping operations can result in smoother and more precise threads, as well as more efficient chip expulsion.

One small consideration is the misalignment between the tool and the sample products during the tapping process. The robot can be uninstalled for performing between batches before being reinstalled. This practice can create a displacement of the robot’s relative position to the workstation, causing the misalignment. Outside of the testing environment, this is unlikely to happen.

# 6 Analyzing and assessments

The time of the tapping operation for each product varies based on how many products are executed in a working shift. The total production time consists of the loading, the tapping process, and the unloading. The loading and unloading processes can be conducted by the operator while the cobot is in the tapping process. Table 2 shows that the tapping process for the first jig takes approximately 6 minutes and 11 seconds (371 seconds) where the assembly time for a jig constitutes just around 32 seconds. The time for tapping process is over 10 times longer than the time for assembly. Therefore, the operator has enough time to do the loading for the next batch or unloading process for the previous one. If there are more jigs available, the operator can prepare for the subsequent batch. With this method of operation, the production time for a product can be reduced significantly. Moreover, when a large number of products is required, this working sequence is more efficient.

This tapping process is more suitable for mass production than production in small amounts. This should be taken into consideration when planning to implement the process. To apply this process to a new design product, it also requires a corresponding new jig design. This step consumes a considerable amount of time and material to produce the new jigs. Therefore, the total time to execute the tapping for one product is increased. This also means more material is used in the process.

By applying the sensor safety system to this workstation, the hazard risk is substantially reduced. Without this safety system, if there is an impact to the cobot, it will automatically stop the program. From there, the cobot needs to be restarted for it to start working again. With the safety system, when movement is detected within the vicinity, the cobot is also stopped. However, when the threat of collision is out of the protective field, the cobot can continue to work from where it stopped before. This application of safety system can not only protect the operator and the cobot but also save time in operation process.

The efficiency of investment is based on the frequency of running the cobot. In another way, reducing the cobot downtime also means that the time for returning of investment is decreased. Considering this aspect, the company can make a decision on investing.

# 7 Conclusions

The thesis objectives of designing an application for cobot tapping are achieved. In this thesis, the jig designs for two different sample products are made. The worktable is also designed. Based on the simulation created, the prototypes of jig are produced. With the jigs and the sample products manufactured, all the components and devices are connected. Next, the cobot's programs are constructed to do the application. After finishing the testing phase, the cobot tapping process application is obtained. The outcome of this thesis is the jigs, the cobot's programs, the real cobot application, and the assessments.

This thesis aims to give a solution for upgrading the current tapping process. Based on the results, the company can easily compare them to the present process and make a decision on investment. However, the requirements for utilizing the use of the cobot application should be taken into account carefully.

There are still limitations during the process of writing the thesis. The reasons for those are mostly from a gap in experience. However, this thesis is a valuable opportunity for applying knowledge into practice. Modifications can be made to improve the use of the jigs by analyzing carefully the given sample products. In addition, understanding how a pneumatic motor works and its working conditions can help in avoiding its malfunctioning.

For future research, there are recommendations to further develop the cobot tapping application. A vision sensor system can be implemented for automatically recognizing the tap hole. By doing that, the cobot programming is able to be more simple but more accurate in practice. To detect if the jig is already fixed to the worktable, a sensor can be employed. With the sensor, the operator does not need to press a button to start the tapping process. This sensor can also be integrated to an automatic fixturing system. The jigs can be fixed to the working table after the operator put them there.

## References

Aaltonen, I., Salmi, T., & Marstio, I. (2018). Refining levels of collaboration to support the design and evaluation of human-robot interaction in the manufacturing industry. *Procedia CIRP, 72*, 93—98. https://doi.org/10.1016/j.procir.2018.03.214

Asimov, I. (1950). *"Runaround". I, Robot.* (The Isaac Asimov Collection ed.). New York City: Doubleday.

Benhabib, B. (2003). *Manufacturing – Design, Production, Automation, and Integration.* CRC Press.

Chapman, M. (2004). *Modern machine shop: Guide to machining operations.* Hanser Gardner Publications.

GlobeNewswire. (2022, January 17). Retrieved from globenewswire.com: https://www.globenewswire.com/news-release/2022/01/17/2367706/28124/en/Global-Collaborative-Robot-Market-2021-to-2030-Opportunity-Analysis-and-Industry-Forecasts.html#:~:text=The%20Collaborative%20Robot%20Market%20size,in%20tough%20or%20difficult%20enviro

ISO 10218-2:2011. (2011). *Robots and robotic devices. Safety requirements for industrial robots. Part 2: Robot system and intergration*. SFS Online.

ISO 12100:2010. (2010). *Safety of machinery. General principles for design. Risk assessment and risk reduction.* SFS Online.

Kennametal Inc. (n.d.). Retrieved from mscdirect.com: http://www1.mscdirect.com/images/solutions/kennametal/tap_die_tech_data.pdf

Kildal, J., Tellaeche, A., Fernández, I., & Maurtua, I. (2018). Potential users' key concerns and expectations for the adoption of cobots. *Procedia CIRP, 72*, 21—26. https://doi.org/10.1016/j.procir.2018.03.104

Malm, T., Salmi, T., Marstio, I., & Aaltonen, I. (2019). *Are collaborative robots safe? In Automatiopäivät 23 (pp. 110—117)*. Finnish Society of Automation. https://www.automaatioseura.fi/site/assets/files/2398/procap23110 malmsma.pdf

Mihelj, M., Bajd, T., Ude, A., Lenarčič, J., Stanovnik, A., Munih, M., Rejc, J., & Šlajpah, S. (2019). *Robotics.* (2nd ed.). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-72911-4

Okpala, C. C., & Okechukwu, C. E. (2015). *The Design and Need for Jigs and Fixtures in Manufacturing*. Science Research.Vol. 3, No. 4, pp. 213—219. https://doi.org/10.11648/j.sr.20150304.19

READY Robotics. (2020, November 4). *Tap Your Parts with a Cobot - Automated Tapping with a Forge Station and FlexArm A-32* [Video]. YouTube. https://www.youtube.com/watch?v=nM9rgvRzqdY

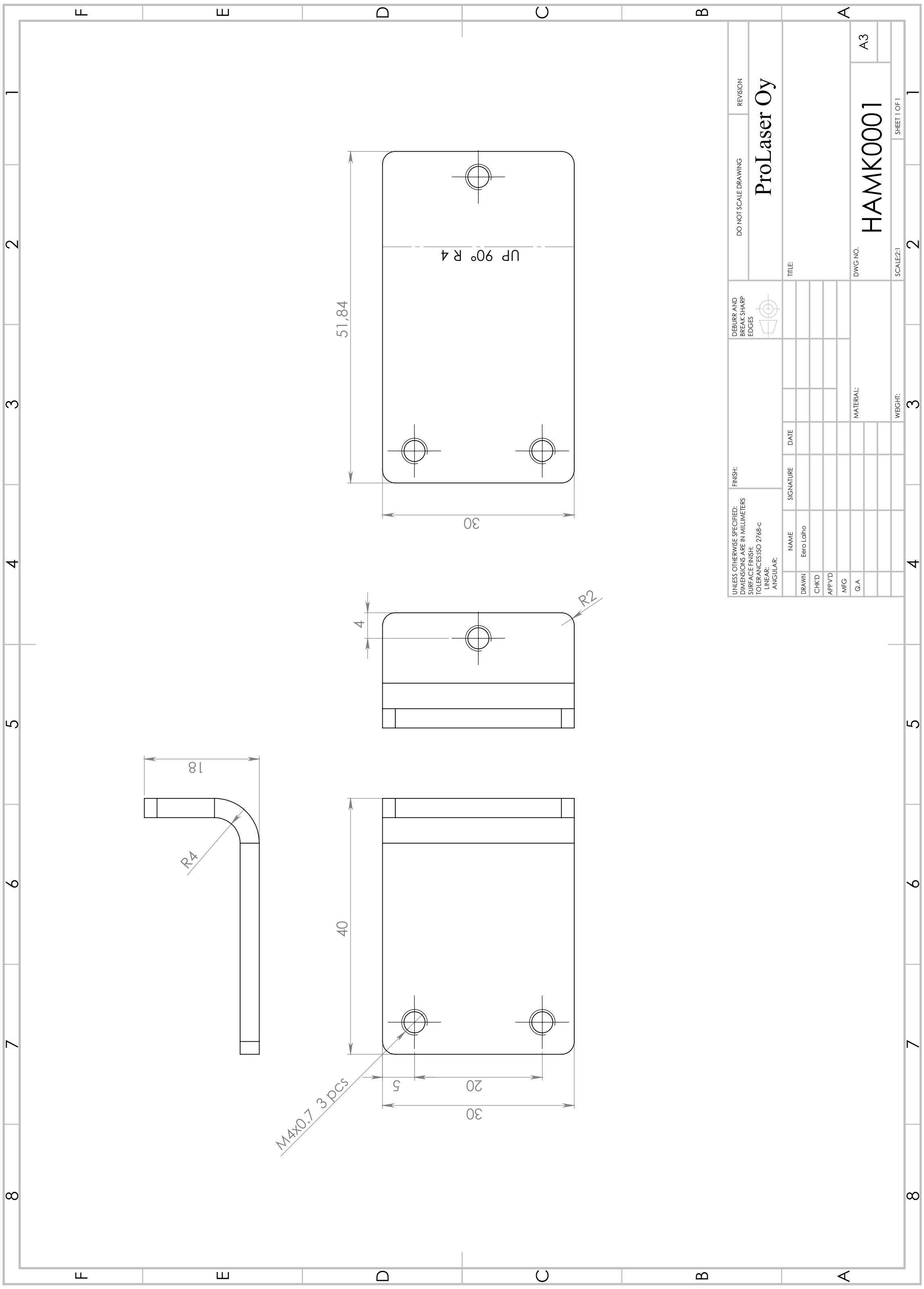
Sandvik Coromant. (n.d.). Retrieved from sandvik.coromant.com: https://www.sandvik.coromant.com/en-gb/knowledge/threading/tapping/pages/how-to-choose-tap-type.aspx

Sick AG. (2020, June 22). *sBot Speed – URe Safety System: Operating instructions.* Sick AG.

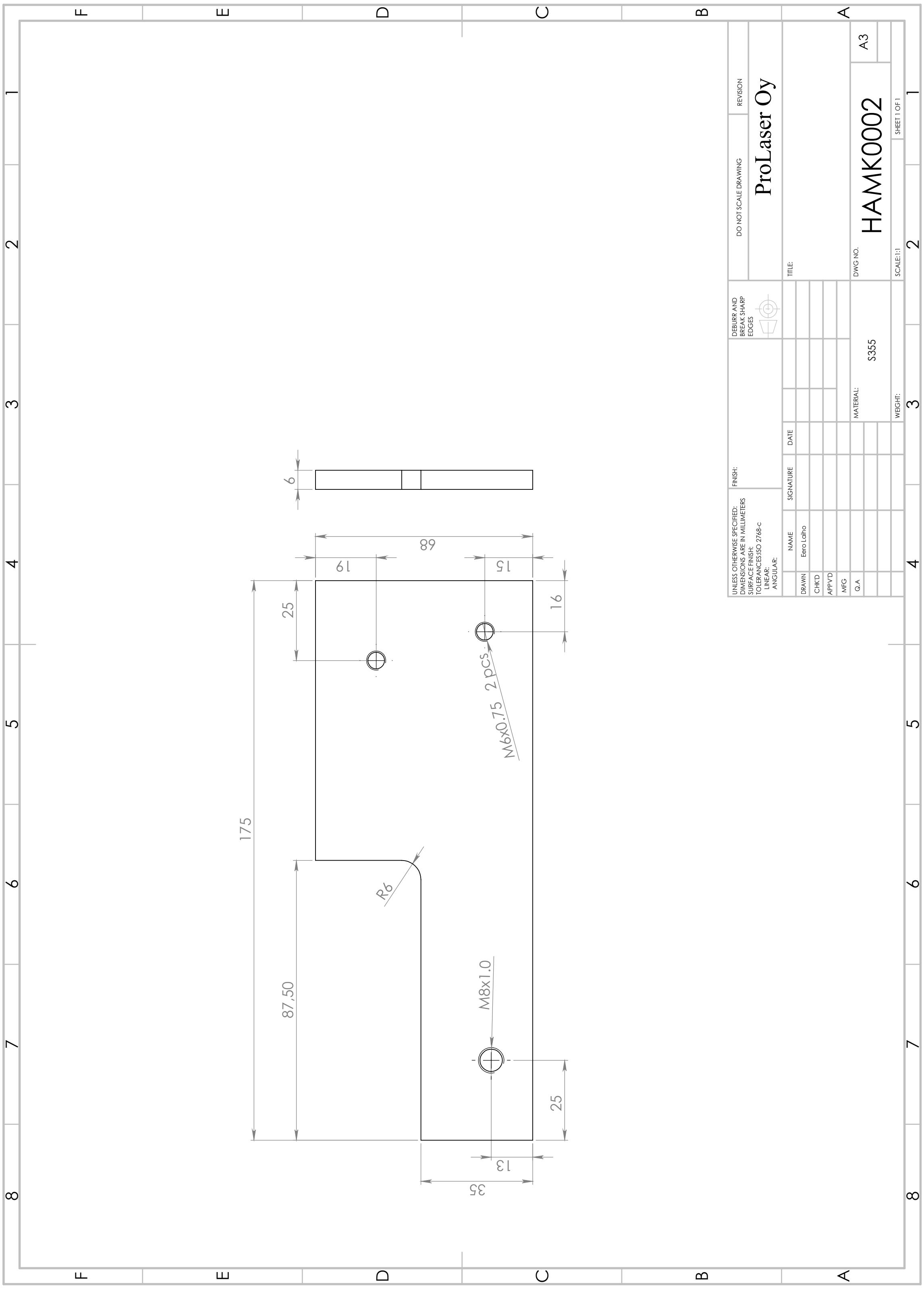
SVL Group. (n.d.). Retrieved from svlgroup.fi: https://svlgroup.fi/en/prolaser/

Syam, W. (2021, September 20). Understanding fixturing constraints: locator, clamping, support and guide. Retrieved May 22, 2022, from https://www.wasyresearch.com/understanding-fixturing-constraints-locator-clamping-support-and-guide/

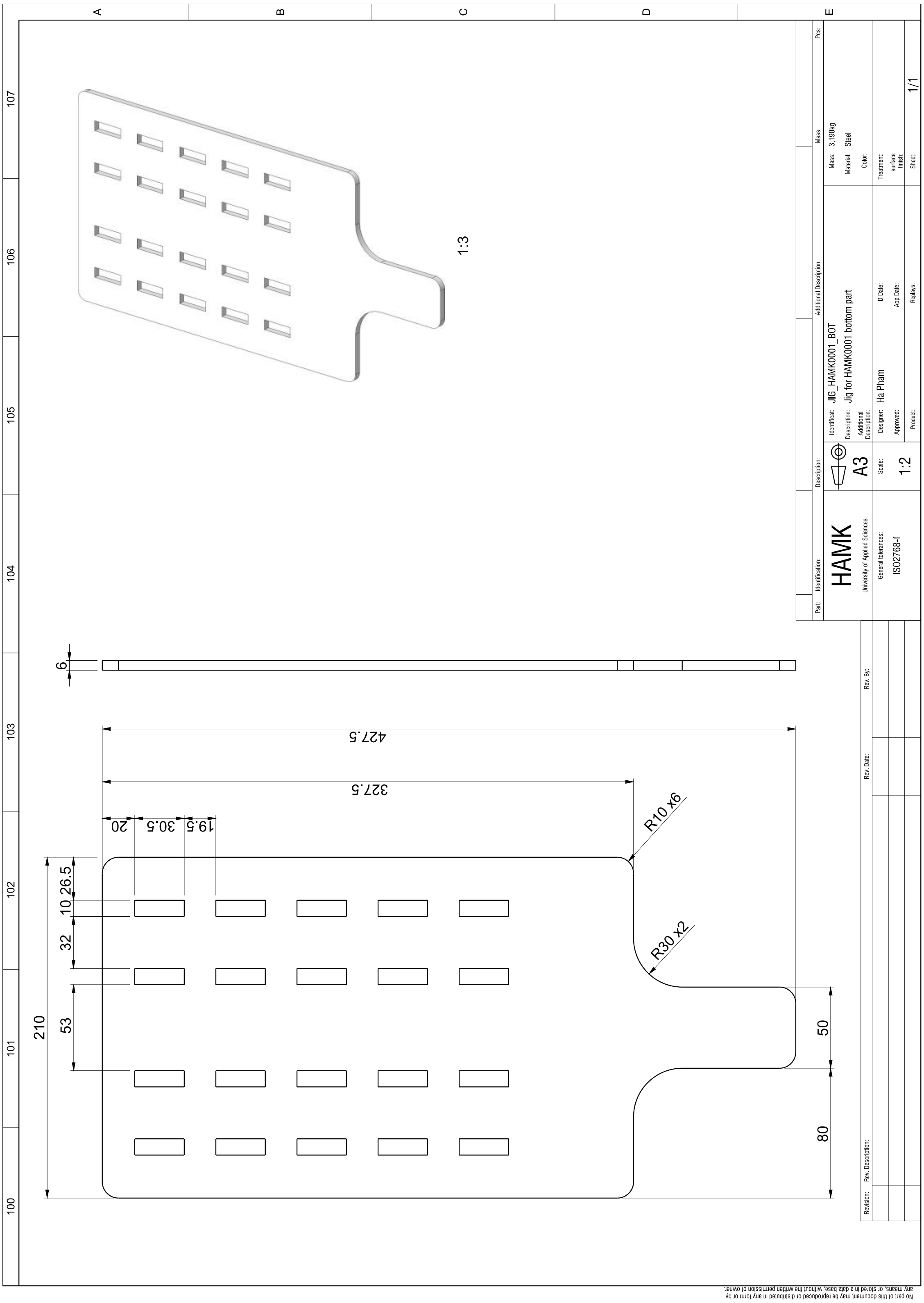
## Appendix 1: Drawing of the first sample product



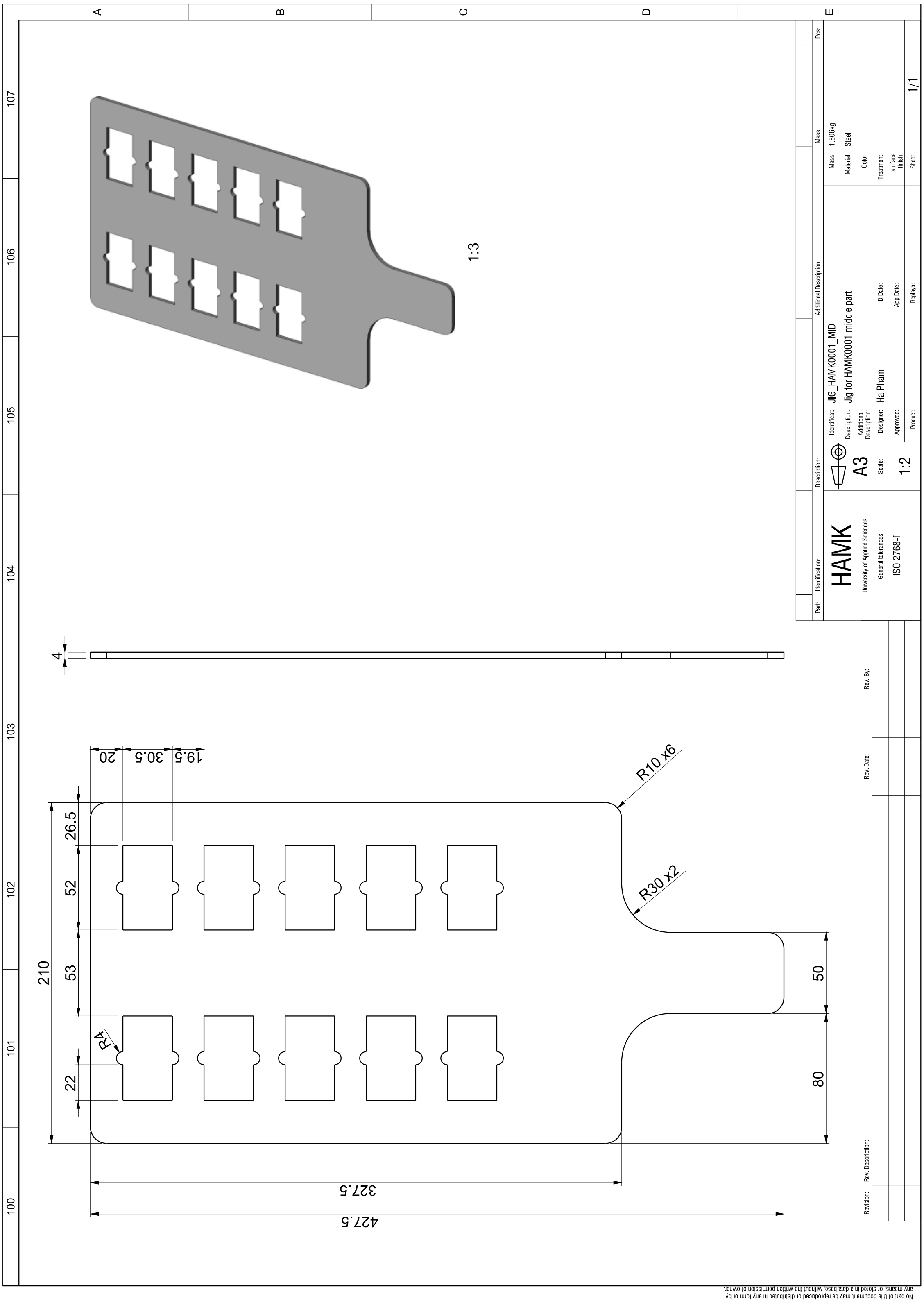
## Appendix 2: Drawing of the second sample product



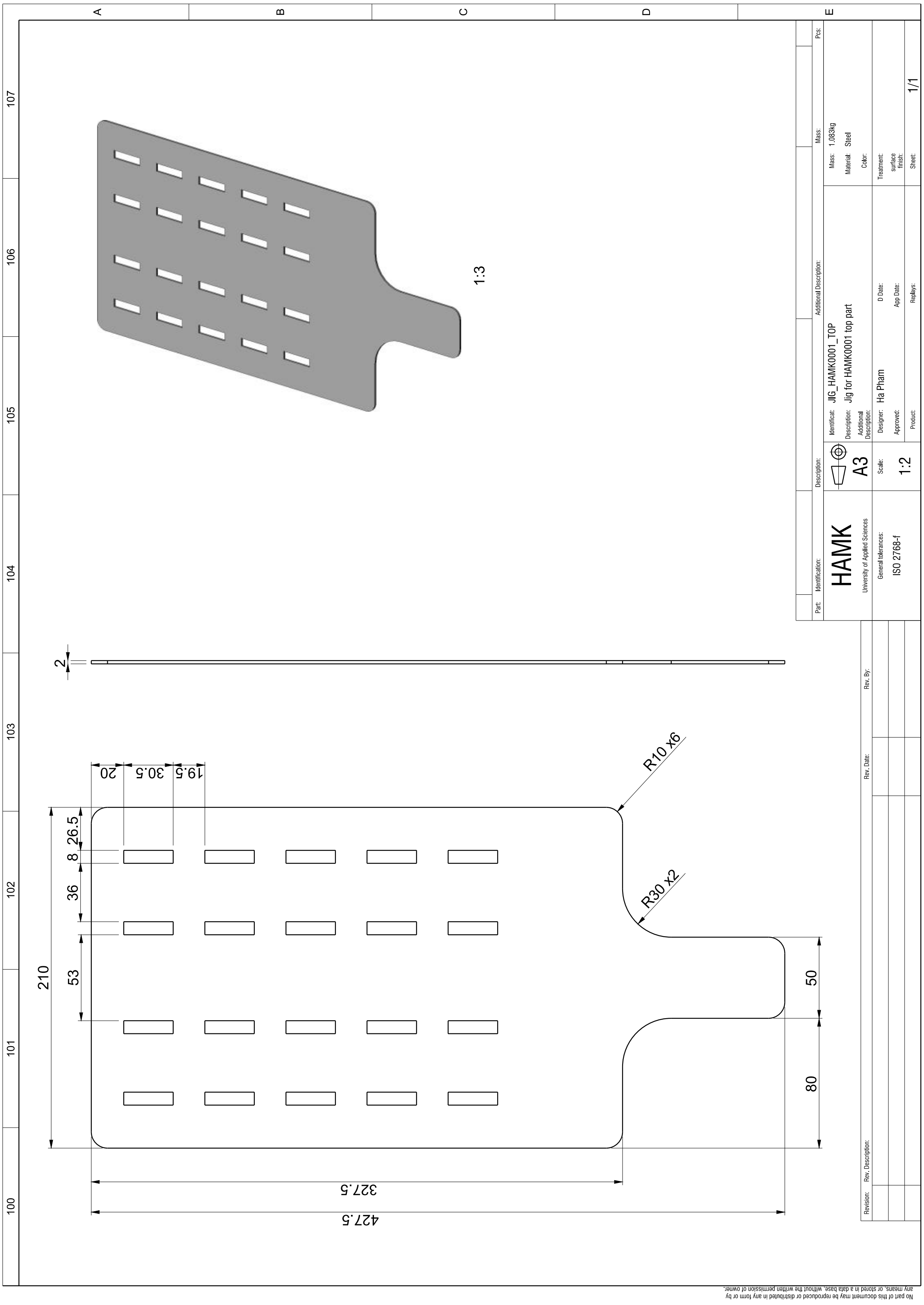
## Appendix 3: Drawing of the jig for the first sample product – bottom part



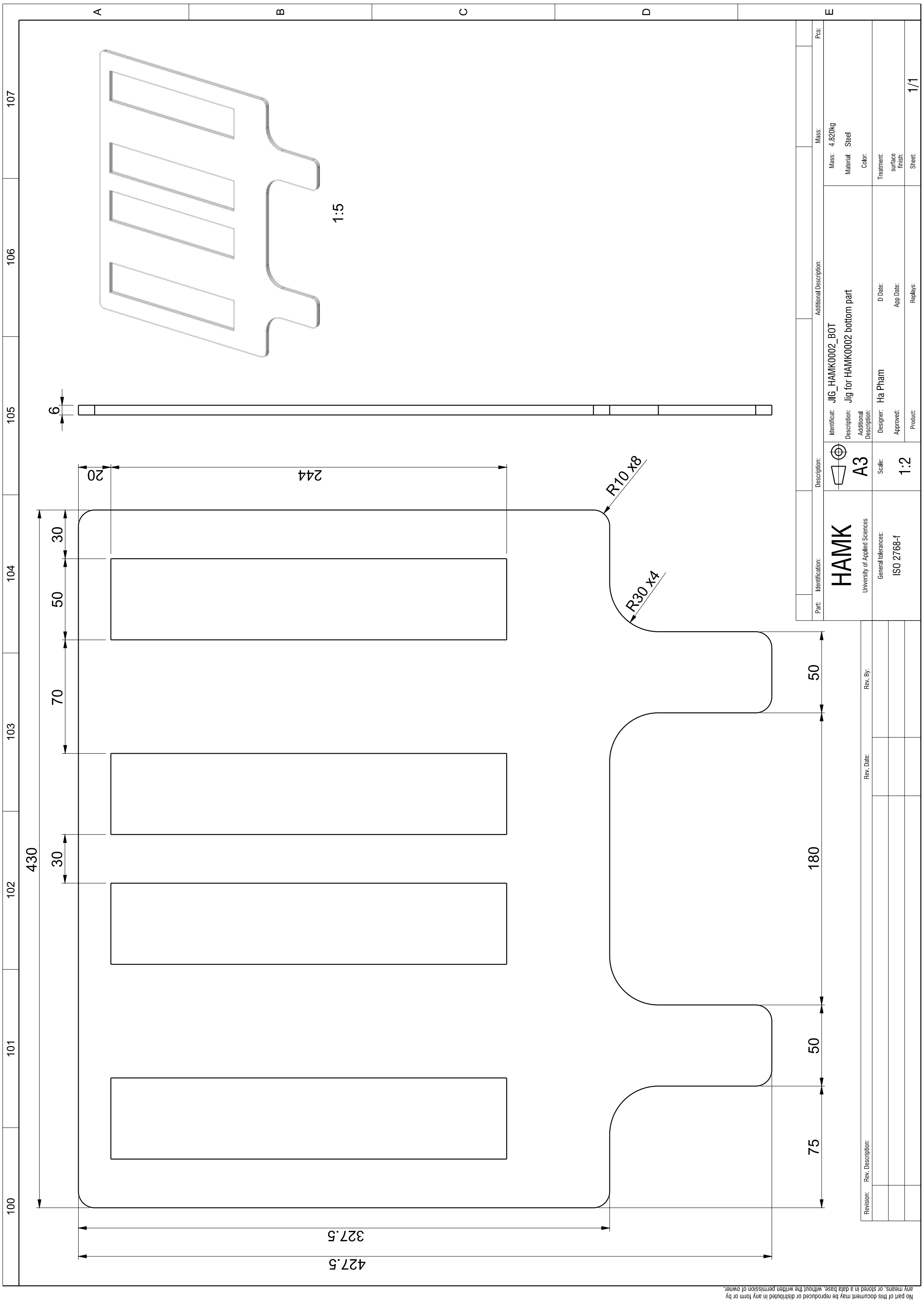
## Appendix 4: Drawing of the jig for the first sample product – middle part



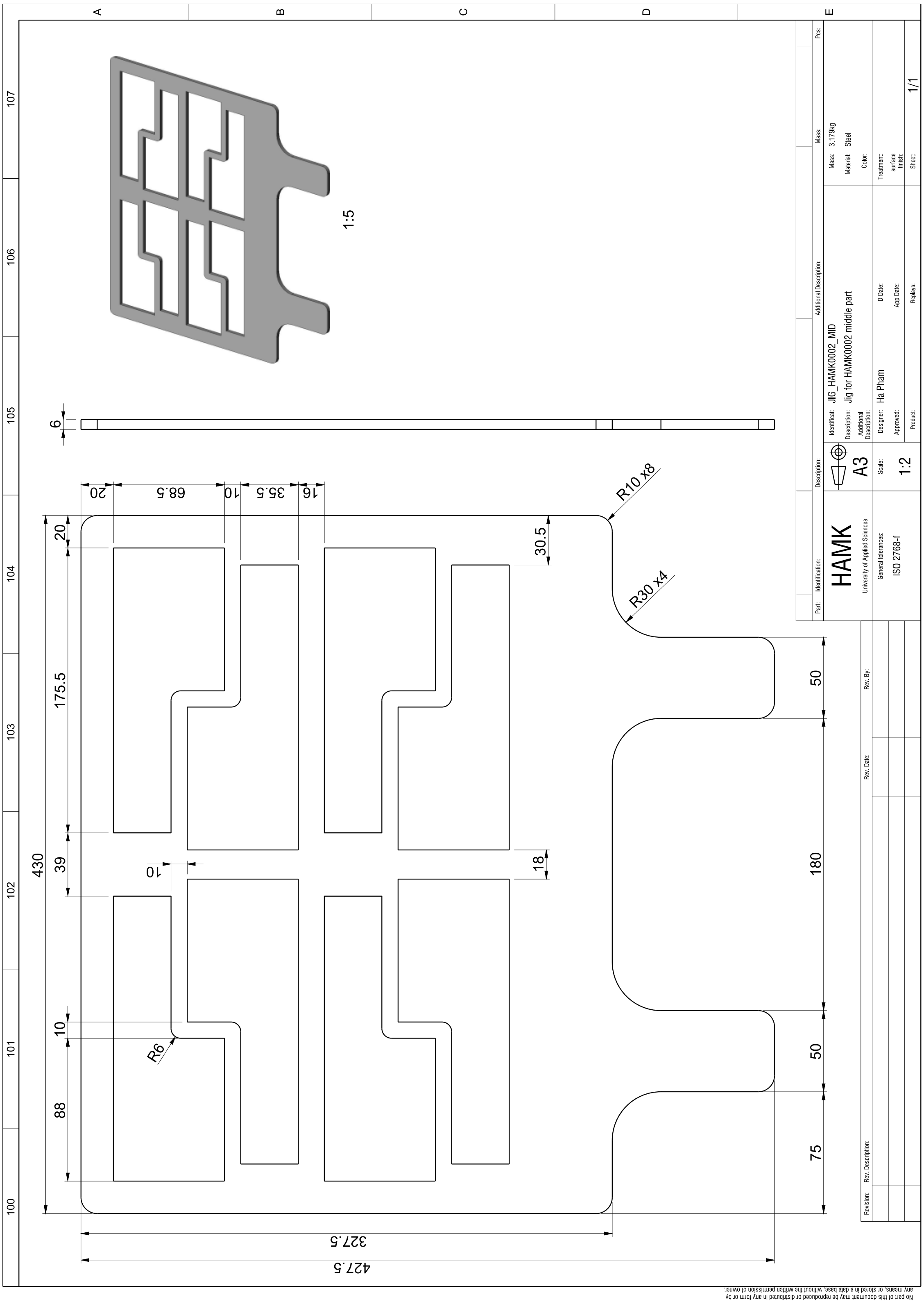
## Appendix 5: Drawing of the jig for the first sample product – top part



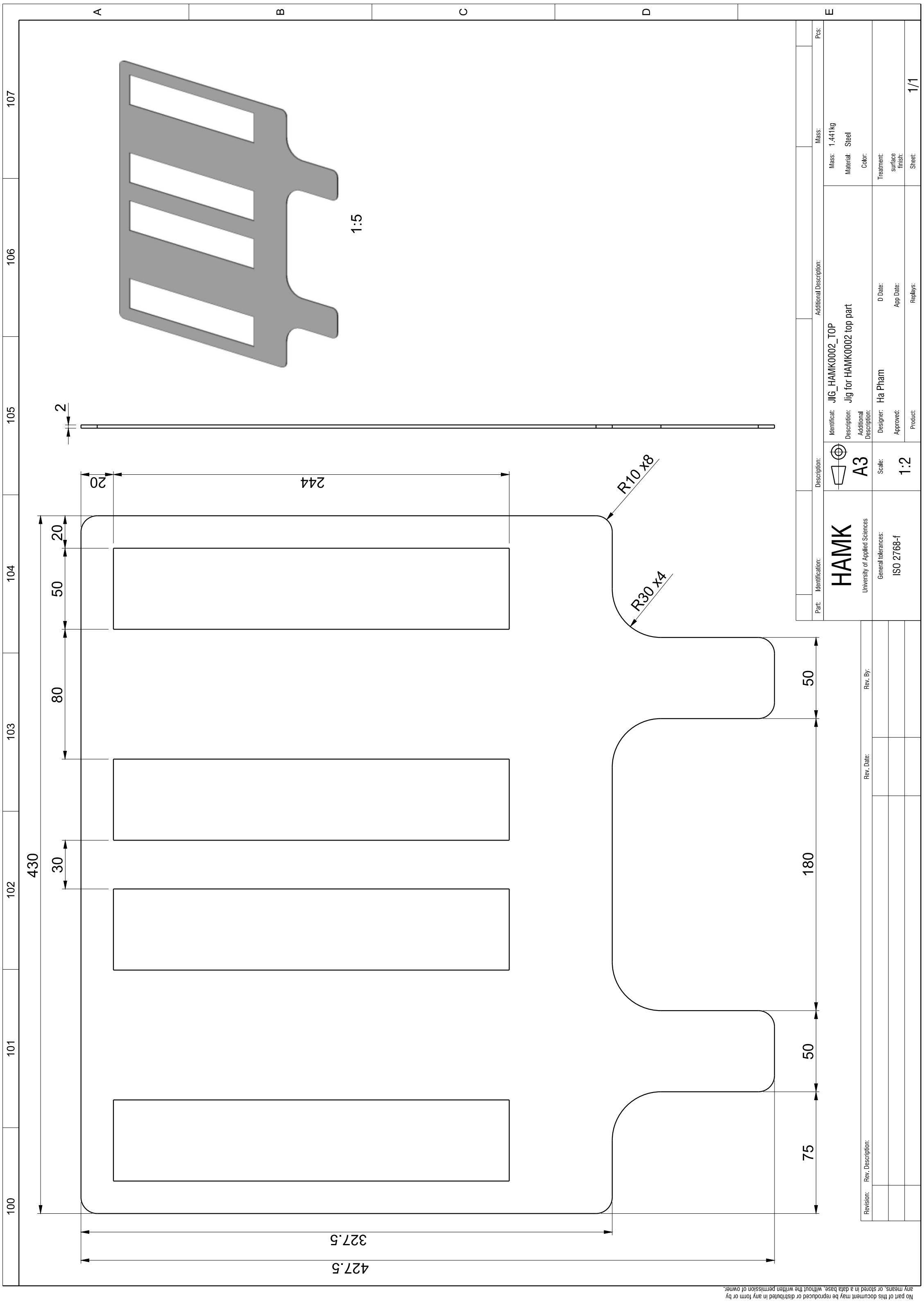
## Appendix 6: Drawing of the jig for the second sample product – bottom part



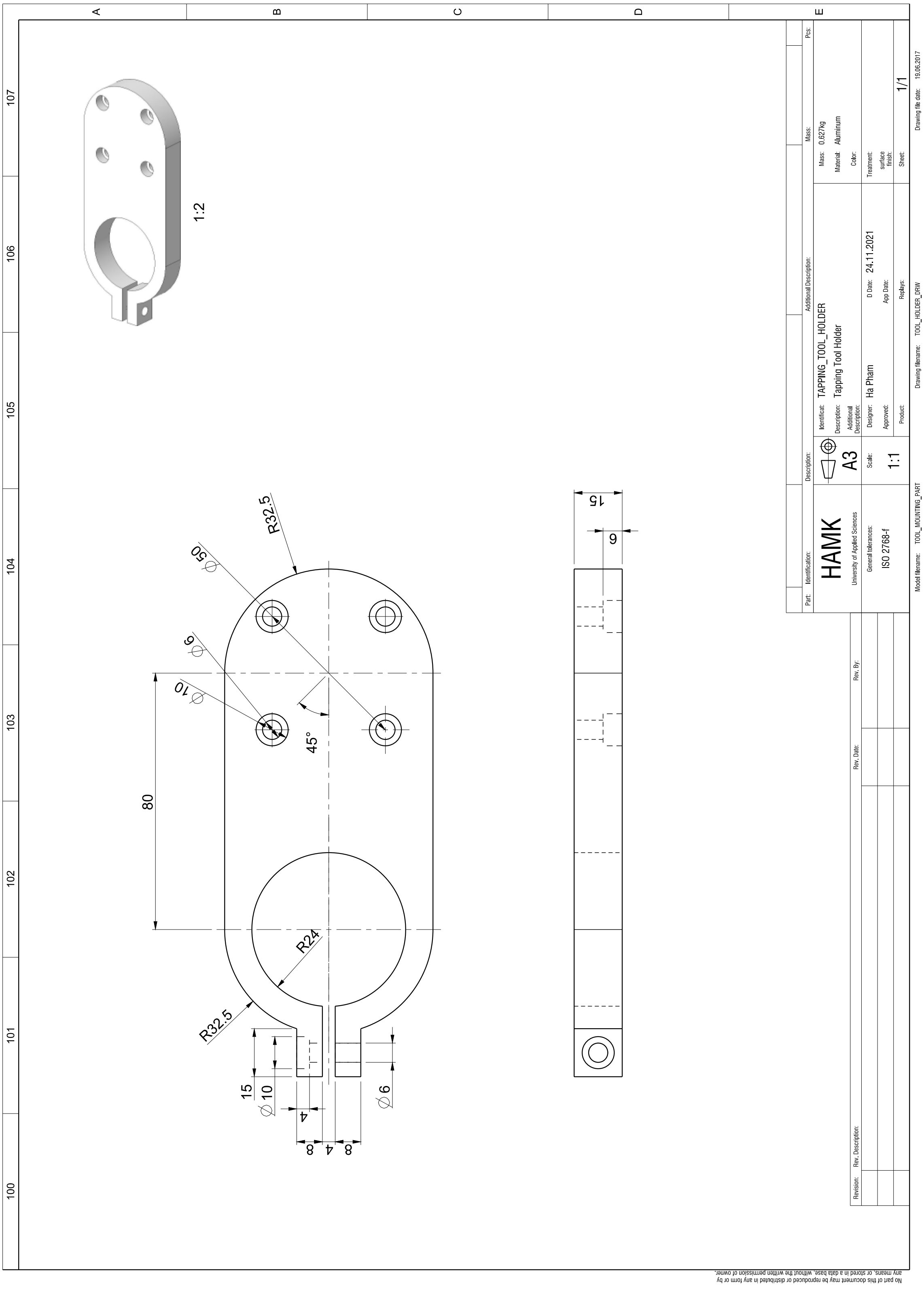
## Appendix 7: Drawing of the jig for the second sample product – middle part



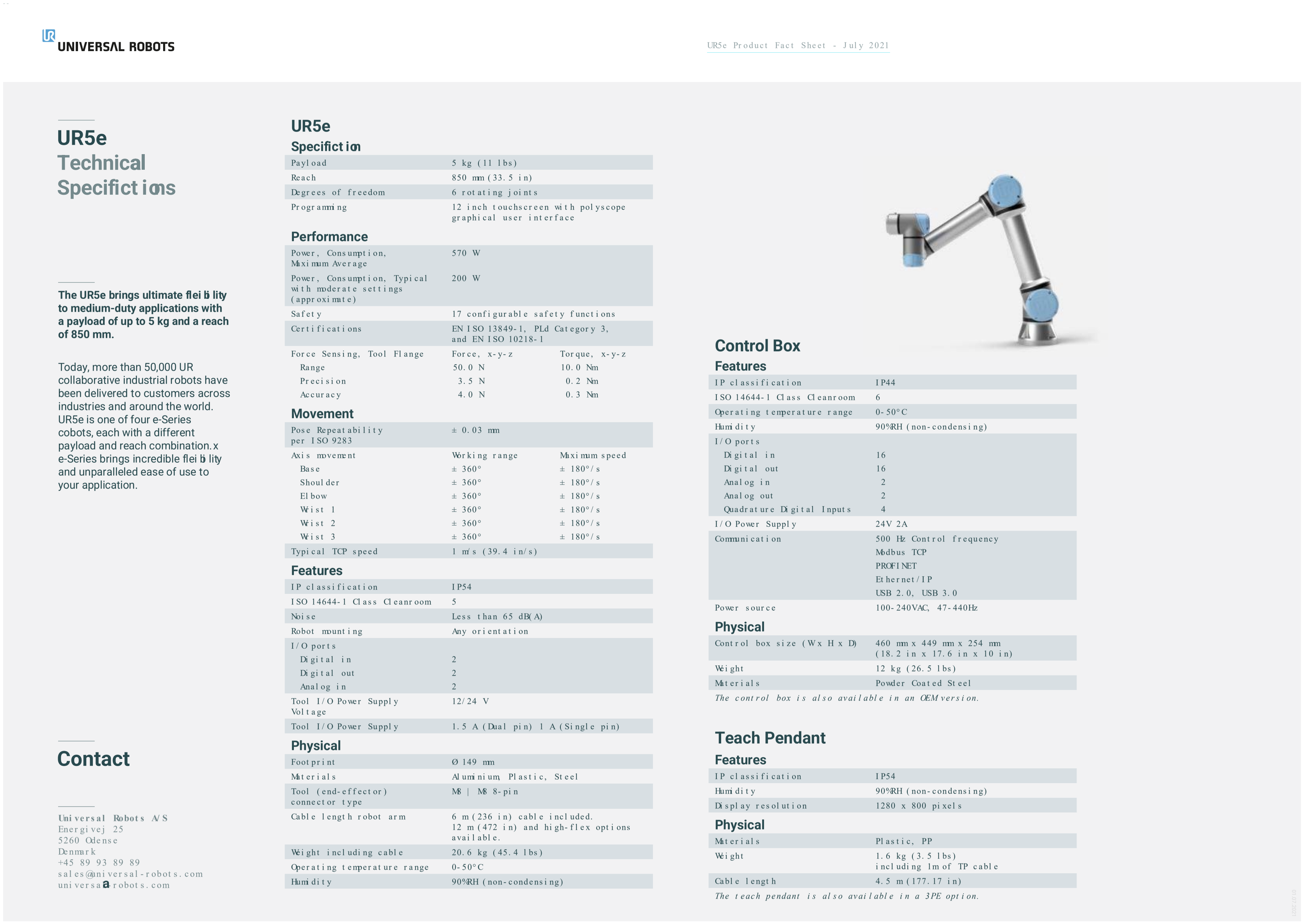
## Appendix 8: Drawing of the jig for the second sample product – top part



## Appendix 9: Drawing of the tool holder



## Appendix 10: Universal robot UR5e technical specifications



UNIVERSAL ROBOTS

UR5e Product Fact Sheet - July 2021

# UR5e
# Technical Specifications

**The UR5e brings ultimate flexibility to medium-duty applications with a payload of up to 5 kg and a reach of 850 mm.**

Today, more than 50,000 UR collaborative industrial robots have been delivered to customers across industries and around the world. UR5e is one of four e-Series cobots, each with a different payload and reach combination.x e-Series brings incredible flexibility and unparalleled ease of use to your application.

## UR5e

### Specification

| | |
|---|---|
| Payload | 5 kg (11 lbs) |
| Reach | 850 mm (33.5 in) |
| Degrees of freedom | 6 rotating joints |
| Programming | 12 inch touchscreen with polyscope graphical user interface |

### Performance

| | | |
|---|---|---|
| Power, Consumption, Maximum Average | 570 W | |
| Power, Consumption, Typical with moderate settings (approximate) | 200 W | |
| Safety | 17 configurable safety functions | |
| Certifications | EN ISO 13849-1, PLd Category 3, and EN ISO 10218-1 | |
| Force Sensing, Tool Flange | Force, x-y-z | Torque, x-y-z |
| Range | 50.0 N | 10.0 Nm |
| Precision | 3.5 N | 0.2 Nm |
| Accuracy | 4.0 N | 0.3 Nm |

### Movement

| | | |
|---|---|---|
| Pose Repeatability per ISO 9283 | ± 0.03 mm | |
| Axis movement | Working range | Maximum speed |
| Base | ± 360° | ± 180°/s |
| Shoulder | ± 360° | ± 180°/s |
| Elbow | ± 360° | ± 180°/s |
| Wrist 1 | ± 360° | ± 180°/s |
| Wrist 2 | ± 360° | ± 180°/s |
| Wrist 3 | ± 360° | ± 180°/s |
| Typical TCP speed | 1 m/s (39.4 in/s) | |

### Features

| | |
|---|---|
| IP classification | IP54 |
| ISO 14644-1 Class Cleanroom | 5 |
| Noise | Less than 65 dB(A) |
| Robot mounting | Any orientation |
| I/O ports | |
| Digital in | 2 |
| Digital out | 2 |
| Analog in | 2 |
| Tool I/O Power Supply Voltage | 12/24 V |
| Tool I/O Power Supply | 1.5 A (Dual pin) 1 A (Single pin) |

### Physical

| | |
|---|---|
| Footprint | Ø 149 mm |
| Materials | Aluminium, Plastic, Steel |
| Tool (end-effector) connector type | M8 \| M8 8-pin |
| Cable length robot arm | 6 m (236 in) cable included.<br>12 m (472 in) and high-flex options available. |
| Weight including cable | 20.6 kg (45.4 lbs) |
| Operating temperature range | 0-50°C |
| Humidity | 90%RH (non-condensing) |

## Control Box

### Features

| | |
|---|---|
| IP classification | IP44 |
| ISO 14644-1 Class Cleanroom | 6 |
| Operating temperature range | 0-50°C |
| Humidity | 90%RH (non-condensing) |
| I/O ports | |
| Digital in | 16 |
| Digital out | 16 |
| Analog in | 2 |
| Analog out | 2 |
| Quadrature Digital Inputs | 4 |
| I/O Power Supply | 24V 2A |
| Communication | 500 Hz Control frequency<br>Modbus TCP<br>PROFINET<br>Ethernet/IP<br>USB 2.0, USB 3.0 |
| Power source | 100-240VAC, 47-440Hz |

### Physical

| | |
|---|---|
| Control box size (WxHxD) | 460 mm x 449 mm x 254 mm (18.2 in x 17.6 in x 10 in) |
| Weight | 12 kg (26.5 lbs) |
| Materials | Powder Coated Steel |

*The control box is also available in an OEM version.*

## Teach Pendant

### Features

| | |
|---|---|
| IP classification | IP54 |
| Humidity | 90%RH (non-condensing) |
| Display resolution | 1280 x 800 pixels |

### Physical

| | |
|---|---|
| Materials | Plastic, PP |
| Weight | 1.6 kg (3.5 lbs)<br>including 1m of TP cable |
| Cable length | 4.5 m (177.17 in) |

*The teach pendant is also available in a 3PE option.*

# Contact

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sales@universal-robots.com
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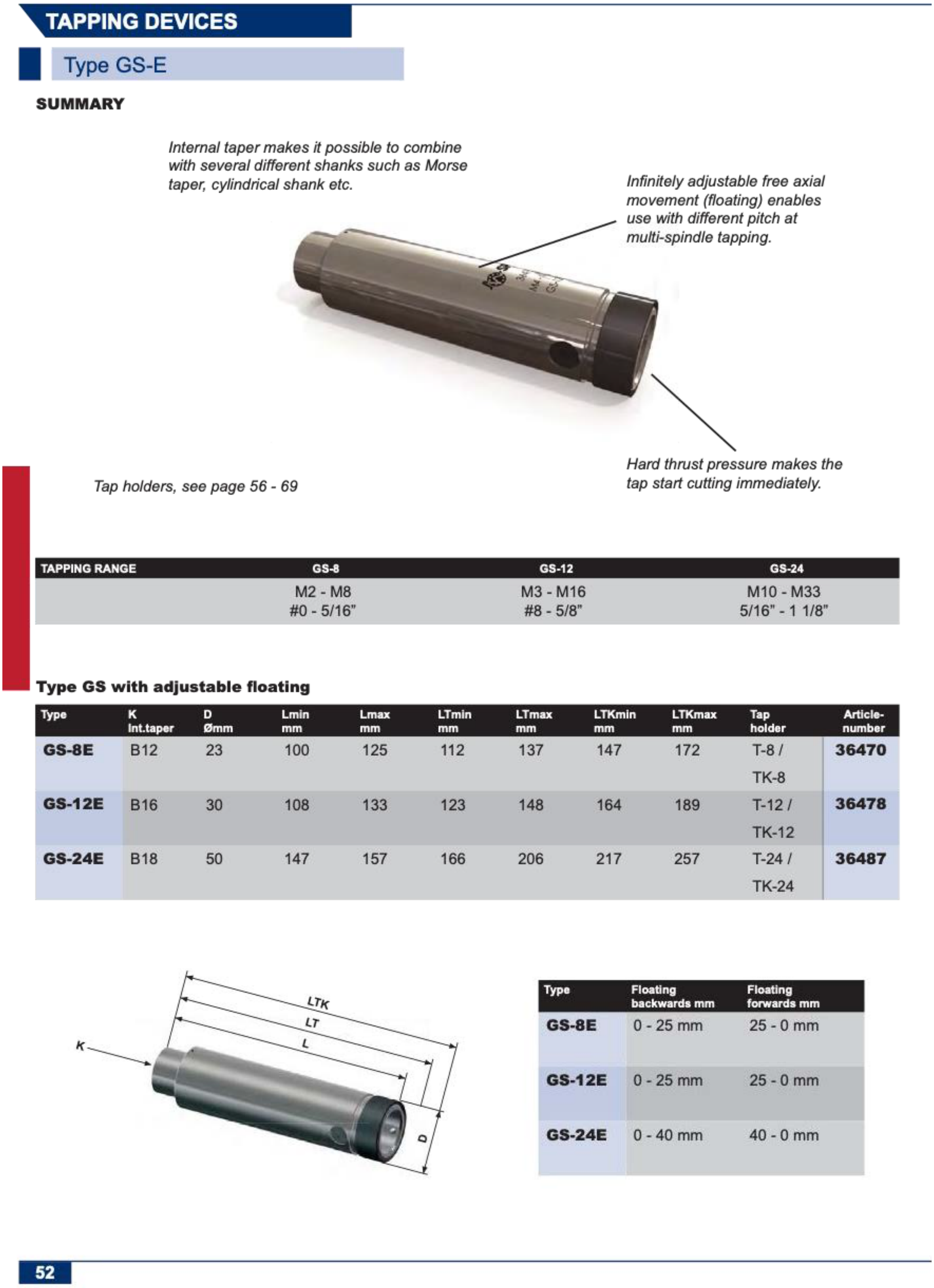
01.07.2021

## Appendix 11: Tapping spindle SPV Spintec GS-8E – 36470 specifications



**TAPPING DEVICES**

Type GS-E

**SUMMARY**

*Internal taper makes it possible to combine with several different shanks such as Morse taper, cylindrical shank etc.*

*Infinitely adjustable free axial movement (floating) enables use with different pitch at multi-spindle tapping.*

*Hard thrust pressure makes the tap start cutting immediately.*

*Tap holders, see page 56 - 69*

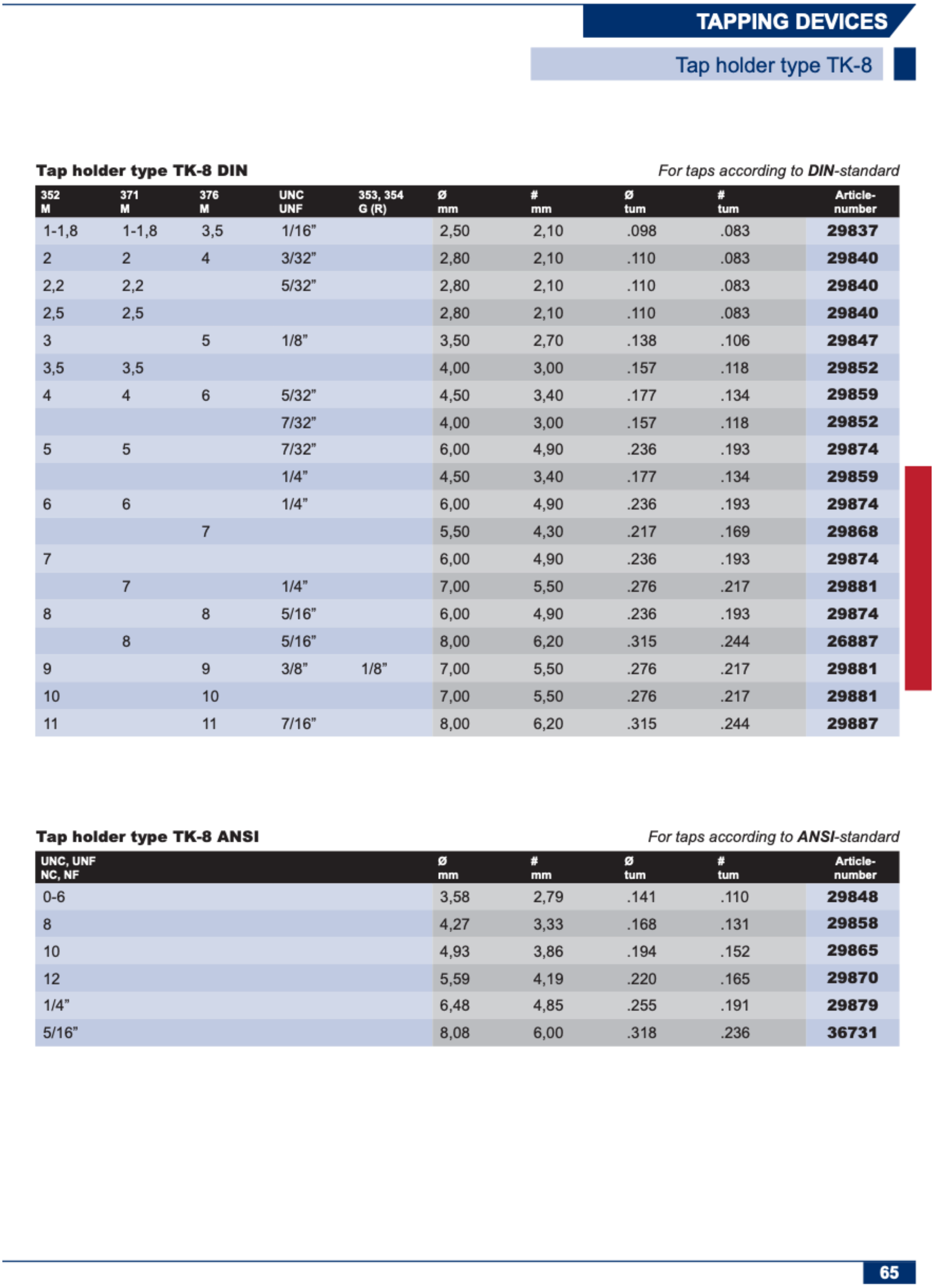
| TAPPING RANGE | GS-8 | GS-12 | GS-24 |
|---|---|---|---|
| | M2 - M8<br>#0 - 5/16" | M3 - M16<br>#8 - 5/8" | M10 - M33<br>5/16" - 1 1/8" |

**Type GS with adjustable floating**

| Type | K Int.taper | D Ømm | Lmin mm | Lmax mm | LTmin mm | LTmax mm | LTKmin mm | LTKmax mm | Tap holder | Article-number |
|---|---|---|---|---|---|---|---|---|---|---|
| **GS-8E** | B12 | 23 | 100 | 125 | 112 | 137 | 147 | 172 | T-8 /<br>TK-8 | **36470** |
| **GS-12E** | B16 | 30 | 108 | 133 | 123 | 148 | 164 | 189 | T-12 /<br>TK-12 | **36478** |
| **GS-24E** | B18 | 50 | 147 | 157 | 166 | 206 | 217 | 257 | T-24 /<br>TK-24 | **36487** |

| Type | Floating backwards mm | Floating forwards mm |
|---|---|---|
| **GS-8E** | 0 - 25 mm | 25 - 0 mm |
| **GS-12E** | 0 - 25 mm | 25 - 0 mm |
| **GS-24E** | 0 - 40 mm | 40 - 0 mm |

## Appendix 12: Tap holder SPV Spintec TK-8 specifications



TAPPING DEVICES

Tap holder type TK-8

**Tap holder type TK-8 DIN**

*For taps according to **DIN**-standard*

| 352 M | 371 M | 376 M | UNC UNF | 353, 354 G (R) | ø mm | # mm | ø tum | # tum | Article-number |
|---|---|---|---|---|---|---|---|---|---|
| 1-1,8 | 1-1,8 | 3,5 | 1/16” | | 2,50 | 2,10 | .098 | .083 | **29837** |
| 2 | 2 | 4 | 3/32” | | 2,80 | 2,10 | .110 | .083 | **29840** |
| 2,2 | 2,2 | | 5/32” | | 2,80 | 2,10 | .110 | .083 | **29840** |
| 2,5 | 2,5 | | | | 2,80 | 2,10 | .110 | .083 | **29840** |
| 3 | | 5 | 1/8” | | 3,50 | 2,70 | .138 | .106 | **29847** |
| 3,5 | 3,5 | | | | 4,00 | 3,00 | .157 | .118 | **29852** |
| 4 | 4 | 6 | 5/32” | | 4,50 | 3,40 | .177 | .134 | **29859** |
| | | | 7/32” | | 4,00 | 3,00 | .157 | .118 | **29852** |
| 5 | 5 | | 7/32” | | 6,00 | 4,90 | .236 | .193 | **29874** |
| | | | 1/4” | | 4,50 | 3,40 | .177 | .134 | **29859** |
| 6 | 6 | | 1/4” | | 6,00 | 4,90 | .236 | .193 | **29874** |
| | | 7 | | | 5,50 | 4,30 | .217 | .169 | **29868** |
| 7 | | | | | 6,00 | 4,90 | .236 | .193 | **29874** |
| | 7 | | 1/4” | | 7,00 | 5,50 | .276 | .217 | **29881** |
| 8 | | 8 | 5/16” | | 6,00 | 4,90 | .236 | .193 | **29874** |
| | 8 | | 5/16” | | 8,00 | 6,20 | .315 | .244 | **26887** |
| 9 | | 9 | 3/8” | 1/8” | 7,00 | 5,50 | .276 | .217 | **29881** |
| 10 | | 10 | | | 7,00 | 5,50 | .276 | .217 | **29881** |
| 11 | | 11 | 7/16” | | 8,00 | 6,20 | .315 | .244 | **29887** |

**Tap holder type TK-8 ANSI**

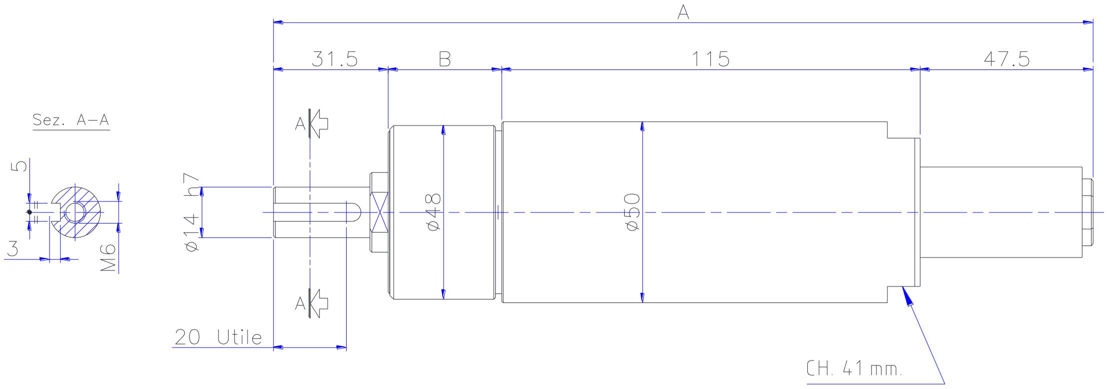
*For taps according to **ANSI**-standard*

| UNC, UNF NC, NF | ø mm | # mm | ø tum | # tum | Article-number |
|---|---|---|---|---|---|
| 0-6 | 3,58 | 2,79 | .141 | .110 | **29848** |
| 8 | 4,27 | 3,33 | .168 | .131 | **29858** |
| 10 | 4,93 | 3,86 | .194 | .152 | **29865** |
| 12 | 5,59 | 4,19 | .220 | .165 | **29870** |
| 1/4” | 6,48 | 4,85 | .255 | .191 | **29879** |
| 5/16” | 8,08 | 6,00 | .318 | .236 | **36731** |

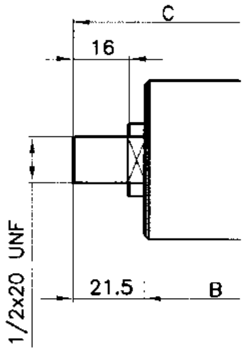
## Appendix 13: Pneumatic motor Ober SP6R – 8731255 specifications

**DIMENSIONI DI INGOMBRO / *DIMENSIONS / OVERALL DIMENSIONS / GESAMTABMESSUNG / DIMENSIONES / GENEL BOYUTLAR***

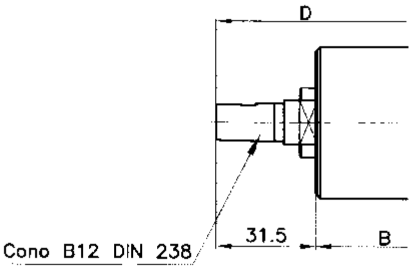
Versione standard: albero di uscita cilindrico (SPH) / con sede chiavetta (SP40-30-20-8-6-4-3-2):
*Standard version: cylindrical shaft (SPH) / cylindrical shaft and key housing (SP40-30-20-8-6-4-3-2):*
*Version standard: arbre de sortie cylindrique (SPH) / avec rainure de clavette (SP40-30-20-8-6-4-3-2):*
*Standardausfürung: zylindrisch Abtriebswelle (SPH) / mit Keilnut (SP40-30-20-8-6-4-3-2):*
*Version standard: eje de salida cilíndrico (SPH) / con chavetero (SP40-30-20-8-6-4-3-2):*
*Standart versiyon: silindirik mil (SPH) / silindirik mil ve anahtar muhafazası (SP40-30-20-8-6-4-3-2)*



Versione a richiesta: albero filettato: (solo per i modelli a rotazione destra SP40-30-20-8-6-4-3-2 D):
*On request: threaded shaft (only for models with right rotation SP40-30-20-8-6-4-3-2 D):*
*Sur demande: arbre de sortie fileté (seulement pour modèles avec rotation à droite SP40-30-20-8-6-4-3-2 D):*
*Auf Anfrage: Gewindeantriebswelle (nur für Modelle mit Rechtslauf SP40-30-20-8-6-4-3-2 D):*
*Version sobre pedido: eje de salida roscado (sólo para los modelos con rotación a derechas SP40-30-20-8-6-4-3-2 D):*
*Talep üzerine: dişli mil (sadece sağdan rotasyonlu modeller için SP40-30-20-8-6-4-3-2 D)*



Versione a richiesta: albero conico:
*On request: tapered shaft:*
*Sur demande: arbre de sortie conique:*
*Auf Anfrage: konische Welle :*
*Version sobre pedido: eje de salida cónico:*
*Talep üzerine: konik mil:*



| | A | B | C | D |
|---|---|---|---|---|
| SP H - 40 - 30 - 20 | 225.2 | 31.2 | 215.2 | 225.2 |
| SP 8 - 6 - 4 - 3 - 2 | 253 | 59 | 243 | 253 |

## *TECHNICAL FEATURES* *Table 1*

GB

| *Model* | *Code* | *Speed (rpm)* | | *Torque (Nm)* | | *Power* | *Air Consump* | *Weight* | *Noise* |
|---|---|---|---|---|---|---|---|---|---|
| | | *No-load* | *max power* | *max power* | *Static* | *(W)* | *(Nl/min.)* | *(Kg)* | Lp*(dB(A))* |
| **SPHD-SPHS** | 8711250-8721250 | 17000 | 8270 | 0,9 | 1,8 | 800 | 1000 | 1.2 | 80.7 |
| **SP40D-SP40S** | 8711251-8721251 | 3500 | 1710 | 4,3 | 9 | 800 | 1000 | 1.2 | 80.7 |
| **SP30D-SP30S** | 8711252-8721252 | 2850 | 1380 | 5,3 | 11 | 800 | 1000 | 1.2 | 80.7 |
| **SP20D-SP20S** | 8711253-8721253 | 2100 | 1015 | 7,3 | 15 | 800 | 1000 | 1.2 | 80.7 |
| **SP8D-SP8S** | 8711254-8721254 | 730 | 350 | 21 | 43 | 800 | 1000 | 1.5 | 80.7 |
| **SP6D-SP6S** | 8711255-8721255 | 580 | 285 | 26 | 53 | 800 | 1000 | 1.5 | 80.7 |
| **SP4D-SP4S** | 8711256-8721256 | 430 | 210 | 35 | 73 | 800 | 1000 | 1.5 | 80.7 |
| **SP3D-SP3S** | 8711257-8721257 | 350 | 170 | 43,5 | 90 | 800 | 1000 | 1.5 | 80.7 |
| **SP2D-SP2S** | 8711258-8721258 | 250 | 125 | 59 | 120 | 800 | 1000 | 1.5 | 80.7 |
| **SPHR** | 8731250 | 14000 | 6920 | 0,8 | 1,5 | 610 | 890 | 1.2 | 80.1 |
| **SP40R** | 8731251 | 2900 | 1430 | 4,1 | 7,4 | 610 | 890 | 1.2 | 80.1 |
| **SP30R** | 8731252 | 2300 | 1150 | 5,1 | 9,2 | 610 | 890 | 1.2 | 80.1 |
| **SP20R** | 8731253 | 1700 | 850 | 6,9 | 12,5 | 610 | 890 | 1.2 | 80.1 |
| **SP8R** | 8731254 | 600 | 295 | 19,8 | 36 | 610 | 890 | 1.4 | 80.1 |
| **SP6R** | 8731255 | 480 | 240 | 24,5 | 44 | 610 | 890 | 1.4 | 80.1 |
| **SP4R** | 8731256 | 350 | 175 | 33,3 | 60 | 610 | 890 | 1.4 | 80.1 |
| **SP3R** | 8731257 | 290 | 140 | 41,2 | 75 | 610 | 890 | 1.4 | 80.1 |
| **SP2R** | 8731258 | 210 | 100 | 56 | 100 | 610 | 890 | 1.4 | 80.1 |

*Air inlet 1/4 GAS; Ø inside tube min. 8 mm. Noise emission levels determined by using ISO/CD 15 744*
*The data are obtained with a supply pressure of 6 bar and an air flow equal to or greater than the consumption level indicated.*

### *NOISE*

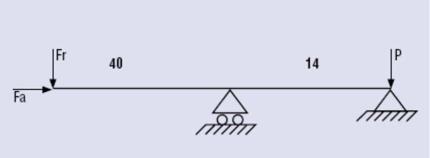
*The table of technical specifications indicates the noise level- where the noise level exceeds 85 dB (A) the noise power is also indicated. Ear protectors must be worn where the noise level exceeds 85 dB (A) at the operator position. We recommend that you also wear ear protectors below this noise level.*
*Noise risk and hearing damage are related to the intensity of the noise source and the length of exposure. Noise risk must be assessed on a case by case basis taking into account these two factors. Measures should be taken against hearing damage in accordance with current Health and Safety regulations.*

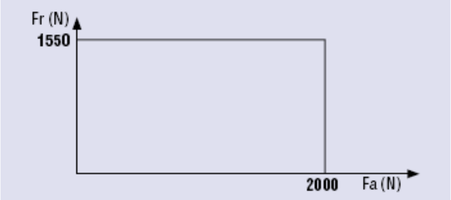
### *CALCULATION OF THE PERMITTED MAXIMUM RADIAL AND AXIAL LOAD OF MOTOR SP(H)*

*Bearing 6203: C=9560 N, C0=4750 N.*
*Using the formula for dimensioning the bearings, the result is:*
*L10=(C/P)3 , where L10 = duration in millions of rotations*
*C = dynamic load coefficient*
*P = equivalent dynamic load on bearing.*

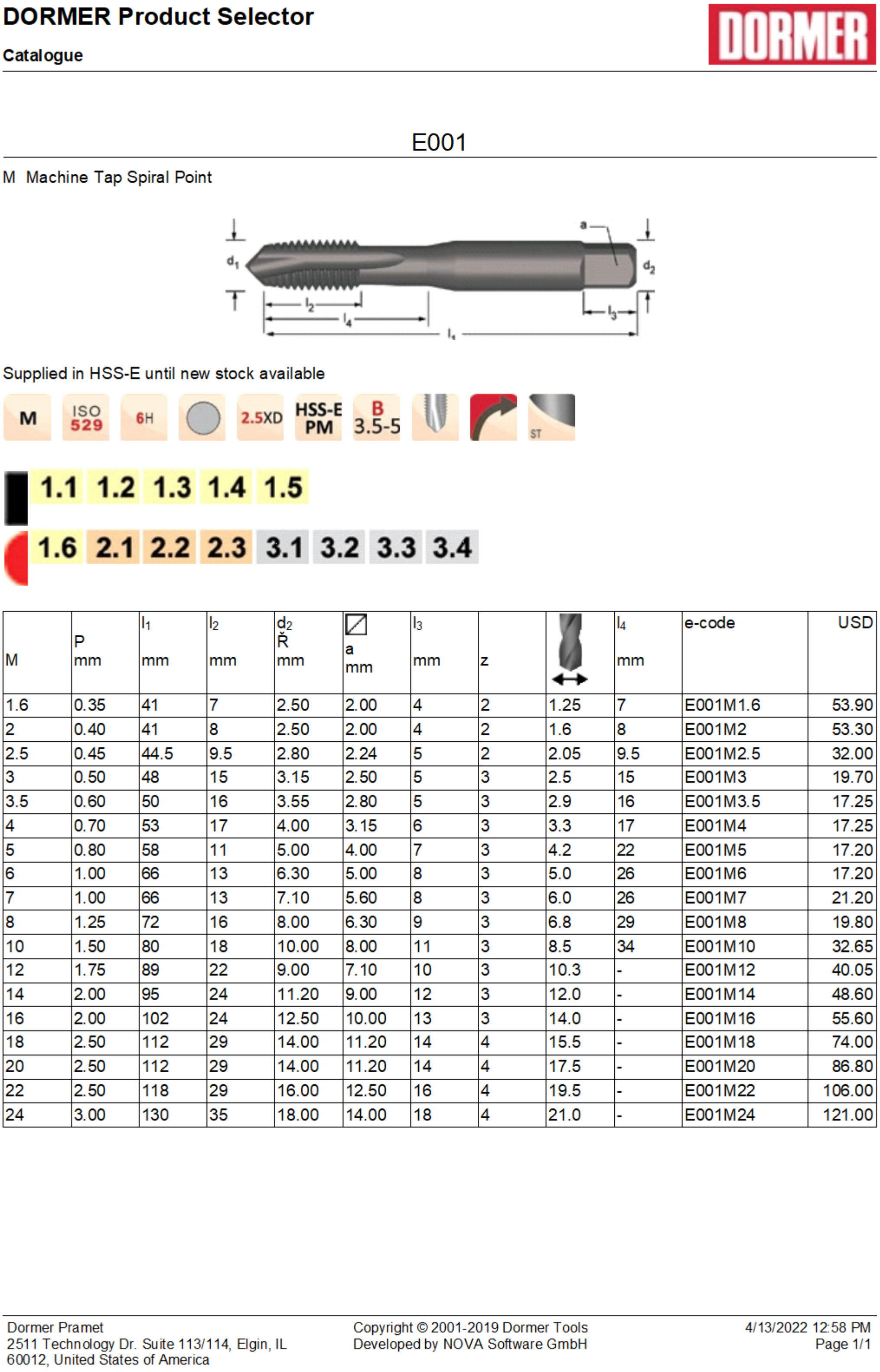
*Taking the number of cycles before failure as 10 million, the result is:*
*10=(9560/P)3, where P=4437 N.*

*Final result:* ***Fr = 1550 N***
*(maximum radial force in the absence of axial load).*
*The maximum axial force in the absence of radial load is:*
***Fa = 2000 N***





# Appendix 14: Tap tool Dormer M4 E001 6H 2RT0845658 specifications



**DORMER Product Selector**

**Catalogue**

DORMER

E001

M Machine Tap Spiral Point

Supplied in HSS-E until new stock available

M | ISO 529 | 6H | ○ | 2.5XD | HSS-E PM | B 3.5-5 | ST

1.1 1.2 1.3 1.4 1.5

1.6 2.1 2.2 2.3 3.1 3.2 3.3 3.4

| M | P<br>mm | $l_1$<br>mm | $l_2$<br>mm | $d_2$<br>Ř<br>mm | ▢<br>a<br>mm | $l_3$<br>mm | z | ↔ | $l_4$<br>mm | e-code | USD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.6 | 0.35 | 41 | 7 | 2.50 | 2.00 | 4 | 2 | 1.25 | 7 | E001M1.6 | 53.90 |
| 2 | 0.40 | 41 | 8 | 2.50 | 2.00 | 4 | 2 | 1.6 | 8 | E001M2 | 53.30 |
| 2.5 | 0.45 | 44.5 | 9.5 | 2.80 | 2.24 | 5 | 2 | 2.05 | 9.5 | E001M2.5 | 32.00 |
| 3 | 0.50 | 48 | 15 | 3.15 | 2.50 | 5 | 3 | 2.5 | 15 | E001M3 | 19.70 |
| 3.5 | 0.60 | 50 | 16 | 3.55 | 2.80 | 5 | 3 | 2.9 | 16 | E001M3.5 | 17.25 |
| 4 | 0.70 | 53 | 17 | 4.00 | 3.15 | 6 | 3 | 3.3 | 17 | E001M4 | 17.25 |
| 5 | 0.80 | 58 | 11 | 5.00 | 4.00 | 7 | 3 | 4.2 | 22 | E001M5 | 17.20 |
| 6 | 1.00 | 66 | 13 | 6.30 | 5.00 | 8 | 3 | 5.0 | 26 | E001M6 | 17.20 |
| 7 | 1.00 | 66 | 13 | 7.10 | 5.60 | 8 | 3 | 6.0 | 26 | E001M7 | 21.20 |
| 8 | 1.25 | 72 | 16 | 8.00 | 6.30 | 9 | 3 | 6.8 | 29 | E001M8 | 19.80 |
| 10 | 1.50 | 80 | 18 | 10.00 | 8.00 | 11 | 3 | 8.5 | 34 | E001M10 | 32.65 |
| 12 | 1.75 | 89 | 22 | 9.00 | 7.10 | 10 | 3 | 10.3 | - | E001M12 | 40.05 |
| 14 | 2.00 | 95 | 24 | 11.20 | 9.00 | 12 | 3 | 12.0 | - | E001M14 | 48.60 |
| 16 | 2.00 | 102 | 24 | 12.50 | 10.00 | 13 | 3 | 14.0 | - | E001M16 | 55.60 |
| 18 | 2.50 | 112 | 29 | 14.00 | 11.20 | 14 | 4 | 15.5 | - | E001M18 | 74.00 |
| 20 | 2.50 | 112 | 29 | 14.00 | 11.20 | 14 | 4 | 17.5 | - | E001M20 | 86.80 |
| 22 | 2.50 | 118 | 29 | 16.00 | 12.50 | 16 | 4 | 19.5 | - | E001M22 | 106.00 |
| 24 | 3.00 | 130 | 35 | 18.00 | 14.00 | 18 | 4 | 21.0 | - | E001M24 | 121.00 |

Dormer Pramet
2511 Technology Dr. Suite 113/114, Elgin, IL
60012, United States of America

Developed by NOVA Software GmbH

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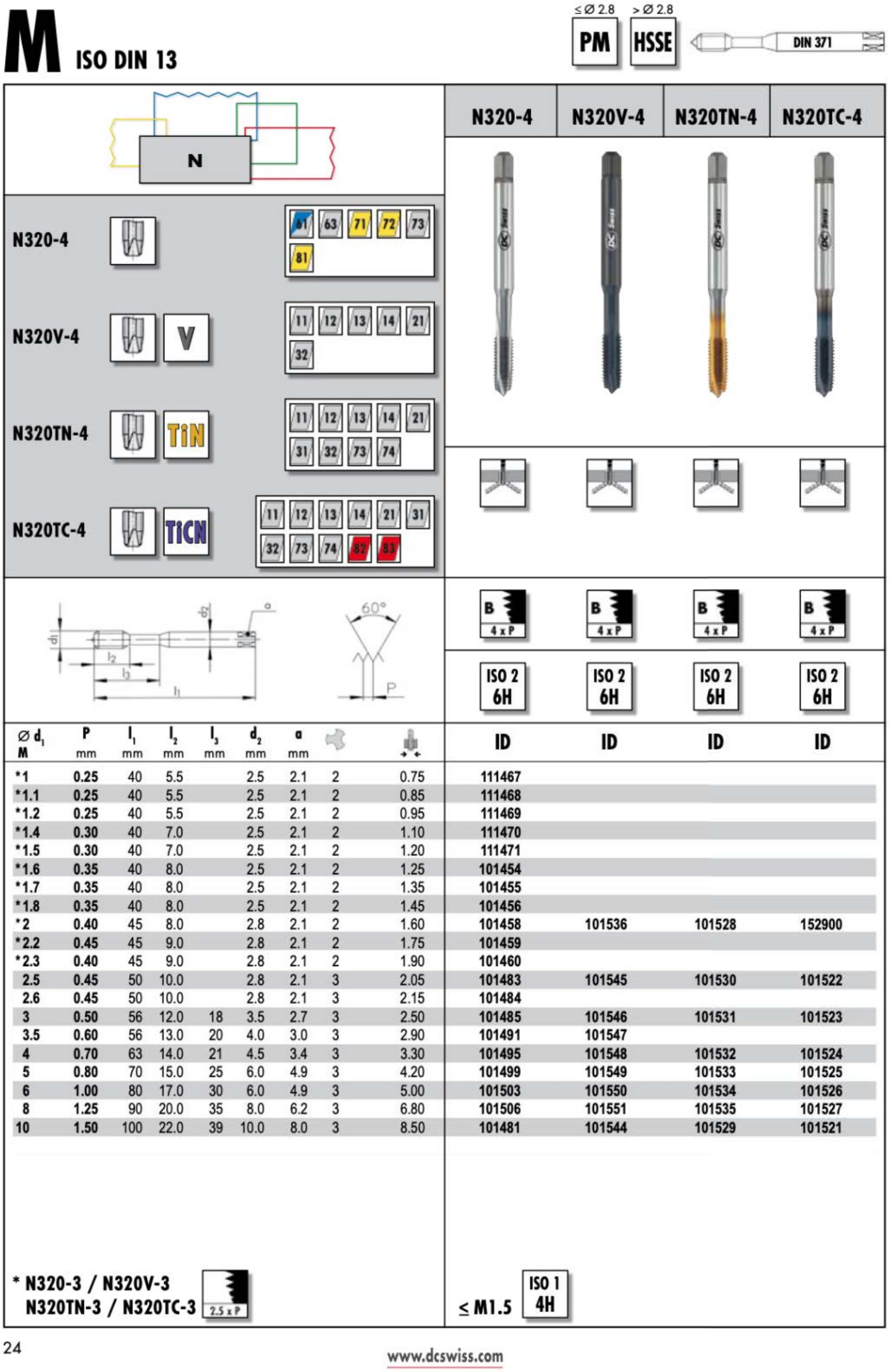
## Appendix 15: Tap tools DC N320V-4 M6 6H HSSE and DC N320-4 M8 6H HSSE specifications



**M** ISO DIN 13

| Ø d1 M | P mm | l1 mm | l2 mm | l3 mm | d2 mm | a mm | | | N320-4 ID | N320V-4 ID | N320TN-4 ID | N320TC-4 ID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1 | 0.25 | 40 | 5.5 | | 2.5 | 2.1 | 2 | 0.75 | 111467 | | | |
| *1.1 | 0.25 | 40 | 5.5 | | 2.5 | 2.1 | 2 | 0.85 | 111468 | | | |
| *1.2 | 0.25 | 40 | 5.5 | | 2.5 | 2.1 | 2 | 0.95 | 111469 | | | |
| *1.4 | 0.30 | 40 | 7.0 | | 2.5 | 2.1 | 2 | 1.10 | 111470 | | | |
| *1.5 | 0.30 | 40 | 7.0 | | 2.5 | 2.1 | 2 | 1.20 | 111471 | | | |
| *1.6 | 0.35 | 40 | 8.0 | | 2.5 | 2.1 | 2 | 1.25 | 101454 | | | |
| *1.7 | 0.35 | 40 | 8.0 | | 2.5 | 2.1 | 2 | 1.35 | 101455 | | | |
| *1.8 | 0.35 | 40 | 8.0 | | 2.5 | 2.1 | 2 | 1.45 | 101456 | | | |
| *2 | 0.40 | 45 | 8.0 | | 2.8 | 2.1 | 2 | 1.60 | 101458 | 101536 | 101528 | 152900 |
| *2.2 | 0.45 | 45 | 9.0 | | 2.8 | 2.1 | 2 | 1.75 | 101459 | | | |
| *2.3 | 0.40 | 45 | 9.0 | | 2.8 | 2.1 | 2 | 1.90 | 101460 | | | |
| 2.5 | 0.45 | 50 | 10.0 | | 2.8 | 2.1 | 3 | 2.05 | 101483 | 101545 | 101530 | 101522 |
| 2.6 | 0.45 | 50 | 10.0 | | 2.8 | 2.1 | 3 | 2.15 | 101484 | | | |
| 3 | 0.50 | 56 | 12.0 | 18 | 3.5 | 2.7 | 3 | 2.50 | 101485 | 101546 | 101531 | 101523 |
| 3.5 | 0.60 | 56 | 13.0 | 20 | 4.0 | 3.0 | 3 | 2.90 | 101491 | 101547 | | |
| 4 | 0.70 | 63 | 14.0 | 21 | 4.5 | 3.4 | 3 | 3.30 | 101495 | 101548 | 101532 | 101524 |
| 5 | 0.80 | 70 | 15.0 | 25 | 6.0 | 4.9 | 3 | 4.20 | 101499 | 101549 | 101533 | 101525 |
| 6 | 1.00 | 80 | 17.0 | 30 | 6.0 | 4.9 | 3 | 5.00 | 101503 | 101550 | 101534 | 101526 |
| 8 | 1.25 | 90 | 20.0 | 35 | 8.0 | 6.2 | 3 | 6.80 | 101506 | 101551 | 101535 | 101527 |
| 10 | 1.50 | 100 | 22.0 | 39 | 10.0 | 8.0 | 3 | 8.50 | 101481 | 101544 | 101529 | 101521 |

* N320-3 / N320V-3
N320TN-3 / N320TC-3 2.5 x P

≤ M1.5 ISO 1 4H

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# Appendix 16: Sick sensor sBot Speed system technical specifications

## SYS/BOT-URE04020102N33 | Safe Robotics Area Protection

SAFETY SYSTEMS FOR ROBOTS

### Ordering information

| Type | Part no. |
|---|---|
| SYS/BOT-URE04020102N33 | 1121078 |

**Included in delivery:** FX3-XTIO84002 (2), FX3-CPU320002 (1), SOW/BOT-URE0402010 (1), FX3-MPL100001 (1), NANSX-AAACAEZZ1 (2), NANS3-CAAZ30AN1 (2)

A safety system consists of optimized hardware, tested functional logic (software) and detailed documentation for easy integration in compliance with relevant standards.

With purchase, you accept the product description available under Downloads > Documentation in connection with the General Terms and Conditions for the Supply of Software Products (AVB Software SICK).

Other models and accessories ➜ www.sick.com/Safe_Robotics_Area_Protection

### Detailed technical data

#### Features

| | |
|---|---|
| **Variant** | sBot Speed – URe |
| **Product type** | System (hardware and software) |
| **Robot controller** | Universal Robots: UR3e, UR5e, UR10e, UR16e |
| **Stopping process of the robot** | With speed reduction |
| **Robot restart** | Automatic or manual |
| **Interfaces** | |
| Communication interface | Discrete I/Os |
| Configuration interface | Ethernet |
| **Safe state in the event of a fault** | The safety-related semiconductor outputs are in the OFF state. |
| **Safety laser scanners** | 2 x nanoScan3 Pro I/O |
| Protective field range | 3 m |
| **Safety task** | Hazardous area protection |
| **Ambient operating temperature** | –10 °C ... +50 °C |
| **Storage temperature** | –20 °C ... +50 °C |
| **Air humidity** | 90% at 50 °C (EN 61131-2) |
| **Safety controller included** | Flexi Soft (CPU3) |
| Safety controller type | Programmable |
| **Voltage supply** | |
| Supply voltage $V_S$ | 24 V DC (16.8 V DC ... 28.8 V DC) |
| **Performance level** | PL d (ISO 13849-1) |
| **Items supplied** | 2 x nanoScan3 Pro I/O safety laser scanners<br>Flexi Soft main module FX3-CPU0<br>1 Flexi Soft system plug FX3-MPL1<br>2 x FX3-XTIO Flexi Soft I/O module<br>2 x nanoScan3 Pro I/O Ethernet system plugs<br>Software (Flexi Soft Designer project file with functional logic, pre-configuration in Safety Designer file for nanoScan3 Pro I/O safety laser scanner, I/O Safety communication setting and UR-specific settings) as well as operating instructions, connection diagram, SISTEMA file and quick reference guide |