## ČESKÉ VYSOKÉ
## UČENÍ TECHNICKÉ
## V PRAZE

## FAKULTA STROJNÍ
Ústav Řízení a Ekonomiky Podniku

# PROJECT FOR MANUFACTURING OF GEARS FOR COMPANY STAB SPOL. S R.O.

Author: Bc. Štefan Staník

Praha, 2019

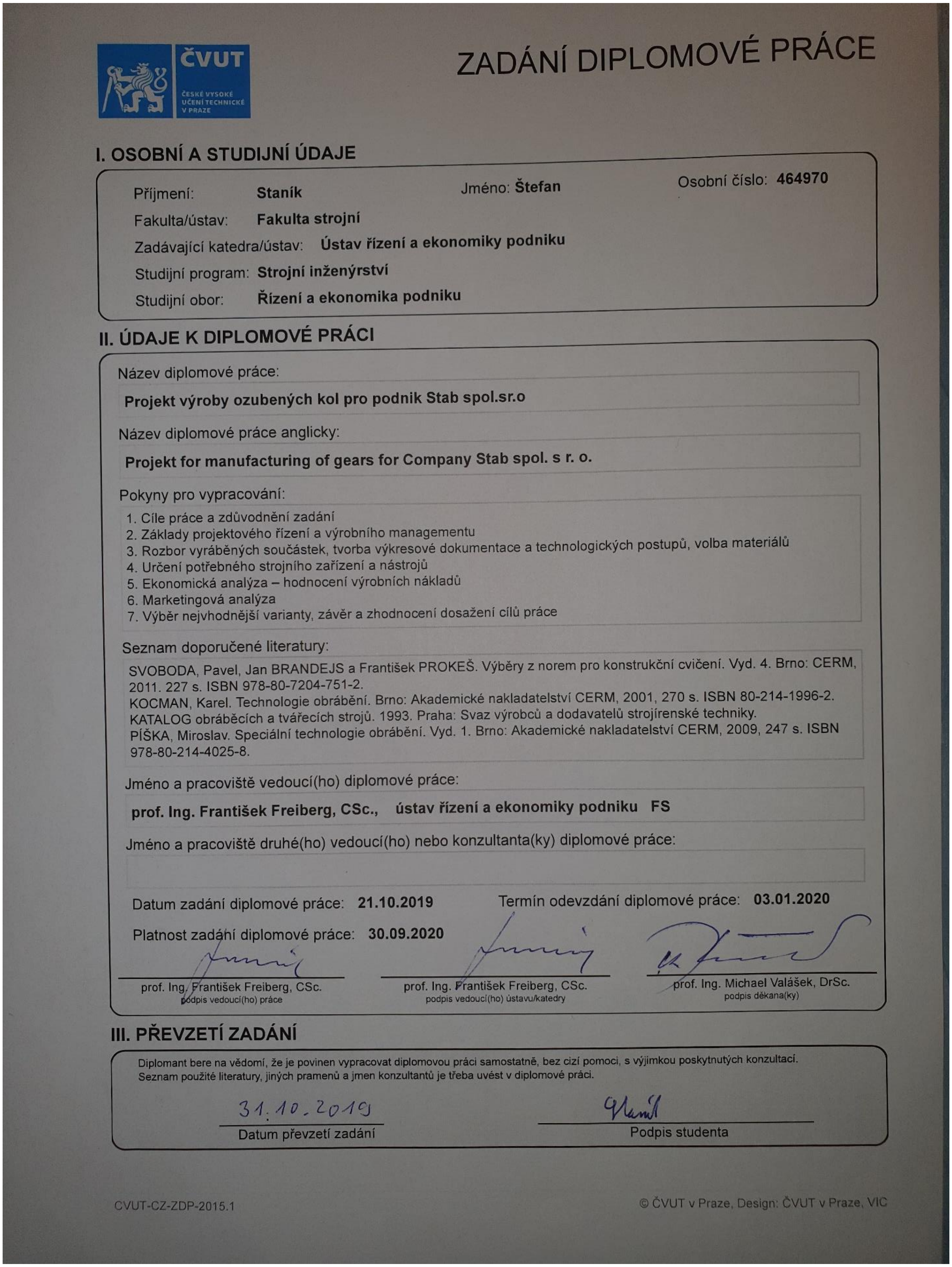
## Statement

I declare that I have elaborated this Master thesis by myself using the above-mentioned literature and sources listed in the appendix of this thesis.

18.12.2019

Date

Bc.Štefan Staník



ČVUT
ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

# ZADÁNÍ DIPLOMOVÉ PRÁCE

## I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Staník** Jméno: **Štefan** Osobní číslo: **464970**
Fakulta/ústav: **Fakulta strojní**
Zadávající katedra/ústav: **Ústav řízení a ekonomiky podniku**
Studijní program: **Strojní inženýrství**
Studijní obor: **Řízení a ekonomika podniku**

## II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

**Projekt výroby ozubených kol pro podnik Stab spol.sr.o**

Název diplomové práce anglicky:

**Projekt for manufacturing of gears for Company Stab spol. s r. o.**

Pokyny pro vypracování:

1. Cíle práce a zdůvodnění zadání
2. Základy projektového řízení a výrobního managementu
3. Rozbor vyráběných součástek, tvorba výkresové dokumentace a technologických postupů, volba materiálů
4. Určení potřebného strojního zařízení a nástrojů
5. Ekonomická analýza – hodnocení výrobních nákladů
6. Marketingová analýza
7. Výběr nejvhodnější varianty, závěr a zhodnocení dosažení cílů práce

Seznam doporučené literatury:

SVOBODA, Pavel, Jan BRANDEJS a František PROKEŠ. Výběry z norem pro konstrukční cvičení. Vyd. 4. Brno: CERM, 2011. 227 s. ISBN 978-80-7204-751-2.
KOCMAN, Karel. Technologie obrábění. Brno: Akademické nakladatelství CERM, 2001, 270 s. ISBN 80-214-1996-2.
KATALOG obráběcích a tvářecích strojů. 1993. Praha: Svaz výrobců a dodavatelů strojírenské techniky.
PÍŠKA, Miroslav. Speciální technologie obrábění. Vyd. 1. Brno: Akademické nakladatelství CERM, 2009, 247 s. ISBN 978-80-214-4025-8.

Jméno a pracoviště vedoucí(ho) diplomové práce:

**prof. Ing. František Freiberg, CSc., ústav řízení a ekonomiky podniku FS**

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

Datum zadání diplomové práce: **21.10.2019** Termín odevzdání diplomové práce: **03.01.2020**

Platnost zadání diplomové práce: **30.09.2020**

prof. Ing. František Freiberg, CSc.
podpis vedoucí(ho) práce

prof. Ing. František Freiberg, CSc.
podpis vedoucí(ho) ústavu/katedry

prof. Ing. Michael Valášek, DrSc.
podpis děkana(ky)

## III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

31.10.2019
Datum převzetí zadání

Podpis studenta

CVUT-CZ-ZDP-2015.1

# Abstract

This Master Thesis describes the project to set up a new division for a company which is refurbishing machines. The first part of the thesis is a theoretical part about the manufacturing processes and the economical part of this thesis. The main parts of the thesis are parts analysis, making of 3D models and drawings of two selected parts and then making of process route sheets. Another part is consisting of material, machines and tools selection. In the last part are done calculations needed to calculate the total costs of the manufacturing process for selected parts.

## Gratitude

I would like to express my gratitude to supervisor prof. František Freiberg for their professional advice, valuable feedback and guidance, which helped me to complete the project.

I am also grateful to Ing.Štefan Staník for his advice to help me with my project.

## Table of Contents

Abstract .... 4

Introduction .... 8

Company Presentation .... 9

Theoretical Part .... 10

- Types of Gears .... 10
- Gear Manufacturing Process .... 10
- Economic Theory .... 13
- Circular Economy .... 17
- Forecasting .... 17
- Market Research .... 18
- Price List of Gears from Other Companies .... 18

Analysis of Manufactured Parts .... 18

- Technical Description of the Parts .... 19
- Subgroup of Lathe SV 18RA Where are Manufactured Gears Located .... 20
- Drawings .... 20
- 3D Models for Visualization .... 23
- 3D Models for 3D printing .... 24
- Process Route Sheets .... 25
- Process Route Sheet for Part 160 682 .... 25
- Process Route Sheet for Part 160 673 .... 26
- Formulas Used for Process Route Sheets .... 28

Material Selection .... 33

- Experimental Materials .... 34
- Material Usage and Efficiency for Parts .... 35

Machines and Tools for Manufacturing Process .... 37

- Band Saw Machine .... 38
- Universal Lathe .... 39
- Milling Machine .... 40
- Grinding Machine .... 41
- Gear Shaping Machine .... 42
- Tools .... 43
- Tools List for Turning Operations .... 43

- Tools List for Milling Operations ........ 47
- Tools List for Grinding Operations ........ 48
- Tools List for Gear Shaping Operations ........ 48
- List of Measuring Tools ........ 49

Alternatives of Manufacturing Process ........ 51

- Machine Alternative Mazak INTEGREX i-200ST ........ 51
- Machine Alternative 3D Printer Pruša Mk3s ........ 52

Calculations and Costs ........ 53

Total Manufacturing Cost per Part ........ 59

Conclusion ........ 60

References ........ 61

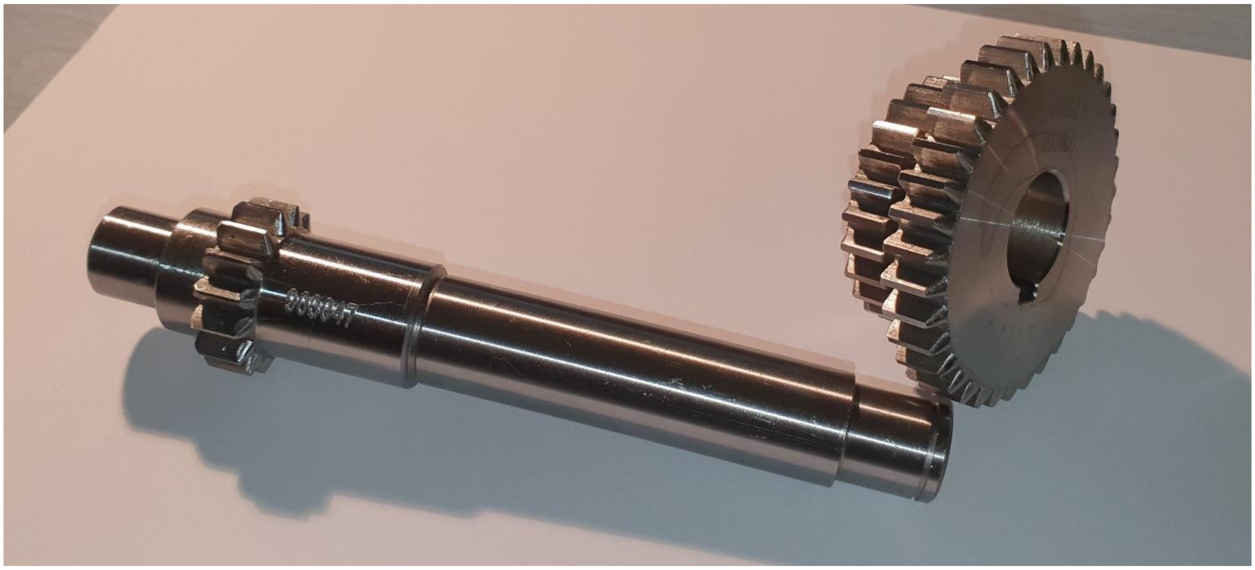
List of Pictures ........ 64

List of Used Symbols ........ 66

Attachments ........ 69

# Introduction

This thesis is going to be dealing with a project to set up a new division for manufacturing gears for a company which is refurbishing metal lathes. Company named Stab spol. s r.o. is currently buying these spare parts when repairing machines and in this thesis, we will consider options for starting such a division. If the results are going to be economically benefiting for the company, they are planning to set up this division. In the first part of the thesis, there will be an introduction of the company and basic description of the parts which are going to be manufactured. The second chapter will show us the theory of making gears and will explain what economic and technological calculations we will make later. In the next chapter will be constructing technical documentation and models of the parts and technical manuals for manufacturing. The fourth chapter will be about machines and tools needed where we will consider conventional machines and CNC machines and we will pick the most suitable solution. The last part will be about economic computations. In the end, we will take a look at what we described, and we will pick the best option for the company and decide if it will be profitable for the company to start up such a division.



Pic.1 Shaft 160 673 and Gear 160 682 [1]

## Company Presentation

Company Stab spol. s r.o. is operating in the city of Trenčín in Slovakia and has over twenty years of experience with refurbishing machines. Their main focus is on overhauling lathes which were made in the 1960s in the previously stated-owned factory named TOS Trenčín. More than half of the company repairs are conventional lathes named SV 18RA. These machines are the most suitable for small volume production and are very useful for tool shops where is required usually a small number of manufactured parts with high variety. The accuracy of the repaired machines is in thousands of millimeters. In the picture below you can see one of the workshops owned by the company with few machines which are currently undergoing a process of refurbishing. Our focus in this will be on one of the subgroups of the machines called Nortonová skriňa which is translated to English as a Norton gearbox. This subgroup consists of twenty-seven gears and seven shafts. These parts are not undergoing any heat treatment, so they were off much faster than gears in other subgroups. The current price of one gear to this subgroup starts at €30 and can go up to €200 for some of the shafts. In the picture [Pic.8] you can see the drawing of the subgroup which we are talking about. We will take a closer look at two of the parts which are always changed when the machines undergo refurbishing. [1]

Pic.2 Company's workshop for assembling machines [1]

# Theoretical Part

In the first part of this chapter, we will talk about the basics of the gears and gears manufacturing process and then we will move onto theory and explanation of the formulas used later in the thesis.

## Types of Gears

Pic.3 Types of gears [2]

The main types of gears we can see in the picture above [Pic.3]. The subject of our thesis is to propose the manufacturing process and machines necessary for manufacturing spur gears. This type of gears is the most used and their high accuracy can be achieved with a relatively easy manufacturing process. Another type of gears is helical gears that can transmit higher loads and are very quiet which is making them suitable for high-speed applications. Gear rack types of gears is used for converting rotational motion into linear motion. Bevel gears can be used to transmit force between two shafts which intersect at one point. Miter gears are used to change the direction and have a speed ratio of one. [2]

## Gear Manufacturing Process

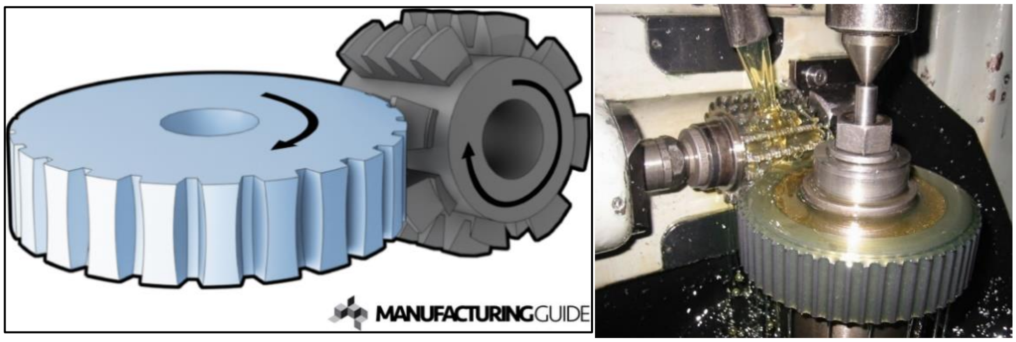
We can divide the gear manufacturing process into two main categories which are gear forming and gear machining. The first category is a process when gears are formed into the desired shape. Ways of forming can be processes like casting or molding. The second process is gear machining. When talking about gear machining we need to divide this process into two separated groups. The first group is rough machining which are processes like gear shaping, hobbing or milling. The second group is the finishing process which is following operations: shaving, lapping, grinding or honing.

Methods of gear manufacturing are the following: Gear teeth may be machined by milling, shaping, hobbing or skiving. The machining process is usually followed by the finishing processes such as shaving, burnishing, grinding, or lapping. Another very common way to manufacture gears is by injection molding but gears manufactured in this way need to be from materials like thermoplastics such as nylon, polycarbonate or acetal. Gears made with this method are lower in precision but have much lower manufacturing cost. [3] Nowadays some of the gears are manufactured by 3D-printing as well. This method is mostly applied to prototyping. In our project, we will use a 3D printer to make a prototype of the gears which we are planning to manufacture.

The first method of gear manufacturing we are going to be talking about is the gear milling method. With this process gear teeth are cut with milling cutter shaped in the way desired gears are. When using this method, it’s theoretically necessary to use for every gear different tool because for example gear with twenty-four teeth has different-shaped tooth space from the ones having twenty-five teeth.[4] This method is suitable for the manufacturing of external gears in small batches. The advantages of this method are the simplicity of the manufacturing process, low cost of tools and the possibility of using this method on conventional machines.in the picture below [Pic.4] we can see the manufacturing process of milling gear using horizontal milling machine type FA3. In our machine suggestion for manufacturing of the gear for our purposes, we have the same machine so we would be able to manufacture gears with this machine too. The disadvantages of this method are low manufacturing accuracy and low manufacturing speed because every gear is cut separately. With this manufacturing method, there are two types of cutting tools which are Involute gear cutter and Shank Type Gear Shaper Cutters. [5]

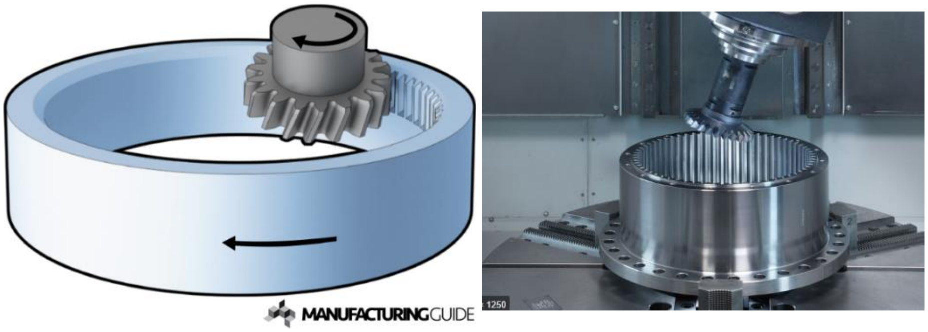
Pic.4 Gear Milling [1], [6]

Another method of manufacturing gear is the gear hobbing method. The method showed in the picture below is using a cutting tool which is called hob and is shaped like a worm. Both hob and the blank must be rotated at the proper angular-velocity ratio where the hob is slowly fed which is done until all the teeth are cut. Gear hobbing is one of the most fundamental ways how to manufacture gears and its great productivity and versatility makes it a top choice for a lot of manufacturers. The disadvantages of this process are high requirements for setting up of machine in the correct way for manufacturing which requires skilled machine operators. Another disadvantage of this method is a limitation to manufacturing possibility of only external gears. [5], [7]



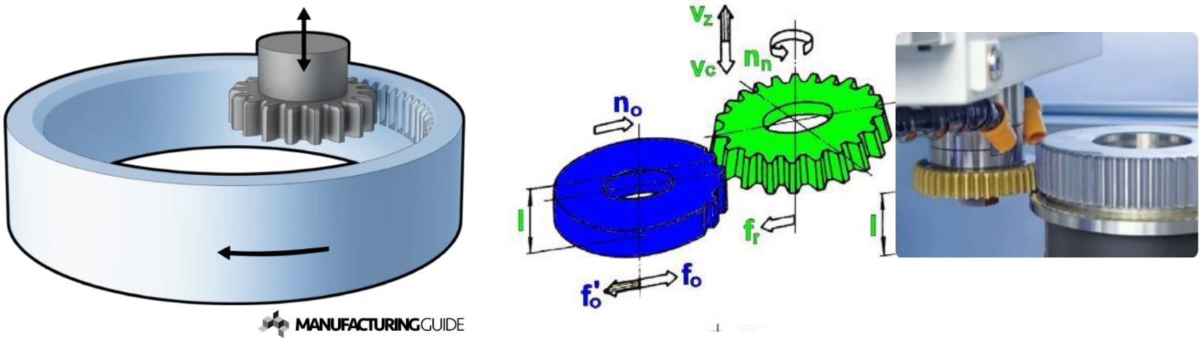
Pic.5 Gear Hobbing method [1], [7]

In Gear Skiving method is an angled cutting tool rotating around its axis while it is moving across rotating workpiece like is showed in the picture [Pic.6]. With this method extremely important is the accuracy of the synchronization between the workpiece spindle and the tool spindle. Gear skiving is faster and more flexible than other methods. This method is mostly used for internal gears and requires perfect synchronization at high spindle speeds and very expensive machining centers.



Pic.6 Gear Skiving Method [1], [8]

The last method that we will talk about is gear shaping. This method is also used for our manufacturing process. When using this method gears can be generated by either a pinion cutter or a rack cutter. The pinion cutter moves along its vertical axis and is slowly fed into a material which is creating gear blank until is reached required teeth depth. The workpiece is rotating along its axis while the cutter keeps cutting the desired shape. In the picture [Pic.7] you can see the kinematics of the movements. Symbols used in the picture are following: l is the length of tool trajectory, $v_c$ is average cutting speed, $v_z$ is the medium value of back movement of the cutting movement and symbol $n_n$ stands for the speed of rotation of the cutting tool and $n_o$ is rotating speed of the workpiece. With this method is possible to manufacture external and internal gears. The advantages of this method are low production cost, lower cost of machine purchase and lower requirements for operating this type of gear shaping machine. [1], [9]



Pic.7 Gear Shaping method [1], [9]

## Economic Theory

As we mentioned before the goal of this thesis is to prepare and analyze the whole project of manufacturing of the gears for the company. When we talk about the project, we need to know what a project is. According to Operations and Supply Chain Management book written by Mr. Jacobs and Mr. Chase project is a series of related jobs and tasks which are focused on a designed goal and require a significant period of time to perform. Projects usually have one-time occurrences, but the fact is that projects are usually repeated or slightly changed to other settings or products. Project management consists of planning, directing and controlling time management, cost, and resources such as people, materials or equipment. In the literature, we can see different types of projects. First mentioned is the Pure project which is characterized by a self-contained team which works full time on the project. The next type is a Functional project where team members are assigned from the functional units of the company. These members remain working their usual jobs and are working on the project on the side. The third type of project is a Matrix project which blends pure and functional project together.

The production process is a process to make a tangible goods and it’s usually divided into three steps. The first step is sourcing the parts we need which is followed by actually making the item and in the last step, the item is sent to the customers. When talking about the Production process we need to mention a few important terms. The first one is the Lead Time which is the time needed to respond to customer order. Another term is a decoupling point which determines where the inventory is positioned in the supply chain. When we talk about our manufacturing process lead time is time to manufacture our parts. The decoupling point for us is going to be in our inventory because we are planning to manufacture a batch of gears that are going to be waiting for us to use in our stock. According to this, we can consider our manufacturing process as a make-to-stock process when the finished goods are waiting for using. This is the opposite of the latest manufacturing trend which is called Lean manufacturing. Lean manufacturing means to achieve high customer satisfaction while having minimum levels of inventory. This principle is widely applied with car manufacturing where all parts for assembly line are delivered just in time of assemble. This principle removes inventories and costs connected with inventories. But in our case, it does not make economical sense to manufacture only a number of parts needed for the ongoing repair of the machine. Because of that, we decided to manufacture parts in batch and then the parts are going to be stored for later use. [10]

In the last part of our thesis, we will compute the total cost of our manufacturing process. For this purpose, we can look at cost accounting that is used for measuring and reporting financial information related to company consumption of resources. Cost management helps us to describe actions which are managers taking to control the costs that are increasing value for the customers and lowering the costs of products and services. An important part of company management is planning. We can define planning as choosing the goals, trying to predict the possible future and deciding how to achieve desired goals. Budget is the quantitative expression used to describe certain value which is going to be needed to achieve the desired goal. When we talk about costs we need to define two types of costs. The first type of costs is direct costs of a cost object. These are costs that are directly related to the particular object and can be traced to it in a cost-effective way. Examples of these costs from our thesis are costs like material costs, worker's salary or the price of the tools needed for the manufacturing process. The second type of costs is indirect costs of cost objects. These costs are related to a particular object but cannot be traced back to this object in an economically feasible way. When we are allocating this type of cost, we use the allocation method. A good example of this type of costs is costs like renting the warehouse for placing of our machine or the bill for gas used for transferring goods needed for manufacturing. In our case we allocate these costs at the end of total manufacturing cost plus twenty percent which will express these indirect costs. Another term we need to mention with our thesis is depreciation. Depreciation is a reduction in the value of an asset over time particularly due to the wear of the object. Depreciation method we use for machines. In our cost formula, we use only one-fifth of the purchasing price of the machines and the rest four-fifths of the price are added to the following four years. In this way, we divide the price of the machine into five years during which are machines going to be used. The formula used for computing of total manufacturing cost of our product consists of the following costs. Direct material costs, direct manufacturing labor costs, and indirect manufacturing costs.

$$N_C = \frac{C_{mat1}+C_{M1}+C_{T1}+C_{W1}+C_{E1}}{n} \times 1{,}2 \qquad [1.0]$$

$N_C$ is the total manufacturing cost. $C_{mat1}$ is the total material cost, $C_{M1}$ is the cost of the machines in total divided by five because we use depreciation method as mentioned earlier. $C_{T1}$ is the total cost of manufacturing tools and measuring tools divided by three because we will apply the depreciation method too but this time for a period of three years because tools wear off earlier. $C_{W1}$ is the salary cost. The last value $C_{E1}$ is the price of energy needed for our manufacturing process. Batch size is two hundred pieces, so our n is expressing this value. The number from the computing of this fraction is multiplied by 1,2 which is expressing indirect costs which are going to be twenty percent of the manufacturing costs. In the following charts, we analyzed how is the total manufacturing cost going to be changing according to the manufacturing batch. As we can see from the graphs [Chart 1] and [Chart 2] manufacturing cost per unit is decreasing with the volume. This effect is happening because the biggest part of the expenses is direct expenses that are not changing with the manufacturing volume. These expenses are the cost of machines, tools for manufacturing and measuring tools. Expenses which are in direct correlation with volume are expenses like the material cost of worker’s salary but in our case, these expenses are not the biggest part of the manufacturing costs. This analysis shows us and gives us the opportunity for offering our capacities on machines for other companies which would even lower our manufacturing costs and would offer for our company to make extra profit from these machines. [10], [11]

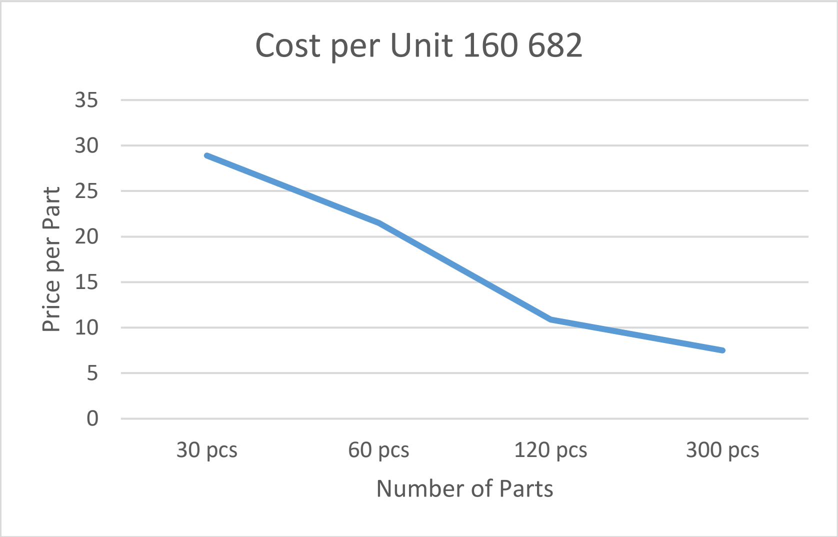


Chart 1. Cost per unit for gear 160 682

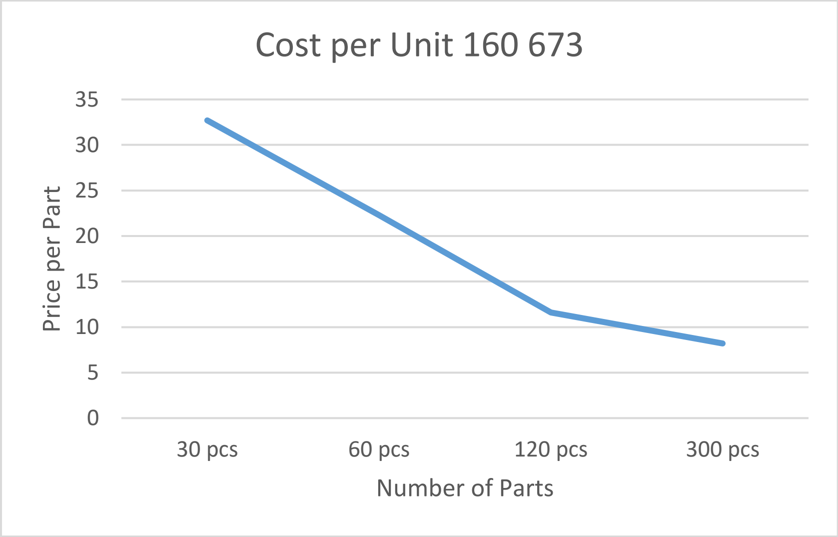


Chart 2. Cost per unit for shaft 160 673

In the following charts, we can see the price per unit with different production batches.

## Circular Economy

This word is becoming more and more popular lately especially when we talk about the protection of our planet. The circular economy is aiming to eliminate waste and is focusing on the continual use of resources. Traditional economy is a take-make-waste model and circular economy is trying to go behind this concept. The main aim of the circular economy is to keep materials and products in use. The advantages of the circular economy are reducing waste and renewing the life cycle of products. When is our company refurbishing machines, which were built in the 1960s we are becoming a part of the circular economy. One of the reasons for the demand for such an old machine is their durability. Other reasons are easiness of use and design of these machines. [13]

## Forecasting

An important part of every project should be forecasting. Thanks to forecasting we can estimate how much we need to produce. For our purpose, the best type of forecasting is going to be Time series analysis. In this type of forecasting, data related to the past are used to predict the future. In the following table [Table 1] we can see how many parts we needed in the past. According to this table, we can forecast for the next five years how many parts we approximately need to manufacture. [10]

| Year | Gear 160 682 | Shaft 160 673 |
|---|---|---|
| 2019 | 45 | 43 |
| 2018 | 55 | 51 |
| 2017 | 61 | 62 |
| 2016 | 59 | 61 |
| 2015 | 54 | 57 |

*data for the year 2019 are until the end of the October [1]

Table 1. Historical data from company database

From Table 1 we can see that we need around sixty pieces of each part per year. So, for five years forecast, we can assume we will need to produce around three hundred pieces of each part. In this table [Table 1] are included parts which the company is also selling to customers, so it is a total number of parts used for their own needs and to satisfy other customers. These other customers are already owning these machines and want to repair their machines by themselves. That adds around twenty to thirty pieces of each product per year. This means in total we can assume we will need to produce sixty pieces of each product which means manufacturing batch is sixty pieces of each part.

### Market Research

In this part, we will analyze companies which are manufacturing similar parts. This part is important for selling parts to customers which will lower the manufacturing cost of parts. Parts which we are planning to manufacture are very specific products and the market size is not very big. Possible customers are as we mentioned before companies who already own this type of machines and want to repair their machines by themselves. Another target group is companies like our company which is performing overhauls of these lathes.[10]

### Price List of Gears from Other Companies

In the table below [Table 2] we can see the prices of parts from other companies which are selling parts which we are planning to manufacture. We got also a price offer from two companies who offer manufacturing in cooperation for better comparison. According to market research, we can compare prices of parts when manufactured at other companies. Table 2 is showing us the price differences. This table will help us later to decide if setting up own manufacturing division is beneficial for our company or it’s better to stick with purchasing parts from the companies which are offering these products.

| Part | Price from other manufacturers | | |
|---|---|---|---|
| | Company 1 [€] | Company 2 [€] | Company 3 [€] |
| 160 682 | 35 | 59 | 65 |
| 160 673 | 39 | 65 | 68 |

Table 2. Competition Prices [1]

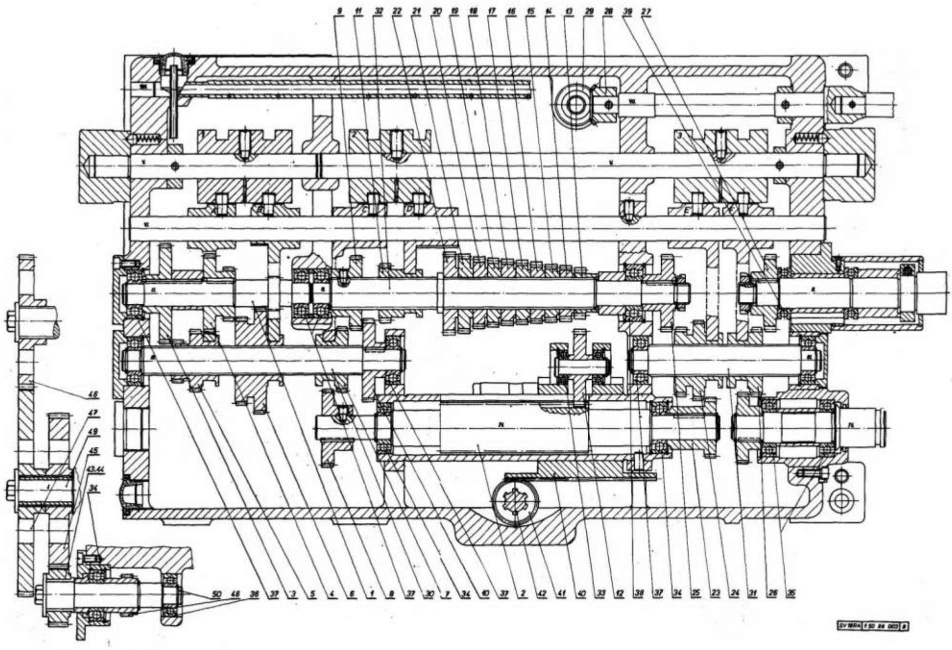
## Analysis of Manufactured Parts

In this part, we will talk about the technical description of the parts and we will show drawings that we made from real pieces of the parts. To make drawings we used software from company Autodesk which is called Inventor 2020. Drawings are followed by 3D models of the parts for better visualization and in the future can be used for the CNC machining when the model can be converted to other formats suitable for CNC machining process.

## Technical Description of the Parts

Gears which we are planning to manufacture are part of the subgroup called Norton box. The main purpose of the subgroup is to power shafts which are moving apron and saddles. In the Norton box, there are twenty-six gears and seven shafts. Most of these gears are module 1.75 with front teeth. These gears do not undergo a heating process after they are manufactured which is causing their earlier wearing off and causing higher noise of the machine. The maximal rotational speed is 3,2 $m.s^{-1}$ for the shaft and 4 $m.s^{-1}$ for the gear. Diameters and lengths of the parts which we are planning to manufacture are thirty-two millimeters and the length of the part is one hundred fifty-five for the shaft and sixty-eight-millimeter diameter for the gear with the length of twenty-seven millimeters. According to this, we will pick suitable machines for the manufacturing process. The surface roughness of these gears needs to be Ra 1,6 which is possible to achieve on the conventional machines when it is used the right manufacturing process. Conventional machines are the best option for our project mainly because of the significantly lower purchase price and also because we are planning to manufacture parts in a small volume (batch size of sixty pieces per part).[1], [14]

## Subgroup of Lathe SV 18RA Where are Manufactured Gears Located



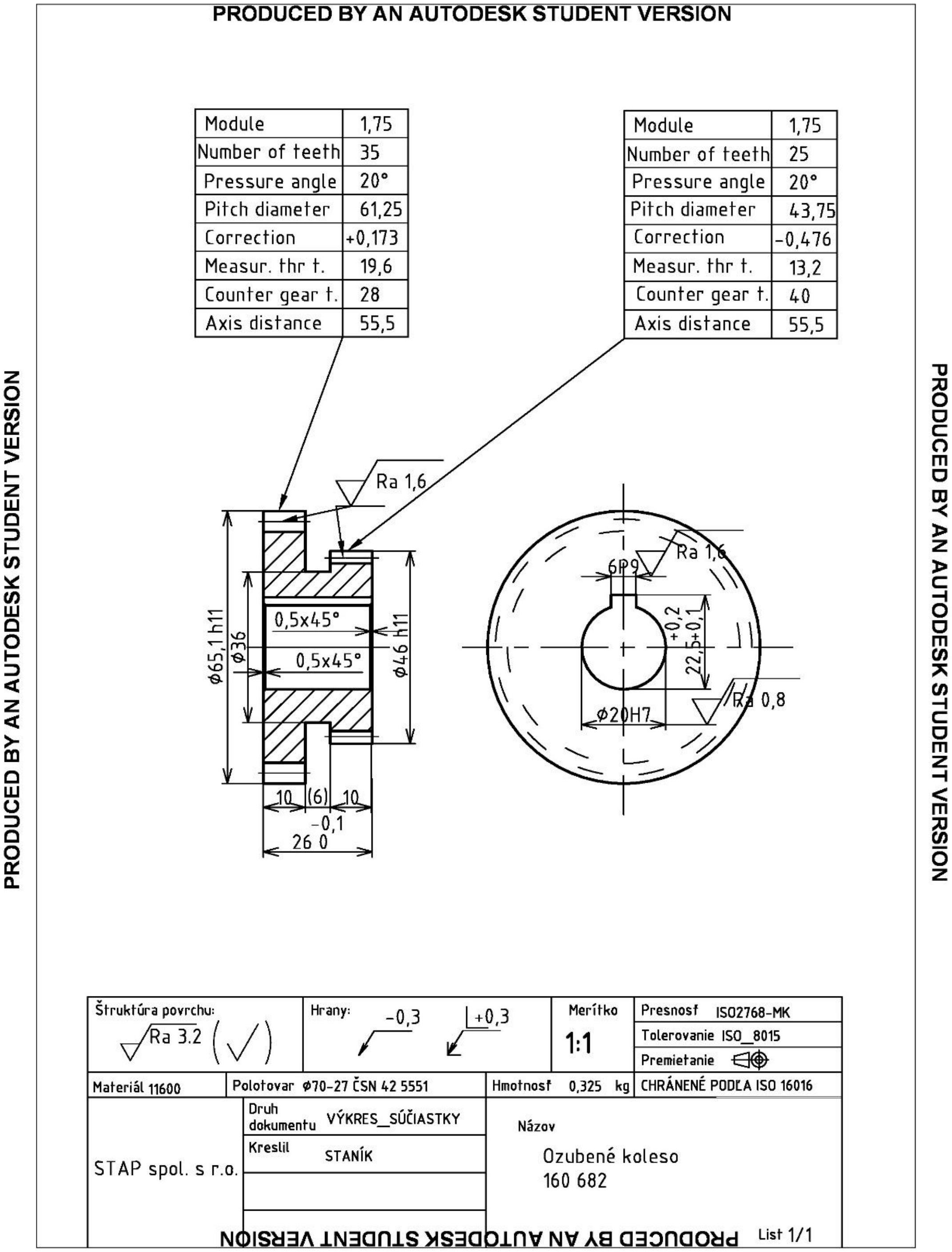
Pic.8 Drawing of Norton box [15]

In this picture above [Pic.8] we can see where manufactured gears are located. The main purpose the Norton gearbox in the lathe is to quickly change feed rate and threading capability. This process is done by changing of the position of gears located in gearbox. The main power input to the Norton gearbox is coming from the spindle box. Coming out of the Norton box are two shafts. The first one is for feed rate and the second shaft is for threading. Both of these shafts are connected to Apron where is the power distributed for desired needs. Our type of Norton gearbox has a very wide variety of threads and feeds which are possible to set up and this is making lathe SV 18RA one of the most variable machines ever manufactured.

## Drawings

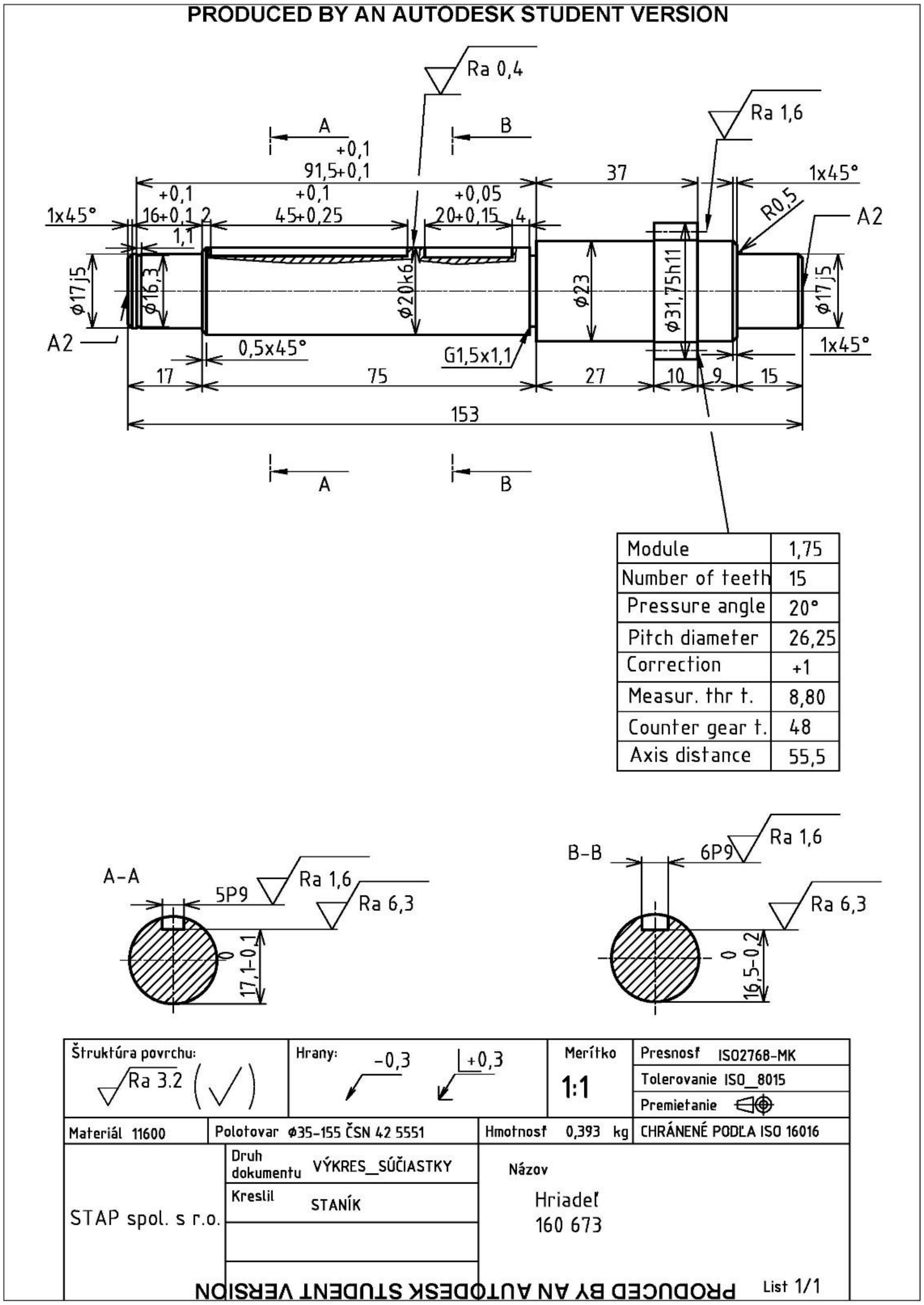
In this part, we can take a look at the drawings of the parts which we will project manufacturing process for. Drawing was made in the software from the company called Autodesk and we used their product Inventor 2020. [14]

Gear 160 682



Pic.9 Gear 160 682 drawing [1]

Shaft 160 673



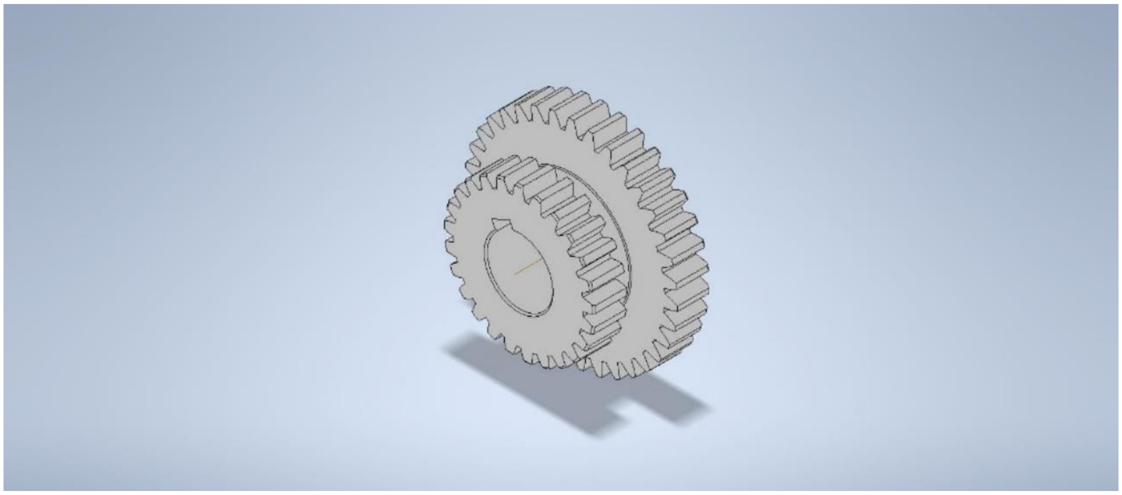
| | |
|---|---|
| Module | 1,75 |
| Number of teeth | 15 |
| Pressure angle | 20° |
| Pitch diameter | 26,25 |
| Correction | +1 |
| Measur. thr t. | 8,80 |
| Counter gear t. | 48 |
| Axis distance | 55,5 |

Štruktúra povrchu: Ra 3.2 (✓)
Hrany: –0,3 +0,3
Merítko 1:1
Presnosť ISO2768-MK
Tolerovanie ISO_8015
Premietanie
Materiál 11600
Polotovar ϕ35-155 ČSN 42 5551
Hmotnosť 0,393 kg
CHRÁNENÉ PODĽA ISO 16016
STAP spol. s r.o.
Druh dokumentu VÝKRES_SÚČIASTKY
Kreslil STANÍK
Názov
Hriadeľ
160 673
List 1/1

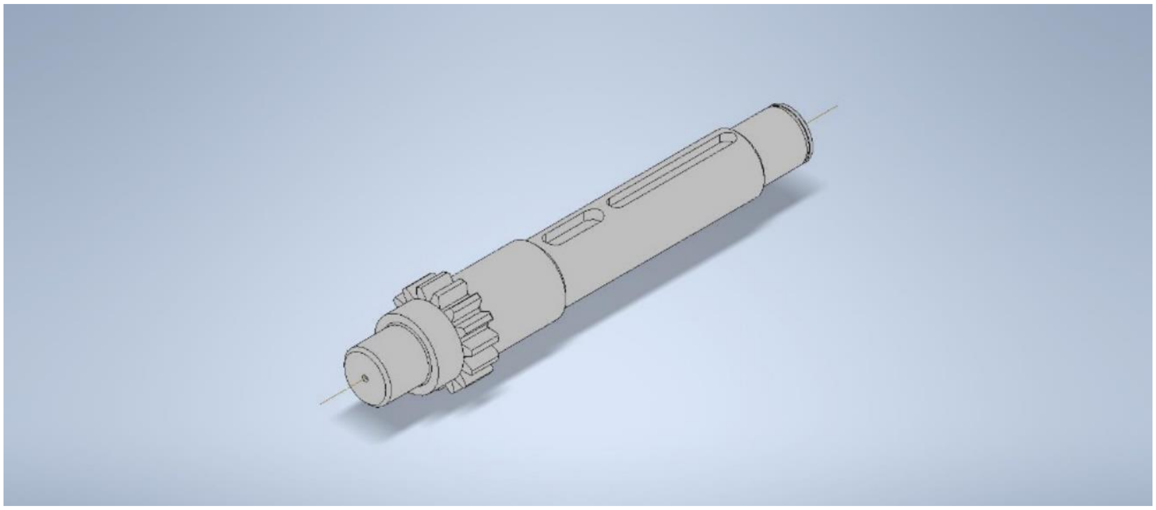
Pic.10 Shaft 160 673 drawing [1]

## 3D Models for Visualization

Another part of this chapter is 3D models of the parts. 3D models are now must-have a thing to have before starting the manufacturing process. In the pictures below we can see the models made in the same software Autodesk Inventor 2020. For the experimental part of our thesis, we converted models made in software to format for 3D printing (STL format).



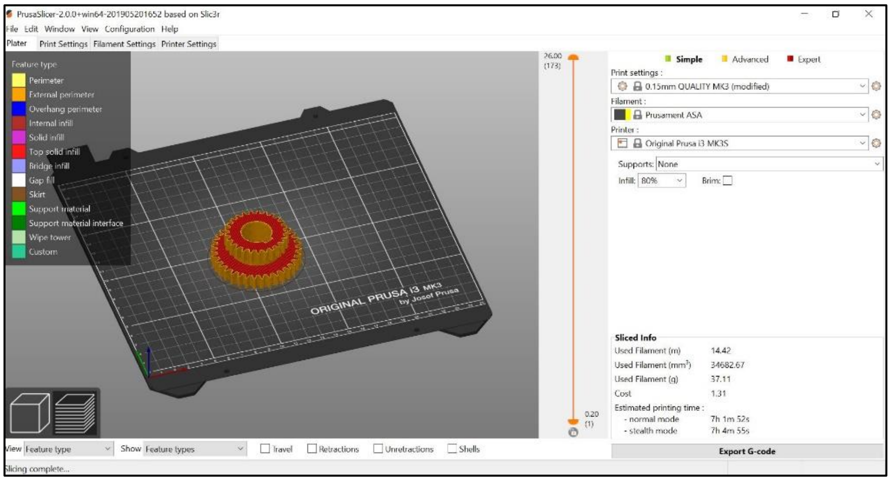
Pic.11 3D model of gear 160 682 [1]



Pic.12 3D model of shaft 160 673 [1]

## 3D Models for 3D printing

As we mentioned before we will manufacture our gears with the help of 3D printing technology for experimental use too. In the pictures below we can see how the models look like in the slicing software PrusaSlicer for 3D printing.



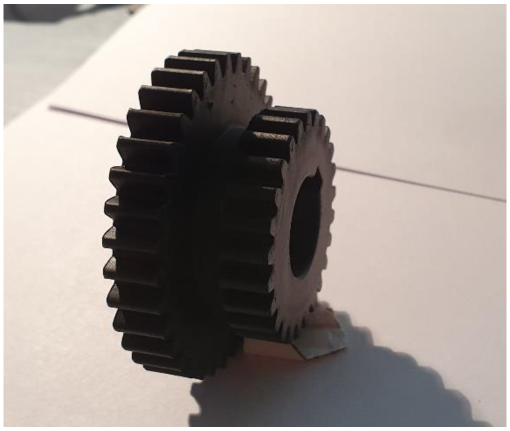
Print settings : 0.15mm QUALITY MK3 (modified)
Filament : Prusament ASA
Printer : Original Prusa i3 MK3S
Supports: None
Infill: 80%
Brim: ☐

View: Feature type
Show: Feature types
☐ Travel ☐ Retractions ☐ Unretractions ☐ Shells

**Sliced Info**

| | |
|---|---|
| Used Filament (m) | 14.42 |
| Used Filament (mm³) | 34682.67 |
| Used Filament (g) | 37.11 |
| Cost | 1.31 |
| Estimated printing time : | |
| - normal mode | 7h 1m 52s |
| - stealth mode | 7h 4m 55s |

Pic.13 Pruša Slicer for 3D printing [1]



Pic.14 3D printed PLA 160 682 [1]

Pic.15 3D printed PLA 160 673 [1]

## Process Route Sheets

The main goal of this part was to make manuals for all of the operations needed when manufacturing the mentioned parts. In the tables below we can see manuals with all its data. [5], [14], [15], [16], [17], [18], [32]

### Process Route Sheet for Part 160 682

| Op. | Operation description | $v_c$ [m.min$^{-1}$] | n [min$^{-1}$]<br>f [mm] | $a_c$[mm]<br>$a_p$[mm] | i | Tool |
|---|---|---|---|---|---|---|
| 01 | Machining of the face ø65.5 | 184 | 900<br>0,15 | 2,5<br>2,5 | 1 | T1 |
| 02 | Drilling the hole ø18 | 70,4 | 2240 | | | T4 |
| 03 | Machining of the hole ø19.5 | 68,6 | 1120 | | | T2 |
| 04 | Machining of the ø65.1h11 | 368 | 1800<br>0,15 | 0,4<br>0,2 | 2 | T1 |
| 05 | Machining of the hole ø20H7 | 113 | 1800<br>0,15 | 0,5<br>0,25 | 2 | T2 |
| 06 | Machining of the bevel 0.5x45° | 113 | 1800<br>0,15 | 0,5<br>0,5 | 1 | T1 |
| 07 | Check the ø65.1h11 20% of parts<br>Check the hole ø20H7 20% of parts | | | | | |
| 08 | Change the part and fix it | | | | | |
| 09 | Machining of the face to L=26.3$^{-0.1}$ | 285 | 1400<br>0,15 | 1,7<br>0,865 | 2 | T1 |
| 10 | Machining of the ø46.3 | 285 | 1400<br>0,15 | 21,7<br>3 | 8 | T1 |
| 11 | Machining of the ø46h11 | 323 | 2240<br>0,15 | 0,3<br>0,3 | 1 | T1 |
| 12 | Machining of the ø36 in width 6 | 253 | 2240<br>0,15 | 10,3<br>3,4 | 3 | T1 |
| 13 | Machining of the bevel 0.5x45° | 113 | 1800 | 0,5 | 1 | T1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 0,15 | 0,5 | | |
| 14 | Check the ø46h11 20% of parts | | | | | |
| 15 | Machining of the groove 6P9 | 18 | 1600<br>0,2 | 6<br>4,5 | 2 | T9 |
| 16 | Machining of the gears z=35, m=1.75/20° | 19,8 | 0,1 | | | T8 |
| 17 | Machining of the gears z=25, m=1.75/20° | 19,8 | 0,1 | | | T8 |
| 18 | Check the gears 100% of parts | | | | | |
| 19 | Visual check of the part 100% | | | | | |
| 20 | Pack finished part | | | | | |

Tab 3. Process Route Sheet 160 682 [5], [14], [15], [16], [17], [18]

## Process Route Sheet for Part 160 673

| Op. | Operation description | $v_c$ [m.min$^{-1}$] | n [min$^{-1}$]<br>f [mm] | $a_c$[mm]<br>$a_p$[mm] | i | Tool |
|---|---|---|---|---|---|---|
| 01 | Divide material into length 155 | 70 | 2640<br>0,05 | | 1 | |
| 02 | Machining of the length $L=153^{+0.1}$ from both sides | 154 | 1400<br>0,15 | 0,2<br>0,2 | 2 | T1 |
| 03 | Machining of the hole A2/60° from both sides | 17,6 | 2800<br>0,15 | | | T5 |
| 04 | Machining of the ø17j5 to ø17.3 | 154 | 1400<br>0,15 | 17,7<br>3 | 6 | T1 |
| 05 | Machining of the ø20k6 to 20.8 | 154 | 1400<br>0,15 | 14,2<br>3 | 5 | T1 |
| 06 | Machining of the ø31.75h11 to 32.2 | 154 | 1400<br>0,15 | 3,25<br>3,25 | 1 | T1 |
| 07 | Machining of the ø23 | 154 | 1400<br>0,15 | 12<br>3 | 4 | T1 |
| 08 | Machining of the ø31.75h11 | 225 | 2240<br>0,15 | 0,45<br>0,23 | 2 | T1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 09 | Machining of the undercut G1.5x1.1 | 141 | 2240<br>0,15 | | | T3 |
| 10 | Machining of the bevel 2 times 1x45° | 150 | 2240<br>0,15 | 1<br>1 | 1 | T1 |
| 11 | Machining of the groove 5P9 | 22,6 | 1600<br>0,2 | 5,0<br>4,5 | 2 | T6 |
| 12 | Machining of the groove 6P9 | 22,6 | 1600<br>0,2 | 6<br>4,5 | 2 | T6 |
| 13 | Check the ø31.75h11 20% of parts<br>Check the groove 5P9 20% of parts<br>Check the groove 6P9 20% of parts | | | | | |
| 14 | Grinding of the 2xø17j5 in centers | 20,15<br>[m×s$^{-1}$] | 2200<br>0,1 | 0,2 | | T7 |
| 15 | Grinding of the ø20k6 in centers | 20,15<br>[m×s$^{-1}$] | 2200<br>0,1 | 0,2 | | T7 |
| 16 | Check the ø17j5 20% of parts<br>Check the ø20k6 20% of parts | | | | | |
| 17 | Machining of the gears z=15, m=1.75/20° | 19,8 | 0,1 | | | T8 |
| 18 | Check the gears 100% of parts | | | | | |
| 19 | Visual check of the part 100% | | | | | |
| 20 | Pack finished part | | | | | |

Tab 4. Process Route Sheet 160 673 [5], [14], [15], [16], [17], [18], [22]

## Formulas Used for Process Route Sheets

In this part, we will show one calculation for every manufacturing process needed for manufacturing. [5], [14], [18]

Turning Operation

$$v_c = \frac{\pi \times D \times n}{10^3}\ [m \times min^{-1}] \qquad [1.1]$$

$$L = l_n + l + l_p [mm] \qquad [1.2]$$

$$t_{AS} = \frac{L}{n \times f}\ [min] \qquad [1.3]$$

| D | [mm] | Diameter of the Parts |
|---|---|---|
| L | [mm] | Length of the tool trajectory |
| f | [mm] | Feed rate |
| l | [mm] | Length of actual cutting trajectory |
| $l_n$ | [mm] | Length of tool onset |
| $l_p$ | [mm] | Length of tool offset |
| n | [$min^{-1}$] | Rotations of the spindle |
| I | [-] | Number of strokes |
| $t_{AS}$ | [min] | Machining time |
| $v_c$ | [$mm.min^{-1}$] | Cutting Speed |

Table 5. Symbols used for Turning Operation

The calculation for turning operation number 01 for gear 160 682

$$v_c = \frac{\pi \times D \times n}{10^3} = \frac{\pi \times D \times n}{10^3} = \frac{\pi \times 68 \times 900}{10^3} = 184\ [m \times min^{-1}] \qquad [1.4]$$

$$L = l_n + l + l_p = 2 + 28 + 2 = 32\ [mm] \qquad [1.5]$$

$$t_{AS} = \frac{L}{n \times f} \times i = \frac{32}{900 \times 0{,}15} \times 1 = 0{,}24\ [min] \qquad [1.6]$$

Milling Operation

$$v_c = \frac{\pi \times D \times n}{10^3}\ [m \times min^{-1}] \qquad [2.1]$$

$$t_{AS} = \frac{L}{v_f} \times i\ [min] \qquad [2.2]$$

$$v_f = f_n \times n\ [m \times min^{-1}] \qquad [2.3]$$

$$L = l_n + l + l_p + l_{nf}\ [mm] \qquad [2.4]$$

$$l_{nf} = \sqrt{H \times (D - H)}\ [mm] \qquad [2.5]$$

| | | |
|---|---|---|
| D | [mm] | Diameter of the Milling tool |
| L | [mm] | Length of the tool trajectory |
| i | | Number of strokes |
| $f_n$ | [mm] | Feed rate |
| l | [mm] | Length of actual cutting trajectory |
| $l_n$ | [mm] | Length of tool onset |
| $l_p$ | [mm] | Length of tool offset |
| n | [$min^{-1}$] | Rotations of the spindle |
| $t_{AS}$ | [min] | Machining time |
| $v_c$ | [$m.min^{-1}$] | Cutting Speed |
| $v_f$ | [$mm.min^{-1}$] | Feed speed |

Table 6. Symbols used for Milling Operation

The calculation for milling operation number 11 for gear 160 673

$$v_c = \frac{\pi \times D \times n}{10^3} = \frac{\pi \times 4{,}5 \times 1600}{10^3} = 22{,}6\ [m \times min^{-1}] \qquad [2.6]$$

$$t_{AS} = \frac{L}{v_f} \times i = \frac{55}{320} \times 2 = 0{,}34\ [min] \qquad [2.7]$$

$$v_f = f_n \times n = 0{,}2 \times 1600 = 320\ [m \times min^{-1}] \qquad [2.8]$$

$$L = l_n + l + l_p = 5 + 45 + 5 = 55\ [mm] \qquad [2.9]$$

Material Cutting

$$t_{AS} = \frac{L}{n \times f}\ [min] \qquad [3.1]$$

| | | |
|---|---|---|
| L | [mm] | Length of the tool trajectory |
| f | [mm] | Feed rate |
| n | [$min^{-1}$] | Rotations of the spindle |
| $t_{AS}$ | [min] | Machining time |
| $v_c$ | [$mm.min^{-1}$] | Cutting Speed |

Recommended cutting speed according to saw manufacturer is $v_c$= 70 [$m.min^{-1}$]

Table 7. Symbols used for Material cutting

The calculation for material cutting for gear 160 682

$$t_{AS} = \frac{L}{n \times f} = \frac{40}{2640 \times 0{,}05} = 0{,}3\ [\mathrm{min}] \qquad [3.2]$$

Grinding Operation

$$v_c = \frac{\pi \times d_s \times n_k}{10^3}\ [m \times s^{-1}] \qquad [4.1]$$

$$t_{AS} = \frac{l_a}{f_a \times n_w} \times \frac{p}{2 \times f_r}\ [min] \qquad [4.2]$$

$$v_w = \frac{\pi \times d_w \times n_w}{60 \times 10^3}\ [m \times min^{-1}] \qquad [4.3]$$

$$l_a = l_{na} + l_w + l_{pa}\ [mm] \qquad [4.4]$$

$$l_{pa} = l_{na} + \frac{b_s}{2}\ [mm] \qquad [4.5]$$

| | | |
|---|---|---|
| $b_s$ | [mm] | Width of the grinding wheel |
| $d_s$ | [mm] | Diameter of the grinding wheel |
| $f_a$ | [mm] | Axial feed |
| $f_r$ | [mm] | Radial feed |
| $n_w$ | [$min^{-1}$] | Frequency of the rotational speed of the workpiece |

| | | |
|---|---|---|
| $l_a$ | [mm] | Axial trajectory of the grinding wheel |
| $l_{na}$ | [mm] | Length of tool onset |
| $l_{pa}$ | [mm] | Length of tool offset |
| $l_w$ | [mm] | Length of the grinding trajectory |
| $n_k$ | [min$^{-1}$] | Frequency of the rotational speed of the grinding wheel |
| p | [mm] | Added material for grinding |
| $t_{AS}$ | [min] | Machining time |
| $v_c$ | [m.s$^{-1}$] | Cutting Speed |
| $v_w$ | [m.min$^{-1}$] | Workpiece peripheral speed |

Table 8. Symbols used for Grinding Operation

The calculation for grinding operation number 14 for 160 673

$$v_c = \frac{\pi \times d_s \times n_k}{60 \times 10^3} = \frac{\pi \times 350 \times 1100}{60 \times 10^3} = 20{,}15\ [m \times s^{-1}] \qquad [4.6]$$

$$t_{AS} = \frac{l_a}{f_a \times n_w} \times \frac{p}{2 \times f_r} = \frac{23}{0{,}1 \times 220} \times \frac{0{,}4}{2 \times 0{,}1} = 2{,}09\ [min] \qquad [4.7]$$

$$v_w = \frac{\pi \times d_w \times n_w}{10^3} = \frac{\pi \times 17 \times 220}{10^3} = 11{,}75\ [m \times min^{-1}] \qquad [4.8]$$

$$l_a = l_{na} + l_w + l_{pa} = 3 + 17 + 3 = 23\ [mm] \qquad [4.9]$$

$$l_{pa} = l_{na} + \frac{b_s}{2} = 3 + \frac{20}{2} = 13\ [mm] \qquad [5.1]$$

The calculation for Gear manufacturing for gear 160 682

$$L_b = l_n + b + l_p [mm] \qquad [6.1]$$

$$v_{cmax} = \frac{L_b \times n_n \times \pi}{1000} \; [m \times min^{-1}] \qquad [6.2]$$

$$t_{AS} = \frac{z \times m \times \pi \times n_o}{n_n \times f_n} \; [min] \qquad [6.3]$$

| | | |
|---|---|---|
| $L_b$ | [mm] | Length of the tool trajectory |
| B | [mm] | Gear width |
| $n_o$ | $[min^{-1}]$ | Rotations of the workpiece |
| $t_{AS}$ | [min] | Machining time |
| $v_c$ | $[m.min^{-1}]$ | Cutting Speed |
| $f_n$ | [mm] | Feed for double up |
| $n_n$ | [mm] | Number of double ups of the tool |

Table 9. Symbols used for Gear manufacturing

The calculation for Gear manufacturing for gear 160 682 operation 17

$$L_b = l_n + b + l_p = 5 + 10 + 5 = 20 \; [mm] \qquad [6.4]$$

$$v_{cmax} = \frac{L_b \times n_n \times \pi}{10^3} = \frac{20 \times 315 \times \pi}{10^3} = 19{,}8 \; [m \times min^{-1}] \qquad [6.5]$$

$$t_{AS} = \frac{z \times m \times \pi \times n_o}{n_n \times f_n} = \frac{35 \times 1{,}75 \times \pi \times 0{,}8}{315 \times 0{,}1} = 4{,}88 \; [min] \qquad [6.6]$$

## Material Selection

For our selection of materials, we will use literature and our knowledge about the materials which we acquired during our studies. As we mentioned before, parts that we are planning to manufacture are used in Norton gearbox and the purpose of these gears is to transfer torque from Spindle box to Apron. According to this knowledge, we will pick a material which is suitable for the parts that are used for transferring dynamical and statical moments, and there is no need for material to be suitable for welding. Materials that have these properties and are economically suitable for us are materials 11 600, 11 700 and 12 050 according to ČSN norms. Materials of the group 11 have predefined content of carbon, phosphor, and sulfur. Materials that are currently used for manufacturing gears and shafts like ours are usually of group eleven. We can see the comparison of the amount of the main elements in the chart below. Materials 11 600 and 11 700 are materials that are used without any chemical or heat treatment. For material 12 050 is common to use process post-processing operation which we are not planning to use at this stage. [14], [19] [20], [21]

| ČSN | ČSN EN | Content %C | Content %S | Content %P |
|---|---|---|---|---|
| 11 600 | E335 | max. 0,27 | max. 0,045 | max. 0,045 |
| 11 700 | E360 | max 0,45 | max. 0,045 | max. 0,055 |
| 12 050 | C45E | 0,42- 0,50 | max. 0,4 | max. 0,03 |

Tab.10 Chemical properties

Following chart is comparing mechanical properties of considered materials.

| Material | $R_m$ [MPa] | $R_e$ [MPa] | A [%] |
|---|---|---|---|
| 11 600 | 590- 710 | 335 | 14 |
| 11 700 | 690-830 | 355 | 15 |
| 12 050 | 630- 780 | 370 | 17 |

Tab.11 Mechanical properties

## Chemical and Heat treatment

Parts we are planning to manufacture were previously made without any heat and chemical treatments. All the gears and shafts placed in the Norton box are made in this way. On the other hand, gears and shafts used in the Speed box or Spindle box are chemically treated and also undergo annealing process. The reason for this is much higher speeds in these subgroups. As we mention before are used in the Norton gearbox where the rotational speeds are lower (v=6ms) and these gears the way they were made were without any heat or chemical treatments. The reasoning for this decision is mainly the price of such a treatment. This would increase the price of the manufacturing process exponentially. In new lathes like SN 50 manufactured by TOS Trenčín is used heat treatment for gears in Norton box. This heat treatment (annealing) requires grinding as the following operation which is again increasing the price. Even though such a treatment would increase the durability of the gears we will stick to the way gears for lathe SV 18RA were made and we will not use heat treatment. [14], [15], [19]

## Experimental Materials

For experimental purposes, we will manufacture one piece of each part using plastic material, mainly PET-G material. Manufacturing gears from plastic material with the help of the 3D printing technology would be much cheaper and wouldn't require the whole line of machines which we are suggesting. We will use this option first for prototyping and visual purposes. Later we will try to produce gear and shaft made from plastic material and then we will run a test if these materials are suitable for gear manufacturing. In the following chart, we can see the comparison of the main properties between steel material and plastic material. [19]

| Material | Density | Compressive Strength | Elastic Modulus | Brinell Hardness | Thermal Expansion |
|---|---|---|---|---|---|
| E360 | 7.9 g/cm3 | 335 MPa | 190 GPa | 210 | 12 µm/m-K |
| PETG | 1.3 g/cm3 | 55 MPa | 2.2 GPa | 105 | 68 µm/m-K |

Tab.12 Experimental materials

According to this table, we can see big differences in materials and to see if these differences are going to affect the possibility of using this material, we will need to test parts first. We will make these parts and let it run on the machine and then we can see the results.

## Material Usage and Efficiency for Parts

In the following tables, we can see the results of the calculations needed to select the right dimensions and amounts of the material for our manufacturing process. Tables are followed by calculations and explanations of the symbols. [5], [19], [20], [21]

| | | | |
|---|---|---|---|
| Diameter | $D_p$ | [mm] | 35 |
| Length | $L_p$ | [mm] | 155 |
| Length of the steel bar | $L_t$ | [mm] | 2000 |
| Batch size (number of parts) | n | [pcs] | 60 |
| Weight of manufactured part | $Q_s$ | [kg] | 0,39 |
| Weight of raw material for one part | $Q_p$ | [kg] | 1,17 |
| Material loss per part | $Z_{mo}$ | [kg] | 0,78 |
| Number of parts from one bar | i | [pcs] | 12 |
| Number of pieces of bars for the whole batch | $i_t$ | [pcs] | 5 |
| Weight of one bar | $m_t$ | [kg] | 15,1 |
| Usage of the material for one part | $v_p$ | [%] | 30,5 |

Tab 13 The material used for shaft 160 673

| | | | |
|---|---|---|---|
| Diameter | $D_p$ | [mm] | 70 |
| Length | $L_p$ | [mm] | 27 |
| Length of the steel bar | $L_t$ | [mm] | 2000 |
| Batch size (number of parts) | n | [pcs] | 60 |
| Weight of manufactured part | $Q_s$ | [kg] | 0,33 |
| Weight of raw material for one part | $Q_p$ | [kg] | 0,82 |
| Material loss per part | $Z_{mo}$ | [kg] | 0,5 |
| Number of parts from one bar | i | [pcs] | 74 |
| Number of pieces of bars for the whole batch | $i_t$ | [pcs] | 1 |

|  |  |  |  |
|---|---|---|---|
| Weight of one bar | $m_t$ | [kg] | 60 |
| Usage of the material for one part | $v_p$ | [%] | 66 |

Tab 14 The material used for Gear 160 682

Formulas for material usage calculations

$$D = (d_{max} \times 0{,}05) + 2\ [mm] \qquad [7.1]$$

$$Z_{mo} = Q_p - Q_s\ [kg] \qquad [7.2]$$

$$i = \frac{L_t}{L_p}\ [pcs] \qquad [7.3]$$

$$i_t = \frac{n}{i}\ [pcs] \qquad [7.4]$$

$$v_p = \frac{Q_s}{Q_p} \times 100\ [\%] \qquad [7.5]$$

Calculations of material used for shaft 160 673

$$D = (d_{max} \times 0{,}05) + 2 = 31{,}75 \times 0{,}05 + 2 = 35\ [mm] \qquad [8.1]$$

$$Z_{mo} = Q_p - Q_s = 1{,}17 - 0{,}39 = 0{,}78\ [kg] \qquad [8.2]$$

$$i = \frac{L_t}{L_p} = \frac{2000}{155} = 12{,}9 \cong 12\ [pcs] \qquad [8.3]$$

$$i_t = \frac{n}{i} = \frac{60}{12} = 5\ [pcs] \qquad [8.4]$$

$$v_p = \frac{Q_s}{Q_p} \times 100 = \frac{0{,}393}{1{,}17} \times 100 = 33{,}6\% \qquad [8.5]$$

## Machines and Tools for Manufacturing Process

In this chapter, we will select machines and tools which are going to be needed for the whole manufacturing process. We will pick machines according to their prices and suitability for our manufacturing process. The most important aspect when choosing these machines will be the price of the machine. Another condition which we need to acknowledge is the size of the batch that we are planning to make. We are talking about small batch production and for this purpose it is the best option for conventional machines which are much cheaper. Machines which we will need for the whole process are the following. First, we will start with cutting the bars of the material for which we will use bend saw. For turning operations, we will use mechanical lather and for milling operation, we will use a conventional milling machine of smaller size. For the operation of gear shaping, we will use the gear shaping machine. For grinding operations, we will need a grinding machine for grinding rotational parts. Tools for these machines we will select according to selected machines. [15], [16], [17], [18], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32]

### Band Saw Machine

A universal band saw is suitable for general use in various workshops. Lifting up of the banded arm needs to be done manually and feed into the cut is done by the own weight of the banded arm. This band saw has an option of purchasing extra continuous regulation for band arm feed. [32]

Pic. 16 Band Saw machine [32]

| Manufacturer | Bernado |
|---|---|
| Type | EBS 115 |
| Max. cutting diameter for full round material | 100 |
| Max. cutting length for full rectangle material | 100x150 |
| Saw blade speed | 20 / 29 / 50 [$m.min^{-1}$] |
| Main motor | 0.37kW |
| Machine dimensions | 895 x 400 x 950 |
| Machine weight | 62 Kilos |
| Machine price | €379 |

Tab. 15 Band Saw machine specifications

| Bernardo EBS 100 S | €639 |
|---|---|
| PROMA PPK-175 | €1,119 |
| Pulldown 160.120 G | €875 |

Tab.16 Band saw machines other alternatives

### Universal Lathe

Universal center lathe SV 18RA with the main motor output of 6 kW. Wide operating speed and feed range and its simplicity of use are making this lathe perfect for manufacturing desired parts. For the purpose of this manufacturing process will be used a machine which is already company owning and is using it currently for manufacturing of the parts. In the following chart are displayed the most important specifications. [15]

Pic.17 Lathe SV 18RA [1]

| Manufacturer | TOS Trenčín |
|---|---|
| Type | SV 18RA |
| Max. swing over bed | 380 |
| Max. swing over cross slide | 215 |
| Distance between centers | 750 |
| Max. spindle speed | 2800min-1 |
| Max. tool size | 22x22 |
| Main motor output | 6kW |
| Machine dimension | 950x2720 mm |
| Machine weight | 1,800 Kilos |

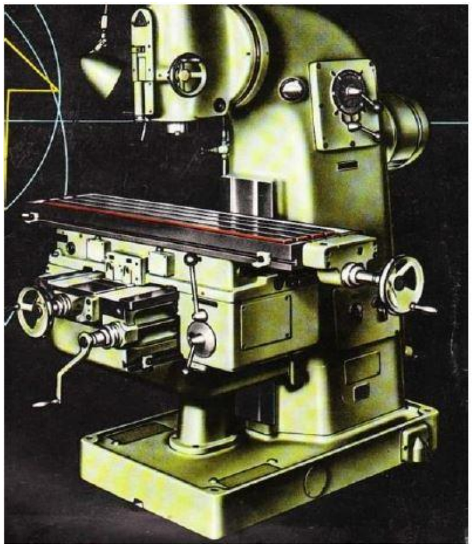
Tab.17 Lathe SV 18RA specifications

| Universal centre lathe SN 32 | €28,400 |
|---|---|
| Proma SPB-550/400 | €1,594 |
| Bernardo Hobby 500 | €1,167 |

Tab.18 Lathe machines other alternatives

## Milling Machine

Universal knee-type milling machine FA 3 is a high-efficiency production milling machine with a horizontal spindle. The design of this milling machine is suitable for high precision and productivity of milling operations. The max weight of the workpiece is 250 kilos. A wide range of spindle speeds and feeds is making this milling machine very universal. [16]



Pic.18 Milling machine FA 3 [23]

| | |
|---|---|
| Manufacturer | TOS Olomouc |
| Type | FA 3 |
| Table size | 250x1250 mm |
| Spindle speed range | 45 – 2000 min-1 |
| Main motor output | 4,2 kW |
| Machine dimension | 2710x1970mm |
| Machine weight | 1,600 Kilos |
| Machine price | €1,800 |

Tab. 19 Milling machine specifications

| | |
|---|---|
| Bernardo Variomill FU 1600 E Servo | €39,900 |
| Proma FP-25VA | €2,134 |
| Bernardo UWF 110 Servo | €13,500 |

Tab. 20 Milling machines other alternatives

## Grinding Machine

Universal cylindrical grinding machine 2UD 500. This grinding machine is used for grinding of workpieces max. diameter of 200 mm and a max. length of 500 mm. the workpiece is clamped between centers or overhung in a chuck with the possibility to use of the internal grinding device. This grinding machine is suitable for precise and high-performance grinding of individual pieces but also for a large series of workpieces. [17]

Pic.19 Grinding machine 2UD 500 [17]

| | |
|---|---|
| Manufacturer | TOS Hostivař |
| Type | 2UD 500 |
| Max. swing diameter | 290 |
| Distance between centers | 500 |
| Max. spindle speed | 1950min-1 |
| Grinding wheel diameter | 350mm |
| Motor outputs | 6,9kW |
| Machine dimension | 3340x1520 mm |
| Machine weight | 2,250 Kilos |
| Machine price | €1,800 |

Tab.21 Grinding machine specifications

| | |
|---|---|
| Bernardo URS 500 N. | €23,774 |
| Proma PBK-1000 | €37,800 |

Tab.22 Grinding machines other alternatives

## Gear Shaping Machine

The gear shaping machines OH4 is a universal machine intended for the shaping of inner and outer gearings. [18]

Pic.20 Gear shaping machine OH4 [18]

| | |
|---|---|
| Manufacturer | TOS Čelákovice |
| Type | OH 4 |
| Max. module of shaped gear | 4 mm |
| Max. Ø of shaped gear | 200 |
| Max. width of shaped gear | 40 |
| Main motor power | 1,2kW |
| Machine dimension | 930x1,200 |
| Machine weight | 1,700 Kilos |
| Machine price | €1,800 |

Tab.23 Gear shaping machine OH4 specifications

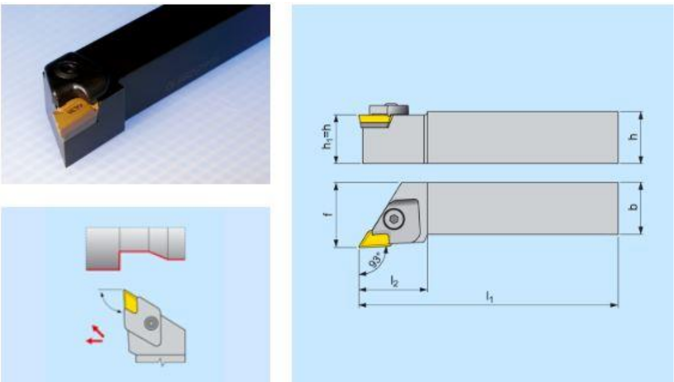
| | |
|---|---|
| TOS OFA 16 | €25,000 |
| Mazak Integrex | €420,000 |

Tab.24 Gear shaping machine other alternatives

## Tools

In this chapter, we will suggest the necessary cutting tools for all of the operations in technological manuals. When selecting the right tools, we will consider the durability of the tools and price.

### Tools List for Turning Operations

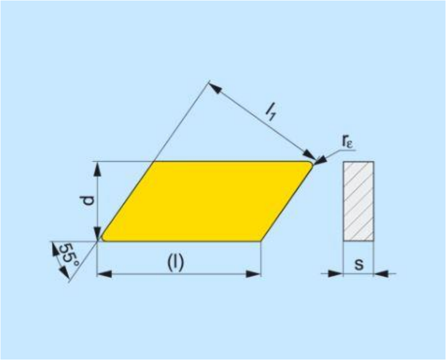


Pic. 21 Cutting tool for external turning [26]

The following chart is showing us the specifications of the tool holder for external turning.

| Specifications | $h=h_1$ [mm] | b [mm] | f [mm] | $l_1$ [mm] | Tool number |
|---|---|---|---|---|---|
| CKJNL 2020 K16 | 20 | 20 | 30 | 125 | T1 |

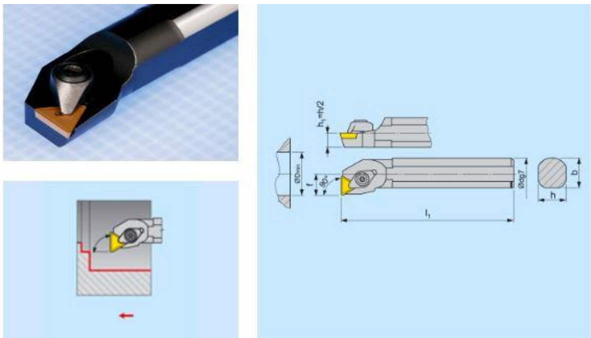
Tab25. Cutting tool for external turning



Pic. 22 Insert for external turning [26]

| Specifications | (l) [mm] | $l_1$[mm] | d [mm] | s [mm] | $f_{min}$ | $f_{max}$ | $a_{pmin}$ | $a_{pmax}$ |
|---|---|---|---|---|---|---|---|---|
| KNUX 160405EL-72 | 16 | 16,15 | 9,525 | 4,76 | 0,15 | 0,23 | 0,4 | 4,0 |

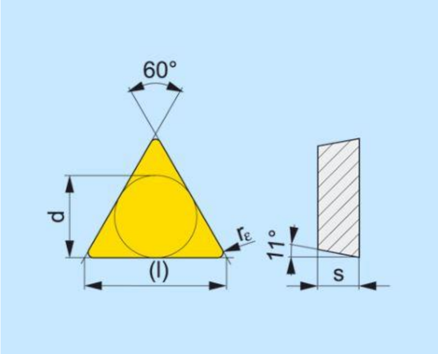
Tab26. Insert for external turning



Pic. 23 Cutting tool for internal turning [26]

| Specifications | dg7 [mm] | f [mm] | $l_1$ [mm] | h [mm] | Tool number |
|---|---|---|---|---|---|
| SM16M-CTFPL 11 | 16 | 11 | 150 | 14,5 | T2 |

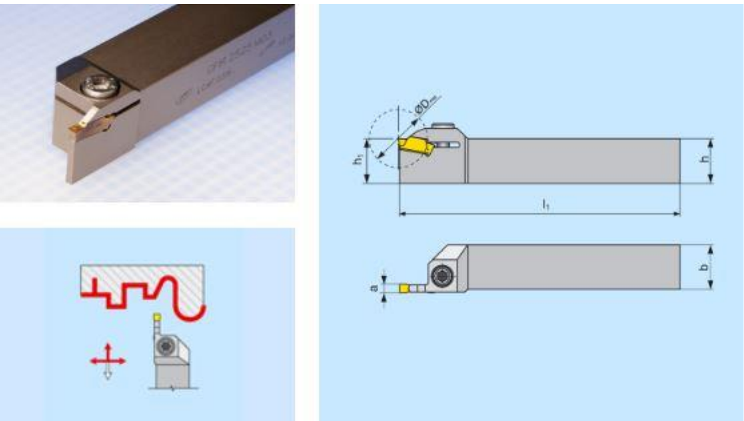
Tab27. Cutting tool for internal turning specifications



Pic. 24 Insert for internal turning [26]

| Specifications | (l) [mm] | d [mm] | s [mm] | $f_{min}$ | $f_{max}$ | $a_{pmin}$ | $a_{pmax}$ |
|---|---|---|---|---|---|---|---|
| TPMR 110304E-46 | 11 | 6,35 | 3,18 | 0,1 | 0,24 | 1,0 | 3,0 |

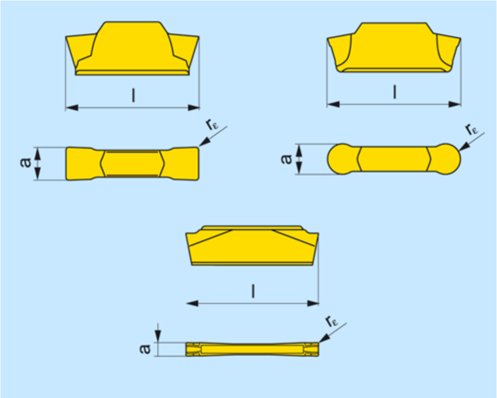
Tab28. Insert for internal turning



Pic. 25 Cutting tool for grooving [26]

| Specifications | $h=h_1$ [mm] | b [mm] | $l_1$ [mm] | a [mm] | $D_{max}$ [mm] | Tool number |
|---|---|---|---|---|---|---|
| GFIL 1616 H 03 | 16 | 16 | 100 | 3 | 38 | T3 |

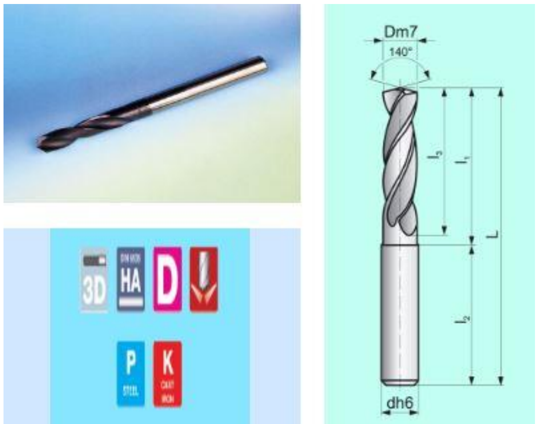
Tab.29 Cutting tool for grooving specifications



Pic. 26 Insert for grooving [26]

| Specifications | a[mm] | l [mm] | $r_e$ [mm] | $f_{min}$ | $f_{max}$ | $a_{pmax}$ |
|---|---|---|---|---|---|---|
| LCMF 031602-CM | 3 | 16,4 | 0,2 | 0,05 | 0,17 | 3,0 |

Tab.30 Insert for grooving specifications



Pic.27 Cutting tool for hole diameter eighteen [24]

| Specifications | $d_{h6}$ [mm] | L [mm] | $l_3$ [mm] | $DM_7$ [mm] | Tool number |
|---|---|---|---|---|---|
| 303DS-18-51-A18 | 18 | 123 | 73 | 18 | T4 |

Tab.31 Cutting tool for hole diameter eighteen specifications

Pic.28 Cutting tool for hole diameter two [25]

| Specifications | D [mm] | L [mm] | l [mm] | Tool number |
|---|---|---|---|---|
| A210200V000S | 2 | 49 | 24 | T5 |

Tab.32 Cutting tool for hole diameter two specifications

## Tools List for Milling Operations

Pic.29 Milling tool for the groove P5 and P6 [31]

| Specifications | D [mm] | L [mm] | Number of Teeth | Tool number |
|---|---|---|---|---|
| Milling Tool | 4,5 | 50 | 6 | T6 |

Tab.33 Milling tool for the groove specifications

Pic.30 Grooving tool for groove 6P69[35]

| Specifications | b f8 [mm] | h [mm] | L [mm] | Tool number |
|---|---|---|---|---|
| Grooving Tool | 6 | 16 | 130 | T9 |

Tab.34 Milling tool for the groove specifications

## Tools List for Grinding Operations

Pic.31 Ceramic Grinding wheel [22]

| Specifications | Catalog number | Recommended cutting speed | Recommended wheel speed | Tool number |
|---|---|---|---|---|
| Ceramic grinding wheel 350x40x127 | 454A46H5V40 | $V_c = 30 \div 40$ m.s$^{-1}$- | n = 1900 ÷ 2100 min$^{-1}$ | T7 |

Tab.35 Ceramic Grinding wheel specifications

## Tools List for Gear Shaping Operations

Pic.32 Gear cutting tool [23]

| Specifications | Module [mm] | Number of Teeth | Diameter [mm] | Tool Number |
|---|---|---|---|---|
| Gear cutting tool Morse 2 | 1,75 | 14 | 24,5 | T8 |

Tab.36 Gear cutting tool specifications

## List of Measuring Tools

Pic. 33 Digital caliper [27]

| Name | Type | Tool number |
|---|---|---|
| Digital caliper | Mitutoyo 200 mm | M1 |

Tab.37 Digital caliper specifications

Pic.34 Digital micrometer [28]

| Name | Type | Tool number |
|---|---|---|
| Digital micrometer | Insize 25-50 mm | M2 |

Tab.37 Digital micrometer specifications

Pic.35 Digital spindle disc micrometer 25-50 [29]

| Name | Type | Tool number |
|---|---|---|
| Digital spindle disc micrometer | Insize 25-50 mm | M3 |

Tab.38 Digital spindle disc micrometer

Pic.36 Digital spindle disc micrometer 50-75 [30]

| Name | Type | Tool number |
|---|---|---|
| Digital spindle disc micrometer | Insize 50-75 mm | M4 |

Tab.39 Digital spindle disc micrometer

## Alternatives of Manufacturing Process

In this chapter, we will show the other alternatives to our suggested manufacturing process. The manufacturing process that we choose to use is selected according to the batch size which is three hundred pieces per part. When the batch size is this small the best option for manufacturing is to use the conventional machines that have a setup cost much lower than using the modern CNC machines. If the company would like to increase the production size or just wanted to use modern technologies for manufacturing without looking at the cost of manufacturing, we could use the alternative machine showed in this chapter. Another possible alternative would be to manufacture gears with the help of 3D printing technology. This method is very new, and testing would be needed.

### Machine Alternative Mazak INTEGREX i-200ST

In this alternative, we will suggest using only one machine for the whole manufacturing process. The advantages of such a decision are less space for machines, fewer workers needed to operate machines and simplification of the whole manufacturing process. Modern machining centers like the one shown below can nowadays perform all tasks like turning, milling or gear shaping in one machine. The main disadvantage of this choice is the price of the machine. Our whole suggested machine park needed for manufacturing cost us €6,039. In comparison, the machining center Mazak INTEGREX i-200ST would cost us €420,000. The machine like this is more suitable for companies whose core business is high volume manufacturing. When purchasing such an expensive machine we need to have the production volume in thousands of parts per year. [33]

Pic.37 Mazak Integrex [33]

### Machine Alternative 3D Printer Pruša Mk3s

Our second suggestion for the machine is to use the 3D printer from the manufacturer Pruša. Printing our parts instead of manufacturing them in a conventional way would dramatically decrease the costs of manufacturing. As was mentioned in previous chapters, for using this method of manufacturing we will need to run tests first and the results of this would answer our question if this manufacturing process is possible. Nowadays manufacturers are implementing 3D printing technologies very often to their manufacturing process but mostly for prototyping. To use 3D printing for manufacturing parts that are going to be used in machines is a different story.

Pic.38 3D Printer Pruša Mk3s [34]

| Type | Printing dimensions | Used material | Bed temperature | Nozzle temperature |
|---|---|---|---|---|
| Pruša Mk3s | 210x210x270 [mm] | PLA, ABS, ASA, PETG | 90°C | 260°C |

Tab.40 3D Printer specifications [34]

## Calculations and Costs

### Material calculations

In the following chart, we will show the prices of the material required for manufacturing our parts. Manufactured batch is going to be sixty pieces for gear 160 682 and sixty pieces of shafts 160 673. According to the chapter about Material selection, we know how much material we need to use for our manufacturing process.

Used material for manufacturing process

| Part | Material | Diameter [mm] | Length [mm] | Length of one bar [mm] | Number of bars [pcs] | Price in total [€] |
|---|---|---|---|---|---|---|
| 160 682 | 11 600 | 70 | 27 | 2,000 | 1 | 59.6 |
| 160 673 | 11 600 | 35 | 155 | 2,000 | 5 | 80.5 |

Tab.41 Required material [20], [21]

Final material cost for each part

| Part | Symbol | Price [€] |
|---|---|---|
| 160682 | $C_{mat1}$ | 59.6 |
| 160673 | $C_{mat2}$ | 80.5 |

Tab.42 Total material cost

### Machine Costs

In the following table, we can see the prices of the machines which we need to buy for our manufacturing process. The company is already owning Lathe SV 18RA so we will not add the price of this machine to the final calculation.

| Machine | Manufacturer | Price of the Machine [€] |
|---|---|---|
| Lathe SV 18A | TOS Trenčín | 0 |
| EBS 115 | Bernado | 639 |

| | | |
|---|---|---|
| FA 3 | TOS Olomouc | 1,800 |
| 2UD 500 | TOS Hostivař | 1,800 |
| OH4 | TOS Čelákovice | 1,800 |
| Total cost of machines | | 6,039 |

Tab.43 Machines cost [15], [16], [17], [18], [32]

For each part, we will add half of the total sum of the price to the cost calculations. This means €3,019.5 We will do the calculation of using the machines for five years so for our cost of one batch we will use one-fifth of the price €3,019.5 which means €603.9 to add to the total cost for each part as the cost of the machines.

Final machine cost for each part

| Part | Symbol | Price [€] |
|---|---|---|
| 160682 | $C_{M1}$ | 603.9 |
| 160673 | $C_{M2}$ | 603.9 |

Tab.44 Total Machines cost

## Tools Cost

In the following table, we can see the prices of the tools needed. For each part, we will add half of the total sum of the price to costs calculations.

| Name | Type | Tools needed | Price in total [€] |
|---|---|---|---|
| Tool holder | CKJNL 2020 K16 | 1 | 49 |
| Insert | KNUX 160405EL-72 | 1 | 6.3 |
| Tool holder | SM16M-CTFPL 11 | 1 | 49 |
| Insert | TPMR 110304E-46 | 1 | 6.3 |

| | | | |
|---|---|---|---|
| Tool holder | GFIL 1616 H 03 | 1 | 113 |
| Insert | LCMF 031602-CM | 1 | 19.6 |
| Drilling bit | 303DS-18-51-A18 | 1 | 122 |
| Drilling bit | A210200V000S | 1 | 1.5 |
| Milling tool | 4,5X1,0mm | 1 | 27 |
| Milling tool | b6f8, L130 | 1 | 45 |
| Grinding wheel | 454A46H5V40 | 1 | 121 |
| Gear shaping tool | Module 1,75 | 1 | 120 |
| Digital caliper | Mitutoyo 200 mm | 1 | 141 |
| Digital micrometer | Insize 25-50 mm | 1 | 90 |
| Digital spindle disc micrometer | Insize 25-50 mm | 1 | 251 |
| Digital spindle disc micrometer | Insize 50-75 mm | 1 | 275 |
| Total cost | | | 1,436.7 |

Tab.45 Tools cost [22], [23], [24], [25], [26], [27], [28], [29], [30], [31]

For each part, for the total cost, we will use the price of €239,5 because we will apply the depreciation theory for three years and then total price for one year, we will divide in half to get the final price for one part.

Final tools cost for each part

| Part | Symbol | Price [€] |
|---|---|---|
| 160682 | $C_{T1}$ | 239.5 |
| 160673 | $C_{T2}$ | 239.5 |

Tab.46 Total Tool cost

Total machining times

Sum of total manufacturing times of each necessary operation for sixty parts.

Part 160682

| Operation | Hours required [Hrs.] |
|---|---|
| Turning | 1.94 |
| Milling | 0.2 |
| Drilling | 0.4 |
| Gear shaping | 13 |
| Measuring and others | 5 |

Tab.47 Machining Times 160 682

Part 160673

| Operation | Hours required [Hrs.] |
|---|---|
| Material cutting | 0.3 |
| Turning | 2.85 |
| Milling | 0.49 |
| Grinding | 8.9 |
| Gear shaping | 4.5 |
| Measuring and others | 5 |

Tab.48 Machining Times 160 783

## Workers salary

In the following table we can the cost of workers salary. Wage per hour is eight Euros.

Part 160682

| Operation | Price per operation [€] |
|---|---|
| Turning | 15.5 |
| Milling | 1.6 |
| Drilling | 3.2 |
| Gear shaping | 104 |
| Measuring and others | 40 |
| Total cost | 164.3 |

Tab.49 Total cost for each machining operation 160 682

Part 160673

| Operation | Price per operation [€] |
|---|---|
| Material cutting | 2.4 |
| Turning | 22.8 |
| Milling | 3.92 |
| Grinding | 71.2 |
| Gear shaping | 36 |
| Measuring and others | 40 |
| Total cost | 176.3 |

Tab.50 Total cost for each machining operation 160 673

Final wage cost for each part

| Part | Symbol | Price [€] |
|---|---|---|
| 160682 | $C_{w1}$ | 164.3 |
| 160673 | $C_{w2}$ | 176.3 |

Tab.51 Total cost for workers salary

Energy cost

In this part, we calculated the total cost for energy consumption for machines needs for our manufacturing process. Price per one Kilowatt is €0.15.

Part 160 682

| Operation | Total price of the energy per operation [€] |
|---|---|
| Turning | 2.1 |
| Milling | 0.15 |
| Drilling | 0.42 |
| Gear shaping | 5.85 |
| Total cost | 8.52 |

Tab.52 Price for energy for 160 682

Part 160 673

| Operation | Total price of the energy per operation [Euros] |
|---|---|
| Material cutting | 0.1 |
| Turning | 2.99 |
| Milling | 0.37 |
| Grinding | 10.68 |
| Gear shaping | 2.1 |

| | |
|---|---|
| Total cost | 16.24 |

Tab.53 Price for energy for 160 673

Final Energy cost for each part

| Part | Symbol | Price [Euros] |
|---|---|---|
| 160682 | $C_{E1}$ | 8.52 |
| 160673 | $C_{E2}$ | 16.24 |

Tab.54 Total cost for energy

Other Manufacturing Cost

Other manufacturing cost includes cost like rent, taxes or logistic cost. For our manufacturing process, we will use the estimated number of the value twenty percent of the total manufacturing cost.

## Total Manufacturing Cost per Part

**Part 160 682**

$$N_C = \frac{C_{mat1} + C_{M1} + C_{T1} + C_{W1} + C_{E1}}{n} \times 1{,}2 = \frac{59.6 + 603.9 + 239.5 + 164.3 + 8.52}{60} \times 1.2$$

$$= \mathbf{21.5\ \mathit{Euro}}$$

**Part 160 673**

$$N_C = \frac{C_{mat1} + C_{M1} + C_{T1} + C_{W1} + C_{E1}}{n} \times 1{,}2 = \frac{80.5 + 603.9 + 239.5 + 176.3 + 16.24}{60} \times 1.2$$

$$= \mathbf{22.3\ \mathit{Euro}}$$

## Conclusion

As a result of the research focused on setting up the new division for the manufacturing of gears in house, we can say that our proposal was successful. Costs of manufacturing with our proposed methods are lower than buying spare parts from current suppliers. The first part of this thesis was focused on the theory about used manufacturing processes and basic explanations about the economical part which was then used in the last part of this thesis. After constructional analysis of desired parts, we created drawing for our selected two parts what was followed by making 3D models of these parts. Another important part was to make process route sheets that are going to be used by operators of the machines to achieve desired dimensions and tolerances of the parts. Then we analyzed necessary machines and tools according to manufacturing manuals created in the previous chapter. We selected machines according to our small manufacturing batch size with consideration of keeping expenses as low as possible. One chapter was describing alternative manufacturing where the first proposal was the universal center for performing the whole manufacturing process at one machine. This variant was too expensive, so we added another alternative variant which was the manufacturing of the parts with the help of 3D printing technology. As we mentioned this method needs to be more deeply analyzed and then tested before starting such a manufacturing process. The last part of this thesis was focused on economic calculations. The result of the chapter were the total manufacturing costs of both parts. As we mentioned previously, we reached lower costs of the parts than is the price that we are buying it now. According to these results, it will be possible to use this thesis as a manual for our company for setting up this division for manufacturing their own parts to lower costs and increase profits.

# References

[1] STAB, Internal Company Database [online]. [quoted 2019-12-09]. Available after logging in to company database

[2] TYPES OF GEARS. Types of Gears | KHK Gears [online]. KHK Gears [quoted 2019-12-12]. Available at: https://khkgears.net/new/gear_knowledge/introduction_to_gears/types_of_gears.html

[3] NISBETT, Budynas. *Shigley's Mechanical Engineering Design,*. Eighth Edition. The McGraw−Hill Companies, 2008. ISBN 0−390−76487−6.

[4] KOCMAN, Karel. Technologie obrábění. Brno: Akademické nakladatelství CERM s.r.o., 2001, 270 s. ISBN 80-214-1996-2.

[5] HUMÁR, Anton. Technologie I [online]. Student handbook "Strojírenská technologie". VUT in Brno, Faculty of Mechanical Engineering, 2003, 138 pgs. Available at: http://ust.fme.vutbr.cz/obrabeni/opory-save/TI_TO-1cast.pdf

[6] Gear milling. Manufacturing guide [online]. Manufacturing Guide Sweden AB [quoted 2019-12-12]. Available at: https://www.manufacturingguide.com/en/gear-milling

[7] Gear hobbing. Manufacturing guide [online]. Manufacturing Guide Sweden AB [quoted 2019-12-12]. Available at: https://www.manufacturingguide.com/en/gear-hobbing

[8] Understanding the Basic Principles of Power Skiving. *Manufacturing guide* [online]. Manufacturing Guide Sweden AB [quoted 2019-12-12]. Available at: https://gearsolutions.com/features/understanding-the-basic-principles-of-power-skiving/

[9] Gear shaping. Manufacturing guide [online]. Manufacturing Guide Sweden AB [quoted 2019-12-12]. Available at: https://www.manufacturingguide.com/en/gear-shaping

[10] JACOBS, F. Robert a Richards B. CHASE. *Operations and Supply Chain Management*. Fourth Edition. The McGraw−Hill International Edition, 2018. ISBN 978-1-259-25352-2.

[11] MACÍK, Karel. Kalkulace a rozpočetnictví. Vyd. 3., přeprac. Praha: Nakladatelství ČVUT, 2008. ISBN 978-80-01-03926-7.

[12] SVOBODA, Pavel, Jan BRANDEJS, Jiří DVOŘÁČEK a František PROKEŠ. Základy konstruování. Vyd. 4. Brno: CERM, 2011. 234 s. ISBN 978-80-7204-750-5.

[13] THE CIRCULAR ECONOMY IN DETAIL. Ellen MacArthur Foundation [online]. Ellen MacArthur Foundation [quoted 2019-12-12]. Available at: https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail

[14] SVOBODA, Pavel, Jan BRANDEJS a František PROKEŠ. Výběry z norem pro konstrukční cvičení. Vyd. 4. Brno: CERM, 2011. 227 s. ISBN 978-80-7204-751-2.

[15] Dokumentácia Sústruh SV 18 RA. Trenčín: TOS Trenčín.

[16] Dokumentácia Frézka FA 3. 1955. Olomouc. TOS Olomouc

[17] Dokumentácia Brúska 2UD 500. Hostivař. TOS Hostivař.

[18] Dokumentácia Obrážačka OH4. Čelákovice. TOS Čelákovice

[19] PTÁČEK, Luděk. *Náuka o Materiálu I*. Brno: Akademické nakladatelství CERM, 2003. ISBN 80-7204-283-1.

[20] Tyč ocelová kruhová válcovaná za tepla, EN 10060 // průměr 70. Ferona a.s. [online]. Ferona [quoted 2019-12-12]. Available at: https://online.ferona.cz/detail/24109/tyc-ocelova-kruhova-valcovana-za-tepla-en-10060-prumer-70

[21] Tyč ocelová kruhová válcovaná za tepla, EN 10060 // průměr 35. Ferona a.s. [online]. Ferona [quoted 2019-12-12]. Available at: https://online.ferona.cz/detail/22251/tyc-ocelova-kruhova-valcovana-za-tepla-en-10060-prumer-35

[22] Kotouč T1 350x40x127 454A46H(2)5V40 305279 TYROLIT. *Techcentrum s.r.o. velkoobchod brusiva* [online]. Techcentrum [quoted 2019-12-12]. Available at: https://www.prodejbrusiva.cz/kotouc-t1-350x40x127-454a46h25v40-305279-tyrolit

[23] Obrážecí kotoučové nože stopkové na evolventní ozubení s přímými zuby. Kasik Tools [online]. Kasik Tools [quoted 2019-12-12]. Available at: https://www.kasiktools.cz/cz/nase-nabidka/obrazeci-kotoucove-noze-stopkove

[24] VRTÁK DO KOVU 18,0 MM HSS DIN338 S OSAZENOU STOPKOU 13MM , 338RNHSS 18,0MM HSS , STOPKA 13MM. Kovonastroje [online]. Kovonástroje.cz [quoted 2019-12-12]. Available at: https://www.kovonastroje.cz/Nastroje-pro-kovoobrabeni/Vrtani/Vrtaky-do-kovu-valc-stopka/Vrtaky-do-oceli-HSS/Klasicke-stredni-rada/HSS-prave/Vrtak-do-kovu-18-0-mm-HSS-DIN338-s-osazenou-stopkou-13mm-338RNHSS-18-0mm-HSS-stopka-13mm.html

[25] PN 2913 - DIN 338 RN. Stimzet [online]. M&V, spol. s r.o. [quoted 2019-12-12]. Available at: https://www.stimzet.cz/data/pn2913_cz.html

[26] Ecat Pramet. *Pramet* [online]. Pramet Tools [quoted 2019-12-12]. Available at: http://ecat.pramet.com/Default.aspx?aspxerrorpath=/tool.aspx

[27] Digitální posuvné měřítko Mitutoyo 200 mm. E-shop | MB Calibr [online]. MB Calibr [quoted 2019-12-12]. Available at: https://eshop.mbcalibr.cz/posuvna-meritka-digitalni/digitalni-posuvne-meritko-mitutoyo-200-mm/

[28] Digitální mikrometr vnější Insize 25-50 mm. *E-shop | MB Calibr* [online]. MB Calibr [quoted 2019-12-12]. Available at: https://eshop.mbcalibr.cz/mikrometry-trmenove-digitalni/digitalni-mikrometr-vnejsi-insize-25-50-mm/

[29] Digitální třmenový mikrometr s nerotujícími talířkovými doteky INSIZE 25-50 mm. *E-shop | MB Calibr* [online]. MB Calibr [quoted 2019-12-12]. Available at: https://eshop.mbcalibr.cz/mikrometry-s-talirkovymi-doteky/digitalni-trmenovy-mikrometr-s-nerotujicimi-talirkovymi-doteky-insize-25-50-mm/

[30] Digitální třmenový mikrometr s nerotujícími talířkovými doteky INSIZE 50-75 mm. *E-shop | MB Calibr* [online]. MB Calibr [quoted 2019-12-12]. Available at: https://eshop.mbcalibr.cz/mikrometry-s-talirkovymi-doteky/digitalni-trmenovy-mikrometr-s-nerotujicimi-talirkovymi-doteky-insize-50-75-mm/

[31] FRÉZA PRO DRÁŽKY ÚSEČKOVÝCH PER 4,5X1,0 MM HSSCO5 , CSN 222185. *Kovonástroje.cz* [online]. Kovonástroje [quoted 2019-12-12]. Available at: https://www.kovonastroje.cz/Nastroje-pro-kovoobrabeni/Frezovani/Frezy/Tvarove-stopkove-frezy/Frezy-pro-drazky-useckovych-per/Freza-pro-drazky-useckovych-per-4-5x1-0-mm-HSSCo5-CSN-222185.html?force_sid=978plduj2icmt7pevpo33fk7u6

[32] Pásová píla Bernardo EBS 115. *Boukal.cz* [online]. Boukal logo [quoted 2019-12-12]. Available at: https://www.boukal.sk/pasova-pila-bernardo-ebs-115/706/produkt

[33] INTEGREX i-300S. *MazakEU* [online]. Yamazaki Mazak UK [quoted 2019-12-12]. Available at: https://www.mazakeu.com/machines/integrex-i-300s/

[34] Original Prusa i3 MK3S 3D printer. *Prusa3d.com* [online]. Prusa Research [quoted 2019-12-12]. Available at: https://shop.prusa3d.com/en/3d-printers/181-original-prusa-i3-mk3-3d-printer.html#

## List of Pictures

| Number | Picture name |
|---|---|
| Pic.1 | Shaft 160 673 and Gear 160 682 |
| Pic.2 | Company’s workshop for assembling machines |
| Pic.3 | Types of gears |
| Pic.4 | Gear Milling |
| Pic.5 | Gear Hobbing method |
| Pic.6 | Gear Skiving Method |
| Pic.7 | Gear Shaping method |
| Pic.8 | Drawing of Norton box |
| Pic.9 | Gear 160 682 drawing |
| Pic.10 | Shaft 160 673 drawing |
| Pic.11 | 3D model of gear 160 682 |
| Pic.12 | 3D model of shaft 160 673 |
| Pic13 | Prusa Slicer for 3D printing |
| Pic14 | 3D printed PLA 160 682 |
| Pic.15 | 3D printed PLA 160 673 |
| Pic.16 | Band Saw machine |
| Pic.17 | Lathe SV 18RA |
| Pic.18 | Milling machine FA 3 |
| Pic.19 | Grinding machine 2UD 500 |
| Pic.20 | Gear shaping machine OH4 |
| Pic.21 | Cutting tool for external turning |

| | |
|---|---|
| Pic.22 | Insert for external turning |
| Pic.23 | Cutting tool for internal turning |
| Pic.24 | Insert for internal turning |
| Pic.25 | Cutting tool for grooving |
| Pic.26 | Insert for grooving |
| Pic.27 | Cutting tool for hole diameter eighteen |
| Pic.28 | Cutting tool for hole diameter two |
| Pic.29 | Milling tool for the groove P5 and P6 |
| Pic.30 | Grooving Tool |
| Pic.31 | Ceramic Grinding wheel |
| Pic.32 | Gear cutting tool |
| Pic.33 | Digital caliper |
| Pic.34 | Digital micrometer |
| Pic.35 | Digital spindle disc micrometer 25-50 |
| Pic.36 | Digital spindle disc micrometer 50-75 |
| Pic.37 | Mazak Integrex |
| Pic.38 | 3D printer Pruša Mk3s |

## List of Used Symbols

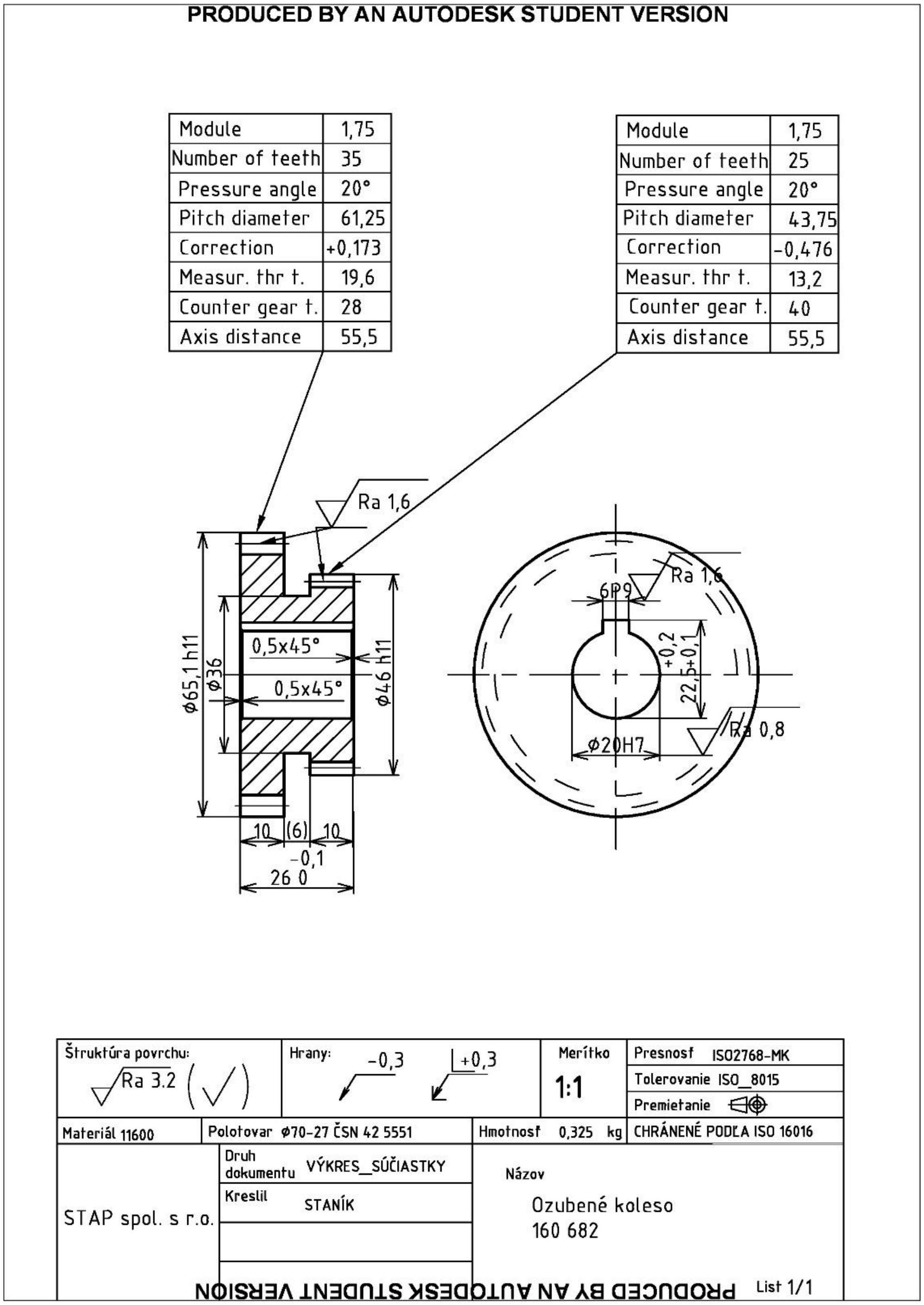
| Symbol | Unit | Meaning |
|---|---|---|
| € | [-] | Currency- Euro |
| D | [mm] | Diameter of the Part |
| L | [mm] | Length of the tool trajectory |
| f | [mm] | Feed rate |
| l | [mm] | Length of actual cutting trajectory |
| $l_n$ | [mm] | Length of tool onset |
| $l_p$ | [mm] | Length of tool offset |
| n | [$min^{-1}$] | Rotations of the spindle |
| i | [-] | Number of strokes |
| $t_{AS}$ | [min] | Machining time |
| $v_c$ | [$mm.min^{-1}$] | Cutting Speed |
| D | [mm] | Diameter of the Milling tool |
| $f_n$ | [mm] | Feed rate |
| $v_f$ | [$mm.min^{-1}$] | Feed speed |
| f | [mm] | Feed rate |
| n | [$min^{-1}$] | Rotations of the spindle |
| $b_s$ | [mm] | Width of the grinding wheel |
| $d_s$ | [mm] | Diameter of the grinding wheel |
| $f_a$ | [mm] | Axial feed |
| $f_r$ | [mm] | Radial feed |
| $n_w$ | [$min^{-1}$] | Frequency of the rotational speed of the workpiece |

| | | |
|---|---|---|
| $l_a$ | [mm] | Axial trajectory of the grinding wheel |
| $l_{na}$ | [mm] | Length of tool onset |
| $l_{pa}$ | [mm] | Length of tool offset |
| $l_w$ | [mm] | Length of the grinding trajectory |
| $n_k$ | [min$^{-1}$] | Frequency of the rotational speed of the grinding wheel |
| p | [mm] | Added material for grinding |
| $v_w$ | [m.min$^{-1}$] | Workpiece peripheral speed |
| $L_b$ | [mm] | Length of the tool trajectory |
| B | [mm] | Gear width |
| $n_o$ | [min$^{-1}$] | Rotations of the workpiece |
| $f_n$ | [mm] | Feed for double up |
| $n_n$ | [mm] | Number of double ups of the tool |
| $a_c$ | [mm] | Total depth of cut |
| $a_p$ | [mm] | Depth of cut for one stroke |
| $D_p$ | [mm] | Diameter of material |
| $L_p$ | [mm] | Length |
| $L_t$ | [mm] | Length of the steel bar |
| n | [pcs] | Batch size (number of parts) |
| $Q_s$ | [kg] | Weight of manufactured part |
| $Q_p$ | [kg] | Weight of raw material for one part |
| $Z_{mo}$ | [kg] | Material loss per part |
| i | [pcs] | Number of parts from one bar |

| | | |
|---|---|---|
| $i_t$ | [pcs] | Number of pieces of bars for the whole batch |
| $m_t$ | [kg] | Weight of one bar |
| $v_p$ | [%] | Usage of the material for one part |
| $N_c$ | [€] | Total cost |
| $C_{mat}$ | [€] | Material cost |
| $C_M$ | [€] | Machine cost |
| $C_T$ | [€] | Tools cost |
| $C_W$ | [€] | Workers salary |
| $C_E$ | [€] | Energy cost |

# Attachments

[1] Drawing part 160 682



| | |
|---|---|
| Module | 1,75 |
| Number of teeth | 35 |
| Pressure angle | 20° |
| Pitch diameter | 61,25 |
| Correction | +0,173 |
| Measur. thr t. | 19,6 |
| Counter gear t. | 28 |
| Axis distance | 55,5 |

| | |
|---|---|
| Module | 1,75 |
| Number of teeth | 25 |
| Pressure angle | 20° |
| Pitch diameter | 43,75 |
| Correction | -0,476 |
| Measur. thr t. | 13,2 |
| Counter gear t. | 40 |
| Axis distance | 55,5 |

Štruktúra povrchu: Ra 3.2 (✓)

Hrany: −0,3 +0,3

Merítko 1:1

Presnosť ISO2768-MK

Tolerovanie ISO_8015

Premietanie

Materiál 11600

Polotovar ⌀70-27 ČSN 42 5551

Hmotnosť 0,325 kg

CHRÁNENÉ PODĽA ISO 16016

STAP spol. s r.o.

Druh dokumentu VÝKRES_SÚČIASTKY

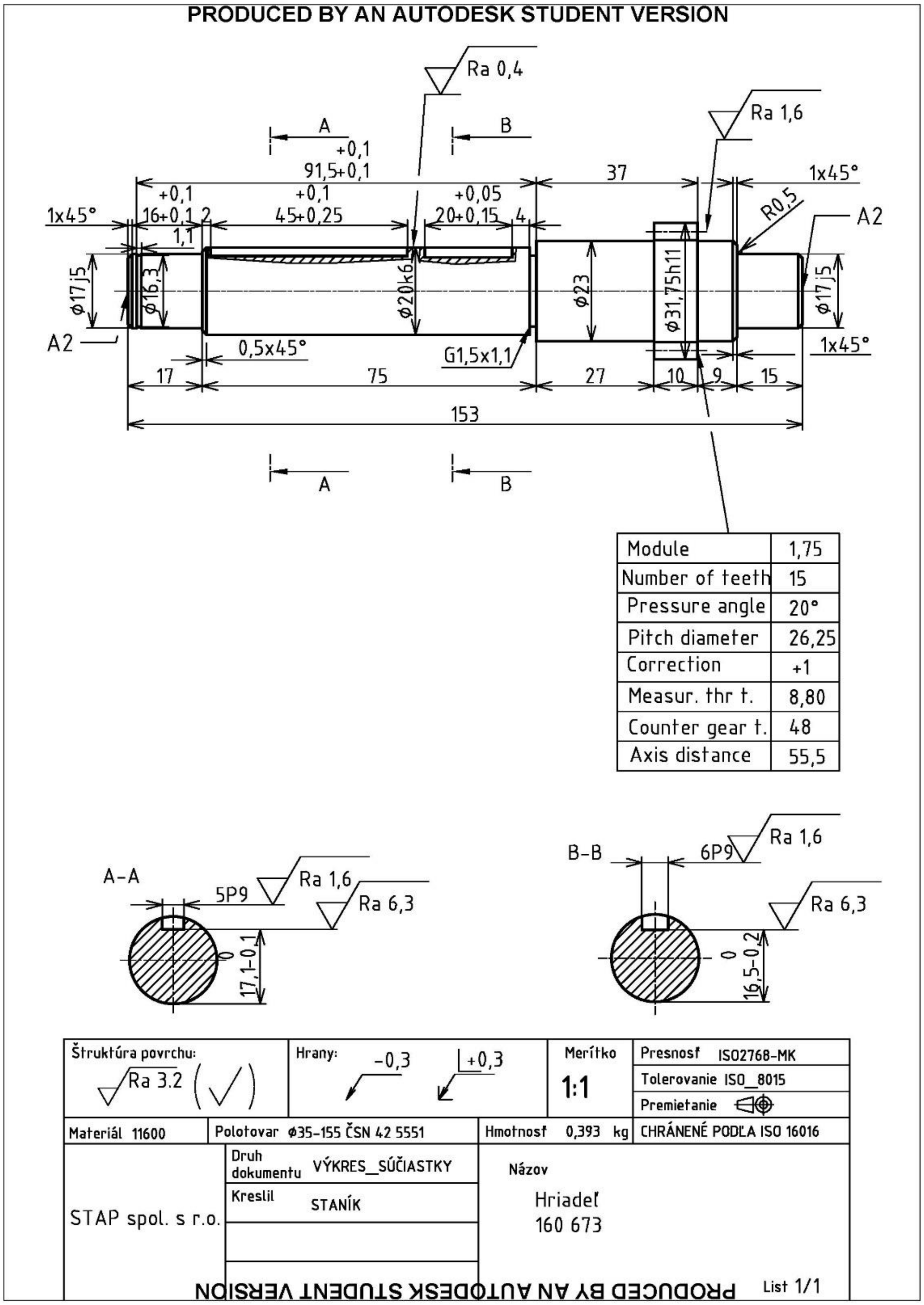
Kreslil STANÍK

Názov

Ozubené koleso
160 682

List 1/1

## [2] Drawing part 160 673



| | |
|---|---|
| Module | 1,75 |
| Number of teeth | 15 |
| Pressure angle | 20° |
| Pitch diameter | 26,25 |
| Correction | +1 |
| Measur. thr t. | 8,80 |
| Counter gear t. | 48 |
| Axis distance | 55,5 |

Štruktúra povrchu: Ra 3.2 (√)

Hrany: −0,3 +0,3

Merítko 1:1

Presnosť ISO2768-MK

Tolerovanie ISO_8015

Premietanie

Materiál 11600

Polotovar ⌀35-155 ČSN 42 5551

Hmotnosť 0,393 kg

CHRÁNENÉ PODĽA ISO 16016

STAP spol. s r.o.

Druh dokumentu VÝKRES_SÚČIASTKY

Kreslil STANÍK

Názov

Hriadeľ
160 673

List 1/1