DESIGN OF AUTOMATIC PLYWOOD DISC CALIBRATION MACHINE

Automatic core plugs manufacturing from blank plywood discs

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Mechanical Engineering and Production Technology Abstract
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The project was developed for Estonian wood processing company. The aim of the project was to design an automated machinery solution for the production of plywood core plugs from blank plywood discs in accordance with customer requirements, which include calibrated outer diameter in a tolerance range of 0,2mm and tapering of the top edge with an angle of 14°. Machinery solution must be automated to the degree, that implies no manual processing of the part, except loading of blank discs and unloading processed core plugs.

Various workplace constraints, such as available tools and raw materials, workforce and equipment of machine whop, as well as available suppliers of standard mechanical components, were required to be taken into account. Compliance with these constraints was necessary to develop a realistic solution, that is possible to build under restricted conditions of the workplace.

Theoretical knowledge about the product was preliminary gathered to ensure the possibility of production under customers' requirements. Detailed constraints of the workplace were described and set to be followed during the machine design process.

A detailed overview of the designed solution was provided. For the purpose of description, the design was broken down into separate units, sub-units and individual parts. Description of units and parts includes general design review, detailed justification of design decisions and features, and analysis of operation principle. Standard purchased components were verified to ensure compatibility of their technical characteristics for the intended application. Verification was implemented by rough estimations and simple calculations based on known values of loads and processing workflow parameters, with at least double the safety factor taken into account.

As a result, mechanical solutions for part processing were developed and a theoretical basis for further production of the machine was built. All requirements prescribed for processing output are theoretically satisfied. The mechanical constituent of machine design implies the possibility of full automation to the requested level. Workplace constraints were followed for the most part with minor, yet justifiable deviation.

The project output in form of a detailed 3D model of machine assembly was presented and backed up with a thorough description of the operating principle.

Keywords Mechanical design, machine building, wood processing, CAD
Pages 64 pages

Contents

List of figures

Figure 16. Internal spindle assembly.

Figure 17. Calibration and tapering unit.

Figure 18. High-speed tool spindle drive Teknomotor 4147-A-DB-P-ER25-RH

> Teknomotor S.r.l. Spindles for CNC router machine applications. (n.d.) https://www.teknomotor.com/product/applications/spindles-for-cnc-router-machine-applications/4147-a-db-p-er25-rh-2/

Figure 19. SMC LEFS slider type electric actuators.

> Direct Industry. Linear actuator LEFS. https://www.directindustry.com/prod/smc/product-82491-1661793.html

Figure 20. Custom milling tool.

Figure 21. Edge sanding unit.

Figure 22. Left – Part treatment unit at part feeding stage. Right – part treatment unit at the part processing stage.

Figure 23. SMC CG3DN25-75 Pneumatic Cylinder.

Figure 24. Top – the type of sanding disc brush used in the edge sanding unit. Bottom – wood polishing machine with disc brushes.

> Cosma Borstelfabriek Holland. Disc brushes for surface treatment. https://www.cosma.nl/en/brushes/62-disc-brushes

> Win Star Machinery webshop. 1300-6y Automatic Horizontal Woodworking Machinery Wood Brush Sanding Polishing Machine. https://winstarmachinery.en.made-in-china.com/product/sXhmuBIgrbYw/China-1300-6y-Automatic-Horizontal-Woodworking-Machinery-Wood-Brush-Sanding-Polishing-Machine.html

Figure 25. Motor mounting bracket on linear guides

Figure 26. Left – unloading table. Right – stacking conveyor.

Figure 27. Stacking conveyor.

Figure 28. Timing belt drive unit.

Figure 29. Cross-section of driving pulley assembly.

Figure 30. Belt tensioning unit.

Figure 31. Core plug lifting mechanism.

Figure 32. Top – front holder. Bottom – Side holder.

Figure 33. Back view of the stacking conveyor with core plug being transported.

1 INTRODUCTION

The basis of the thesis lies in the problem that the commissioning company (onwards CC) has faced regarding the particular inquiry from the client. The industrial packaging solutions provider is in search of a manufacturer, which can produce core plugs for cardboard cores of various diameters in huge batches over an extended period. The aim of the thesis is to design an automated machinery solution that is capable of mass production of core plugs. This solution must be built using widely available standard components and materials available at the company's warehouse. The project must be implemented in a way that takes various conditions and constraints of the workplace into account and that the output of the project in form of a 3D model would allow to create a package of technical documentation needed to build the machine designed in a reasonable amount of time so that the CC can accept the project from the client.

1.1 Product description

Core plugs or core protection plugs are used in the packaging industry as an element of cardboard core structure for increased durability and rigidity. Cardboard cores are widely used in paper, textile, plastic film or foiled metal industries. Plugs are pressed into a cardboard core's inner diameter creating an interference fit for tight positioning to prevent damaging a core. Plugs greatly decrease the possibility of core-collapse during shipment or storage.

Figure 1. Collapsed cardboard core and cardboard cores with plugs.

1.2 Choice of product material

The most common materials used for manufacturing core plugs are plastic, particleboard, MDF, moulded wood and plywood.

The choice of plywood as a material for manufacturing plugs is based solely on the availability of other production lines at CC's facilities. There are several facilities that work with plywood to produce furniture parts and plywood flanges for drums in huge volumes. CC has previously developed solutions for efficiently cutting plywood discs from plywood boards of various thicknesses. The idea behind the production of plywood core plugs is to produce plywood discs similar to those used in drums for coiling lightweight material such as rope or tape as a base using already available machinery and conduct additional operations to add required features to make a final product.

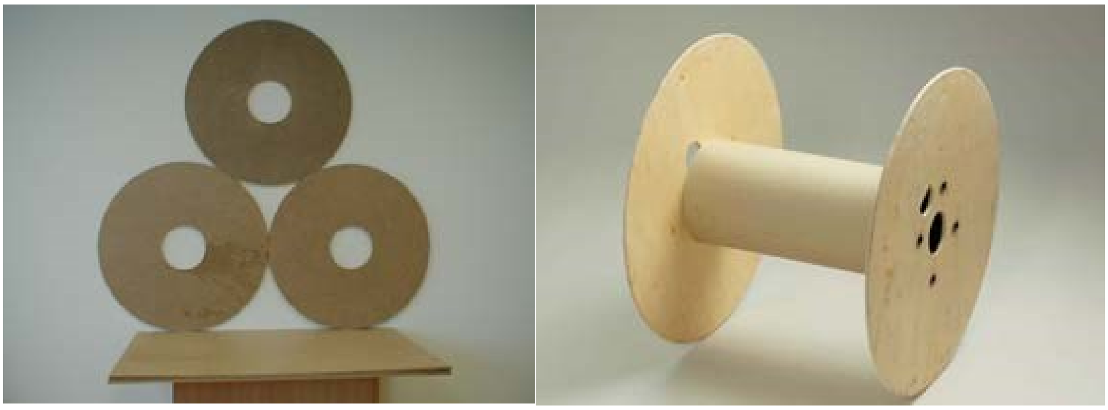


Figure 2. Plywood flange base discs and plywood cable drum.

Plywood boards with a standard thickness of 18mm are chosen as a base material.

The following are the additional operations that must be conducted with plywood disc to add needed features to produce a core plug:

1. Make a tapering or chamfer one edge of a disc for easier assembly into the core
2. Calibrate diameter to required tolerances
3. Remove chips and burrs from the calibrated sides to ensure safe following manipulation by hands

1.3 Product requirements and related problems

- There are several standard diameters of cores:

The main goal for the manufacturer is to be able to produce large volumes of parts of different base sizes. This means that the machine should be easily adjustable. There is no point in building a separate machine for each standard diameter of core plugs, as requirements can be changed or additional orders may be placed for other diameters, which differ from the first batch order. The currently known range of requested outer diameters varies from 210mm up to 350mm.

- Requirement for the diameter tolerance on the entire range of diameters is 0.2mm:

The requirement for the narrow diameter tolerance is justified by the need for further automatic assembly of a core with core plugs at the customer's site. The 0.2mm tolerance is unusual for mass production of plywood goods, however, the requirement is realistic. This tolerance lies within the boundary that is possible to measure and control, considering the so-called wood movement. Wood movement is a dimensional shrinkage, which is caused by a range of factors, of which humidity is the main to consider when storing and processing large volumes of material. As a reference point, according to Metsä wood spruce plywood manual, p.52 (2018), the dimensional change of plywood across the length and width of a panel averages a 0.01% increase per 1% increase of moisture content (MC) of plywood. Considering that CC takes reasonable measures for correct wood processing, such as controlled constant temperature and humidity within the range of 45-55% in storing and processing facilities it is possible to keep the complete process within adequate boundaries of dimensional shrinkage. To calculate the maximum expected dimensional change of plywood discs the graph in Figure 3 is used to determine the relation between relative humidity of air and MC of plywood. From the graph, it is possible to withdraw, that at 45% of air humidity the MC of plywood is close to 8%. With an increase of air humidity to 55%, the MC of plywood increases to about 11%, which gives an MC change of 3%. Given that the maximum diameter of core plugs requested by the customer is 340mm, even the largest possible change of moisture content of 3% would result in a dimensional change of 0.1mm.

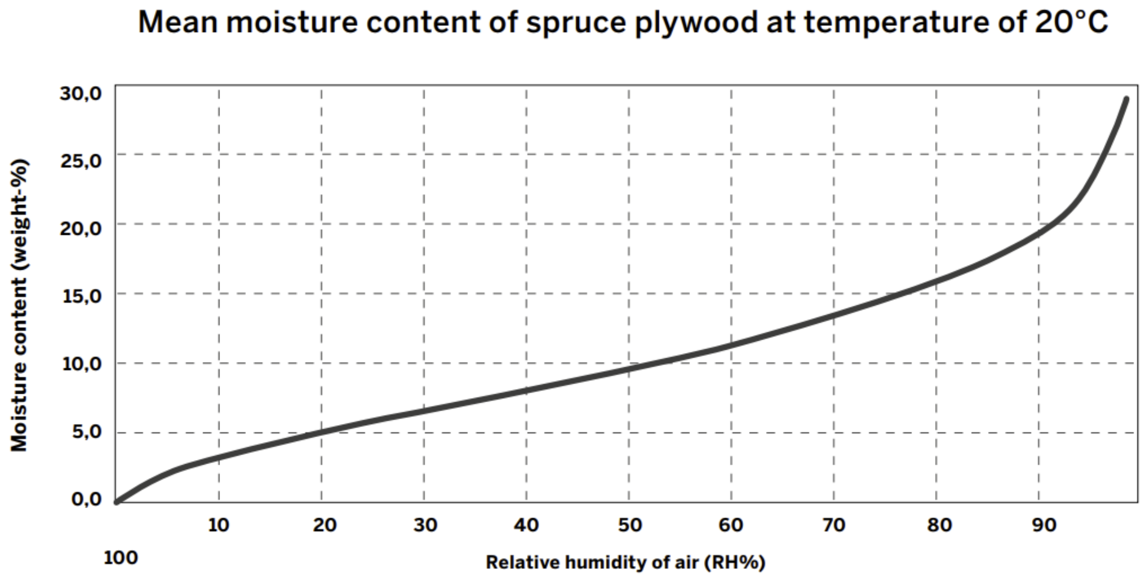


Figure 3. Graph showing mean equilibrium moisture content of spruce plywood

To meet the tolerance requirement metal processing principles must be applied and considered in the machine design process. Plywood disc must be properly fixed in place, machine structure must be rigid to prevent relative movement of units that work in synchronization, and vibrations from spinning and moving parts reduced. Forces that are applied to plywood blank disc by fixtures and cutting tools should not bend or twist it to any notable degree.

One more problem caused by strict requirements for tolerances is quality control. Complex quality control procedures involving additional personnel and tools, which require additional training are followed by unnecessary production costs. Ideally, quality control of random samples should be done by the same employee that operates the machine. The simplest way to ensure compliance with requested tolerances is to use gauges. The cost of designing and building an additional workbench with gauges for several standard diameters is justified by the expected high volume of production.

The design of gauges is not presented in the following project.

- Expected large volumes of production with years-long contracts:

Mass production and huge batches require automatic and effective manufacturing solutions to ensure economic feasibility for both client and manufacturer. The major component of production cost for most mass-produced products is direct labour. To present the most economical and appealing solution, the process of executing and controlling additional operations presented earlier must involve the direct labour of only one employee. The machine must be automated to such a degree that only setting up, loading blank discs, and unloading the final product is done by hand.

To justify costs of engineering and machine building, only widely available components, which are in stock at the CC's warehouse and components purchased from reliable contracted suppliers, can be used. The assembly of the machine and manufacturing of engineered components is preferable to be conducted only by CC's employees and using only the tools available at the CC's workshop without the involvement of any subcontractors.

- Not standard tapering angle of 14˚ requested

The custom milling tool for disk edge chamfering must be designed, as the requested value of 14˚ is not a standard value and such a tool cannot be purchased. There is no point in using a standard 15˚ tool and fine-tuning the assembly of a chamfering sub-unit to cut the edge at 14˚, either. Calibrating a base diameter of a disk and making a chamfer using different tools and therefore designing additional components and sub-units is unjustifiably cost-ineffective. The idea is to design a custom shaped milling tool that will be driven by only one motor to calibrate the base diameter and make a tapering of the requested angle at the same time.

Figure 4 sums up all requirements for the product in form of a technical drawing.

The diameter "d" is not relevant for the disc calibration operation as the central hole feature is made at the previous production step with a different machine. But the position of the central hole and its diameter must be considered for proper fixing of the disk at the calibration unit of the machine.

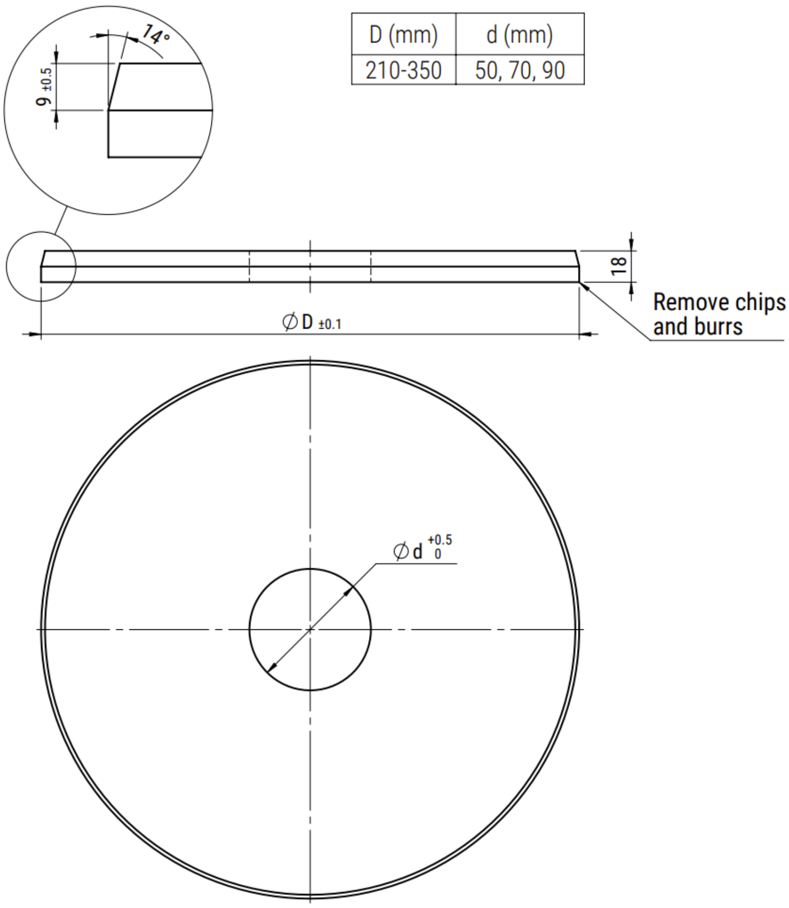


Figure 4. Drawing of the core plug

2 CONDITIONS AND CONSTRAINTS

The design process is tightly linked to the constraints of the workplace. It must be realistic in terms of available tools and should be framed within constraints of the workplace, which are mostly based on the possibilities of the mechanical workshop. Available machinery and skills of the staff must be considered to make a design that is physically possible to build in given conditions. The use of widely available materials and standard components purchased from contracted suppliers will ensure that the time frames for building the machine are not stretched out with unpredictable components delivery times.

2.1 Tools to be used

2.1.1 Software

The main engineering software tool to be used is Solidworks Standard 2021. This version only has basic functionality for modelling and technical drawings. If any calculations or simulations are required, these must be conducted using different tools.

Some of the auxiliary tools for mechanical calculations were custom created in Excel, using knowledge and experience gained during the employment at CC and utilizing data from international standards. The purpose of creating custom calculation tools is to save time on repeated operations, such as choosing a timing belt length or correct fittings for bearings.

Used file templates for parts, assemblies, and drawings as well as custom property files in Solidworks are also custom made for the developed and established engineering workflow at CC.

2.1.2 Standards

The main source for mechanical engineering standards used for the design of custom parts is the Handbook Of Mechanical Engineer, Anuryev V. I., 2001. In 3 volumes. It is based on GOST standards, which are for the most part interchangeable with ISO or DIN. Workflow processes in the mechanical workshop and inside the engineering team at CC were built around available GOST standards for at least two decades. But as mentioned earlier, these are used exclusively for the design of custom parts. The reason behind this is that all standard components that are available for purchase in the EU are made according to ISO or DIN standards. Standard equipment catalogues from European suppliers are mostly accompanied by detailed descriptions of fittings and other key details that ensure correct compatibility with fitted parts.

2.1.3 Methods and workflow overview

The engineering and design process generally consists of rough modelling of sub-units, followed by detailed modelling of separate components of these sub-units, assembling detailed sub-units from created components and making the main assembly from these sub-units. Then, if necessary, technical documentation is created. All this process can be described in the following steps.

1. Preliminary non-detailed design to make decisions on overall size, needed components and their location. The basic design of the unit should be generally decided on this step to eliminate the need for full remodelling at later steps that will require much more time. This step may be skipped for simple assemblies.
2. After the basic design is elaborated and the mapping of components is clear, design separate detailed components or download models for standard components.
3. Make a sub-assembly of the unit from the components created.
4. Put sub-assemblies in the main assembly and make sure that everything is aligned as required. At this stage, it is still easy to change the orientation of components and their main sizes if something is misaligned.
5. Produce technical documentation. Technical documentation should be preferably produced at the later steps when all design decisions are fully elaborated. Creating technical drawings at earlier stages may lead to lots of unnecessary work since the design may be altered, and some components replaced or eliminated. For the same reason, though fits and tolerances should be considered and decided by a mechanical engineer at an earlier design stage, their full description and double-checking are only done when creating technical drawings.

2.2 Workforce and machinery

It is important to mention that the mechanical engineering team does not produce schemes for any of the electrical, pneumatic, or hydraulic equipment and its installation, as well as does not program the work logic of these components. However, is responsible for choosing the correct components based on requirements. Following routing, scheming and programming are implemented by the team of electricians and automation engineers, who are closely working with the engineering team after the design process but do not participate in design decision making.

All parts that are designed specifically for the project and cannot be purchased have to be manufactured in the companies' mechanical workshop without the involvement of subcontractors unless absolutely necessary. This allows to work in a narrower timeframe and be more flexible with design changes as manufacturing does not depend on that many external variables. This is also much more cost-effective than ordering manufacturing of custom parts from subcontractors.

The main thing to consider is the lack of any CNC machine tools. Available machinery is manually operated and relatively old. However, these are properly maintained and capable of producing metal parts with tolerances narrow enough to satisfy required standards.

There are machines and tools for every basic metal and sheet metal working operation, such as cutting, bending, milling, turning, drilling, welding, grinding, and polishing. The staff at the workshop includes fifteen people, most of them have an experience in mechanics and metalworking of more than two decades.

2.3 Materials and suppliers

The main reasons for restrictions on available suppliers are contracts and delivery times. Contracted suppliers do not require payment confirmation before shipping the order and are familiar with companies' operation principles. That means shorter delivery times and more productive negotiations. Delivery times also depend on the availability of components at warehouses. There is only a limited list of manufacturers, whose components are always available in local warehouses and usually, those, that are available are the most commonly used standard sizes and types. However, it is allowed to order components that can be installed as the last step of machine assembly and do not need to be reworked in the workshop with longer delivery times. For example, frequently there is a need for custom linear motion components, gearmotors or other actuators, which usually have a delivery time from 4 to 8 weeks. Machine assembly workflow and design principles require these components to be easily accessible for maintenance. Also, the required parameters for these types of components and their installation dimensions are mostly known in advance, so these can be ordered even during the design planning phase.

Some varieties of structural elements, such as standard round and square tubes, beams, angles and others are available at CC's warehouse and it is preferably to use those when possible.

Following is the list of manufacturers, whose components can be ordered through available contracted suppliers.

Structural elements and raw materials:

1. Various European manufacturers – structural elements (bars, tubes, angles, beams, channels, etc.) made from steel, stainless steel, and aluminum.
2. Minitec – aluminum profile systems and components
3. Uddeholm – diverse types of hot and cold rolled tool steel

Various standard components for mechanics:

1. Maedler – standard mechanical engineering components
2. Lesjofors – springs
3. Optibelt – timing belts, conveyor belts

Motion technology:

1. Hiwin – linear motion control components
2. SKF – bearings
3. SMC – pneumatic and electric motion components
4. Varvel – gearmotors
5. BEVI – drives

3 PURPOSE AND OBJECTIVE

3.1 Aim for the output of the process

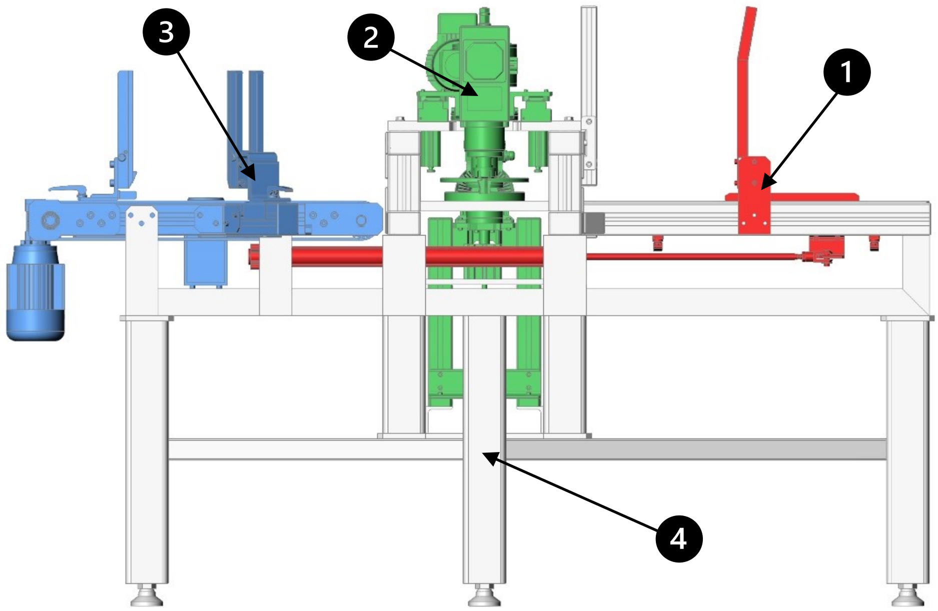
1. The machine is adjustable within the range of required diameters
2. The processing is fully automated and controlled by one operator with the following manual steps:
    a. Set up the machine
    b. Load blank discs
    c. Unload processed core plugs
    d. Random sample control using gauges
3. Tolerance for the outer diameter is 0.2mm
4. Tapering angle is 14˚
5. Remove chips and burrs for safe following manual handling

3.2 Aim for the development work

1. Follow materials and components constraints
2. Follow workshop machinery constraints
3. Justify design and component choice decisions
4. Follow design for manufacturing principles
5. Follow standards for the design of standard features and components
6. Produce accurate technical drawings, which can be clearly read and used for production

4 MACHINE DESIGN BREAKDOWN

Machine design breakdown and justification of design decisions is done by describing the complete 3D model.



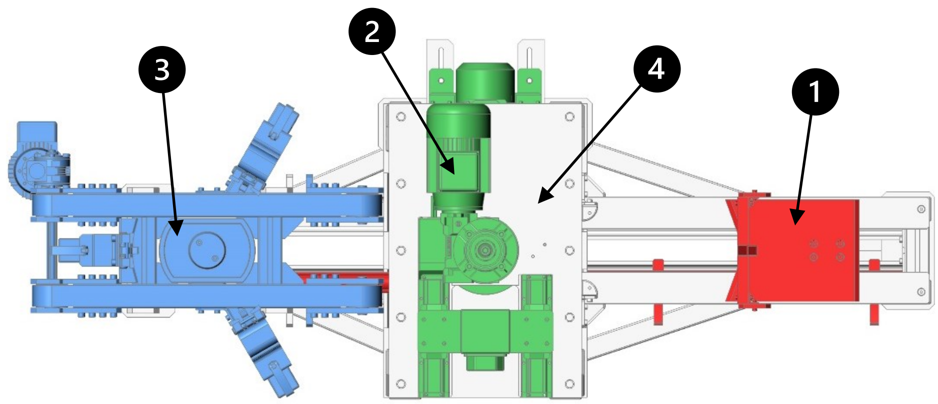


Figure 5. Automatic plywood disc calibration machine. (1) Feeding Unit. (2) Part treatment unit. (3) Stacking unit. (4) Frame

The machine consists of three main separate units, which are connected by a frame. These units are:

- Feeding. Up to 20 blank discs are stack loaded at the feeding unit. The lower disc is pushed from underneath the stack and transferred to the part treatment unit.

- Part treatment. The single blank disc is fixed on a spindle and rotated. While it makes two full rotations its’ diameter is calibrated and the upper edge is tapered with a custom milling tool, while at the same time discs’ side is sanded to remove chips and burrs left from milling.
- Stacking and unloading. When the feeding unit feeds the next blank disc to the treatment, the complete core plug from the treatment unit is also pushed forward until it reaches the unloading table or stacking conveyor depending on the configuration of the unloading unit. An unloading table is a completely manual solution, where the operator collects processed core plugs one by one. A stacking conveyor is an automated solution that forms stacks of up to ten core plugs.

Further breakdown and analysis of design decisions are shown as a description of separate units and parts of the machine. For each unit, there is a description of a design idea, a breakdown to sub-units and parts with a more detailed explanation of design decisions and justification of design features and choice of standard components.

4.1 Blank disc loading and feeding

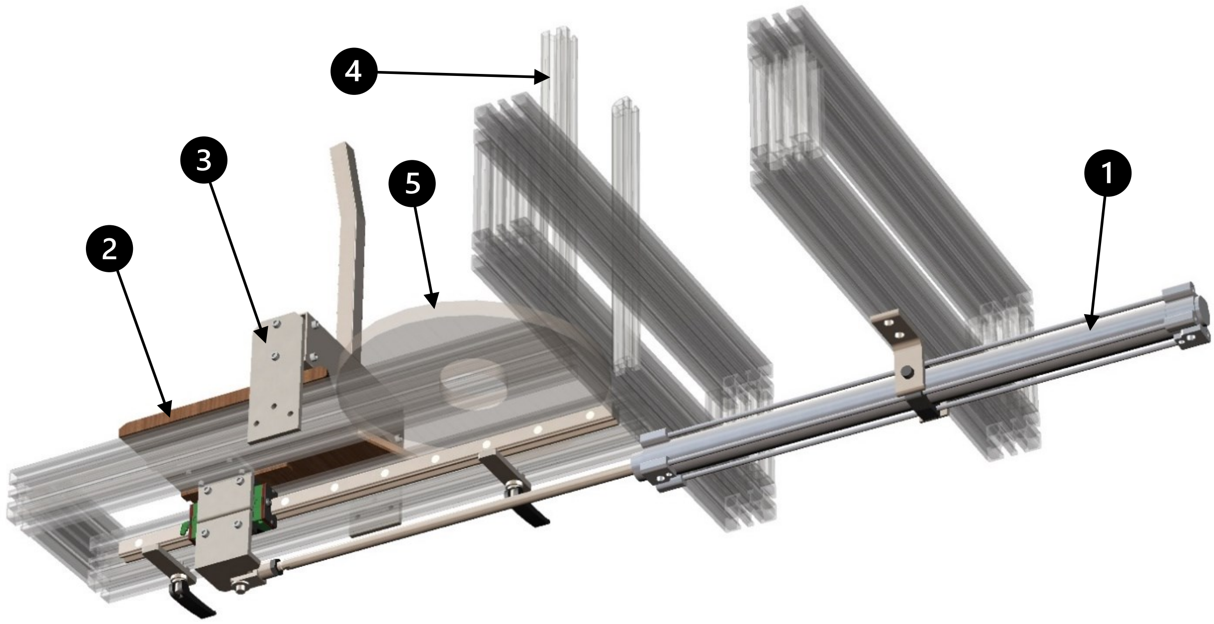


Figure 6. Blank disk loading and feeding mechanism. Bottom isometric view. (1) Cylinder. (2) Disc pushing plate. (3) Moving restrainer. (4) Fixed rests. (5) Blank disc.

Figure 6 shows a blank disc loading and feeding unit which consists of a pneumatic cylinder, a disk pushing plate connected to a rail guide which is actuated by the cylinder, a moving restrainer and fixed rests. Blank discs are loaded between a moving restrainer that can be adjusted according to the required diameter of the discs and fixed rests which are attached to the frame of the machine. The bottom disc is not restrained by the restrainer nor by rests, but all the discs above are. It allows the bottom disc to be pushed from underneath the stack of discs.

4.1.1 Restrainer

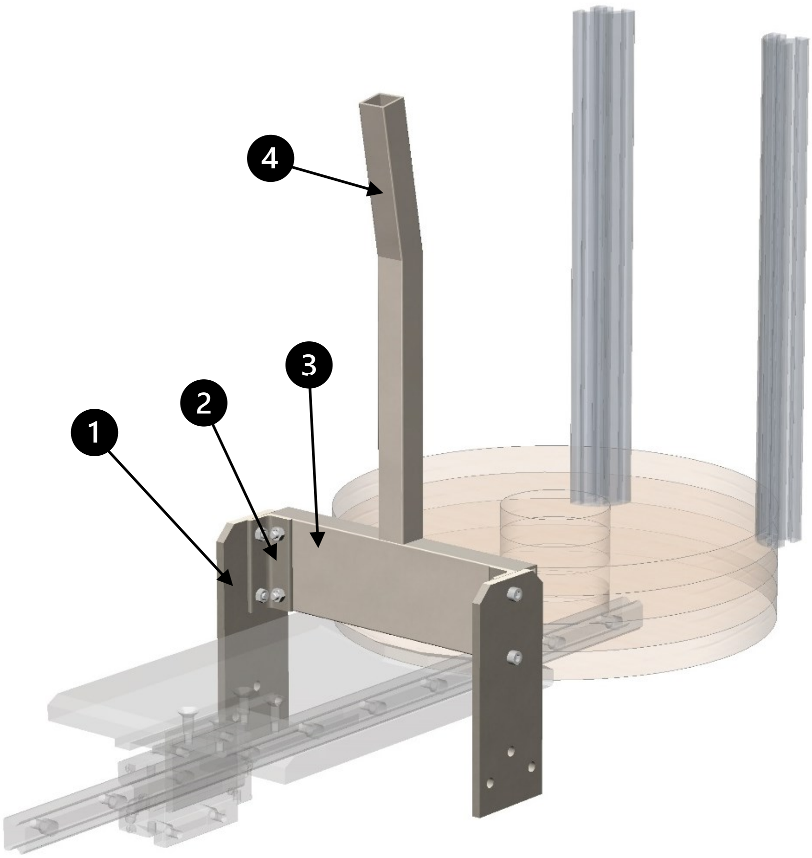


Figure 7. Restrainer in context with pushing plate and fixed rests.
(1) Bracket. (2) Fixture. (3) Rectangle tube. (4) Square tube

Figure 7 shows the restrainer which is made from simple standard steel elements. 8x60mm bar for the bracket, 20x20x3mm equal angle for the fixture, 60x20x2mm rectangle tube and 20x20x2 square tube. Two square tubes of different lengths are welded at an angle to create a widening at the top, which makes loading a stack of blank discs easier. Square tubes are welded to the narrow side of the rectangular tube right in the middle. This welded construction makes a restrainer itself. Then, at both ends of the rectangular tube this construction is attached to the brackets by bolts using an angled fixture as an adapter. Later, brackets are attached to the profile frame of the machine by bolts. Loosening these bolts allow for a linear movement of the restrainer along the profile frame, which in its turn is needed to set the restrainer at the desired location for different diameter of blank discs.

4.1.2 Disc pushing mechanism

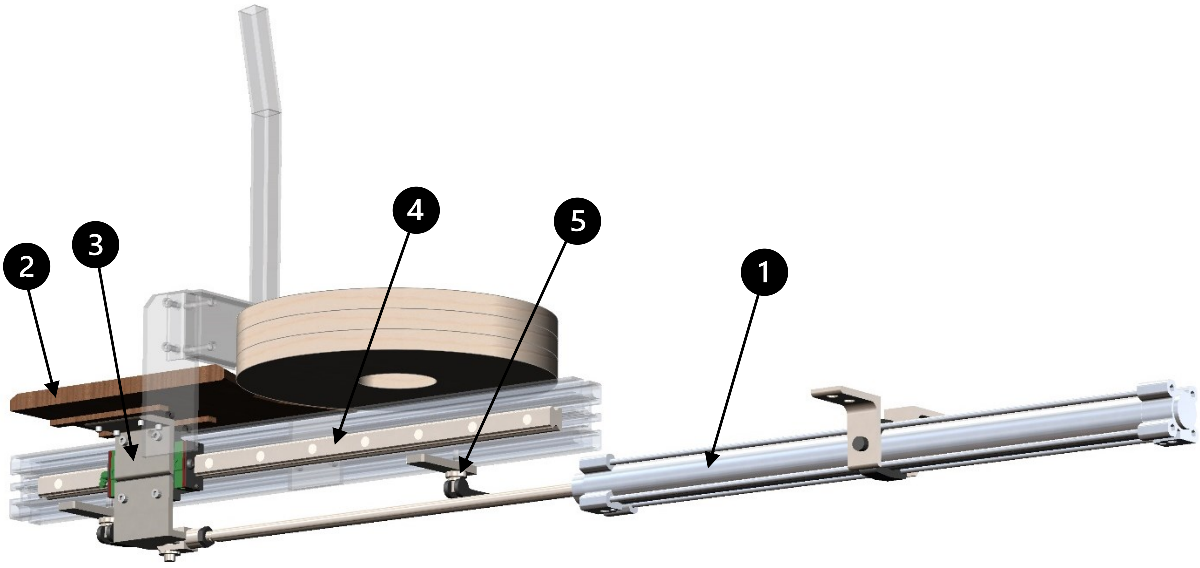


Figure 8. Disc pushing mechanism. (1) Pneumatic Cylinder. (2) Pushing plate. (3) Brackets. (4) Linear guideway. (5) Stopper

The main idea behind the disc pushing mechanism shown in Figure 8 is to move a single blank disc from underneath the stack by a certain distance to position it in the part treatment unit. In the presented assembly the guide rail and pneumatic cylinder body are fixed to the machine frame. The pushing plate is connected to the guide block by one of the brackets. The piston of the cylinder is also connected to the guide block by another bracket. When the cylinder is actuated, the piston moves a guide block along the rail and moves a pushing plate that in its turn pushes a lower disk from underneath the stack. The movement of the pushing plate is limited by two stoppers. The bracket connecting cylinder to a linear guide is forced into stoppers before the cylinder reaches its limited stroke. The first one limits how far the part is pushed to its position in the part treatment unit, while the second one restricts the end position of the pushing plate before the beginning of the new cycle.

Pneumatic cylinder

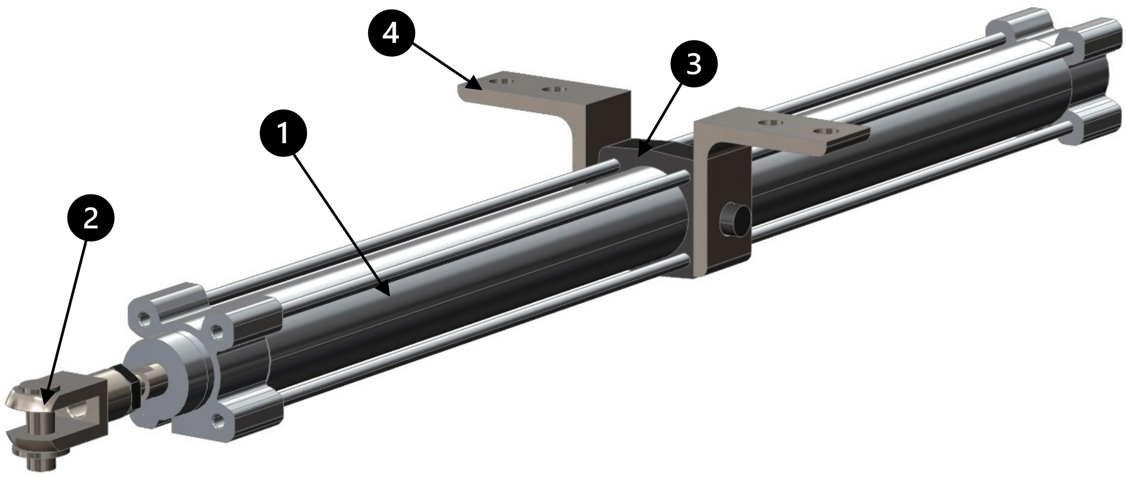


Figure 9. SMC C96SDT32-500C Pneumatic Cylinder. (1) Cylinder. (2) Rod clevis. (3) Center trunnion. (4) Bracket.

SMC C96SDT32-500C is a single rod, double stroke cylinder with a bore size of 32mm and a stroke length of 500mm. The cylinder is equipped with rod clevis and a center trunnion body fixture. To fix the center trunnion on the machine frame two custom brackets are made using 60x60x6 equal angle. Both rod clevis and center trunnion fixtures provide some degrees of freedom for cylinder movement. This is needed to lower the negative influence of forces by reducing stress-induced to components of the assembly.

To operate in this assembly the cylinder must be able to produce enough force with IN movement to push a single blank disk form underneath the stack countering static friction forces. Needed force can only be estimated as exact values of friction coefficients are not known. The estimated value should be compared to 346N, which is a theoretical output force for the presented cylinder exerted at 0.5MPa operating pressure for movement IN. The value at 0.5MPa operating pressure is taken to ensure a safe margin. For reference, the maximum theoretical output at 1.0MPa operating pressure for movement IN is 691N.

To estimate friction forces mass of the stack of discs should first be calculated. The volume of a single disc at a maximum size of 350mm at outer diameter, 70mm at inner diameter and 18mm thickness is 0,00166m^3. Up to 20 discs can be stacked at the feeding unit. By multiplying the volume of one disc by a number of discs, which is 20, and by the density of plywood, which is about 500kg/m^3 the mass of 16,6kg is calculated for the stack of discs. Mass of 16,6kg is then converted to a weight of around 163N by multiplying with a gravitational acceleration value of 9,8m/s^2. Estimated maximum static coefficients of friction for wood-wood contact and steel-wood contact are 0,5 and 0,6 respectively. Multiplying the weight of discs to each of the coefficients and adding them together gives a summarized static friction force of around 180N, which is almost two times lower than theoretical cylinder output force at half operating pressure.

Pushing plate with a guide rail

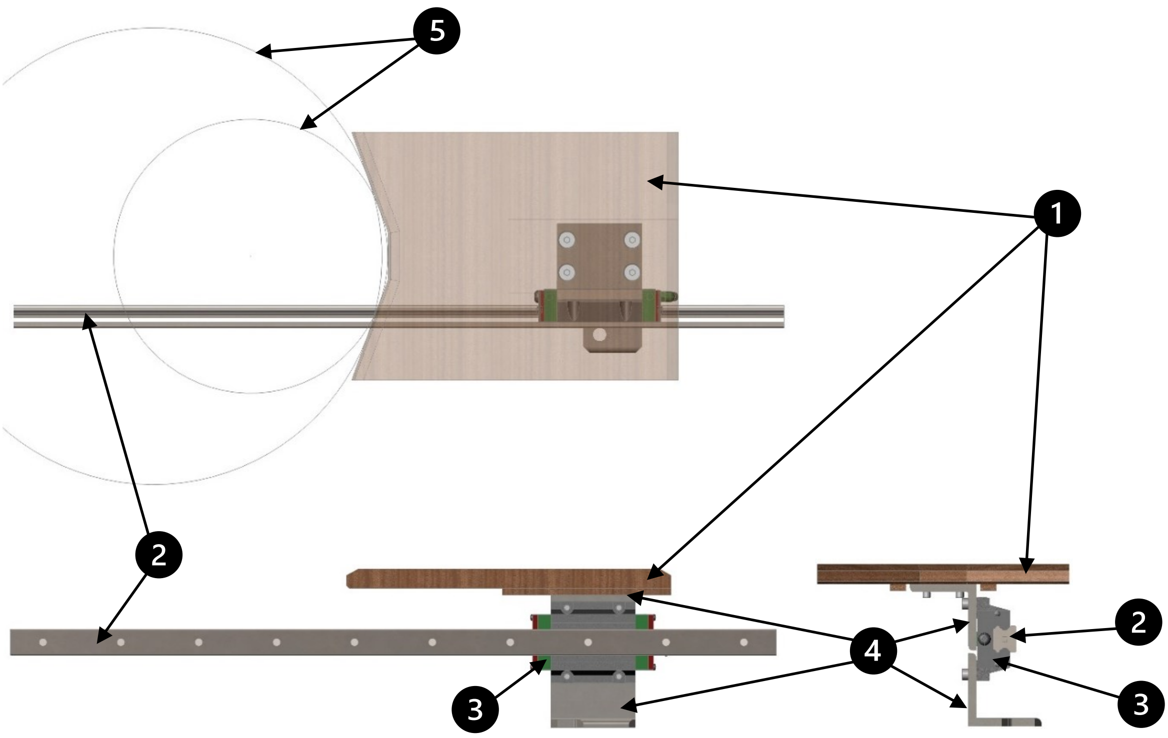


Figure 10. Pushing plate connected to the linear guideway. (1) Pushing plate. (2) Guide rail. (3) Guide block. (4) Brackets. (5) 210mm and 350mm diameter sketches.

For this assembly HIWIN HGW20HC1Z0H linear guideway combination is chosen. The guide block is a smaller size, but flanged type. A bigger size block would not fit in a limited space on the machine frame, but a bigger contact surface is desirable for mounting brackets to be properly fixed, so a flanged type block is the most suitable variant for this scenario.

Guide block must be checked for the ability to withstand twisting forces created by the cylinder when the blank disc is pushed from underneath the stack, as there is a lever created because of the difference in mounting heights of the cylinder, guideway and pushing plate. According to data from HIWIN chosen block allows for torque for 350Nm on each of the axels. The difference of heights between the cylinder piston and the lower part of the disc stack is about 115mm. The previously calculated force needed to push a disc is around 180N. These values are not even close to creating a momentum of 350Nm at the guide block, so no further calculations are needed.

The pushing plate is made from composite epoxy plate, similar to ones that are used in the production of printed circuit boards. This material is available in huge quantities at CCs' warehouse. Advantages of using composite epoxy plates are easy manufacturability and therefore flexibility, good wear resistance in contact with wooden parts, and last, but not least, in contrast to some common metals, it does not leave any colored marks on the surface of wooden parts.

All design features of the pushing plate are made on purpose. Its length is chosen such as to never go past the center of the disc stack when pushing a lower disc to the treatment unit to prevent the stack from collapsing backwards. Angled indented edge is made at an angle of 135 degrees, which allows disks of all diameters from 210mm to 350mm to be pushed with two angled surfaced instead of a straight front edge. This directs pushing forces to the center preventing the disc from sliding to the side while being pushed. The bottom part of the plate has two guides which keep it between parts of the machine frame reducing possible rotation of the plate.

Brackets, connecting cylinder and pushing the plate to the guide are made from 55x55x6 and 50x50x6 equal angles respectively.

Pushing plate stoppers

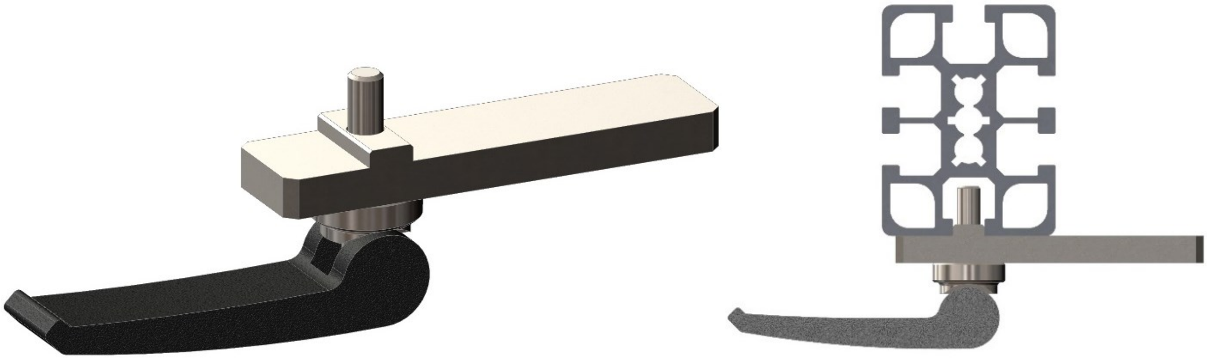


Figure 11. Pushing plate stopper. Stopper inserted into aluminum profile.

A pushing plate stopper is a quite simple assembly that consists of a clamping handle and a stopper. The clamping handle is a standard part from MAEDLER. The stopper itself is a flat 20x10 steel bar, which is milled from one side to create a 3x8 rectangular guide that is meant to be inserted in an 8mm gap in the aluminum profile of the machine frame and prevent the stopper from rotating. The stopper is easily adjustable thanks to a clamping handle which is screwed into a nut in the T-shaped gap in the aluminum profile.

Choice of physical stoppers in contrast to magnetic sensors embedded into a cylinder for limiting its movements is made purely because of the simplicity of the set up of the machine. Also, it is easier to fine-tune position by physical movement of stoppers than by repositioning magnetic sensors and tuning their sensitivity.

4.2 Part treatment

Part treatment unis is the main unit of the machine where all needed operations to produce core plug from the blank disc are done simultaneously. Figure 12 shows how part treatment unit is divided into sub-units and depicts it in an active processing stage.

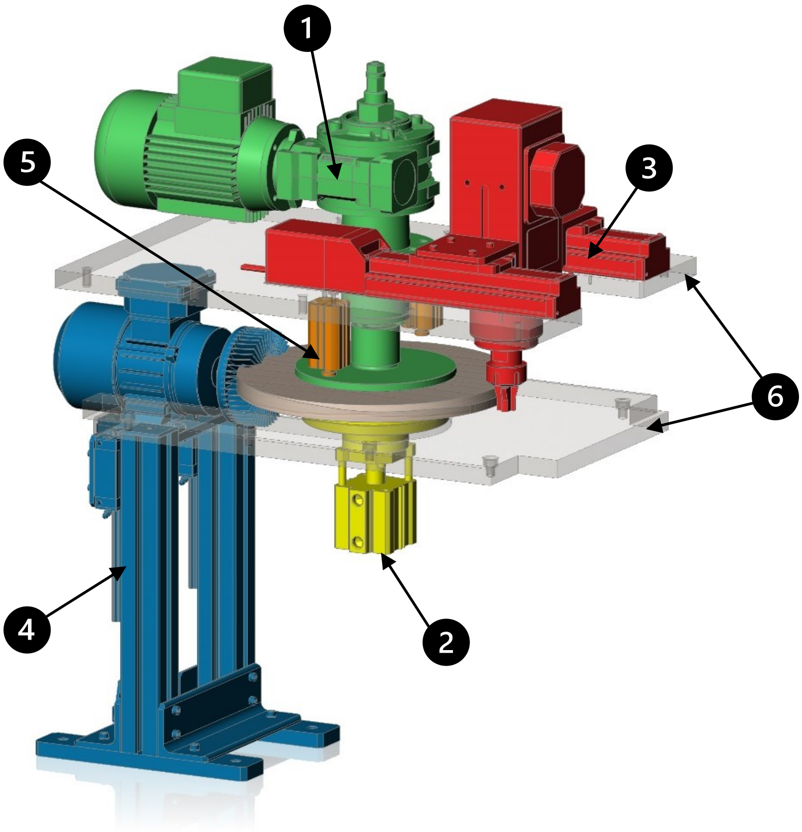


Figure 12. Part treatment unit. (1) Spindle. (2) Fixture-compensator. (3) Cutting unit. (4) Edge sanding unit. (5) Down pushing cylinders. (6) Steel plates, parts of the machine frame.

The disc pushing mechanism pushes the disc until its center roughly reaches the axis of rotation of the spindle. When part is roughly located, the fixture-compensator lifts it and pushes the central hole of the disc on a tapered fixture on the spindle and holds it there during processing. Cutting unit with custom milling tool calibrates discs' diameter and cuts 14° tapering. While at the same time edge sanding unit removes chips and burrs left from milling with a special circular sanding brush. After the process is finished, down pushing cylinders push the processed part down from the fixture of the spindle as it may be stuck on a transition-fit fixture. The processed part is removed from the processing unit by being pushed with the next fed blank disc

4.2.1 Fixture-compensator

The purpose of the fixture-compensator is to lift the blank disk and by pressing with force fix it on a spindle and hold it there during the processing. The idea is also to compensate for any angular unevenness that may be caused by blank disk bending, surface imperfections, low parallelism tolerances of fixture disks and the blank disk itself or any mismatch of the axles of the fixture-compensator and the spindle, which may cause unnecessary radial forces and uneven pressure on the part.

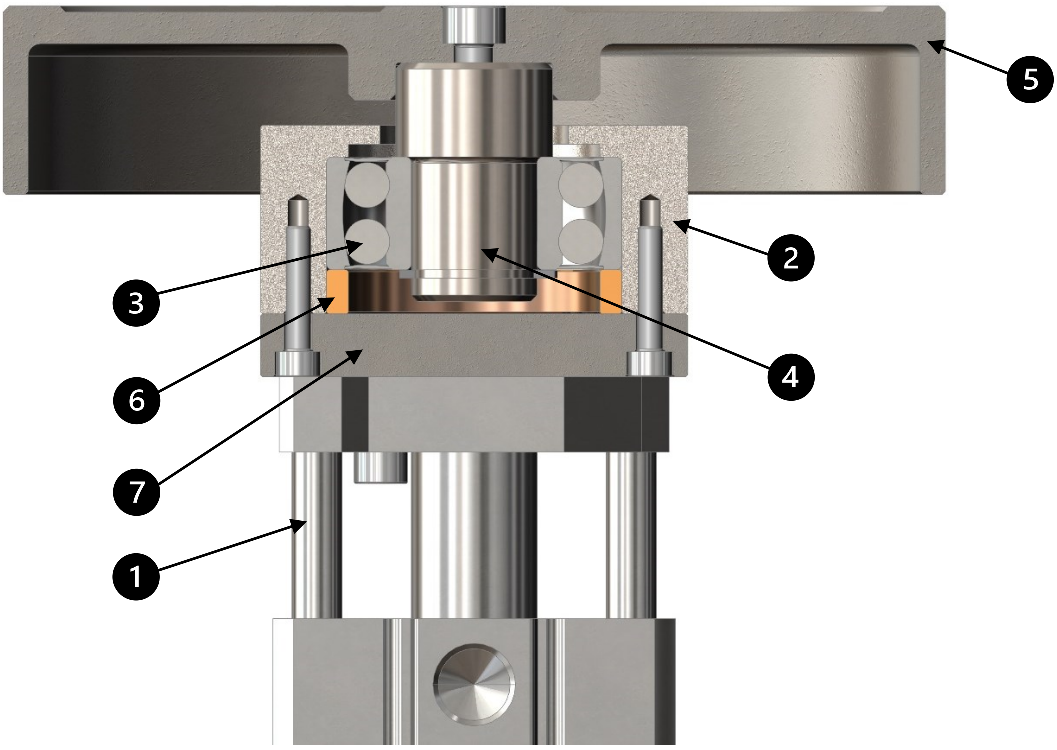


Figure 13. Fixture-compensator. (1) SMC CDQMA50TF-25 guide-rod cylinder. (2) Housing. (3) SKF 2204 E 2RS1TN9 self-aligning ball bearing. (4) Axle. (5) Fixture disc. (6) Hub. (7) Lid-Flange

The fixture-compensator unit consists of the pneumatic guide rod cylinder on which the housing that encloses the self-aligning ball-bearing is installed. The axle is pushed into the inner ring of the bearing and the fixture disk is attached to the axle. The fixture disk rotates with the part and the spindle due to the friction force created by the pneumatic cylinder pressing the blank disk against the fixture disk on a spindle. There is a gap between the axle and the housing which allows for an angular movement of the axle due to the allowance of angular movement in self-aligning bearing.

Cylinder

Figure 14. SMC CQM guide rod compact cylinder.

SMC CQM is a guide rod type compact cylinder series. This type of cylinder is particularly suitable for the required application scenario. CQM series cylinders offer increased bore diameters with quite short stroke lengths. These notably compact cylinders can produce powerful output force. Guide rod design is perfect for lifting applications as it eliminates the need for a separate linear guiding mechanism for attaching the load. Last, but not least, CQM series cylinders are extremely easy to use in assembly. The top plate at the piston end features two through holes and two threaded holes, which gives great flexibility in choosing how to fix a load. A cylinder body can also be chosen with through holes to fix it with tie rods or threaded holes for simple assembly with bolts.

CDQMA50TF-25 features 50mm bore and 25mm stroke, equipped with auto-switch, and tapped holes for body fixture. The cylinder is capable of producing an output of around 1,4kN for movement OUT and 1,15kN for movement IN at 0,7MPa operating pressure.

Bearing

SKF 2204 E 2RS1TN9 is a self-aligning ball bearing with a contact seal on both sides and a reinforced cage. Self-aligning rings allow for angular misalignment of 1,5˚. Contact seals are needed to protect the bearing from dust as wood processing is associated with lots of solid dust particles which can easily damage the bearing when mixed with lubricant.

The bearing should be checked for the ability to withstand axial loading. In this application, there are negligible, in comparison to the declared load rating of the bearing, radial forces produced by the cutting tool pressing on the processed part. Some minor radial forces may also occur if there is axial misalignment or low parallelism between the spindle fixture disc and the compensator fixture disc. The suitability of the bearing for certain application scenarios can be checked using the SKF Bearing Select tool. In the studied application, there is a maximum axial force of 1,4kN, which is the maximum force produced by the cylinder pressing a part to the spindle, 15rpm rotation speed, which will be explained in later parts of the report, but it is a very low speed that should not affect bearing service life to any notable degree and estimated possible 0,1kN radial force, which in fact should be even lower. With this input information bearings' safety factor is 1,07, which is close to the minimal satisfactorily value of 1. If the axial force is reduced to 0,6kN, which is the output of the cylinder at 0,3MPa operating pressure, a safety factor of bearing is increased to the value of 2,39. This verification concludes that it is recommended to operate a cylinder with lower operating pressure to reduce the axial load on the bearing which will greatly extend its service life.

Custom parts design. Fits and tolerances.

As can be seen in Figure 13, the assembly is designed in such a way that does not allow any axial movement for the bearing. On the axel, the bearing is locked with abutment and a circlip, and in the housing, it is locked with abutment and an additional hub, which is pushed into the housing and propped up with the lid.

The axle, which accommodates most loads in this unit is made from Uddeholm UHB11 tool steel which is similar to standard C45 steel. It is divided into two zones: 20mm to accommodate the bearing and 25mm which is a recommended value for the shaft abutment for the selected 2204 bearing according to SKF. Circlip groove is made on a 20mm part of the axle following DIN 471 standard and is needed to lock the bearing in place with a circlip. According to SKF recommendations, j6 tolerance with 1,6μm surface roughness should be used for bearing seat on a shaft where the only axial load is present. In combination with bearings' inner ring tolerance, ±3σ probable seat fit lies in a range from negative 16μm to positive 1μm, which makes for mostly interference fit, and therefore bearings' inner ring is locked and rotates with the axle.

Axels' 25mm diameter does not require any special tolerance or surface treatment as it is not used as a contact surface for any other elements. On the flat surface from the side of 25mm diameter, there is a threaded hole for assembly of fixture-disc with the axle.

Housing is made from standard S355J2 steel as it does not require increased durability. Its' inner diameter of 47mm also acts as a seat for the bearing. According to SKF recommendations, tolerance for the housing seat where the light indeterminate load is present is J7 with a surface roughness of 3,2μm. In this case, ±3σ probable seat fit lies from negative 6μm to positive 20μm, which makes for transition fit in mostly clearance range, which means that in some cases outer ring of the bearing may slide inside the housing. There is a 40mm diameter abutment for bearing accommodation in the housing. On one side of the housing, there is a 47mm opening that allows for the assembly of internal components, while on the other side there is a 30mm diameter hole, from which the axel comes through. The difference between axels' 25mm diameter and 30mm diameter of the hole in a housing allows for unobstructed angular movement of the axis inside the housing. Four threaded holes in the bottom part of the housing are made for assembly with a lid-flange.

A copper hub with an outer diameter of 47mm and an inner diameter of 40mm is inserted into the housing after the bearing and acts as an abutment for the outer bearing ring to axially lock it inside when the lid-flange is assembled with a housing.

Lid-flange is made from S355J2 steel and acts both as a lid for housing that props up the internal assembly and as a flange that connects the housing assembly to the cylinder. It has four through holes with a counterbore for concealing bolts that are screwed into the housing, and two threaded holes to which the cylinder is attached.

The fixture disc is made from Uddeholm UHB11 steel and acts as a grip that pushes the blank disk to the rotating spindle. It does not require any narrow tolerances and fits and could easily be made with durable cast iron with following machining of contact surfaces, but due to manufacturing restrictions at CC's machine shop, it must be made by turning and milling from a raw steel disc.

4.2.2 Spindle

The main idea behind the spindle is to produce an even rotation of the part while it is being milled and sanded. To meet narrow tolerance requirements for the core plug diameter spindle must be produced with special precision. Any occurring wobbling and vibrations reduce the possibility of producing parts with narrow tolerances. It is a low-speed 15rpm spindle, which makes for about 4 seconds for one full rotation of the blank disk while it is being processed. Low-speed rotation means that vibrations are not the highest concern, but the stability of the rotation axis should be the main priority. All rotating parts require narrow run-out tolerances to reduce possible radial movement of the spindle.

The spindle rotates a blank disc that is pressed to the spindles' fixture-disc with a fixture-compensator. Gearmotor is connected to a hollow shaft with a keyway, the shaft in its turn holds a fixture-disc. The shaft is accommodated in the housing with two ball bearings. A combination of two ball bearings installed at a certain distance from each other is required to hold the shaft radially in place and reduce wobbling.

The shaft is held in place by tightening nut on the top of the shaft and the assembly of the spindle is made so, that tightening the shaft does not induce any axial load on the bearings.

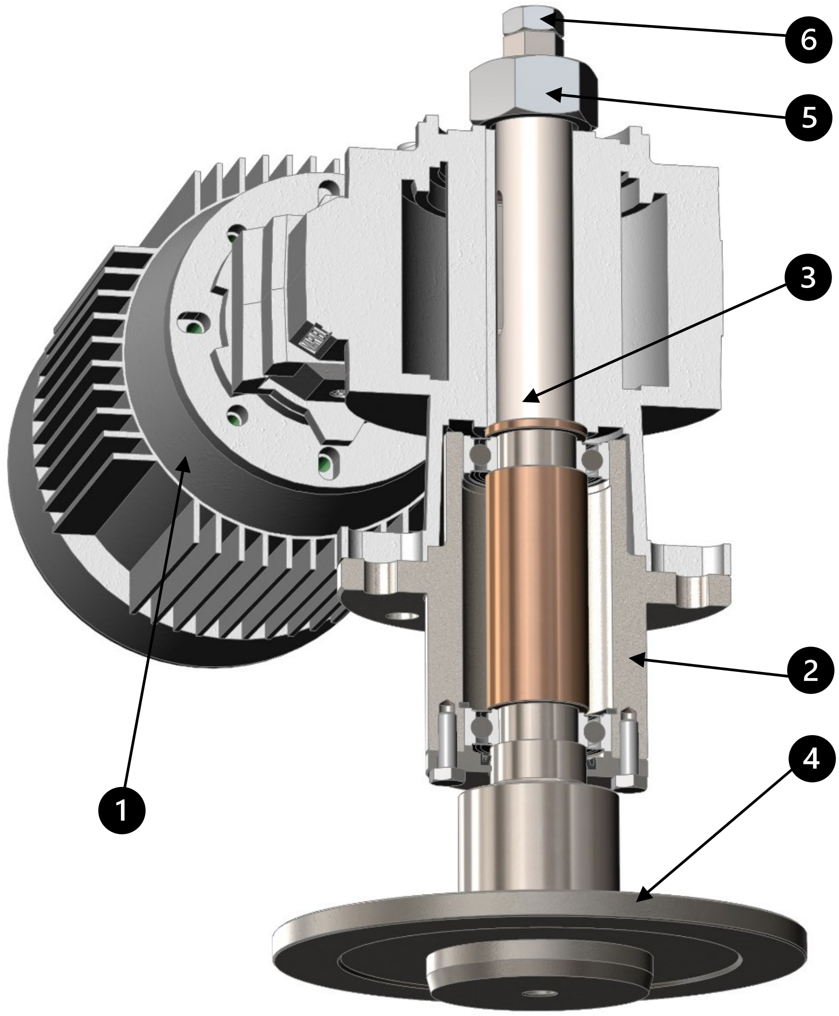


Figure 15. Spindle. (1) Gearmotor. (2) Housing with internal assembly. (3) Shaft. (4) Fixture-disc. (5) Shaft tightening nut. (6) Fixture-disc tightening nut.

Gearmotor

Varvel 8-pole MRS50 i=49 0,12kW is a gearmotor based on an 8-pole 71 size IEC standard electric motor with a power of 0,12kW and worm gearbox with a reduction ratio of i=49. This combination produces 43,32Nm of rated output torque and a rotation speed of 14,29rpm. The service factor with rated parameters is equal to 2.

This combination of rated parameters allows for great fine-tuning flexibility and the ability to test different work cycles of the machine. Using various frequency drive controller, it is possible to change electrical input parameters to fine-tune motors speed and torque, and a service factor value of 2 suggests, that this fine-tuning of the motor can be done without seriously affecting the service life of the gear-motor combination. While it is not an objective of the mechanical designer to choose exact tuning parameters for electric drive, ensuring a safe margin for tuning is important in the machine design stage. Moreover, there is a high probability that the machine would have to work for several shifts in a row. According to Varvel recommendations, uniform load for a continuous 24 hours operation cycle requires a service factor of a minimum 1,6. If the spindle will be programmed to work in a start-stop cycle, for example, stopping between every part, the safety factor value must be multiplied by 1,2, which will result in an overall required safety factor of 1,9. Taking this information is a consideration, it is highly recommended for the motor to work in a uniform, rather than a star-stop cycle. However, a high rated service factor allows for different work cycles to be used.

Despite worm gearbox being not a commonly used or recommended type for the continuous rotating application in this low-speed low-power case it can well be used. The huge advantage of using a worm gearbox for application on this particular machine is its design and simplicity. The hollow shaft option together with a choice of mounting flanges and perpendicular motor attachments allows for very compact, durable, and convenient installation from an assembly and maintenance perspective.

Bearings

SKF 6005 2RSH is a commonly used simple type of ball bearing with contact seals on both sides. According to technical data from SKF, the radial run-out tolerance class for the selected bearing is P5, which means inner ring run-out is 4μm and the outer ring run-out is 7μm. This tolerance margin is narrow enough for the needed application. Further radial axis stability will be dependent on spindle housing and shaft tolerances.

No further calculations for the bearings are needed, as operating conditions are quite sparing, including low speed and negligible direct loads both radial and axial. Radial loads produced by pressing the cutting tool are minimal compared to the dynamic load rating of 11,9kN declared in technical data for the bearing. While axial loads are distributed between other parts inside the spindle housing assembly.

Custom parts design. Fits and tolerances.

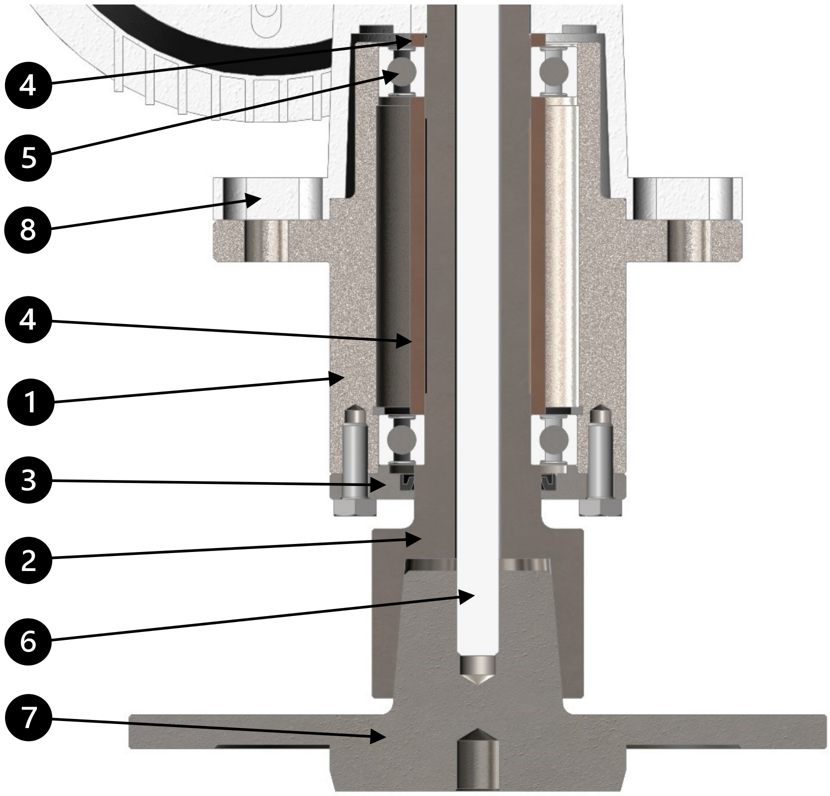


Figure 16. Internal spindle assembly. (1) Housing. (2) Shaft. (3) Lid. (4) Hubs. (5) SKF 6005-2RSH bearings. (6) Threaded rod. (7) Fixture disc. (8) Gear-motor flange.

Housing is a core part of spindle assembly. It holds every single part of the unit together. It acts both as a shell for the internal assembly of all unit components and as a counter flange for mounting the gearmotor.

Housing is machined from a single circular bar of Uddeholm IMPAX Supreme steel. IMPAX Supreme is high purity prehardened tool steel with increased toughness and excellent machinability properties that allow for exceptionally fine surface finishes. According to information from Uddeholm, Its' hardness is 310HB, which is about the same as of C45 steel, however, declared ultimate tensile strength at room temperature is 1020MPa, compared to 565MPa of C45, and yield strength is 900MPa, compared to 310MPa of C45. It is one of the most used steels at CCs' machine shop for complex parts of increased importance.

There are several key features of the housing that require narrow tolerancing. First of all, bearing seats have to be machined in accordance to SKF recommendations with load type taken into consideration. The outer ring of the bearing is stationary in the housing, and there is a radial load from the milling tool acting on a bearing when the tool is pressed into a core plug to cut it. For this type of stationery light to average load recommended housing seat is H8, which together with bearings' outer ring tolerance provides ±3σ probable clearance fit of positive 7µm to positive 43µm. The lower bearings' outer ring is axially held in place with a housing lid and a circlip. The groove for the circlip is cut right above the bearing seat by DIN 471 standard. The upper bearing's outer ring is not axially fixed to accommodate for axial displacement that may occur with thermal expansion of the shaft as well as to compensate for the accumulation of tolerances of assembly components that may change the distance between bearings.

Housings' flange, to which the gearmotor is attached and which at the same time serves as a mounting surface for the whole spindle assembly to the machine frame must feature quite narrow flatness and parallelism tolerances as this will affect the perpendicularity of the rotating shaft to the surface the spindle is mounted to. Gearmotors' mounting flange features a groove with calibrated diameter that is meant for precise axial installation. The groove on the gearmotors' flange is 70mm with H8 tolerance. Spindles' housing features the same calibrated diameter of 70mm but with a tolerance of g6 to create a clearance fit for precise motor installation on the flange. This calibrated diameter on the housings' flange also must have narrow run-out tolerance in relation to bearing seats inside the housing.

The shaft of the spindle is also made from IMPAX Supreme tool steel. It is a hollow shaft with two bearing seats, tapered inside cut on one end for fixture-disc installation, external hexagonal cut and thread for installation of tightening nut on the other end and a keyway to transfer torque from the motor. The shaft also features an abutment that supports the lower bearings' inner ring. Bearing seats are machined with j6 tolerance to create mostly interference fit. Bearings are fully axially fixed on the shaft with help of abutment and additional copper hubs.

A fixture disc is meant to fix a blank disc on a spindle radially by its inner diameter and prevent its' sliding rotation by friction forces produced by the fixture compensator pressing from the bottom. On the bottom part of the fixture-disc, there is protruding diameter with a tapered edge. This diameter is made to be in a transition fit with blank discs' inner diameter, so a part is tightly fixed on a fixture-disc when pushed there by the fixture-compensator.

Different fixture-discs with different protruding diameters have to be made for different inner diameters of core plugs. However, setting up different fixture-discs on the spindle is made as easy as possible. On the top part of the fixture-disk, there is a tapered cone of the same profile as a tapered cone cut on the shaft end. There is also a threaded hole in the middle of the top surface of the cone. The Cone of the fixture-disc is inserted into the conical cut of the shaft and is tightened with a threaded rod, which is assembled from the other side of the shaft through the shafts' hollow centre. The threaded rod is screwed into a threaded hole in the fixture-disc and axially tightened with a nut on the other end of the shaft. Conical coupling, if made properly, provide excellent concentricity and coaxial alignment of coupled parts. In some cases, with moderate loads, it also eliminates a need for a keyway to transfer torque as conical coupling provides a big contact surface of the coupled parts, especially when tightened axially, so friction forces occurring in the contact area are more than enough for transferring torque.

Copper hubs act as abutments for fixing inner rings of bearings, but they also take all the axial loads that occur from tightening the shaft on the gearmotor with a tightening nut or when the fixture-compensator pushes the part fixing it on a spindle. Forces are transferred from the shaft to the inner ring of the first bearing which is in direct contact with the abutment on the shaft. Then with a longer hub force is transferred the rom inner ring of the first bearing to the inner ring of the second bearing. And lastly from the inner ring of the second bearing with a shorter hub load is transferred to the gearbox housing. This way bearings do not carry any axial load; they are just clamped between hubs and abutments by their inner rings.

The lid, which is made from S355J2 steel, closes the housing from below by being tightened to the housing with bolts through four holes patterned along the diameter. The lid features a lip that acts as an abutment for the lower bearings' outer ring. The shaft is assembled through a hole in the middle of the lid. There is a groove machined along the diameter of the central hole to accommodate the radial shaft seal SKF 30x37x4 HM4 R. The seal is needed to protect an opening between stationary and rotating components i.e., between the lid and the shaft, from solid dust particles that may damage tightly fitted rotating components of the spindle.

4.2.3 Calibration and tapering

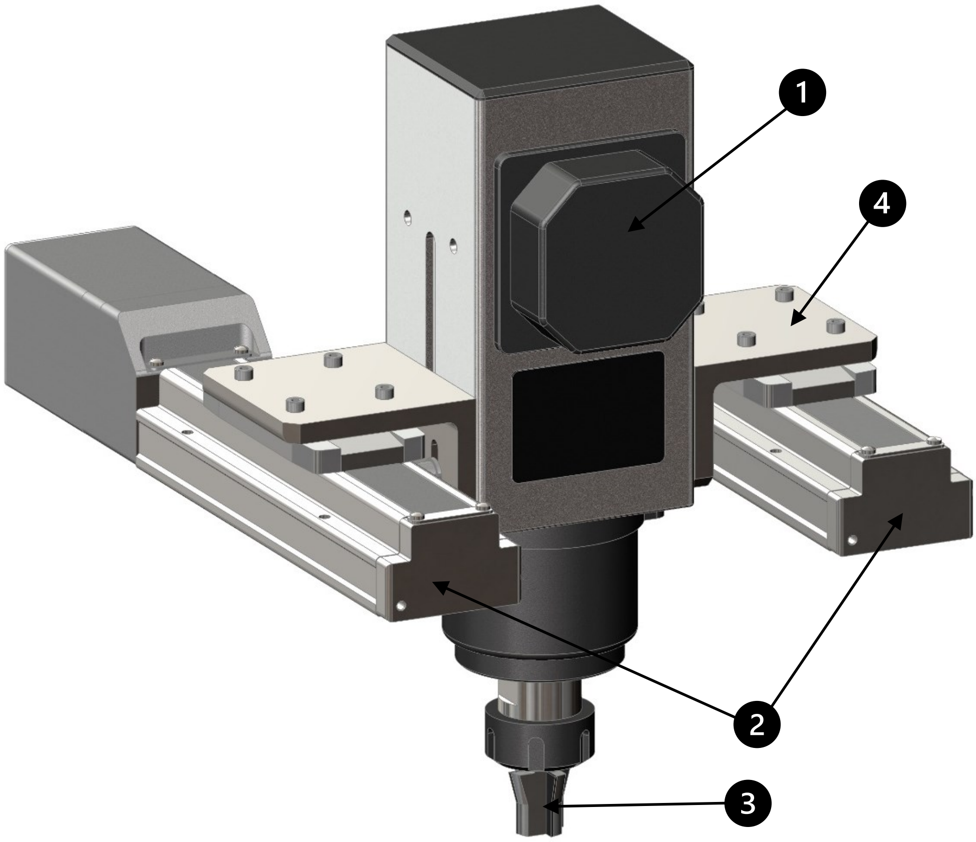


Figure 17. Calibration and tapering unit. (1) Tool spindle drive. (2) Ball screw slider with step motor and additional support rail. (3) Milling tool. (4) Mounting brackets.

The calibration and tapering unit is quite simple in its idea. A custom milling tool is installed into a collet cartridge of the high-speed tool spindle drive. The drive itself is held by two brackets one of which is mounted to a ball screw slider with a step motor while the other is attached to a support rail. Tool spindle drive moves when ball screw sliders’ step motor is actuated. This is the only unit of the whole machine that requires a separate controller and programming to operate.

Tool spindle drive

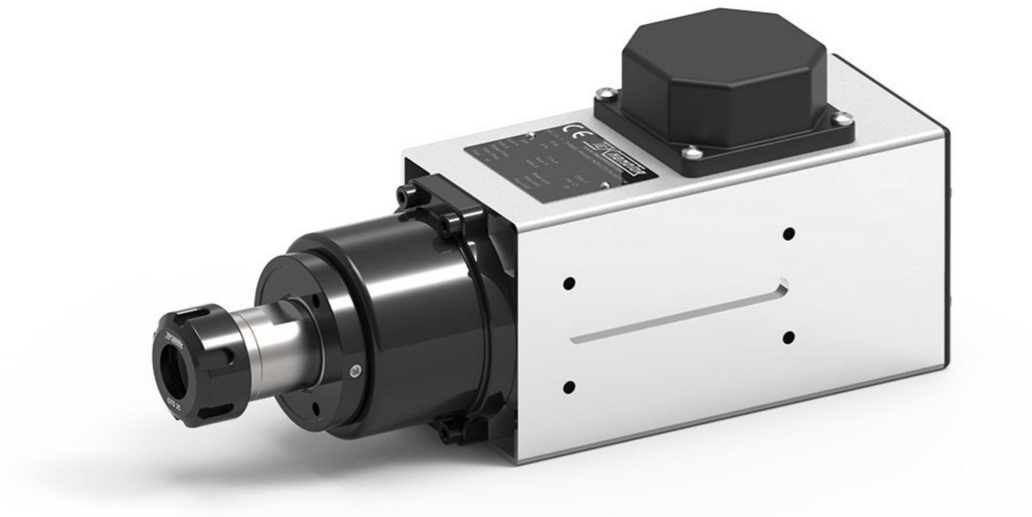


Figure 18. High-speed tool spindle drive Teknomotor 4147-A-DB-P-ER25-RH

Teknomotor 4147-A-DB-P-ER25-RH is a compact high-speed tool spindle drive designed for wood, aluminum or PVC machining applications with both radial and axial loads. The nominal rotation speed of the tool is 18000rpm. It is equipped with a standard ER25 collet tool holder and tightening nut. Threaded mounting holes from three sides of the motors' body provide great flexibility in mounting options. The mass of the motor is 6,67kg.

Using a high-speed spindle motor for cutting provide some particular advantages, especially when combined with low feeding speed. First of all, a high rotation speed of the tool allows for precise, high frequency and low depth cuts. This combination of parameters first creates a smoother surface finish after the cut, and then leaves fewer chips and burrs on edges, as it shaves off an extremely thin layer of material with each cut. Thin high-speed cuts do not leave visible steps left by the tools' blade with each cut, as the distance between cuts is extremely short and virtually not distinguishable. This also means that surface of the cut does not require any additional processing for smoothing out. No less important is the fact, that higher speed compensates for lower torque, which in the case of this spindle motor is just 0,58Nm, and therefore allows for a more compact size of the motor.

Ball screw slider with step motor

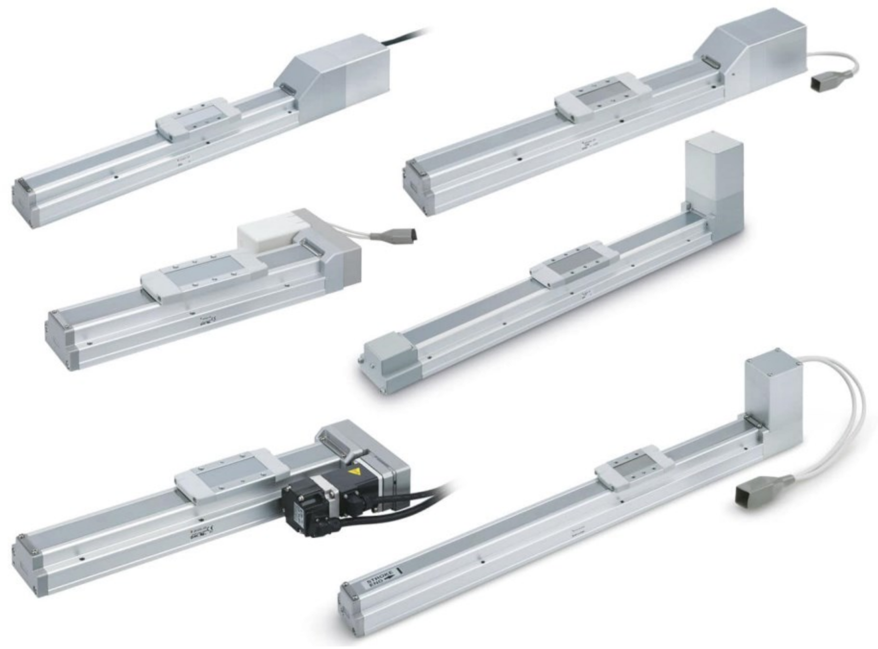


Figure 19. SMC LEFS slider type electric actuators.

SMC LEFS25B-100 is a ball screw slider equipped with an in-line step motor and a controller. The model used in the project has a 100mm stroke length and features a 6mm lead ball screw. Declared positioning repeatability for slider equipped with step motor is ±0,02mm and lost motion is up to 0,1mm. These values can be lowered even more with a high precision slider version, to ±0,015mm positioning repeatability and up to 0,05mm of lost motion. However, even base version characteristics are suitable for the project. The vertical load-carrying capacity of the slider is 15kg, which - considering that the spindle motor is mounted on two supports - exceeds the requirement almost five times. Horizontal load carrying capacity is 30kg, which is much higher than the expected load. Load-carrying ability decreases with faster movement speeds, however, only extremely low speeds are expected to be used. The slider can be equipped with a lock unit to hold it in a certain position. This may be useful for application in this project to lock the slider when the tool reaches its extreme position of required calibration diameter, however, expected loads induced by the cutting process are quite small, so locking is not a compulsory solution.

Ball screw slider is used in combination with support guide LEFG25-S-100. The dimensions of the support guide are exactly the same as of ball screw slider, so it makes installation extremely simple. A support guide is meant for overhang loads, that the ball screw slider alone cannot withstand due to induced moment. Both ball screw slider and support guide are standard equipped with a seal that prevents external matter from entering greased parts.

The decision to use a complete product for linear movement of the spindle motor instead of designing a custom solution is made due to cost-effectiveness. The cost of separate components that are needed to create a custom linear guide, that is flexible in resetting up for different sizes of processed parts and at the same time allows for fine-tuning and extremely high tolerances of linear movement, is about the same as that of a complete solution, not even considering the cost of manufacturing all the custom parts that would be needed in custom build linear guide. Also, a complete solution is made simple, so it requires minimum time and workforce for setting up. Even considering additional time and costs for programming step motor controller.

Custom milling tool

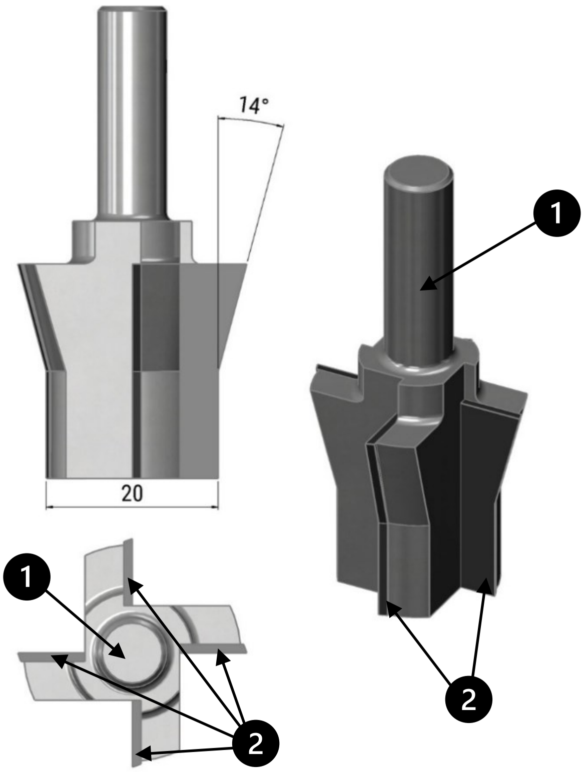


Figure 20. Custom milling tool. (1) Tool body. (2) Cutting blades

The idea behind making a custom tool for core plug processing operation is to conduct two operations at the same time: diameter calibration and edge tapering. Also, the edge tapering requested by the customer is 14˚, which is not a standard value, so the custom solution for the tool is necessary.

The tool consists of two parts. The body, which is made of quite soft C20 steel and cutting blades made of 42CrMo4 steel alloy, which features high hardenability and has high hardness values up to 355HB and yield stress of 750MPa.

The tool body is divided into four base surfaces for the installation of cutting blades. The tool body itself does not require narrow tolerancing since cutting blades are first soldered to the body and only then all important cutting features are machined, and blades are finely sharpened to meet required parameters. Although soldering blades to the tools' body is not a practical solution from a maintenance perspective, it is not possible to produce a high precision cutting tool with replaceable blades using machinery available at CCs' machine shop. So, after the tools' body is made, roughly cut cutting blades are soldered in place against four base surfaces, after that, blades are machined to meet tool diameter and angle values. Following the machining, the tool is sharpened to produce fine cutting edges on blades. Lastly, sharpened edges are locally hardened. This solution means, that in case of damaging a blade a completely new tool is needed to be remade.

Motor fixing brackets

Motor fixing brackets are two identical parts made of S355J2 steel equal angles with dimension of 80x80x10mm. One side of the angle is shortened, its outer surface is machined to narrow flatness tolerance and two circular slots are made there for motor mounting. Slots are meant for motors' mounting height fine-tuning. Another side of the angle also requires machining, but from the inner side, which is mounted in contact with the sliding guide. Four through-holes are drilled on this side for assembly with a sliding guide. Two machined surfaces must have narrow parallelism tolerance in relation to each other to ensure precise motor positioning and reduce bending of slider guides when tightened in assembly.

Cutting process parameters

Although, there was no information found on how to properly calculate cutting forces for the processing cycle similar to the one that presented in this project, some of the parameters at least must be estimated for an intuitive understanding of the process to find any possible obvious problems and understand if there are any unrealistic expectations from the process. So, parameters that must be estimated are the depth of one cut, the length between cuts, and cutting speed.

First of all, it is important to mention, that blank disc is about 2-3mm bigger in diameter, than required calibrated diameter. That already gives an understanding that only little amount of the material has to be removed. For example, just comparing volume of 3D models for blank disc of 353mm and processed core plug of 350mm calibrated diameter shows difference in material volume of 5696mm^3. Following estimation are also made using 350mm part as an example, as this is the biggest part that is made with machine presented.

Spindle rotates blank disc at 15rpm, which converts to 4sec per full rotation. The part is expected to pass through two full rotations while being processed, so about 8 seconds of processing for one part. Although material removal rate is not linear and is difficult to retrieve a formula for due to complex shape of tool travelling path, on average around 712mm^3 of material is being removed per second, what converts to material removal rate of 4,272*10^{-5} m^3/min which is an extremely slow rate for any kind of processing. Speed of tool travelling in relation to parts edge is about 16,5m/min, which is derived from multiplying edge length of 350mm diameter part with 15rpm rotation speed.

The idea behind processing cycle is to gradually move the tool to requested calibration diameter during the first full rotation of the part. Remaining material is removed during the second rotation. To calculate the depth of single cut, minimal diameter of core plug at the top edge of tapering has to be considered. Although, movement of the tool is not linear regarding speed and acceleration some average values can be estimated. Biggest base disc diameter is 353mm, diameter of top edge of tapering after calibration is 345,5mm. So, radial travel distance for this cut is 3,75mm. Tool spindle drive rotates at 18000rpm, which translates to 1200 revolution per 4 seconds during which part makes one full rotation. The tool has four cutting blades, which makes for 4800 cuts per these 4 seconds. So, 3,75mm radial distance is cut through with 4800 cuts for 4 seconds. Based on this data, average depth of one cut is estimated to be 0,0008mm.

Estimated distance between cuts for 350mm part is derived by dividing feed rate of 16,5m/min with 18000rpm rotation speed of a tool spindle and number of four cutting blades of the tool and comes to make up 0,23mm. Circular shape of the cut edge is not taken into consideration when estimating distance between cuts and represents linear distance between extreme contact points of blades with part at mentioned feed rate and rotation speed. However, this estimation still represents how small each cut is.

Although, all calculations represented above are only rough estimations, they still give some general understanding about cutting process and show, that no abnormal or inadequate behavior is expected in combination of chosen components and process cycles.

4.2.4 Edge sanding

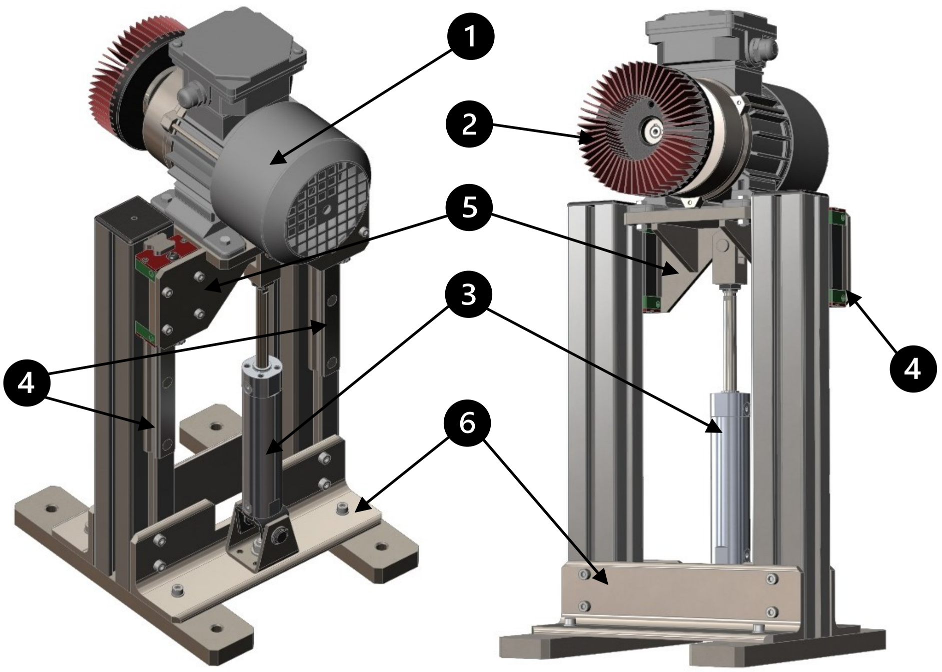


Figure 21. Edge sanding unit. (1) Motor. (2) Disc brush. (3) Cylinder. (4) Linear guides. (5) Bracket. (6) Frame.

The aim of edge sanding unit, which is showed in figure 21, is to remove chips and burrs that may be left on a processed part after milling. This is an auxiliary unit. It can be completely removed from the machine or left inactive.

Principle of operation is as simple as it gets. There is a disc brush with sandpaper flaps, which is mounted directly onto electric motors' shaft. The motor is mounted on a bracket, which on its turn is attached to two vertical linear guides. Pneumatic cylinder is connected to motors' mounting bracket also in vertical position. Actuating a cylinder moves a motor with brush vertically along linear guides.

The whole unit is mounted to the lower part of the machine frame below processed part. When cylinder is in compressed state the disc brush is located right below the edge of processed part. When cylinder is actuated, the motor is lifted so that the brush is in contact with parts edge. Figure 22 shows edge sanding unit in two positions: part feeding stage when motor is lowered, and part processing stage when motor is lifted.

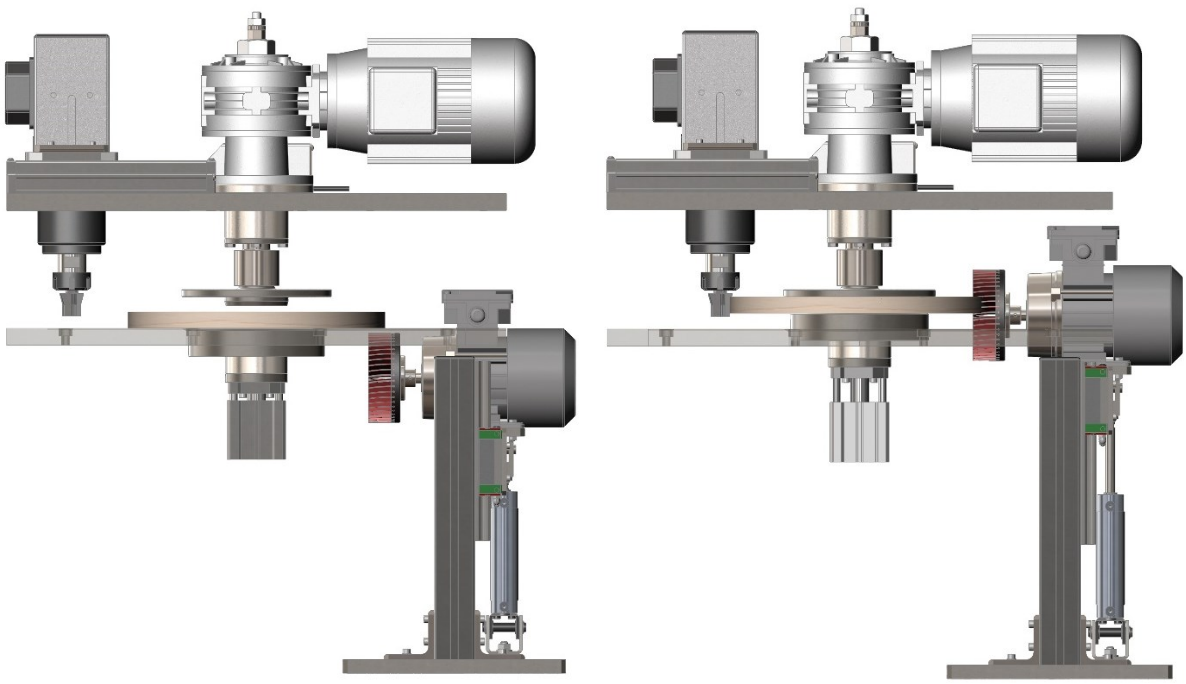


Figure 22. Left – Part treatment unit at part feeding stage. Right – part treatment unit at part processing stage.

Motor

BEVI SH56-2B 2-pole 0,12 kW is the smallest two-pole electric motor in Bevis' lineup. Its' nominal rotation speed is 2800rpm. The motor features a 9mm shaft and is feet mounted. There are not any specific requirements for the motor used in such a simple operation.

Pneumatic cylinder

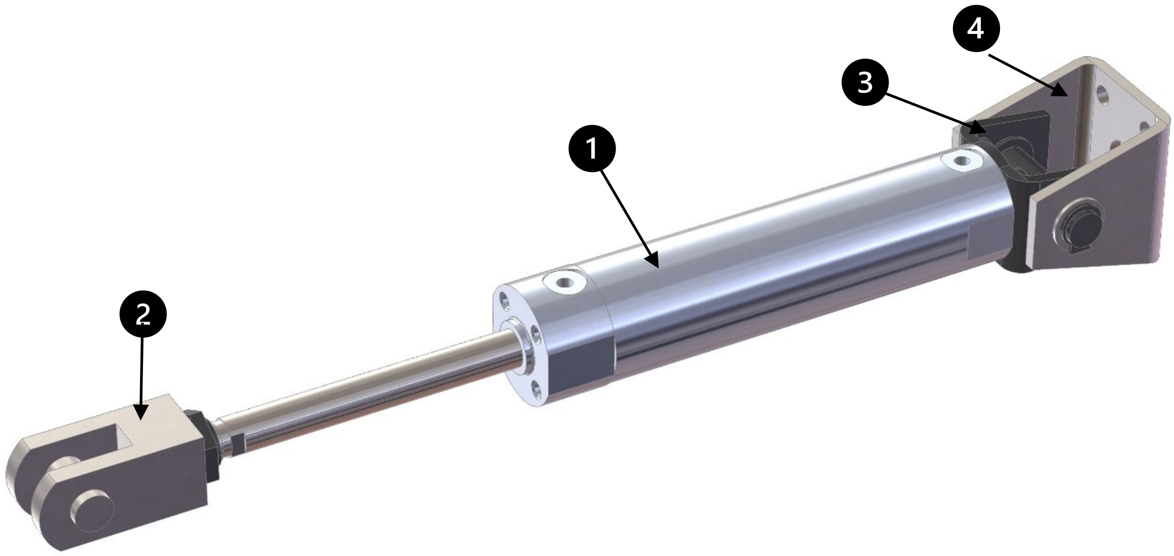


Figure 23. SMC CG3DN25-75 Pneumatic Cylinder. (1) Cylinder. (2) Knuckle joint. (3) Clevis. (4) Pivoting bracket.

SMC CG3 cylinder series is a short type cylinder with lots of mounting options. Cylinder used in a project is a double acting cylinder with rubber bumper that features 25mm bore and 75mm stroke length. It is equipped with knockle joint, mountig clevis and pivoting bracket for installation. This combination of mounting accessories gives certain freedom of movement and reduces negative effect of forces that could damage fully fixed cylinder.

Declared theoretical outputs at 0,7MPa operating pressure are 343,7N for movement OUT and 288,4N for movement in, which is absolutely suitable for lifting a 3,4kg motor with mounting bracket and two linear guide blocks.

Although cylinder features installed magnes and auto-switches they are not required for proper operation in presented assembly, as cylinders' stroke length is used within the whole range during the operation. Position 0mm for resting, and position 75mm for processing.

Sanding brush

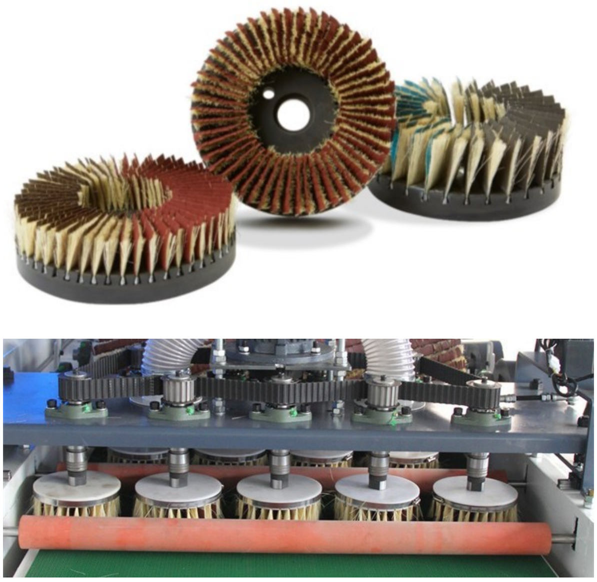


Figure 24. Top – type of sanding disc brush used in edge sanding unit. Bottom – wood polishing machine with disc brushes.

Sanding disc brush with sandpaper flaps mounted discs' face (figure 24) is recommended to use on edge sanding unit. Although, this type of sanding brushes is most commonly used in wood face polishing machinery (figure 24), it has several advantages over conventional radial type when used in edge sanding operations. When side face of processed part is placed in the middle of the brush, like showed in figure 22, top and bottom edges of the part are sanded at the same time, while side face remains almost intact. In case of core plug edge sanding that means that calibrated diameter will not be affected by sanding operation, but only chips from top and bottom edges will be removed for safe manual operation with processed disc.

Unfortunately, no suppliers from which this type of sanding brush can be directly purchased were found among CCs' contracted partners, so no detailed model nor technical drawings could be obtained during initial design phase to design a fixture mechanism for mounting a disc on a motors' shaft. However, there are several wooden part processing industrial machines in CCs' facilities that use this type of sanding discs for face polishing, like one shown in figure 24. So practically sanding discs can be quoted from companies, that build or provide maintenance for these wood processing machines. This also means, that fixture for the brush can be designed only when one is received and measured.

Bracket on linear guides

Figure 25. Motor mounting bracket on linear guides

HGH20CA1R200Z0C linear guides are almost the same as one used in part feeding unit, with difference of guide block being regular type, instead of flanged. Also, guide blocks on edge sanding unit are equipped with more advanced dust protection plates. No calculations of loads and moments acting on guides are required as only minor loads are obviously present in this assembly.

This design of lifting mechanism with use of linear guides and a cylinder is conditioned by need to dampen vibrations from the motor. Technically, single guided cylinder similar to one used in fixture-compensator assembly could be used for lifting a motor. However, cylinders, especially of complex design prone to damaging when influenced by constant vibrations. In presented design vibrations are dampen by linear guides, which are less likely to be damaged by vibration, while cylinder is used just for lifting. Even in case of guide block malfunction these are much cheaper to replace than to repair a complex guided cylinder.

Motor mounting bracket is a welded construction that consists of four steel plates. Motor mounting plate is made from 10mm thick plate and milled to 9mm for smoother mounting surface. It features a groove for easier fit with perpendicular guide mounting plate when welding. Guide mounting plate is 5mm think with 3mm long horizontal slots for mounting it to guide blocks. Slots are meant to compensate for inaccurate positioning, hence changing distance between guides during assembly. There is also a through hole, to which knuckle joint of the cylinder is attached with a hub to lift the motor. The hub between a knuckle joint and the hole in plate is needed for tighter fit and to prevent the hole form wearing out by influence of frequently changing force induced by cylinder. Construction of two perpendicularly welded plates is strengthened by two 5mm thick ribs connecting faces of two plates together.

Frame

Frame can be seen in figure 21. It is assembled from two flat bars, two equal angles and two aluminum profiles.

Vertical aluminum profiles are meant for mounting linear guides. Use of aluminum profiles with T-slots instead of, for example, regular rectangular tubes, is dictated by ease of installation of guide rails to profiles using position fixing nuts and by great structural strength of profiles even in small cross section size.

Profiles are perpendicularly mounted on 15mm thick flat bars. There is a threaded part inside a profile from the side that is in contact with flat bar, and a through hole with countersink on a bottom part of flat bar to accommodate a countersunk screw, which tightens a profile to a flat bar. To fully fix this construction in place, two equal 55x55x6mm angles are mounted from opposite sides of profiles and tightened both to flat bar and to aluminum profile. One of the angles features a hole for mounting a cylinders' pivoting bracket and a rectangular cutout that opens access to cylinders' mounting clevis for more convenient assembly.

Through holes on further sides of flat bars are for installation of the unit on machine frame with bolts and nuts. Loosening those allow unit to be positioned for different part sizes.

4.3 Unloading and stacking

There are two ways provided for unloading processed parts. Two different interchangeable units supported by the same machine frame are designed for that purpose, both shown in figure 26.

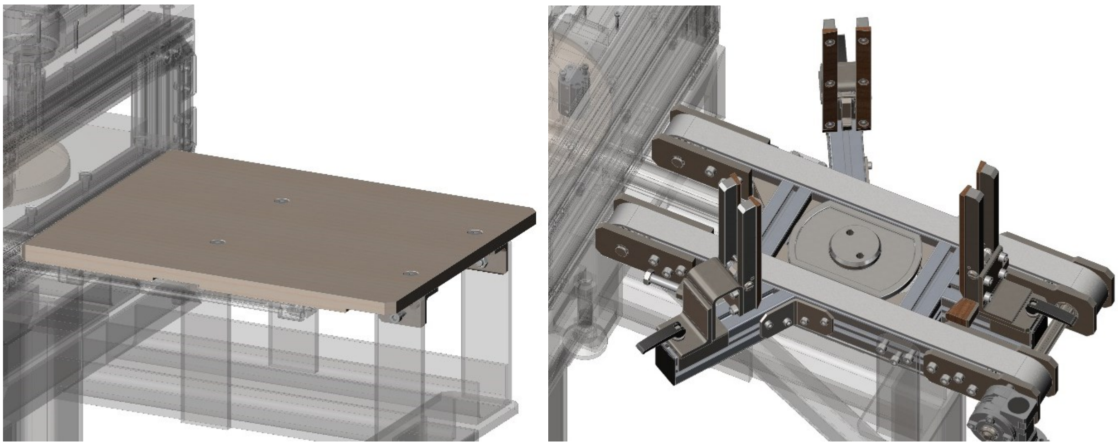


Figure 26. Left – unloading table. Right – stacking conveyor.

Unloading table – a simple construction for completely manual sequential unloading of parts. There is a 20mm thick plywood plate with milled grooves for mounting angles and one chamfered edge to prevent part, which is pushed to the table after processing, from balking against the edge of the plywood plate. Four mounting angles are inserted into grooves and fastened with countersunk head screws. The table is attached to the machine frame by the same four mounting angles with bolts and nuts. No further analysis of this unit required due to its simplicity.

Stacking conveyor – an automated solution for unloading processed parts into a vertical stack of up to ten pieces. This is basically a standalone unit build separately from the main machine around its own aluminum profile frame, which is mounted to the frame of the main machine with screws and rectangular positioning nuts inserted into T-slot of aluminum profile. After being pushed from processing unit a core plug is caught by constantly moving timing belt conveyor and transported forward until it hits the stopper. When located at the stopper it is lifted with a pneumatic cylinder and fixed with three spring loaded latches by its bottom side, between three holders. Following core plugs are stacked from underneath the previous ones by lifting already formed stack.

Figure 27 presents full stacking conveyor assembly.

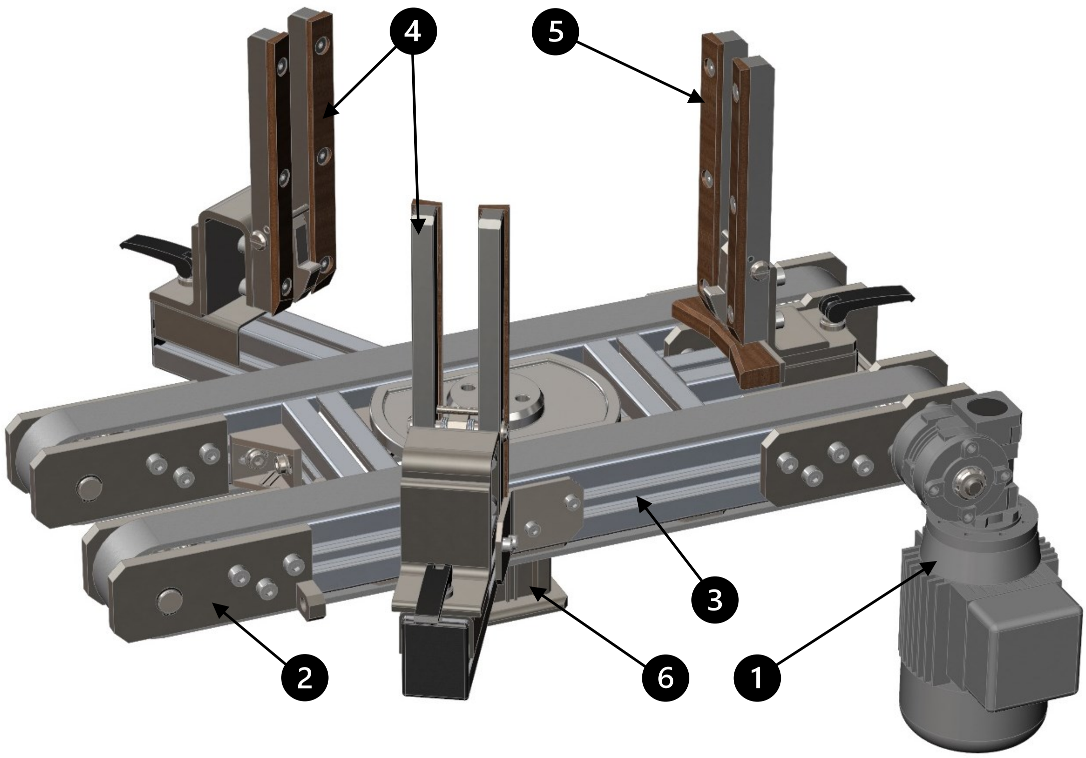


Figure 27. Stacking conveyor. (1) Drive unit. (2) Belt tensioning unit. (3) Frame. (4) Side holders. (5) Front holder. (6) Part lifting mechanism.

4.3.1 Timing belt conveyor

The conveyor consists of two separate T10 type timing belt carriers with belt width of 40mm. Each carrier is built around an aluminum profile with toothed pulleys attached to either side, with one being driving pulley, and other – tensioning. Carriers are connected to each other by two perpendicular beams made of the same aluminum profile. Carriers are parallel and their pulleys are coaxially aligned. Driving pulleys are connected by a splined shaft and are driven simultaneously with a gearmotor.

Driving pulley unit

Design principle and components of the driving pulley unit are shown in figure 28. The basic idea is to create a fixed connection between a gearmotor and two driving pulleys. It is done with a splined shaft, which is inserted into a splined hub, which in its turn connected to a timing belt pulley by a keyway. The rotation of splined shaft is supported with bearings. However, bearings cannot be directly put on a shaft, so copper hubs that acts as adapters and bearing supports are designed for the purpose.

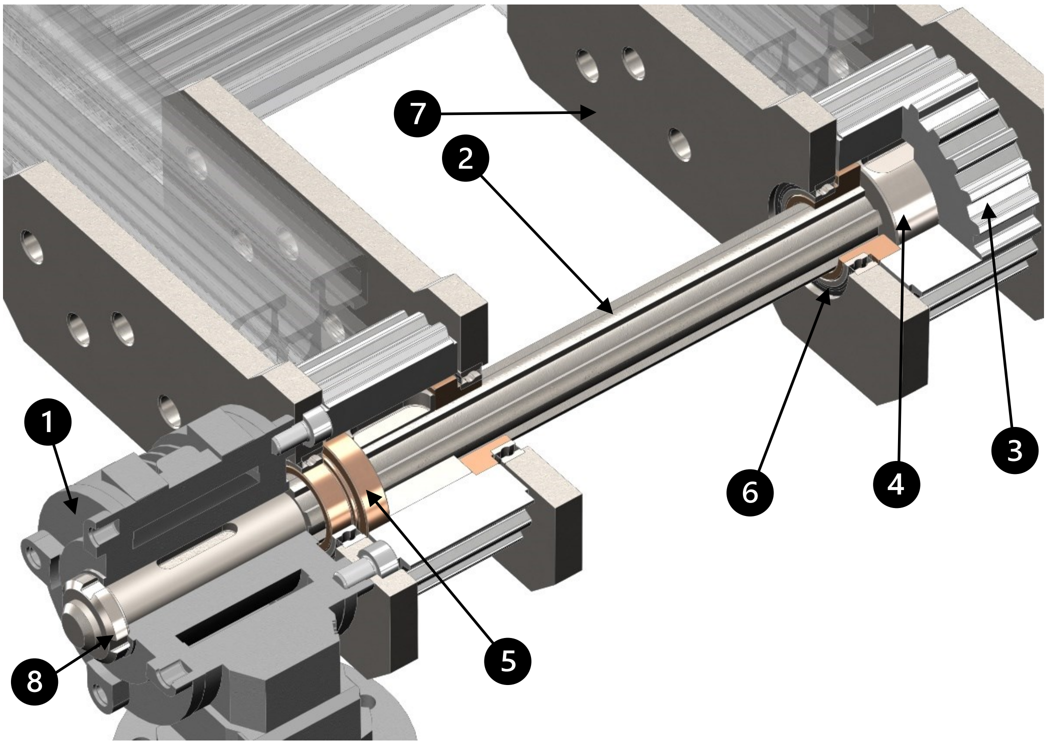


Figure 28. Timing belt drive unit. (1) Gearmotor. (2) Splined shaft. (3) Timing belt pulley. (4) Splined hub. (5) Bearing seat hub. (6) Ball-bearing. (7) Mounting bracket. (8) Locking nut.

Timing belt pulleys, splined hubs and splined shaft are all standard components produced by MAEDLER but modified to fit the designed assembly.

Splined shaft is a KW 16x20 profile type similar to DIN ISO 14 and is made of C45 steel. One end of the shaft is machined by turning to create a seat that is inserted into a gearmotors' 14mm diameter hollow shaft. Machined seat features a keyway for torque transfer and a M14x1,5 thread on the very end to accommodate DIN 70852 locknut for axial fixture of the shaft. If shaft connects two separate pulleys that are installed on a distance from each other, it is usually preferable to split a driving shaft in that space and use a torsionally and angularly elastic coupling to compensate for inaccuracy of axial alignment or bending of central axis. However, in presented design distance between pulleys is relatively small, just 170mm between virtual central planes. And carried load is negligible, as only one core plug at a time is transferred on a conveyor. For these reasons elastic coupling between pulley can be omitted.

For more clear understanding of the driving pulley assembly and component fits figure 29 shows a cross-section of an assembly.

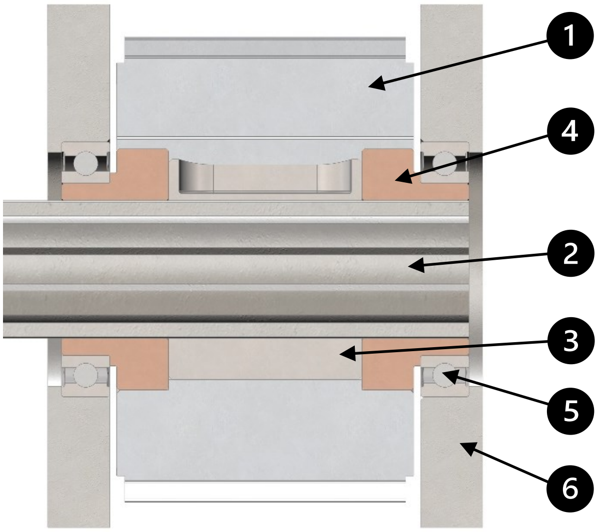


Figure 29. Cross-section of driving pulley assembly. (1) Pulley. (2) Splined shaft. (3) Splined hub. (4) Bearing seat hub. (5) Ball-bearing. (6) Mounting bracket.

Standard type 55 T10/22-2 driving pulley by MAEDLER is made of aluminum similar to AW2017A and comes with belt supporting flanges. However, due to limited space in the assembly, flanges must be removed. Other modifications to standard pulley include machining of a central hole to accommodate a splined hub with outer diameter of 32mm and a keyway groove. Two coaxial counterbores are made on both sides of the pulley and are meant as seats with abutment for bearing seat hubs to be mounted.

KN 16x20 splined hub made of C45Pb steel has suffered minor changes from its original design. It is shortened from 45mm to 28mm and has a keyway groove cut from its outer cylindrical face.

Copper hub is fully custom designed and has couple distinct functional features. Its design idea is based on three main diameters. Inner diameter of 20mm for the splined shaft to be installed through, bigger 35mm outer diameter that is meant for mounting into a seat in a pulley, and smaller 25mm outer diameter as a bearing seat. Narrow step of 28mm diameter is made between two main outer diameters to act as an abutment for inner ring of the 61805 bearing. Inner diameter of the hub is in clearance with splined shaft for easier assembly. Outer diameter of 35mm is in interference fit with a seat in a pulley to prevent untimely wearing out. Bearing seat is made with j6 tolerance, which is a recommended value for a light revolving load and together with inner bearings ring tolerance creates transition fit with prevailing interference.

Mounting brackets made from S355J2 steel plate of 10mm are machined to 9mm from the side that is in contact with aluminum profile for the purpose of creating contact surface with better properties. Each bracket features a counterbore hole that acts as a bearing sit. Main diameter of 37mm is made in H8 tolerance range as recommended for a housing seat in scenario with light stationery load. It creates full clearance fit with bearings' outer ring. The hole features an abutment of a 32mm diameter for bearings' outer ring.

SKF 61805-2RZ ball-bearing is equipped with non-contact seals on both sides, which prevent solid dust particles from penetrating into a lubricated inner part of the bearing. The bearing does not require any additional engineering analysis as it is used in a low speed and light load application.

Belt tensioning unit

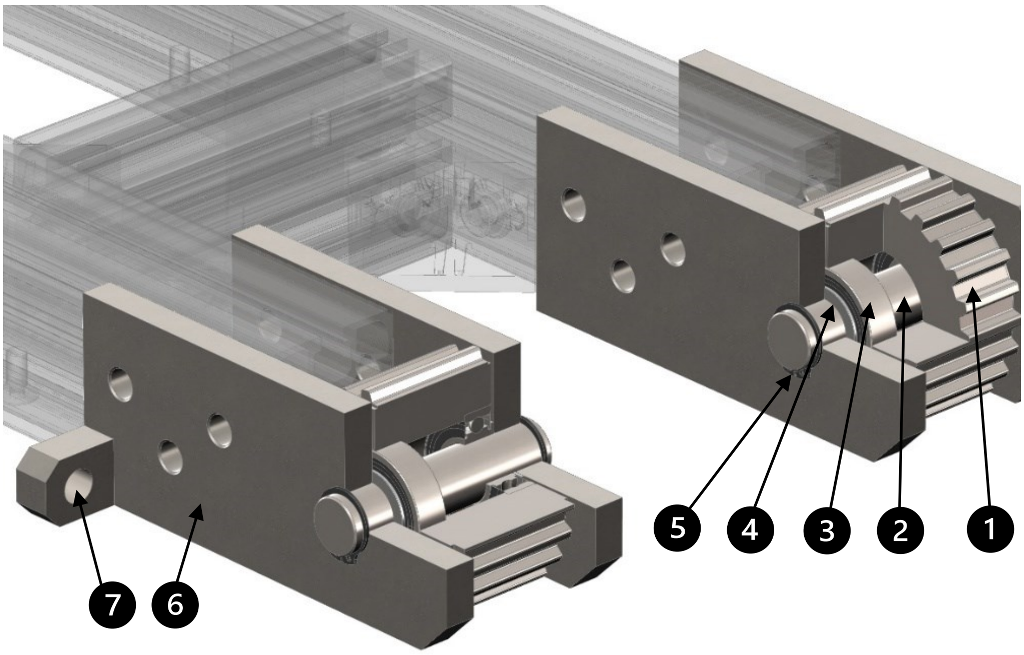


Figure 30. Belt tensioning unit. (1) Timing belt pulley. (2) Axle. (3) Bearing. (4) Shim ring. (5) Circlip. (6) Mounting bracket. (7) Tensioning ear.

Belt tensioning unit, which is shown in figure 30, consists of the same timing belt pulleys as used in driving unit, installed on an axle, and supported by 6003 bearings. Each bearing is held in place by an abutment on a timing belt pulley that supports outer ring, and a shim ring, which acts as an abutment for inner ring from the opposite side.

Timing belt pulleys used in tensioning unit are modified similarly to ones used in driving unit. The difference is a missing keyway groove, and more precise machining of 35mm counterbores within M7 tolerance range, which are meant for direct installation of bearings in transition fit with prevailing interference.

Axle is machined from S355J2 circular bar and features bearing seats machined for clearance fit with inner bearings' ring within g6 tolerance range. Two circlip grooves are made on each end of the axle, to prevent its axial movement in assembly.

Mounting brackets are manufactured from 10mm S355J2 plate with the same principle in mind as mounting brackets for driving pulleys. Besides changes in overall size and mounting holes, two outer tensioning unit brackets feature tensioning ear welded to their side. Tensioning ear has a threaded hole, which is meant for installation of tensioning bolt with counter nut for more precise and convenient tensioning of the belt with wrench tool. When stacking conveyor unit is assembled to the main frame of the machine, tensioning bolts' end rests against a similar ear, but without a hole, that is welded to the frame of the machine, so that conveyors belt is tensioned by bolt pushing against it as bolt is rotated.

Gearmotor

Varvel MRS28 i=49 56 0,06kW gearmotor is a 4 pole 56 size 0,06kW electric motor linked to a smallest available worm gear unit with reduction ratio of 49. Its rated output speed is 28,57rpm and output torque is 11,43Nm. Even such a small torque is more than enough for the purpose. This can be seen just by looking at values in question. According to data from SKF, combined frictional moment from four 61805 bearings with non-contact seal and four 6003 bearings with contact seal, which are used in a conveyor assembly, is just around 69Nmm at 300N load. The load comes mostly from belt tensioning and in fact will be even smaller, than value of 300N used for calculation. At the same time, frictional force induced by a single biggest core plug sliding on a conveyor is estimated in a range from 3N to 5N (uncertainty comes from unknown frictional coefficients, that are only estimated based on values from multiple sources), while rated gearmotor output torque exerts around 154N of force at an outer surface level of belt wrapped around a pulley, which is about 74mm in diameter considering belt thickness.

Rated output speed of 28,57rpm equals to about 220mm per second linear speed at the belt surface level, which is located at 37mm radius from center of rotation. Distance that the smallest core plug of 210mm outer diameter must be transported at after being pushed from processing unit until it reaches the stopper of stacking conveyor is around 310mm. It will be covered in about 1,4 seconds.

This gearmotor combination is rated with service factor of 1,5, which is closely suitable for 16 to 24 hours of uninterrupted operation with uniform light loads, according to recommendations from Varvel.

4.3.2 Part lifting

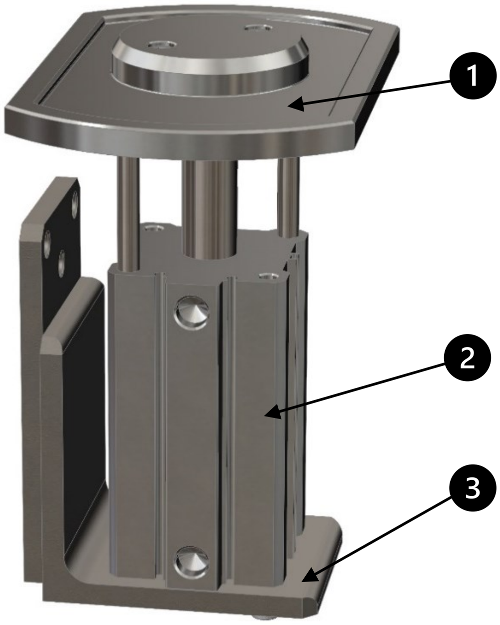


Figure 31. Core plug lifting mechanism. (1) Lifting plate. (2) Pneumatic cylinder. (3) Mounting bracket.

The lifting mechanism shown in figure 31 represents a simple pneumatic cylinder mounted to a bracket, that is attached to a frame of the conveyor with a lifting plate attached to pistons’ head. When core plug is stopped by the part stopper and its center hole is approximately located above the lifting plates’ centering ledge, the cylinder is actuated, centering ledge of the lifting plate is inserted into a core plugs’ center hole and a core plug is lifted, pushing spring-loaded latches of part holders apart and then released once it is lifted high enough that latches return to their original position.

The cylinder CDQMA50-75 is the same type and size as used for the fixture-compensator, but with an increased stroke length of 75mm. Part lifting cylinder is equipped with built-in magnets and positioning sensors that are meant to control its stroke by registering extreme positions, which are set by locating positioning sensors along cylinders' body. Rated theoretical output of the cylinder gets as high as 1370N for movement OUT at operating pressure of 0,7MPa.

The lifting plate is made from a 20mm thick S355J2 steel plate. Its overall size is predetermined by the limited space available between conveyors' frame elements, however, it is made with the purpose to have as big contact surface with core plug as possible for more stability when core plug is being pushed against spring-loaded latches. It features a circular centring ledge with a tapered top edge, which is meant to help with a more accurate centring of a core plug. Centering ledge has the same diameter as core plugs' center hole but is made to fit with quite loose clearance to prevent core plug from being stuck in inclined position. This feature requires for different lifting plates to be produced for different central hole diameters. However, the lifting plate is extremely easy to replace, as it is held by two screws fastened to the cylinders piston head.

The mounting bracket is made of 8mm thick plate and a 100x100x8 equal angle welded together. A cylinder stands on the inner side of an angle fastened with two screws inserted directly into threaded holes in the cylinders' body. Plate is attached to inner side of the conveyors aluminum profile frame. It can be easily moved along the profile during assembly, which allows for position fine-tuning.

4.3.3 Part holders

There are three adjustable part holders located circularly around the center of the lifting mechanism. There is one front holder with a stopper on its bottom part, which besides holding a stack of discs is meant for stopping the part at a lifting point. Two side holders are located at 120˚ to each side of the front holder, so they support a stack of core plugs at equidistant points along the circumference. Two types of holders have identical spring-loaded latch mechanisms and supporting ribs design but differ in mounting bracket design. Front and side holders can be seen in figure 32.

Mounting brackets of each holder, despite being different in design, have the same fastening and positioning principle. The bottom-most part is a guide brace made of a 50x50 rectangular tube with a wall thickness of 2,5mm. One wall of the tube is removed so that a three-sided brace is formed. Due to the walls being 2,5mm thick, the inner dimension of this brace comes to be 45mm, which is exactly the width of the aluminum profile it is mounted to. The brace forms a close to a tight fit with an aluminum profile and acts as a guide block for the holder. Then it is simply fastened to the profile with a clamping handle and a nut inserted into the profiles' T-slot. When the clamping handle is released, a holder can be freely repositioned along the profile, which allows it to be set up for accommodating core plugs of any required size.

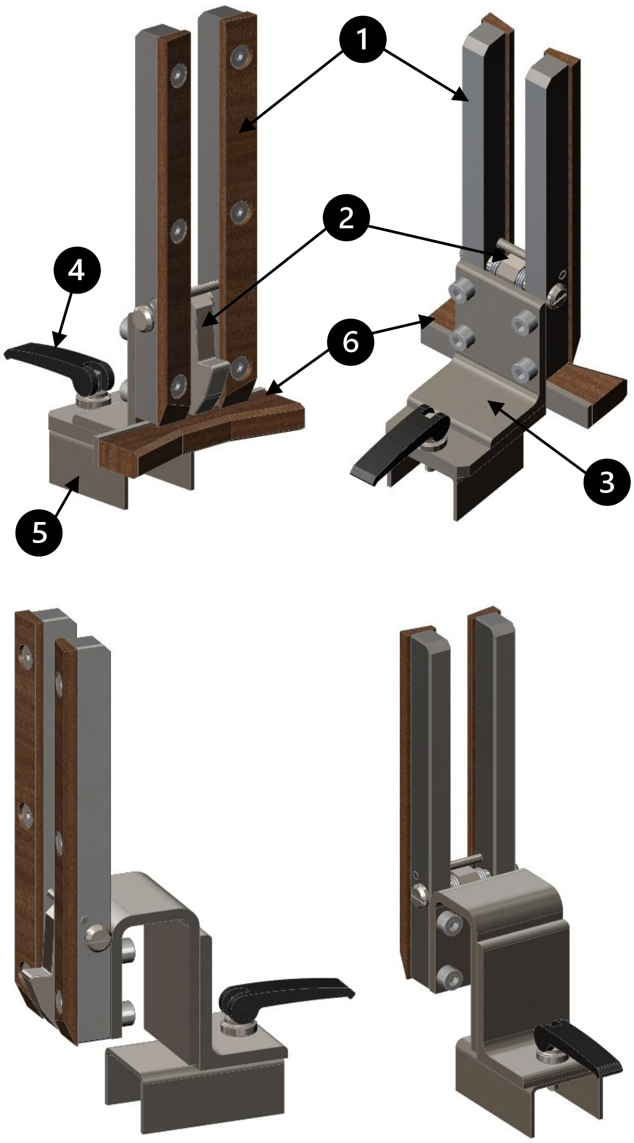


Figure 32. Top – front holder. Bottom – Side holder. (1) Support ribs. (2) Spring-loaded latch. (3) Bracket. (4) Clamping handle. (5) Guide brace. (6) Part stopper.

The front holder exclusively features a stopper, which can be seen in figure 32. It is made either from plywood or composite epoxy plate, as it should be soft enough not to damage the core plug being bumped into it and not to leave colored marks. Stoppers' front surface is an angled indented edge similar to one on a pushing plate at the feeding unit. It is made for the same reason to help to centre a core plug.

Mounting brackets of side holders differ from the front holder because of their positioning. Due to side holders being located not 180˚ opposite to each other on both sides of the conveyor, but slightly shifted to the back of a core plug to form equidistant supporting points, the distance between support ribs of side holders is less, than a diameter of a core plug that must pass between them while moving along the conveyor. For that reason, mounting brackets of side holders are shifted back, to let core plug pass between them, so support ribs are hanging above it not obstructing the transportation, as shown in figure 33.

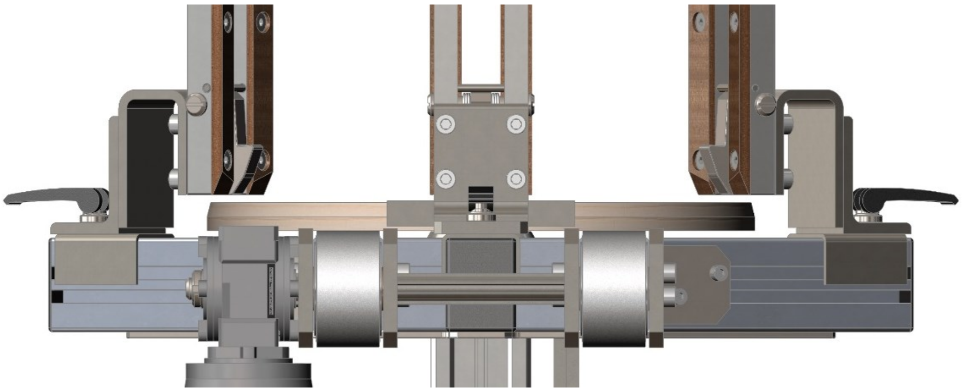


Figure 33. Back view of the stacking conveyor with core plug being transported.

The spring-loaded latch can be seen in figure 34. It is an assembly of an aluminum latch, revolving around a two-part axle. The axle is divided into two parts connected by a thread in the middle. A double torsion spring is installed on an axle, with its end wires resting against a mounting bracket, and its frame pushing on the back of the latch. A pin, installed above the latch, is obstructing it from being pushed too far up, keeping a spring always slightly preloaded.

The spring is a double torsion spring 8574 from Lesjofors. Its load rate is 15Nmm per degree of torque. Its end wires and frame are bent to the same side in a neutral position. When the spring is installed in the assembly being compressed by twisting for about 4˚, it preloads a latch with a torsional moment of 60Nmm. Springs' frame length from the central axis is 16mm. A Force of 3,75N at the frame of the spring pushing a latch can be derived from those values. The preloaded position of a latch is depicted in figure 34, left side image.

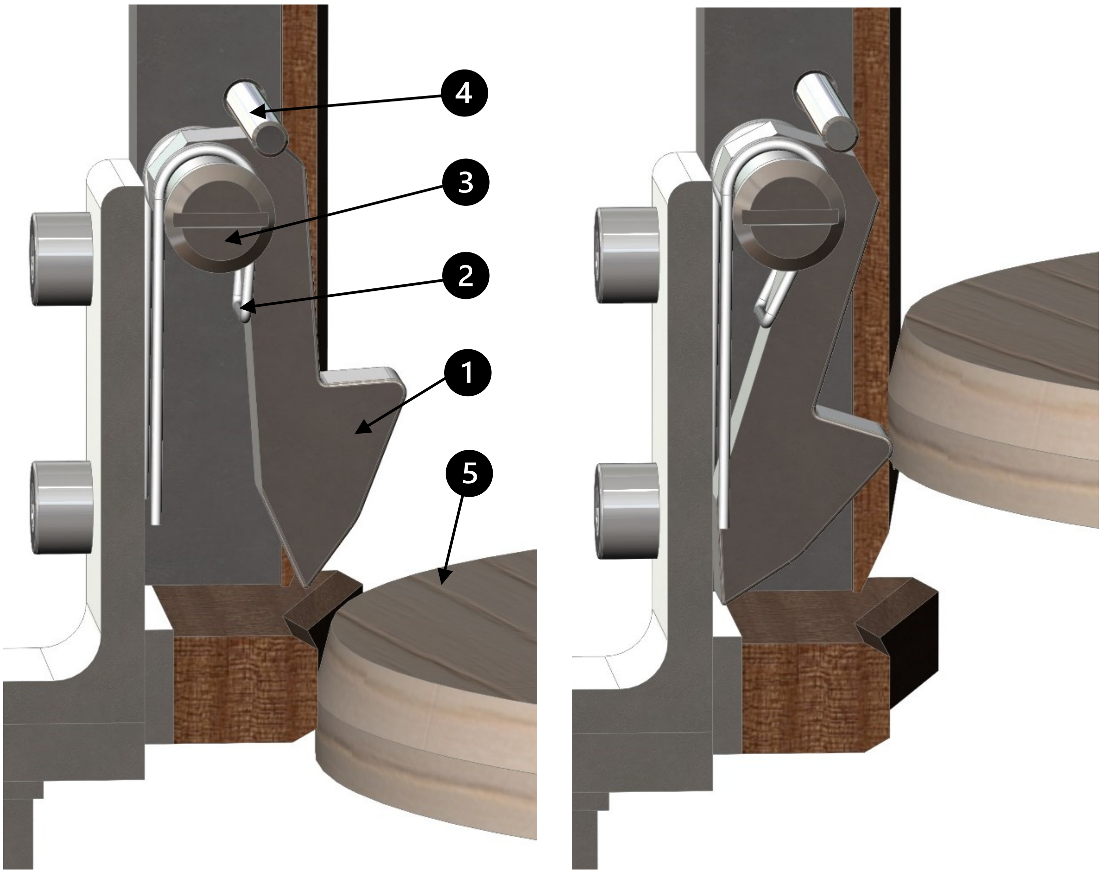


Figure 34. Spring-loaded latch in the preloaded state (left) and plug loading state (right). (1) Latch. (2) Spring. (3) Axle. (4) Pin. (5) Core plug

When a core plug is being lifted and the latch is pushed back compressing the spring, as shown in figure 34, right side image, the pushback force from the spring increases. The estimated twist of the spring in this extreme position is 25˚ from a neutral position, which translates to the torque of 375Nmm at the axle. At that moment, the frame of the spring pushes a latch with an estimated force of 23,4N. At the contact point of the latch with a core plug, which is located about 38mm away from the axis of rotation, there is an estimated force of nearly 10N acting on a core plugs' side.

This estimation of forces confirms that latches are quite lightly loaded and most likely will not damage a core plug while it is being lifted, nor will not they cause any notable resistance for a lifting cylinder.

Figure 35 shows how the layout of part holders is changed in two extreme positions, with 210mm and 350mm core plugs. It can be noted that the centre of a lifting unit is not moved regardless of core plug size. Points of support are also always in the most possibly stable configuration equally spread along the circumference of a core plug.

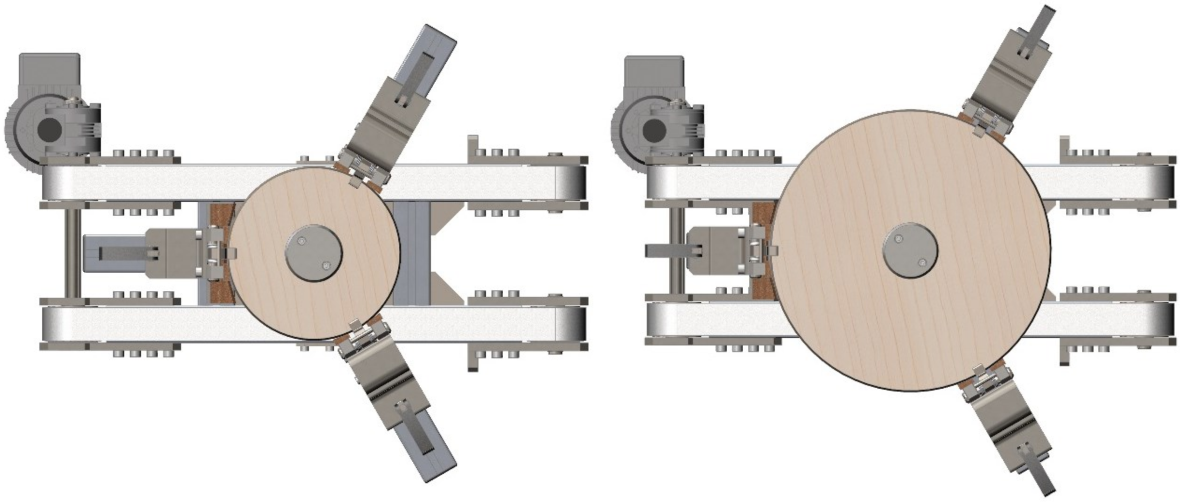


Figure 35. The layout of the stacking conveyor. Left – with 210mm core plug. Right – with 350mm core plug.

4.3.4 Frame and fixture components

The frame of the stacking conveyor is built with a 45x60mm aluminum profile from Minitec. Two main beams are supported with two cross members. Three additional profiles are added for part holders' installation. Two side profiles are cut at a 60˚ angle.

Besides using standard fastening elements provided by Minitec, three custom support plates were designed. The angular bracket, which is made from a 4mm steel sheet is bent at a 60˚ angle and is meant for the secure joining of angular side profiles. Two more types of fastening plates were made from a 4mm steel sheet for bottom support of additional profiles and are used in combination with angular supports for more rigid construction.

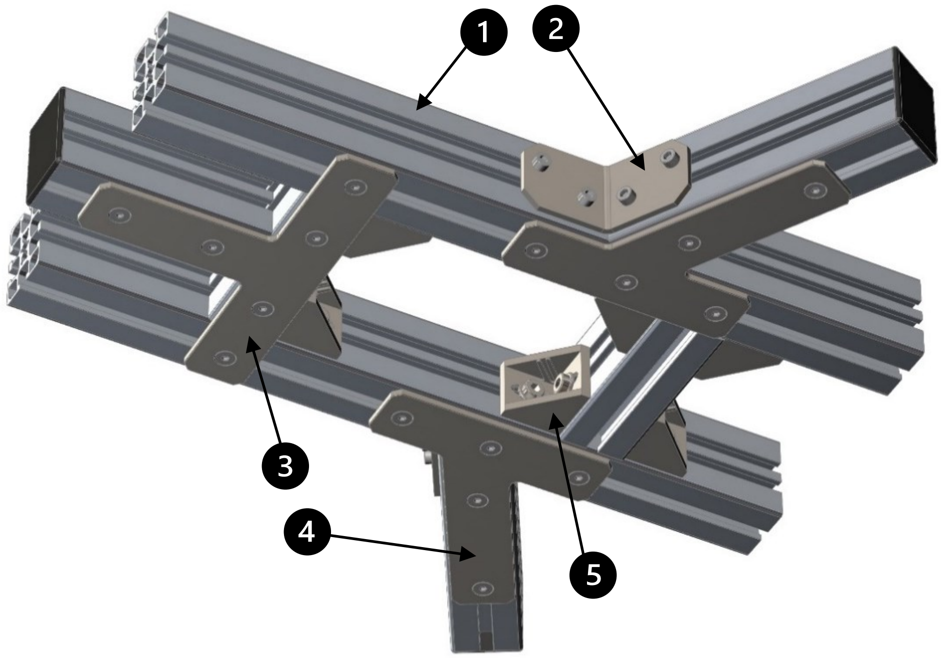


Figure 36. Stacking conveyor frame. (1) Aluminum profile. (2) Angle bracket. (3) Front holder bracket. (4) Side holder bracket. (5) Angle mount.

Typically, mechanical designers at CCs' technical department are not requested to be detailed with profile constructions. The main point is to show the basic layout of a structure, cut length and joining angles. If necessary, the layout is presented in context with other features, to avoid overlapping other parts of the assembly. All other assembly decisions are made by fitters at the machine shop.

4.4 Frame

The main frame of the machine is divided into three distinguishable sections, which are shown in figure 37. Profile frame section, which is built with aluminum profiles and steel plates, and is designed to accommodate all main units of the machine. Reinforcing frame section, built using UPE80 beams, for rigidity and integrity of the whole structure, and as a base for attachment of aluminum profile frame and stacking conveyor. The supporting frame section, made mostly with square tubes as vertical beams for installation and support of the whole machine. The support section is welded to the reinforcing section and stands on levelling feet.

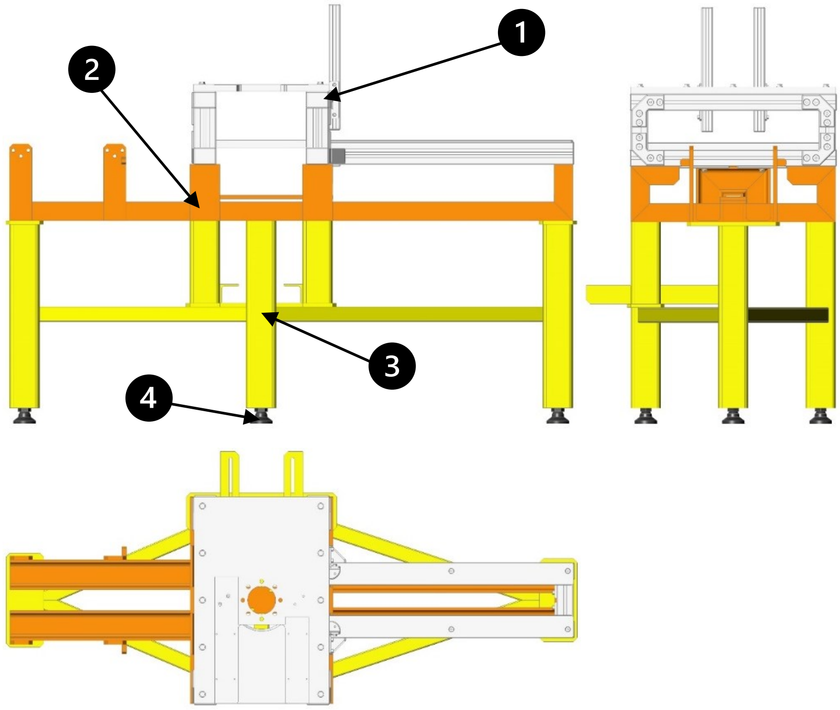


Figure 37. The main frame of the machine, divided into distinct sections. (1) Profile frame. (2) Reinforcing section. (3) Support section. (4) Leveling feet.

4.4.1 Profile Frame

The profile frame presented in figure 38 is the main element of the frame structure. It is made for flexible accommodation of main machine units: feeding unit, spindle, and calibration unit.

The profile frame is made based on a 45x60 aluminum profile by Minitec and assembled using mainly standards fixture components from Minitec, such as power-lock fasteners, mounting brackets, connecting plates, and mounting angles. Standard fixture components are specially designed for building a structure with maximum integrity and rigidity. Additional 30 R90˚ profiles are used as blank disc rests and are mounted with custom-designed angle mounts.

The top and bottom plates are the heaviest parts of the whole frame structure. Made from 20mm thick steel plates and bolted with two rectangular aluminum frames, they make a heavy rigid cage that can be observed in figure 38. This cage accommodates the whole part treatment unit.

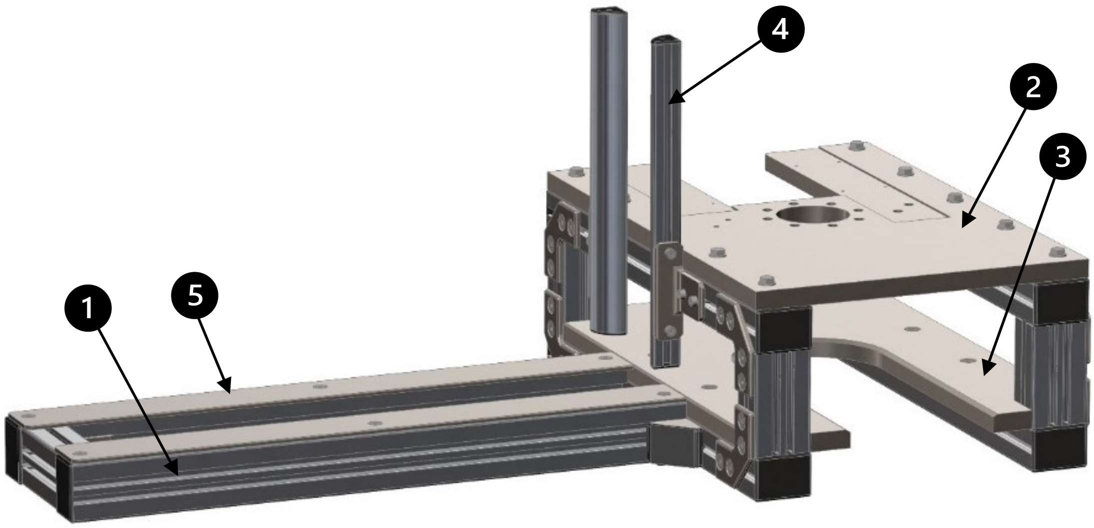


Figure 38. Profile frame. (1) Aluminum profile. (2) Top plate. (3) Bottom plate. (4) Blank disc rests. (5) Sliding strips.

The bottom plate is machined to a thickness of 19mm requiring processing of both faces to increase flatness and parallelism as well as the overall quality of mounting surfaces. A 155mm wide and 350mm long slot is cut through the plate to create space for moving parts of the fixture-compensator and edge sanding unit. The plate is bolted to aluminum profiles through counterbore holes to hide bolt heads, as its top surface acts as a sliding face for a blank disk that is being loaded into a part treatment unit.

The top plate is one of the most responsible parts of the structure and it requires complex, preferably CNC processing. First, it is machined the same way as a bottom plate to the thickness of 19mm to increase the quality of surfaces. However, then several additional features must be made. First, place for mounting a spindle. Though it allows for some inaccuracy for hole positioning, mounting surfaces should be perfectly flat to ensure vertical straightness of the spindles' rotation axis. Two 2mm deep surfaces are milled for installation of ball screw guide and support guide of calibration unit. The purpose of milling these surfaces is to produce perfectly parallel abutments and installation surfaces for the accurate positioning of guides. Then, besides holes for spindle installation, 22 other through or threaded holes must be made for the installation of the calibration unit, down pushing cylinders, and mounting of the plate itself to aluminum profile.

Sliding strips are meant for sliding of blank discs that are fed into a part treatment unit. Experience with aluminum profile structures at CC showed, that aluminum easily leaves markings on wooden parts, which slide directly on the aluminum surface. Steel is more suitable for sliding of wooden parts. These 4mm thick sliders are fastened to an aluminum profile with hidden countersunk screws. They also form the same level surface with the bottom plate of the part treatment unit as profiles used for mounting 19mm thick plate and 4mm thick strip are aligned by different surfaces, which can be noted in figure 38.

4.4.2 Welded frame

The reinforcing section is a fully welded structure made from UPE80 beams. Its purpose is to accommodate a profile frame, adding more weight and integrity. Reinforcing frame features additional 10mm thick brackets for unloading unit to be installed to, including brackets with tensioning ears, which are used for belt tensioning when stacking conveyor is installed. A fixture compensator mount is added for installation of the fixture compensator and is made from a 20mm thick steel bar but machined to 18mm for more precise alignment of units in complete assembly.

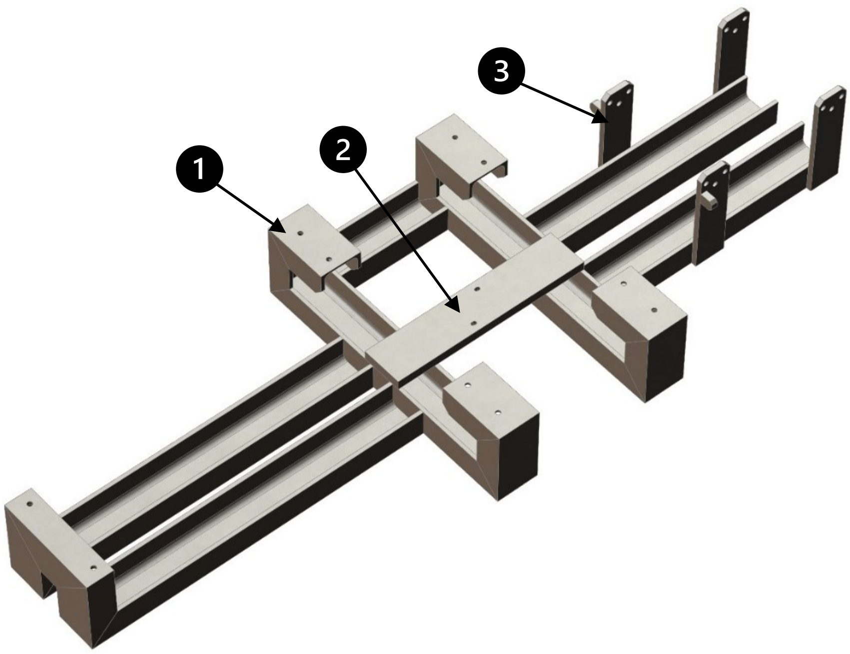


Figure 39. Reinforcing frame section. (1) UPE80 beam. (2) Fixture compensator mount. (3) Unloading unit brackets.

The supporting section acts as a stand for the whole machine. It is fully welded together with a reinforcing section.

The basis of the supporting section shown in figure 40 is made of 80x80x5 square tubes, that act as main vertical beams, and 40x40x3 square tubes used as cross-members. Cross-members form two horizontally located triangles with one common side. This layout adds great integrity to the whole structure. Support plates at the top of two farther beams are there to increase the length of welds between the reinforcing frame and the supporting frame. One of the side beams is divided into two levels to integrate sliding rails for the edge sanding unit. Sliding rails are made of 50x50x5 equal angles with 310mm long horizontally cut slots, that allow the whole edge sanding unit to be linearly moved to and from the centre of the structure.

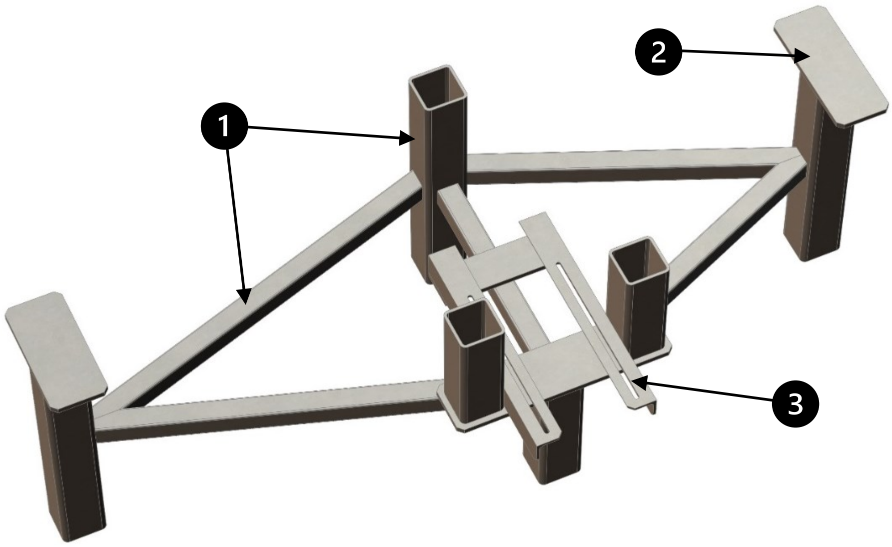


Figure 40. Supporting frame section. (1) Main structural members. (2) Support plates. (3) Edge sanding unit slider frame.

There are four 20mm thick plates inserted and welded into a hollow part of vertical beams from the bottom, one plate in each beam. M20 threads are made in the middle of those plates for levelling feet to be inserted into. Levelling feet are standard parts from MAEDLER. They feature ball joints that allow them to be installed even on notably inclined surfaces, levelling nut that is meant for alignment of installation height, and a counter nut to fix set height. Additional flanges can be put over levelling feet supports to safely secure them to the ground by anchoring.

5 CONCLUSION

The aims and objectives of the project were generally met with minor, but permissible and justifiable deviations from some of the constraints.

5.1 Project outcome

The main project outcome is met, as the machine designed is theoretically capable of producing core plugs with requested parameters and implies automation to the requested level.

The requirement of set-up flexibility that is needed to process core plugs in a range of diameters is met with minor nuisances and compromises. Generally, all main units are designed to be easily readjusted. However, these adjustments must mainly be done by using a sample part of the requested diameter to manually move adjustable components to fit its size. To make adjustments easier, length measurement scales may be attached to machines' frame along movement lines of adjustable components, for them to be set in relation to that scale. However, such a set-up should preferably be double-checked with the sample part. Especially, it concerns stacking conveyor unit, and particularly part holders, which should be adjusted quite tightly to the diameter of a processed part that is located precisely at the centre of the lifting mechanism, for correct operation. The calibration and tapering unit is the only one that does not require to be set up by the manual movement of components. Its set-up happens from a controller, that controls the location of the ball screw guide.

Automation logic is not described in the project, nor is requested to be developed by a mechanical designer. However, a designed machine implies full automation, therefore mechanical constituent of the machine is built with consideration of automation needs and the theoretical workflow of the whole operating process meets automation requirements. Blank discs are manually loaded in batches up to twenty and processed core plugs are manually collected, also in batches up to ten. All in between, including feeding, processing, and unloading in stacks, is theoretically being automated.

The outcome of calibration and tapering operation theoretically meets requirements, including the requested tolerance for the diameter of a core plug. Standard components chosen for fixture-compensator, spindle, and calibration units are of sufficient quality level to be used in the application, where narrow tolerancing is necessary. Designated quality requirements and tolerancing ranges for custom components are theoretically suitable to form assemblies of accuracy enough for the objective of the project to be met. The real result only depends on the production quality of custom components and the alignment of assemblies and sub-assemblies.

The custom milling tool is designed to meet requirements for calibration and tapering unit. The shape of the tool is designed to make a tapering of 14˚ and calibrate the diameter of parts at the same time.

5.2 Development process outcome

Development process objectives are fulfilled for the most part. Constraints are followed with minor deviations. Available tools were enough for the preliminary design of the machine to be produced. No other software except Solidworks Standard 2021 was required to be used.

Design for manufacturing principles were being considered in the design of every custom part. Parts are not overworked and only include justified features necessary for operation. However, no optimization was done due to stress analysis not being conducted. Though some complex components e.g., housing and shaft of the spindle, or top mounting plate of the part treatment unit, should preferably be produced with CNC machining centres, the project does not include a single part, that is not possible to produce with tools and machinery available at CCs' machine shop.

Standard components used in the presented design are purchased from contracted suppliers, with only one exception of edge sanding disc brush, with its reasons described in part 4.2.4. Raw materials used for the production of custom components are, as requested, in stock at CCs' warehouse or are available for purchase from contracted suppliers.

Technical parameters, features, and constraints of purchased components are verified for compliance with working conditions and suitability for necessary applications using rough estimations and simple calculations with at least double safety factors. No deeper analysis, such as thermal, frequency, fatigue, or dynamic was conducted.

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