KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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Design of Post Processing Equipment for Selective Laser Sintering 3D Printing Technology

Master's Degree Final Project

Supervisor
Assoc. prof. dr. Marius Rimašauskas

KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

DESIGN OF POST PROCESSING EQUIPMENT FOR SELECTIVE LASER SINTERING 3D PRINTING TECHNOLOGY

Master's Degree Final Project

Industrial engineering and management (621H77003)

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"Design of Post Processing Equipment for Selective Laser Sintering 3D Printing Technology"

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Design of Post Processing Equipment for Selective Laser Sintering 3D Printing Technology Lazerinio sukietinimo 3D technologijos baigiamosioms operacijoms skirto įrenginio projektavimas

Approved by the Dean Order No.V25-11-8, 21 April 2017

2. Aim of the project

Design post processing equipment for Selective Laser Sintering (SLS) technology

3. Structure of the project

The work consist of four main chapters named: Review of additive manufacturing and SLS technology; Design of post processing equipment; Most efficient vibration frequency determination; Post processing stations economic review. The work shortly review additive layer manufacturing, especially SLS, present unpacking and sieving station for post-processing operations, justify economic benefit of it.

4. Requirements and conditions

The designed station must be about 80 % cheaper and meet all below listed requirements for it: opportunity to fill or add new powder from powder supply container; opportunity to weigh unused powder; safe workplace for worker and product assurance; sift unused powder and transfer them to supply container; opportunity to easily change sieving nets; opportunity to operate without fill container; comfortable products unpacking.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 20__ ________ __st.

Student ______Tomas Kuncius__________ ______________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor Assoc. Prof. Marius Rimašauskas_ ______________________
(*Position, Name, Surname*) (*Signature, date*)

Tomas Kuncius. Design of Post Processing Equipment for Selective Laser Sintering 3D Printing Technology. *Master's* Final Project / supervisor assoc. prof. dr. Marius Rimašauskas; Kaunas University of Technology, Faculty of Mechanical Engineering and Design, Production Engineering department.

Research field and area: Technological Science, Production Engineering

Keywords: *Selective Laser Sintering, 3D printing, post processing operations*

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SUMMARY

Master degree final project main aim is to become familiar with 3D printing methods, especially with Selective Laser Sintering (SLS) method and with gathered knowledge create post processing unpacking and sieving equipment for it. To achieve this aim these goals and tasks was completed: reviewed main 3D printing methods in today's industry, familiarized with SLS printing technology essence, rules, process (main steps), used materials and other things. After that, unpacking and sieving station prototype was created using "SolidWorks 2016" in regard of gathered knowledge and experience. Final equipment model with sieving and lifting subassemblies was created in evaluation of requirements and researches data. For final model individual parts was created, standard parts, suppliers and manufacturers for it was chosen. Finally, required budget for station manufacturing was calculated and alternatives provided.

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Mokslo kryptis ir sritis: Technologiniai Mokslai, Gamybos Inžinerija

Reikšminiai žodžiai: *Selektyvus lazerinis sukietinimas, 3D spausdinimas, baigiamosios operacijos*

Kaunas, 2017. 58 p.

SANTRAUKA

Magistro baigiamojo darbo pagrindinis tiklas yra susipažinus su 3D spausdinimo technologijomis, ypač atkreipiant dėmesį į selektyvaus lazerinio sintetinimo metodą, sukurti šio metodo baigiamosioms operacijoms skirtą išpakavimo ir sijojimo įrenginį. Norint įgyvendinti pagrindinį tikslą, darbo metu buvo atlikti šie darbai: apžvelgti pagrindiniai šiuo metu egzistuojantys 3D spausdinimo metodai, susipažinta su SLS spausdinimo technologijos esme, taisyklėmis, eiga (pagrindiniais žingsniais), naudojamomis medžiagomis ir t.t. Atsižvelgus į surinktą informaciją ir praktiką sukurtas išpakavimo ir sijojimos įrenginio prototipas naudojantis „SolidWorks 2016“ programa. Įvertinus reikalavimus įrenginiui ir atlikus reikiamus tyrimus, buvo sukurtas galutinis įrenginio modelis su dviem pagrindiniais įrenginio mazgais: sijojimo ir pakėlimo, parinktos standartinės detalės ir sukurtos individualios, parinkti tiekėjai ir gamintojai. Apskaičiuotas reikiamas biudžetas įrenginio gamybai, pateiktos alternatyvos.

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INTRODUCTION

In today’s industry companies searching methods and processes to produce parts, prototypes or even complex assemblies faster, cheaper, without exes work and with less scrap. All production technologies can be divided into two main groups: 1. Traditional technologies (milling, drilling, casting, stamping and others), 2. Innovative technologies (additive layer manufacturing (ALM), laser machining (LM), electrical discharge machining (EDM), electrochemical machining and others). Traditional processes such as milling, turning and others is constantly improving. However, sometimes such methods and equipment cannot be used because of parts complexity, economical or time reasons. Now companies start to search alternatives and one of the best alternative is additive layer manufacturing.

Additive layer manufacturing (ALM) was developed in the 1980 and refers to various processes used to synthesize a three-dimensional object [1, 2]. Differently from traditional processes in additive layer manufacturing object is formed by adding material layer-by-layer, copying shape from CAD file instead of removing material from blank. It let to produce almost any geometry or shape objects, so engineers and designers has a lot of freedom and space to improvise. Moreover from point of view of designer ALM can be called unlimited technology. Futurologists Jeremy Rifkin believe that 3D printing marks the beginning of industrial revolution, which successfully changing the production line phenomenon that dominated in production starting in the late 19th century [3, 4]. From first view it seems that all you need to start manufacturing is computer, 3D printer and material, but it is really so simple?

The main aim of master thesis is to design post-processing equipment for Selective Laser Sintering (SLS) technology.

For achieving this aim, four tasks should be completed:

1. Make theoretical review of additive manufacturing technologies and deeper analysis of selected SLS technology.
2. Design and present post processing equipment.
3. Find out most efficient vibration frequency, for vibro-motor selection.
   - create sieving sub-assembly prototypes;
   - make prototypes sieving test;
   - make statements and present observations of test;
4. Make designed station economic analysis.
   - calculate designed station price;
   - present alternative design according to most expensive elements;
   - economically justify station creation;

1. RIEVIEW OF ADDITIVE MANUFACTURING AND SLS TECHNOLOGY

Today time is one of most valuable resources in our world. Money and time rules today's world and especially industry. Engineers, designers, managers, researchers, logicians and other searching methods to produce and present products and services faster. Shorter production time lets companies to save up money, energy, resources; lets manufacture more in short time and earn bigger profit. Saved up time can be spend to improve current manufacturing processes or to create new more efficient and effective product or process. However, today exists many different tools, which can help save time, increase productivity or minimize costs:

- computer-aided software (CAD, CAE, CAM, QAQC and etc.);
- machining centres, machines with active tools; CNC and coordinate measuring machines, etc.;
- innovative manufacturing technologies (ALM, LM, EDM and others);
- managerial and manufacturing philosophies (JIT, Kaizen, LEAN and others).

Additive manufacturing combines most of above-mentioned tools. It makes production, prototyping, and design operations faster, easier and cheaper.

1.1. ADDITIVE MANUFACTURING

Additive manufacturing (AM) is one of innovative manufacturing technology; it refers to various processes used to synthesize a 3D object. In AM, final product is created layer-by-layer using computer controlled methods. Created parts can be very complex, have various shapes and geometries, can consist of sub-assemblies, and have inner channels because they are produced from 3D model or other electronical source by fully automated process. Additive layer manufacturing can be called 3D printing, additive manufacturing, additive fabrication, additive processes, additive techniques, layer manufacturing, and freeform fabrication [5]. A 3D printer is like the industrial robot. The additive manufacturing started in 1981, when Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two AM technologies [1, 6]. On 1984 Alain Le Méhauté, Olivier de Witte and Jean Claude André patented the Stereolithography 3D printing technology, one of the most popular AM technologies. However, AM technologies never was used to produce end product (mostly used for rapid prototyping) and only in 2010 metal parts such as engine brackets and large nuts was produced by AM technologies instead of traditional methods.

1.1.1. Additive manufacturing engineering and manufacturing process

From the first look, additive manufacturing technologies can look easy and simple. In the reality, 3D printing methods it is a lot more complex. Whole 3D printing process can be divided into three main operations group steps:

- preparation step;
- printing step;
- finishing step.

The first preparation step includes all necessary actions for final printing part file preparation. Picture 1.1 shows, that during this step engineer should prepare part CAD file, check it using CAE programs, optimize it, change part CAD file format to STL or other acceptable AM format, slice part to layers using AM specific software and make final configurations such as parts orientations in printing space.

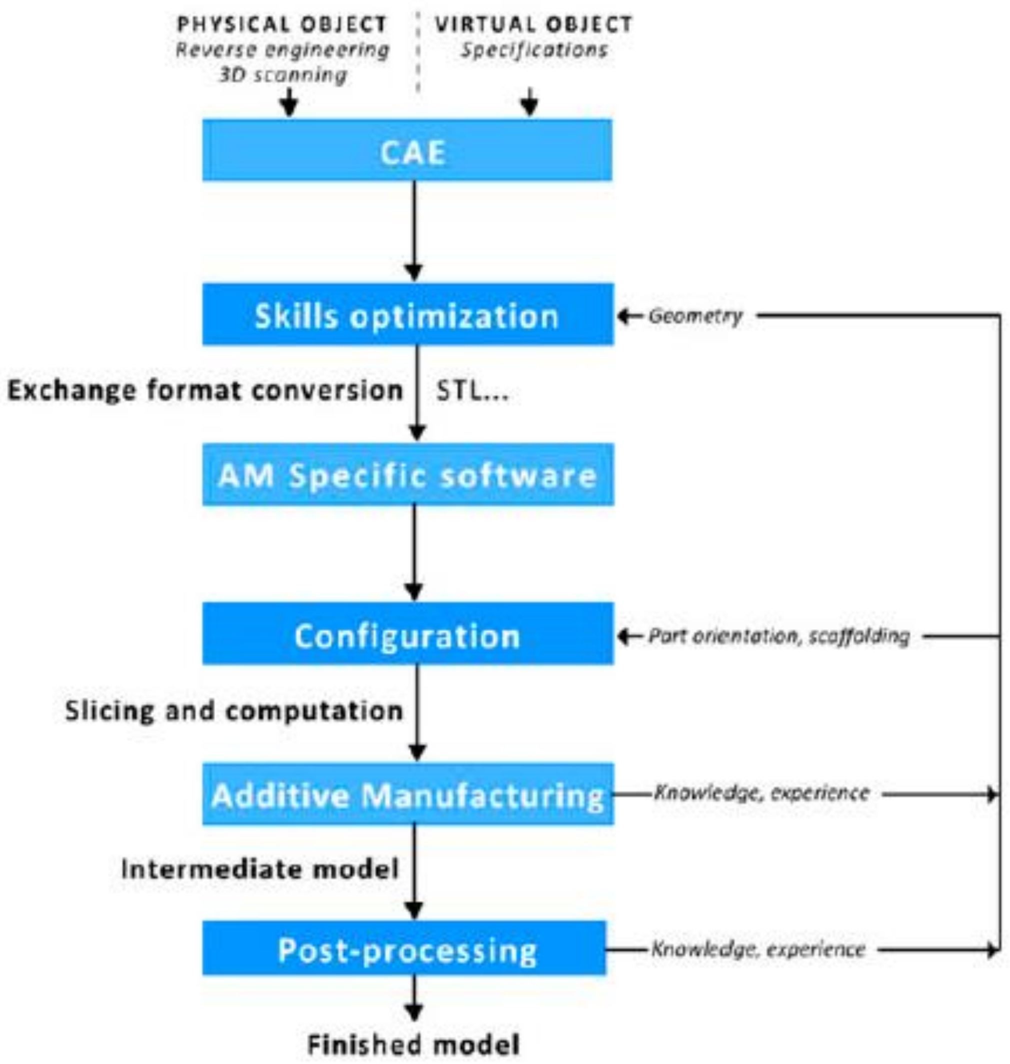


Fig. 1.1 AM engineering and manufacturing cycle [7]

STL (file format)

STL (STereoLithography) is a file format used in AM, which has several different names depending from literature such as "Standard Triangle Language" and "Standard Tessellation Language" [8]. STL as the file format describe only the surface geometry of a three-dimensional object without any other representations of most general characteristics such as colour and texture of it. In STL file object surface is described by triangles, in accordance with several rules, using Cartesian coordinate system. Figure below shows, that triangles number directly affects model accuracy. Number 3 is the best choice for AM, because number 2 distorts real part shape. Number 4 is more accurate than number 3 however, it can cause handle, overlay problems or make process longer.

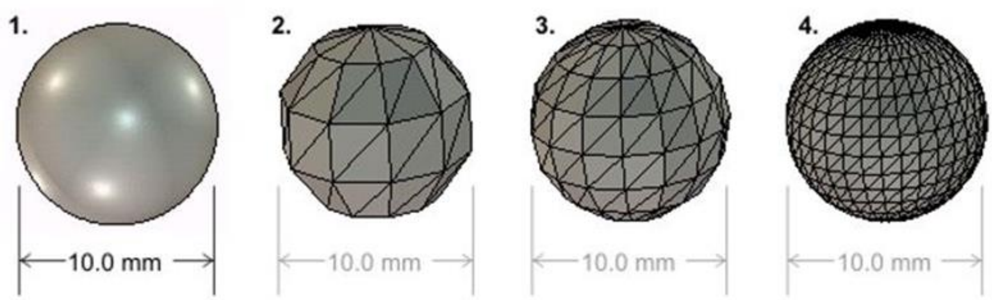


Fig. 1.2 SolidWorks model transformation to stl file format [9]

The second step includes all required actions from printer preparation to printed parts extraction from it. When engineer has final part CAD file, he should choose corresponding AM technology, which depends from final product material. 3D printing offering high variety of materials: plastics, ceramics, resins, metals, sand, textiles, biomaterials, glass, food and even lunar dust [10]. After printing technology selection, printing machine should be fully prepared for printing. This step also include actions after printing process such as cleaning and others. Printed part accuracy and quality depends from several factors, but two of most important is printer resolution and layer thickness. Layer thickness and X-Y resolution is described by printer resolution in dots per inch (dpi) or micrometres (µm). Most common layer thickness is ~100 µm (250 DPI), however, today technologies can offer 16 µm (1,600 DPI) or even thinner layers [11].

The third step is the finishing. This step requires specific skills, materials and equipment. Object after printing should be treated, often it cannot be directly used or delivered until it has been sanded, lacquered or painted to achieve required quality. Sometimes operations such as milling, turning, grinding, polishing or others may be necessary, especially for metal parts.

1.1.2. 3D techniques for each group of materials

As mentioned before additive manufacturing can offer wide range of production materials. Different materials requires corresponding printing technologies. Below presented main materials groups and respective production methods with short description.

Plastic or Alumide

- Fused Deposition Modelling (FDM) Technology – working material is fed to heated printing head or nozzle where it being melted and sprayed layer by layer to create a part.
- ***SLS Technology*** - part is created by selectively sintering plastic or other material powder particles together using laser power. Most commonly used laser type is CO_2. This technology will be deeply reviewed in the second chapter.

Resin or Wax

- Stereolithography (SLA) – is one of the oldest and most common AM technologies. Using this method model or part is created layer-by-layer by hardening photopolymer resin using ultraviolet light source.
- Digital Light Processing (DLP) – almost identical manufacturing process to SLA. The only sharp difference is here photopolymer resin is treated by safelight instead of ultraviolet light.
- Continuous Liquid Interface Production (CLIP) - works by projecting a continuous sequence of UV images, generated by a digital light projector, through an oxygen-permeable, UV-transparent window below a liquid resin bath [10].
- MultiJet printers – printing process essence is comparable to SLA: photopolymer is hardened by affecting it with ultraviolet light. However, this method sprays small drops in the shape of the first layer and lock the desired shape by instantly hardening it by UV lamp attached on the printer head.

Metal

- DLP casting – is the combined manufacturing method for metal parts. This method uses Digital Light Processing to produce model for casting. During casting metal melts wax model and fills mold, creating metal part.
- Direct Metal Laser Sintering (DMLS) - uses a laser as a power source in order to sinter metal powder by aiming a laser and tracing a cross section of the object layer by layer. Direct Metal Laser Sintering is similar to the Selective Laser Sintering process [10].
- Electron Beam Melting (EBM) – similar to DMLS, but instead of laser uses electron beam power as source to melt powder particles.

Multicolor

- Binder Jetting - an automated roller is used to spread a layer of powder onto the build platform. Excess powder is pushed to the sides and ensures that the bed is filled with a layer of packed powder. On a fast axis, the print heads apply a liquid binder and colour simultaneously to create a cross section of the object on the powder [10].

- Selective Deposition Lamination - a 3D printing process using paper. This process is similar to Laminated Object Manufacturing (LOM) rapid prototyping method. The process involves layers of adhesive coated paper (or plastic or metal laminates) that are successively glued together with a heated roller and cut to shape with a laser cutter layer by layer. A roller with the material moves each new sheet of material over the last and repeats the process until the object is completed [10].
- Triple-jetting technology – method that use three different colours material or materials to print precise colourful part by mixing colours.

1.1.3. Advantages/Limitations and applications of AM

After short review of additive layer manufacturing, conclusion can be made, that this innovative technology has some important advantages comparing with traditional manufacturing methods:

- gives designers more opportunities and freedom during design step;
- saves time, materials, money;
- speeds up the design and prototyping process;
- parts design can be changed easily before production;
- parts can be manufactured in few ours.

As all manufacturing methods, it has some problems and drawbacks:

- expensive equipment and materials;
- requires a CAD designer to create part model;
- part complexity directly affects manufacturing expenses;
- printed part can require traditional manufacturing processes for finishing;

From first look may seem that AM technology can be used only for prototypes or few complex parts creation, however today 3D printing finding its place in:

- biomedical engineering;
- aerospace and automobile manufacturing;
- construction and architecture;
- prototyping;
- art and design.

More commonly, it is used for small batch of complex, free form, individual parts manufacturing. Absence of restrictions, creation freedom, higher opportunities, constantly improving methods and materials, fully automated manufacturing process, very small or no scrap is giving AM advantages against traditional manufacturing methods.

1.2. SELECTIVE LASER SINTERING (SLS)

Before wide list of 3D printing technologies was reviewed, which depends from using materials. From the list, Selective Laser Sintering (SLS) was selected as our station design method. Main reasons of choice were:

- need of post processing station;
- absence of alternative stations;
- high cost of original station;
- SLS printing is one of the most promising additive manufacturing technologies;
- very wide used worldwide;
- SLS printing lets produce large number of parts during one session;
- high variety of materials can be used;
- complex parts can be easily produced.

Selective Laser Sintering (SLS) is a maturing additive manufacturing technique, first demonstrated in the 1980s and, which enables fast, flexible and cost-effective fabrication of highly complex monolithic polymer parts [12]. Of all RP techniques, Selective Laser Sintering (SLS) seems to be one of the most consolidated processes to create solid objects, layer by layer, from plastic, metal, ceramic powders or pre-coated sands that are sintered using laser energy. SLS not only reduces the time and cost of prototyping components, obtaining the same dimensional accuracy, surface finish and repeatability as common manufacturing process, but also reduces the energy intensity and the environmental impacts of the process [13]. Selective Laser sintering can be simple explained as additive manufacturing technique that uses a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal (direct metal laser sintering), ceramic, or glass powders into a mass that has a desired three-dimensional shape [14]. In this technology laser power is used to selectively fuse material powder together by following shape description provided by CAD model. After one layer is fully complete, working area is lowered by layer thickness and all actions is repeated until part is finished. Full process way from CAD to final part is provided at subchapter 1.2.2. Because finished part density depends on peak laser power, rather than laser duration, a SLS machine typically uses a pulsed laser [14].

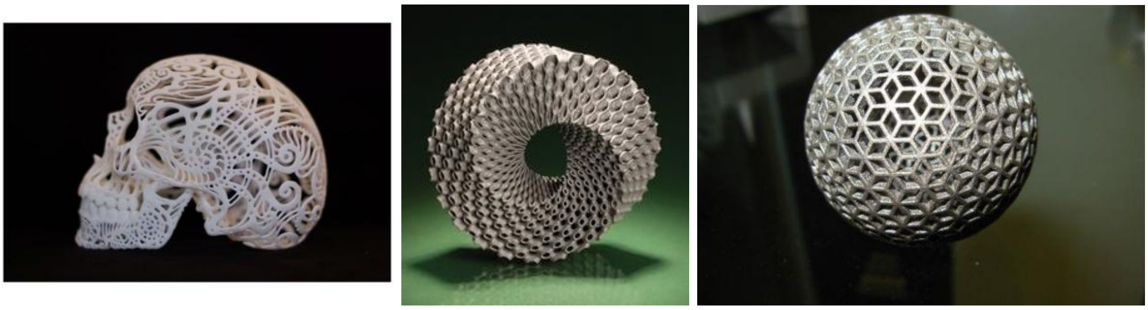


Fig. 1.3 Example of products made by SLS, SLM and DMLS [15, 16, 17]

1.2.1. History

Selective laser sintering (SLS) is a modern manufacturing technology that was created in the 1980s at The University of Texas at Austin's Mechanical Engineering Department (UT ME). Originally developed by an undergraduate and later master's and Ph.D. student Carl Deckard, SLS has grown to be one of the world's most advanced and promising manufacturing methods in use today [18].

1986

Under the guidance of mechanical engineering professor Joe Baeman, Deckard builds first selective laser sintering machine, which they eventually names Betsy [19].

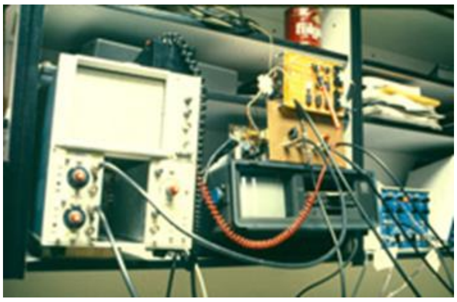


Fig. 1.4 Instrumentation for the Betsy machine: an oscilloscope, Deckard's custom board, a Commodore 64, and scanner drivers [19]

1989

Deckard and fellow graduate student of Beamans Paul Forderhase, build a second SLS machine, called Bambi [19].

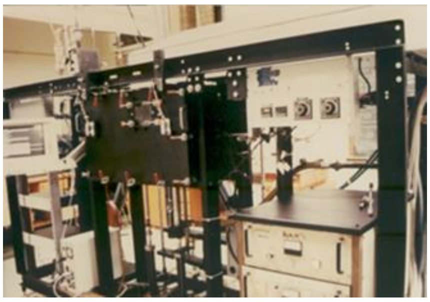


Fig. 1.5 The Bambi machine [19]

1992

Deckard’s and Beamans Company, DTM, launches its first line of commercially successful SLS machines, called the SinterStation [19].

Fig. 1.6 The Beta machine, built in 1992 by DTM [19]

2000

SLS and other layered manufacturing processes begin to be commonly used in production of molds, prototypes and parts that need to be made from strong, durable material. It is widely used in aerospace and medical device industries [19].

2008

Professor Rick Neptune began using SLS to produce custom-fit prosthetics to U.S. veterans. Neptune uses SLS to transform nylon powders into a hard but elastic prosthetic foot [19].

Today

SLS techniques continue to be used in the manufacturing of parts and molds for products in various industries in order to streamline production and development [19].

This subchapter showed, that Selective Laser Sintering took only about thirty years to become really serious competitor for traditional manufacturing methods. SLS technology walked long way from laboratory to industry. Today offering not only rapid prototyping, but and fully automated manufacturing for dental, automotive, aerospace industries.

1.2.2. Way from CAD to the end product

3D printing may initially seem simple and fast manufacturing technology, which does not required a lot of experience, knowledge and post processing operations. Most people imagine that you can simple import CAD file from SolidWorks for example to SLS printer and after few hours hold finished part. Below manufacturing way from CAD to the end of the product step by step for plastic parts can be find:

Step 1 Idea of the product

Engineer designer before starting to create CAD model, should decide what is best way to produce his part. Maybe part is very simple and easily produced by standard manufacturing technologies: milling, drilling, turning, casting etc. and to produce it by SLS technology is uneconomic and inexpedient. Maybe part requires some features like high accuracy and surface roughness or others which access is impossible using 3D printing. If constructer decide to use SLS technology, he should consider all recommendations for printing parts geometry and other parameters.

Step 2 CAD model creation

CAD model can be created using all most common design software for example SolidWorks, AUTODESK Inventor, Rhino, Magic, Freeform and others.

Step 3 CAD format changing to .stl

If CAD program lets, file should be saved as .stl file if not other model format should be changed to .stl using third party software, using this method model can lose accuracy, objects, elements etc., so recommended to create model using programs capable to save parts at .stl format.

Step 4 Model (part) strength and reliability checking

After model, creation it should be checked how it withstands forces during operation time using finite element software such Nastran, CosmosWorks, ANSYS, ADINA or other.

Step 5 .stl model scanning and errors fixing

Even though the .stl file has been created and saved using same software during transformation from native save format .sldrp, .step or .igs to .stl format errors can appear which need to be corrected using software such as Magic or other. During correction model should be monitored all the time because it can lose elements, objects, real form etc. Model can be very inaccurate and cannot be printed.

Step 5 Press preparation

During press preparation, printing detail or details are positioned in space (printer container) using special software in accordance with all the requirements for specific printer or material etc.

Step 6 Prepared press slicing to layers

After press preparation saved project is imported to special software which slice it to layers in specific thickness for example 60 µm, 80 µm, 120 µm, 150 µm.

Step 7 Printing

All printing process can be divided into two smaller steps:

Printer preparation

Cleaning if printer has not been cleaned after last printing, all systems checking (powder containers filling, not used powder containers cleaning, room air temperature, humidity, process container position and air pressure checking), sliced CAD uploading into printer computer, building platform coating with few powder layers, building platform and process container warming until 170 ^{0}C.

Printing

After first step operator starts printing process by pressing button at printer software. Printing process starting by security layers coating (picture below) for example powder from right powder container flowing to recoater and moving to left powder container by laying set layer thickness, after that building platform (stage) descends by layer thickness and recoater lays another layer. When set security thickness is achieved laser starts sintering powders to part (using uploaded CAD) layer by layer. Every job layer is coated by exactly same scheme as security layers and laser sinters every layer. All excess powder is pushed to unused powder containers and will be used once again in future printings.

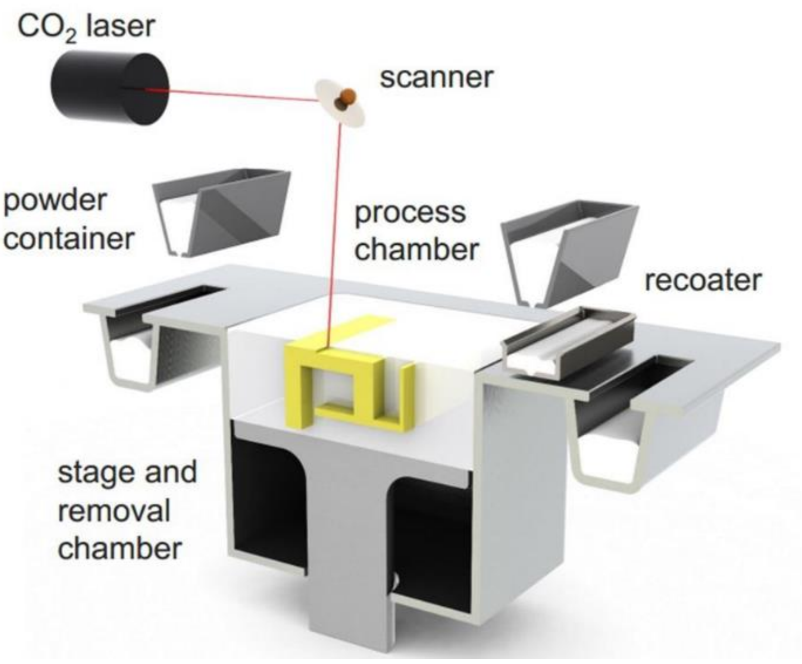


Fig. 1.7 SLS printer scheme [20]

Step 8 Post processing operations

When printing ends operator takes out container with parts and unused powder (picture 1.8), using unpacking station and additional equipment such as different size brushes, needles and others removes all excess powder from parts (picture 1.9). All excess powder will be used again after mix with new powder in proportion 30 – 70, 40 – 60 (old – new powder).

Fig. 1.8 Container content after printing [21]

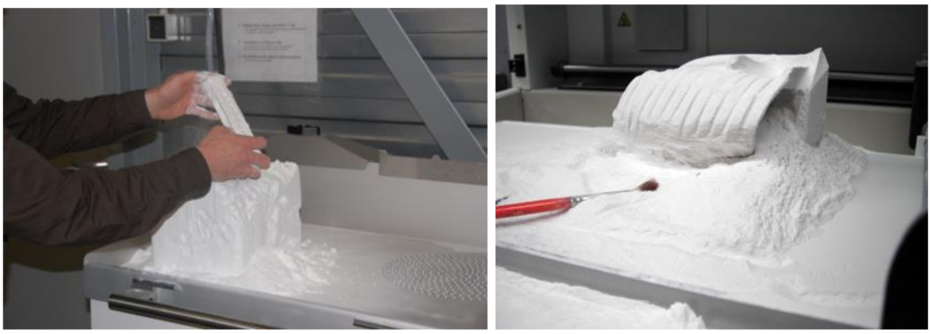


Fig. 1.9 Excess powder removing from parts using unpacking station [22] [23]

After parts is separated from powder, it travel to bead blasting station, where powder is removable from hard-to-reach areas like holes, angles, gaps and etc.

Fig. 1.10 SLS printed part cleaning using bead blasting station [24]

The end post processing operations is parts washing with high-pressure water jet and drying by blowing with air jet or leaving to dry naturally.

Fig. 1.11 Main post-processing operations for SLS printing technology [25]

These steps are only example some of them can be skipped or changed. After understanding main principles of SLS printing, this technology benefits, constrains and applications can be reviewed.

Benefits

As mentioned before Selective Laser Sintering has many important benefits over traditional manufacturing methods. The main advantages are production speed and opportunity to easily and cheap produce complex parts. Prototypes or final assemblies (products) can be produced in a matter of few hours because additional machining steps rarely needed. SLS uses most common alloys, which leads to more suitable and accurate prototype testing. Additive manufacturing technique lets to produce parts, which cannot be produced, or production time and cost is very high using traditional methods such as casting, milling, and turning. SLS can be used for short production runs because it does not require special tools like custom cast, models in casting.

- can produce functional, complex and durable parts;
- parts has high heat and chemical resistance;
- produced parts can have mechanical joints, snap fits or living hinges and inner channels;
- wide variety of materials can be used and parts can be easily processed by traditional methods;
- short lead times;
- creation freedom;
- opportunity to create sub-assemblies.

Constraints

The main constrains of this technology is parts size, feature details, surface finish and potential through errors in the Z axis. However, appropriate build planning can eliminate Z axis errors, surface can be machined using traditional methods. Parts size is limited by 3D printer working area and powder container size. Another big problem is quite high technology equipment price.

Applications

The main industries which using SLS printing for direct parts is aerospace, dental, medical, automotive, tooling and other industries that produce small to medium size, highly complex parts. Selective Laser Sintering ability to produce multiple parts during one cycle lets companies minimize production cost and times, effectively use resources. In addition, this technology can be used for rapid prototyping because it lets to decrease development time for new products.

2. DESIGN OF POST PROCESSING EQUIPMENT

Main aim of the work is to design unpacking and sieving station for EOS SLS printer Formiga P110 shown in picture 2.1.

Fig. 2.1 Formiga P110 EOS printer for SLS technology [26]

The main problem of original EOS Modular Unpacking and Sieving Station is price, which seeks 30000 €. Designed station should be about 80 % cheaper and meet all below listed requirements for it.

Main requirements for unpacking and sieving station:

- opportunity to fill or add new powder from powder supply container;
- opportunity to weigh unused powder;
- safe workplace for worker and product assurance;
- sift unused powder and transfer them to supply container;
- opportunity to easily change sieving nets;
- opportunity to operate without fill container;
- comfortable products unpacking.

In the picture 2.2 the original EOS station can be seen, which will be the basis for designing station.

Fig. 2.2 Original EOS unpacking and sieving station [27]

The station model will be developed using SolidWorks software. After creation of model, information will be gathered, how much standard and specific parts will need, what kind of motors, drives will be used and all design questions will be answered.

Main rules for creating and designing unpacking and sieving station:

a) should be used as mush standard parts as possible;
b) station design should be compact;
c) individual or specific parts should be easily producible;
d) all parts should be easily replaceable;
e) design should be as simple as possible;
f) station should be easily upgradable;
g) station assembly should be simple.

In the picture 2.3 first prototype model created using SolidWorks software can be seen. It is worth mentioning that this concept is not final and can be changed and can be different in the final product.

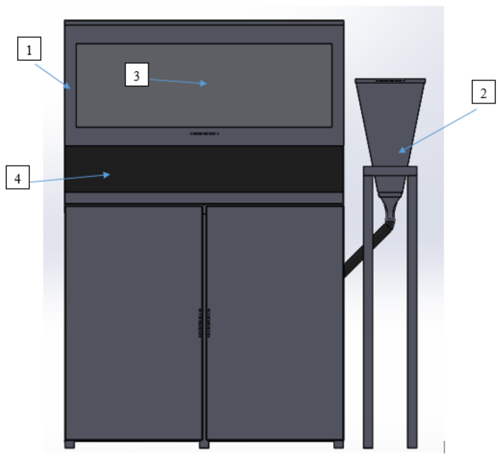
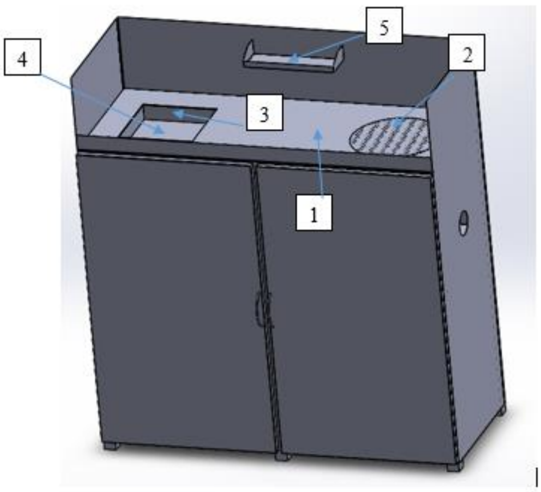
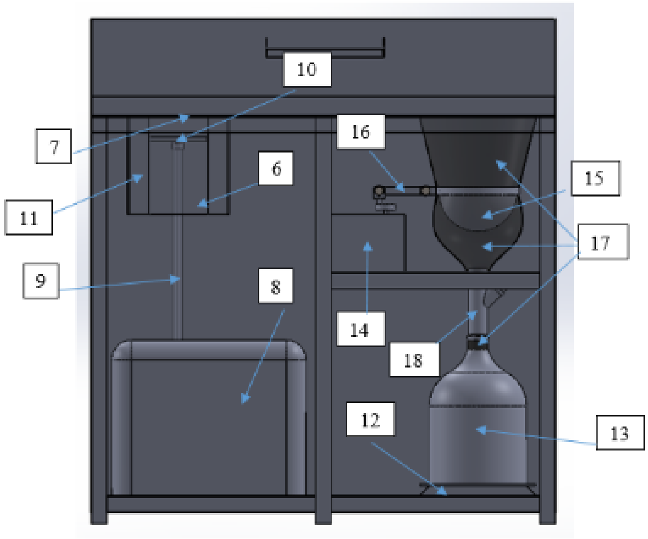


Fig. 2.3 Early designed station prototype with cover and filling container: 1 – cover, 2 – new powder bunker, 3 – glass window, 4 – security rubber

The main difference from original station is cover and new powder bunker. Station is designed with opportunity to operate without them. The main cover purpose is to secure worker and environment from powder. When the cover is closed, worker sees working area through glass and work by putting his hands into the work area through the security rubber. Main filling bunker purpose is new powder provision to powder bunker.



a)



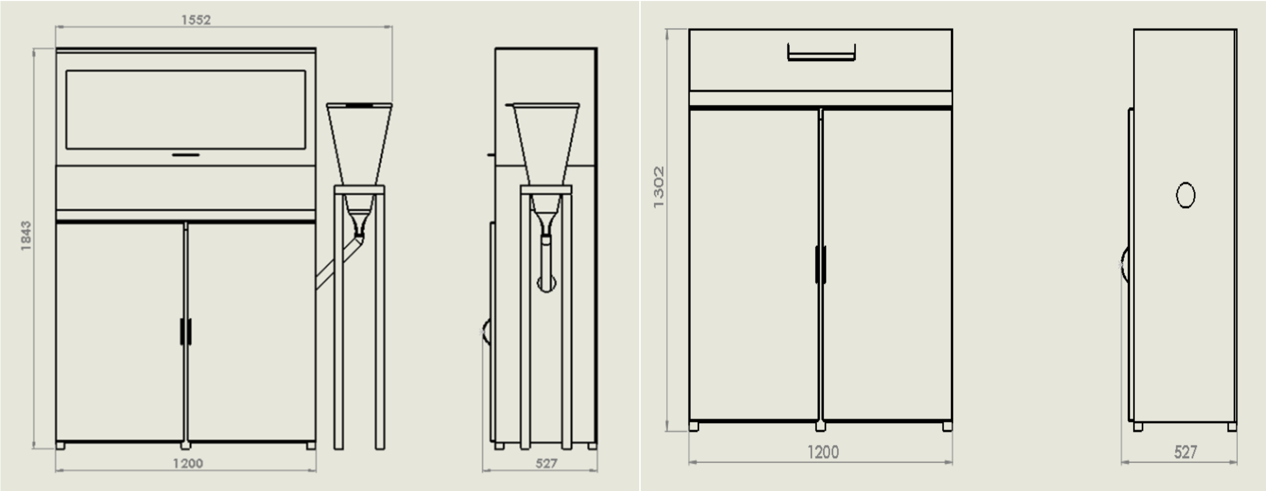
b)

Fig. 2.4 Early station prototype: a) outside and b) inside; 1 and 7 – working area, 2 – large grid, 3 and 6 – print container, 5 – shelf, 8 – electric drive, 9 – worm, 10 – rising plane, 11 – guides, 12 – scales, 13 – sieved powder bunker, 14 – vibrations causing drive, 15 – fine mesh, 16 – joint part, 17 – rubbish joints, 18 – forked tube

At the outside basic station parts can be seen (Fig. 2.4 a). More interesting things and design decisions is revealed inside the station. Fig. 2.4 b presents unpacking and sieving stations interior. Inside, production container is clamped to work area plane using electric drive and worm with at the end mounted to rising plane. Container will be guided by guides to maintain lifting accuracy. The main goal of electric drive is to rise production container to work plane with container content to work area. On the right side, we can see electronic scales with powder bunker, vibrations causing drive, fine mesh which size depends from powder particle size, joint part joins vibration causing drive with fine mesh and rubbish joints. New and sieved powder containers and spreader joint over forked tube. The main spreader goal is to sift unused powder and transmit it to powder container.

Prototype overall dimensions

Below presented dimensions can be different in the final product. These dimensions is only for guidelines for next design and detail step. Picture 2.5 a shows overall dimensions with filling bunker and cover and the picture 2.5 b without filling bunker and cover.



a) b)

Fig. 2.5 Overall early design station dimensions: a) with cover and filling bunker b) without it

Final station design

After early prototype creation, all required information and directions for final station design was gathered. Most important findings:

- most complex and complicated sub-assemblies is lifting and sieving;
- station frame should have opportunity to be easily reassembled;
- guidelines for overall station dimensions;
- most suitable parts and equipment selection;
- guidelines for station design;
- cover and refill bunker is only additions and station can easily operate without it, so final station will be designed without them, but with opportunity to add it in the future;
- final station should consist mostly from standard parts;
- custom parts should be simple and easily producible.

In the picture 2.6, final station model design can be seen. Comparing it with early prototype these main similarities:

- lifting and sieving sub-assemblies kept same position;
- overall design is almost the same;
- size of final station almost identical.

Main differences between stations:

- welded rectangular frame changed with modular frame, for easy reassembly and upgrade in the future;
- final station has four braking wheels and two adjustable legs for mobility;
- two doors design was changed to one door design; right sieving sub-assembly doors was changed with removable security panel.

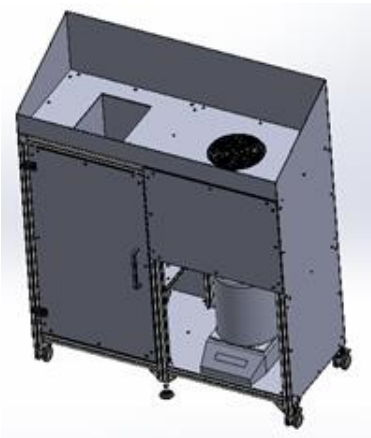


Fig. 2.6 Final station design

Most interesting design decision hiding behind stations doors. Final station interior can be seen in figure 2.7. Comparing early prototype and final model, similarities can be seen. Both stations consist of two main sub-assemblies lifting and sieving with almost identical parts in it. However, in final model we have finalized view. Lifting job will be completed using DC 12V electric car jack, sieving work will be completed using vibro-motor, which will be selected after completion of most efficient frequency research (Chapter 3).

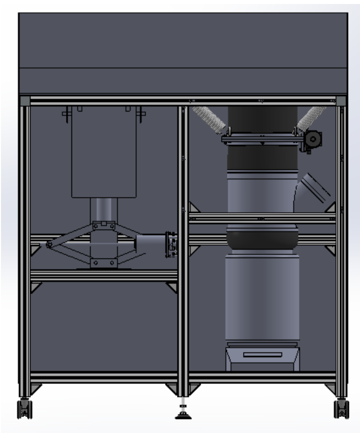


Fig. 2.7 Final design station interior

As mentioned before final station will be designed without security cover and refilling bunker. However, future addition of it is provided right away. Forked tube in the sieving sub-assembly should provide powder directly from refilling bunker to powder container and unpacking area walls keep opportunity easily add security cover in the future.

Final station overall dimensions

Picture 2.9 shows that final station became narrower from 527 mm to 513 mm and higher from 1302 mm to 1480 mm.

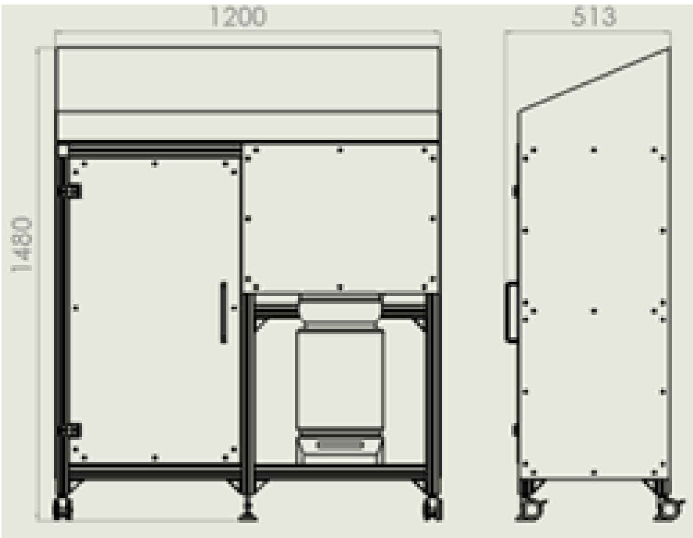


Fig. 2.8 Final design station overall dimensions

Design stations assembly drawings and specifications can be found at appendixes 1 and 2.

3. MOST EFFICIENT VIBRATION FREQUENCY DETERMINATION

For successful excess powder secondary usage, it should be prepared correctly. All excess powder should be sieved using relevant sieving net, which should be selected considering powder particle size. At the picture below, designed sieving assembly can be seen.

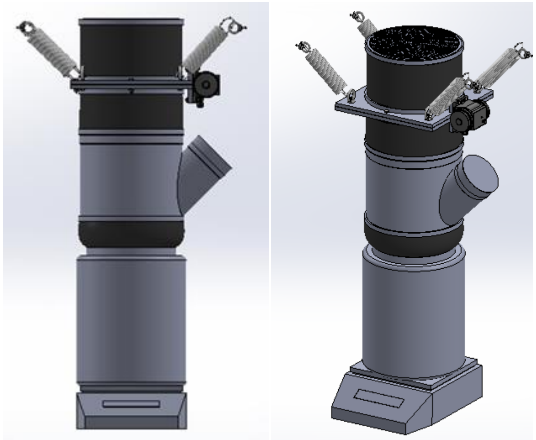


Fig. 3.1 Designed sieving assembly

Sieving cannot be skipped because after printing and parts primary cleaning, a lot of powder being stacked together (figure 3.2). Such powder subjects cannot be used second time, because that will damage SLS printer.

Fig. 3.2 Example of powder accumulations [28]

Sieving efficiency and time directly depends from vibration frequency and system itself. Because not all system impacts for sieving quality can be tested, to find out best frequency, test will be completed only by changing frequency range.

3.1. RESEARCH EQUIPMENT

Because that, designing station is only completed in SolidWorks, for most suitable frequency finding, imitation with similar system by creating two different prototypes was completed. Below presented during research used equipment and main (short) description of it.

Bench scale KERN FCB30k1

Fig. 3.3 Bench scale KERN FCB30k1

Main specifications

Table 3.1 Main scales parameters [29]

Model	Weighing range [max], kg	Readout [d], g	Reproducibility, g	Linearity, g	Min. piece weight [Counting] g/piece
FCB 3K0.1	3	0.1	0.1	± 0.3	0.2

Power amplifier HQ POWER VPA2100MN

Fig. 3.4 Power amplifier HQ POWER VPA2100MN

Main specifications

Table 3.2 Main amplifier specifications [30]

Output power	LED indication	Cooling control	Input connections	Speaker connections	Power supply	Dimensions	Weight
stereo: 2 x 60 Wrms / 4 ohm stereo: 2 x 50 Wrms / 8 ohm	signal, clip, power	auto	XLR and jack 6.35 mm	screw / banana plug	max. 230 Vac, 50 Hz	482 x 240 x 95 mm	7.4 kg

Waveform generator Rigol DG1032Z

Fig. 3.5 Wave form generator Rigol DG1032Z

Main specifications

Table 3.3 Waveform generator Rigol DG1032Z [31]

Channels	2
Signal Output	Sine, Rectangle, Pulse, Ramp, Noise, Harmonics, 160 predefined arbitrary Waveforms, free definineable arbitrary Waveforms

Table 3.3 Waveform generator Rigol DG1032Z [31]

Vertical Resolution	14 bit
Amplitudes	≤10 MHz: 2.5 mVpp to 10 Vpp ≤30 MHz: 2.5 mVpp to 5.0 Vpp ≤60 MHz: 2.5 mVpp to 2.5 Vpp
DC Offset	±5 V (50 Ω)
Sample Rate	200 MSa/s
Frequency Range Sine	1 µHz - 30 MHz
Frequency Range Rectangle	1 µHz - 15 MHz
Frequency Range Pulse	1 µHz - 15 MHz
Frequency Range Ramp	1 µHz - 500 kHz
Frequency Range Harmonics	1 µHz - 10 MHz
Frequency Range Arbitrary	1 µHz - 10 MHz
Frequency Range Noise	30 MHz (-3db)
Resolution	1 µHz

Vibro motor

Fig. 3.6 Vibro-motor

Auxiliary equipment

- container;
- dosing cup;
- vacuum cleaner;
- sieving assembly with net (60 µm);
- frame;

- four springs;
- chronometer (accuracy 0.1 s);

Of course, most important equipment for successful and informative research was two sieving sub-assemblies prototypes. In the pictures below, both of them can be seen. The first one shown in the picture 3.7. It is very simple and early sieving prototype, where sieving grid area is restricted by assembly frame, which is suspended on springs. Vibro-motor causes linear motion and assembly vibrates.

Fig. 3.7 Early sieving sub-assembly prototype

Fig. 3.8 Sieving assembly prototype according to designed station

In the figure 3.8, prototype can be seen, which is almost exact copy of the originally designed station sieving element. Prototype frame is formed from cold rolled stainless steel sheet. Formed cylinder diameter is 238 mm same as in designed station. Vibro-motor purpose is the same as at early prototype.

3.2. RESEARCH DESCRIPTION AND RESULTS

As mentioned before this test results is very important for further station designing, during this test we try to find out several things:

1. Most suitable and efficient vibration frequency and time.
2. How different powder (self-separation and forced separation) affects sieving time.
3. How different system affects sieving time.
4. Try out designed sieving assembly in real test.

Short research process description

Research process starts with all necessary equipment connection and adjustment. One factor should be highlighted, that adjustments made to waveform generator and amplifier was the same during both test with both prototypes. Picture below shows waveform generator settings:

- frequency: 50 -110 Hz, step 5 Hz;
- amplitude: 5 Vpp;
- wave form: sinusoidal;

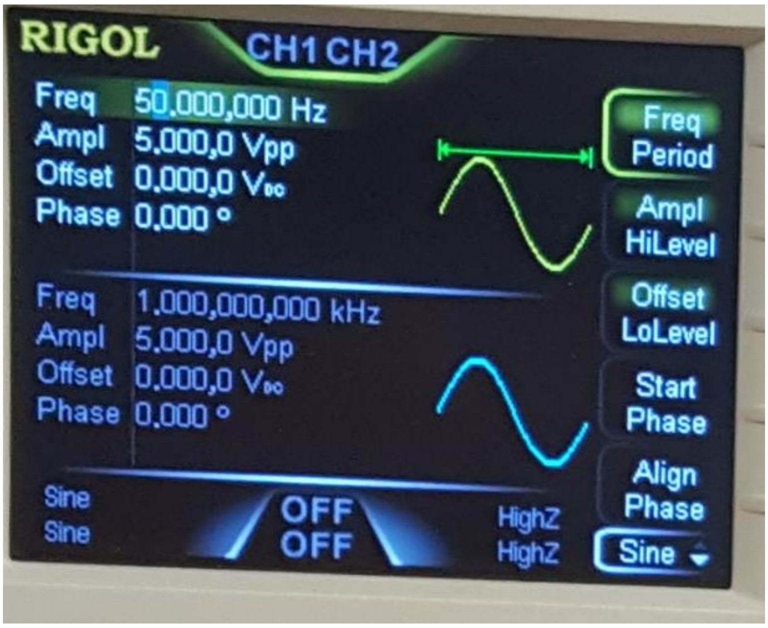


Fig. 3.9 Wave form generator display with setting

Fig. 12 Amplifier setting panel

Figure 3.10 shows that amplifiers power level was set to one fourth of all amplifier power capability.

After equipment preparation and setting, following step was used powder weighing. During both prototypes tests, 300 g used powder was weighed. This amount of powder was selected, because during real sieving operation at designed station powder should not exceed this amount. In the picture below, powder weighing can be seen.

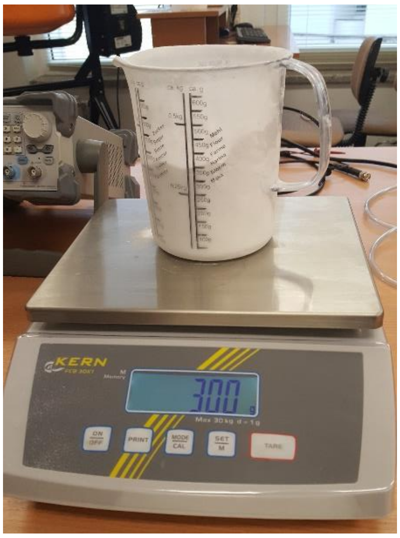


Fig. 3.11 Powder weighing

After weighing, powder was poured to sieving assembly prototype. Sieving test was started from 50 Hz and ended with 110 Hz. During every sieving cycle, sieving process time was recorded. As mentioned before, after every sieving cycle, sieving net was cleaned with vacuum cleaner from powder stacks.

Research results

All research result data presented below in tables and graphics.

Test 1 with early prototype

Fig. 3.12 Early sieving prototype

The first test was completed with two different powder examples:

- self-separated powder – is powder which easily without any force separated from parts;
- forced-separated powder – is powder which separated from parts using outer forces;

Below tests results for each powder example is presented.

Self-separation powder sieving times and graphics

Table 3.4 Self-separation powder sieving time

Frequency, Hz	Time, s
50	26.35
55	25.89
60	23.33
65	23.62
70	21.18
75	20.44
80	18.1
85	17.59
90	18.17
95	18.5
100	19.21
105	22.66
110	23.14

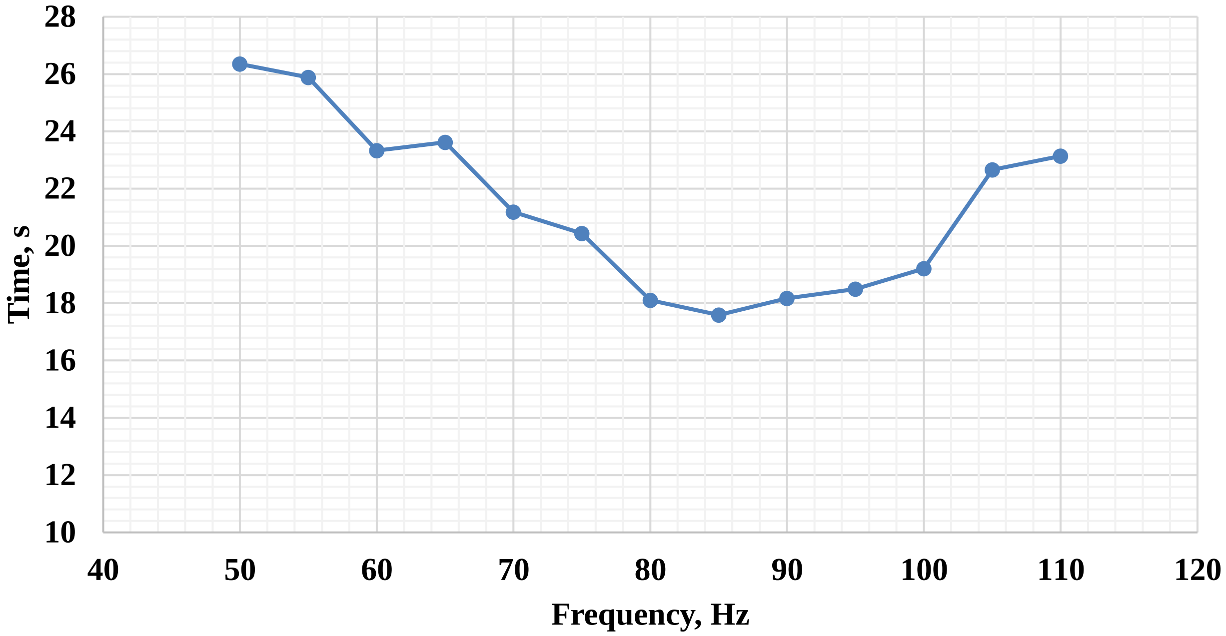


Fig. 3.13 Self-separation sieving time dependency from frequency

Table 3.4 and figure 3.13 shows measured time data. From table and graphic conclusion can be made, that the shortest sieving times was between 80 and 90 Hz, respectively time fluctuated from 18.1 to 17.59 s. For best frequency finding, test was repeated in range from 80 – 90 Hz with step 2 Hz. Results of repeated test can be found in table 3.5 and figure 3.14.

Table 3.5 Fastest frequency section repeated test times

Frequency, Hz	Time, s
80	17.63
82	16.73
84	17.08
86	17.85
88	18.01
90	18.1

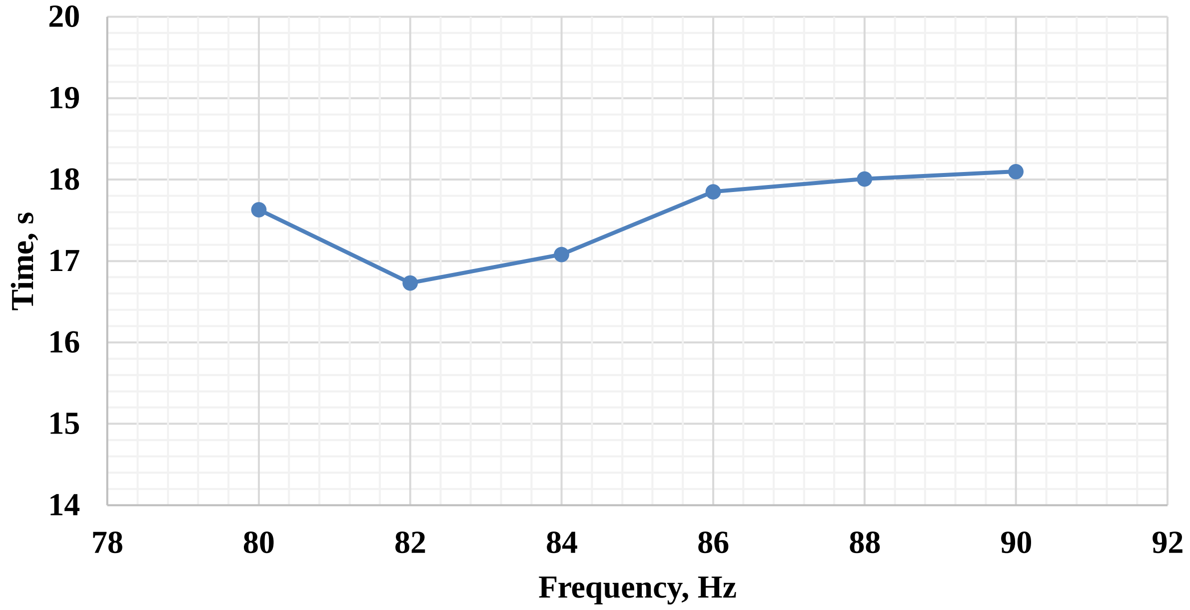


Fig. 3.14 Self-separation sieving time dependency from frequency

Graphic and data in the table shows, that the most efficient frequency for self-separated powder is 82 Hz.

Forced-separation powder sieving times and graphics

Table 3.6 Forced-separation powder sieving time

Frequency, Hz	Time, s
50	32.68
55	36.27
60	30.74
65	22.36
70	20.83
75	16.73
80	15.95
85	15.53
90	18.93
95	19.5
100	21.22
105	21.95
110	22.62

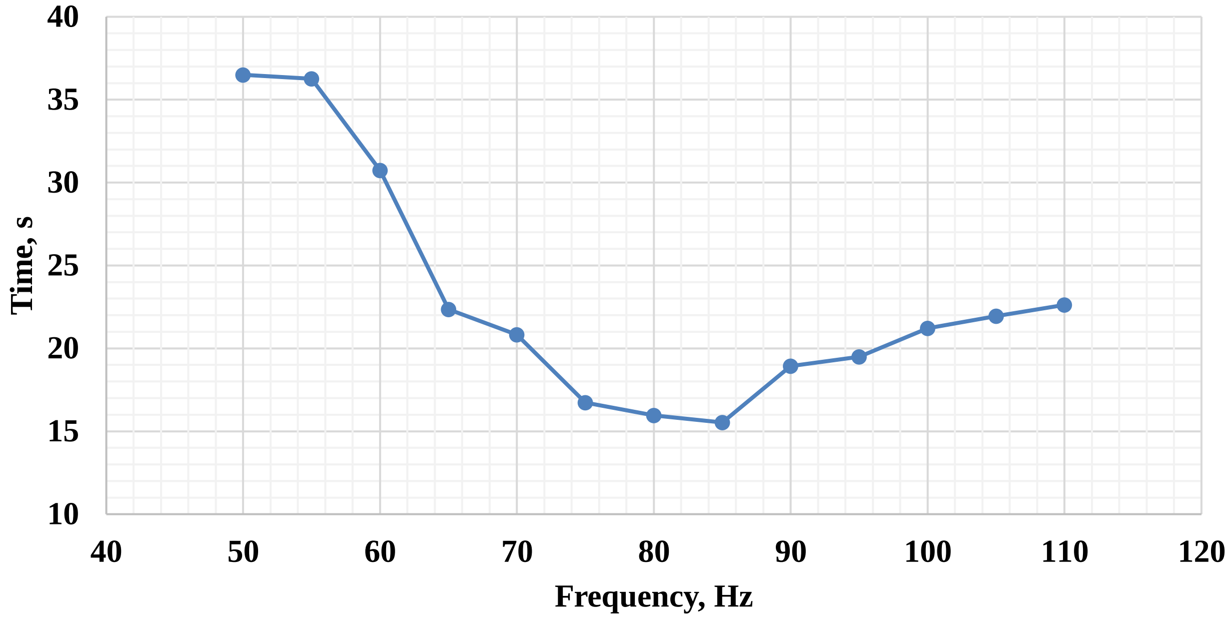


Fig. 3.15 Forced-separation powder sieving time dependency from frequency

In table 3.6 and figure 3.15 measured time data can be seen. From table and graphic conclusion can be made, that the shortest sieving times was between 75 and 85 Hz, respectively time fluctuated from 16.73 to 15.53 s. For best frequency finding, test was repeated in range from 75 – 85 Hz with step 2 Hz. Results of repeated test can be found in table 3.7 and figure 3.16.

Table 3.7 Fastest frequency section repeated test times

Frequency, Hz	Time, s
75	15.94
77	15.61
79	15.92
81	15.81
83	15.83
85	15.6

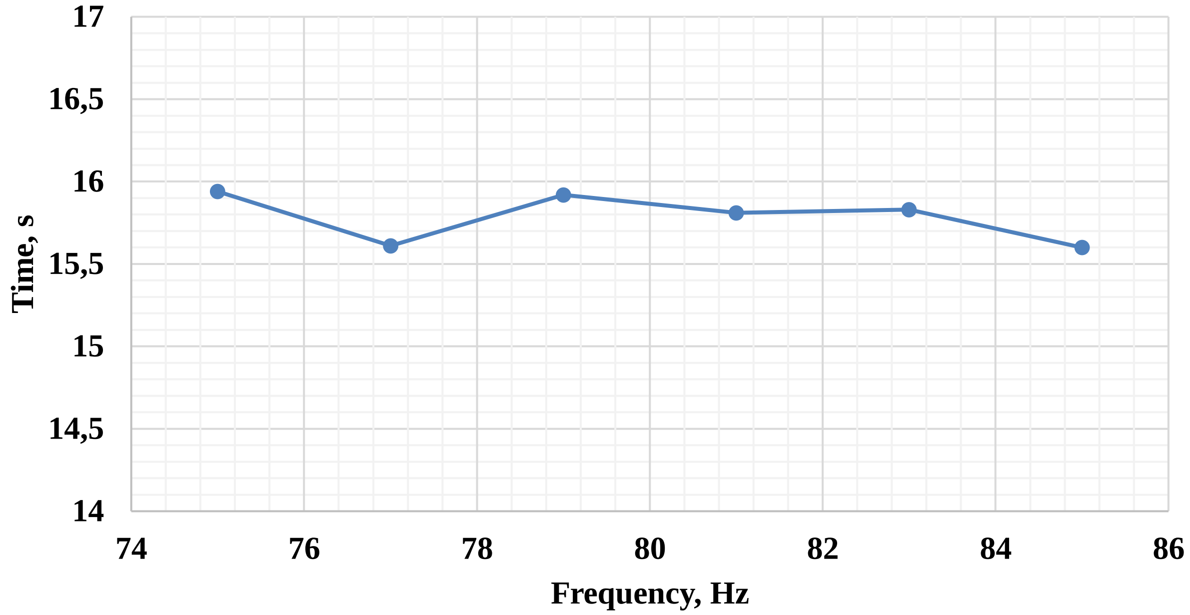


Fig. 3.16 Fastest frequency section repeated test time dependency from frequency

Graphic and data in the table shows, that the most efficient frequency for forced-separated powder is 85 Hz. However, the all range from 77 to 85 Hz is very efficient for sieving.

Remark – Tests showed that forced-separated powder sieving time is 1.13 s shorter than self-separated, but it should be reversed. This is due powder stacks, which remains on net and is vacuumed.

Test 2 with designed station prototype

Fig. 3.17 Designed sieving station prototype

During the second test, designed station prototype was tested, which can be seen at figure 3.17. Cold rolled cylinder part diameter was accurate to designed assembly dimension (D-238 mm). Test results can be found below. Test was completed only with self-separated powder, because as seen from the first test powder seperation have not significant influence.

Table 3.8 Second test with designed station prototype

Frequency, Hz	Time, s
50	90.3
55	89.94
60	89.45
65	88.34
70	88.13
75	88.21
80	80.15
85	75.32
90	82.15
95	91.2
100	92.1

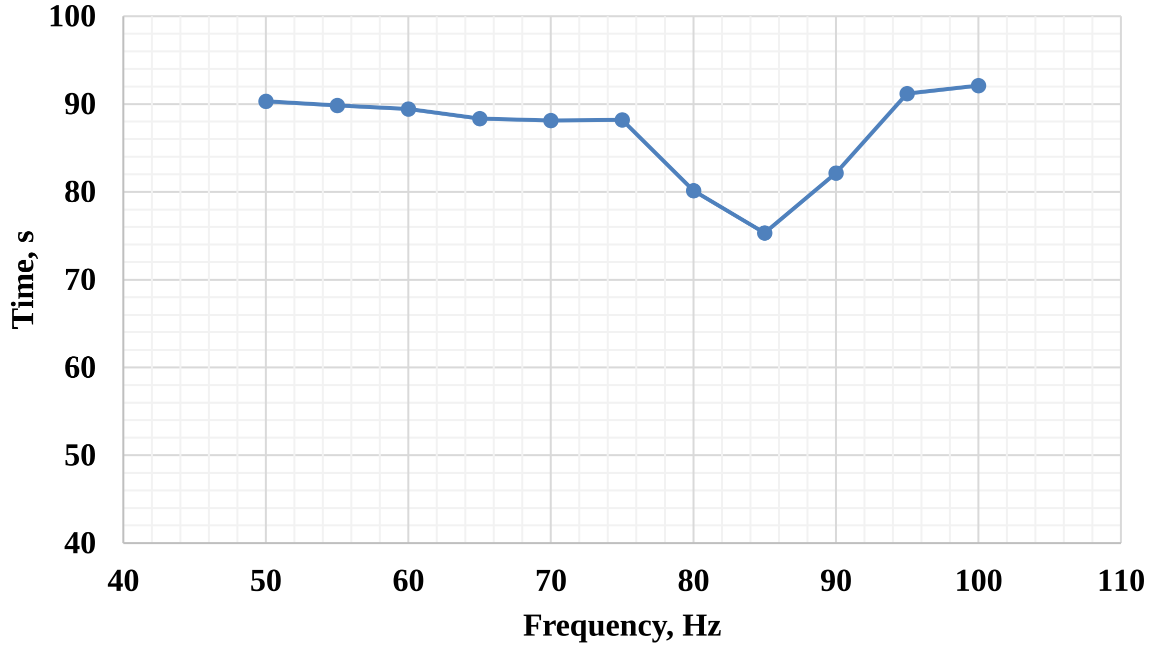


Fig. 3.18 Second test with designed station prototype, time dependency from frequency

Table 3.8 and figure 3.18 shows, that prototype shortest sieving time was 3.5 times longer than with early prototype. The main reason for that is smaller work (sieving) area, changed system (more stretched springs influence more solid system). During this test, was found that exactly the same tendency is valid and for this prototype, most beneficial frequency range is from 80 to 90 Hz. From this, conclusion can be made that frequency range about 80 - 90 Hz is most beneficial with different system and vibro motor for real sieving station should be selected in this frequency range.

Test conclusion

During these test, was diagnosed powder sieving time dependence from vibration frequency at different conditions and found most efficient vibration frequency for designing unpacking and sieving station, which after test was in range from 80 to 90 Hz. After test with two different sieving systems, conclusion and remarks can be done:

- sieving time strongly depends from system itself, especially from sieving area size and systems flexibility;
- sieving time is independent from powder separation;
- most efficient frequency range after tests is about 80 - 90 Hz and vibro motor should be selected in this vibration frequency;
- designed system is functional and prepared for manufacturing.

As from first look 80.15 seconds its long time, however factor that system in real product will work closed and vibrating assembly will work all unpacking time can be forgoten. From that conclusion can be made, that sieving assembly fulfil its duty properly. By the way, that time can be minimized by making system more flexible.

4. POST PROCESSING STATIONS ECONOMIC REVIEW

Designing is only the first step in the way to the final product. Other very important factors should be considered such as:

- budget;
- suppliers;
- design alternatives;
- final product price;
- competitors;
- strengths, weaknesses, opportunities and threats;
- others.

This chapter presents approximate station price, possible alternatives of station design according to most expensive assemblies, short competitors review, SWOT analysis and manufacturing economic justification.

4.1. DESIGNED STATION PRICE REVIEW

As stated before, the main reason of this custom station creation was very high price of original station. Before development of unpacking and sieving station, aim was set, that designed station should be about 80 % cheaper than original, so it should cost no more than 6000 €. For better understanding of main required parts groups for station manufacturing figure 4.1 is presented.

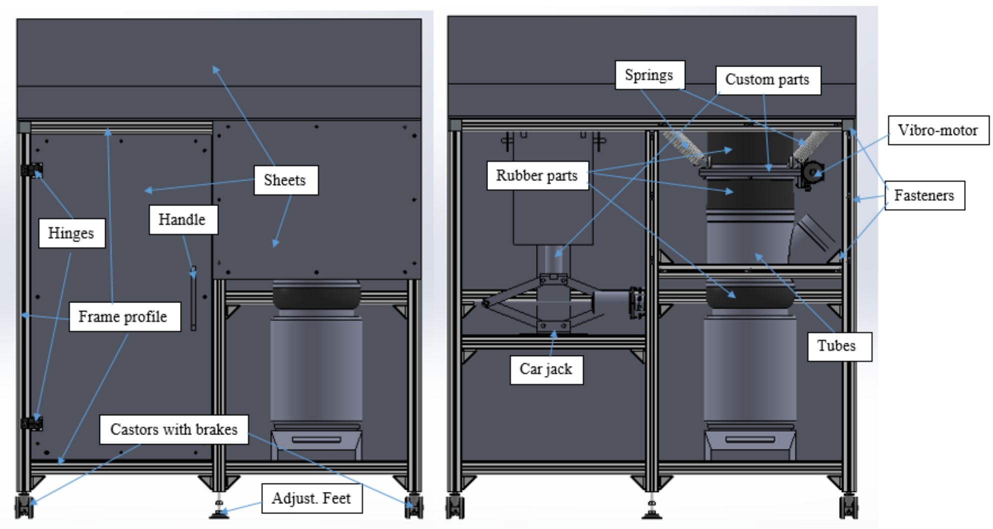


Fig. 4.1 Final design station main parts and part groups

To find out how much designed station will cost, Lithuanian companies, which can be possible suppliers and manufacturers of required elements was reviewed. In the Table 4.1 brief list of needed parts groups and approximate prices of it, that helps to calculate overall designed station price, is presented. More detailed prices summary can be found at appendix number 3.

Table 4.1 Parts and part group approximate price

Part or Parts group	Overall price, €
Frame profile	537.13
Sheets	250.64
Fasteners	409.46
Handle	2
Hinges	11.64
Castors with brakes	16
Adjustable feet	35.28
Custom parts	200
Car jack	93.64
Rubber parts	60
Springs	25
Tubes	69.56
Vibro-Motor	200
Total:	**1910.35**

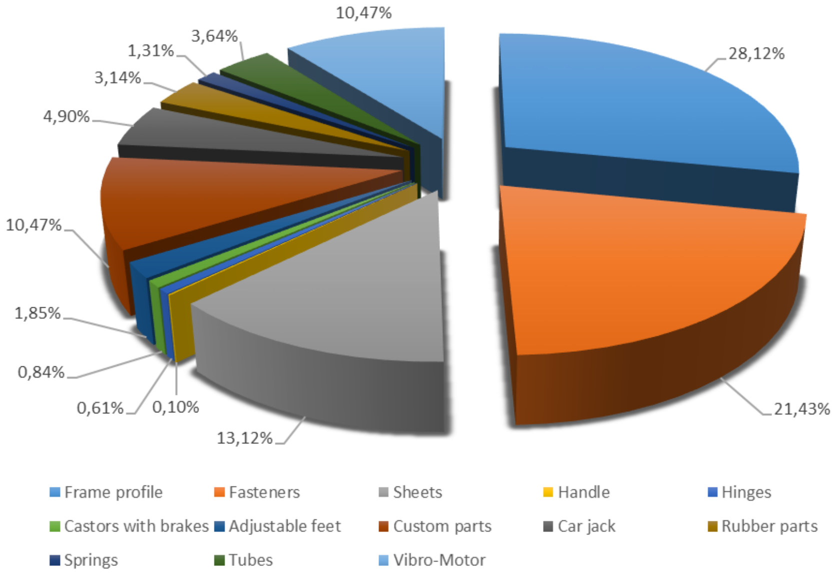


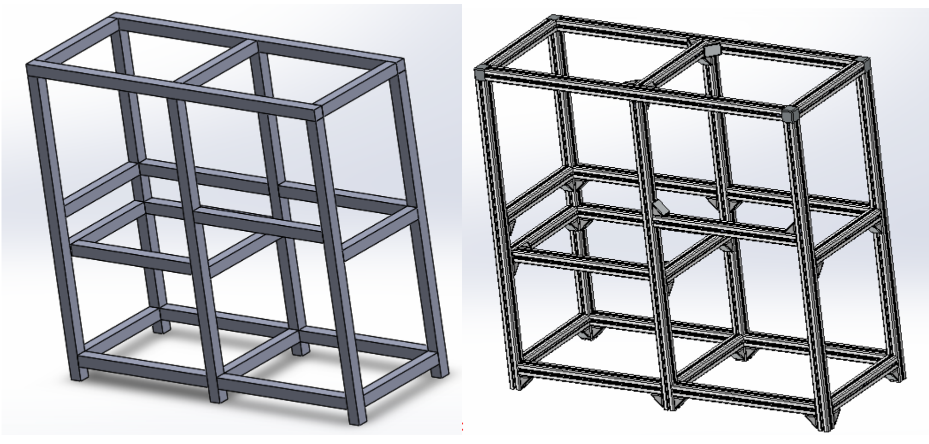
Fig. 4.2 Elements percentage of overall station price

Table 4.1 and circular diagram, shows that most expensive part groups of designed equipment is fasteners and profiles: respectively 21.43 % and 28.43 % of overall station price. However, overall price (1910.35 €) is a lot smaller than the set budget 6000 €. One very important factor should be highlighted, that during overall station price calculation only price of parts was included. Things like cost of designing and assembling processes not included, because all these works will be completed by me and at this time, only one station is planned to manufacture.

At the end the conclusion can be made, that aim of 20 % price from other alternatives stations was achieved successfully and about 13 % was reserved for earlier mentioned additional expenses.

4.2. ALTERNATIVE FOR STATION DESIGN

Earlier price analysis showed that two elements groups or in other words frame assembly consist half of overall price. To minimize these expenses, alternative could be found. One of simpler and most effective alternative is to change modular frame profiles to simple aluminum rectangular profiles. That means frame and left door sub-assemblies should become cheaper. In the figure 4.3 both alternative (a) and original (b) station frames can be seen. Both frames has exactly the same design and size 40x40 mm. The main difference between them is that alternative frame profiles will be joined by welding. Cheaper profiles and simple fastening should minimize most expensive assembly's price significantly. In the Table 4.2 cost difference between sub-assemblies before and after can be seen. During price calculation only part prices was included without additional works.



a) b)

Fig. 4.3 Frame assemblies: a) alternative welded frame, b) original modular frame

Table 4.2 Price comparison between alternative and original station design

Frame			
Alternative		Original	
Profile			
Total, €:	72.48	Total, €:	462.15
Welding		Fasteners	
Total, €:	371.2	Total, €:	343.98
Overall total, €:	443.68	Overall total, €:	806.13
Left doors			
Profile			
Total, €:	11.83	Total, €:	74.98
Welding		Fasteners	
Total, €:	25.6	Total, €:	36.68
Overall total, €:	37.43	Overall total, €:	111.66
Frame total price €:	481.11	**Frame total price €:**	917.79

Table 4.2 shows that overall savings by selecting alternative design solution will be about 436.68 €. That is approximately 22.87 % from overall designed station. That is quite a big saving, however original design have some very important advantages, which outweighs it:

- modular frame lets easily change damage parts;
- using modular parts station can be easily reassembled;
- in future frame can be adjusted depending from situation and requirements;
- it gives opportunities to upgrades station in the future;
- modular frame is more durable and stronger.

Of course, alternative design station can be manufactured, if above listed statements looks not significant or price is most important factor for customer.

Economic analysis of different designs showed:

a) The cost of developed design based on extruded aluminium profiles was approximately 1910.35 €.

b) The cost of alternative design based on standard aluminium profiles was approximately 1473.73 €.

However, before final decision all advantages and disadvantages like flexibility, easy of assembly, welding process and other should be considered.

c) Both presented stations are much cheaper that other alternatives existing in the market. For detailed economic analysis assembly time of different processes, should be considered.

Picture 4.4 perfectly illustrates prices differences between EOS unpacking and sieving station and designed station with original frame and alternative.

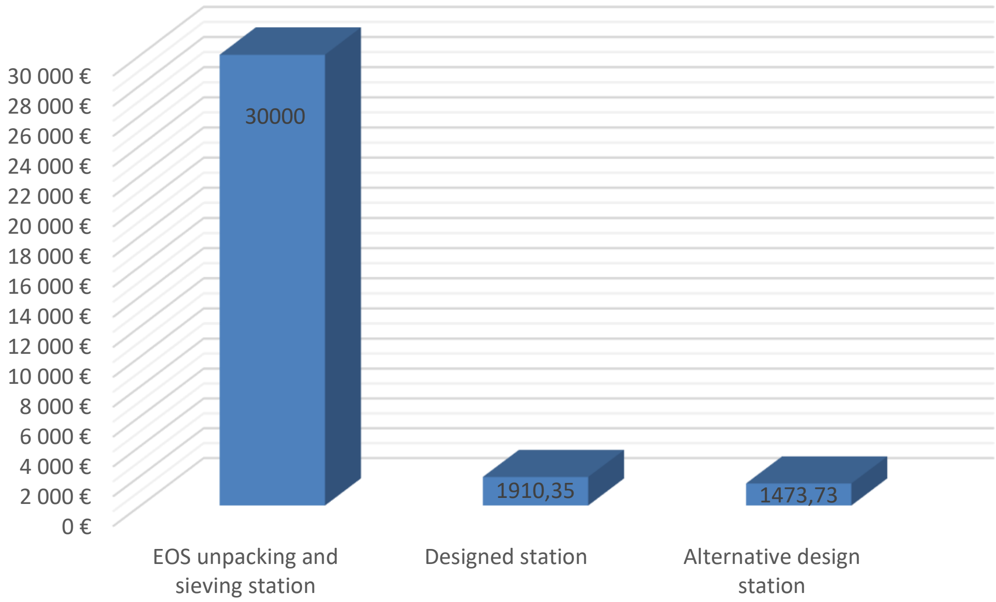


Fig.4.4 Price difference between stations

4.3. COMPETITORS REVIEW

As mentioned before Selective Laser sintering is one of the most promising and efficient additive layer manufacturing technologies. However, only two companies control most of SLS market: EOS and 3D Systems.

The only one, which produce post-processing stations for its printers, is EOS. At this time every company which use SLS printers does not have any alternatives and should purchase manufacturer stations or design individual. The biggest problem of manufacturer equipment is price and standardization.

Main competitor review

EOS is the global technology and manufacturer of Additive Manufacturing (AM) equipment. Founded in 1989, EOS is a pioneer and world leader in the field of Direct Metal Laser sintering (DMLS) and provider of a leading polymer technology. For these industrial 3D Printing processes, EOS offers a modular solution portfolio including systems, software, materials, technical and consulting services.

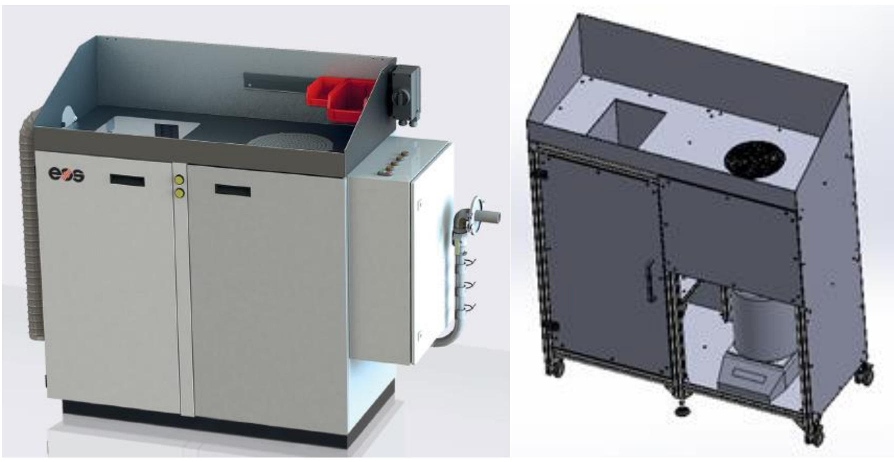
Strengths of EOS: Experience, brand, monopoly, leadership in SLS technology

Weakness of EOS: Low competition, standard products

Fig. 4.5 Positioning map

Picture above shows targeted position of designed station in comparison with competitor. The main criteria is device individuality level and price. Map shows that custom station offering high individuality and reasonable price unlike the competitor product.

Stations comparison



a) b)

Fig. 4.6 Unpacking and sieving stations: a) EOS, b) designed

Figure 4.6 shows individual designed and original EOS unpacking and sieving stations. Below presented main similarities - differences between designed and EOS stations.

Similarities:

- both of stations main purpose is to unpack and sieve;
- both of stations have similar build: sieving elements, unpacking elements;
- both of them make unpacking and sieving more comfortable, easier and faster;

Differences:

- designed station can be produced with specific requirements;
- user can choose almost everything from dimensions to materials and design;
- designed station is easily relocatable;
- designed station comes with scales for faster powder mixing;
- price;
- easier maintenance and opportunity to upgrade because of construction;
- opportunity to participate in product creation process.

4.4. SWOT ANALYSIS

For better understanding of designed stations strength and weakness and identification of both the opportunities and the threats for it now and in the future Strengths, Weaknesses, Opportunities and Threats analysis was be made.

Table 4.3 SWOT analysis

Strengths	**Weaknesses**
Individual design	New product (name) in the market
Any dimensions	No international market experience
Recyclable parts and materials	New relations with partners
Only one direct competitor at this time	High dependence from SLS technology popularity
Low price	Dependents from partners and suppliers
High customizable product	Narrow product line
Easy to maintain and clean product	Not first priority product
Opportunity to easy upgrade	Dependents from printer manufacturers
High mobility	
Easy assembly	

Table 4.3 SWOT analysis

Opportunities	**Threats**
Growing additive manufacturing market	Big competition in future
Developing east markets	Economic recession
Wider partnership with partners	Complex client requirements
More deeply participation in R&D of 3D technologies	Competitor has superior access to channels of distribution
Deeply integration in automated production	Low investments to unknown product (company)
More features	

Table 4.3 shows that main strengths of the station is low price and custom-individual design. Post-processing equipment can be manufactured following customer requirements and wishes. However, high customizable product requires many different parts, slow manufacturing process and makes station very depended from suppliers and partners. These weaknesses can be eliminated or minimized by developing closer and wider partnership with partners, expanding market and suppliers circle. Of course, the biggest threats is high future competition, economical situation and investments attraction.

4.5. CUSTOM STATION CREATION ECONOMIC JUSTIFICATION

In the earlier chapters need of unpacking and sieving station was reviewed and analysed. As mentioned before the main reasons for designing equipment was:

- high price of original station;
- more comfortable unpacking;
- easier used powder preparation for second usage;
- **faster and less work steps requiring unpacking and sieving.**

Time in today's world is one of most valuable resources. Time is money and station should minimize time required for post processing operations after printing. Today in the university, all with post-processing linked works is completed at two different equipment: unpacking table (Fig. 4.7) and sieving assembly:

- earlier sieving assembly before prototype creation (Fig. 4.8 a);
- sieving assembly prototype manufacture according to designed station (Fig. 4.8 b)

Works distribution at different equipment makes unpacking and sieving process longer, more complicated and uncomfortable. Designed station should join both of these processes. This chapter presents how much time it lets to save.

Fig. 4.7 Unpacking table

a) b)

Fig. 4.8 Sieving prototypes: a) early sieving assembly, b) later sieving assembly

For time saving approximate calculation test was completed. After printing, required time for unpacking and sieving was recorded. Gathered data with operation steps was filled in the table 4.4 left side. In the right side of the table approximate steps and time, working at unpacking and sieving station was recorded.

a) b)

Fig. 4.9 Post-processing; a) container after printing, b) powder removing from parts

Table 4.4 Post-processing approximate times in minutes

Two different equipment: Unpacking table and sieving subassembly		**Designed unpacking and sieving station**	
Operation	Time, min	Operation	Time, min
Container content lifting	4	Container content lifting	1
Content cooling time	20	Content cooling time	20
Parts unpacking	60	Parts unpacking and unused powder sieving and weighing	60
Unused powder transportation to sieving subassembly	2		
Normalized unused powder sieving	30		
Sieved powder gathering	15		
Sieved unused powder weighing	5		
Total time:	**136**	**Total time:**	**81**

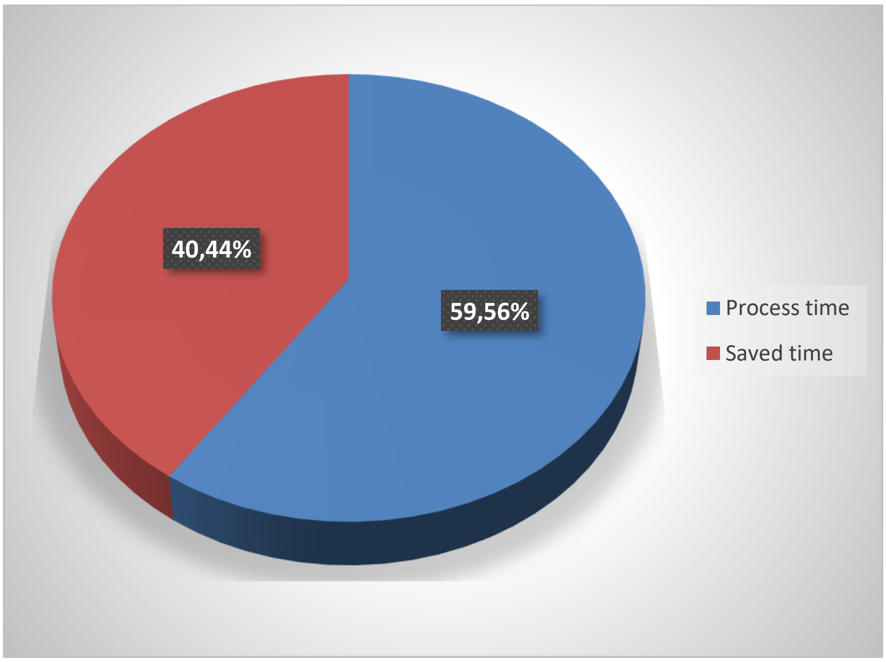


Fig. 4.10 Designed station process and saved time percentage in comparison with two equipment post-processing

Some remarks before results analysis and conclusions:

- exactly the same print during both test;
- times at “Designed unpacking and sieving station” graph is approximate;
- main idea that unpacking and sieving process occurring at the same time in designed station;

Table 4.4 shows that overall post-processing time decreased by 55 min. That is big time saving. As figure 4.10 shows in comparison with two equipment post-processing, designed station occupy only 59.56 % worker time and helps save 40.44 %. However, not only time is saved. Station join unpacking and sieving processes (both occurring and same time), minimize process steps from 7 to 3 and makes it easier and comfortable, less equipment needed, that saves space and working area. At the end conclusion can be made, that custom station creation is economically very needed, recommended and reasoned.

CONCLUSIONS

3D printing technologies has a lot of potential in future manufacturing. Working together with traditional manufacturing technologies such as milling, turning, grinding and others, additive manufacturing opens doors to faster, cheaper, more complex and custom production. At first sight, it is seem that 3D printing is very simple manufacturing method: you just make model and print it for end part or product. In real life, you need experience, knowledge and special equipment like post processing unpacking and sieving station for safer, faster and cleaner process finishing. During this work, unpacking and sieving station was successfully designed. For successful creation of the station these tasks and tests was completed:

1. Theoretically reviewed additive layer manufacturing. Deeply analysed Selective Laser Sintering technology, cleared up method pros: short lead times, wide variety of materials can be used, complex parts can be produced; cons: limited parts size, feature details and surface finish, high equipment; applications: aerospace, dental, medical, automotive, tooling.
2. Designed and presented post-processing equipment: unpacking and sieving station. Created station consist of two main subassemblies: unpacking and sieving. Main purposes of the station - make part unpacking from printing container easier and more comfortable and prepare unused printing powder for secondary usage.
3. For most efficient vibration frequency, finding sieving test was completed. For test, two different sieving prototypes was created: one simple and one according to designed station sieving subassembly. Test completed with two different powder examples: self-separation and forced-separation. After test conclusions was made that sieving time strongly depends from system itself, especially from sieving area size and systems flexibility, sieving time independent from powder separation method; designed system is functional and performance is acceptable. System is prepared for manufacturing. Most efficient frequency range after tests is about from 80 Hz to 90 Hz;
4. Designed unpacking and sieving station economic analysis was completed. During analysis determined that most expensive part groups was profile and fasteners or in other words frame assembly, because of modular parts. Alternative for most expensive station assembly was suggested: frame with standard aluminium profiles joined by welding. However, before final decision of frame selection, all advantages and disadvantages like flexibility, easy of assembly, welding process and other should be considered.
   - the cost of developed design based on extruded aluminium profiles was approximately 1910.35 €;

- the cost of alternative design based on standard aluminium profiles will cost approximately 1473.73 €;
- alternative designed lets save about 22.86 %. However, overall modular frame advantages overweight cost savings;
- completed test for designed station economic justification. Found that using it post-processing time decreased by 55 min in comparison with current situation. Comparison with two equipment post-processing showed, that designed station occupy only 59.56 % worker time and helps save 40.44 %. Designed station minimize process steps from 7 to 3 and makes it more easier and comfortable, less equipment needed, that saves space and working area.

At the end conclusion can be made that, that custom station creation is economically very needed, recommended and reasoned.

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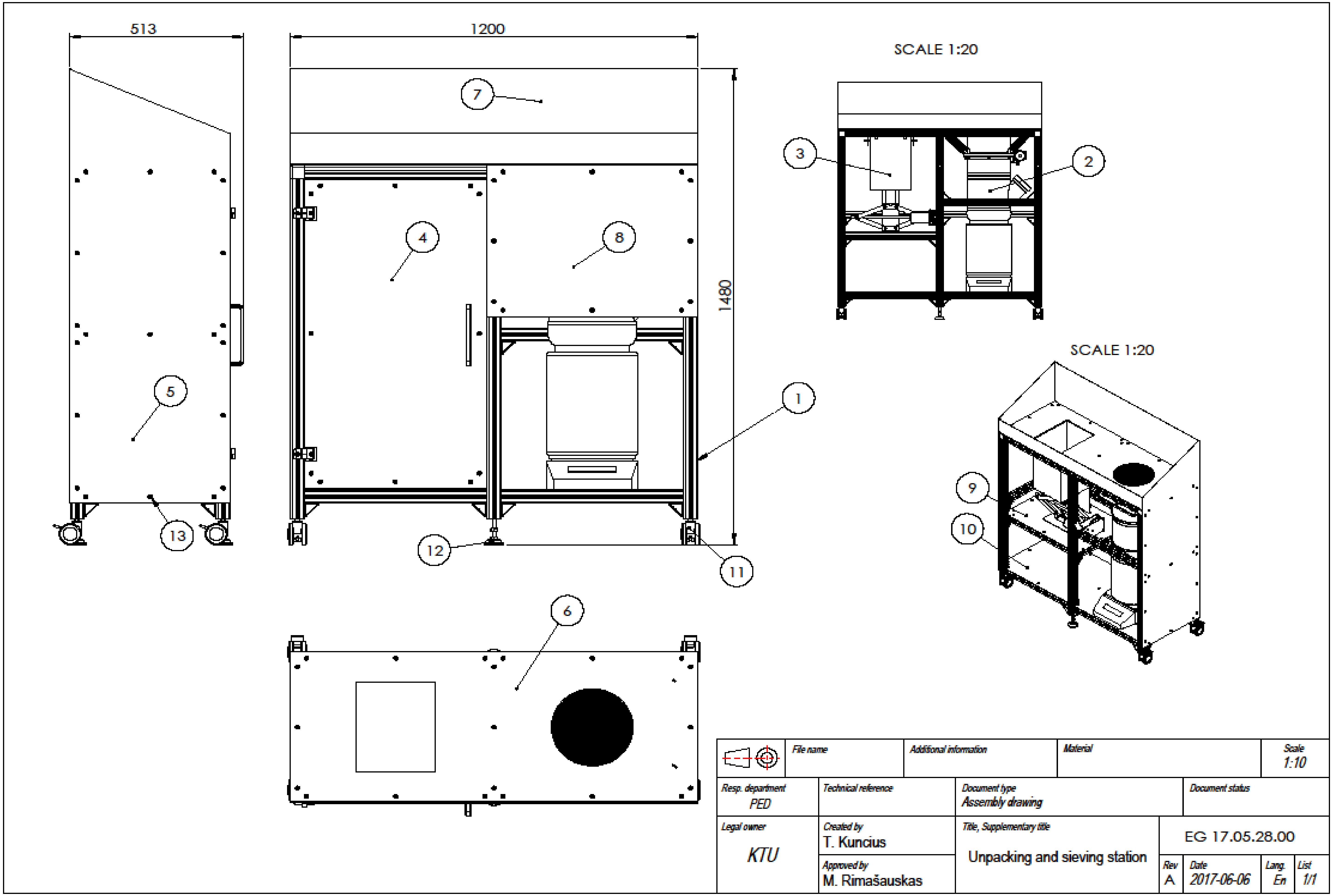
APPENDIXES



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Scale
1:10
Resp. department
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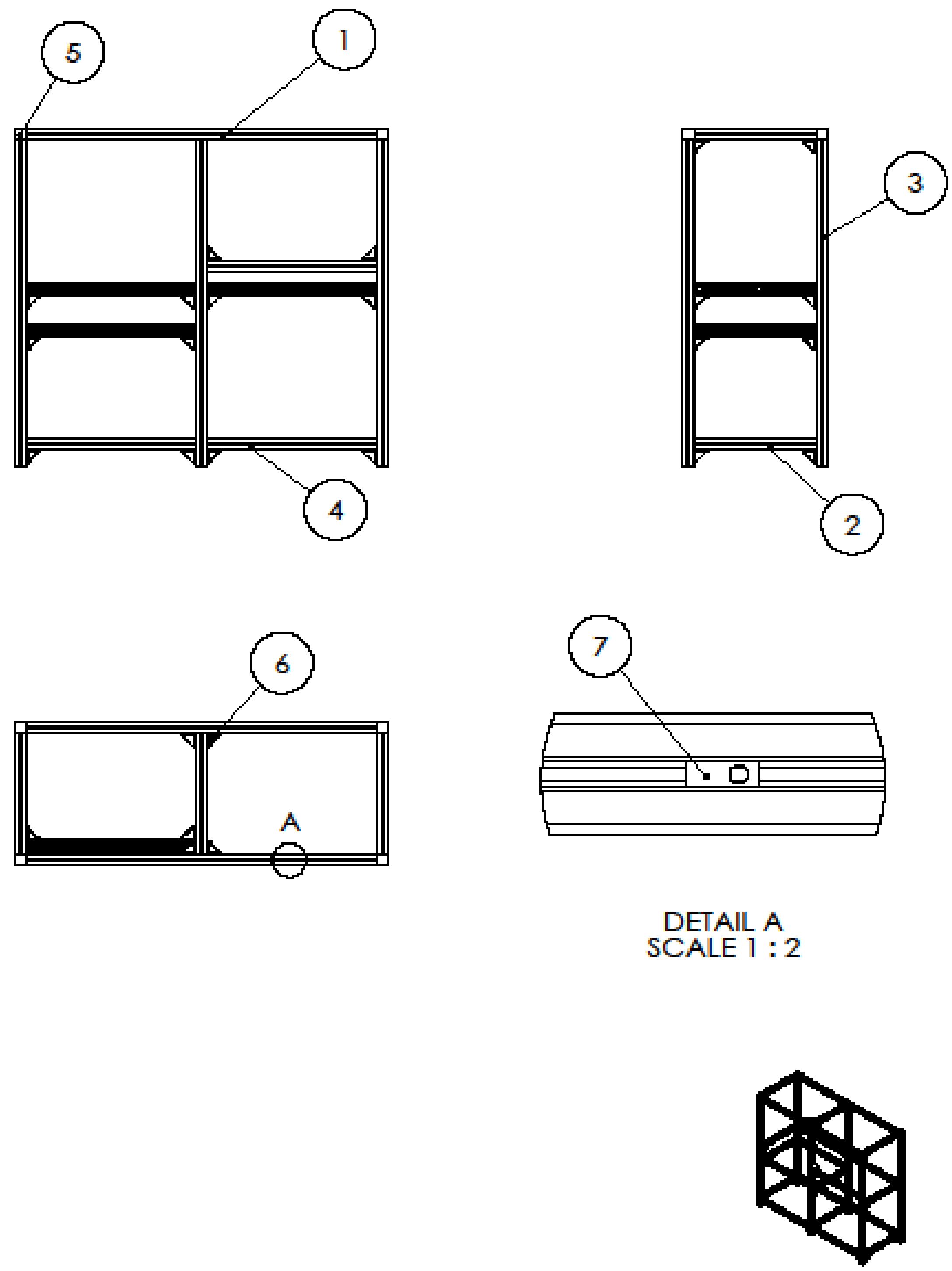
KTU
Created by
T. Kuncius
Approved by
M. Rimašauskas
Title, Supplementary title
Unpacking and sieving station
EG 17.05.28.00
Rev
A
Date
2017-06-06
Lang.
En
List
1/1

Appendix No. 1



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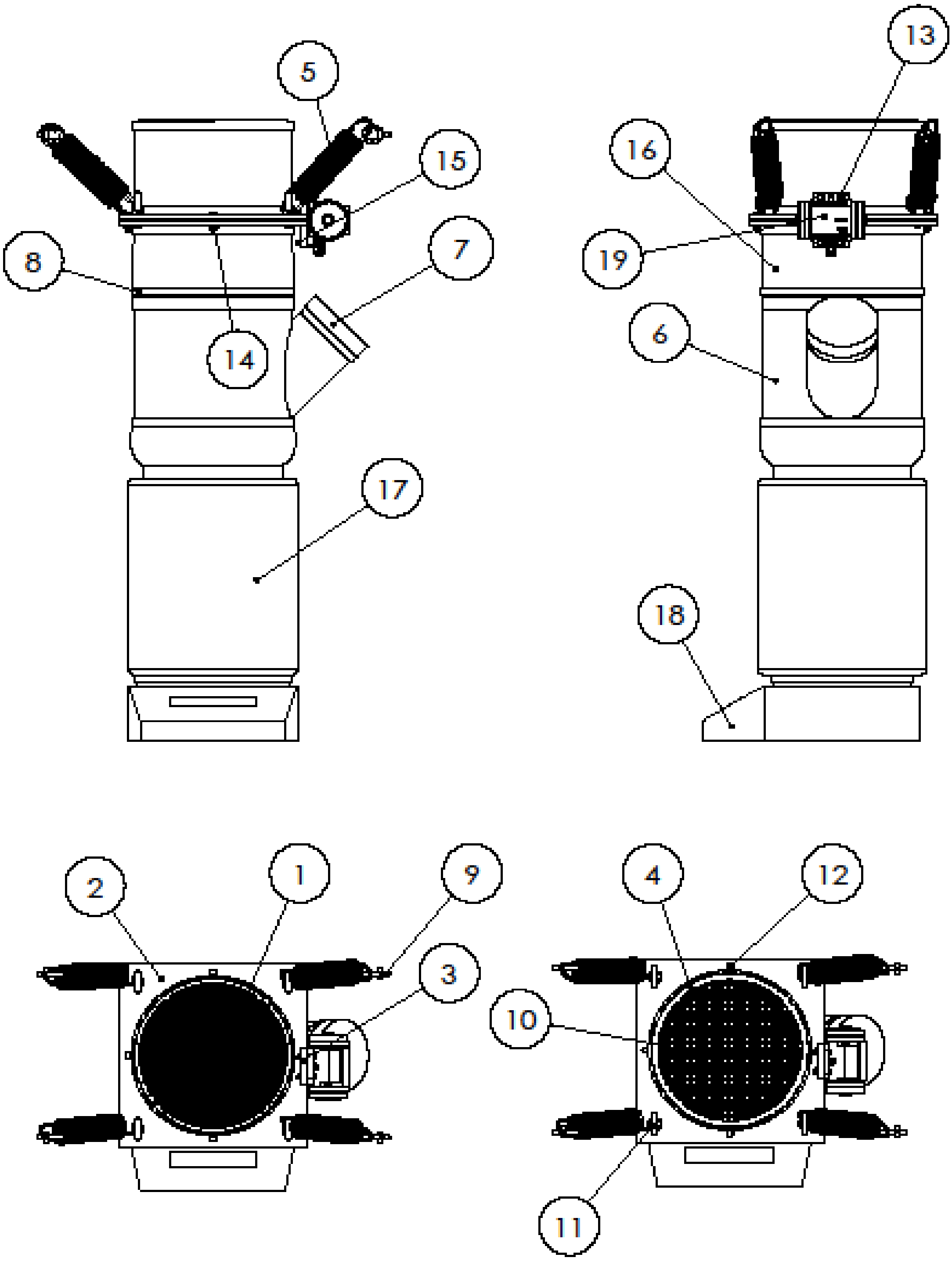

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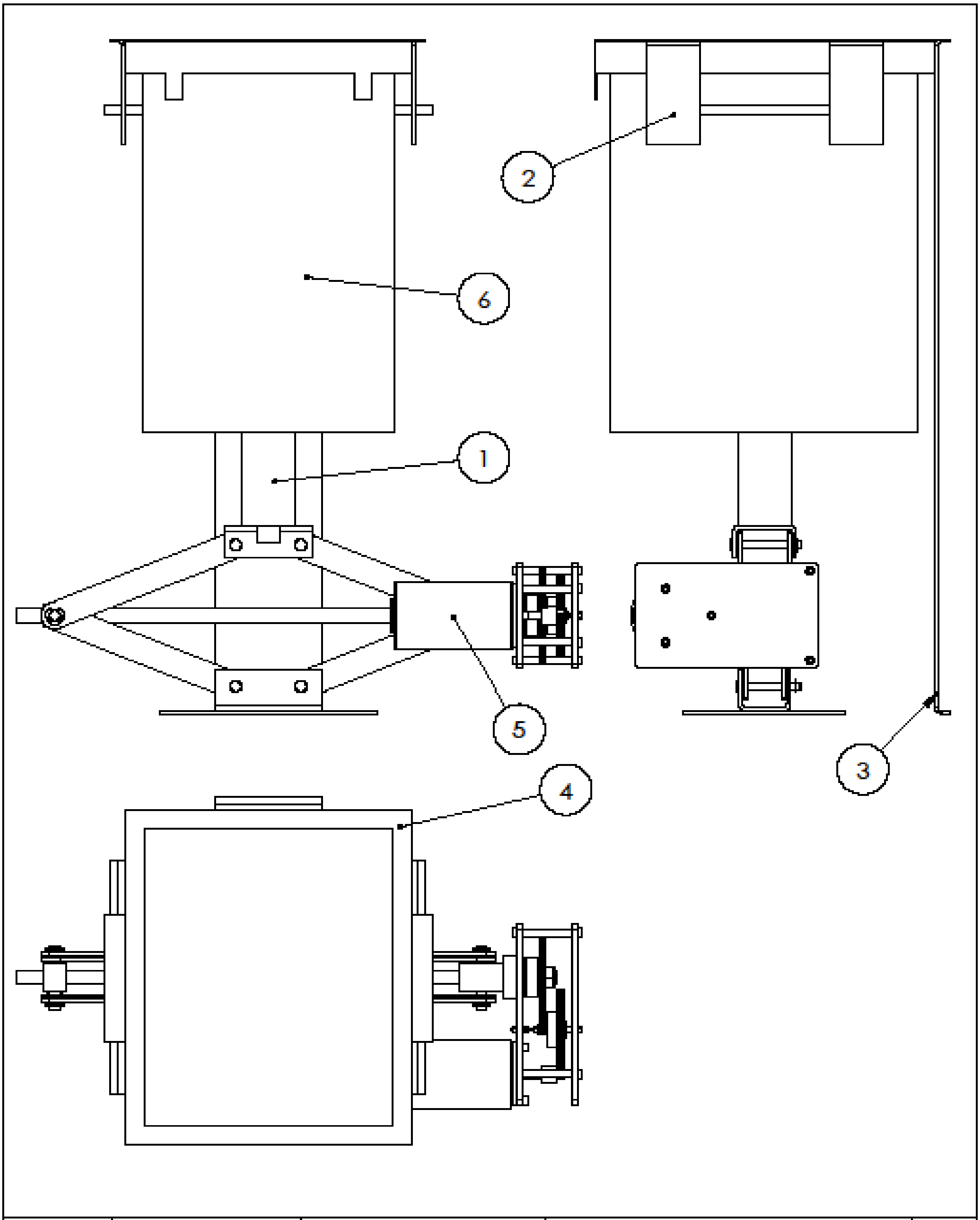
	Approved by M. Rimašauskas		Rev. A / Date 2017.05.30 / Lang. En / Sheet 1/1	



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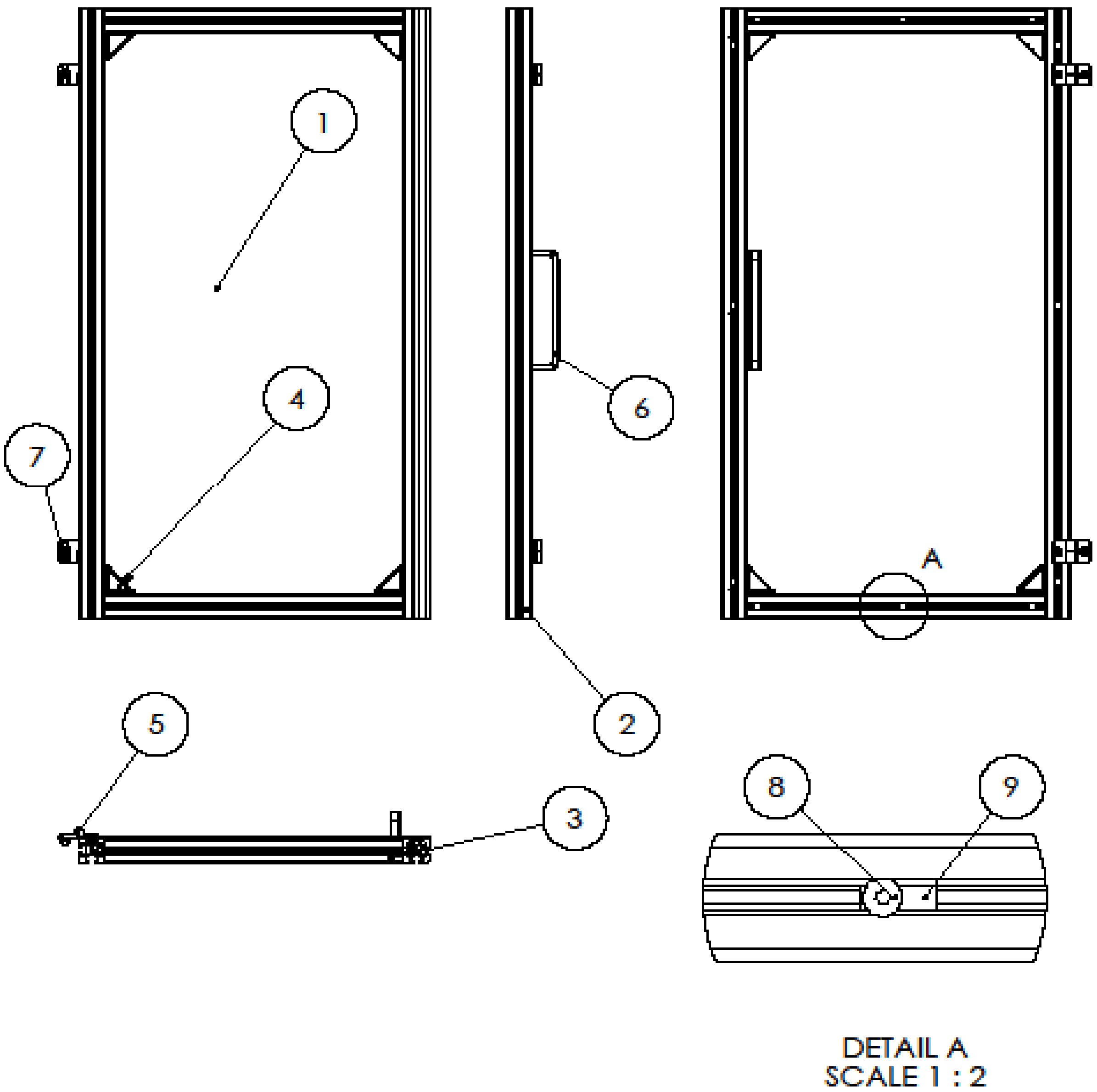
	Approved by M. Rimašauskas		Rev. A	Date 2017.05.30	Lang. En	Sheet 1/1



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	Approved by M. Rimašauskas		Rev. A	Date 2017.05.30	Lang. En	Sheet 1/1

Format	No.	Designation	Name	Qty	Notes
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A3		EG 17.05.28.00 AD	Assembly drawing		
A4	1	EG 17.05.29.00 AD	Assembly drawing		Frame
A4	2	EG 17.05.30.00 AD	Assembly drawing		Sieving
A4	3	EG 17.05.31.00 AD	Assembly drawing		Lifting
A4	4	EG 17.05.32.00 AD	Assembly drawing		Door
			<u>Parts</u>		
	5	EG 17.05.28.01	Side panel	2	
	6	EG 17.05.28.02	Top panel	1	
	7	EG 17.05.28.03	Back panel	1	
	8	EG 17.05.28.04	Right security panel	1	
	9	EG 17.05.28.05	Small base plate	1	
	10	EG 17.05.28.06	Base plate	1	
			<u>Standard parts</u>		
	11		Caster with brake	4	
	12		Adjustable leg	2	
	13		Bolt Din 7991 M6x14	150	

Resp. Department	Technical reference	Document type	Document status			
PED		Specification				
Legal owner	Created by	Title, Supplementary title				
KTU	Kuncius Tomas	Unpacking and sieving station				
	Approved by		Rev	Date	Lang.	Sheet
	Rimašauskas Marius		A	2017-05-30	En	1/5

Format	No.	Designation	Name	Qty	Notes
			<u>Documentation</u>		
A4		EG 17.05.29.00 AD	Assembly drawing		
			<u>Standard parts</u>		
	1		Profile 8 40x40 l=1117	2	
	2		Profile 8 40x40 l=390	10	
	3		Profile 8 40x40 l=1060	6	
	4		Profile 8 40x40 l=538.5	9	
	5		Joint 8 40x40x40	4	
	6		Angle joint 8 40x40	38	
	7		Nut 8 St M6	148	

Resp. department	Technical reference	Document type	Document status			
PED		Specification				
Legal owner	Created by	Title, Supplementary title				
KTU	Kuncius Tomas	Frame				
	Approved by		Rev	Date	Lang.	Sheet
	Rimašauskas Marius		A	2017-05-30	En	2/5

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	1	EG 17.05.30.01	Large grid	1	
	2	EG 17.05.30.02	Sieving platform base	2	
	3	EG 17.05.30.03	Mounting plate	2	
			Standard items		
	4		Round tube D250x60	1	
	5		Springs	4	
	6		Forked tube 250x110x45	1	
	7		Cover D110	1	
	8		Brace	5	
	9		Eye bolt DIN 580 M6x13	4	
	10		Fine grid	1	
	11		Ring nut DIN 582 M6	4	
	12		Bolt DIN 933 M6x30	7	
	13		Bolt DIN 933 M5x25	4	
	14		Nut DIN 6923 M6	3	
	15		Nut DIN 6923 M5	4	
	16		Rubber tube D250x1000	1	
			Accessories		
	17		Sieved powder container	1	
	18		Scale	1	KERN FCB30k1
	19		Vibro-motor	1	NEA 504

Resp. department	Technical reference	Document type	Document status			
PED		Specification				
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KTU	Kuncius Tomas	Sieving assembly				
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	Rimašauskas Marius		A	2017-05-30	En	3/5

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			<u>Parts</u>		
	1	EG 17.05.31.01	Rise plane	1	
	2	EG 17.05.31.02	Side tin guides	4	
	3	EG 17.05.31.03	Back tin guide	1	
			<u>Standard items</u>		
	4		Rubber sheet	1	
			<u>Accessories</u>		
	5		Electric car jack	1	
	6		Print container	1	

Resp. department	Technical reference	Document type	Document status
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	Approved by: Rimašauskas Marius		Rev: A; Date: 2017-05-31; Lang.: En; Sheet: 4/5

Format	No.	Designation	Name	Qty	Notes
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			Parts		
	1	EG 17.05.32.01	Doors panel	1	
			Standard parts		
	2		Profile 8 40x40 l=961	2	
	3		Profile 8 40x40 l=455	2	
	4		Angle joint 8 40x40	4	
	5		Left hinge	2	
	6		Handle	1	
	7		Fastening set for hinge	4	
	8		Bolt DIN 7991 M6x14	12	
	9		Nut 8 M6	12	

Resp. Department PED	Technical reference	Document type Specification	Document status
Legal owner KTU	Created by Kuncius Tomas Approved by Rimašauskas Marius	Title, Supplementary title Left door	Rev: A Date: 2017-05-30 Lang.: En Sheet: 5/5

Appendix No. 3

Unpacking and sieving station price

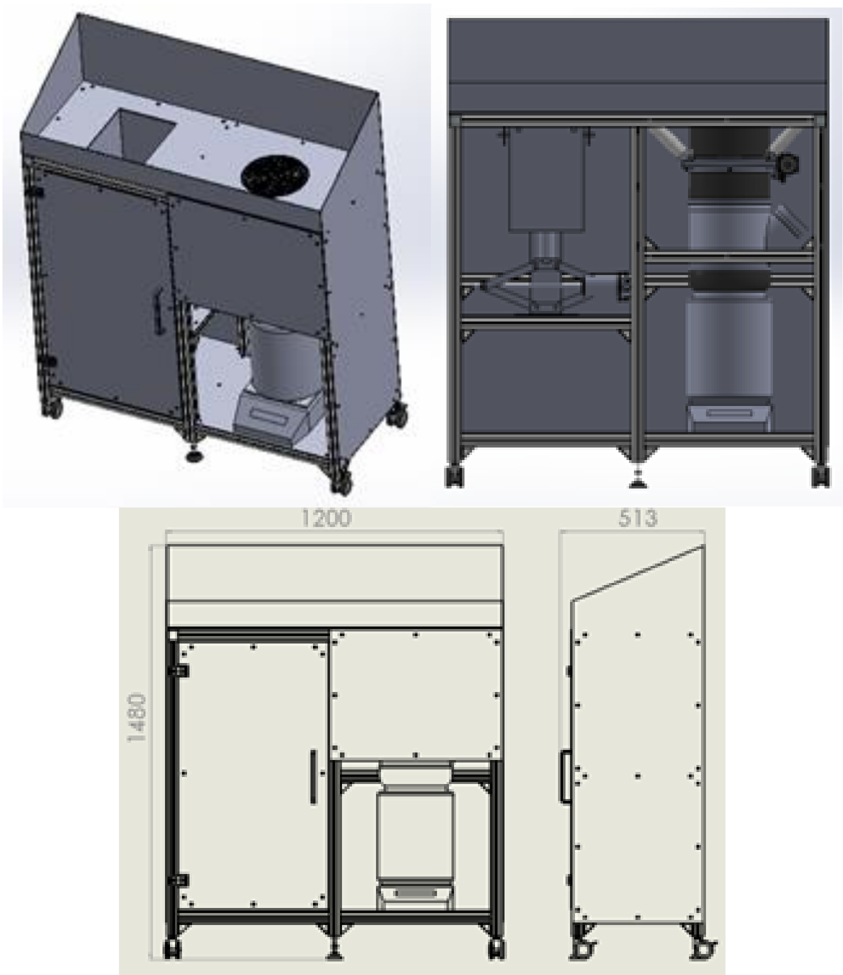

Table 1 Prices of designed station parts

Frame assembly				
Name	Order no.	Price of one meter €	Amount	Total with cutting €
Profile 8 40x40 l=1117 mm	0.0.026.03	24.73	2	57.70
Profile 8 40x40 l=390 mm	0.0.026.03	24.73	10	108.80
Profile 8 40x40 l=1060 mm	0.0.026.03	24.73	6	164.70
Profile 8 40x40 l=538.5 mm	0.0.026.03	24.73	9	130.95
Name	Order no.	Unit price €	Amount	Total €
Joint 8 40x40x40 kompl.	0.0.640.32	8.65	4	34.60
Angle joint 8 40x40	0.0.411.15	6.35	38	241.30
Nut 8 St M6	0.0.026.23	0.46	148	68.08

Left door assembly				
Name	Order no.	Price of one meter €	Amount	Total with cutting €
Profile 8 40x40 l=961 mm	0.0.026.03	24.73	2	50.00
Profile 8 40x40 l=455 mm	0.0.026.03	24.73	2	24.98
Name	Order no.	Unit price €	Amount	Total €
Angle joint 8 40x40	0.0.411.15	6.35	4	25.40
Handle		2	1	2.00
Hinge joint 8 PA	0.0.026.28	1.17	4	4.68
Hinge 8 PA Kairys	0.0.026.10	5.82	2	11.64
Bolt DIN 7991 M6x14		0.09	12	1.08
Nut 8 St M6	0.0.026.23	0.46	12	5.52
Doors plate		15	1	15
Frame with plates assembly				
Name	Order no.	Unit price €	Amount	Total €
Back plate		15	1	15
Side plate		15	2	30
Base plate		33	1	33
Top plate		33	1	33
Security plate		15	1	15
Small base plate		33	1	33
Caster with brake		4	4	16
Adjustable leg	0.0.439.30	2	17.64	35.28
Bolt DIN 7991 M6x14		0.09	150	12.96
Sieving assembly				
Name	Order no.	Unit price €	Amount	Total €
Large grid		33	1	33
Round tube 250x60		69.56	1	69.56
Springle		9.87	4	39.48
Forked tube PVC 250x110x250mm45		28.64	1	28.64
Cover 110mm		0.92	1	0.92
Brace		1.14	5	5.7
Eye bolt DIN 580 M6x13		0.95	4	3.8
Vibro-motor NEA 504		200	1	200

Sieving platform base		70	2	140
Fine grid		0	1	0
Mounting plate		12.5	2	25
Ring nut DIN 582 M6		0.95	4	3.8
Bolt DIN 933 M6x30		0.18	7	1.26
Bolt DIN 933 M5x25		0.15	4	0.6
Nut DIN 6923 M5		0,08	4	0.32
Nut DIN 6923 M6		0.12	3	0.36
Rubber tube D250x1000		50	1	50
Lifting assembly				
Name	Order no.	Unit price €	Amount	Total €
Rubber sheet		10	1	10
Rise plane		1		30
Tin guides				5
Electric car jack		1	93.64	93.64
			Total:	1910,75

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Development of Post Processing Equipment for Additive Layer Manufacturing Technology

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1. Introduction

In today's industry companies searching methods and processes to produce parts, prototypes or even complex assemblies faster, cheaper, without exes work and with less scrap. All production technologies can be divided into two main groups: 1. Traditional technologies (milling, drilling, casting, stamping and others), 2. Innovative technologies (additive layer manufacturing (ALM), laser machining (LM), electrical discharge machining (EDM), electrochemical machining and others). Traditional processes such as milling, turning and others are constantly improving; we have CNC machines with active tools, machining centers. However sometimes such methods and equipment can't be used because of parts complexity, economical or time reasons. Now companies start to search alternatives and one of the best alternatives are additive layer manufacturing.

Additive layer manufacturing (ALM) was developed in the 1980 and refers to various processes used to synthesize a three-dimensional object [1, 2]. Additive layer manufacturing can be called 3D printing, additive manufacturing, additive fabrication, additive processes, additive techniques, layer manufacturing, and freeform fabrication [3]. Differently from traditional processes in additive layer manufacturing object is formed by adding material layer-by-layer, copying shape from CAD file instead of removing material from blank. It let us to produce almost any geometry or shape objects, so engineers and designers has a lot of freedom and space to improvise. Moreover from point of view of designer ALM can be called unlimited technology. Futurologists Jeremy Rifkin believe that 3D printing marks the beginning of industrial revolution, which successfully changing the production line phenomenon that dominated in production starting in the late 19th century [4,5]. From first view it seems that all you need to start manufacturing is computer, 3D printer and material, but it is really so simple?

The main aim of this work is to develop post-processing equipment for additive layer manufacturing technology. However to achieve this aim we have to complete several goals:

- Understand the principles of additive manufacturing technologies;
- Review the 3D printing types, capabilities and opportunities;
- Select one 3D printing technology, analyze it and design post processing equipment;
- Prepare CAD model of post processing station;
- Perform required experiments to collect important data;

2. Analysis of additive layer manufacturing

As we already know 3D printing belongs to group of innovative manufacturing technologies. Like all manufacturing processes, 3D printing can be divided into steps. The first step is the preparation. It consists of all preparation works before printing and includes design of 3D model, checking and repairing of errors in the model or stl file, positioning model on building tray and preparation of equipment. 3D CAD model can be created using CAD software, scanned with a 3D scanner or simply downloaded from an online marketplace. The second step is the actual printing process. First of all necessary material should be selected. The variety of materials used in 3D printing is very broad. It includes plastics, ceramics, resins, metals, sand, textiles, biomaterials, glass, and food. The third step of the ALM technologies can be called post-processing or finishing and includes removal of printed part from building tray and preparation part for final usage. However it can cover very different works and devices and mainly depend on 3D printing technology. For example selective laser sintering (SLS) needs unpacking station and sand blasting cabinet, Polyjet needs water jet cabinet while fused filament fabrication (FDM) needs a lot of manual work.

As we already can see, 3D printing looks simple and easy method, however like all manufacturing methods it requires specific knowledge, skills and equipment. On the other hand, it offers a lot of different production possibilities, materials and methods. So until now we become familiar with usable materials, main 3D printing technologies. Below we can find advantages / limitations and applications of additive manufacturing:

Advantages

- Allows much greater flexibility and creativity in the design process.
- Designers can create a part that is lighter and stronger by means of better design.
- Speeds up the design and prototyping process.
- Parts design can be changed each time it is produced.
- Parts can be created within hours.

Limitations

- Expensive hardware and expensive materials.
- Requires a CAD designer to create what the customer has in mind
- Parts can be expensive if the part is very intricate.
- Printed parts requires traditional manufacturing processes for finishing

Current and future applications of 3D Printing

- Biomedical Engineering
- Aerospace and Automobile Manufacturing

- Construction and Architecture
- Product Prototyping

3. Selection of additive manufacturing technology

From very wide list of 3D printing technologies selective laser sintering (SLS) was selected. Main reasons of choice were:

- Need of post processing station;
- High cost of original station;
- SLS printing is one of the most promising additive manufacturing technologies;
- Very wide used worldwide;
- SLS printing lets produce large number of parts during one session;
- High variety of materials can be used;
- Complex parts can be easily produced;

SLS is an additive manufacturing technique, founded in 1980, that uses a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal (direct metal laser sintering), ceramic, or glass powders into a mass that has a desired three-dimensional shape [6]. The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed. Depending on the material, up to 100% density can be achieved with material properties comparable to those from conventional manufacturing methods [6].

All printing process can be divided into two smaller steps:

Printer preparation - this step includes:

Cleaning if printer hasn't been cleaned after last printing, all systems checking (powder containers filling, not used powder containers cleaning, room air temperature, humidity, process container position and air pressure checking), sliced CAD uploading into printer computer, building platform coating with few powder layers, building platform and process container warming until 170 ^{0}C.

Printing

After first step operator starts printing process by pressing button at printer software. Printing process starting by security layers coating for example powder from right powder container flowing to recoater and moving to left powder container by laying set layer thickness, after that building platform (stage) descends by layer thickness and recoater lays another layer. When set security thickness is achieved laser starts sintering powders to part (using uploaded CAD) layer by layer. Every job layer is coated by exactly same scheme as security layers and laser sinters every layer. All excess powder is pushed to not used powder containers and be used once again in future printings.

When printing ends operator takes out container with parts and not used powder (Fig. 1a), using unpacking station and additional equipment such as different size brushes, needles and others removes all excess powder from parts (Fig. 1b). All excess powder will be used again after mix with new powder in proportion 30 – 70, 40 – 60 (old – new powder). The proportions can differ a lot but mainly depends on type of material and process parameters.

a) b)

Fig. 1 Post-processing; a) container after printing, b) powder removing from part

After parts is separated from powder, its travel to bead blasting station, where powder is removed from hard - to - reach areas like holes, angles, gaps and etc.

The last post processing operations are parts washing with high-pressure water jet and drying by blowing with air jet or leaving to dry naturally. These steps are only example some of them can be skipped or changed.

After understanding main principles of SLS printing we can finally review this technology benefits, constrains and applications.

Benefits

As mentioned before Selective Laser Sintering has many very important benefits against traditional manufacturing methods. The main advantages are production speed and opportunity to easily and cheap produce complex prototypes. Moreover SLS can be used like technology for fully functional final product production. Prototypes or final assemblies (products) can be produced in a few hours because additional machining steps rarely needed. SLS can be used for short production runs because it doesn't require special tools like custom cast, models in casting [7].

Applications

The main industries which using SLS printing for direct parts is aerospace, dental, medical, automotive, tooling and other industries that produce small to medium size, highly complex parts. Selective Laser Sintering ability to produce multiple parts during one cycle let to minimize production cost and time, effectively use resources. Also this technology can be used for rapid prototyping because it lets to decrease development time for new products [7].

4. Design of post processing equipment for SLS 3D printing technology

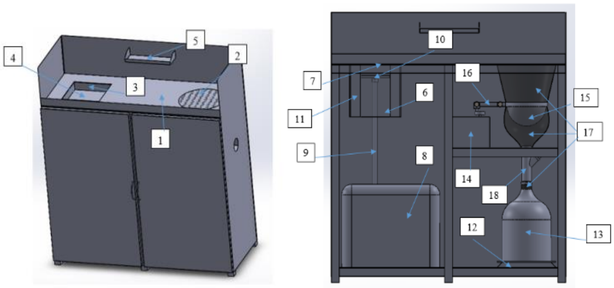
As mentioned before the main aim is to design post-processing equipment with two main sub-assemblies: unpacking and sieving stations for EOS SLS printer Formiga P110. The main challenge is to design equipment which can be till 80% cheaper and meet all requirements for it.

Main requirements for unpacking and sieving station:

- Opportunity to fill or add new powder from powder supply container;
- Opportunity to weigh unused powder;
- Safe workplace for worker and product assurance;

- Sift unused powder and transfer them to supply container;
- Opportunity to easily change sieving nets;
- Opportunity to operate without fill container;
- Comfortable products unpacking;
- Light, simple and easy to assembly construction;
- Construction mostly should consist from standard parts;
- Station design should be compact
- Individual or specific parts should be easily producible
- All parts should be easily replaceable
- Station should be easily upgradable

In the picture (Fig. 2a) we can see first prototype, model which was created using SolidWorks software, it is worth to mention that this concept is not final and can be changed and can be different in the final product. It is possible to see station working area (1), large grid (2), container (3) with adjustable work plane (4) and shelf (5) for cleaning equipment.



a) b)

Fig. 2 First prototype; a) exterior, b) interior

Inside the device (Fig. 2b), it is possible to see production container (6) which is clamped to work area plane (7) using electric drive (8) and worm (9) with at the end mounted rising plane (10). Container will be guided by guides (11). The main goal of electric drive is to rise production container to work plane with container content to work area. On the right side, we can see electronic scales (12) with powder bunker (13), vibration causing drive (14), fine mesh (15) which size depends from powder particle size, part (16) joins vibration causing drive with fine mesh and rubbish joints (17). New powder container, powder container and spreader joint over forked tube (18). The main spreader goal is to sift unused powder and transmit it to powder container.

In the picture (Fig. 3), we can see final station model interior. Comparing early prototype and final model, we can see obvious similarities. Both stations consist of two main sub-assemblies lifting and sieving with almost identical parts in it. However, in final model we have finalized view. Lifting job will be completed using electric car jack, sieving work will be completed using vibro motor. Other visible difference is frame. During early stages of creation, frame consisted from rectangular steel bars joined by welding. Final model frame consist from rectangular construction profiles joined by screws and other fasteners.

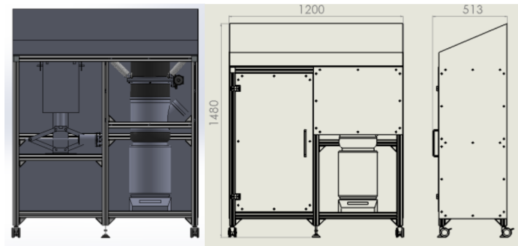


Fig. 3 Final station interior

In the figure 3, we can see final station model overall dimensions in mm.

5. Experimental details

As mentioned before two most important sub-assemblies for unpacking and sieving station is lift and sieving. Most important sub-assemblies parts are car jack and vibro-motor respectively. Standard hand control electric jack will be chosen without speed control, so we don't need to check or research required speed. Vice versa with vibro-motor. Vibration frequency is very important for sieving speed and permeability. Therefore, the main goal of experiment is to find out most suitable frequency or frequency range for efficient sieving. That frequency lets easily select suitable motor for sieving sub-assembly.

As mentioned before for successful excess powder secondary usage, they must be prepared correctly. All excess powder has to be sieved using relevant sieving net, which selected considering powder particle size. At the picture (Fig. 4) we can see designed sieving station assembly.

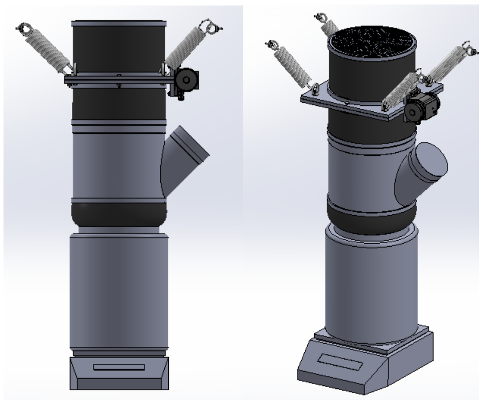


Fig. 4 Designed sieving assembly

Sieving can't be skipped because during printing powder particles stick together (Fig. 5). It is happening because of usage of high temperature and process cannot be avoided. Such powder can't be reused, because it can influence quality of the part or even worse damage the printer. Sieving efficiency and time directly depends from vibration frequency and system itself. Because we can't test all system impact for sieving quality, we tried to find out optimal frequency.

Research equipment

For most suitable frequency, we tried to imitate similar system to our final station by creating sieving prototype. Equipment list which was used during experiments are presented below.

- Bench scale KERN FCB30k1

- Power amplifier HQ POWER VPA2100MN
- Waveform generator Rigol DG1032Z
- Vibro motor

Auxiliary equipment

- Container
- Dosing cup
- Vacuum cleaner
- Sieving assembly with net (60 µm)
- Frame
- Four springs
- Chronometer (accuracy 0.1 s)

Fig. 5 Example of powder accumulations

In the picture (Fig. 6), we can see the prototype of sieving assembly, which will be used for experiment. For more accurate test results cold rolled cylinder was produced with exactly same dimensions (D-238 mm) as would be at the final design station.

Fig. 6 Designed sieving station prototype

Research description

During this test, we tried to find out several things:

1. Most suitable and efficient vibration frequency and time;

2. Find out how different powder (self-separation and forced separation) affects sieving time;

3. Try designed sieving assembly in real test;

Short research process description

Research process starts with all necessary equipment connection and adjustment. We should mention that adjustments made to waveform generator and amplifier was the same during both tests. In the picture below, we can see waveform generator settings:

- Frequency: 50 -100 Hz, step 5 Hz
- Amplitude: 5 Vpp
- Wave form: Sinusoidal

As we can see from figure 7, amplifiers power level was set to one fourth of all amplifier power capability. After equipment preparation and setting, following step was used powder weighing. During both tests we used the same amount (300 g) of powder. After weighing, powder was poured on the net in sieving assembly prototype. Sieving test was started from 50 Hz and ended with 110 Hz. During every sieving cycle, sieving process time was recorded. As we mentioned before, after every sieving cycle sieving net was cleaned with vacuum cleaner from powder stacks.

Fig. 7 Waveform generator and amplifier setting

6. Results

The test was completed with two different powder examples:

- Self-separated powder – is powder which easily without any force separated from parts.
- Forced-separated powder – is powder which separated from parts using outer forces.

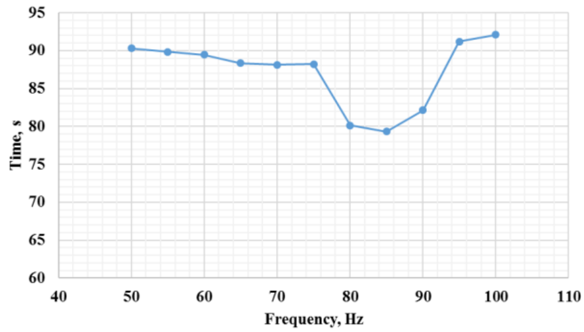


Fig. 81 Self-separation sieving time dependency from frequency

In figure 8, we can see measured time data. As we can see from graphic that the shortest sieving times was between 80 and 90 Hz, respectively time fluctuated from 80.15 to 82.15 s. We can make the conclusion that time difference in most efficient frequency range was about two seconds.

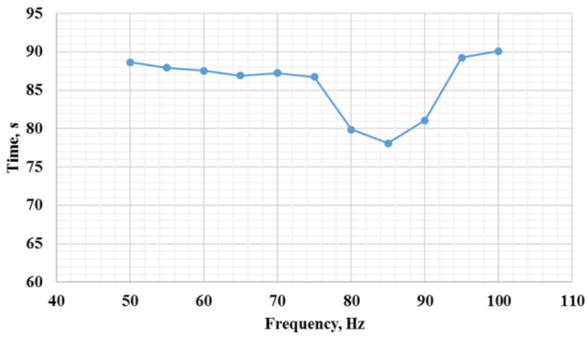


Fig. 9 Forced-separation powder sieving time dependency from frequency

In figure 9, we can see measured time data. As we can see from graphic that the shortest sieving times was between 80 and 90 Hz, respectively time fluctuated from

79.89 to 81.09 s. We can make the conclusion that time difference in most efficient frequency range was about 1.2 seconds.

Remark – As we can see forced-separated powder sieving time is 1.43 s shorter than self-separated, but it should be reversed. This is due powder stacks, which remains on net and are vacuumed.

Other interesting observation is that independently from powder separation method graphic curve and most efficient vibration frequency range is almost exactly the same. Therefore, we can make the conclusion that powder separation method don't have direct impact on sieving frequency selection.

7. Conclusions

At the end, we can say that 3D printing technologies has a lot of potential in future manufacturing. Working together with traditional manufacturing technologies such as milling, turning, grinding and others, additive manufacturing opens doors to faster, cheaper, more complex and custom production. At first sight it's seem that 3D printing is very simple manufacturing method: you just make model and print it for end part or product. In real life, you need experience, knowledge and special equipment like post processing unpacking and sieving station for safer, faster and cleaner process finishing.

During test, we determined powder sieving time dependence from vibration frequency at different conditions and found most efficient vibration frequency for designing unpacking and sieving station, which after test is about 80 Hz. After test with two different powder examples, we can make this conclusions and remarks:

- Sieving time strongly depends from system itself, especially from sieving area size and systems flexibility;
- Sieving time independent from powder separation method;
- Most efficient frequency range after tests is about from 80 Hz to 90 Hz;
- Designed system is functional and performance is acceptable. System is prepared for manufacturing;

As from first look average sieving time (for both self-separated and forced-separated powder) 86.48 seconds its long time, we can't forget that system in real product will work closed and vibrating assembly will work during all unpacking time. From that we can say that sieving assembly fulfill its duty properly. By the way that time can be minimized by making system more flexible.

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T. Kuncius, M. Rimašauskas

DEVELOPMENT OF POST PROCESSING EQUIPMENT FOR ADDITIVE LAYER MANUFACTURING TECHNOLOGY

Summary

Additive layer manufacturing (ALM) technologies takes more and more place among traditional production technologies. That is because ALM technologies are very flexible and efficient moreover it can be said that possibilities of ALM technologies are almost unlimited. In other hand there are technological factors which are challenges for everyone who use ALM technologies. One of these challenges is post processing. It is very well known that ALM technologies could be used without any surveillance, while post processing needs human work. This article presents new post processing equipment development for selective laser sintering (SLS) technology. Design of equipment, experiments and economical calculations is discussed in the article.

Keywords: 3D printing, additive manufacturing, post processing equipment

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POST PROCESSING STATIONS FOR SLS PRINTING ECONOMIC REVIEW

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Key words: additive manufacturing, selective laser sintering, post-processing equipment

1. Introduction

Today time is one of most valuable resources in our world. We can bravely say that money and time rules today's world and especially industry. Engineers, designers, managers, researchers, logicians and other searching methods to produce and present products and services faster. Shorter production time lets companies to save up money, energy, resources; lets manufacture more in short time and earn bigger profit. Saved up time can be spend to improve current manufacturing processes or to create new more efficient and effective product or process. However today we have many different tools, which can help save time, increase productivity or minimize costs:

- Computer aided software (CAD, CAE, CAM, QAQC and etc.)
- Machining centres, machines with active tools; CNC and coordinate measuring machines and etc.
- Innovative manufacturing technologies (ALM, LM, EDM and others).
- Managerial and manufacturing philosophies (JIT, Kaizen, LEAN and others).

First additive layer manufacturing (ALM) technologies was developed in the 1980 and refers to various processes used to synthesize a three-dimensional object [1, 2]. Additive layer manufacturing can be called 3D printing, additive manufacturing, additive fabrication, additive processes, additive techniques, layer manufacturing, and freeform fabrication [3]. Differently from traditional processes such as milling or turning, in additive layer manufacturing object is formed by adding material layer-by-layer, copying shape from CAD file instead of removing material from blank. It let us to produce almost any geometry or shape objects, so engineers and designers has a lot of freedom and space to improvise. Freedom of this method is one of most important factor, which lets us to minimize or skip preparation operations.

Moreover no special or individual tools needed, parts can be produced from start to finish without human interference, minimal-zero scrap, during one manufacturing session batch of parts can be produced.

The main aim of this work is to evaluate designed post processing station for additive manufacturing economically.

2. Presentation of design post-processing station

There are few popular methods in ALM such as: Selective Laser Sintering (SLS), Stereolithography (SLA), Fused Deposition Modeling (FDM) and others. All methods has pros-cons and different usage. From quite wide list of 3D printing technologies, Selective Laser Sintering (SLS) was selected as research object. Main reasons of choice were:

- Need of post processing station;
- High price of original station;
- SLS printing is one of the most promising additive manufacturing technologies;
- Very wide used worldwide;
- SLS printing lets produce large number of parts during one session;
- High variety of materials can be used;
- Complex parts can be easily produced;

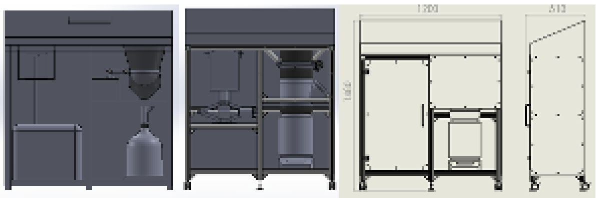
SLS is a maturing additive manufacturing technique, first demonstrated in the 1980s and, which enables fast, flexible and cost-effective fabrication of highly complex monolithic polymer parts. [4] Of all RP techniques, Selective Laser Sintering (SLS) seems to be one of the most consolidated processes to create solid objects, layer by layer, from plastic, metal, ceramic powders or pre-coated sands that are sintered using laser energy. SLS not only reduces the time and cost of prototyping components, obtaining the same dimensional accuracy, surface finish and repeatability as common manufacturing process, but also reduces the energy intensity and the environmental impacts of the process. [5]

The main two purposes of post-processing station are to make part unpacking from printing container easier, more comfortable and prepare unused printing powder for secondary usage. Design of post-processing station consist of two main sub-assemblies: unpacking and sieving stations. The main challenge is to design equipment that can be until 80% cheaper than other existing alternative and meet all requirements for it. The main requirements for unpacking and sieving station are:

- Opportunity to fill or add new powder from powder supply container;
- Opportunity to weigh unused powder;
- Safe workplace for worker and product assurance;
- Sift unused powder and transfer them to supply container;

- Opportunity to easily change sieving nets;
- Opportunity to operate without fill container;
- Comfortable unpacking procedure of the products;
- Light, simple and easy to assembly construction;
- Construction mostly should consist from standard parts;
- Station design should be compact;
- Individual or specific parts should be easily producible;
- All parts should be easily replaceable;
- Station should be easily upgradable.

In the picture below, we can see early prototype (Fig. 1a) and final design station (Fig. 1b) created using SolidWorks software. From pictures, we can see that final product kept all main sub-assemblies and design ideas. In the picture (Fig. 1c) we can see final design station overall dimensions, frontal and side appearance.



a) b) c)

Fig. 1 a) Early prototype, b) Final station design, c) Dimensions of the station

3. Economical review of designed station

In this chapter, we tried to calculate approximate station price, evaluated possible alternatives of station design according to most expensive assemblies.

As we stated before, the main reason of this custom station creation, was very high price of original station. Before development of unpacking and sieving station, we set aim that designed station must be about 80 % cheaper than original, so it should cost no more than 6000 €. To find out how much designed station will cost, we look up Lithuanian companies, which can be our possible suppliers and manufacturers of required elements. In the Table 1 brief list of needed parts and approximate prices that helps to calculate overall designed station price are presented.

From the Table 1 and Fig. 2, 3 we can see most expensive part groups, which is fasteners and frame material respectively 21.43 % and 28.43 %. We can see that our designed station cost is about 1900 Eur.

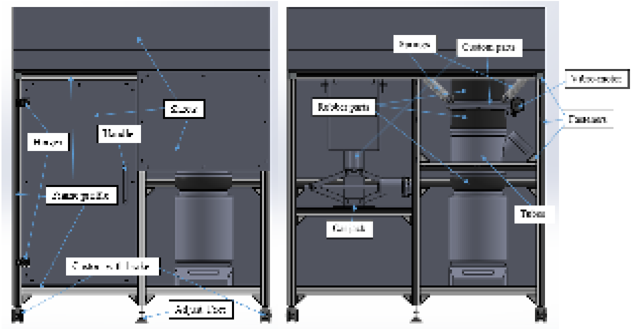


Fig. 2 Final station main parts and part groups

Table 1

Part or parts group approximate price

Part or Parts group	Overall price, €
Frame profile	537.13
Sheets	250.64
Fasteners	409.46
Handle	2
Hinges	11.64
Castors with brakes	16
Adjustable feet	35.28
Custom parts	200
Car jack	93.64
Rubber parts	60
Springs	25
Tubes	69.56
Vibro-Motor	200
Total:	1910.35

We can make a conclusion that our aim of 20 % price from other alternatives stations was achieved successfully and we have about 13 % reserved.

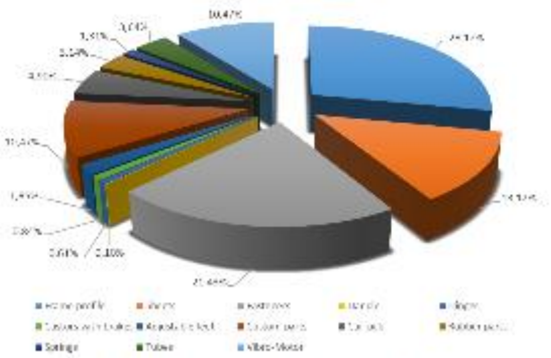
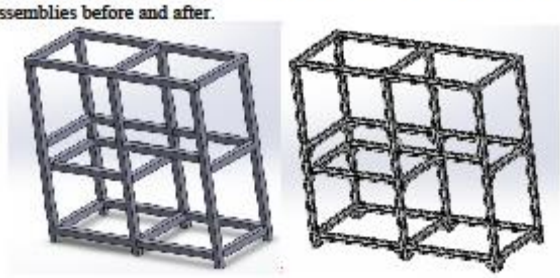


Fig. 2 Elements percentage of overall station price

As we can see the two elements groups consist half of overall price. To minimize this expensive developed the alternative design. We can change modular frame profiles to simple aluminium rectangular profiles. That means frame and left door sub-assemblies should become cheaper. In the figure 3 we present both alternative (Fig. 3 a) and original (Fig. 3 b) station frame as example. We can see that both frames has exactly the same design. The main difference between is that alternative frame profiles will be joined by welding. Cheaper profiles and simple fastening should minimize most expensive assembly's price significantly. In the Table 2, we can see cost difference between sub-assemblies before and after.



a) b)

Fig. 5 a) Alternative welded frame, b) Original modular frame

Table 2

Price comparison between alternative and original station design

Frame			
Alternative		Original	
Profile			
Total, €:	72.48	Total, €:	462.15
Welding		Fasteners	
Total, €:	371.2	Total, €:	343.98
Overall total, €:	443.68	Overall total, €:	806.13
Left doors			
Profile			
Total, €:	11.83	Total, €:	74.98
Welding		Fasteners	
Total, €:	25.6	Total, €:	36.68
Overall total, €:	37.43	Overall total, €:	111.66

As we can see from table, overall savings by selecting alternative design solution will be about 436.62 €. That is approximately 22.86 % from overall designed station. That is quite a big saving, however original design have some very important advantages, which outweighs it:

- Modular frame lets easily change damage parts.
- Using modular parts station can be easily reassembled.
- In future frame can be adjusted depending from situation and requirements.
- It gives opportunities to upgrades station in the future.

Of course, alternative design station can be manufactured, if above listed statements looks not significant.

4. Conclusions

As we can see from unpacking and sieving station economic analysis, our designed station overall cost consists only 6.37 % of alternative station price or 1910.35 €. We determined that most expensive part groups was frame and fasteners, because we used modular parts. Alternative design with simple, rectangular aluminium profiles and welding joints lets us to save about 22.86 %. However, modular frame advantages overweight cost savings.

1. Two different designs of sieving and unpacking stations was developed.
2. Economic analysis of different designs was performed:
   a) The cost of developed design based on extruded aluminium profiles was approximately 1910.35 €.
   b) The cost of alternative design based on standard aluminium profiles was approximately 1473.73 €.

However before final decision all advantages and disadvantages like flexibility, easy of assembly, welding process and other must be considered.

3. Both presented stations are much cheaper that other alternatives existing in the market. For detailed economic analysis assembly time of different processes, must be considered.

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