VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
DEPARTMENT OF MECHANICS AND MATERIALS ENGINEERING

HARI SHANKAR GOVINDASAMY

DESIGN OF 3D PRINTER

Final Bachelor Graduation Thesis

Mechanical engineering Study programme, Study Code: 612H33001
Machine design specialization

Vilnius, 2019

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
DEPARTMENT OF MECHANICS AND MATERIALS ENGINEERING

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HARI SHANKAR GOVINDASAMY

DESIGN OF 3D-PRINTER

Bachelor's degree final work 3

Mechanical engineering study programme, state code 612H33001
Machine design specialisation
Mechanical engineering study field

Supervisor Dr. Sigitas Petkevičius
(Title, Name, Surname) (Signature) 2019.05.30 (Date)

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Vilnius, 2019

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

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2019.02.22
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OBJECTIVES FOR BACHELOR'S DEGREE FINAL WORK (PROJECT)

20190222 No. 25
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For student :	HARI SHANKAR, GOVINDASAMY
Final work (project) title:	Design of 3D Printer
Approved on:	04-12-2018 by Dean's degree No. 291 ME

The Final work has to be completed by 26th May, 2019

The Objectives:

Data:	Dimension of Printer not greater than $(100\times100\times100)$ mm^3;
Electrical power:	4 Stepper motors not exceeding 12v
Control unit:	ARDUINO, RAMPS 1.4 SHIELD

Explanatory note:
Introduction; Analysis of similar devices; Argument of selected decisions; Necessary calculations of construction: stiffness and kinematic; Calculations of power of the drive; Description of control system.
Technological path of the part; Determination of the requirements of safety work using the device; Environmental requirements; Economical calculations; Conclusions; List of references.

Drawings:
Drawings of assembly (1 page A1); Drawings of parts (1 page A1); Technological sketches (1 Page A1); Indicators of economics (0.5 page A1); Control scheme (0.5 page A1).

Consultants of the final degree work (project): DESIGN OF 3D PRINTER

Academic Supervisor .... (Signature) Assoc. prof., Dr. SIGITAS PETKEVICIUS (Title, Name, Surname)

Objectives accepted as a quidance for my Final work (project)

....
(Student's signature)

Hari Shankar Govindasamy
(Student's Name, Surname)

13.02.2019
(Date)

(the document of Declaration of Authorship in the Final Degree Paper)

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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(Student's given name, family name, certificate number)

Faculty of Mechanics

(Faculty)

Mechanical Engineering, MPfuc-15

(Study programme, academic group no.)

DECLARATION OF AUTHORSHIP
IN THE FINAL DEGREE PAPER

May 28, 2019

I declare that my Final Degree Paper entitled „Design of 3D Printer" is entirely my own work. The title was confirmed on February 18, 2019 by Faculty Dean's order No. 69me. I have clearly signalled the presence of quoted or paraphrased material and referenced all sources.

I have acknowledged appropriately any assistance I have received by the following professionals/advisers: Doctor Sigitas Petkevičius.

The academic supervisor of my Final Degree Paper is Doctor Sigitas Petkevičius.

No contribution of any other person was obtained, nor did I buy my Final Degree Paper.

(Signature) Hari Shankar Govindasamy

(Given name, family name)

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Bachelor Degree Studies **Mechanical Engineering** study programme Bachelor Graduation Thesis 3

Title	**Design of 3D Printer**
Author	**Hari Shankar Govindasamy**
Academic supervisor	**Sigitas Petkevičius**

Thesis language: English

Annotation

In this final Bachelor's thesis, "Design of 3D-Printer" provides advanced design model of SLS 3D-Printer after reviewing several existing printers. Some of them were compared with overall designs. New technology of twin laser system is introduced. Advanced analysis and calculation for Sintering process and necessary calculations for drive components has derived. CAD model of the entire printer is designed with some unique features. Strength calculation has been made and electrical control scheme has been designed. Physical properties of the material that are to be sintered is analyzed (Nylon PA-12). Requirements of the laser system have been shown.

In the technological part, the work and machining details are shown for the chosen part. The machining environment and work safety requirements have been detailed for the machine and operator. The economic calculations have been made for the making of this printer such as fixed costs, variable costs versus sales cost for mass production is derived.

This work contains 50 pages of text without appendixes, 20 figures, 29 references, Graphical part consist of 4 pieces A1 sheets.

Keywords: Selective Laser Sintering, Additive Manufacturing, Laser Sintering

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Pirmosios pakopos studijų **Mechanikos inžinerijos** programos bakalauro baigiamasis darbas 3

Pavadinimas	**3D spausdintuvo projektavimas**
Autorius	**Hari Shankar Govindasamy**
Vadovas	**Sigitas Petkevičius**

Kalba: anglų

Anotacija

In this final Bachelor's thesis, "Design of 3D-Printer" provides advanced design model of SLS 3D-Printer after reviewing several existing printers. Some of them were compared with overall designs. New technology of twin laser system is introduced. Advanced analysis and calculation for Sintering process and necessary calculations for drive components has derived. CAD model of the entire printer is designed with some unique features. Strength calculation has been made and electrical control scheme has been designed. Physical properties of the material that are to be sintered is analyzed (Nylon PA-12). Requirements of the laser system have been shown.

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Prasminiai žodžiai: Selective Laser Sintering, Additive Manufacturing, Laser Sintering

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NOMENCLATURE

AM	-	Additive Manufacturing
FDM	-	Fused Deposition Modelling
SLM	-	Selective Laser Melting
SLS	-	Selective Laser Sintering
SLA	-	Stereolithography
MJ	-	Material Jetting
BJ	-	Binder Jetting
ASTM	-	American Society of Testing Materials
EBM	-	Electron Beam Melting
PBF	-	Powder Bed Fusion
UV	-	Ultraviolet rays
SA	-	Activated area
SV	-	Spot Volume
Ph	-	Ball Screw Pitch
GDP	-	Gross Domestic Product
CAD	-	Computer Aided Designing
CAM	-	Computer Aided Manufacturing

INTRODUCTION

Before we dive into history and development of 3d printing and additive manufacturing, we need to analyse the entails and imposing factors which leads us to the utilization of Additive Manufacturing. Hands make us humans; Hands makes us makers, Makers made tools, Tools created machines, Machine created industries, Industry demanded a trade, we evolved news ways to make, build and change the world. But at some point, things got out of hand, nature got settled, environmental pollution, less availability of resource global warming which accelerates climatic changes, less groundwater supply and we already broke the recovery stage, as time goes by we are getting in demand for resource for example For example, “40% of the world’s coal disappeared in 3-years,” says U.S. Geological Survey coal expert Harold Gluskoter in “NEW FOCUS” Science magazine-2009.

Many frontier countries were being in alert to face the effects. Unmanaged and unorganized industrialization makes our environment tough to live with. We catch resource which exceeds our requirements; there is a need to efficient this by demanding what we utilize and want and produce only what needed. By resulting from this technique where the supply is equal to demand, there is no wastage of resource, evolving new ideas concepts designs, prototypes and for that our future generation would take the lead by this tool. By keeping this tool in mind, there is the urgency to get the mechanism used in our industrial environment. So, there is a need for today's automation world to explore the new production technology like Additive manufacturing.

If optimizations yield’s efficiency, there is no choice but to enterprise to unlock tremendous opportunities offered by Additive manufacturing. Additive Manufacturing is the investment for human resource because of its unique manufacturing techniques. One of the major factors that attract industrial production to AM is making manufacturing with reduced waste materials.

Featuring limitless design possibilities and cost-effective production of small, medium, and huge productions. The task is getting it to ground with industries, and researches were factors like cost per part mass production, rapid manufacturing economic efficiency comes to play. To analyse the actual result, the only way is by getting hands on its AM environment. But both aspects are holding much importance while developing a successive and positive business model, but it well contains complex tasks to get out with.

It is one of rapidly developing technology were beside it is getting ready for its standards. For now, it’s named as “Rapid Prototyping,” “3D-Printing”, “Layered Manufacturing,” “Self-Freeform Fabrications” but its majorly called “Additive Manufacturing. The history starts from developing first 3D-Printer by Charles Chuck Hull (BBC, 2014), which is Stereolithography printer in 1983, But Japanese engineer Hideo Kodama already invented in 1980 (Sculpteo, Capucine Lonjon).

SLA approach by using UV after several years in 1986 Chuck first patented this technology and, he founded company which is now called "3DSystems". While Chuck developing SLA machines, other innovators developed new AM technologies one of the main is "Selective Laser Sintering" by Carl Deckard and Dr. Joe Beaman (Ashley Lindstrom, 2012). SLS places under Metal Additive Manufacturing otherwise known as "Powder Bed Fusion" where the fine polymer powder selectively melted by laser beam and forms a solid layer under specific temperature constrained. AM doesn't stop with this, which continuous to evolve other kind of technologies such as Electron Beam Melting (EBM), Laser Engineering Net Shape (LENS), Fused Decomposition Modeling for metal (FDM), Binder Jetting (BJ), Nano Particle Jetting (NPJ) and Electron Beam Additive Manufacturing (EBAM) (lboro, 2012).

So, knowing that science and engineering is leader to the technology and have power to implement new things we are the first person to lead this change by getting hands with advanced technologies on top of that whereas production and manufacturing plays huge role in engineering and having direct bonding to materials and resources we should get veteran in new ideology and convey this path to other sectors.

This is the project which makes AM available to the small-scale sector to utilize this demanding technology. This paper guide process of making the SLS machine form process of designing to manufacturing and assembling entire machine in elaborated way.

The machine that is going to be built is from the technology of "Selective Laser Sintering" SLS. The main reason for choosing this exact technology is because of building materials. The parts build with this machine can be varied materials like plastics, rubber as well as metals, which is not available in any other AM technology. This special feature gives access to make multi-material parts which can be upgraded in future versions.

AIM:

The aim of this thesis is to design SLS 3D-Printer which overcomes disadvantages of current SLS printers and comes with new design including additional unique advantages.

TASK TO DO:

1. To give a basic annotation of AM technological process and review about similar technologies.
2. To give detailed look about design properties of sintering model and review about "Design for Additive Manufacturing". To analyse about the materials and its physical properties to make sintering.
3. To give analysis of similar devices and to produce the challenges in SLS process to solve for those problems in my system and overview of my design.
4. Theoretical calculations for the process of sintering and its materials. Mechanical calculations for drive systems which are used such as gantry and lead screw manipulation for the model.
5. To produce overall work environment for the machine and catalogue the safety requirements for the machine and the worker in those environments.
6. To sketch the electric scheme of the entire machine and plan for build.
7. To review the cost for build the entire system, manufacturing and assembling process.

1. LITERATURE REVIEW

1.1. Experts view

With Additive manufacturing AM even though discovered several decades ago still it’s relatively young technology and facing the acceptance and implication problems in industries. The industries thus still not have full implementation idea of AM in several industries. Despite being, the industry getting momentum on several industries were Aerospace is planning to use at larger production scale, Automotive has already started using prototypes in the mainstream along with trust into technology is increasing. Every AM process offers full design freedom, but the manufacturers and designers should use the possibility and design the parts creatively to enable its full potential benefits. For example, “Powder Bed Fusion” PBF process enables easy manufacturing conformal channels, which would be difficult or not possible with conventional CNC machining. However, the designers should understand whether this task needs solution in AM or not. So, designing for AM requires and technical understanding of complete manufacturing cycle, including technical principle of working of AM, it’s post-processing and inspection of part, (Antonov, 2005).

1.2. Analysis of similar technology

Imagine a manufacturing technology that defies the rules itself by no compromise with complexity and accuracy. Yes, it’s AM. Despite of complexity solution to a problem, AM has its own solution in different ways. This is not a single technological and make single solution, this process but consist of several technologies which commonly called Additive Manufacturing Family. It’s divided upon several categories according to its printing material:

- plastic 3d printing;
- metal 3d printing;
- ceramic 3d printing;
- rubber material based 3d printing.

Even though it’s divided upon printing material, industries tend to separate these by its own principles of working but the name such as “material jetting” and “electron beam melting” and “Fused filament decomposition”. At some point when numerous companies evolved in this sector and patenting their technologies for both legal and for marketing purposes individual manufactures remained to intend their own terms and acronyms to refer their technology which are potentially meant same exact process. These unique trademarks and technological labels made confusion among the customers of the industries. For example, the company 3d Systems refers plastic material extrusion process as “Plastic Jet Printing (PJP)” and other companies named this as “Fused Decomposition Modelling (FDM)”, “Fused Filament Modelling (FFM)”.

1.3. Classes of additive manufacturing

In 2012, as a solution to this different trademark problems “American Society for Testing and Material (ASTM)” formalized and categorized all these technologies under seven common names by its working principle on both metals and plastics (ASTM, 2012):

- Material extrusion.
- Vat photo-polymerisation.
- Material jetting.
- Binder jetting.
- Powder bed fusion.
- Directed energy deposition.
- Sheet lamination.

Material extrusion, with the common ideology by its name, this process works by extrusion of semi-liquified plastic or metal heated spools through the heated nozzle with a specified diameter of 0.2 mm to 0.6mm and extruded on the stable or moving surface to form the first layer. After the printing surface moved either up or down to specifies length which results in layer thickness, next successive layer is build and this continues repeatedly again and again to form further layers of build and finally forms solid part model, (Shiwpursad Jasveer, 2018).

Figure 1.1. The original prusa i3 mk3s (prusa, 2018)

1 Printing material; 2 Heated build plate; 3 Extruder; 4 Control unit.

This extrusion process has significant competitors on other conventional manufacturing techniques namely “Plastic Injection Moulding”, which both technology shares advantages and disadvantages. Those several advantages and disadvantages are stated after.

This advantages and disadvantages are compared over “Fused Deposition Modeling” FDM and Injection Moulding:

Fused decomposition modelling:

- good - complex part manufacturing is possible;
- bad - low surface finish quality;
- good - standard cost-per-part;
- bad - need of support material;
- good - multi material fusion is possible.

Injection moulding:

- good - low cost mass production;
- good - uniform perfection in finished materials;
- bad - not efficient in small scale production;
- bad - need of actual moulds for injection.

Vat photo-polymerization, the generic process uses a light source (UV/Laser) to solidify a successive layer of liquid photopolymer and continue to form the next layer after recoating to bind with the pervious layer repeatedly. It is one of first 3d printing process commonly known as “Stereolithography”, “Two-photon polymerization” (BBC, 2014). Unlike others, these produce parts which overhang and some strong first support material is a must for holding, and post-processing is must for this. Advantages and disadvantages are followed by:

Advantages:

- silent process and machine not occupy large area;
- highest percent of uniformity in finished products.
- one of good surface finishes than other process.

Disadvantages:

- must of first supportive structure for hanging;
- must of post processing procedures;
- printing resin is potentially harmful when exposed to human body.

Material Jetting, it is similar to material extrusion, it’s also one of mainstream printing technology based on solidification of photopolymer liquid resins. The process started by spraying a layer of photopolymer and solidified using UV light emitted from the print head. It has one of the unique advantages of printing Nano-objects precisely up to 0.1mm in length. Some key features of advantages and disadvantages are followed by.

Key features:

- multi material is possible;
- printing NANO components is easy;
- complexity in machine managing and process itself;
- only UV resistant objects can be printed.

Binder Jetting, this contains the same working principle but differ in printing material which is metallic powdered is used here. The process begins with a layer of powder is coated, and the binding agent is applied on the required amount, and the next powder layer is recoated, which bind to the previous layer forming a perfect solid part.

Key features:

- no support material;
- post processing is needed;
- reuse of powder is possible with some procedures;
- need process of "infiltration" to seal air pockets in surface if any;
- one of quickest printing process.

Selective laser sintering/melting, this process starts with layer of powder granules is coated across sintering bed following which laser beam traces out first layer by heat generates from the laser hits powder granules causing each granules melt and fuse with adjacent granules shown in (Figure 1.2). The process is taking over again to form the next layer and build up a solid part at final (SLS, 2015).

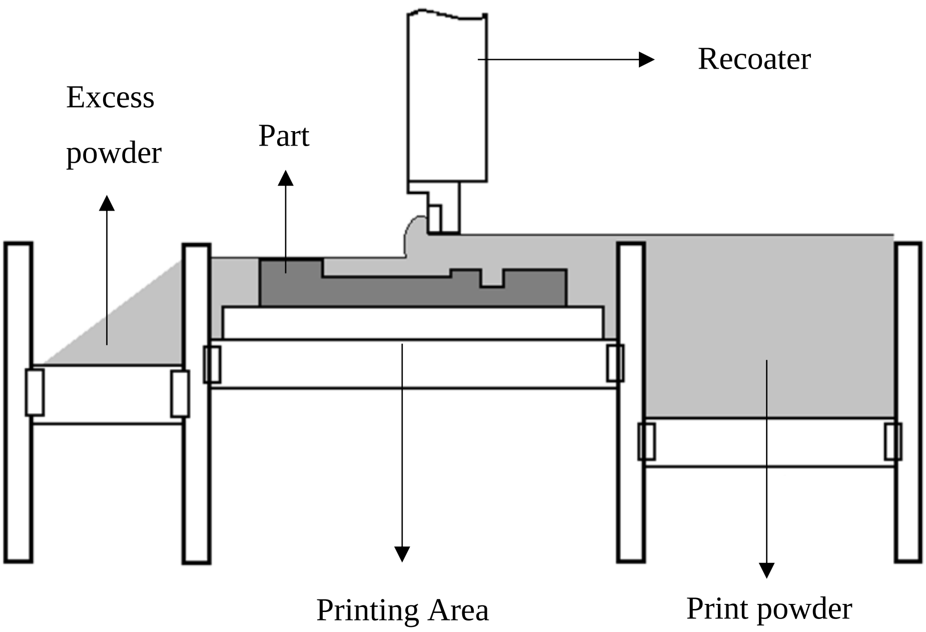

Figure 1.2. Working of SLS/SLM process (Author)

To elaborate on this process, machine consist of dispenser, printing area, Collector platform where steps are followed:

step 1:

With the motion of re-coater metal powder is coated on building platform from dispenser platform;

step 2:

Laser scans small granules and traces out the first layer to be sintered;

step 3:

Building platform gets lowered for each sintered process, and next raw granules are coated for next sintering, remaining powder transferred to the collector as we overview several processes (Sintering, 2010).

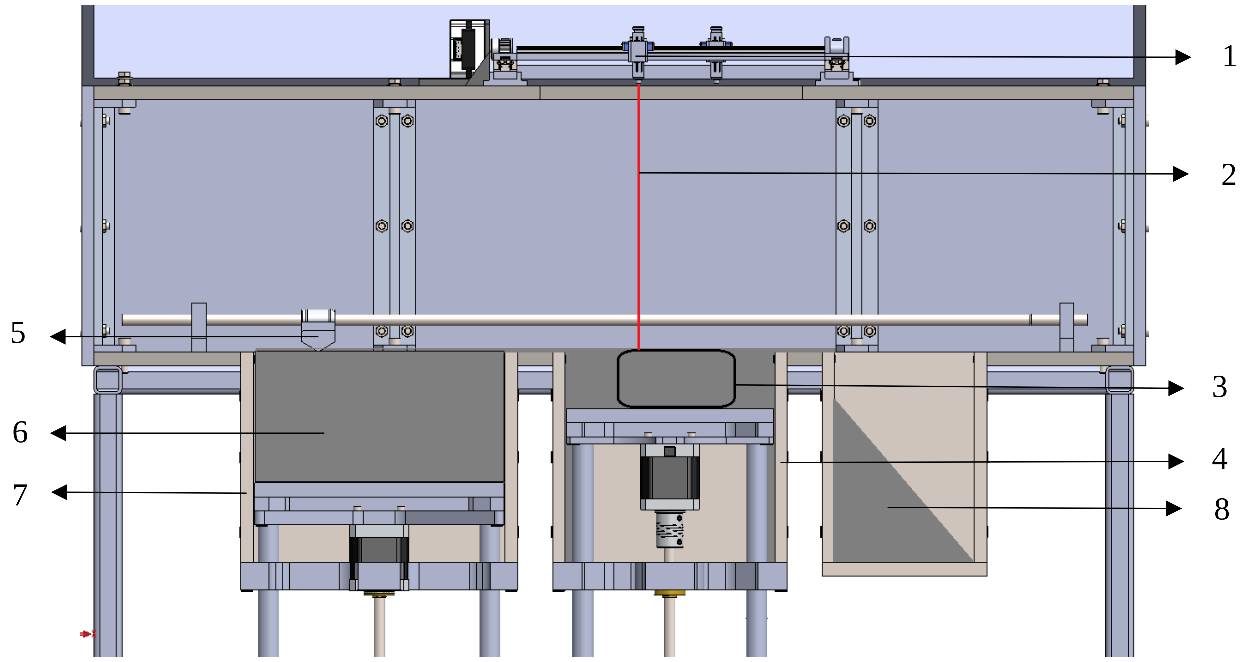

Figure 1.3. Typical parts of SLS printer

1) Laser system in gantry system; 2) Laser beam; 3) Sintered part; 4) Printing container; 5) Feeding system; 6) Unsintered powder; 7) Powder container; 8) Excess powder.

Comparisons with similar technologies as follows:

- It results in good surface finishing than other technologies. The flexibility of using multi-material and build objects form two-component powder material. Its one of the accurate processes that expand the variety of material usage from plastics to metals and polymers.
- Un-sintered powder binds with sintered part there is no need of support material preventing uses of enough material.

- A die-mould is not needed in SLS; unlike Injection Moulding, SLS can have various complex draft, and interior features.
- This SLS technology used to reduce costly tooling, which makes it an affordable choice for small series production.
- When compared to SLM were powder is completely melted which needs more input energy, thus in SLS saves energy by sintering (welding of minute granules and not by melting).
- Final products can be used directly for engineering applications in automotive or in aviation. Where not possible with other due to insufficient mechanical properties.
- By eliminating complex post-processing, SLS makes part faster manufacturing, which is important for mass production. Similar process like BJ, NPJ needs some more efforts on post-processing.

2. GEOMETRY THAT CAN BE SINTERED

With different types of manufacturing processes need different basic shape requirement for doing specific work and some have high design requirements. And these requirements aimed to make the production part more feasible and make the part more successful in reducing the production failure rates.

This geometry requirements of sintered metal parts are a consequence of the following determining conditions:

1. robust tooling;
2. design outcomes;
3. wall thicknesses;
4. feasibility of the green part;
5. gear geometries.

2.1. Robust Tooling and Design outcomes

Design for AM requires the design in the way that the process of compaction tooling makes it robust and does not fail during the process. General designing parameters are shown in (Figure 2.1), (EOS, GmbH).

	min. wall thickness	embossed and engraved details	min. vertical holes	min. horizontal holes	interlocking parts clearance	overhangs	unsupported edges	powder removal holes	min. feature size	min. pin diameter	aspect ratio	layer thickness
Polymer (PA2200)	1mm	+/- 1 mm	1,5 mm	1,5 mm	~0,5 mm	not an issue	not an issue	~10 mm	~0,5 mm	1 mm	not an issue	60 – 180 µm

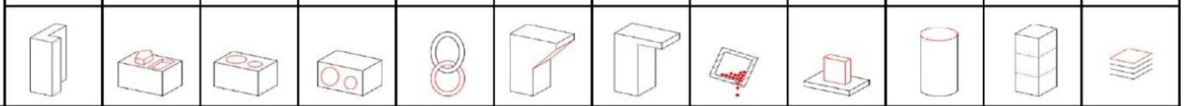

Figure 2.1. Recommendation for Design for AM. (EOS, GmbH)

Basic recommendation techniques for designing are:

- The minimum frontal holes are less than 1.5 mm in diameter.
- Minimum wall thickness should be a minimum of 1 mm.
- Overhang parts is not an issue but should have support to attach with the final part.
- If the part is closed there should be minim of 10 mm hole to get the excess powder out of the closed container.
- The layer thickness is around 60 to 180 micrometres.
- Avoid severe tooling transitions.

Design outcomes, the design geometry should be considered for ejection from the compaction tool used for sintering process also through from sizing tool. The recommended design consideration should also be taken too.

Considerations that should be taken into account:

- The support material that holds the component form ejecting (such as undercuts and holes) should be reduced.
- Introduce overhanging angles that are higher than 7°C.

(Note: that these angles can be smaller, depending on the final component).

Minimum Wall Thicknesses, In terms of design the following considerations must be taken into account:

- Wall thickness of minimum of 1 mm is required because it depends on the size of the laser beam, so the tolerated amount is 0.8 to 1.5 mm is possible.
- The powder filling in the building container is one of the essential factors that each space container should not be left as space and filled with granules.

2.2. Feasibility of the Green Part

The basic formation of the sintering process where the powder material converted to metal starts from the formation of green-part.

Green-Part, Is the bonding happens between two in the process of sintering. Which makes them more rigid and this apply for whole single layer of granules (figure 2.2). And it's one of the essential steps for sintering has several process of boding, necks, pores and boundary.

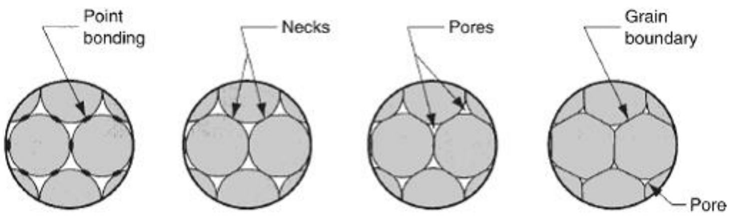

Figure 2.2. Green-Part formation. (Encyclopaedia of Engineering, Sintering).

Here, the following considerations must be considered:

- All the edges should be in some radii, and the shape colours should be avoided in the overall design.
- The ration of width and wall thickness should not be greater than 5mm.

- Flanges and other parts should contain minimum wall thickness of 2mm (sometimes changes according to design).
- It is recommended that the first layer should have some support like raft or brim so that it can withstand the part in stationary until it finishes.

2.3. Gear Geometries

While considering the making standard parts such as gears in 3d printing, there are enormous factors to be considered. Gears are one of accurate and exact ability part for running the applications smooth and more lifetime **(**Marhellabs, SLM).

Figure 2.3. Gear made by SLM process. **(**Marhellabs, SLM).

For making it clear, some of the factors are:

- All gear should be printed in a way that the axis of its should be normal to the print bed.
- The layer height should be lower as possible for higher definition and roughness.
- the laser speed should be reduced as compared to regular printing speed.

With the process of SLS and SLM other mechanical parts and tools can also be produced with increased strength. Mainly components for aviation and automotive.

3. JUSTIFICATION OF DESIGN

3.1. Analysis of similar devices

SLM125, Selective Laser Melting machine SLM125 from SLM Solutions GmbH is of market available low-cost machine from its kind perfect for the price, economic and suitable for research and development and small batch productions. It uses patented bi-directional powder re-coater movement to achieve fast build. Supporting input formats of CAD/STL and use its slicing firmware with freedom of customer setting parameters for support structure (Figure 3.1), wall thickness, etc.

Figure 3.1. Metal 3d printer (SLM-125, 2017)

1 Building chamfer; 2 Powder storage area; 3 Control unit; 4 Laser system.

The Technical Specification of this machine is shown in (Table 4.1). And Some key features are:

- high productivity using patented multi-laser technology;
- it can able to print higher quality reliable print;
- the post-processing is included in the separate compartment where air casting and other way are done to remove residual powders;
- completely sealed powder management in the inert gas atmosphere;
- highest material density and build part quality through their innovative gas steam management;
- supported materials Al-alloys, Ni-alloys, Ti-alloys, Co-alloys, Fe-alloys, Cu-alloys.

Table 3.1. SLM-125 technical specification (SLM, 2017).

Parameter	Value
Build Volume (L x W x H)	$(125 \times 125 \times 125)\ mm^3$
Laser	Single (1x400W) IPG fiber laser
Build Rate	Up to 25 cm^3 /h
Variable layer thickness	20 to 75 µm
Beam focus Diameter	70 to 100 µm
Max. scan speed	10 m/s
Inert gas	Argon
E-connection	400 volts, 3 kW
Machine dimension	$(1400 \times 900 \times 2460)\ mm^3$
Weight	700 kg

Dynamic tools ST30, is one of the professional SLS machines from Dynamic Tools GmbH, Germany (Figure 3.2). ST30 is a 3D laser sintering printer that offers professional and industrial improvements at an affordable price in a wide range of applications (Dynamic Tools, 2019).

Figure 3.2. ST-30 (DT-30, 2019)

In the (figure3.2), the systematic look of SLS 3d-Printer from “Dynamic Tools” is shown with parts of (1. Building chamfer; 2. Powder storage area; 3. Control unit; 4. Laser system). The Technical Specification of this machine shown in “Table 3.2”. (Dynamic Tools, 2015).

Table 3.2. ST-30 technical specification

Build Envelope (L × W × H)	(300 × 300 × 300) mm^3
Laser	CO_2 laser
Motion driver	Precision optics F-theta-lens
Max. Environment temperature	200℃
Speed layer	0.1 mm
Variable layer thickness	60 µm to 120 µm
Inert Atmosphere	Argon
E-connection	220-240 volt, 3kW/h
Machine dimension	(1750mm × 780mm × 1960) mm^3

This above (table 3.2) will give the overall review about the technical parameters, which is very useful to make a unique design in this 3D machine to solve the challenges in this ST-30 Printer.

3.2. Overview of my design

In regular SLS/SLM machines making a part of 50 mm^3 could take 6 to 8 hrs of production time. This is huge disadvantage of today's technical requirements, affect the possibility of mass production, increased usage of fresh powder per part.

These disadvantages can be turns as advantages by adding one more additional laser head, which results:

- doubling production capacity;
- reducing unused powder (shown in fig 3.3).

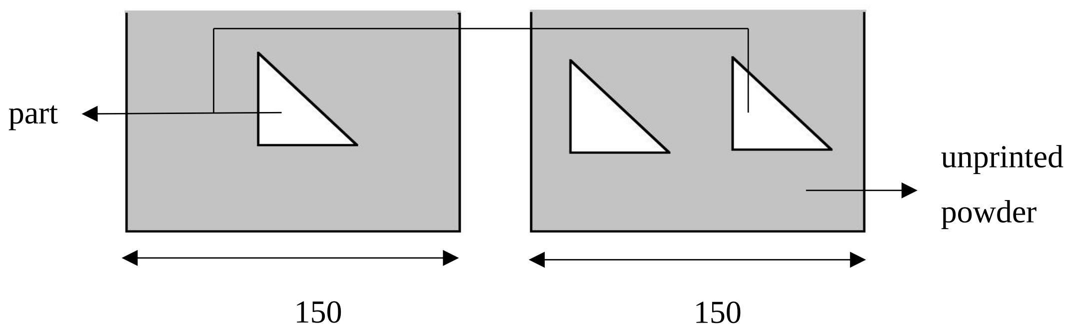

Figure 3.3. Printing multi parts with multi-laser source

In this concept by using dual printing part at same time will have significant uses of time and reduce of wastage of powders and much more. So, this concept is taken as theme and transferred to new design parameter and introduced dual printing container itself which shown in (figure 3.4).

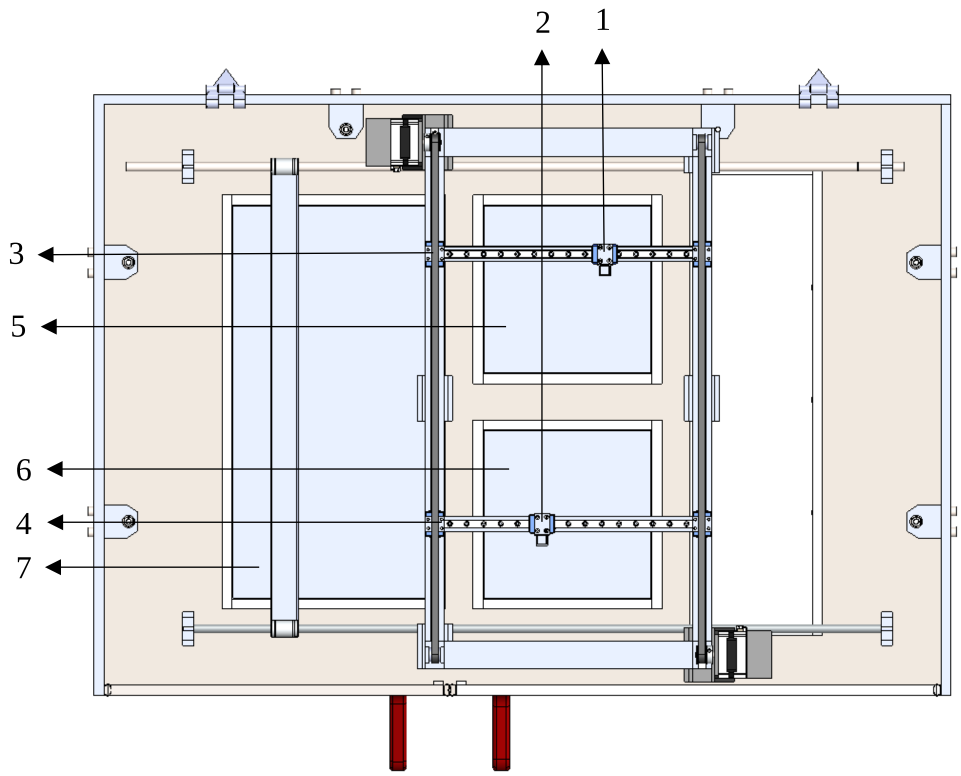

Figure 3.4. Twin Laser printing scheme (Author, 2019)

1) Laser 1 x-axis; 2) Laser 2 x-axis; 3) Laser 1 y-axis; 4) Laser 2 y-axis; 5) Printing container-1; 6) Printing container-2; 7) Feeding system.

In the (figure 3.3) it’s shown when the number of parts increases in the same single chamfer unit, the usage of unused powder area is lowered results in less wastage (Kruth, 2005).

For easy manipulation and eliminating motion complexity, Control Unit Arduino mega 2650 Rav-3 is used with shield Ramps 1.4 board. To control micro stepping Stepper driver A4988 is used.

According to stepper motor power print volume of 100 mm^3 is chosen with the high-performance CO_2 laser.

Printing specification:

- print volume of (300 × 300 × 300) mm^3;
- laser   high performance CO_2 laser;
- maximum environment temperature 200℃.

Control system specification:

- control Unit Arduino mega 2650;
- shield board Ramps 1.4;
- stepper driver A4988 is used.

Motion system:

- source from NEMA-17 stepper motor;
- timing belt GT2 for *X* and *Y* axis of laser movements;
- lead screw T8 for Re-coater manipulation.

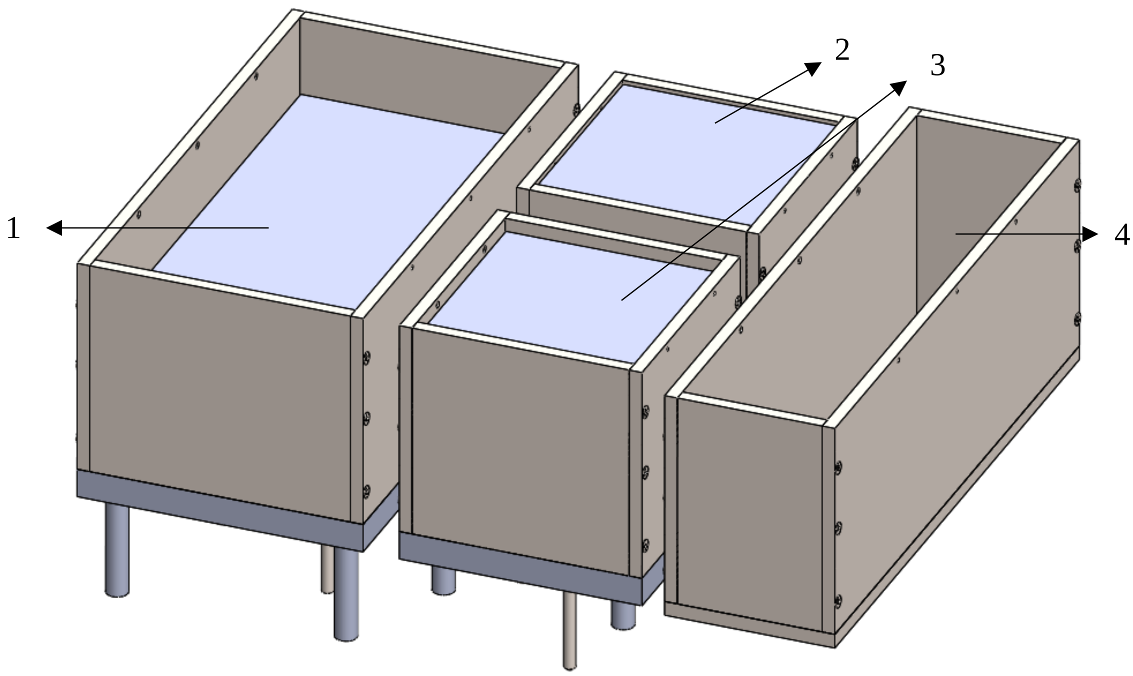

Figure 3.5. Container placement in this machine
1) Powder container; 2) Printing container-1; 3) Printing container-2; 4) Excess powder container.

For linear motion drive system timing belt drive and lead screw is used for laser movements, re-coater and build chamfer movements. The overall aim is to make industrial quality printing technology under a low-cost machine system without compromising in quality (Rechtenwald, 2004).

4. PROCESS AND CALCULATION OF SINTERING

4.1. Steps for sintering

To achieve the process of sintering and get the quality sintered parts and components, the process undergoes varies steps and procedures which need more accuracy in processing and study of parts that are gone to be sintered. The following procedures are:

a) blending;

b) compaction;

c) sintering.

Blending, In Blending process, the powdered metals are blended with an iron-based powder additive mix material. On the context of properties required for alloying elements and additives are added. Some lubricant is also mixed sometimes; the lubricant is needed in order to reduce the friction between the powder granules for easy sintering. Because of this blending process, the uniform mixture is achieved and provides the required mix for properties of sintered material.

Compaction, is the process where the powder which is going to be sintered in the powder container will be axially loaded in the required amount to get the thickness. The needed amount of powder is pre-calculated and the delivered in the powder container. The filing device is used to fill the powder material to the feeder system with force between 400 to 800 Mpa. Because of this initial compaction, the green part formation has a significant role in this, resulting around 85 %to 95 % formation. Also, this process has a considerable effect on the pars support structure and the shrinkage of the part itself and keeping the part in a stationary position by increasing the density of the granules.

This compaction process has a tendency for allowing a wide range of aspects and design flexibility.

Sintering, in the process of compaction where the materials are already reached the required stage of mechanical properties and the ready to for green-part. Now the heat treatment process starts in a controlled atmosphere; the atmosphere is controlled with inert gases to reduce the oxidation of parts and materials is heated below the melting temperature.

During the process of sintering green-part formation starts by visible of diffusion bonds by each granules resulting in increased strength to its original material. By this process, many parameters could have the chance such as shrinkage and uneven formation. After the process of sintering the parts tends to cool down, cool down process is one of critical stage where it not get too fast nor too slow. The cooling rate is directly affects physical properties of the part itself. This sintering process can be further explained in detailed way as in the name of Furnace zone.

The Furnace:

In the Furnace zone where the actual sintering process is going to take place and consist of three stages as follows as:

a) pre-heating;
b) sintering;
c) cooling.

Pre-heating:

Here, the lubricant melts, exudes to the surface or vaporizes. Note that an in-adequate de-lubrication can lead to blistering of parts in the Sintering or Hot Zone.

Sintering:

This part is commonly known as “Hot Zone”. Here the oxides in the controlled atmosphere is reduced and the diffusion process takes place in which the powder particles bond.

Cooling:

The part undergoes cooling processes in which the ingress of air and the oxidation of parts are prevented.

4.2. Actual process

According to the past theoretical and analogical procedures for the process of Sintering, we should specify the details of powered *(printing material)* to be sintered then we can obtain the further required calculations for the procedure.

For this experiment, the Powder Material: Nylon PA12 is used which has the melting point of 185℃ the further properties are as shown below:

- specific heat : 1.185 kJ/kg·k;
- sintering temperature : 178℃;
- density of powder : 0.00101 g/mm^3;
- thermal conductivity : 0.26.

The melting point or the point of temperature where the particle bonding takes place in the area after the spectrum building temperature which is denoted in T_{pm} (Figure 4.1).

So We need to calculate amount of powder going to be sintered at a single point of time. In our specification, we are using CO_2 laser of 445 nm of maximum 1W power. The beam width is 0.5mm So, the area of hitting plane of 0.5 mm width of the beam.

While Sintering the goal is to melt the PA 12 granules lower to melting point which results in formation of neck (figure 2.2), (Encyclopaedia of Engineering, Sintering).

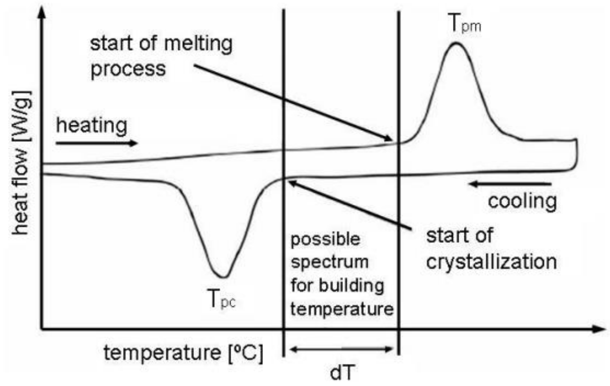

Figure 4.1. DSC-Curve for melting and crystallization of PA12 (Salmoria, 2007).

The flow and sintering rate will be less, resulting in a lower degree of consolidation, higher porosity, less strength, but also a lower shrinkage that is favourable in cases of SLS of patterns for producing mould for moulding or casting (i.e. Indirect Rapid Tooling, investment casting patterns, etc.).

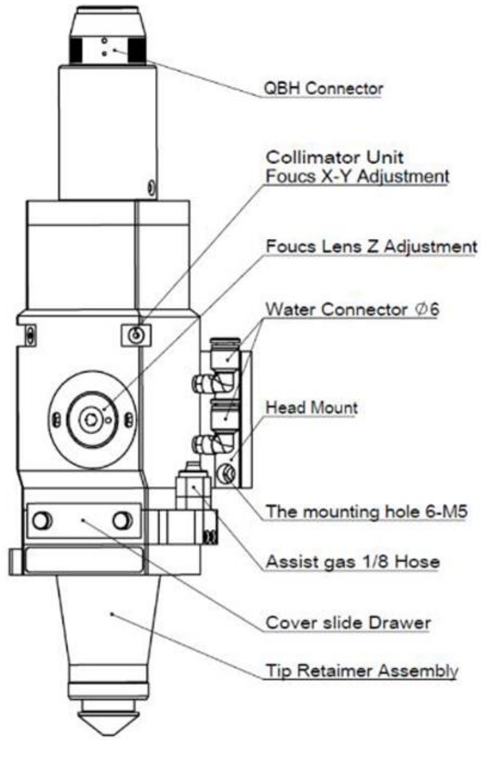

Figure 4.2. D-B1000 laser system from Shenzhen Optlaser (D-B1000, 2015).

The Primary technical parameters of this chosen laser to be perfectly aligned with our required current data, which is powered as 1W in 445 nm wavelength, so this laser is used for the sintering purpose.

This following table contains the entire technical parameters of chosen laser provided by the manufacturer. As this laser system uses manual voltage regulator, which is must require for our system this suits perfectly for our process of sintering of Nylon PA-12 materials.

Table 4.1. Technical parameters of D-B1000 Laser system (Shenzhen Optlaser, 2015)

Item	**Project**	**Technical parameters**
1	Laser Wavelength	445±5nm
2	Output power	＞1000mW
3	Laser Classification	Class 4
4	TTL output power	＞1K HZ Output power at work = Continuous power × 40%
5	Output stability	±5%
6	Beam Mode	Circular spot
7	Focus spot size	≤0.5mm
8	Lens material	Professional focusing optical glass
9	Beam divergence	<2mrad
10	Power board input voltage	DC 12 volt
11	LD Input voltage	5.6 volt
12	LD Input Current	1.7A
13	Modulation mode	TTL/Analog
14	TTL trigger mode	Active high（>DC 2.0 volt）
15	Working frequency	<30KHz
16	Analog control input voltage	DC 0 volt to 5.0 volt
17	Ambient temp	15℃ to 50℃
18	Preheating time	<1 Minute
19	Working life	>10000 Hours
20	Product weight	40g

As we have chosen the required laser, the next part is finding the bonding requirements of materials which are calculated in following procedures. The higher porosity is also favourable to avoid breaking the ceramic investment casting shell when heating the SLS pattern during the rebinding cycle intended to release the mould cavity. In several applications, post-infiltration of the pores of the SLS part is applied to consolidate it, (Kruth, 2005).

The actual process of sintering is mentioned and the formation of green particles or also known as bonding formation is detailed in microscopic view. The material is in powder form with a certain particle size distribution shown in (*Figure 4.3*).

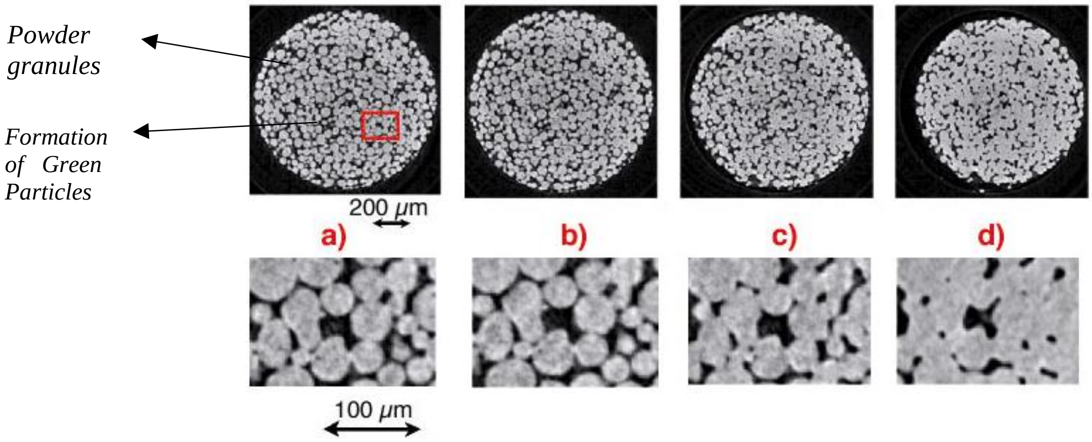

Figure 4.3. Microscopic view of bonding formation of SLS process (ESRF, 2005)

And the induced energy, heating the fine powder particles, may lead to evaporation or disintegration, which in turn disturbs the process. It shields off the laser window and the IR heating elements. In short, this has a negative influence on the process consistency and the economy of the process. Further, the fine particles may create either a dusty atmosphere or coagulations clustering preventing the homogeneous deposition of layers, thus preventing right layer consolidation. (Zhao M, 2015).

Activated spot area *SA* can be calculated by surface area formula and the concluded SA formula of the formula Spot Area is:

$$SA = \pi r^2; \tag{4.1}$$

by keeping the constant π as 3.141 and the surface radius as 0.25 (i.e. Beam diameter is 0.5 mm) the calculated *SA* is,

$$SA = 3.141 \times (0.25^2) = 0.19635 \text{ mm}^2.$$

We are keeping the layer height to 0.5 mm, by having the layer height as depth and SA as area the total Activated Volume *"SV"* will be calculated through volume formula:

$$\text{Spot Volume } SV = \pi r^2 \times h. \tag{4.2}$$

Here the r is known as radius of Spot Area SA and the height is depth, which is layer height, 0.25 mm in our case. The Spot Volume SV is then calculated:

$$SV = 3.141\times (0.25^2) \times 0.5 = 0.09817 \text{ mm}^3;$$

For finding the time for melting one layer of powder which is known as "Spot volume exposure"- SE is (we keep Feed rate as 30 mm/s):

$$\text{Spot volume exposure } SE = \text{beam diameter} \times \text{Feed rate}; \tag{4.3}$$

$$\text{SE} = 0.5 \times 30 = 0.0167 \text{ sec};$$

So, each surface are should have laser effect for 0.0167 seconds on them for perfect sintering. So total Activated mass is calculated to find the power required for heat the following formula will do the specific area and this:

$$m = \text{Spot Volume} \times \text{Density}; \tag{4.4}$$

$$m = 0.09817 \times 0.00101 = 0.0000991517 \text{ g}.$$

As we obtained the Active Mass that to be sintered at single point of time, by going further the energy can be calculated by formula of Energy calculation and the required thermal Energy chance is followed by:

$$Q = mc \times \Delta T; \tag{4.5}$$

Here the m is Active Mass, *'c'* is constant, and *'T'* is the Temperature change.

$$Q = 99.1517 \times (10^{-6}) \times 1.185 \times 185 = 0.0217 \text{ J}.$$

The total energy required for sintering the specified area is 0.0217 Joules. By keeping this data, the power requirement can be calculated by following equations.

Power required

$$P(\text{W}) = Q\ (\text{J}) / t\ (\text{s}); \tag{4.6}$$

here 'Q' is Energy and *'t'* is time in seconds from which the power is calculated.

The calculated power is:

$$\text{Power } P = 0.0217 \times 0.05 = 0.434 \text{ Watt.}$$

At the end we got the major data requirements for the sintering process which we have to choose the perfect laser system to match our obtained values. The D1000 Laser system of 1W power is more than enough for our application. This laser system works in 12v DC power supply and other parameter of the laser system is shown in the following (table 4.2).

Table 4.2. Electrical parameters of D-B1000 Laser system.

Item	Project	Technical parameters
1	Input voltage	DC 12V
2	Input power	20.4W（12V/1.7A）
3	Output current	LD<2A
4	Constant current accuracy	Output current stability less than 1%， Output ripple is less than 100mV
5	Drive and power connection	22 AWG
6	TTL input maximum voltage	DC 5 volt
7	TTL input response voltage	DC 2.0 volt
8	LD output waveform	

This laser system is placed in our gantry system. As we have the two building are the combination of same laser is used for both of build platform. And these two lasers are connected to our machine which has the single linear guide ways manipulation system. Gantry calculations and specification are as followed.

4.3. Linear Guide Calculation

First, the X-axis: gantry system is calculated and this applies for both of the laser systems as both have same physical requirements. So this calculation will conclude the requirements for single laser module. The actual mass which will be in motion is 0.35 kg in X - axis rail guide. Required acceleration is A = 0.08 m/s^2. so, the force is:

$$F = m \times a; \tag{4.7}$$

$$F = 0.35 \times 0.1 = 0.035 \text{ N}.$$

Torque calculation:

$$T_X = \frac{F \times d}{2 \times \eta \times i}; \tag{4.8}$$

where, the parameter are chosen from (B&B Manufacturing, Belt Length Calculator):

- F – force (N);
- d - Pully pitch diameter (mm);
- η – Efficiency in percentage;
- i – Pully ratio (which is 1 in this case).

$$T_X = \frac{0.035 \times 12.7}{2 \times 0.9 \times 1} = 0.2479 \approx 0.25 \text{ Nm}.$$

The required torque of the guideway requirement is obtained which is 0.25 Nm by keeping this data the Timing belt is chosen as followed.

4.4. Timing Belt

As we need feed rate greater than 30 mm/s (from equation 4.3), we are choosing the maximum velocity of 0.1 m/s for safe. So, the required maximum speed velocity is v = 0.1 m/s and acceleration a = 0.08 m/s^2. Due to same diameter from either end pully for our gantry system the pully ratio i = 1.

Each laser is 75 g of weight and the beam has 100g of weight so the total mass to be in motion is 0.350 kg.

We need to find total force to move the component, so the total force is summation of pull force F_m and frictional force F_f is calculated.

Opposing force due to friction is product of mass, frictional factor and gravity so,

$$F_f = m \times \mu \times g; \tag{4.9}$$

where, m is mass, g is force due to gravity, μ is friction coefficient.

Motional force is

$$F_m = m \times a = 0.350 \times 0.08 = 0.028 \text{ N}.$$

The frictional factor μ for the chosen bearing is 0.002, mass is 0.35 kg and gravity g = 9.81 constant. Total force is:

$$F_t = F_m + F_f. \tag{4.10}$$

$$F_t = 0.006867 + 0.028 = 0.0348 \approx 0.035 \text{ N}.$$

The operational and acceleration factor C_2 chosen as 1.4 so, the total force is from the (equation 4.1),

$$\text{max force required } F_{m\,max} = 0.035 \times 1.4 = 0.049 \text{ N},$$

so total maximum force required is 0.049 N. Teeth mesh factor C_1 = 10 for open material. Pitch diameter = 12.7 mm and number of teeth is 20:

$$F_{U\,req} = \frac{F_{m\,max}}{C_1} = \frac{0.049}{10} = 0.0049 \text{ N}; \tag{4.11}$$

$$\text{Calculated rpm is} = \frac{0.1 \times 19.1 \times 10^3}{d_0\,(mm)} = 150.4 \approx 151 \text{ min}^{-1}. \tag{4.12}$$

By having the required rpm and the Maximum force the Belt is chosen from the Standard belt systems. As this case the maximum rpm is about 150 min^{-1} So, I am choosing GT2 belt of 2 mm pitch and 5 mm thickness is more than enough for our application.

4.5. Feeder Lead Screw Calculation

For selecting the Lead Screw, the following data requirements are taken from the previous results and our design systems.

For the vertical applications, the torque is very important for determining whether the load will fall with its weight or if the ball screw assembly provides enough resistance to hold the load in place when no brake is applied. (Figure 4.4) Shows the vertical system for calculation of ball screw All parameters are calculated according to (THK A-679 Global Solution, 2018).

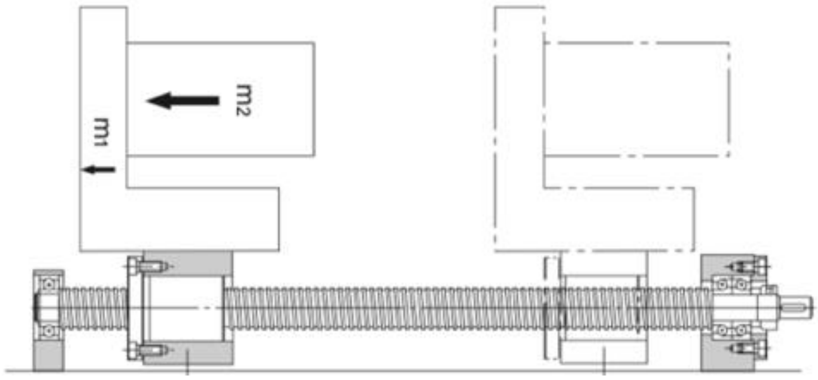

Figure 4.4. The vertical conveyance system calculation

The known parameters for the ball screw are very important to calculate the selection of ball screw and the motor. (Table 4.3) Shows the known parameters for our machine.

Table 4.4. Parameters to be considered for vertical conveyance

Parameter	Value	Units
Table mass (m_1)	5	Kg
Work mass (m_2)	2	Kg
Stroke length (l_s)	600	mm
Maximum speed (V_{max})	0.3	m/s
Time for Acceleration (s)	0.2	s
Deceleration time (s)	0.2	s
Backlash	0.1	mm
The friction coefficient of the guiding surface (μ)	0.003	---
Guide surface resistance	20	N
Motor Inertial moment (J_m)	5×10^{-5}	$kg.m^2$

Selecting the Lead Angle Accuracy: to achieve a positioning accuracy of ± 0.7 mm/600 mm.

$$\frac{\pm 0.7}{600} = \frac{\pm 0.35}{300} \ ;$$

The lead angle accuracy should be ±0.35 mm/300 mm or greater. Therefore, the accuracy of the ball screw in (figure 4.4) needs to be C10.

Table 4.3. Accuracy grade selection for ball screw

		Precision Ball Screw												
												Rolled Ball Screw		
Accuracy grades		C0		C1		C2		C3		C5		C7	C8	C10
Effective thread length		Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Travel distance error	Travel distance error	Travel distance error
Above	Or less													
—	100	3	3	3.5	5	5	7	8	8	18	18			
100	200	3.5	3	4.5	5	7	7	10	8	20	18			
200	315	4	3.5	6	5	8	7	12	8	23	18			
315	400	5	3.5	7	5	9	7	13	10	25	20			
400	500	6	4	8	5	10	7	15	10	27	20			
500	630	6	4	9	6	11	8	16	12	30	23			
630	800	7	5	10	7	13	9	18	13	35	25			
800	1000	8	6	11	8	15	10	21	15	40	27			
1000	1250	9	6	13	9	18	11	24	16	46	30	±50/300mm	±100/300mm	±210/300mm
1250	1600	11	7	15	10	21	13	29	18	54	35			
1600	2000	—	—	18	11	25	15	35	21	65	40			
2000	2500	—	—	22	13	30	18	41	24	77	46			
2500	3150	—	—	26	15	36	21	50	29	93	54			
3150	4000	—	—	30	18	44	25	60	35	115	65			
4000	5000	—	—	—	—	52	30	72	41	140	77			
5000	6300	—	—	—	—	65	36	90	50	170	93			
6300	8000	—	—	—	—	—	—	110	60	210	115			
8000	10000	—	—	—	—	—	—	—	—	260	140			

Assuming the length of the screw shaft. Assuming the maximum nut length to be 100 mm and the ball screw shaft end length to be 100 mm. Therefore, the total length is determined as follows based on the stroke length.

$$600 + 200 = 800.$$

Thus, the shaft length is assumed to be 800 mm. Selecting the ball screw lead with the stepper driving motor's rated rotational speed being 3000 min^{-1} and the maximum speed 0.3 m/s, for the Ball Screw lead is obtained as follows:

$$\frac{0.3 \times 60 \times 1000}{3000} = 6 \text{ mm}.$$

Therefore, it is important to choose a type with lead 6 mm or longer. In addition, the Ball Screw and the motor can be mounted in direct coupling without using a reduction gear.

The minimum resolution per revolution of an AC servomotor is obtained based on the resolution of the encoder.

To achieve the minimum feed amount of 0.010 mm/pulses, which is the selection requirement, the following should apply (table 4.5).

Table 4.4. Lead and speed selection requirement

Lead	Speed
6 mm	3000 p/rev
8 mm	4000 p/rev
10 mm	1000 p/rev
20 mm	2000 p/rev

However, we select the lead of 10mm and not more than that because of larger the lead larger the torque and cost.

Selecting the Screw Shaft Diameter:

Those ball screw models that meet lead being 10mm as described in section. Selecting the screw shaft on (Figure 4.6) are as follows.

Table 4.5. Screw shaft diameter selection

Screw shaft outer diameter	Lead																			
	1	2	4	5	6	8	10	12	16	20	24	25	30	32	36	40	50	60	80	100
6	●																			
8		●																		
10		●			○															
12		●				○														
14			●	●																
15							●			●			●							
16				●					●											
18						●														
20				●			●			●						●				
25				●			●					●					●			
28					●															
30																		●		
32							●							●						
36							●			●	●				●					
40							●									●			●	
45								●												
50									●								●			●

Accordingly, to the data of shaft diameter of 10 mm and lead 10 mm is selected and calculated.

Selecting the Screw Shaft Support Method: as we assumed the Screw has a stroke length of 600 mm and operated at the 0.3 m/s maximum speed of (Ball Screw rotational speed: 1,800 min^{-1}), select the fixed-supported configuration for the screw shaft support.

Calculating the maximum axial Load: the required parameters are taken from design requirement, where velocity maximum is 0.3 m/s and acceleration time is t_1 = 0.2s for moving table mass m_1 = 5 kg and work material mass m_2 = 2 kg. Guide surface resistance f = 20N (without load), $\alpha =$ Acceleration m/s^2:

$$\alpha = \frac{V_{max}}{t_1} \; ; \tag{4.13}$$

$$\alpha = \frac{0.3}{0.2} = 1.5\,\mathrm{m}/s^2 \; ;$$

during acceleration:

$$Fa_1 = (m1 + m2) \times g + f_t + f + (m1 + m2) \times \alpha; \tag{4.14}$$

$$Fa_1 = 99.17 \text{ N};$$

during uniform motion:

$$Fa_2 = (m_1 + m_2)g + f_t + f; \tag{4.15}$$

$$Fa_2 = 88.67 \text{ N};$$

during deceleration:

$$Fa_3 = (m_1 + m_2)g + f_t + f - (m_1 + m_2) \times \alpha; \tag{4.16}$$

$$Fa_3 = 78.17 \text{ N}.$$

Thus, the maximum axial load is applied on the ball screw is as follows:

$$Fa_{max} = Fa_1 = 99.17 \text{ N};$$

(Note: as the lead screw is horizontal these values are applicable to backward motion too).

Buckling load on screw shaft: factors according to the mounting method, $\eta_2 = 20$ is selected as it is fixed – fixed (Table 4.7.).

Table 4.6. Mounting method for linear screw

Mounting method	η_1	η_2
Fixed- free	0.25	1.3
Supported - supported	2	10
Fixed - fixed	4	20

Distance between two mounting surfaces $l_a = 600 + 100 = 700$ mm (estimate)
Screw shaft minor diameter $d_1 = 12.5$ mm:

$$P_1 = \eta_2 \times \frac{{d_1}^4}{{l_a}^2} \times 10^4. \quad (4.17)$$

$$= 20 \times \frac{12.5^4}{700^2} \times 10^4 = 9960 \text{ N};$$

so the total buckling load from above calculation is 9960 N of total.

Allowable tensile and compressive load of the screw shaft: Thus, the buckling load and the permissible compressive and tensile load of the screw shaft are at least equal to the maximum axial load.

$$P_2 = 116 \times d_1; \quad (4.18)$$

where: $P_2 =$ Permissible compressive and tensile load in N;
$d_1 =$ screw shaft thread minor diameter in mm;

$$P_2 = 116 \times 12.5^2 = 18100 \text{ N};$$

therefore, a Ball Screw that meets these requirements can be used without a problem.

Maximum rotational speed: screw shaft diameter: 10 mm, lead: 10 mm, maximum speed $v_{max} = 0.3$ m/s.

$$N_{max} = \frac{V_{max} \times 60 \times 10^3}{ph}; \quad (4.19)$$

$$N_{max} = 1800 \text{ min}^{-1}.$$

Calculating permissible rotational speed determined by critical speed, N_1 (min^{-1}): mounting method Factor according to manufacturer, $\lambda_2 = 15.1$ (See table 4.8).

Distance between two mounting surfaces, $l_b = 700$ mm. Screw minor diameter, $d_1 = 12.5$ mm.

Table 4.7. Mounting method for vertical conveyance, Permissible speed

Mounting method	λ_1	λ_2
Fixed- free	1.875	3.4
Supported – supported	3.14	9.7
Fixed – supported	3.92	15.1
Fixed – fixed	4.73	21.9

$$N_1 = \lambda_2 \times \frac{d_1}{l_b^2} \times 10^7 = 15.1 \times \frac{12.5}{700^2} \times 10^7 = 3852 \text{ min}^{-1}; \quad (4.20)$$

permissible rotational speed, the screw shaft diameter is 10 mm; lead is 10 mm (from table 4.6):

$$N_2 = \frac{70000}{D} = \frac{70000}{15.75} = 4444 \text{ min}^{-1};$$

Selecting a "Nut model": the rolled screw with a screw shaft diameter of 10 mm and lead of 10 mm is the following large – lead rolled ball screw model "BLK1510-5.6". Basic static load rating, $C_0a = 25.2$ kN.

Calculating the permissible axial load, assuming that the impact load is applied during acceleration and deceleration, set the static safety factor (f_s) at 2 since our system runs in medium speed, (table 4.9).

$$Fa_{max} = \frac{C_0a}{f_s}; \quad (4.21)$$

$$Fa_{max} = \frac{C_0a}{f_s} = \frac{25.2}{2} = 12600 \text{ N}.$$

From above calculation we got the permissible axial load of 12600 N on total.

Table 4.8. Static safety factor for bearing

Vibrations/impact	Speed (V)	f_s / f_w
Faint	Very low, $V < 0.25\ m/s$	1 to 1.2
Weak	Slow, $V\ 0.25 - 1\ m/s$	1.2 to 1.5
Medium	Medium, $V\ 1 - 2\ m/s$	1.5 to 2
Strong	Medium, $V > 2\ m/s$	2 to 3.5

The obtained axial load is greater than the maximum load of 99.17 N, and therefore, there will be no problem with this model.

Calculating the travel distance: from the (table 4.3) we get the required parameter for calculating travel distance for each part:

maximum speed $V_{max} = 0.3\ \mathrm{m/s}$;

travel distance during acceleration is:

$$l_{1-4} = \frac{V_{max} \times t_1}{2} \times 10^3\ ; \tag{4.22}$$

$$= \frac{0.3 \times 0.2}{2} \times 10^3 = 30\ \mathrm{mm};$$

travel distance during uniform motion:

$$l_{2-5} = l_s - \left(\frac{V_{max} \times t_1 + V_{max} \times t_3}{2}\right) \times 10^3\ ; \tag{4.23}$$

$$= 600 - \left(\frac{0.3 \times 0.2 + 0.3 \times 0.2}{2}\right) \times 10^3 = 540\ \mathrm{mm}\ ;$$

travel distance during deceleration:

$$l_{3-6} = \frac{V_{max} \times t_3}{2} \times 10^3; \tag{4.24}$$

$$= \frac{0.3 \times 0.2}{2} \times 10^3 = 30\ \mathrm{mm};$$

So we get the acceleration for each part of motion (accelerating, uniform and decelerating) and detailed in this (table 4.10):

Table 4.9. Travel distance for each part of motion.

Motion	Applied axial force Fa_n (N)	Travel distance l_n (mm)
During acceleration	99.17	30
During uniform motion	88.67	540
During deceleration	78.17	30

Average Axial Load: for calculating average axial load from the data calculated before from the (table 4.10), we get 75 N,

$$F_m = \sqrt[3]{\frac{1}{2 \times l_s}\left(\sum Fa_n{}^3 \times l_n\right)} = 74.1984 \text{ N } \approx 75 \text{ N.} \tag{4.25}$$

Nominal Life: for calculating the normal life from dynamic load rating $C_a = 9800$ N and load factor $f_w = 1.5$, average load $F_m = 75$ N **(**from table 4.9),

$$\text{Nominal Life } L = \left(\frac{C_a}{f_w \times F_m}\right)^3 \times 10^6; \tag{4.26}$$

$$= \left(\frac{9800}{1.5 \times 75}\right)^3 \times 10^6 = 6.826 \times 10^{11} \text{ rev}.$$

Average Revolutions per Minute can be calculated from the following formula, l_s and P_h are from (table 4.3 and table 4.6).

$$\text{Avarage revolution } N_m = \left(\frac{2 \times n \times l_s}{P_h}\right)^3 ; \tag{4.27}$$

$$= \left(\frac{2 \times 5 \times 600}{10}\right)^3 = 600 \text{ min}^{-1} ;$$

calculating the Service Life Time on the Basis of the Nominal Life,

$$L_h = \frac{L}{60 \times N_m} = \frac{6.8268 \times 10^{11}}{60 \times 600} = 190 \times 10^4 \text{ hrs} ; \tag{4.28}$$

calculating the Service Life in Travel Distance on the Basis of the Nominal Life,

$$L_s = L \times P_h \times 10^{-6} = 6.83 \times 10^8 \text{ kms.} \tag{4.29}$$

With all the conditions stated above, model BLK1510-5.6 satisfies the desired service life time of nearly 190×10^4 hrs and can run for 6.83×10^8 kms from service life calculation.

Frictional torque cause of external load: the friction due to external load is used to find the maximum top friction hold in the bearing due to internal and external force is calculated this gives prediction of failure and extend the boundary for effective working of the feeding system.

$$T_t = \frac{Fa_2 \times Ph}{2 \times \pi \times \eta}; \tag{4.30}$$

$$= \frac{88.67 \times 10}{2 \times \pi \times 0.9} = 156.80 \text{ N. mm.}$$

Torque Required for Acceleration: since the inertial moment per unit length of the screw shaft is 3.9 x 10^{-4} kg•cm^2/mm the inertial moment of the screw shaft with an overall length of $l_b =$ 800mm is obtained as follows.

The inertial moment per unit length of the ball screw is 5×10^{-5} kg • cm^2/mm

$$J_s = J_L \times l_b = 0.312 \times 10^{-4} \text{ kg. m}^2. \quad (4.31)$$

From above equation the inertial moment of screw is calculated.

$$J = (m_1 + m_2) \times \left(\left(\frac{Ph}{2 \times \pi}\right)^2 \times 10^{-6}\right) + J_s\,; \quad (4.32)$$

$$= 4.89 \times 10^{-5} \text{ kg. m}^2.$$

For our overall length the calculated inertial moment is 4.89×10^{-5} kg. m^2 for calculating the overall torque required in each part of motion the following formula is used. Calculation of angular acceleration:

$$\omega' = \frac{2\pi \times N_{max}}{60 \times t_1}; \quad (4.33)$$

$$= \frac{2 \times 3.1416 \times 1800}{60 \times 0.2} = 942 \text{ rad/s}^2;$$

- T_n – nominal torque.
- T_m – torque for uniform motion.
- T_d – torque for deceleration.

The required nominal Torque is (equation 4.29):

$$T_n = (J + J_s)\omega'; \quad (4.34)$$

$$= (4.89 \times 10^{-5} + 0.312 \times 10^{-4}) \times 942 = 93.2404 \text{ N. mm.}$$

During acceleration:

$$T_a = T_t + T_n = 157 + 93 = 250 \text{ N. mm.} \quad (4.35)$$

During uniform motion:

$$T_m = T_t = 156.8 \text{ N. mm.}$$

During deceleration:

$$T_d = T_t - T_n = 157 - 93 = 64 \text{ N.mm.} \tag{4.36}$$

Load inertial moment is calculated using motor sizing online calculator with the obtained values from the ball screw calculation (Oriental motor selection calculator, 2019). Obtained values are:

- Inertial moment,
- required speed, $V_m = 1000$ rpm;
- required stopping accuracy, $\Delta\theta = 18°$.

$$J_L = 5 \times 10^{-5} \text{ kg.}\frac{\text{cm}^2}{\text{mm}} \text{ ;}$$

Therefore, the rated torque of the motor must be 250 N.mm or greater (from eaquation 4.34). Rotational speed: since the Ball Screw lead has been selected based on the given rotational speed of the motor:

maximum working rotational speed: 1800 min^{-1};

rated rotational speed of the motor: 3000 min^{-1}.

Normally, the motor needs to have an inertial moment at least one-tenth of the inertial motor applied to the motor, although the specific value varies depending on the manufacturer. Therefore, the inertial moment must be 4.89×10^{-6} kg.m^2 or greater.

We select lead screw of length 600 mm, diameter 10 mm and a lead of 10mm. So we will select Neema-17 motor as we have calculated the required torque, rpm and inertial moment required for our *Z*-axis. Thus, the selection is completed.

4.6. Deflection calculation

The deflection of the beam of laser shaft for the both axis *X* and *Y* Axis are calculated at the maximum value at the centre of the beam of 200 mm shaft of 5 mm diameter of total force of applied weight.

In laser gantry system the weight of each systems as follows:

- First laser system m_1 = 350 g.
- Second laser system m_2 = 350 g.
- 4 × Mass of roller bearing = 4 × 37.5g = 150 g.
- 2 × mass of X axis stepper motor = 2 × 50 = 100 g.

So, the total mass is:

$$m = 350 + 350 + 150 + 100 = 950 \text{ g}.$$

We purpose of goodness it's considered as 1000 g which is the total for acting at the centre of beam is:

$$P = m \times g; \tag{4.37}$$

$$P = 1 \text{ kg} \times 9.81 = 9.81 \text{ N} \approx 0.01 \text{ kN}.$$

The force P is directly acting to the centre of the beam.

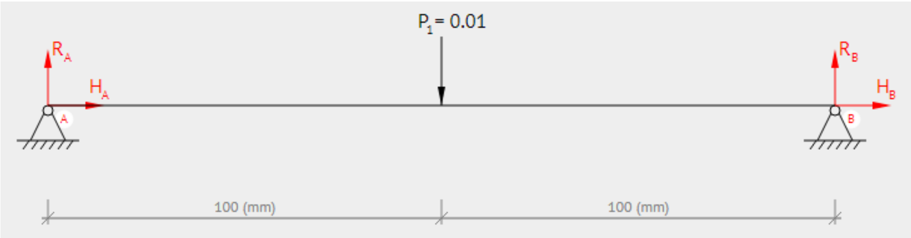

Figure 4.5. Kinematical diagram of gantry shaft

By Macaulay's method,

$$B_{MX} = EI\frac{d^2y}{dx^2} = 5 \times 10^{-3} \times (-0.01) \times (-0.1); \tag{4.38}$$

Integrating with double integration:

$$EI\frac{dy}{dx} = 5 \times 10^{-3}\frac{x^3}{6} - \frac{0.01}{6}(x - 0.1)^3 + C_1x + C_2. \tag{4.39}$$

At $x = 0$; $y = 0$ which results in $C_2 = 0$;

At x=0.1; y=0 which result in $C_1 = 8.3 \times 10^{-6}$;

by applying these values in deflection formula, we get total deflection Δd is,

$$\Delta d = 1.859 \times 10^{-7} \text{ mm}. \tag{4.40}$$

Considering the value of Δd which very smallest faction which can be negligible, hence from this we are concluding the precision and repeatability of the laser systems is not affected due deflections.

5. SAFETY REQUIREMENTS AND WORK ENVIRONMENT

The requirements and safety of work environment for both the machines and the person who is working with the device; safety measures include the safe production of parts, security for the machine operator, the safety of work environment for the machine safety of post-processing of parts. We use Laser systems in the printing mechanisms (SLS), which has separate work and safety requirements. For the materials printed which has tiny granules of powder, which has another safety requirement (AMFG, RP Platform).

Lasers damage can cause to biological tissues, both to the eye and to the skin, due to several mechanisms. The minute granules have the chance of colliding with ear and forms dust particles which have several damages to human as well as to the environment. Most of the SLS and DMLS has the post-processing chamber in separate space which is not included in the machine itself which needs to be handled safely and with more conscious, because where media blaster or compressed air is used to clean the excess granules. When using the laser systems, damages like thermal damage, or burn can occur. Another damage is when light triggers chemical reactions in tissue can lead to photochemical damage. It occurs mostly with short-wavelength (blue and ultra-violet) light and can be accumulative. Lasers shorter than about 1 μs could have a tendency to a rapid rise in temperature, for example, up to the boiling point of water. (Osama Bader, 1996).

Many scientists involved with lasers agree on the following guidelines:

- Everyone who is working with the process of SLS, SLA, and DMLS have to be near to the laser systems. So appropriate awareness is needed for not with short time contrary for a long period in dealing with risks.
- The appropriate essential pieces of equipment are necessary for worker safety like UV glass, and other peripherals need for the worker according to the EU workers laws.
- The person who is concerning with post-processing needs more consciousness than others where proper safety needs to be ensured while working primarily in the post-processing of manufactured parts.
- Adequate eye protection is always must be required for everyone in the working environment; otherwise, there is an appropriate risk for eye injury.
- Alignment of beams and optical components should be performed at a reduced beam power whenever possible.

5.1. Installation environment

The professional AM machine which has certain criteria of placing in environment like other conventional machines. This includes the machine placing surface tolerance requirements and environmental requirement like temperature air and distance from the room walls and other parallel machines.

As the SLS process needs the post processing where there is a chance of tiny granules can get the proper exhaust system is required for maintaining the air dust quality which does have a significant role to workers who are working in the machine environment. These requirements are divided into major three categories:

- Placement environment.
- Temperature.
- Dust and air quality.

While placing the machine, the machine should be separated in the required distance as each industries firm have several standards like ISO requirements and 5S-program. For this system, the minimum of 1m free space is needed in all direction. This should give enough space for maintaining the surrounding temperature and for an essential operation like opening the doors and such others.

These SLS systems which work on Lasers from low to high power the lasers need the significant cooling system, so the heat is elevated room temperature should be maintained on average of 15 to 35 degree approximately. As each machine uses different lasers system, each needs separate cooling requirements so this should be taken note too.

Usually, after making, the parts are taken out of the machine and separated for air casting which removes the excess powders which are done in a separate machine. The worker needs to make sure there is no leakage in the dust particles. In maintaining the air dust rate controlled, which have benefits for both the machine and the workers too.

6. ELECTRIC SCHEME

For this SLS printer, it uses 8 NEMA 17 stepper motors which are:

- 2 × motors for 1st laser gantry;
- 2 × motors for 2nd laser gantry;
- 2 × motors for 1st and 2nd build containers;
- 1 × motor for powder container;
- 1 × motor for feeding system.

These stepper motors which runs in 12v DC current for drive systems and runs in Arduino mega 2563 with the primary driver of Ramps 1.4 which requires 5v DC and secondary driver A4988. Each stepper motor has separate limit switch for notifying the limit of the drive system. the laser system is powered by 5v DC power supply.

The primary power system is 240v AC power supply where the derived by two more sub power system of 12v DC and 5v DC for lasers and stepper motors.

Other components like cooling fans and heater works on 5v DC power. The Arduino is programmed by MARLIN firmware where it can able to run all those components from the primary of Ramps 1.4 driver.

The Marlin firmware is downloaded in the Arduino and is customised for ramps 1.4 board and its open source. Can be edited whenever the

Table 6.1. Major electric components.

No.	Components	Numbers
1	Ardruino mega	1
2	Ramps 1.4	
3	Limit switch	8
4	Stepper motor	8
5	A4988 driver	8
6	Cooling fan	2
7	DB-1000 laser	2

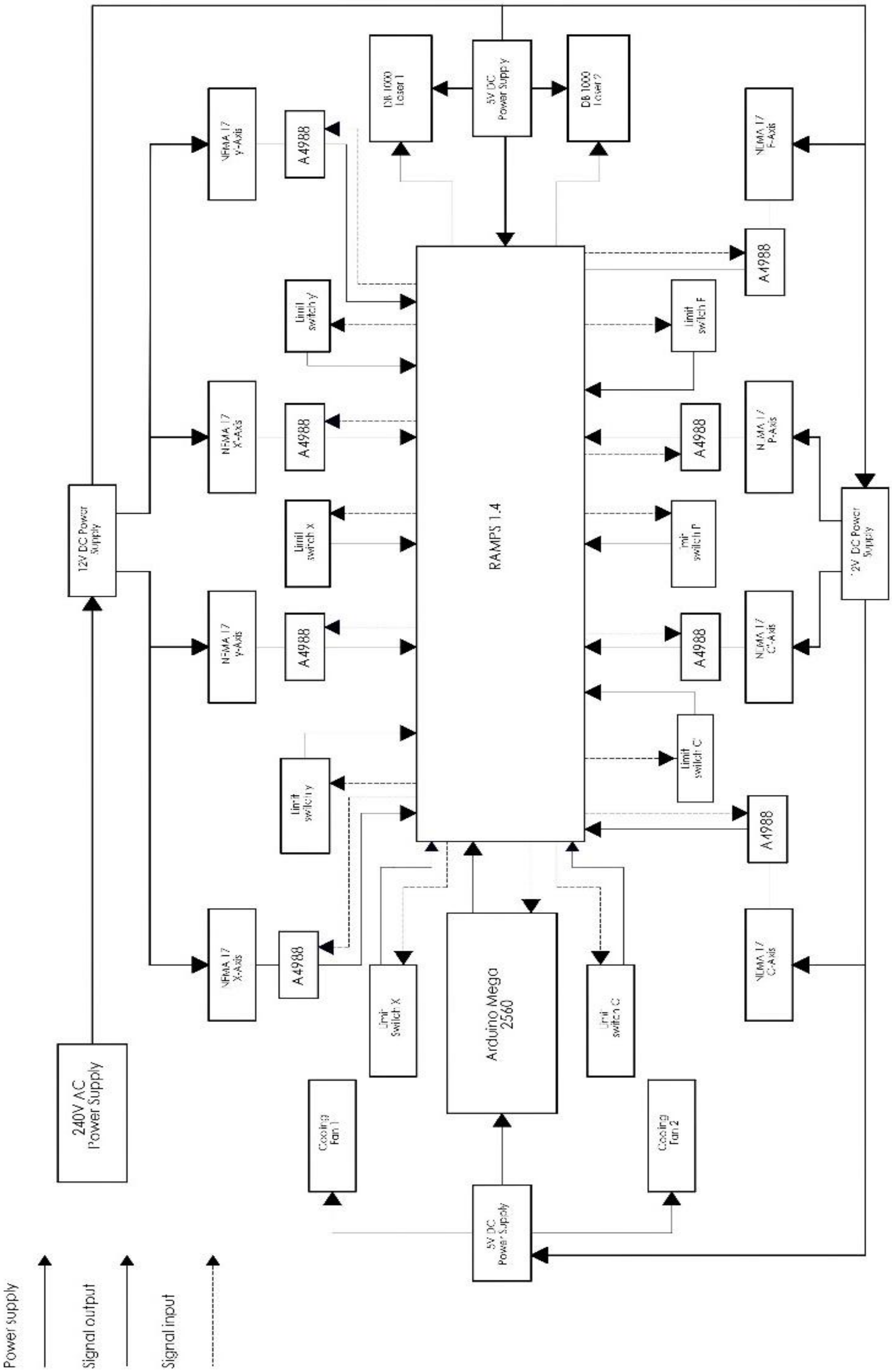

Figure 6.1. Control Schematic diagram

7. ECONOMIC INDICATORS

Production activity is an indicator of the state of the economy and stage analysis for the gain of the enterprise. Like same is the role of GDP being the vital role of countries economic growth shower, the economic indicator is significant to the manufacturing firm to know about the range of goods produced and to get an overlook of profit over gain. Moreover, since workers are required to manufacture new products, increases in manufacturing activity also boost employment and possibly wages as well. All the calculations presented below are not precise and showed as if any company would start to produce the body frame and assemble the machine. The predictions of costs, revenues, profits, and other parameters will be performed in this chapter.

7.1. Calculations of fixed assets and production costs

The beginning of the production starts with some investments. They are made once and are not changed during a long period of time.

Table 7.1. Initial investments of the company producing the mechanisms

Type of the long-time fixed costs	**Price of the investment, Euros**
Office and manufacturing premises	2 50 0000
Machinery (Cutting, drilling and polishing machines, welding and other equipment)	75 000
Lifting/loading equipment	40 000
Office and manufacturing premises furniture	4 500
Software	5 000
Total:	**3 74 500**

The goal of these calculations is to find the minimum production level that will bring benefit and define the payback period for the estimated volume of production. For that reason, total fixed and variable costs, variable costs per unit, total costs and revenues, breakpoint and payback period will be used to perform calculations.

Table 7.2. The mechanism component price list

No:	Component name	Quantity	Price of one piece, Euros	Total price, Euros
1.	ϕ 5mm shaft holder	4	8	32
2.	ϕ 8mm shaft holder	4	10	40
3.	20 x 420 x 305 mm Weldment profile	6	12	72
4.	ϕ 8mm Rover Bearing -screw	2	12	24
5.	ϕ 8mm x 220 mm stainless steel Rod	6	8	48
6.	D1000 Laser System	2	75	150
7.	T8 x 400 mm Lead Screw	1	15	15
8.	ϕ 8mm x 400 mm Stainless steel S-304	1	18	18
9.	420 x 245 x4 mm Steel Plate	3	45	135
10.	420 x 103 x 4 mm Steel Plate	2	28	56
11.	250 x 108 x 4 mm Steel Plate	2	20	40
12.	150 x 150 x 4 mm Steel Plate	10	21	210
13.	150 x 150 x 10 mm Steel Plate	2	15	30
14.	ϕ 25 mm x 160 mm Steel Shaft	4	24	96
15.	ϕ 35 mm x 160 mm Steel Shaft	4	25	100
16.	200 x 100 mm UV glass	2	20	40
17.	Arduino Mega 2560	1	30	30
18.	Ramps 1.4	1	15	15
19.	NEMA 17 S. Motor	7	15	105
20.	Stepper encoder	7	10	70
21.	Atmospheric Heater	1	25	25
22.	GT2 Belt	4	8	32
23.	12 V Power Supply	1	16	16
24.	5 V Power Supply	1	10	10
25.	Thermometer	2	7	14
26.	120 x 120 mm Heat Bed	5	11	55
		TOTAL		1478 Euros

The next step is to calculate the variable and fixed production costs. The price list of components is presented in (Table 7.2). The total price of the entire components and materials for mechanism manufacturing I_1 = 14 78 Euros.

The salary of the company's employee must be calculated. Supposed that there are needed four workers to manufacture and assemble one product: cutting machine operator, drilling and polishing operator, and two assemblers. To produce one product, the first worker needs 6 hours.

The second one – 8 hours and the assemblers need 6 hours to transport and assemble the device. The average monthly wage in the Republic of Lithuania in the IV quarter of the 2018 year was 970.3 Euros (Finansistas, Average wages). The price of the workplace was calculated using the calculator and is 1 272.84 Euros. In the Republic of Lithuania, the workday consists of 8 hours and 40 hours per week. An average number of working days per month is 20. For the 8-hour working day the employee will receive the daily wage will be:

$$I_2 = \frac{1\,272.84}{20} \times 1 = 63.6 \text{ Euros.} \quad (7.1$$

To manufacture one part the second employee needs a whole working day and receives 63.6 Euros, while operator and assembly workers – 53 Euros (per 6-hour working day).The energy costs are also included in the manufacturing price. To produce one device the following equipment is used: cutting, drilling and polishing machines, as well as portable welding station. The total power of all required equipments is 150 kW. Supposing all required equipment is used for 20 hours to produce the final product. The price of 1 kWh is 0.130 Euros (BSS, Remuneration Tax). The total cost of electric energy for one product is:

$$I_3 = 100 \text{ x } 20 \times 0.130 = 260 \text{ Euros.} \quad (7.2$$

During the production process, there are used additional materials like wires for welding materials, cables, and wires, lubricants, packing materials, etc. Expenses for those materials regularly appear during the production process.

To continue the calculations, suppose that those costs are $I_4 = I_5$ Euros for one product. Moreover, the wearing of tools (drills, welding equipment parts, etc.) of manufacturing equipment also creates some costs for the company to replace and maintain. It is supposed that technological wearing costs for production of one device will be: $I_6 =$ 25 Euros.

The products will be delivered to an order by the assemblers. It means that the fuel will be used, likely more than the average as the weight and size of the device transported are big. We can assume that it would be I_5 = 10 Euros for one product if the product is assembled in Lithuania and more if the product is assembled abroad.

Table 7.3 Variable direct and non-direct costs for manufacturing one product

No:	Direct costs	Amount, Euros
1.	Components and materials	1,478.0
2.	Wages of the company's employees	63.6
3.	Energy	260
4.	Non-direct costs	25
5.	Additional materials	15
6.	Transportation costs	10
7.	The technological wearing of tools	25
	Total variable costs (AVC)	**1 876.66**

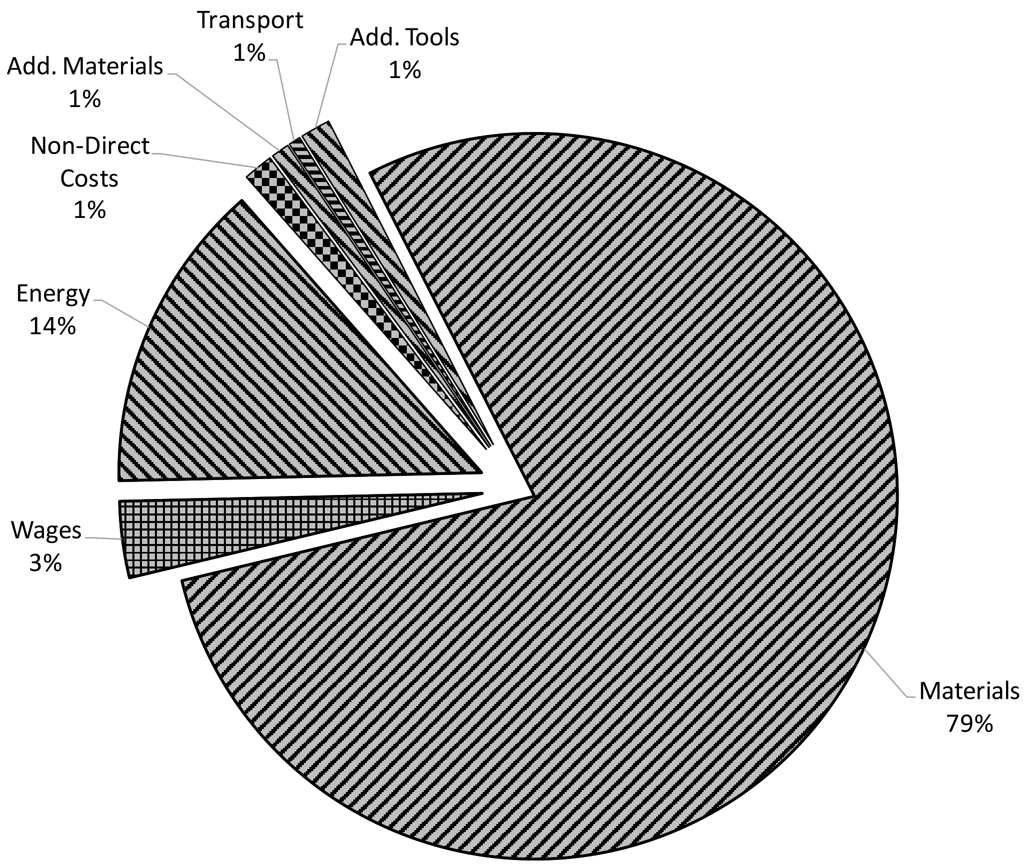

Figure 7.1. Variable Cost for product manufacturing

1. Components and materials; 2. Wages of the company's employees; 3. Energy 4.Non-direct costs; 5. Additional materials; 6. Transportation costs; 7. The technological wearing of tools.

The variable direct costs consist of the materials and components costs, energy costs, and workers' salaries. The variable non-direct prices include the costs of additional materials, transportation costs, and costs of the technological wearing of tools, (Table 7.3), presents these costs.

7.2. Calculation and determination of fixed costs

The next step in the economic calculations is to evaluate fixed costs which primarily consist of administration and general staff wages. As the complexity of the structure is not high, we can assume that there are 6 employees participate in the production process of those mechanisms. The workplace's price of one employee is 1 272.84 Euros as was mentioned. The salaries of 6 employees per year will cost the company the next amount of money:

$$I_7 = 1272.84 \times 12 = 61\,096 .32 \text{ Euros.} \tag{7.3}$$

The off take of the company heavily depends on the advertising of the product. There is no sense to rent a billboard in the centre of the city because the manufactured mechanisms are not the mass-consumption product. It was decided to advertise the product on the Internet. The price of advertising is 150€ per month (three times per day in the 50 qualified proclaiming lists) + GOOGLE advertising (https://pigiaireklama.lt/kainos). The cost of advertising per year will be:

$$I_3 = 100 \times 12 = 1\,800 \text{ Euros.} \tag{7.4}$$

CAD design software is necessary for the company. Designer and production engineer use the Solid works and AutoCAD programs. The cost of the licenses for both programs per year is I_9 = 5000 Euros. Sometimes the cost of CAD design software can be eliminated by using the open source software.

The manufacturing premises should be serviced every year. Amortization costs are included in the fixed costs and calculated according to the following formula:

$$I_{10} = \frac{p1-p2}{T} \tag{7.5}$$

where I_{10} – amortization costs per year,
p1 – the price of the obtained manufacturing and office premises),
p2 – the price of the liquidated fixed assets.

T - time of exploitation (the building wearing normative *T* = 15 years according to 2008 04 10 LR law Nr. X-1484 of fixed assets wearing or amortization normative).The calculated wearing amortization costs of the premises are:

$$I_{10} = \frac{p1-p2}{T} = \frac{250000-25000}{15} = 15\,000 \text{ Euros.} \quad (7.6)$$

Table 7.4. Fixed costs of the company

No:	Fixed costs	Amount, Euros
1.	Administration and general staff employees' salaries and social insurance	61 096.32
2.	Advertising	1 800
3.	Software	5 000
4.	Office and manufacturing premises amortization	4 500
5.	Utility rates	7 000
6.	Clerical and communicational expenses	3 000
	Total fixed costs (FC)	**82 396.32**

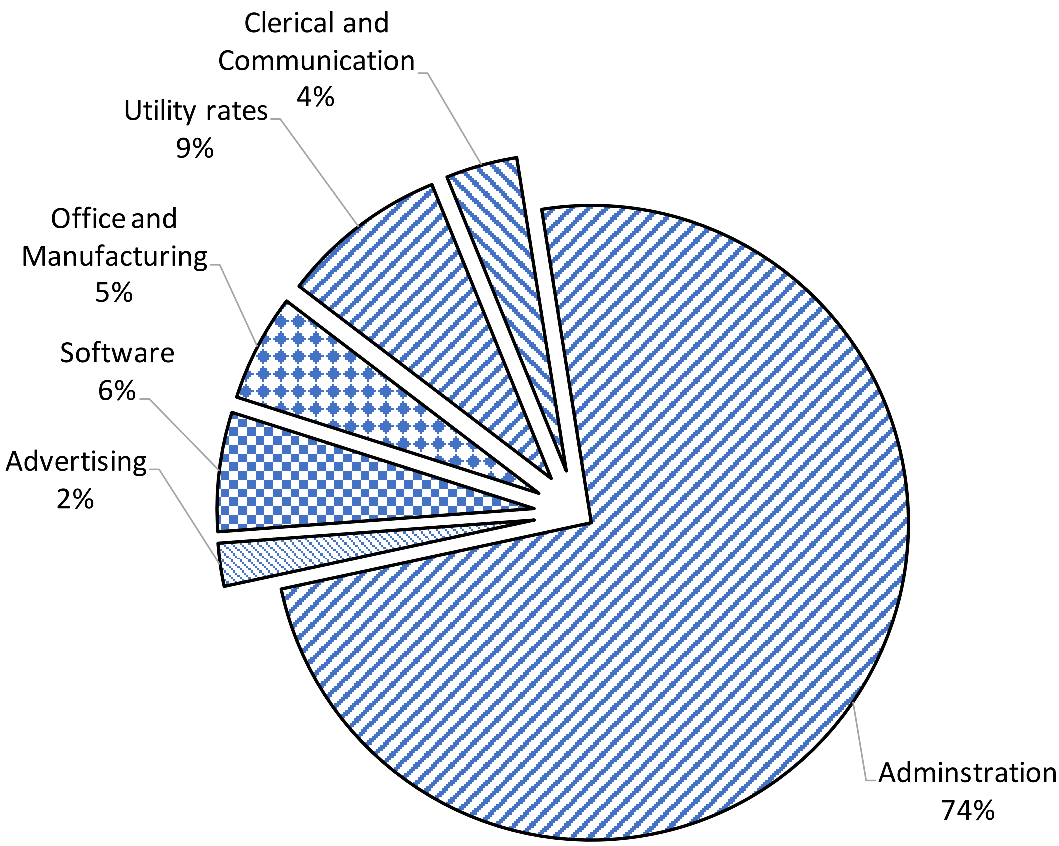

Figure 7.2. Fixed cost pie chart

The administrative expenses, costs of communicational service (telephone, Internet) and utility rates are also included in the fixed costs.

Supposed that clerical and communicational expenses will be I_{11} = 3000 Euros and utility rates I_{12} = 7000 Euros. The list of the fixed costs of the company that is planning to produce sealing-cutting mechanisms is presented in (Table 6.1).

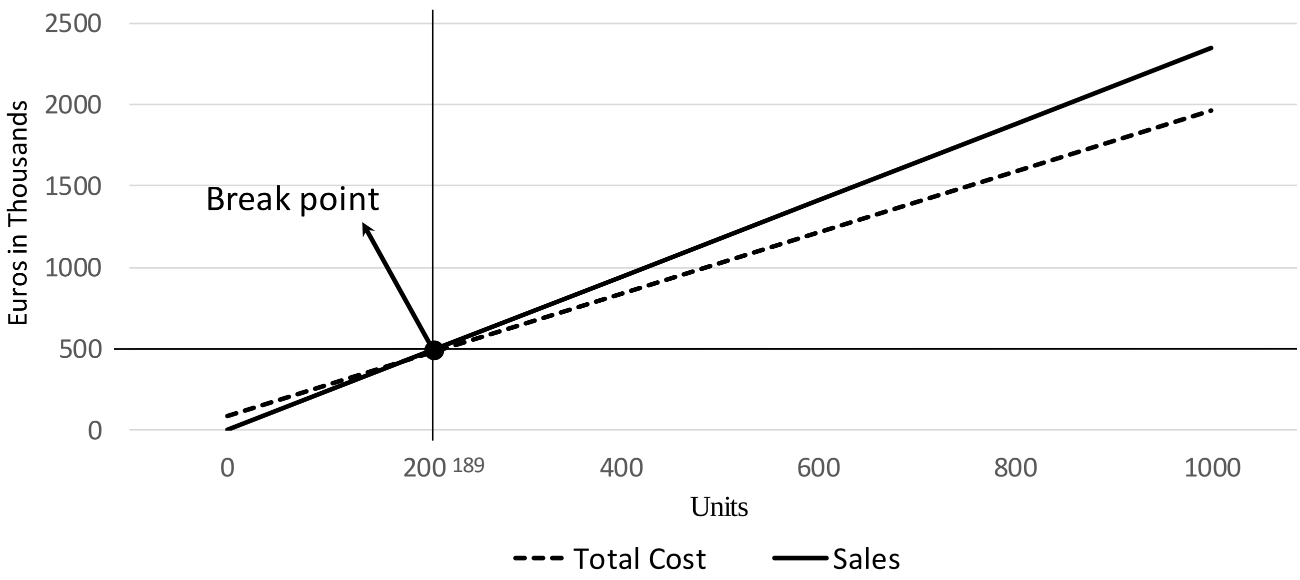

Figure 7.3. Break Point Chart

So, we got at the near 189 units of production at the rate of 500000 Euros. After that the sales go higher, and the profit becomes more.

8. CONCLUSIONS

1. By having the task of building the entire SLS system first importance of the AM is explained, the advantage and disadvantage of each different technologies in AM shown such as quality, strength of build part and other difference in each SLS, SLS, FDM, DMLS have been mentioned. That makes SLS superior to others and reason for choosing SLS technology has proved.
2. Stating important part design properties such as wall thickness, interlocking part clearance, overhang support, and layer thickness. Relation between cooling rate of printed part with has effects on its own strength (rate of temperature decrease is directly proportional to its own strength).
3. Similar 3D-Printers from same SLS technology are compared with parameters like rate of sintering, and its strength of printed parts. From converting one of its major disadvantages of "inability in dual part printing at same time" has analysed.
4. The calculation for this machine has derived and chosen 1-watt power laser of 445 nm wavelength is required for sintering Nylon PA-12 material. GT2 belt is chosen for our calculated 0.1 m/s velocity and 0.08 m/s^2 acceleration in our manipulation system. For the feeder system, THK A-679 ball screw system is chosen according to the calculated values, and nut model of BLK1510-5.6 is chosen.
5. Its recommended to use appropriate necessary work safety peripherals like UV eyeglass, hand gloves, etc. Recommending the worker to perform beam alignment at reduced beam power to prevent its dangerous consequences. Strictly follow "Accessible emission limits (AEL) rules" have been established for each class of laser below “*Class 4”*. Machine working environmental temperature of 15℃ to 45℃ degree is recommended to overcome unwanted thermal deflection of parts.
6. In the electrical part, the required electric scheme is planned, and scheme diagram is charted. Overall machine runs in Arduino mega with primary driver of Ramps 1.4 and runs on Marlin software. For this electric scheme calculated average power supply of 0.5 kWh is required.
7. The economic part calculated overall machine cost is around 1478 Euros (including electric components). Concluding 79% for material, 14% for Energy (Machinery and Power requirement) and others. In mass production, the profit can start after nearly 190 units of production by having profit of 200000 Euros.

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APPENDIX

Format	Zone	Position	Mark	Name	Amount	Note.
				Documents		
A1			VGTU BM 19 25 00 01 00 AD	Assrmbly of 3d printer		
				Subassemblies		
			VGTU BM 19 25 00 02 00 AD	Container Plate Assembly		
			VGTU BM 19 25 00 13 00 AD	Build Plate Assembly-1		
			VGTU BM 19 25 00 28 00 AD	Gantry Assembly		
			VGTU BM 19 25 00 31 00 AD	Bottom leg assembly		
			VGTU BM 19 25 00 37 00 AD	Feeding Assembly		
			VGTU BM 19 25 00 38 00 AD	Build Plate Assembly-2		
				Parts		
		1	VGTU BM 19 25 00 01 01 GD	Powder Container	1	
		2.1	VGTU BM 19 25 00 02 01 GD	Powder Plate	1	
		2.2	VGTU BM 19 25 00 02 02 GD	Powder Plate Holder	1	
		2.3	VGTU BM 19 25 00 02 03 GD	Powder Plate Shaft	6	
		2.4	VGTU BM 19 25 00 02 04 GD	Powder Motor Plate	1	
		3	VGTU BM 19 25 00 01 03 GD	Powder Shaft Holder Bottom	1	
		12	VGTU BM 19 25 00 01 12 GD	Part Container-1	1	
		13.1	VGTU BM 19 25 00 13 01 GD	Build plate holder-1	1	
		13.2	VGTU BM 19 25 00 13 02 GD	Build Plate-1	1	
		13.3	VGTU BM 19 25 00 13 03 GD	Build Motor Plate-1	1	
		13.4	VGTU BM 19 25 00 13 04 GD	Build Plate Shaft-1	1	
		18	VGTU BM 19 25 00 01 18 GD	Part Container-2	1	
		18.1	VGTU BM 19 25 00 18 01 GD	Build plate holder-2	1	
		18.2	VGTU BM 19 25 00 18 02 GD	Build Plate-2	1	
		18.3	VGTU BM 19 25 00 18 03 GD	Build Motor Plate-2	1	
		18.4	VGTU BM 19 25 00 18 04 GD	Build Plate Shaft-2	1	
		18.5	VGTU BM 19 25 00 18 05 GD	Build Shaft Holder Botoom-2	1	
		19	VGTU BM 19 25 00 01 19 GD	Storage Container	1	
		24	VGTU BM 19 25 00 01 24 GD	Feeding Deck	1	

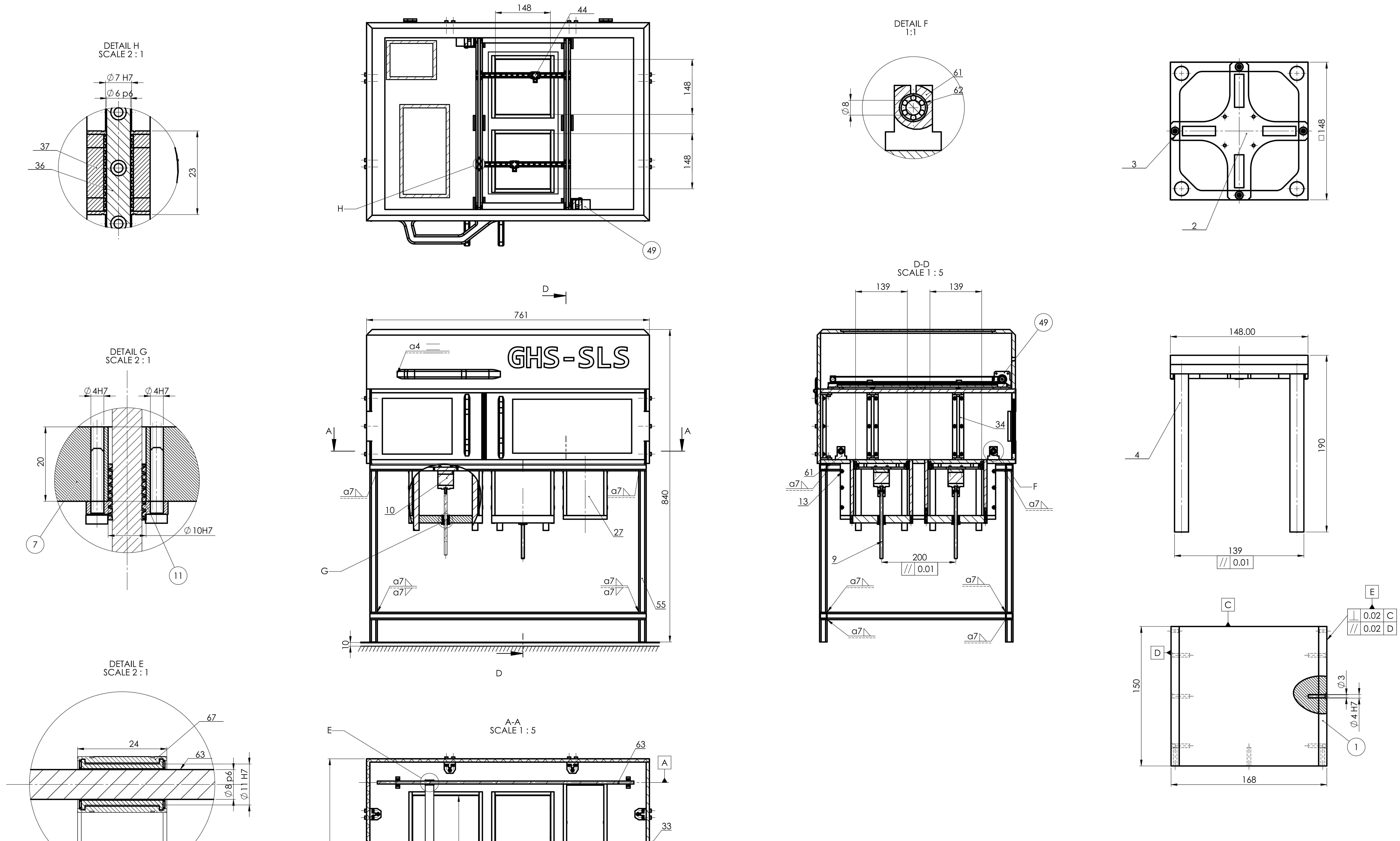
	File no. 1	Additional information	Material	Scale
Responsible agency MEMD	Consultant	Document type: Specification Sheet	Document status: Educational	
Owner VGTU MPfuc-15	Compiled: HARI SHANKAR GOVINDASAMY	Title: Design of 3d-Printer	Mark: VGTU BM 19 25 00 00 00 TS	
	Checked: Dr., Prof., SIGITAS PETKEVICIUS		Rev. 0 / Date 29.05.2019 / Lan. En. / Sheet 1/3	

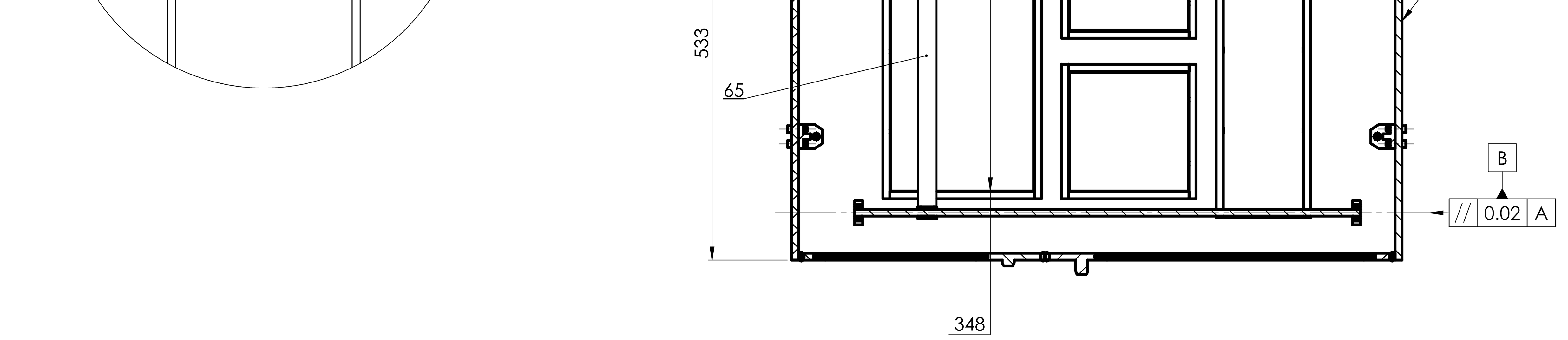
Format	Zone	Position	Mark	Name	Amount	Note.
				Parts		
		25	VGTU BM 19 25 00 01 25 GD	Build Area Cover	1	
		26	VGTU BM 19 25 00 01 26 GD	Main Clamp	1	
		27	VGTU BM 19 25 00 01 27 GD	Sintering Deck	1	
		28.3	VGTU BM 19 25 00 28 03 GD	Holding Clamp	2	
		28.4	VGTU BM 19 25 00 28 04 GD	Clamp	2	
		28.6	VGTU BM 19 25 00 28 06 GD	Centre Holder	2	
		28.7	VGTU BM 19 25 00 28 07 GD	Rail Holder	4	
		28.8	VGTU BM 19 25 00 28 08 GD	Lasser Holder	2	
		28.13	VGTU BM 19 25 00 28 13 GD	Motor Holder	2	
		28.14	VGTU BM 19 25 00 28 14 GD	Pully Holder	2	
		29	VGTU BM 19 25 00 01 29 GD	Door Left	1	
		30	VGTU BM 19 25 00 01 30 GD	Door Right	1	
		31	VGTU BM 19 25 00 01 31 GD	Gantry Cover Top	1	
		33	VGTU BM 19 25 00 01 33 GD	Front Cover	2	
		34	VGTU BM 19 25 00 01 34 GD	Side Cover	2	
		35	VGTU BM 19 25 00 01 35 GD	Hing Upper Body Opener	2	
		36	VGTU BM 19 25 00 01 36 GD	Hing Upper Body Holder	2	
		37.1	VGTU BM 19 25 00 37 01 GD	Shaft Holder 10mm	2	
		37.5	VGTU BM 19 25 00 37 05 GD	Feeder	1	
		38	VGTU BM 19 25 00 01 38 GD	Shaft Connector	2	

	File no. 1	Additional information	Material	Scale
Responsible agency MEMD	Consultant	Document type Specification Sheet	Document status Educational	
Owner VGTU MPfuc-15	Compiled HARI SHANKAR GOVINDASAMY	Title Design of 3d-Printer	Mark VGTU BM 19 25 00 00 00 TS	
	Checked Dr., Prof., SIGITAS PETKEVICIUS		Rev. 0 / Date 29.05.2019 / Lan. En.	Sheet 2/3

Format	Zone	Position	Mark	Name	Amount	Note.
				Strandard Parts		
		2.5	IS 7485 Screw	IS 7485 - M4 X 25 - Z -- 25N	4	
		4	IS 7046 Screw	ISO 7046-1 - M4 X 40 - Z - 40C	6	
		5	TR8X8-4 Lead screw	TRAPEZOIDAL LEAD SCREW TR8X8-4	1	
		7	TR8X8 Lead nut	LEADSCREW NUT	1	8x2mm
		8	IS 7485 Screw	IS 7485 - M3 X 20 - Z -- 20C	16	
		9	IS 7485 Screw	IS 7485 - M4 X 20 - Z -- 20N	24	
		10	IS 2269 Screw	IS 2269 - M3 X 16-N	8	
		11	IS 7485 Screw	IS 7485 - M4 X 16 - Z -- 16C	2	
		13.5	ISO 7046 Screw	ISO 7046-1 - M4 X 20 - Z - 20C	1	
		15	IS 7485 Screw	IS 7485 - M4 X 20 - Z -- 20C	44	
		16	IS 2269 Screw	IS 2269 - M3 X 16-C	4	
		17	IS 7485 Screw	IS 7485 - M3 X 20 - Z -- 20N	8	
		20	IS 2269 Screw	IS 2269 - M5 X 20-N	36	
		21	IS 1364 Screw	IS 1364-4 - M5-N	36	
		22	IS 2269 Screw	IS 2269 - M5 X 20-C	12	
		23	IS 15581 Bolt	IS 15581 - M5-C	6	
		28.1	Y-axis rail	Y-axis rail-1	2	
		28.2	Guideway	Guide	6	
		28.5	X-axis rail	X-axis rail-2	2	
		28.9	IS 2269 Screw	IS 2269 - M2 X 3-N	9	
		28.10	Laser	Laser	2	
		28.11	Nema 17 motor	Nema 17 motor	2	
		28.12	Pully	Pully	2	5mm
		28.15	Belt-1	Belt-1	1	
		28.16	Belt-2	Belt-2	1	
		31.1	Weldment Profile	Weldment Profile	8	
		31.2	Bearing	Bearing	4	10mm
		37.3	Feeding Lead screw	Feeding Lead screw	1	10mm
		37.4	Feeding shaft	Feeding shaft	1	10mm
		37.6	LU10mm Bearing	LU10mm Bearing	2	10mm

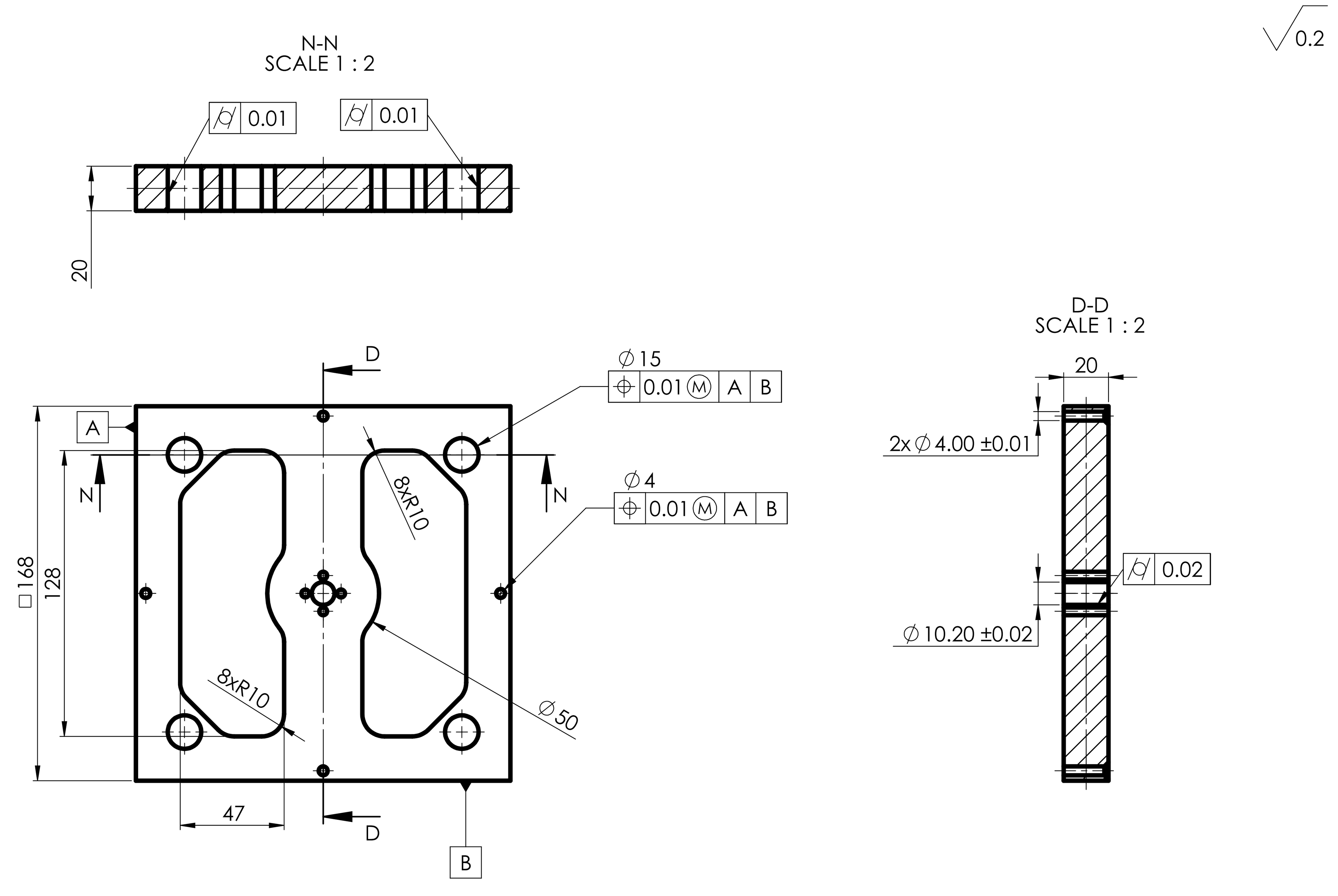
	File no. 1	Additional information	Material	Scale
Responsible agency MEMD	Consultant	Document type Specification Sheet	Document status Educational	
Owner VGTU MPfuc-15	Compiled HARI SHANKAR GOVINDASAMY	Title Design of 3d-Printer	Mark VGTU BM 19 25 00 00 00 TS	
	Checked Dr., Prof., SIGITAS PETKEVICIUS		Rev. 0 / Date 29.05.2019 / Lan. En. / Sheet 3/3	





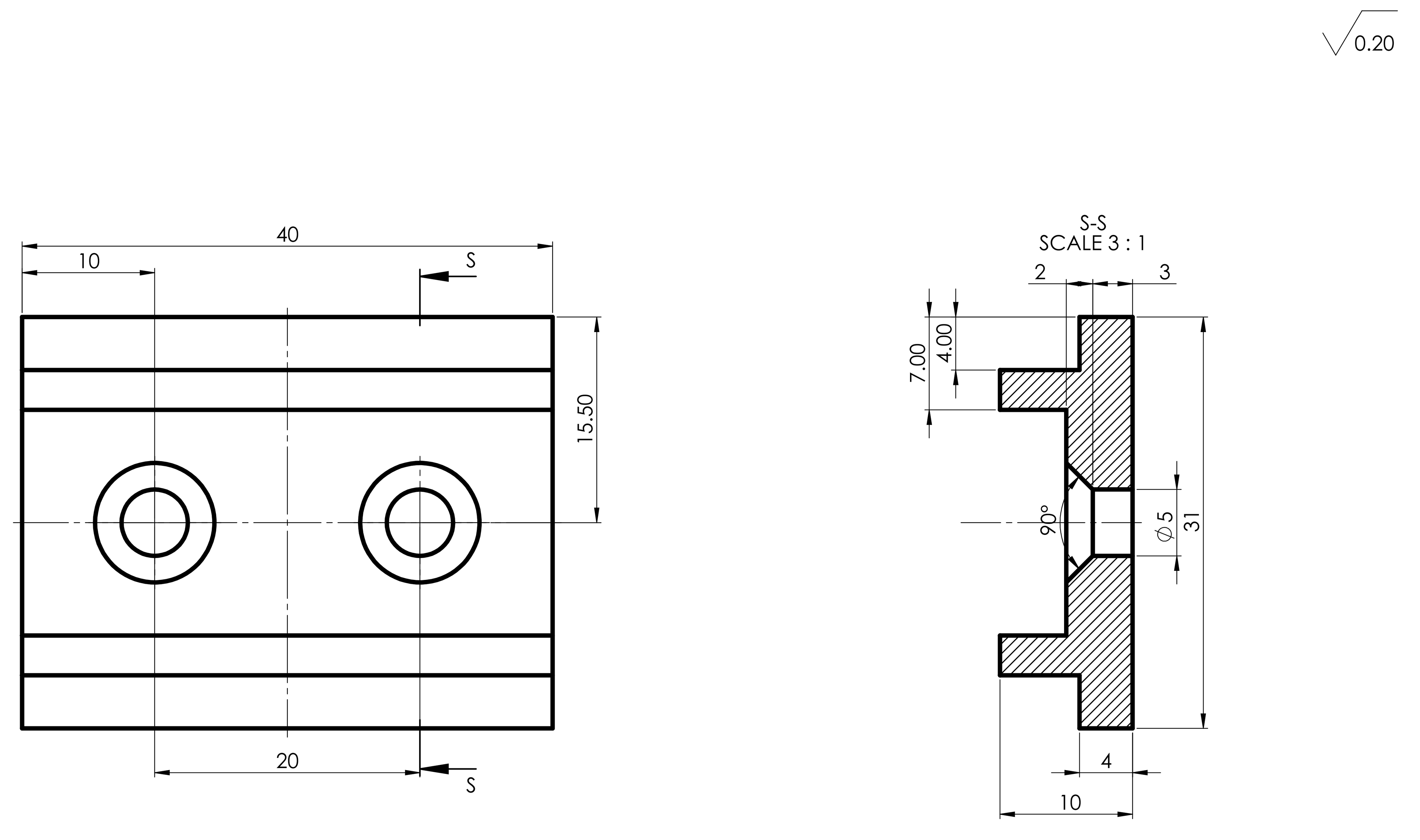
Informarion:
1. While placing the machine should be in flat surface, and it works in 240volts AC.
2. For assembling Bolts and nuts the required torque is 7N.
3. Build container should be achieved in given tolerance zone.
4. Lubrication system (linear guide): Grease nipple is available for MGN15, lubricated by grease gun.
5. Dust protection system: End seal, bottom seal (optional size 9,12,15), cap (size12,15) for the linear guideways.
6. Use thread -locker paste for the screws.

	File no. 1	Additional information	Material	Scale 1:5
Responsible agency MEMD	Consultant	Document type Assembly drawing	Document status Educational	
Owner VGTU MPfuc-15	Compiled Hari Shankar Govindasamy	Title Design of 3D-Printer	Mark VGTU BM19 25.01.00.00.AD	
	Checked Prof., Dr. SIGITAS PETKEVICIUS		Rev. 0 / Date 28.05.2019	Lan. En. / Sheet 1/8



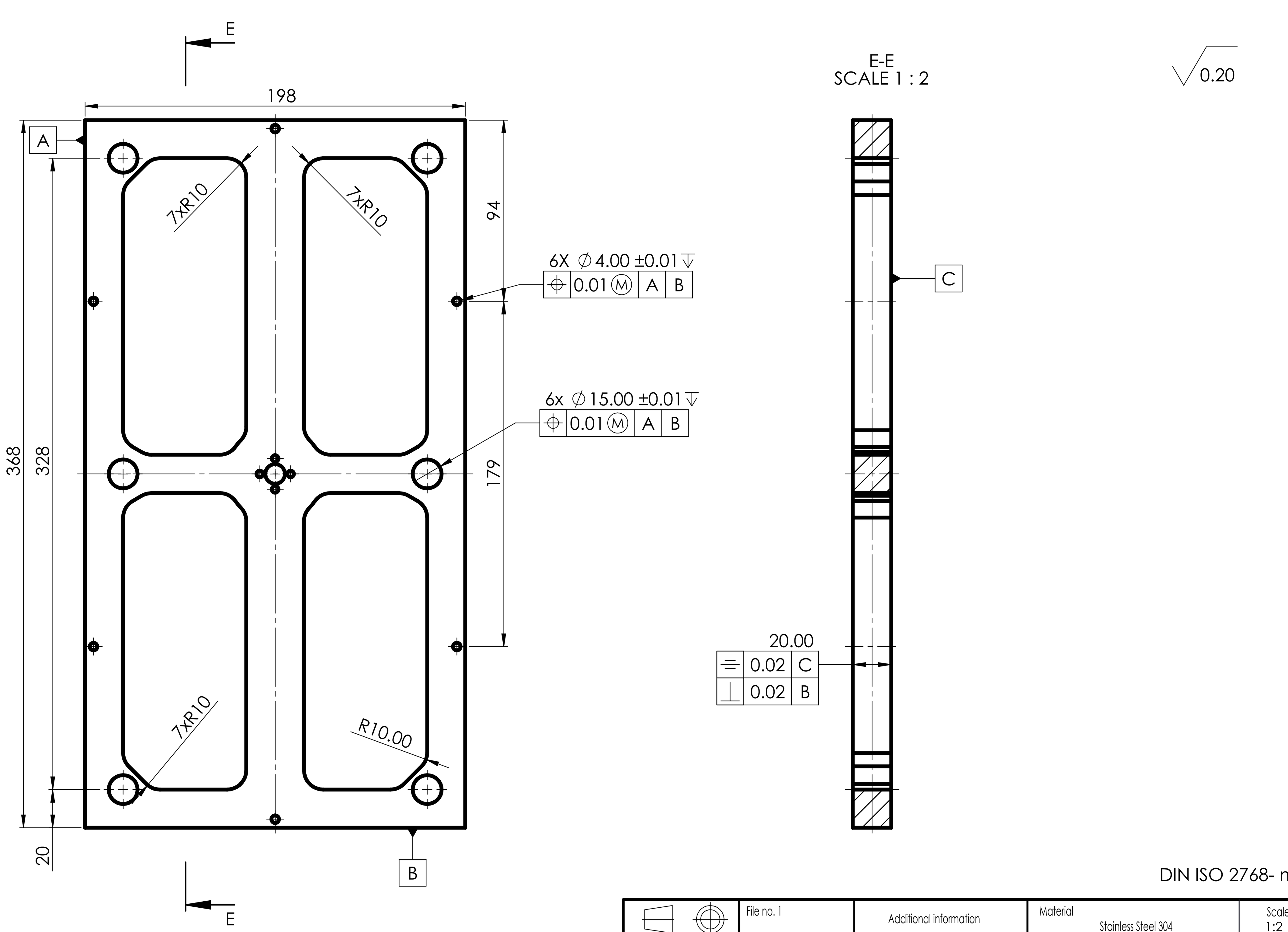
DIN ISO 2768- mk

	File no. 1	Additional information	Material: Stainless Steel 304	Scale: 1:2
Responsible agency: MEMD	Consultant	Document type: Part Drawing	Document status: Educational	
Owner: VGTU MPfuc-15	Compiled: HARI SHANKAR GOVINDASAMY	Title: Build Shaft Holder Bottom-1	Mark: VGTU BM 19 25 02 00 14 PD	
	Checked: Prof., Dr. SIGITAS PETKEVICIUS		Rev. 0, Date 19.05.2019, Lan. En., Sheet 2/8	



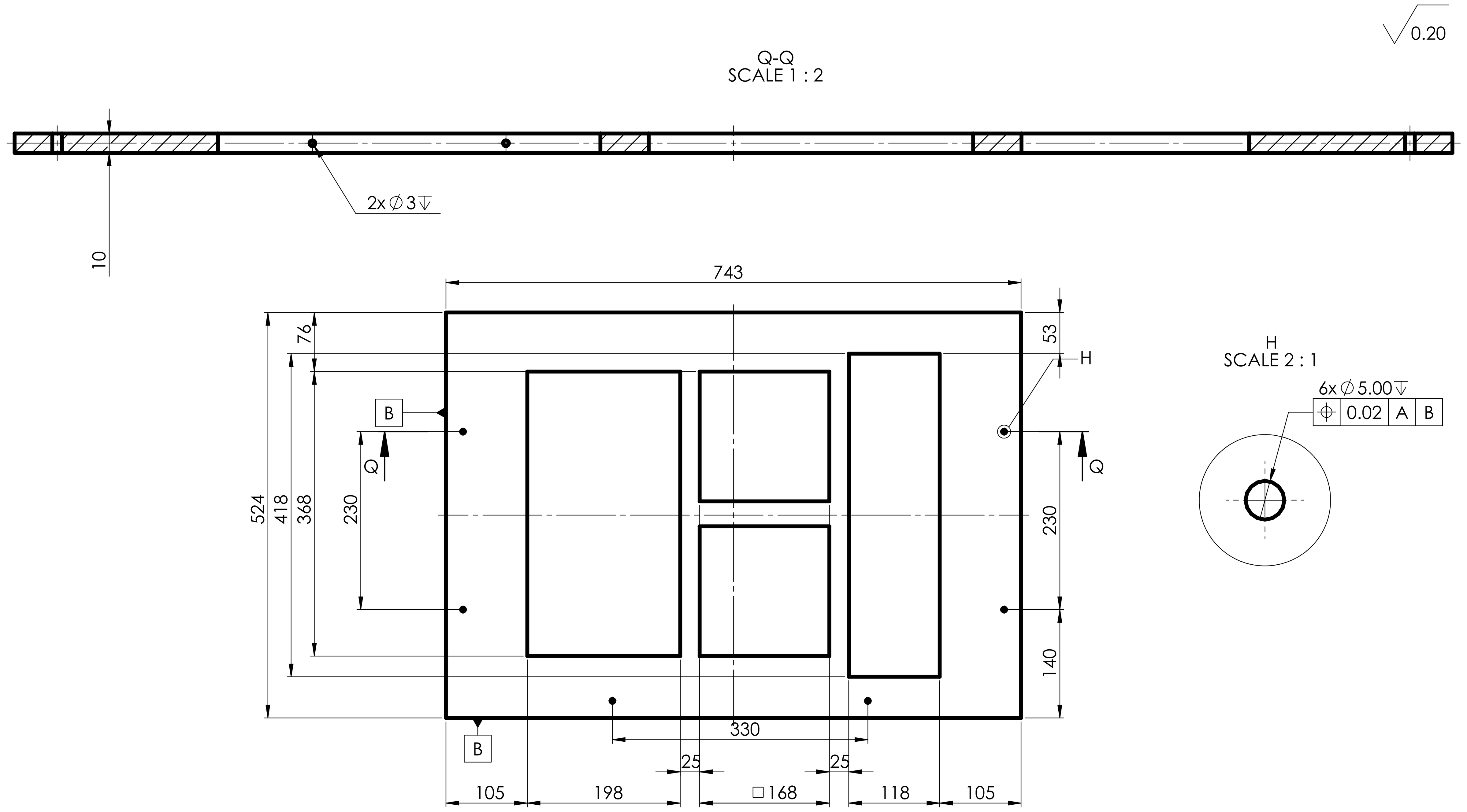
DIN ISO 2768- mk

	File no. 1	Additional information	Material: Stainless Steel 304	Scale: 3:1
Responsible agency: MEMD	Consultant	Document type: Part Drawing	Document status: Educational	
Owner: VGTU MPfuc-15	Compiled: HARI SHANKAR GOVINDASAMY	Title: Centre Holder	Mark: VGTU BM19 25 02 28 06 PD	
	Checked: Prof., Dr. SIGITAS PETKEVICIUS		Rev. 0, Date 19.05.2019, Lan. En., Sheet 4/8	



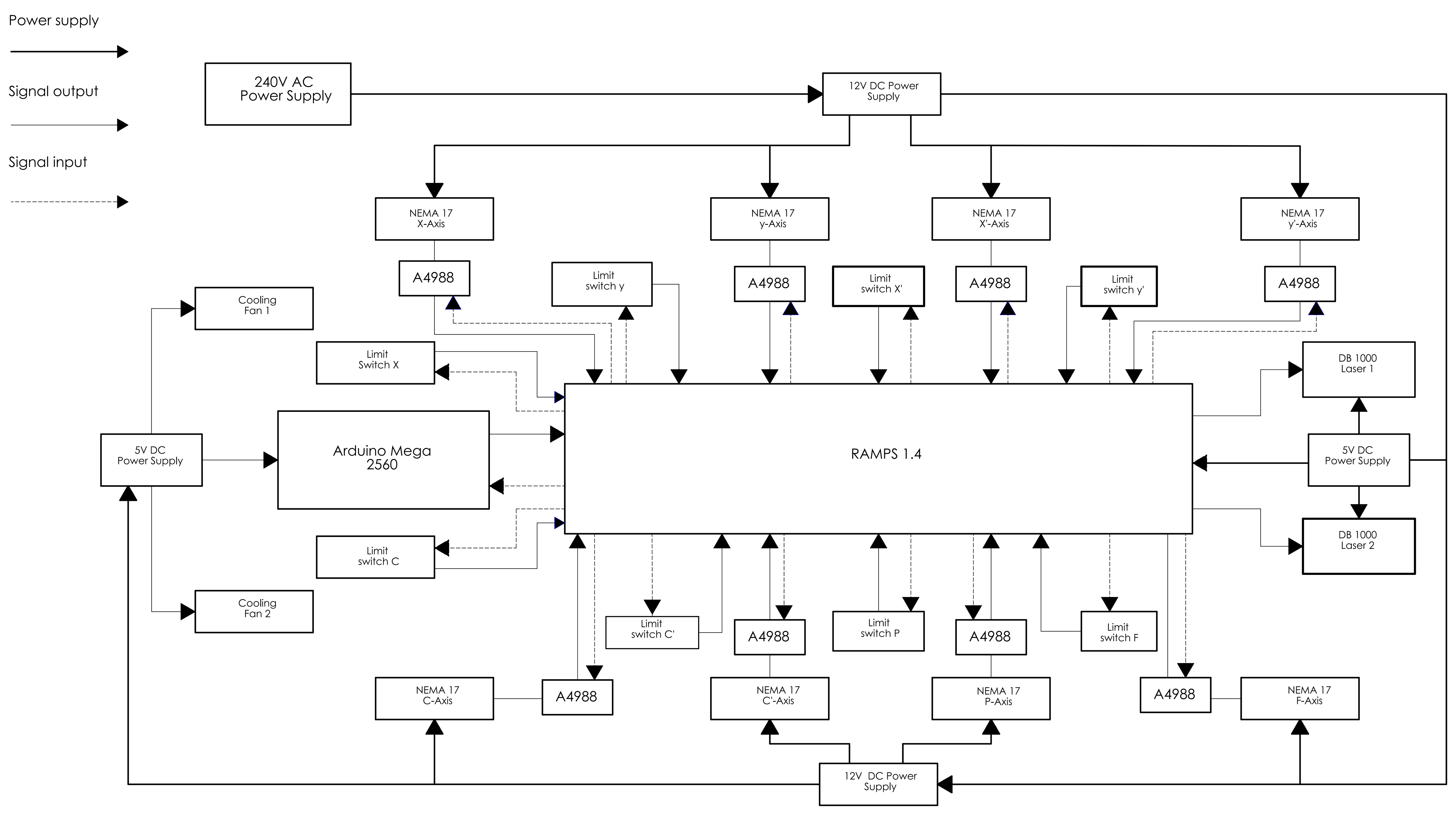
DIN ISO 2768- mk

	File no. 1	Additional information	Material: Stainless Steel 304	Scale: 1:2
Responsible agency: MEMD	Consultant	Document type: Part Drawing	Document status: Educational	
Owner: VGTU MPfuc-15	Compiled: HARI SHANKAR GOVINDASAMY	Title: Powder Shaft Holder Bottom	Mark: VGTU BM 19 25 02 00 03 PD	
	Checked: Prof., Dr. SIGITAS PETKEVICIUS		Rev. 0, Date 19.05.2019, Lan. En., Sheet 3/8	

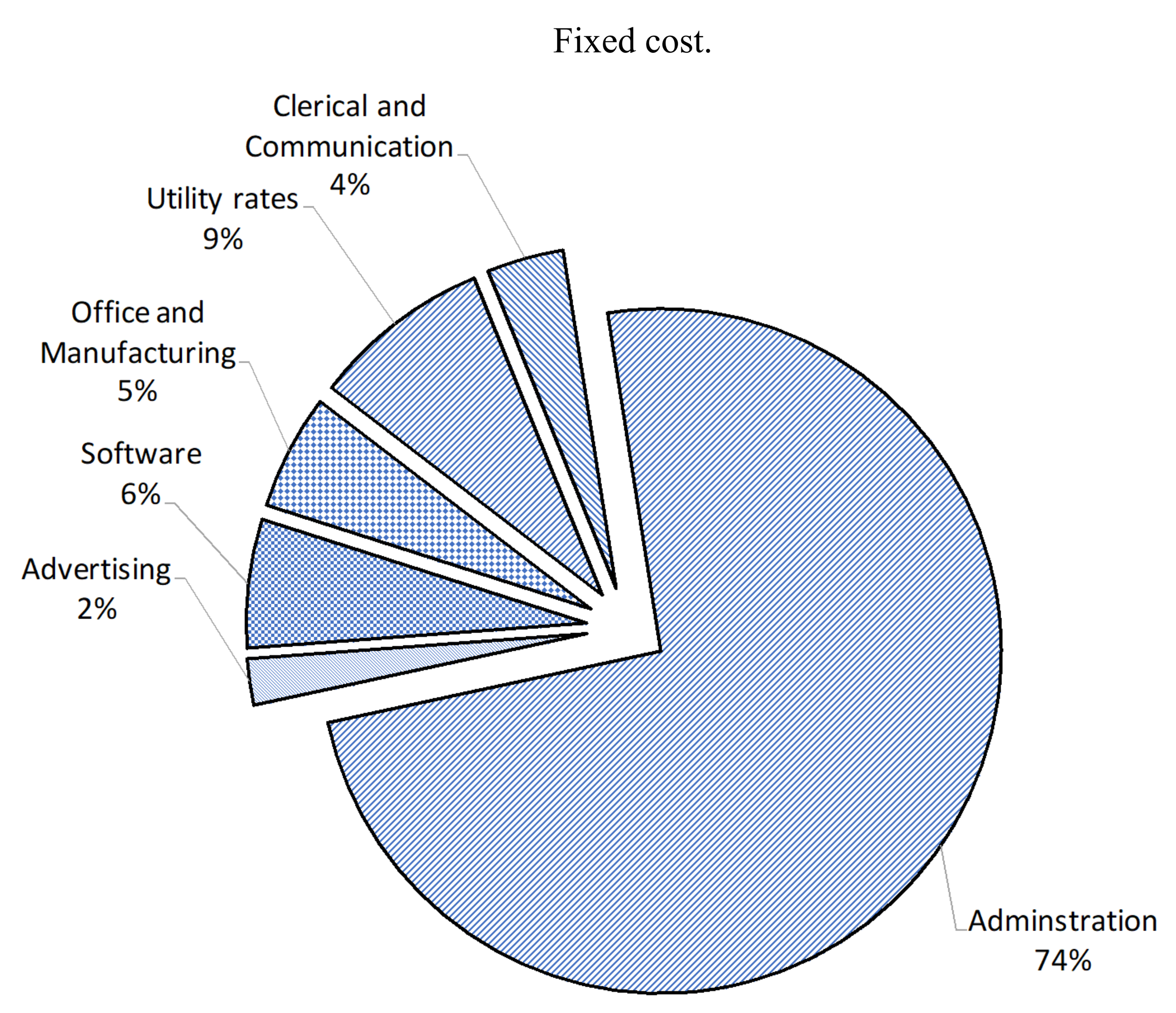


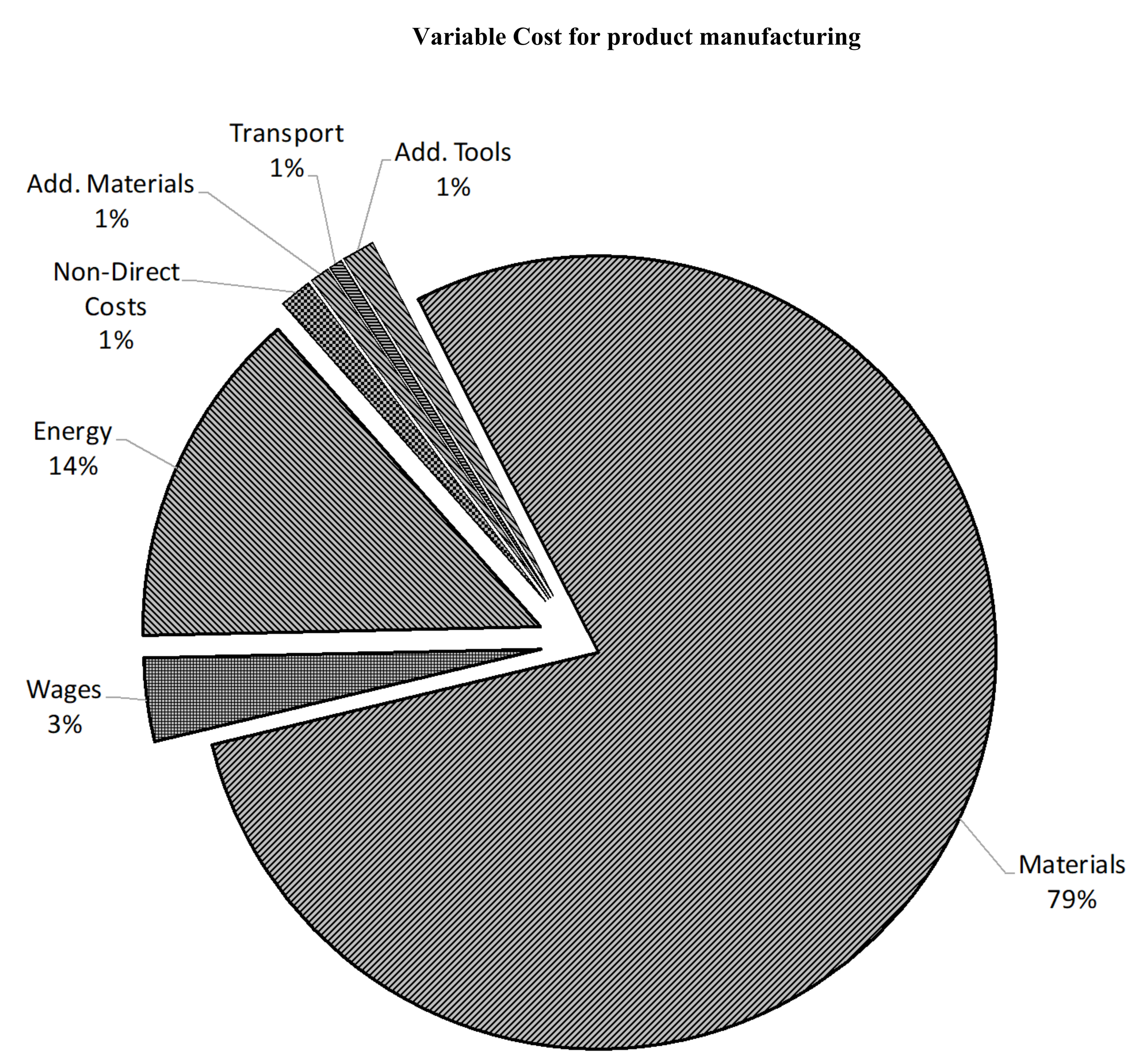
DIN ISO 2768- mk

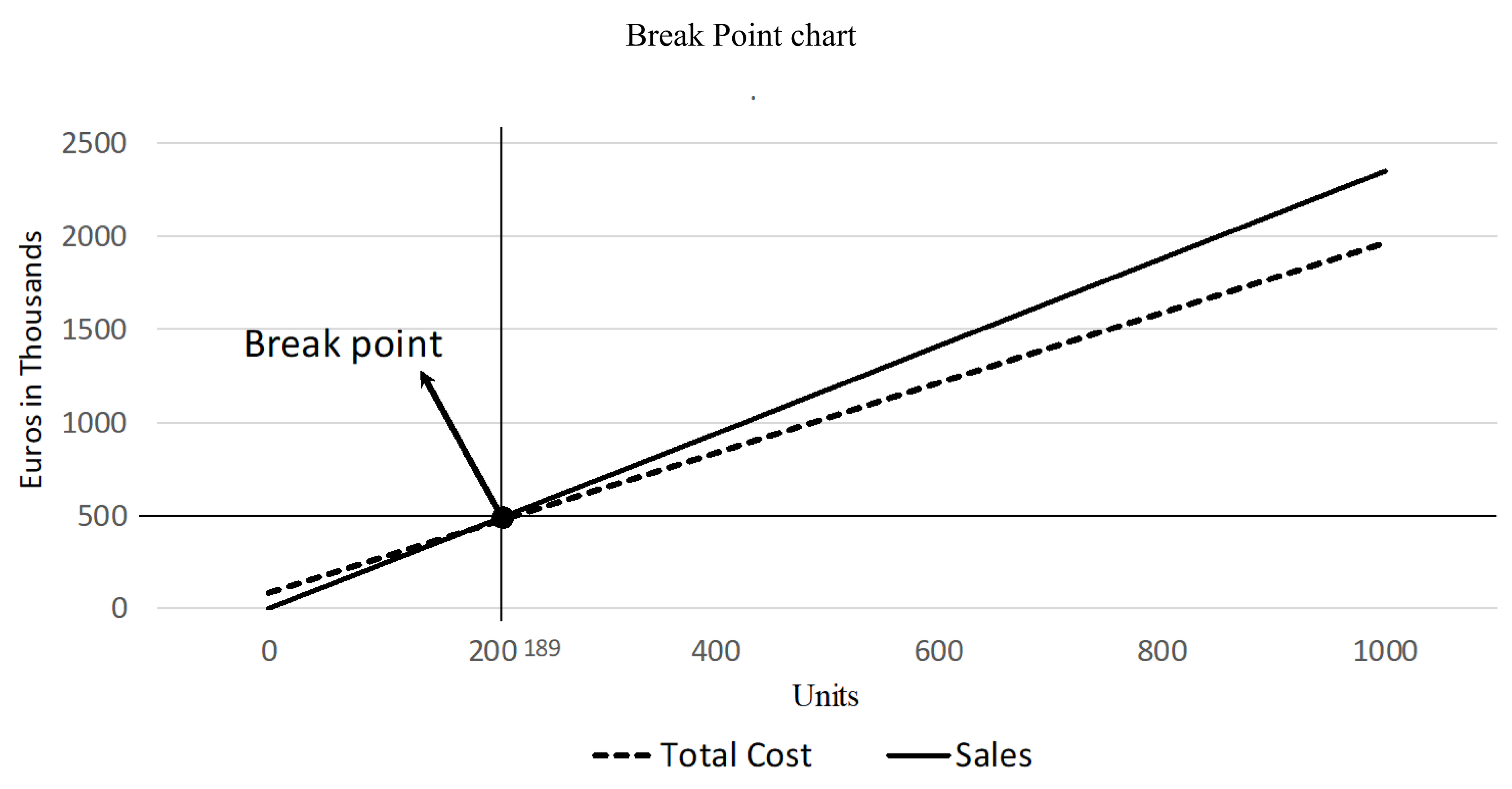
	File no. 1	Additional information	Material: Stainless Steel 304	Scale: 1:5
Responsible agency: MEMD	Consultant	Document type: Part Drawing	Document status: Educational	
Owner: VGTU MPfuc-15	Compiled: HARI SHANKAR GOVINDASAMY	Title: Feeding Deck	Mark: VGTU BM19 25 02 00 24 PD	
	Checked: Prof., Dr. SIGITAS PETKEVICIUS		Rev. 0, Date 19.05.2019, Lan. En., Sheet 5/8	



File no. 1 | Additional information | Material | Scale
Responsible agency MEMD | Consultant | Document type: Control Scheme | Document status: Educational
Owner: VGTU MPfuc-15 | Compiled: Hari Shankar Govindasamy | Title: Design of 3d Printer | Mark: VGTU BM19 25.05.00.00.CS
Checked: Prof., Dr. SIGITAS PETKEVICIUS | Rev. 0 | Date 2019.05.20 | Lan. En. | Sheet 6/8







File no. 1 | Additional information | Material | Scale
Responsible agency MEMD | Consultant | Document type: Economic Indicators | Document status: Educational
Owner: VGTU MPfuc-15 | Compiled: Hari Shankar Govindasamy | Title: Design of 3d Printer | Mark: VGTU BM19 25.04.00.00.G
Checked: Prof., Dr. SIGITAS PETKEVICIUS | Rev. 0 | Date 2019.05.20 | Lan. En. | Sheet 7/8

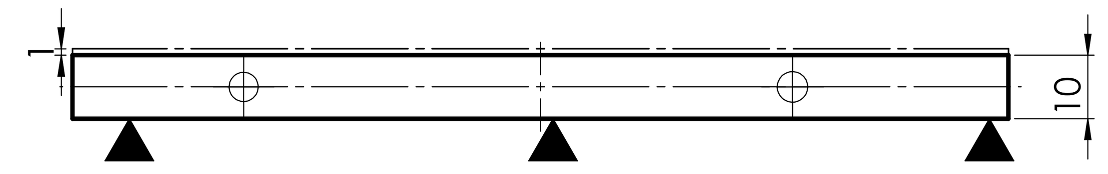
CNC Vertical milling center "HAAS Minimill" coordination sheet			
Part number:	Side frame	Operator:	Harishankar Govindasamy
Part material:	Aluminium 1060 alloy	Date of issue:	2019-05-05
part drawing marking:	MBP.122.434.005.004	Due date:	2019-06-04
Operation number:		Part count:	1
Operation name:	Milling, drilling, tapping		
Program name:	O08041		
Dimensions:	148 X 148 X11		
Holding device:	Vise		

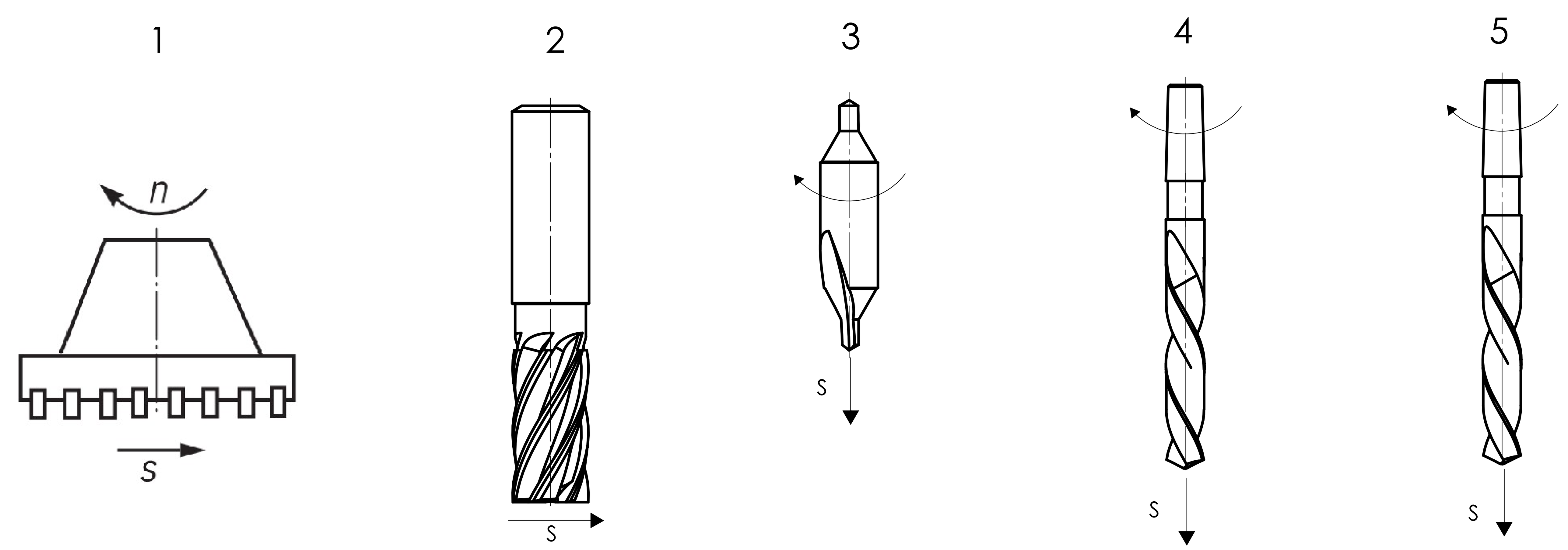
Operation content

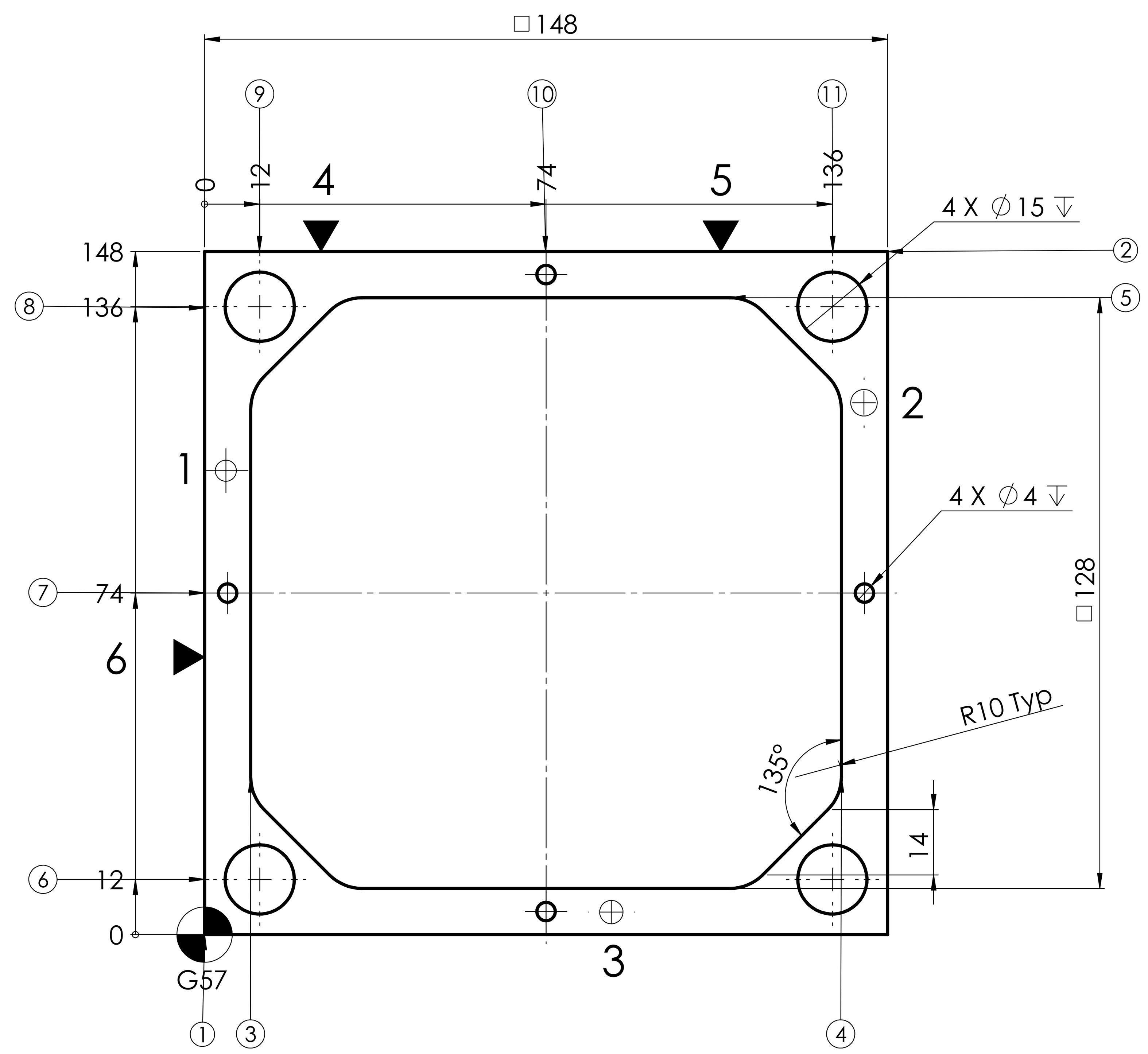
Step no.	Step details
1	Face milling of point 1 and 2 depth 1mm
2	Pocket milling for point 3 to 6 thru
3	Spot Drilling of dia 5mm of dimensions 6 to 11
4	Drilling 4mm from dimesions 7,9 and 11
6	Drilling of dia 14.8mm dimesions 4,6,8,9 and 11

Step	Type	Vc m/min	Vf mm/min	fZ mm/t	n rev/min
1	Face milling	105.38	512	0.08	1600
2	Pocket milling	37.68	640	0.08	2000
3	Drilling	30	400	0.08	1500

Technological Sketches







File no. 1	Additional information	Material: Stainless Steel 304	Scale 1:1
Responsible agency MEMD	Consultant	Document type: Technological Sketch	Document status: Educational
Owner: VGTU MPfuc-15	Compiled: Hari Shankar Govindasamy; Checked: Prof., Dr. SIGITAS PETKEVICIUS	Title: Build Plate Holder -1	Mark: VGTU BM 19 25 03 13 01 TS; Rev. 0; Date 2019.05.20; Lan. En.; Sheet 8/8