UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

Diseño de un sistema automático para ayudar a personas con movilidad reducida a levantarse de la cama.

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Valladolid, Julio 2020.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO:	Design of automated system for helping people with reduced mobilty to get up from bed
ALUMNO:	Carlos Izquierdo Conde
FECHA:	17/06/2020
CENTRO:	Faculty of Mechanics
UNIVERSIDAD:	Vilnius Gediminas Technical University
TUTOR:	Paulius Ragauskas

Resumen en español (max 150 palabras)

Diseño de un sistema capaz de ayudar a personas con movilidad reducida a levantarse de la cama de manera autónoma. El objetivo del sistema es colocar al usuario sentado al borde de la cama. Esto se lleva a cabo mediante la creación de dos máquinas. Primero un respaldo que coloca el tronco del usuario en una posición recta. A continuación, un sistema piñón-cremallera que empuja las piernas fuera de la cama para alcanzar la posición final. Ambas maquinas son motorizadas por dos motores eléctricos.

Los cálculos realizados se focalizan en las cargas soportadas y la transmisión de potencia, incluyendo el diseño de los ejes, sistema de engranajes, selección de los motores eléctricos y rodamientos. También se incluye una estimación económica del proyecto.

Palabras clave: Respaldo, cama, autonomía, personas, movilidad reducida.

Abstract (max 150 words)

In this bachelor`s degree final work was designed a system capable of helping people to get up from bed. The main objective of the system is to put the user ln a sit position on the edge of the bed. This is fulfilled by the creation of two machines.

Firstly, the back`s lift system put the user`s trunk on a straight position. This system is powered by an electric motor that transmits the power by a gear system to the back`s lift. Secondly, a pinion rack system, also powered by an electric motor, push the legs out of bed in order to get the final position. Literature review of this paper presents information about the systems used nowadays to help disabled people to move from bed and to transport them. Therefore, it is explained the advantages and disadvantages of this systems and the reason to design a new one. Calculations parts focus on the load supported and power transmission, including the design of shafts, gear system, selection of electric motors and bearings. Economical estimation is also included.

Keywords: Back`s lift, bed, reduced mobility, automated, people.

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHANICAL AND MATERIAL ENGINEERING

Carlos Izquierdo Conde

Design of Automated System for Helping People with Reduced Mobility to get up from Bed

Bachelor‘s degree final work (project)

Mechanical Engineering study programme, state code 612H33001

Machine design specialisation

Mechanical engineering study field

Vilnius, 2020

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

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Carlos, Izquierdo Conde

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2020.06.01
(Date)

OBJECTIVES FOR BACHELOR'S DEGREE FINAL WORK (PROJECT)

2020.06.01 No. 30

Vilnius

For student **Carlos Izquierdo Conde**

(Name, Surname)

Final work (project) title: **Design automated system for helping people with reduced mobility to get up from bed.**

Approved on 12 – 03 –, 2020 by Dean's decree No. 60me
(day, Month) (year)

The Final work has to be completed by 01 06, 2020
(Day, Month) (Year)

THE OBJECTIVES:

The aim of this project is to design an automated system to help old people and moderate disable people to get up from bed without assist from other person. This is going to be achieved by designing two machines. Firstly one machine to lift up the person`s back. Secondly designing a system to move his legs out of the bed and get the person sit down on the bed.

Data:

Explanatory note:

Introduction; Literature Review ;Calculations necessary to ensure proper work and stability,Description of the design and operating principle; Design of manufacturing technological process;Composing of the work safety and environmental protection requirements;Economical estimation of the project with analysis; Conclusions and recommendations;List of references.

Drawings:

General view drawing of the system (1 A1 sheet); Assembly drawings of the subassembly "Gear Box" (1 A1 sheet); Work drawings of selected parts of assembly or subassemblies (1 A1 sheet); Technological sketches of part machining operation (0,5 A1 sheet);Economical rates (0.5 of A1 sheet)

Consultants of the final degree work (project): ....

....
(Title, Name, Surname)

Academic Supervisor .... (Signature) Paulius Rapalavičius (Title, Name, Surname)

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

....
(Student's signature)

....
(Student's Name, Surname)

....
(Date)

Vilnius Gediminas Technical University
Mechanics faculty
Mechanics and materials engineering department

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

Title: **Design of Automated System for Helping People with Reduced Mobility to get up from Bed**

Author **Carlos Izquierdo Conde** Academic supervisor **Paulius Ragauskas**

Thesis language

	Lithuanian
X	Foreign (English)

Annotation

In this bachelor`s degree final work was designed a system capable of helping people to get up from bed.The main objective of the system is to put the user ln a sit position on the edge of the bed.This is fullfilled by the creation of two machines.

Firstly, the back`s lift system put the user`s trunk on a straight position. This system is powered by an electric motor that transmits the power by a gear system to the back`s lift. Secondly, a pinion rack system, also powered by an electric motor, push the legs out of bed in order to get the final position.

Literature review of this paper presents information about the systems used nowadays to help disabled people to move from bed and to transport them. Therefore, it is explained the advantages and disadvantages of this systems and the reason to design a new one.

Calculations parts focus on the load supported and power transmision, including the design of shafts, gear system, selection of electric motors and bearings. Economical estimation is also included.

Structure: introduction, literature review, calculations,design of technological process,work safety and environmental requirements, economical estimation , conclusions and suggestions, references.

Thesis consist of: 80 p. text without appendixes, 58 pictures, 38 tables, 30 bibliographical entries.

Keywords: Back`s lift, bed, reduced mobility..

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

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Carlos Izquierdo Conde, 20195918

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

Faculty of Mechanics

(Faculty)

Mechanical Engineering, MPfu-16

(Study programme, academic group no.)

DECLARATION OF AUTHORSHIP
IN THE FINAL DEGREE PROJECT

June 11, 2020

I declare that my Final Degree Project entitled „Design of Automated System for Helping People with Reduced Mobility to get up from Bed“ is entirely my own work. The title was confirmed on March 12, 2020 by Faculty Dean's order No. 60me. I have clearly signalled the presence of quoted or paraphrased material and referenced all sources.

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

The academic supervisor of my Final Degree Project is Doctor Paulius Ragauskas.

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

(Signature) Carlos Izquierdo Conde (Given name, family name)

List of contents

1. INTRODUCTION.

Nowadays, technology has improved daily lives of people. For disabled people too, but not enough for the complete independence. Some of them need help for the daily routine or it takes them some time to do simple things. At this moment, hospitals have the facilities, necessary equipment and well-prepared people to get this kind of tasks done. The problem is when this person is at home.

Transfer cranes are usually expensive and most of them need another person to make them work. The aim of this paper is to help people with mobility problems to get up from bed by their own, with no help of nurses or other people. This aim is going to be achieved by the system proposed in this paper.

It consists of two machines. Firstly, a machine capable of lifting the back until a straight back position. This machine is managed by an electric motor controlled by the patient. When the user is on a sit position, the second machine begins to work. It is composed by a pinion rack system that will push the legs out of bed, leaving the patient sit on the edge of the bed. The system must be managed by the patient himself with a remote control that is not going to be consider in this project. The system must be adaptable to different sizes of beds and people with different physical constitution. It also must be easy to assemble and to install on user`s home, without previous works needed. The design has to be simple and using appropriate safety coefficients for the user`s safety. Standard parts will be used when possible to reduce manufacturing costs.

2. LITERATURE REVIEW.

2.1- Related work.

References: [1], [2], [3], [4], [5], [6], [7], [8], [9]

In this section the information of previous work related to this topic is written. It also includes previous research and a catalogue of different systems available on market.

Previous transfer systems

Most used system for moving a person from his bed are transfer cranes. There are lot of different types for each situation. Transfer cranes attached to a wall are more suitable for bathroom and bedrooms, only requiring a bar on the wall to hold the crane. On the other hand, cranes attached to the ground are the most suitable for swimming pools. Mobile cranes are the most commonly used at hospitals and nursing homes since more space is needed. One of the most important part of the crane is the harness that allows to transport people. It exists different kinds of them. There are two pieces harness, that allows to bathe the person; hammock type, it is the most comfortable for people with mobility difficulties in the trunk. Plastic chairs are also used, specially indicated for swimming pools or showers. In addition to the harness other important design aspects to take into consideration are handle height for the caregiver, the height of the legs to go through under armchairs and beds and the width of the crane so that allow a person to be lifted from the wheelchair. Transfer cranes use is specially indicated for people suffering any mobility deficiency. They present a series of advantages that should be highlighted, both for the user and caregiver, instead of manual transfer.

User advantages:

- Decrease the discomfort and, in some cases, pain that usually causes manual transfer.
- More security for the transfers since it avoids risk of falling.
- More autonomy for user.

Caregiver/familiar advantages:

- Decrease backpains since it avoids doing excessive force.
- One caregiver is enough for moving a person.

One Spanish company (Virmedic) has carried out the development of four transfer cranes models with the following specifications:

- Crane for hospitals and big capacity nursing homes (up to 240 kg)

- Crane for hospitals and standard capacity nursing homes (up to 185 kg)
- Crane for private homes (up to 150 kg)
- Crane for small private homes (up to 130 kg)

Validation process of the cranes took place in different hospitals, nursing homes and twelve private homes of the Spanish region of Valencia, for fifteen days. The results of the research project and the conclusions reached are:

Global results

- Possibility of making transfers with minimum effort.
- Good system for preventing pain and back injuries for the caregiver.
- Light and strong simultaneously
- Great stability
- Easy transportation
- It allows transportation from the ground
- Very suitable for shower use
- Correct battery duration
- Space needed for a correct use.

Workgroup conclusions

- Users and experts' criteria have been essential for the crane's development.
- Initial rejection for using cranes at homes and hospitals due to ignorance of use and advantages that provides.
- Good training is necessary to ensure the correct use of the cranes.

The following is a list of different transfer systems available on market, and their characteristics:

- Molift partner - TB05001
  Electric lift crane. Each of the support legs has three pairs of wheels to ensure the movement. It has adjustable handles. Hanger design allows to modify the position of user in bed. Different types and harness sizes. Characteristics: Material: steel and aluminium. Max Load: 60 kg. Weight:28 kg.

Figure 2.1.Molift Partner

- Sumax electronic lifter-TB05002

  Electronic operation by their own batteries. With a complete charge can do from forty to fifty hauls. Central Control Unit with digital indicator of battery level and emergency stop button. Sound indicator of battery recharge. Remote control. Electrical mains connection for recharging and use. 100 mm swivel wheels; both rear ones equipped with self-locking brake to secure the elevator. Support base adjustable in width to facilitate access to its interior in wheelchairs or similar. Easy to clean and waterproof harnesses, made from special anti-allergic materials. Structure made of steel tube and painted in the oven with high-strength bilayer metallic paint baked with high scratch resistance bilayer metallic paint. Partial folding for daily storage. Adjusted dimensions for use in confined spaces. Characteristics: Maximum load: 140 Kg. Full folding for transport or storage (up to 155x55x35 cm).

Figure 2.2. Sumax electronic lifter.

- Hydraulic elevator Tempo-TB05003

  Hydraulic piston drive by lever. 100 mm swivel wheels; both rear ones equipped with self-locking brake to secure the elevator. Support base adjustable in width to facilitate access to its interior in wheelchairs or similar. Easy to clean and waterproof harnesses, made of special anti-allergic materials. Structure made of steel tube and painted in the oven with metallic paint bilayer with high resistance to scratching. Partial folding for daily storage. Adjusted dimensions for use in confined spaces. Characteristics: Maximum load: 140 kg. Full folding for transport or storage (up to 155x55x35 cm).

Figure 2.3. Hydraulic elevator Tempo.

- Sunlift Major Crane- TB05006

  Specially designed for those who require a lightweight crane that is easy to carry or who need to move in tight spaces. Because of its size and features it is specially designed for use in residences and hospitals. Available in hydraulic and electric version. Lifting capacity: 175 Kg.

Figure 2.4. Sunlift Major Crane.

- Electric Crane AKS- TB05007

  Electric crane to transport a person safely and effortlessly, a single person can do it so by simply pressing a button. The legs are opened with a pedal for greater stability or to approach chairs or sanitary facilities, etc. After its use it can be fold up in seconds without tools. Batteries do not need maintenance and they are charged automatically. Characteristics: Maximum height:2 m. Weight:38 kg. Maximum load:150 kg. Width: 61 cm. Total length: 120 cm.

Figure 2.5.Electric Crane AKS.

- Mobile crane for general use-TB05009

Mobile crane of general use with 1 wheel on each leg and double front wheels. It is detachable, it has a two pieces harness, hammock for separated legs. Electric lifting system for the radial arm. Characteristic: Max load:135 kg. Weight:33,8 kg.

Figure 2.6. Mobile Crane.

- Oxford Voyager 550- TB05013

  Transfer crane, it increases caring of the sick quality and gives maximum security to user in his daily routine. Easy handling. Different rails to avoid every obstacle. Different

Figure 2.7. Oxford Voyager 550.

type of harnesses allows to transfer from bed to wheelchair, transfer to bathroom, nappy change, transfer to shower. Different sizes for every harness.

- Molift Quick Raiser- TB05014

  Biped station crane with platform to support the feet, padded support for knees and special belt that is placed under the armpits. Weight: 30 kg.

Figure 2.8.Molift Quick Raiser

- Oxford Stand aid - TB05015

  Electric crane designed to transport the person in semi-erguid position. Patient rests knees on crane so it goes perfectly attached, feeling much safer and more comfortable than on a conventional crane. Features: Available in foldable version, lightweight and easy to carry. Maximum load: 135 kg.

Figure 2.9.Oxford Standaid.

- Fixed Crane Curator - TB05016

  It is installed on the room or bathroom`s wall to do the transfers from the bed to wheelchair, shower, WC. Its measurements were studied for the case to be installed in a double room could do the transfer between the two beds.

Figure 2.10. Fixed Crane Curator.

- Fixed Crane PoolVir- TB05018

  Fixed Crane for swimming pool and bathroom, with two pieces harness and separated legs hammock. Hydraulically operated radial arm lifting system. Two types of bases anchored to the ground or recessed. The whole set is removable which allows us to have several bases and have more than one point of use. Characteristics: Max weight. user: 185 Kg. Crane weight: 39 Kg.

Figure 2.11. Fixed Crane PoolVir

- Oxford Mermaid - TB05019

Its small size and versatility define this crane as an indispensable help to do the bath transfers. It lifts and descend the seat inside the bath. The seat turns in the highest position. Characteristics: Material: Steel. Maximum load:127 kg. Weight: 32 kg.

Figure 2.12. Oxford Mermaid.

- Carix Crane- TB05021

  This crane is specially indicated for no mobility people and they must be transferred on a stretcher. Characteristics: Total length:120 cm. Total height: 136 cm. Width: 60 to 120 cm. Maximum user height: 190 cm.

Figure 2.13. Carix Crane.

- Letix Crane - TB05022

  The crane introduces o mobility people onto the bath. It is suitable with all stretchers available on market. It can be hydraulic or electric. Characteristics: Total length: 188 cm. Total height: 119 cm. Widht:57 a 65 cm.

Figure 2.14.Letix Crane

- Aquatic Lifter

  Hydraulic lift that facilitates access to water for people with physical limitations. User can do it by himself. The seat can be placed perpendicular or parallel to the edge of the pool. Only a water intake with a pressure of 3.5 kg per cubic centimetre is required for operation. Easy to install. It has a single-control shower built in so that the user can shower before and after the bath without great effort. Maximum load of 120 kg.

Figure 2.15. Aquatic Lifter.

- Domus crane- TB05028

  Crane suitable for use in homes, especially those whose architectural characteristics prevent the use of a portable crane. Its dimensions and arm articulation system allow it to be used for transfers from the wheelchair to the bed, the bath, the sofa. By using various supports and due to the ease of placement of the crane and its folding system and reduced weight, all transfer needs in a home can be covered. It can rotate more than 180 degrees depending on the placement of the bracket. Maximum load: 130 kg.

Figure 2.16. Domus Crane.

- Driver Crane-TB05029
  This crane has been designed to be installed on all type of vehicles. Easy transfer between wheelchair and vehicle. It is connected to the car`s battery system, Maximum load: 120 kg.

Figure 2.17.Driver Crane

As seen before, there are different kind of systems to transfer people from one place to another. There are mobile cranes like the top of the list above. Basically, it is a two-leg structure with wheels to move it, and a hydraulic or electric arm with a harness attached to it. Then, fixed cranes are the same system but instead of wheels it is attached to the wall. It can hold more weight than the mobile ones. There are aquatic cranes too, to transfer people to bath or swimming pool, t made of stainless steel. And finally, other systems not related to this topic like cranes to move people from the driver seat to a wheelchair and systems of bipedsation, to hold people on a standing position.

Beds

Although there are lots of different cranes to help patients to get up from bed like it is seen before, the bed itself can help to do the required task. Along history, hospital beds have been improved to offer comfortability and a better performance, both to patient and nurse. First push-button hospital beds were created in the 40s (figure 18a). The bed movements were inspired by the principle of foil movement, inspired by the movements when nurses change patients' position. In 1946, after a plane crash, Howard Hughes created a hospital bed adapted to him. It consisted on 6 sections, 30 electric engines and cold and hot water flow

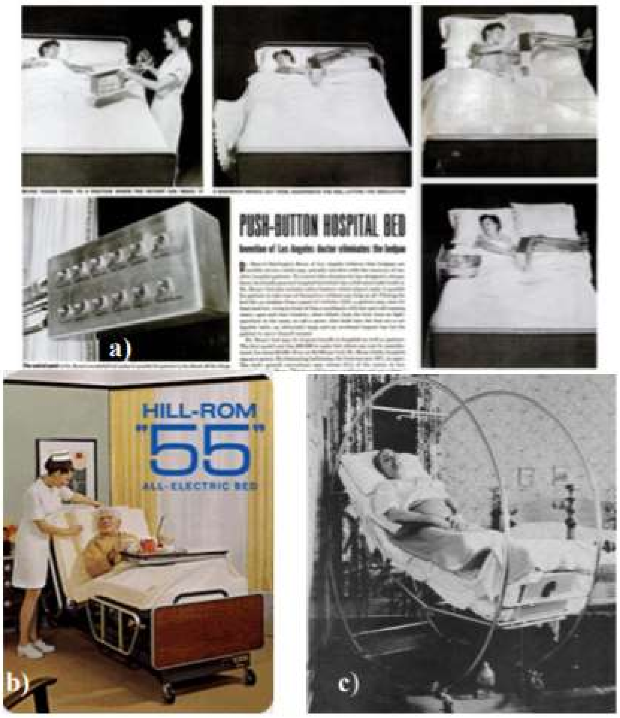


Figure 2.18.a) Example of one of the first push-button hospital beds. 1945 b) Hill`s first bed with electric engine, 1952. c)Circ-Oèlectric bed 1958.

. In the 50`s, the Hill-Rom company, built and marketed its first electrical beds (figure 18b). In the 60`s and 70`s appeared different models for special care cases, such as the Circ-O`lectric bed (figure 18c). This design allowed the caregiver to control body rotation by electric actuators.

From 1970 all hospital beds incorporated rails with control panels. The first mattresses for preventing pressure ulcers appeared. The use of hospital beds for home use increase in this time. During 80`s and 90`s medical devices suffered a great improvement. Some patents included a weighing scale incorporated to bed (figure 19). Others included new systems to call nurse for disabled patients. In the 90`s, more beds with improved mechanical systems appeared, such as the possibility of sitting in a chair position to exit the bed (figure 20).

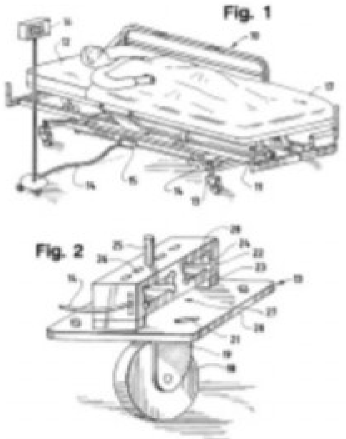


Figure 2.20. Images of a 1994 patent showing a weighing scale included in the wheels.

Figure 2.20. Hill-Rom Total Care model of 1998.

The voice control system is mentioned in some patents during this time. However, its efficiency in the 90`s was limited compared to present ones. The first regulation on medical devices appears in 1993 (the Council Directive 93/42/CEE), and the first standard for electrically operated hospital beds is published. In 2000 the European standard EN1979, was published. Then, the ISO standard was published in 2009 and enforced in 2013, dealing with basic safety and essential performance of medical beds.

The analysis of the timeline of hospital beds allows highlighting some conclusions:

- Increasing delegation of functions. Easing the work of caregivers and facilitating the independence care of user.
- Growing specialization in different models of electric beds, with morphologic, functional aspects made for specific environment and groups of patients (for hospitals, private homes, geriatrics…)
- At last, there is a growing trend towards relocating and re-discovering new implementations for the increasing range of technologies available. This fashion will attain the advances for current marketplace demands, such as: inclusion of tactile interfaces, functions of connectivity and complex real-time monitoring, as properly as of recent sensors and actuators. These factors permit the creation of new and improved

versions of those devices, making a new way for builders to advocate new editions of added value for this family of products (focused in the experience of the user), while preserving the equipment's basic functions. This synthesis and technological growth have changed the visible face of the market of high complexity mechatronic beds in the last decades.

Basic structure

The electric bed movements were based on the study of the biomechanics of the care givers, which was translated to technological principles. Figure 2,21 shows the support structure of a conventional electric bed.

Figure 2.21. View in perspective an electrical bed, with 4 sections a support surface and elevation control.

The surface of support is divided in three sections that can be driven by the user or caregivers: Back, thighs and calves. In this kind of product is typical to have a fourth section fixed to an end of the back and another one to the thighs support. This allows to avoid significant deformation in the mattress, even when all sections are in limit position. Two different actuator drive individually the back and leg section. movement of the las one allows to achieve chair position. There is a high risk of suffering falls for patients, when the support level is elevated, both when trying to enter or exit the bed. This situation led to the development of a new segment of ¨ low beds ¨ in the market, especially created to avoid those problems. Likewise, it turns appropriate for the medical personnel to be able to rely on ways that set the elevation of the patient, according to the different stages of treatment or care, as well as on ergonomic aspects of managing the patient and the product, facilitating the performance of these tasks. In addition to have siderails, electric beds have different means to control the elevation of the support surface of the patient, through actuators that activates ¨scissor¨ type mechanism or through extensible columns. Moreover, if the bed has two or more independent elevation mechanisms over the support surface, they allow to achieve specific positions as cardiac chair. In general, these beds measure 1 m of width and 2m of length, admit elevations from 0,4 m to 0,8 m for the base support level of the patient. The sections of the back support admit angles up tom 70 º. The siderails are made in order to minimize risks of trapping and injuring during operations. New versions of electrical beds are leading to the incorporation of additional mechanisms of mobilization on the basis structure.

Control system

There have been studies about different control systems for electric beds at hospitals. Chi-Chun Lo proposed a non- contact control system on 2016. The proposed system shows a new way of operating the electric bed without manual operation. This way patients can use can control position of medical bed without help of nursing assistants. In the traditional medical beds, there are two different kinds of adjustment, foot-operated mode and hand-shaken mode. The modern electric beds are operated by control panel and remote controller. In addition, electric beds are more comfortable than the conventional ones, and more suitable for long-stay patients. The system works with a tablet with icons of the different bed positions. User must focus on the wanted position, and the bed receive the signal and change its position. The first step for patient at using this system is to focus on the unlock icon to unlock system and then focus on the icon. After that, he can lock the system again.

Figure 2.22. Icons of the different position showed in a tablet.

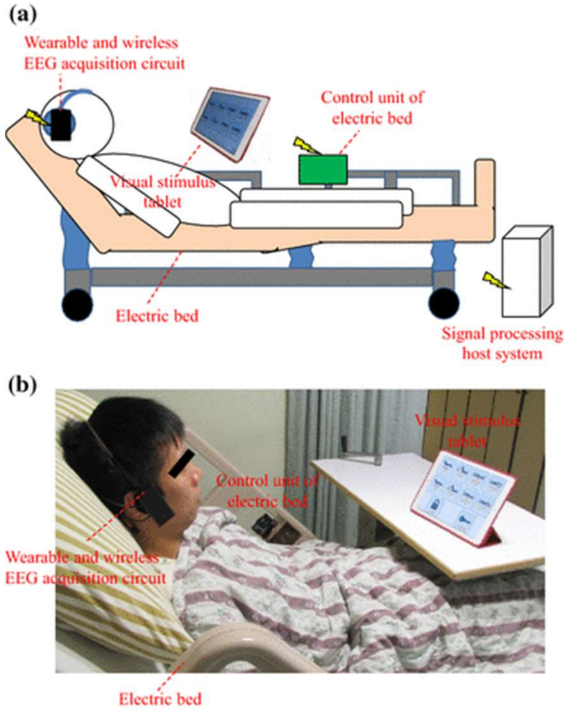


Figure 2.23.a) Basic scheme. b)Photograph of proposed non-contact controller of the electric bed.

Previous Patents

- Height Adjusting Lifter for Hospital Bed

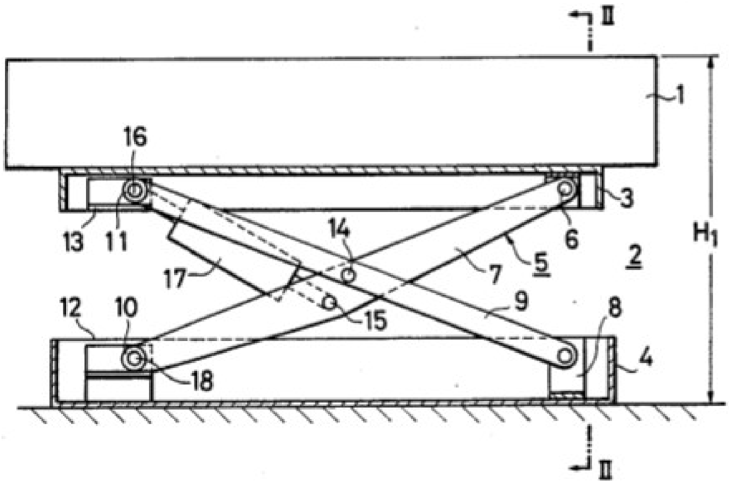


Figure 2.24. Drawing of the height adjusting lifter for hospital bed.

This invention was made in order to allow the patient to get in and out of bed, for that purpose the height of the bed is desired to be as small as possible, and , on the other hand to allow nurses and medics to get the most appropriated position to do their job, usually, the bed has to be on a higher level. For the lifter, a vertically expandable and collapsible link mechanism is used, as in an industrial table lifter of the hydraulic type. The link mechanism is actuated by an actuator device such as a hydraulic cylinder so that the bed may be moved up and down. The link mechanism should be capable of minimizing the bed`s height when it is on the lowest position.

- Hospital Bed with Electric Emergency Lowering Device

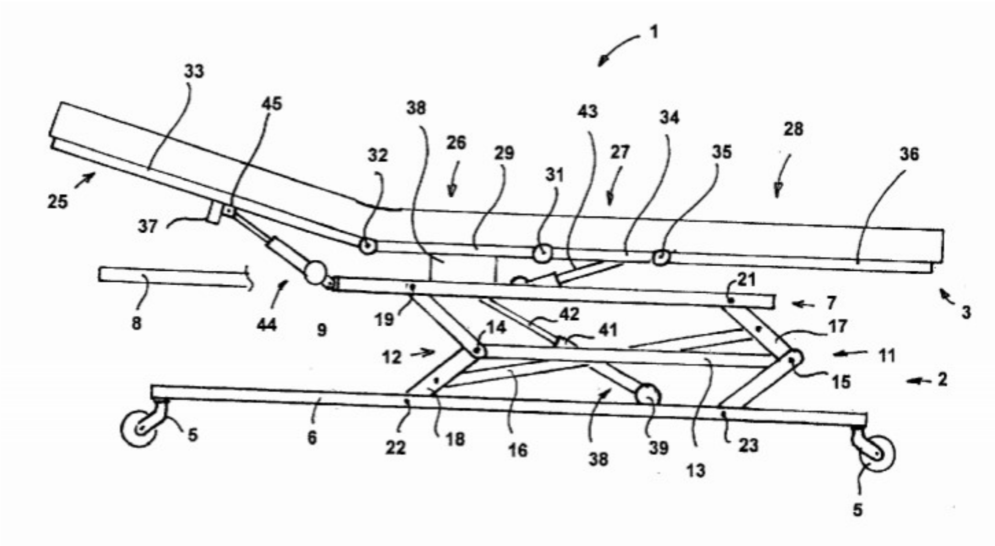


Figure 2.25. Drawing of the patent.

The objective of this invention is bringing the upper part of the body back to a horizontal position as fast as possible in order to revive collapsed patients in the event of a cardiac arrest or other emergency. If the back section of the hospital bed is manually operated, this operation is relatively easy. However, the problems appear when the hospital bed is driven by an electric motor, like the ones that the back section is adjusted by the patient. The actuators used for this purpose are self-blocked to keep the bed in the desire position. Typically, this problem was overcome by decoupling the gearing of the actuator to neutralize the self-locking effect. Even though, other parts of the gearing still act as a brake. The speed of the back section is a result of the weight of the patient ant the friction in the gearing. This may lead to an abrupt lowering, if the patient is heavy, that must be solved by the hospital personnel. On the other hand, lightweight patients may require hospital personnel to make an additional force upon the back section. In any case, this type of lowering disengaging the gearing is quite problematic. Based on this, the objective of the invention is to develop a new system in which the emergency lowering is achieved electrically.

- Electric Hospital Bed

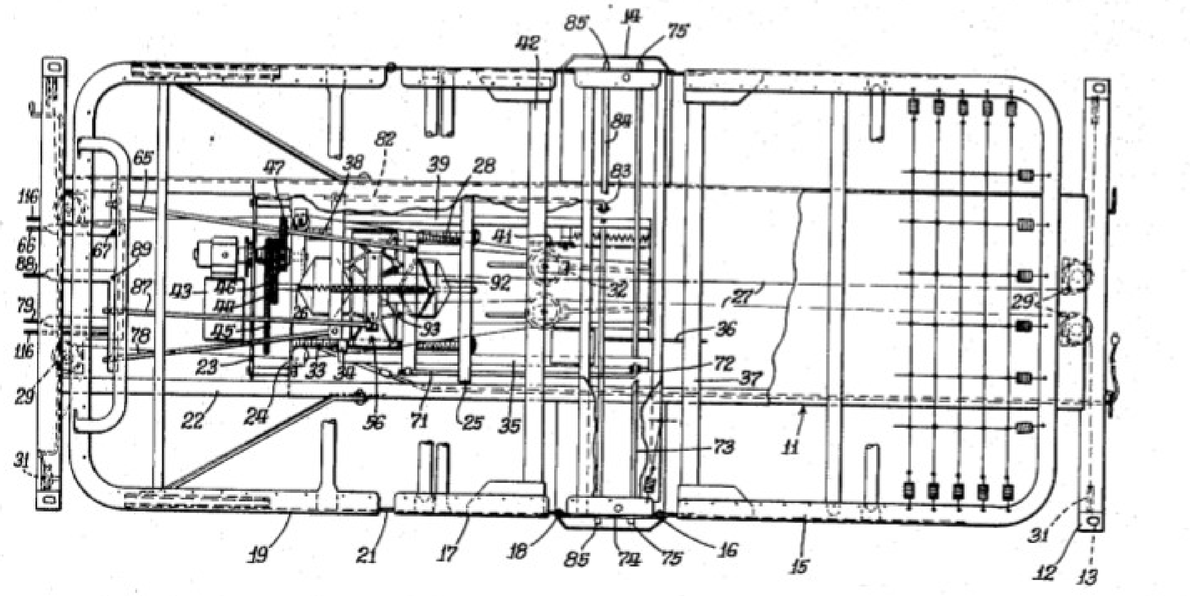


Figure 2.26. Drawing of the electric hospital bed.

This patent of the 70`s tried to solve the problems caused using clutches in hospital beds. Various type of clutches was interposed between the electric motor and the driving mechanisms that perform the movements required by the patient, the invention employs gear selector mechanism instead of clutches, providing a single manually operable member for each three functions: High-Low, head and knee.

- Control Device for a Hospital Bed

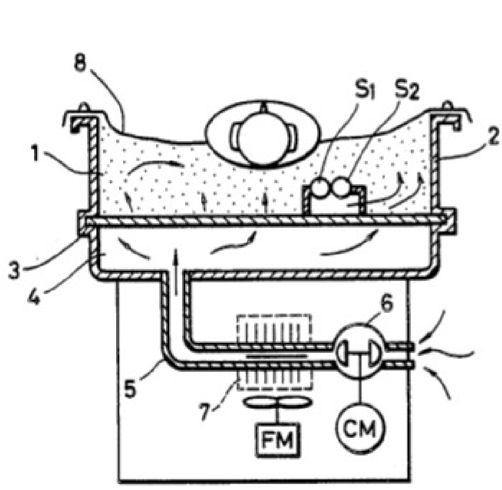


Figure 2.27. Drawing of the control device for a hospital bed.

Some hospital beds have a bed-mat made of movable particles. This sensor`s objective I to detect an excessive bad temperature in the case of a controller malfunction and control the operation of a cooler. The circuit is designed so that an air compressor runs intermittently with the aid of timers while the sensor performs its functions at a temperature above the predetermined temperature level.

- Double Insulated Electric Hospital Bed

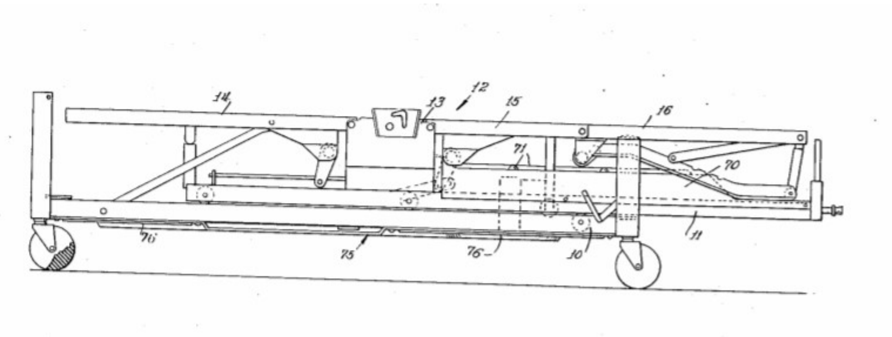


Figure 2.28. Drawing of a double insulated hospital bed.

During the 60`s, The Electronic News and the National Enquirer both report that an estimated 1.200 patients were killed in electric beds each year in hospitals in the United States. One of these articles reported that some electrics equipment furnished to hospitals had excessive leakage and when that equipment is connected to a patient can result into an electrocution due to the patient touch something that is connected to ground. The aim of this invention is to reduce the possibility of electrocution of a patient by grounding the motor case and then isolating it from the bedframe through the use of high dielectric materials to ensure that the maximum leakage from the grounded apparatus to the bedframe is less than one microampere. This way, the danger of electrocuting a patient is almost eliminated, even under the most dangerous circumstances.

2.2- **Conclusion.**

As seen before, there are plenty of ways to help people to get up from bed, even some of them can move people from bed to other places. All these systems are expensive and many of them need to be used by another person, not only patient. Cranes seen above are big, heavy and need some training to use them properly. Hospital beds are expensive and complex. The system proposed in this papercan be used by the patients with no help of other people. It is made to be installed in a conventional bed.

3. CALCULATIONS NECESSARY TO ENSURE PROPER WORK AND STABILITY OF THE OBJECT DESIGNED, DESCRIPTION OF THE DESIGN AND OPERATING PRINCIPLE OF THE OBJECT DESIGNED.

The system designed consist on an automatic lift for the patient`s body and a pinion-ruck system to move the legs out of bed in order to leave the patient on a sit position. The automatic lift is actuated by an electric motor. This motor can be managed by the patient with a remote control, as well as the electric motor that controls the pinion-rack.

The system is developed for an individual bed with the following measures: 190 cm length, 90 cm width, 50 cm height .In order to satisfy the greatest number of potential clients, all the anthropometric data is referred to the average of the Lithuanian population.

3.1- **Anthropometric data.**

References: [10], [11], [12]

In the first place, the weight and length of the patient`s trunk is needed to design the back`s lift. The lift`s aim is to move the superior part of the body from zero degrees to eighty eighty-five degrees. The superior part consists on the trunk, head, neck and complete arms. The total mass m_t is calculated like:

$$m_t = m_{trunk} + m_{head+neck} + m_{arms} \quad \textbf{(3.1.1)}$$

Where m_t is total mass,kg; m_{trunk} is mass of the trunk,kg; $m_{head+nec}$ is mass of head and neck,kg; m_{arms} is mass of the arms, kg.

The mass of each part can be calculated like a percentage of the total person`s mass:

$$m_{trunk} = 0{,}5 \cdot Totalmass \quad \textbf{(3.1.2)}$$

$$m_{head+neck} = 0{,}084 \cdot Totalmass \quad \textbf{(3.1.3)}$$

$$m_{arms} = 0{,}051 \cdot Totalmass \quad \textbf{(3.1.4)}$$

The average weight for a male person in Lithuania is 86,8 kg, and the average height is 1,79 m.Resolving equations 3.1.2, 3.1.3, 3.1.4 and then equation 3.2.1: m_t=55,12 kg. Expressed in Newtons **P1=540,14 N.**

The mass center of the superior part can be also calculated. The position of the mass center of each part is showed in the following picture:

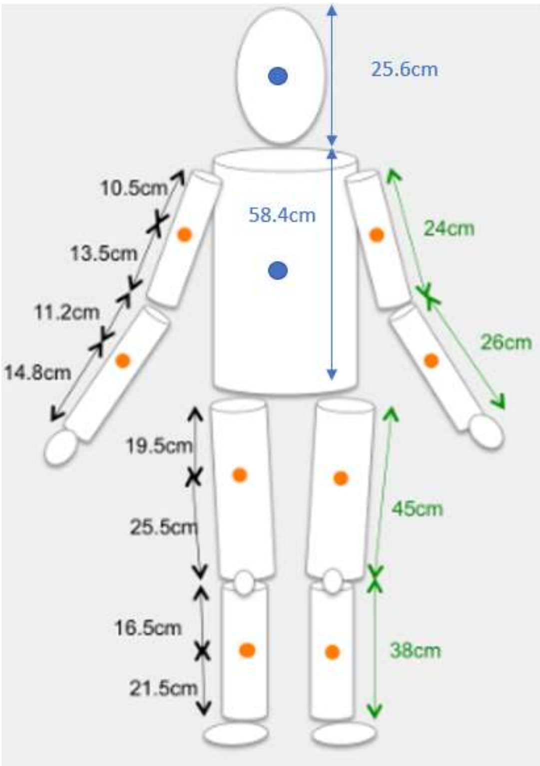


Figure 3.1. Mass centre positions of different parts of human body.

It is assumed that the arm ends in the bottom part of the cylinder that represents the trunk to ease the calculations. It is only needed the y position; it is assumed that the body is perfectly symmetric, and the origin is situated on the symmetry axis at the bottom of trunk`s cylinder. The mass of the arm and forearm is distributed in proportion to the length.

$$Ycm = \frac{\sum_i m \cdot y}{\sum_i m} \quad \textbf{(3.1.5)}$$

Where *Ycm* is position of the absolute mass centre, cm; *y* is position of the mass centre of each part of the body, cm; *m* is the mass of each part of the body, kg.

The result is **Y_{cm}=34,15 cm**.

3.2- **Back`s lift design.**

The mass centre of it should be as close as possible to the position calculated before to avoid inertia problems .It must have a part to support the head while the system is moving in order to avoid any back injuries. It must be light and strong enough to bear the loads are going to be applied. Taking these into consideration a first design of it is made on Solidworks.

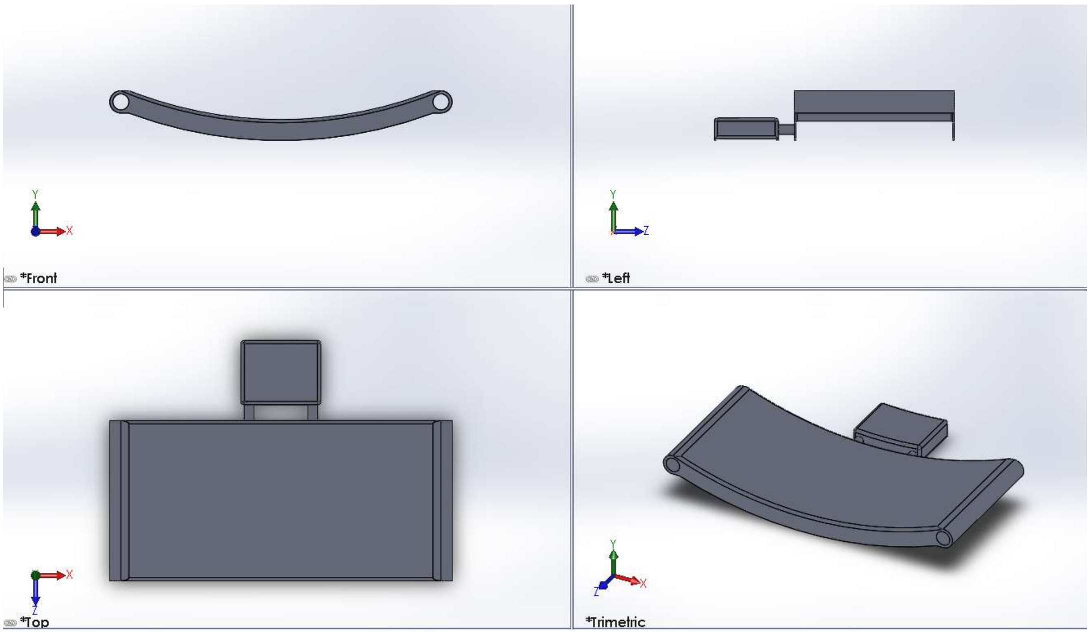


Figure 3.2.Views of the back`s lift.

Figure 3.2 shows the design of the lift. It has a curved shape to be ergonomic and improve the comfortability of the user. The holes at the sides are for the arms that transmit the rotational movement. It is shell in order to be as light as possible. This first design is 1-meter width from 50cm diameter holes centre and 750 cm length. Material chosen is polypropylene copolymer (see properties of the material on Table 3.1).

Table 3.1. Properties of Polypropylene Copolymer.

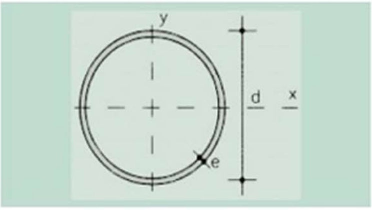
Properties	
Name:	**PP Copolymer**
Model type:	**Linear Elastic Isotropic**
Tensile strength:	**2,76e+07 N/m^2**
Elastic modulus:	**8,96e+08 N/m^2**
Poisson's ratio:	**0,4103**
Mass density:	**890 kg/m^3**
Shear modulus:	**3,158e+08 N/m^2**

It is light and can bear the different loads applied. Weight of the piece is **P2=52,0631 N.**

3.3- **Arms` lift design.**

The arms have a Ø50.4 standard profile. Standard tubular profiles are shown on Table 3.2.

Table 3.2. Tubular section properties.



u = Perimeter
A = Section area
S = Static momentum
I = Moment of inercia
W = Strength module
i = Turning radius
I_t = Torque module

Profile	Dimensions			Section Terms						Weight	
	d mm	e mm	u mm	A cm^2	S cm^3	I cm^4	W cm^3	i cm	I_t cm^4	p kp/m	
Ø 40.2	40	2	126	2,39	1,44	4,33	2,16	1,35	8,66	1,88	P
Ø 40.3	40	3	126	3,49	2,05	6,01	3,00	1,31	12,00	2,74	P
Ø 40.4	40	4	126	4,52	2,60	7,42	3,71	1,28	14,80	3,55	C
Ø 45.2	45	2	141	2,70	1,85	6,26	2,78	1,52	12,50	2,12	P
Ø 45.3	45	3	141	3,96	2,65	8,77	3,90	1,49	17,50	3,11	P
Ø 45.4	45	4	141	5,15	3,37	10,90	4,84	1,45	21,80	4,04	C
Ø 50.2	50	2	157	3,02	2,30	8,70	3,48	1,69	17,40	2,37	P
Ø 50.3	50	3	157	4,43	3,31	12,20	4,91	1,66	24,50	3,47	P
Ø 50.4	50	4	157	5,78	4,23	15,40	6,16	1,63	30,80	4,53	P
Ø 55.2	55	2	173	3,33	2,81	11,70	4,25	1,87	23,40	2,61	C
Ø 55.3	55	3	173	4,90	4,06	16,60	6,04	1,84	33,20	3,85	C
Ø 55.4	55	4	173	6,41	5,21	21,00	7,64	2,01	42,00	5,03	C

In order to choose the material of them, a static and fatigue studies are carried out.

3.4- **Static study.**

References: [13], [14], [15], [16], [17]

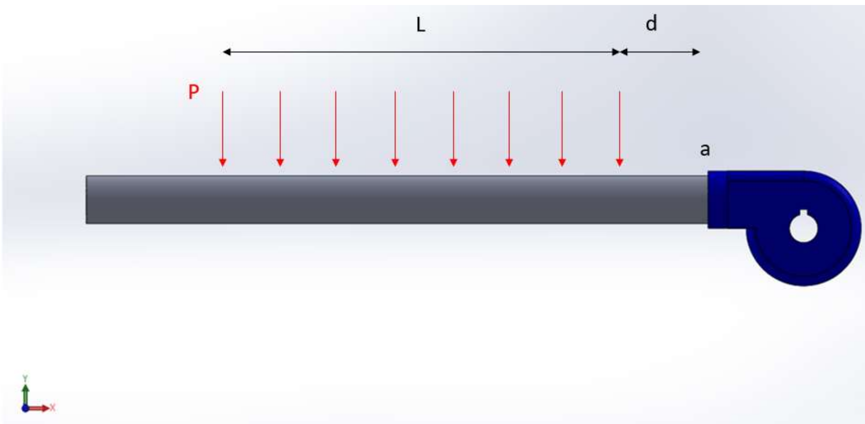


Figure 3.3.Representation of the loads applied to the arm.

Figure 3.3 shows a distributed force called "P" that represent the weight of the patient`s body and of the back`s lift. It doesn't consider the part for the head, so it is irrelevant and simpler to calculate. For this part it is assumed that the mass centre of body and lift coincide. "L" is the length of the lift in cm and d is the distance between the lift and the end of the arm. Blue part is the piece that join the arm with the rotation axis.

Most critical section is on point “a”. There is a change of section and a discontinuity that can lead to fatigue problems even to a break of the piece.

Momentum respect point a is calculated:

$$\sum M = 0 \tag{3.4.1}$$

$$M_a = P \cdot L \cdot (\frac{L}{2} + d) \tag{3.4.2}$$

Where M_a is the bending moment respect the point a, Nm; P distributed force, N/m; L is distance of distributed force, m; d is distance from P to point a, m.

L=0,5 m, P=1184,40 N/m, d=0,05 m, **Ma=177,66 Nm**

It is also considering the torque produced on the arms by the load P.

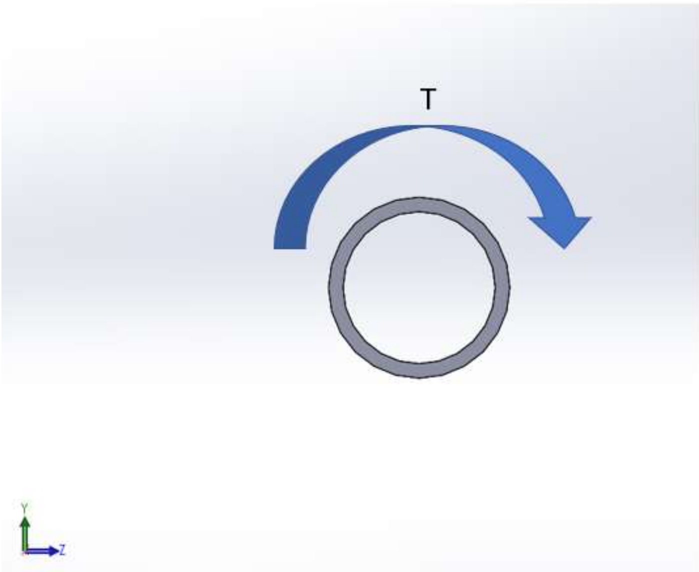


Figure 3.4. Torque produced in one of the arms.

$$T = P \cdot Lt \tag{3.4.3}$$

Where T is torque, Nm; L_t is the distance between the centre of the arm and the mass centre of the group lift and body, m.

L_t=0,535 m. **T=316,83 Nm** .Now the maximum flexion strength “σ_{max}" and maximum torsional strength "τ_{max}" can be calculated.

$$\sigma_{max} = \frac{32 \cdot M}{\pi \cdot D^3} \quad \textbf{(3.4.4)}$$

$$\tau_{max} = \frac{16 \cdot T}{\pi \cdot D^3} \quad \textbf{(3.4.5)}$$

Where D is the external diameter of the arm, m ; σ_{max} is the maximum flexion strength, MPa; τ_{max} maximum torsional strength, MPa.

D=0,05 m; **σ_{max}=14,48 MPa; τ_{max}=12,91 MPa**

Then, Von-Misses criteria can be applied.

$$\sigma_{eq} = \frac{S_y}{n} \quad \textbf{(3.4.6)}$$

Where Sy is yield strength of material, MPa; n is the safety coefficient and "σ_{eq}" is equivalent strength,MPa:

$$\sigma_{eq} = \sqrt{{\sigma_{max}}^2 + 3{\tau_{max}}^2} \quad \textbf{(3.4.7)}$$

In this case the loads can be calculated, and the operation of the machine is taking place on common environments, like a house, safety coefficient value is n=2. Result of equation 3.4.7 is **σ_{eq}=26,65 MPa.** Replacing on eq 3.4.6 ,Sy is calculated, **Sy=53,3 MPa.**

3.5- **Fatigue study.**

First step is to represent the loads within the time.

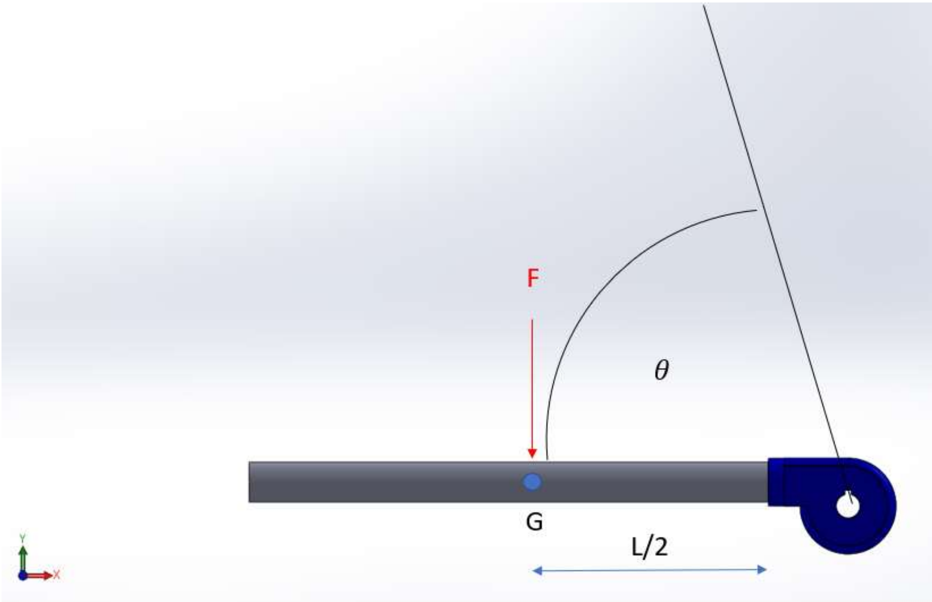


Figure 3.5. Representation of the movement and loads of the system.

Figure 3.5 shows the movement of the arm along the θ angle (0º to 85º), where G is the centre of mass of the group body and lift and F is the distributed force P concentrated on the centre of mass.

$$M(\theta) = F \cdot L/2 \cdot cos\theta \qquad \textbf{(3.5.1)}$$

F=592,20 N, L=0,5 m.

Bending moment depending on θ is represented on figure 3.6.

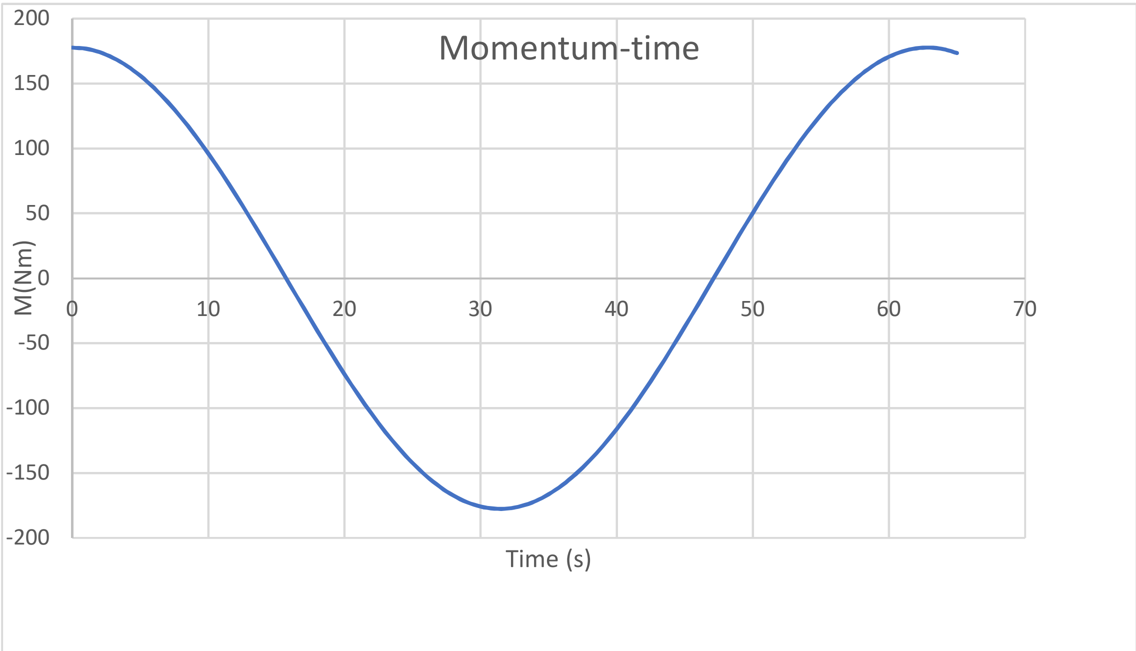


Figure 3.6. Representation of momentum vs time.

On figure 3.6 the maximum momentum coincides with the alternating momentum "Ma"(Ma=177,66 Nm) and the medium value is zero. The Torque is also represented on a figure 3.7.

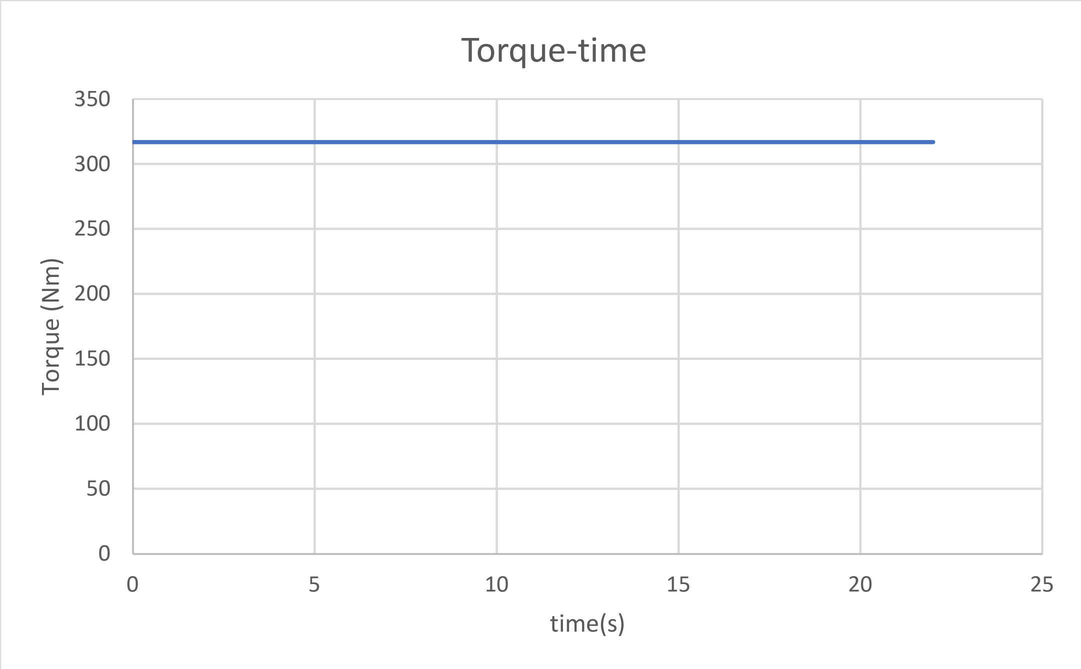


Figure 3.7. Representation of torque vs time.

In this case, torque does not depend on time so in the graphic is a straight line.

On figure 3.7 medium torque "T_m" (Tm=316,83 Nm) has a constant value and alternating torque is zero.

Goodman criteria is applied, in order to get the ultimate strength in tension of the material, S_{ut}.

$$\frac{\sigma_m^{eq}}{S_{ut}} + \frac{\sigma_a^{eq}}{S_e} = \frac{1}{n} \quad \textbf{(3.5.2)}$$

Where Se is the endurance limit, PA; σ_m^{eq} is the equivalent medium strength,MPa; σ_a^{eq} is the equivalent alternating strength,MPa; $S_{ut}$is the ultimate strength limit, MPa; n is the safety coefficient.

Firstly, piece is defined, that means to calculate Se value,

$$Se = Ka \cdot Kb \cdot Kc \cdot Kd \cdot Se` \quad \textbf{(3.5.3)}$$

Where K values are coefficients and Se` is endurance limit estimation, MPa.

- Ka: Surface finish factor, Table 3.3.

Table 3.3. Surface finish factor values .

Surface finish	FACTOR a		
	kpsi	MPa	b
Sanding	1.34	1.58	−0.085
Machining or cold drawing	2.70	4.51	−0.265
Hot rolling	14.4	57.7	−0.718
Forged	39.9	272.	−0.995

$$K_a = a \cdot S_{ut}^b \quad \textbf{(3.5.4)}$$

Part will be manufactured by turn machining.

- Kb: Size factor, Table 3.4

Table 3.4.Size factor values.

$$k_b = \begin{cases} (d/0.3)^{-0.107} = 0.879d^{-0.107} & 0.11 \le d \le 2 \text{ pulg} \\ 0.91d^{-0.157} & 2 < d \le 10 \text{ pulg} \\ (d/7.62)^{-0.107} = 1.24d^{-0.107} & 2.79 \le d \le 51 \text{ mm} \\ 1.51d^{-0.157} & 51 < d \le 254 \text{ mm} \end{cases}$$

Diameter is expected to be between 2,79 and 51 mm.

- Kc: Reliability factor, Table 3.5.

Table 3.5. Reliability factor values.

Reliability, %	Reliability factor, Kc
50	1.000
90	0.897
95	0.868
99	0.814
99.9	0.753
99.99	0.702
99.999	0.659
99.9999	0.620

It is supposed a reliability of the 99%.

- Kd: Temperature factor, Table 3.6.

Table 3.6. Temperature factor values.

Temperature, °C	S_T/S_{RT}	Temperature, °F	S_T/S_{RT}
20	1.000	70	1.000
50	1.010	100	1.008
100	1.020	200	1.020
150	1.025	300	1.024
200	1.020	400	1.018
250	1.000	500	0.995
300	0.975	600	0.963
350	0.943	700	0.927
400	0.900	800	0.872
450	0.843	900	0.797
500	0.768	1 000	0.698
550	0.672	1 100	0.567
600	0.549		

The machine will work on standard conditions.

Factor values chosen are shown on Table 3.7.

Table 3.7. Different factor values used for the fatigue calculations.

Factor values	
Ka	$4{,}51 \cdot Sut^{-0{,}265}$
Kb	0,81
Kc	0,814
Kd	1

Se`: Endurance limit estimation,

$$Se` = 0{,}504 \cdot S_{ut} \quad \textbf{(3.5.5)}$$

With all the values mentioned before, Se can be calculated depending on Sut (eq. 3.5.2). After defining the piece, load can be defined. By replacing M_a and T_m on the equations number 3.4.4 and 3.4.5, respectively, σ_a and τ_m can be calculated. **σ_a=14,48 MPa; τ_m=12,91 MPa**. To correct their values, next formulas are used:

$$\sigma_a^{corr} = K_f \cdot \sigma_a \quad \textbf{(3.5.6)}$$

Where Kf is the notch correction factor; σ_a^{corr} is the corrected alternating strenthg,MPa.

Kf: Notch correction factor.

$$K_f = 1 + q \cdot (K_{tf} - 1) \quad \textbf{(3.5.7)}$$

Where q is the notch radius, mm.

For the case of a chamfer with sharp edge, **Kf=2,5 [B]**

For torque the same is done.

$$\tau_m^{corr} = K_f \cdot \tau_m \quad \textbf{(3.5.8)}$$

Where τ_m^{corr} is the corrected medium torsional strength, MPa.

Kf is the same.

q=0,95;Kt=1,4;Kf=1,38.

σ_a^{corr}=36,21 MPa; τ_m^{corr}=32,38 MPa

Finally, the equivalent strengths can be calculated.

$$\sigma_m^{eq} = \sqrt{\sigma_m^{corr} + 3\tau_m^{corr\,2}} \quad \textbf{(3.5.9)}$$

$$\sigma_a^{eq} = \sqrt{\sigma_a^{corr} + 3\tau_a^{corr\,2}} \quad \textbf{(3.5.10)}$$

σ_m^{eq}=55,92 MPa; σ_a^{eq}=36,21 MPa

Replacing all on equation 3.5.2, S_{ut} is calculated. **S_{ut} =337,8 MPa**. Strenthg limits are shown on Table 3.8.

Table 3.8. Strength limits of the arm.

Strength limits of the arm.	
S_{ut} (MPa)	337,8
Sy (MPa)	53,3

Knowing the values of Sut and Sy, the election of the material of the arms can be done.Properties of different types of steel are shown on Table 3.9.

Table 3.9.Specifications of different standard steels..

1 UNS núm.	2 SAE y/o AISI núm.	3 Manufacturing	4 Sut, Mpa(kpsi)	5 Sy, Mpa(kpsi)	6 Stretching ,%	7 Area reductior	8 Brinell hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

The material chosen must have strength values bigger than the ones calculated before to ensure the endurance of the piece during its work-life. S_{ut} and S_y correspond to columns 4 and 5 , respectively. Material chosen is steel **AISI 1015 Cold Drawing**, it fits the specifications and it is available on Solidworks. Weight of one arm is **P3=28,97 N.**

A simulation is carried out on Solidworks, with all specifications mentioned before (See figure 3.8). Back`s lift material is PP Copolymer, arms` material is Steel 1015 CD. For the pieces connected to the arm (Arm Support) the same material is given.

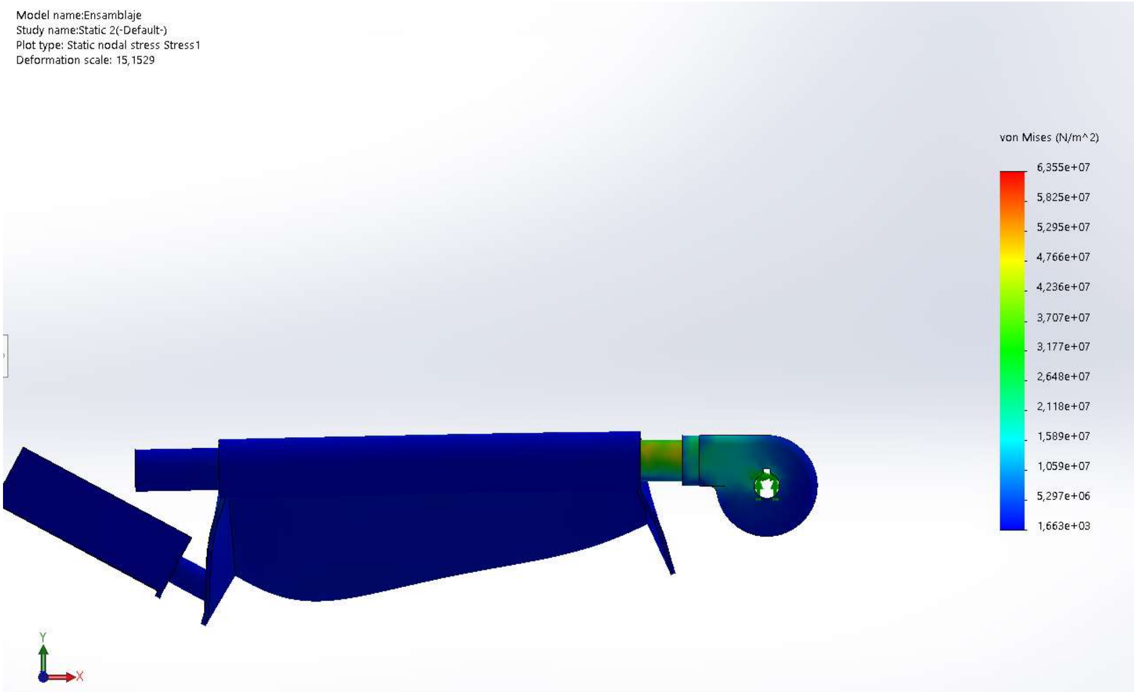


Figure 3.8. Simulation of Von-Misses strength.

Most critical section is placed on the joint between the arm and the arm support like predicted.

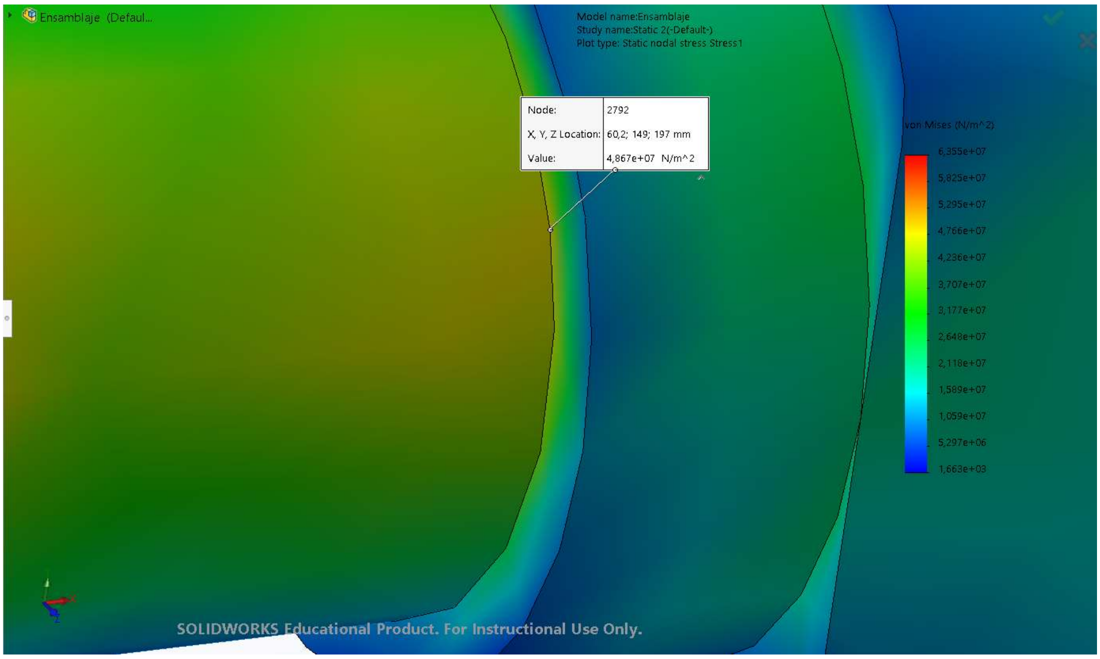


Figure 3.9. Zoom into the most critical section.

As shown in figure 3.9, on the part analysed in the static study, strength is 48 MPa, very close to 53 MPa calculated by hand.

3.6- Electric motor.

In order to manage the lift, an actuator is needed. In this case an electric motor. This motor must ensure to produce more than the bending moment needed in the lift`s axis, and also the speed required. This moment is called Mc.

$$Mc = P1 \cdot Ya \cdot cos\theta + P2 \cdot Yb \cdot cos\theta + 2 \cdot P3 \cdot Yc \cdot cos\theta \quad \textbf{(3.6.1)}$$

Where Mc is the bending moment produced on the axis, Nm; P1 is load applied by the body, N; P2 is the load applied by the back`s lift weigth,N; P3 is the load applied by the arms weigth, N; $Y_i$ are the mass center position of the body, back`s lift and arm, respectively,mm.

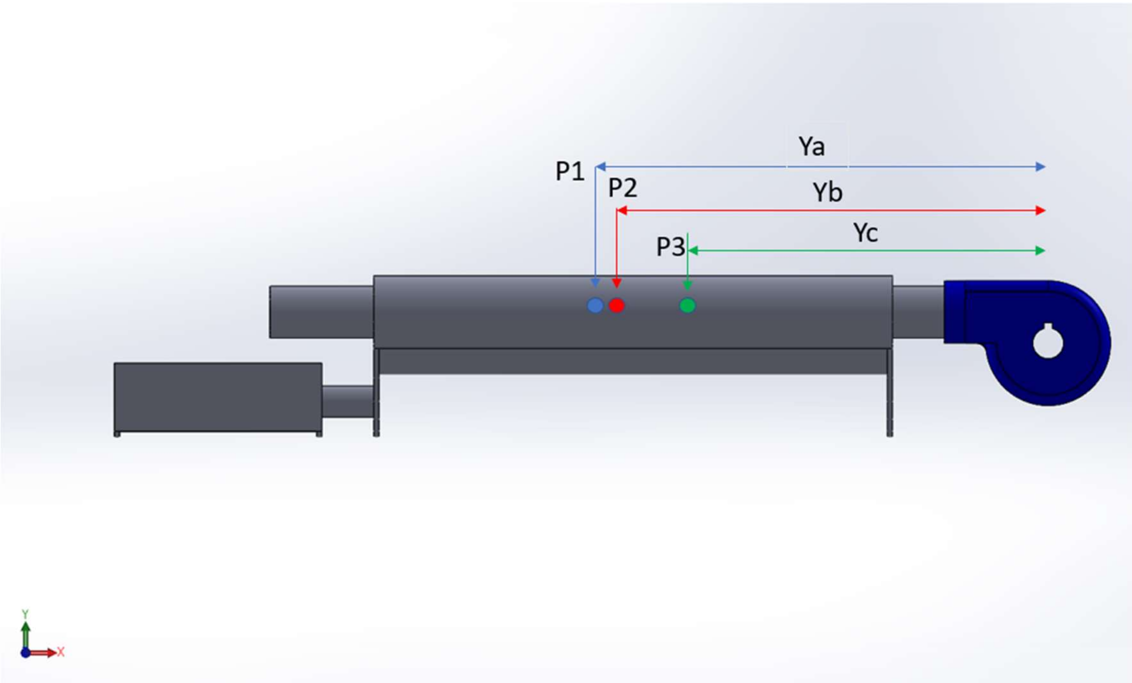


Figure 3.10. Mass centre`s locations of the different parts of assembly, respect the rotation axis.

Ya=510,91 mm; Yb=511,5 mm; Yc=445 mm.

Equation 3.6.1 will reach its maximum value when θ value is zero. **Mc(θ=0)=328,66 Nm.**

Place of Origin:	Zhejiang, China
Brand Name:	ZD MOTOR
Model Number:	Z82BLDPN24200-30S/82PN_K
Usage:	Boat, Car, Electric Bicycle, Fan, Home Appliance
Certification:	CCC, CE, ROHS, UL
Type:	Gear Motor
Torque:	300 N.M
Construction:	Permanent Magnet
Commutation:	Brushless
Protect Feature:	Waterproof, IP65
Speed(RPM):	1.5 rpm- 822 rpm
Continuous Curre...	9 A
Efficiency:	IE 2
Function:	Driving

Figure 3.11. Image and specifications of the electric motor.

The motor chosen is from the Chinese company ZD Motor. It produces 300 Nm at 1,5 rpm speed (see figure 3.11). It fits with our needs, though a gear system is needed to get the speed and the momentum on the axis.

3.7- **Gear system.**

References: [13], [14] , [18], [19].

A gear system is needed in order to transmit the speed and momentum from the motor to the shaft of the system.

Table 3.10. Boundary conditions for the shaft.

	Motor	Machine
w (rad/s)	0,157	0,1
M (Nm)	300	328,66

Gear ratio is calculated;

$$i = \frac{w_1}{w_2} = \frac{Z_2}{Z_1} \qquad \textbf{(3.7.1)}$$

Where I is the gear ratio; w_1 is the rotational speed of the pinion, rpm; ; w_2 is the rotational speed of the secondary gear, rpm; Z_1 is the tooth number of the pinion; Z_2 is the tooth number of the secondary gear.

i=1,57.

Knowing that the height of the bed is 50 cm, the distance between axis is going to be 33 cm, in order to avoid the gear touching the floor and other interferences. Next step is to choose the size of gear from a catalogue.

$$a = \frac{m}{2}(Z_1 + Z_2) \quad \textbf{(3.7.2)}$$

a: distance between axis, mm ; m:module.

In the catalogue of Transmisiones Zaragoza S.L it is found that module 4 may fit the specifications. Equation 3.7.1 can be written like Z_2=1,57 Z_1, replacing it on equation 3.7.2 and knowing a=330 mm and m=4, Z1=64 and Z_2=100,8**.** In catalogue the closest numbers are **Z1=65** and **Z_2=100.** Dimensions are shown on Table 3.11.

Table 3.11. Dimensions of the gear.

Dimensions of the gear.				
Number	Z	De(mm)	Dp(mm)	Dm(mm)
1	65	268	260	-
2	100	408	400	-

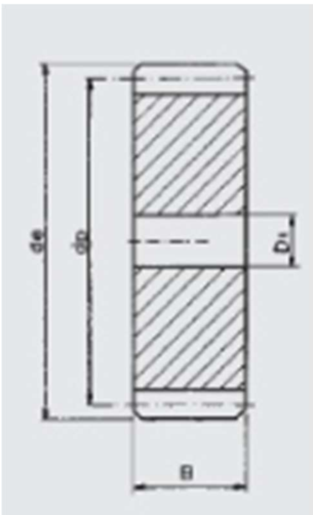


Figure 3.12. Dimensions of gear

Once the size of gear is chosen, next step is to choose the material of them. For gear is necessary to consider shearing of the teeth and wear on surface.

3.7.1 **Shearing of the teeth.**

Criteria follow the ISO methodology:

$$\sigma_{blim} = \frac{S_{107}}{Y_{sa} \cdot C_s} \quad \textbf{(3.7.1.1)}$$

σ_{blim}:Limit strength, MPa; S_{107}:Strength of material, MPa; $C_{s:}$ Safety coefficient; Y_{sa}: Stress concentration factor.

$$Plim = \frac{10^{-6}}{1{,}96} \cdot \sigma_{blim} \cdot b \cdot \frac{m^2}{\cos{(Ba)}} \cdot \frac{n \cdot Z}{Y_{fa} \cdot Y_\varepsilon \cdot Y_B} \quad \textbf{(3.7.1.2)}$$

Plim: Power Limit, kW; b:gear`s width, mm ; Ba: tangent plane angle, º; n=rotation speed ,rpm; Z: number of teeth; Y_{fa}: Shape factor ; Y_ε:Driving factor; Y_B: Inclination factor.

$$Plim = M \cdot w \quad \textbf{(3.7.1.3)}$$

Where M is the bending moment, Nm; w is the rotational speed , rpm.

Plim=14,1 W.

$$Y_\varepsilon = 0{,}25 + \frac{0{,}75}{\varepsilon_\alpha} \quad \textbf{(3.7.1.4)}$$

$$\varepsilon_\alpha = \frac{1}{\pi \cdot cos\alpha} \cdot (\sqrt{\frac{Z1^2}{4} \cdot sen^2(\alpha) + y1^2 + Z1 \cdot y1} + \sqrt{\frac{Z2^2}{4} \cdot sen^2(\alpha) + y2^2 + Z2 \cdot y2} - (\frac{Z1+Z2}{2}) \cdot sen\alpha) \quad \textbf{(3.7.1.5)}$$

Where ε_α: Glacing degree, º ; α: Pressure angle=20º ; y=1 (straight round teeth)

$\boldsymbol{\varepsilon_\alpha}$:1,82 ; $\boldsymbol{Y_\varepsilon}$=0,66

Stress concentration factor is obtained from figure 3.13.

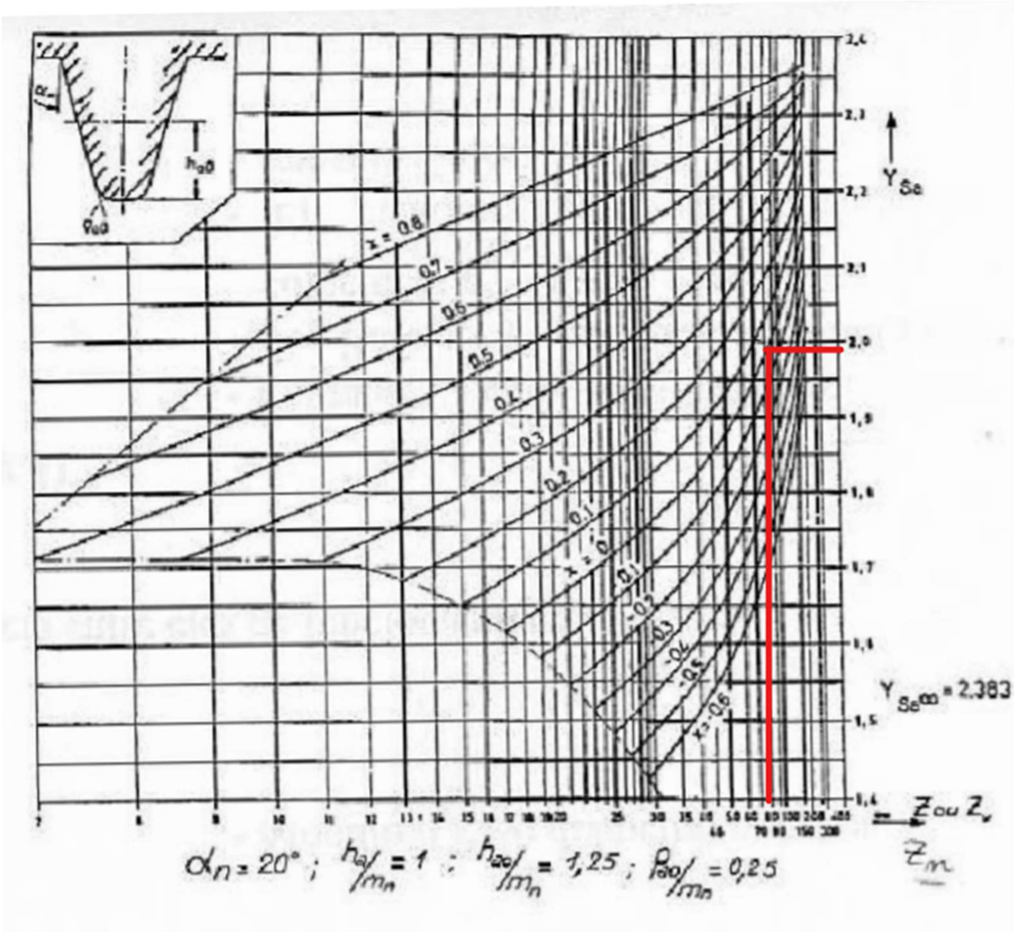


Figure 3.13. Stress concentration factor.

On the abscissa axis is represented number of teeth. On the ordinate axis is represented the stress concentration factor. x curves represent the displacement tool distance, in this case x=0.The intersection between the number of teeth value Z, and x=0 provides the value of Ysa=1,98.

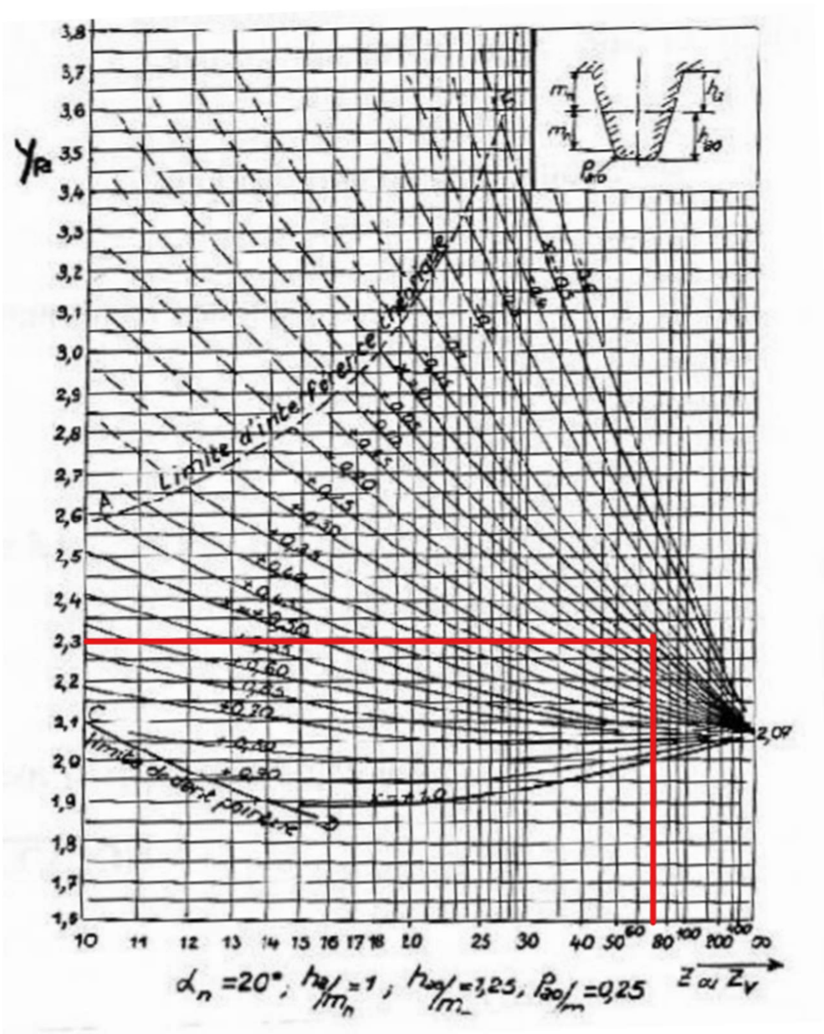


Figure 3.14. Size factor graphic.

On figure 3.14 is represented number of teeth on the abscissa axis and size factor on the ordinate axis. The intersection with the x=0 curve provides a value of Y_{fa}=2,3.

Knowing that: b=40 mm; m=4; cos(Ba)=1; n=1,5 rpm ;Z=65 for the pinion. Replacing these values on equation 2.7.1.2 results on $\boldsymbol{\sigma_{blim}}$**=2,24 daN/mm^2.** Replacing it on equation 3.7.1.1 with C_s=1 (on the limit), $\boldsymbol{S_{107}}$**=4,44 daN/mm^2.** With this value, the material can be found in figure 3.15.

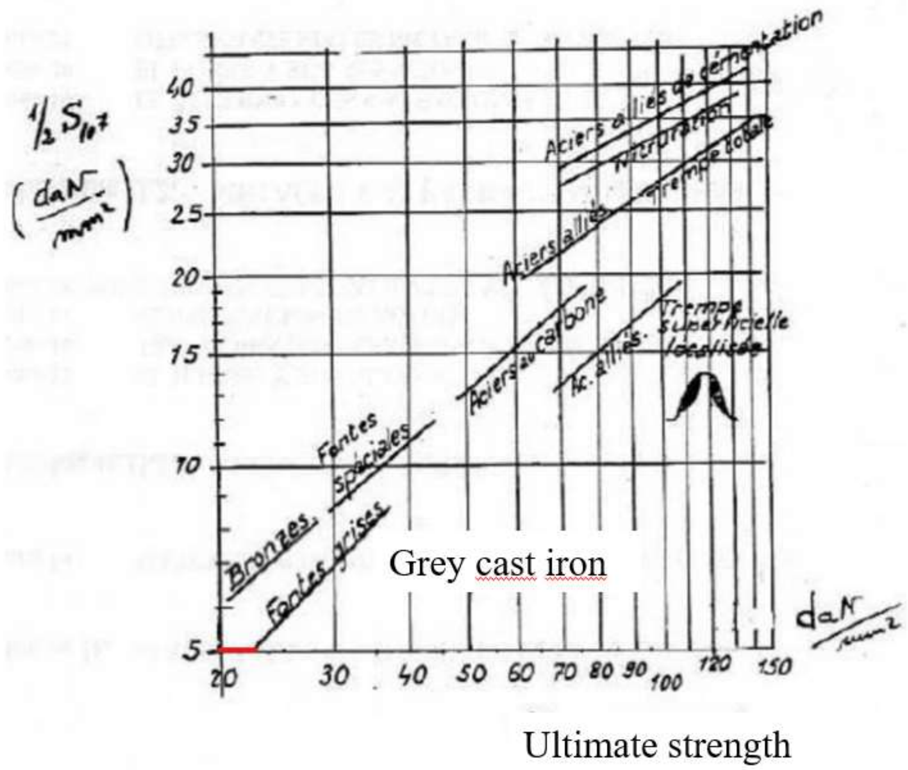


Figure 3.15. Ultimate strength of different materials.

So, the material for the pinion will be grey-cast iron. Doing the same for the secondary gear the following results are obtained:

Table 3.12. Specifications of gear system.

Specifications of gear system.						
	Z	n(rpm)	Ysa	Yfa	σ_{blim}(daN/mm²)	S_{107}
Pinion (1)	65	1,5	1,98	2,3	2,24	4,44
Secondary(2)	100	0,95	2,05	2,2	2,2	4,51

The other data is the same for pinion and secondary. Secondary gear material will be also grey-cast iron with an ultimate tension strength, S_{UT}, bigger than **23 daN/mm²**

3.7.2 Wear on surface.

Wear on surface strength, σ_{Hlim}, is obtained from the following equations:

$$Padm = \frac{10^{-6}}{1{,}96} \cdot \sigma_{Hlim}^2 \cdot b \cdot (m \cdot z)^2 \cdot \frac{i}{i+1} \cdot \frac{n}{Z_H^2 \cdot Z_E^2 \cdot Z_\varepsilon^2} \qquad \textbf{(3.7.2.1)}$$

Where σ_{Hlim} is wear on surface strength, MPa; Z are different factors:

- Z_ε: Driving Factor

$$Z_\varepsilon = \sqrt{\frac{(4-\varepsilon_\alpha)}{3}} \quad \textbf{(3.7.2.2)}$$

- Z_E: Elastic Factor.

$$Z_E = \sqrt{0{,}175 \cdot E} \quad \textbf{(3.7.2.3)}$$

Where E:Elasticity modulus.

- Z_H: Geometrical Factor.

$$Z_H = \sqrt{\frac{2 \cdot cosBa}{sen\alpha \cdot cos\alpha}} \quad \textbf{(3.7.2.4)}$$

Factor values are presented on Table 3.13.

Table 3.13. Factor values and strength of gear system.

Factor values and strength of gear system.						
	Z	n(rpm)	Z_ε	Z_E	Z_H	σ_{Hlim} (daN/mm^2)
Pinion (1)	65	1,5	0,85	107,55	2,49	24,13
Secondary (2)	100	0,95	0.85	150,6	2,49	2,69

Knowing wear on surface strength value , stiffness of the material needed can be found on figure 3.16.

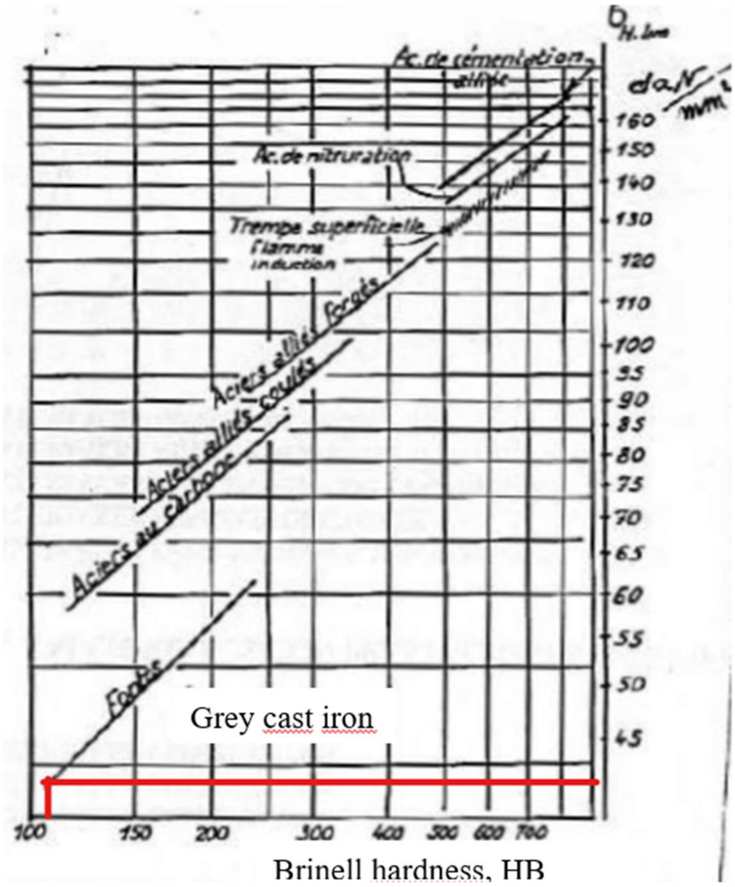


Figure 3.16. Brinell hardness for different materials depending on wear on surface strength.

On the abscissa axis Brinell Hardness is represented and on the ordinate axis wear on surface strength limit , σ_{Hlim}.Material will be grey-cast iron with more than **100 HB** stiffness for both gear and S_{ut} bigger than **23 daN/mm²**. Exact specifications are obtained from Table 3.14 .

Table 3.14. Properties of different types of grey- cast iron.

ASTM	Sut, kpsi	Suc, kpsi	Ssut, kpsi	Elasticity module, Mpsi		Se, kpsi	Brinell Hardness, HB
				Tensión†	Torsiór		
20	22	83	26	9.6-14	3.9-5.6	10	156
25	26	97	32	11.5-14.8	4.6-6.0	11.5	174
30	31	109	40	13-16.4	5.2-6.6	14	201
35	36.5	124	48.5	14.5-17.2	5.8-6.9	16	212
40	42.5	140	57	16-20	6.4-7.8	18.5	235
50	52.5	164	73	18.8-22.8	7.2-8.0	21.5	262
60	62.5	187.5	88.5	20.4-23.5	7.8-8.5	24.5	302

Gear will be made of **ASTM 25** grey-cast iron.

3.8- **Shafts.**

References:, [14], [16], [17], [20] , [20].

Shafts will be design considering the fatigue study. Material for both shafts will be Steel 4130 tempering at 540 Cº**, Sut=1030 MPa**. The minimum diameter capable of bear the external forces will be calculated using Goodman Criteria.

3.8.1 **Input shaft.**

Input shaft critical sections are shown on figure 3.17.

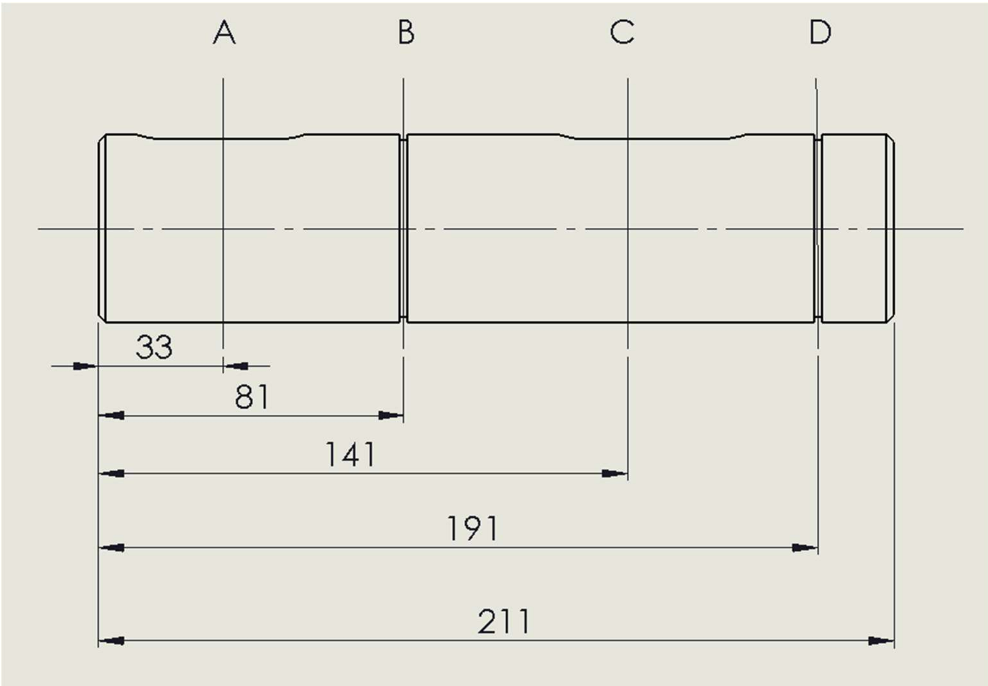


Figure 3.17. Input shaft critical sections.

First, exterior forces are calculated. Radial force applied from the electric motor (section A) can be calculated as:

$$F_r = \frac{T}{2 \cdot d} \quad \textbf{(3.8.1)}$$

Where Fr is the radial force applied from the electric motor, N;T is the torque applied to the shaft, Nm ; d the diameter of the shaft, m.

Gear apply a torque, T, same as before, and radial Force, F (Section C).

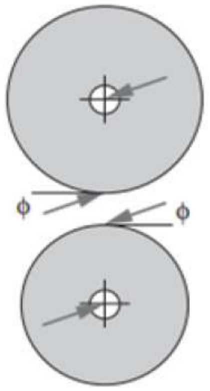


Figure 3.18. Vectorial scheme of the forces over gear.

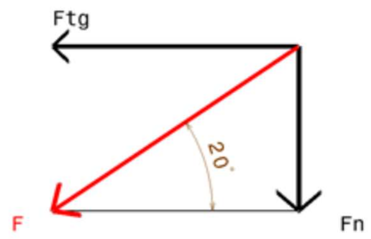


Figure 3.19. Breakdown of forces over the gear.

$$F_{tg} = \frac{T}{r_g} \tag{3.8.2}$$

Where F_{tg} is tangential force,N: r_g is radius of gear.

$$F = \frac{F_{tg}}{cos\alpha} \tag{3.8.3}$$

Where F is the normal force produced by gear, N; α is the pressure angle=20 º.

F_{tg}=±2238,8 N; F=±2383,5 N

In this case, Goodman criteria is like:

$$\frac{\sigma_a^{eq}}{S_e} = \frac{1}{n_f} \tag{3.8.4}$$

The forces are alternating so $\sigma_m = 0$.

Se is obtained from equation 3.5.3, but a new term is added: $Ke = \frac{1}{Kf}$, where Kf is the notch factor. For keyways it is Kf=1,6 and for security rings grooves it is Kf=2,2. Security factor nf is 2. Most critical section is D.

In section D, **T=Ta=300 Nm**. Calculating the bending moment in section D as:

$$M = \sum F_i \cdot d_i \tag{3.8.5}$$

Where M is the bending moment over the section,N; F_i forces applied on other sections, N; d_i between section D and sections where are forces applied (A y C), m.

$\boldsymbol{M = Ma = (\frac{24}{d} + 142,95\ )Nm.}$ σ_a and τ_a(eqs 3.4.4 and 3.4.5) are calculated in function of d. Then , they are replaced on equation 3.4.7 to get σ_a^{eq}.For Se , factors are obtained the same way as previously mentioned in this paper but adding the new factor Ke.

Table 3.15. Correction factors for the input shaft.

Ka	0,71
Kb	0,87
Kc	0,814
Kd	1
Ke	0,45
Se`(MPa)	519,12

Se=118,68 MPa

Replacing everything on equation 3.8.4 and calculating the diameter, d=48,97 mm. In order to get standard items **d=50 mm.**

3.8.2 Output shaft.

Critical sections of the output shaft are shown on figure 3.20

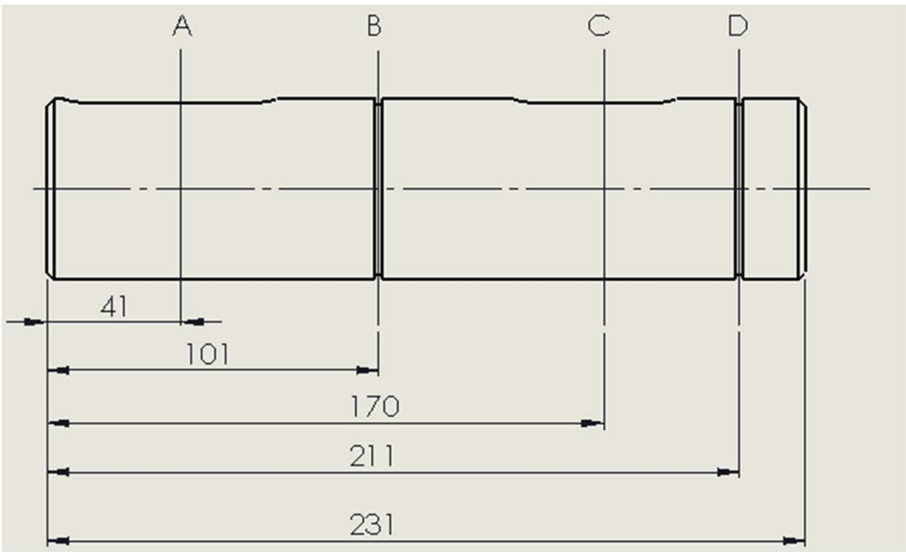


Figure 3.20. Output shaft critical sections.

Most critical section is D. Forces are applied on sections A and C. Bigger bending moment is placed on section Equations are the same as before, results are presented on Table 3.16:

Table 3.16.Results for calculations of output shaft.

Fr (N)	$\frac{462}{2d}$
Ftg (N)	$\pm 2264{,}7$
F (N)	$\pm 2410{,}05$
Ma (Nm)	$(\frac{36{,}96}{\mathrm{d}} + 144{,}603)$
Ta(Nm)	462
Ka	0,71
Kb	0,87
Kc	0,814
Kd	1
Ke	0,45
Se`(MPa)	519,12
Se (MPa)	118,68
d	53,7 mm

In order to get standard **d=55mm.**

3.9- **Bearings.**

References: [14], [15], [16] , [20], [21].

The shafts will be held by two ball bearings each. Failure criteria will be:

$$C \cdot [\frac{10^6}{L_{10}}]^{\frac{1}{a}} = C_{serv} \cdot F_{eq} \qquad \textbf{(3.9.1)}$$

Where C is the Dynamic rating, N ; L_{10} is Rating life, h; a=3 ; Cserv is the Service rating; F_{eq} are Equivalent forces, N.

$$F_{eq} = F_r + F \qquad \textbf{(3.9.2)}$$

Cserv is obtained from Table 3.17.

Table 3.17. Service rating factors.

Tipo de aplicación	Factor de carga
Engranajes de precisión	1.0-1.1
Engranajes comerciales	1.1-1.3
Aplicaciones con sellos deficientes en los cojinetes	1.2
Maquinaria sin impactos	1.0-1.2
Maquinaria con impactos ligeros	1.2-1.5
Maquinaria con impactos moderados	1.5-3.0

For commercial gears the factor is Cserv=1,3.Rating life is obtained from Table 3.18.

Table 3.18.Rating life for different operations.

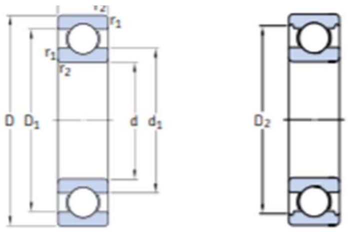
Tipo de aplicación	Vida, kh
Instrumentos y aparatos de uso poco frecuente	Hasta 0.5
Motores de aeronaves	0.5-2
Máquinas de operación corta o intermitente, donde la interrupción del servicio resulta de poca importancia	4-8
Máquinas de servicio intermitente donde una operación confiable es de gran importancia	8-14
Máquinas para servicio de 8 h, que no siempre se usan completamente	14-20
Máquinas para servicio de 8 h, que se utilizan plenamente	20-30
Máquinas para servicio continuo las 24 h	50-60
Máquinas para un servicio continuo de 24 h, donde la confiabilidad es de suma importancia	100-200

For short-operation machine L_{10}=8 kh.

	Input Shaft	Output shaft
C (kN)	1,415	1,718

Knowing this value, it is possible to go to the manufacturer catalogue, SKF in this case, and choose the ball bearings.

Table 3.19.SKF Ball bearings catalogue



Principal dimensions			Basic load ratings dynamic	static	Fatigue load limit	Speed ratings Reference speed	Limiting speed	Mass	Designation
d	D	B	C	C_0	P_u				
mm			kN		kN	r/min		kg	–
40	52	7	4,49	3,75	0,16	26 000	16 000	0,032	**61808**
	62	12	13,8	10	0,425	24 000	14 000	0,12	**61908**
	68	9	13,8	10,2	0,44	22 000	14 000	0,13	*** 16008**
	68	15	17,8	11	0,49	22 000	14 000	0,19	*** 6008**
	80	18	32,5	19	0,8	18 000	11 000	0,37	*** 6208**
	80	18	35,8	20,8	0,88	18 000	11 000	0,34	**6208 ETN9**
	90	23	42,3	24	1,02	17 000	11 000	0,63	*** 6308**
	110	27	63,7	36,5	1,53	14 000	9 000	1,25	**6408**
45	58	7	6,63	6,1	0,26	22 000	14 000	0,04	**61809**
	68	12	14	10,8	0,465	20 000	13 000	0,14	**61909**
	75	10	16,5	10,8	0,52	20 000	12 000	0,17	*** 16009**
	75	16	22,1	14,6	0,64	20 000	12 000	0,24	*** 6009**
	85	19	35,1	21,6	0,915	17 000	11 000	0,42	*** 6209**
	100	25	55,3	31,5	1,34	15 000	9 500	0,84	*** 6309**
	120	29	76,1	45	1,9	13 000	8 500	1,55	**6409**
50	65	7	6,76	6,8	0,285	20 000	13 000	0,052	**61810**
	72	12	14,6	11,8	0,5	19 000	12 000	0,14	**61910**
	80	10	16,8	11,4	0,56	18 000	11 000	0,18	*** 16010**
	80	16	22,9	16	0,71	18 000	11 000	0,26	*** 6010**
	90	20	37,1	23,2	0,98	15 000	10 000	0,45	*** 6210**
	110	27	65	38	1,6	13 000	8 500	1,1	*** 6310**
	130	31	87,1	52	2,2	12 000	7 500	1,95	**6410**
55	72	9	9,04	8,8	0,375	19 000	12 000	0,083	**61811**
	80	13	16,5	14	0,6	17 000	11 000	0,19	**61911**
	90	11	20,3	14	0,695	16 000	10 000	0,27	*** 16011**
	90	18	29,6	21,2	0,9	16 000	10 000	0,39	*** 6011**
	100	21	46,2	29	1,25	14 000	9 000	0,61	*** 6211**
	120	29	74,1	45	1,9	12 000	8 000	1,35	*** 6311**

Ball bearings input shaft: **SKF 61910**

Ball bearings output shaft: **SKF 61911**

3.10- **Protective casing.**

The protective casing protects and isolates the internal elements from the corrosive external agents. It also works as the structural support of the elements designed before. Protective casing must be rigid enough to avoid deformation produced by the different loads of the system. If it is not like that, deformations would be produced, both for shafts and gears, causing malfunction and a premature failure. To ensure that it meets all mechanical requirements, and given these are not very strict, grey cast iron will be used. This material is optimal for this task due to its good ability to shape and is easy to machine. It consists of five parts, bottom , middle, top, input-shaft cover, output-shaft cover. This arrangement is used to easily assemble the elements. Joints will be made using screws. It also has holes for the lubrication filling and emptying.

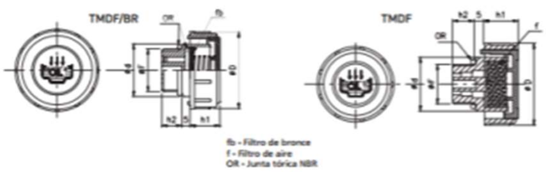
3.11- **Gear lubrication.**

Lubrication of the gear system will be made by splash oil lubrication. A fling plug is placed on the top of the protective casing in order to ease the filling process. It is selected from the Tecnodin catalogue shown on Table 3.20.

Table 3.20. TECNODIN catalogue for filling plugs.

4853-4870 TAPÓN DESVAPORIZADOR TMD CON FILTRO

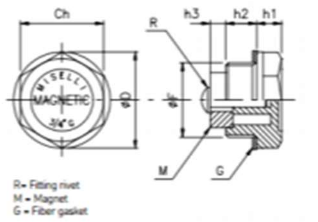
Código sin filtro	P(l/min) sin filtro	Código con filtro	P(l/min) con filtro	F	D	d	h1	h2
485309000	230	487003038	200	G 3/8"	36	23	17	11
485312000	260	487004012	230	G 1/2"	41	28	18	12
485319000	430	487006034	350	G 3/4"	47	33	17	12
485325000	430	487008001	400	G 1"	52	38	20	12
485331000	660	487010014	600	G 1 1/4"	63	49	23	13
485338000	660	487010112	600	G 1 1/2"	63	55	23	13,5
485316000	260	487016000	230	M 16x1,5	36	23	17	11
485318000	260	487018000	230	M 18x1,5	41	28	17,5	12
485320000	260	487020000	230	M 20x1,5	41	28	17,5	12
485322000	260	487022000	230	M 22x1,5	41	28	17,5	12



Filling tap 487016000 is chosen. A emptying tap is also installed on the bottom part of the protective casing in order to ease the emptying process. Selected from Table 3.21.

Table 3.21.TECNODIN catalogue for drain plugs.

TM - DRAIN PLUGS WITH MAGNET (PLASTIC)



-Thermoplastic hex plug with magnet

-The plug is fitted to the bottom of the transmission or tank, to be used as drain plug.: the magnet attract ferrous metal parts, preventing damage to gears and othe moving components

-Production colour black, marked MAGNETIC on the hex surface.

-Oil resistant asbestos-free seal

-In larger quantities, these plugs are available with threads other than those shown, ie M16-18-20-22

Code	F	Ch	D	h2	h1	h3
TM-14	G 1/4"	17	20	9	7	5
TM-38	G 3/8"	18	22	10	7.5	10
TM-12	G 1/2"	24	27	11	8	9
TM-34	G 3/4"	30	34	11	9	6.5
TM-1	G 1"	35	42	12	10.5	14
TM-1415	M14X1.5	17	20	9	7	5

T,-1415 drain plug is selected. Lubricant used will be ISO VG 320.

3.12- **Shaft shoulder.**

On the other side of the machine there is a 55 mm diameter shaft of the same material as the output shaft. This shaft it is supported by a triangle support attached to the ground, with a ball bearing and two covers of grey-cast iron in each side of the shaft to avoid its longitudinal movement. This part is made in grey-cast iron.

3.13- **Legs pusher design.**

The system that will move legs out of bed, it is composed by a pinion managed by an electric motor and a rack connected to a surface that will move the legs. Rack is attached to a plastic arm which is also connected to a plastic paddle that moves the legs. Both of them made in Polypropylene Copolymer to be as light as possible. The arm slides over two rails.

3.14- **Pinion and rack.**

References: [14] , [15] , [16], [20], [21], [22], [23], [24].

Firstly, it is necessary to calculate the force generated by the legs.

$$F_f = M \cdot g \cdot \mu \qquad \textbf{(3.14.1)}$$

Where F_f is the frictional force, N:M:mass of the legs,kg; μ: coefficient of friction of the bed.

M is obtained from equations 3.1.2, 3.1.3 and 3.1.4, giving the percentage of the total mass that correspond to legs. In this case M=36,5%Totalmass=31,68 kg. The friction between the legs and the bed is difficult to calculate, it depends of the type of the bedsheet, mat. It is supposed to value μ=0,1. So **F=31,05 N**. The pinion used for the system will be with Z=12, chosen from Transmisiones Zaragoza S.L catalogue.

Table 3.22. Pinion gear dimensions.

Z	De(mm)	Dp(mm)	Dm(mm)
12	14	12	-

The rack is also chosen from the same catalogue.

Table 3.23. Rack dimensions.

A (mm)	B(mm)	L(mm)	p(mm)
15	15	1000	3,14

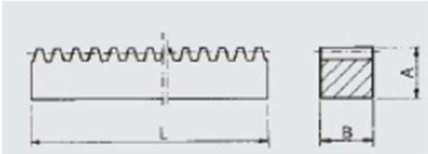


Figure 3.21. Rack dimensions.

Torque generated can be calculated by:

$$T = \frac{F \cdot d_g}{2000} \quad \textbf{(3.14.2)}$$

Where d_g is diameter of gear,mm.

T=0,186 Nm.

Next step is to calculate turns of the pinion need to complete the 1000 m of the rack.

$$L = p \cdot n_p \quad \textbf{(3.14.3)}$$

L:Length of rack,m; p:tooth pitch,mm; n_p: number of tooth pitch.

$$Turns = \frac{n_p}{z} \quad \textbf{(3.14.4)}$$

Turns=26,5.

The objective is to move the legs in 10 s. So, speed will be 2,65 rps, expressed on rpm, **n=160 rpm.** Now the electric motor is chosen.

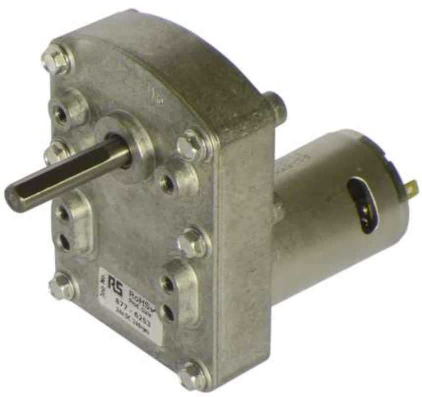


Figure 3.22.Electric motor for pinion-rack.

Table 3.24. Specifications of the electric motor.

Attribute	Value
Exit Speed	240 rpm
Supply Voltage	24 V dc
Maximum Output Torque	0,3 Nm
DC Motor Type	With brushes
Shaft Diameter	8mm
Length	63.5mm
Width	101mm
Depth	84mm
Dimensions	63,5 x 101 x 84 mm
Axis angle	Straight
Normative compliance	BS EN ISO 9001: 2008, UL
Serie	UBD

At the speed required, n=160 rpm, the motor provides T=0,2 Nm.

3.8.3 **Shaft.**

Diameter of shaft is known d=6 mm, so the material needs to be calculated.

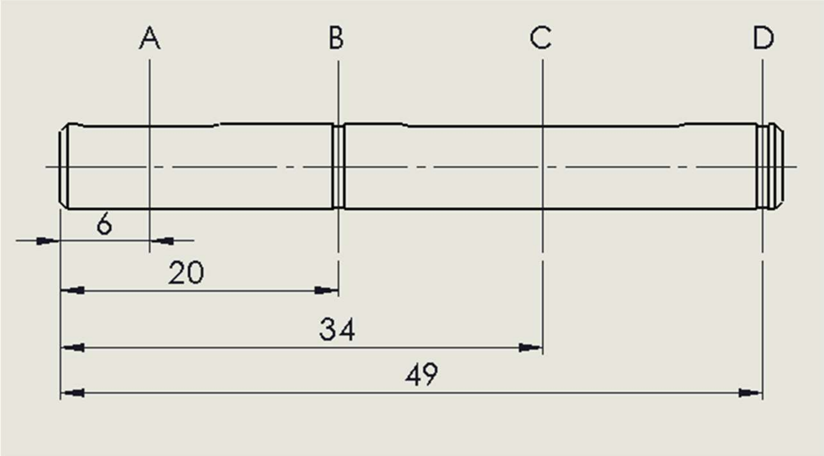


Figure 3.23. Critical sections of the shaft.

Goodman criteria is used, like on equation 3.8.4. Most critical section is D. Equations are the same as before, results are shown in Table 3.25:

Table 3.25.Results for the pinion-rack shaft calculations.

Fr (N)	12,5
Ftg (N)	$\pm 33{,}3$
F (N)	$\pm 35{,}47$
Ma (Nm)	1,2
Ta(Nm)	0,2
Ka	$4{,}51 \cdot Sut^{-0{,}265}$
Kb	1,023
Kc	0,814
Kd	1
Ke	0,45
Se`(MPa)	0,504 Sut
σ_a (MPa)	56,58
τ_a(MPa)	4,71
σ_a^{eq}(MPa)	57,16
Sut(MPa)	785

Material is chosen from Table 3.9. Shaft will be made of steel 1095 Hot Rolled with an ultimate strength, **Sut=830 MPa.**

3.8.4 Bearings.

Ball bearings are calculated using equation 3.9.1 and 3.9.2. Same factors as before.

Feq (N)	47,97
C(kN)	0,012

Ball bearings **SKF 618/6.**

3.8.5 Shaft support.

A plastic support for the shaft is also designed. It is attached to the rails by screws and provides the accommodation for the bear.

4. DESIGN OF MANUFACTURING TECHNOLOGICAL PROCESS FOR THE INPUT SHAFT.

This section defines the technological conditions and operations by which the different parts are achieved. The component selected for this study is the Input Shaft of the gear box.

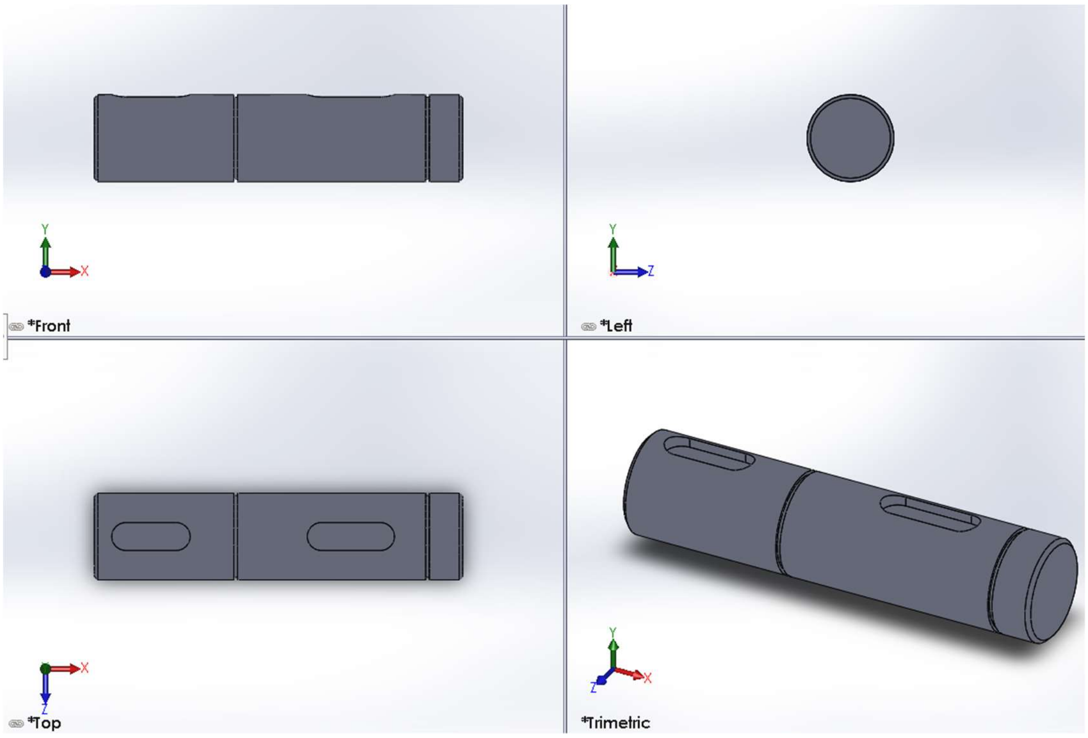


Figure 4.1.Input shaft views.

The shaft is machined from a round bar stock of Steel 4130 tempering at 540 C^{o}, with 55 mm diameter and 265 mm length. The stock presents an offset of material in order to avoid any surface imperfection. Surface roughs values for typical applications are shown on Table 4.1,

Table 4.1. Approximate values of surface roughness for fits.

Table 4.1 Aproximate values of surface roughnes for fits												
Nominal diameter	From 1		6		10		18		80		250	
	To 6		10		18		80		250		500	
ISO quality	Admissible value µm											
	Ra	Rz	Ra	Rz	Ra	Rz	Ra	Rz	Ra	Rz	Ra	Rz
5	0,4	2,5	0,4	2,5	0,8	4	0,8	4	0,8	6,3	0,8	6,3
6	0,8	4	0,8	4	0,8	4	0,8	6,3	1,6	10	1,6	10
7	0,8	6,3	0,8	6,3	0,8	6,3	1,6	10	1,6	16	1,6	16
8	1,6	6,3	1,6	10	1,6	10	3,2	3,2	3,2	25	6,3	40
9	1,6	10	3,2	16	16	3,2	16	16	3,2	25	6,3	40
10	3,2	16	6,3	25	6,3	25	6,3	40	6,3	40	12,5	63
11	6,3	25	12,5	40	12,5	40	12,5	6,3	12,5	6,3	25	100

The final surface roughness of the external surface is Ra=0,8 µm and for the keyways Ra=2 µm.

4.1- **Material.**

References: [25], [26].

Material for the part was chosen before (see section 2.8.1).AISI 4130 steel is a chrome-molybdenum series low alloy steel with high strength, toughness and hardenability. It is usually used in quenched and tempered condition. Chemical composition of the AISI 4130 is presented on Table 4.2.

Table 4.2. AISI 4130 Chemical Composition.

	AISI 4130 Chemical Composition (%)						
Steel Grade (UNS)	C	Si	Mn	P (≤)	S (≤)	Cr	Mo
4130 (G41300)	0.28-0.33	0.15-0.35	0.40-0.60	0.035	0.040	0.80-1.10	0.15-0.25

AISI SAE 4130 alloy steel can be made into steel plate, steel sheet, steel pipe or tube. In this case stock is obtained from a round bar. Material properties are presented on Table 4.3.

Table 4.3.AISI 4130 properties.

Steel (UNS)	Tensile strength (Mpa)	Yield strength (Mpa)	Elongation in 50 mm, %	Reduction in area, %	Hardness (HB)	Sample diameter	Conditions
AISI 4130 (G41300)	670	435	25.5	59.5	197	25mm (1 inch)	Normalized at 870 °C (1600 °F)
	560	460	21.5	59.5	217		Annealed at 865 °C (1585 °F)
	1040	979	18.1	63.9	302		Water quenched from 855 °C (1575 °F) & tempered at 540 °C (1000 °F)

Its high tensile strength allows the shaft to work properly fatigue conditions.

4.2- **Machines.**

References: [27].

Machining process of the shaft consists in turn operations in order to get the revolution shape and in mill operations to get the keyways.

Machining operations are performed on the JYOTI AX 200 Turn-Mill Center. Its specifications are shown on Table 4.4.

Table 4.4. Turn- mill machine specifications.

Capacity		**AX 200**
Swing Over Bed	mm	550
Swing Over Carriage	mm	395
Max. Turning Dia.*	mm	370
Max. Turning Length*	mm	325 | 625
Chuck Dia.	mm	200
Slides		
X-Axis Travel	mm	200
Y-Axis Travel	mm	NA
Z-Axis Travel	mm	325 | 625
Rapid Travel (X, Y & Z - Axis)	m/min	24 / NA / 35
Main Spindle (Motorized)		
Spindle Motor Power (Cont.)-Siemens/Fanuc	kW	9.15
Spindle Nose		A₂6
Max. Bar Capacity	mm	52
Spindle Speed Range	rpm	4500
Sub-Spindle (Motorized)		
Spindle Motor Power (Cont.)-Siemens/Fanuc	kW	NA
Spindle Nose		NA
Spindle Speed Range	rpm	NA
Spindle Travel	mm	NA
Turret		
Turret Type		Servo
No. of Stations		12
Max. Boring Bar Capacity	mm	40
Tool Size (Cross Sectional)	mm	25 x 25
Live Tool Power (Siemens/Fanuc)	kW	NA
Live Tool Speed (Siemens)	rpm	NA
Live Tool Speed (Fanuc)	rpm	NA
Live Tool Type		NA
Tail Stock		
Tailstock Type		Digital
Tailstock Travel	mm	330 | 630
Live Quill Taper		MT 3
Quill Dia.	mm	85
Thrust	kgf	350
Accuracy (As per DGQ 3441)		
Positioning Uncertainty (P)	mm	0.005
Repeatability (Ps Medium)	mm	0.003
Other Data		
Machine Weight #(Approx.)	kg	4100 | 4500
Machine Dimension #(Approx.)		
Length	mm	2610 | 2910
Width	mm	1735
Height	mm	1960

This election is made in order to perform all operations in the same machine, without losing time changing the part between turn and mill machines.

The shaft will be hold by a three jaw chucks in order to get the part`s axis aligned with turn`s rotation axis.

Figure 4.2. Three jaw chucks.

4.3- **Tools and inserts.**

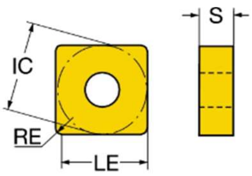
References: [28].

The inserts and the corresponding tools are chosen using Sandvik Tool guide, introducing the values required for each operation.

- ISO SNMG 12 04 12-PR 4325;ISO DSSNR 2020K 12

Specifications presented on Table 4.5 and Table 4.6.

Table 4.5.Insert specifications.



Generic representation

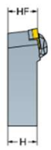
Product data

Material classification level 1 (TMC1ISO) P K	Insert size and shape (CUTINTSIZESHAPE) SN1204
Cutting edge count (CEDC) 8	Inscribed circle diameter (IC) 12.7 mm
Insert shape code (SC) S	Cutting edge effective length (LE) 11.5 mm
Corner radius (RE) 1.1906 mm	Wiper edge property (WEP) false
Hand (HAND) N	Grade (GRADE) 4325
Substrate (SUBSTRATE) HC	Coating (COATING) CVD TICN+AL2O3+TIN
Insert thickness (S) 4.763 mm	Clearance angle major (AN) 0 deg
Weight of item (WT) 0.009 kg	Sensor embedded property (SEP) 0
Life cycle state (LCS) Released	Release pack id (RELEASEPACK) 13.2

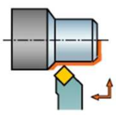
Start values

P	ap 4 mm(1-7) fn 0.41 mm/r(0.26-0.72) vc 315 m/min(380-240)	K	ap 4 mm(1-7) fn 0.41 mm/r(0.26-0.72) vc 160 m/min(200-115)

Table 4.6.Tool specifications.



Generic representation



Generic representation

Product data

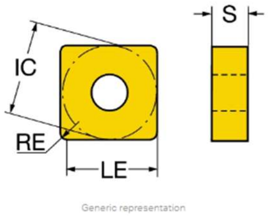
Tool cutting edge angle (KAPR) 45 deg	Tool lead angle (PSIR) 45 deg
Part 2 of cutting item interface identifiers (CUTINTMASTER) SNMG 120408	Adaptive interface machine direction (ADINTMS) Rectangular shank -metric: 20 x 20
Maximum ramping angle (RMPX) 0 deg	Workpiece side body angle (BAWS) 0 deg
Machine side body angle (BAMS) 0 deg	Maximum overhang (OHX) 27.5 mm
Hand (HAND) R	Damping property (DPC) false
Coolant entry style code (CNSC) 0: without coolant	Coolant exit style code (CXSC) 0: no coolant exit
Shank width (B) 20 mm	Shank height (H) 20 mm
Protruding length (LPR) 133.32 mm	Functional length (LF) 125 mm
Functional width (WF) 25 mm	Functional height (HF) 20 mm
Orthogonal rake angle (GAMO) -8 deg	Inclination angle (LAMS) 0 deg
Torque (TQ) 3.9 Nm	Body material code (BMC) Steel
Master insert identification (MIIDM) SNMG 12 04 08	Weight of item (WT) 0.393 kg
Sensor embedded property (SEP) 0	Life cycle state (LCS) Released
Release pack id (RELEASEPACK) 98.1	

Squared insert suitable for external rough turning operations like facing or chamfered.

- ISO SNMG 25 07 24-PR 4325;ISO DSDNN 4040S-25

Specifications presented on Table 4.7 and Table 4.8.

Table 4.7. Insert specifications.



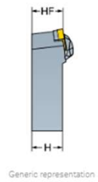
Product data

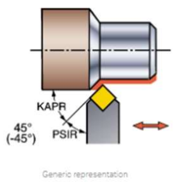
Material classification level 1 (TMC1ISO) P K	Insert size and shape (CUTINTSIZESHAPE) SN2507
Cutting edge count (CEDC) 8	Inscribed circle diameter (IC) 25.4 mm
Insert shape code (SC) S	Cutting edge effective length (LE) 23 mm
Corner radius (RE) 2.3812 mm	Wiper edge property (WEP) false
Hand (HAND) N	Grade (GRADE) 4325
Substrate (SUBSTRATE) HC	Coating (COATING) CVD TICN+AL2O3+TIN
Insert thickness (S) 7.938 mm	Clearance angle major (AN) 0 deg
Weight of item (WT) 0.066 kg	Sensor embedded property (SEP) 0
Life cycle state (LCS) Released	Release pack id (RELEASEPACK) 14.1

Start values

P	ap 6 mm(2-15) fn 1.04 mm/r(0.41-1.24) vc 190 m/min(315-170)	K	ap 6 mm(2-15) fn 1.04 mm/r(0.41-1.24) vc 90 m/min(160-75)

Table 4.8. Tool specifications.





Product data

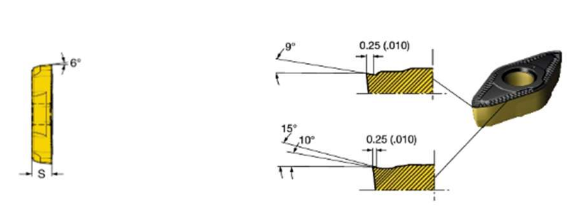
Tool cutting edge angle (KAPR) 45 deg	Tool lead angle (PSIR) 45 deg
Part 2 of cutting item interface identifiers (CUTINTMASTER) SNMG 250724	Adaptive interface machine direction (ADINTMS) Rectangular shank -metric: 40 x 40
Maximum ramping angle (RMPX) 40 deg	Workpiece side body angle (BAWS) 0 deg
Machine side body angle (BAMS) 0 deg	Maximum overhang (OHX) 57.2 mm
Hand (HAND) N	Damping property (DPC) false
Coolant entry style code (CNSC) 0: without coolant	Coolant exit style code (CXSC) 0: no coolant exit
Shank width (B) 40 mm	Shank height (H) 40 mm
Functional length (LF) 250 mm	Functional width (WF) 21 mm
Functional height (HF) 40 mm	Orthogonal rake angle (GAMO) -6 deg
Inclination angle (LAMS) -6 deg	Torque (TQ) 9.5 Nm
Body material code (BMC) Steel	Master insert identification (MIIDM) SNMG 25 07 24
Weight of item (WT) 2.93 kg	Sensor embedded property (SEP) 0
Life cycle state (LCS) Released	Release pack id (RELEASEPACK) 03.1

Squared insert suitable for external rough turning operations.

- ISO CP-B1108-M5 4325; ISO CP-25BR-2020-11

Specifications presented on Table 4.9 and 4.10.

Table 4.9. Insert specifications.



resentation

Generic representation

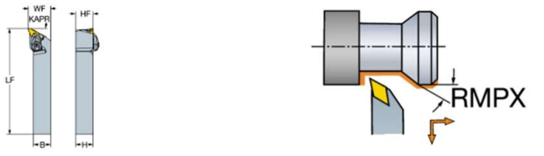
Product data

Material classification level 1 (TMC1ISO): P K	Insert size and shape (CUTINTSIZESHAPE): CoroTurn PRIME CP-B11
Cutting edge count (CEDC): 2	Inscribed circle diameter (IC): 11 mm
Corner radius (RE): 0.8 mm	Wiper edge property (WEP): false
Hand (HAND): N	Grade (GRADE): 4325
Substrate (SUBSTRATE): HC	Coating (COATING): CVD TICN+AL2O3+TIN
Insert thickness (S): 5 mm	Clearance angle major (AN): 6 deg
Weight of item (WT): 0.01 kg	Sensor embedded property (SEP): 0
Life cycle state (LCS): Released	Release pack id (RELEASEPACK): 17.1

Start values

P	ap 2 mm(0.5-4)
	fn 0.59 mm/r(0.31-1.21)
	vc 380 m/min(450-280)

Table 4.10. Tool specifications.



Generic representation

Generic representation

Product data

Tool cutting edge angle (KAPR): 95 deg	Tool lead angle (PSIR): -5 deg
Part 2 of cutting item interface identifiers (CUTINTMASTER): CoroTurn PRIME CP-B (CP-B1108)	Adaptive interface machine direction (ADINTMS): Rectangular shank -metric: 20 x 20
Maximum ramping angle (RMPX): 23 deg	Workpiece side body angle (BAWS): 0 deg
Machine side body angle (BAMS): 0 deg	Minimum overhang (OHN): 37.88 mm
Maximum overhang (OHX): 40 mm	Hand (HAND): R
Damping property (DPC): false	Coolant entry style code (CNSC): 0: without coolant
Coolant exit style code (CXSC): 0: no coolant exit	Shank width (B): 20 mm
Shank height (H): 20 mm	Functional length (LF): 125 mm
Functional width (WF): 25 mm	Functional height (HF): 20 mm
Orthogonal rake angle (GAMO): 0 deg	Inclination angle (LAMS): 0 deg
Torque (TQ): 4 Nm	Body material code (BMC): Steel
Master insert identification (MIIDM): CP-B1108	Weight of item (WT): 0.359 kg
Sensor embedded property (SEP): 0	Life cycle state (LCS): Released
Release pack id (RELEASEPACK): 17.1	

Rhombic shape insert suitable for turn finishing operation.

- ISO N123E2-0200-0002-GM 4325; ISO N123E20-25A 2

Specifications presented on Table 4.11 and 4.12.

Table 4.11. Insert specifications.

Generic representation

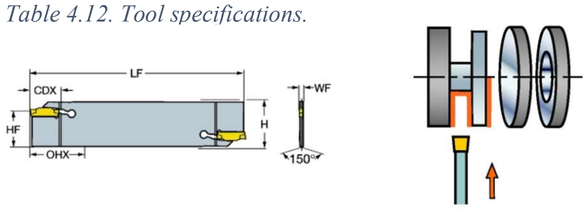
Product data

Material classification level 1 (TMC1ISO)	P K	Chip breaker manufacturer's designation (CBMD)	GM
Insert size and shape (CUTINTSIZESHAPE)	CoroCut 1-2 -size E2	Cutting edge count (CEDC)	2
Cutting width (CW)	2 mm	Cutting width lower tolerance (CWTOLL)	0 mm
Cutting width upper tolerance (CWTOLU)	0.1 mm	Corner radius left (REL)	0.2 mm
Corner radius right (RER)	0.2 mm	Corner radius lower tolerance (RETOLL)	-0.1 mm
Corner radius upper tolerance (RETOLU)	0.1 mm	Cutting depth maximum (CDX)	18.8 mm
Machine side body angle (BAMS)	0 deg	Hand (HAND)	N
Grade (GRADE)	4325	Coating (COATING)	CVD TICN+AL2O3+TIN
Clearance angle major (AN)	7 deg	Length interfering edge (LIG)	19.58 mm
Weight of item (WT)	0.003 kg	Sensor embedded property (SEP)	0
Life cycle state (LCS)	Released	Release pack id (RELEASEPACK)	14.2

Start values

P	fnx 0.07 mm/r(0.05-0.1) vc 250 m/min(290-230)	K	fnx 0.07 mm/r(0.05-0.1) vc 190 m/min(220-175)

Table 4.12. Tool specifications.



Generic representation

Generic representation

Product data

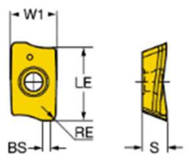
Cutting depth maximum (CDX)	20 mm	Part 2 of cutting item interface identifiers (CU	CoroCut 2 -size E (N123E2-0200-0002-CM)
Insert seat size code (SSCM)	E	Adaptive interface machine direction (ADINTI	Parting off and grooving blade -size 25
Workpiece side body angle (BAWS)	0 deg	Maximum overhang (OHX)	55 mm
Hand (HAND)	N	Coolant entry style code (CNSC)	0: without coolant
Coolant exit style code (CXSC)	0: no coolant exit	Shank height (H)	31.9 mm
Functional length (LF)	150 mm	Functional width (WF)	1.75 mm
Functional height (HF)	25 mm	Weight of item (WT)	0.072 kg
Sensor embedded property (SEP)	0	Life cycle state (LCS)	Released

Insert suitable for grooving operations.

- ISO R390-11 T3 12E-PM 1130; ISO RA390-016M19-11L

  Specifications presented on Table4.13 and 4.14.

Table 4.13. Insert specifications.



Generic representation

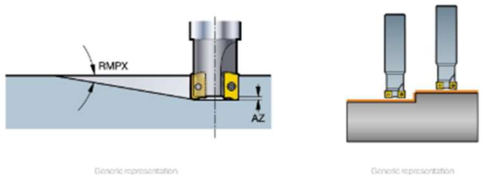
Product data

Material classification level 1 (TMC1ISO)	P M N S H	Insert size and shape (CUTINTSIZESHAPE)	CoroMill 390 -11T3
Cutting edge count (CEDC)	2	Insert width (W1)	6.8 mm
Insert shape code (SC)	L	Cutting edge effective length (LE)	10 mm
Wiper edge length (BS)	0.8 mm	Corner radius (RE)	1.2 mm
Major cutting edge angle (KRINS)	90 deg	Hand (HAND)	R
Grade (GRADE)	1130	Substrate (SUBSTRATE)	HC
Coating (COATING)	PVD ALTICRN	Insert thickness (S)	3.59 mm
Weight of item (WT)	0.002 kg	Depth of cut maximum (APMX)	10 mm
Sensor embedded property (SEP)	0	Life cycle state (LCS)	Released
Release pack id (RELEASEPACK)	15.2		

Start values

P	fz 0.12 mm(0.08-0.2) vc 275 m/min(280-265)	M	fz 0.12 mm(0.08-0.2) vc 265 m/min(270-255)

Table 4.14. Tool specifications



Generic representation

Generic representation

Product data

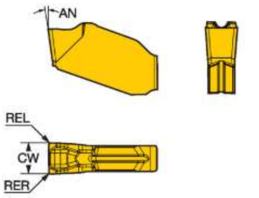
Cutting diameter (DC)	15.875 mm	Cutting item count (CICTTOT)	2
Cutting item count (CICT)	2	Part 2 of cutting item interface identifiers (CUTINTMASTER)	CoroMill 390 -size 11 (R390-11)
Depth of cut maximum (APMXPFW)	10.008 mm	Centre cutting capability (CCC)	false
Depth of cut maximum (APMXFFW)	10.008 mm	Depth of cut maximum (APMXEFW)	5.5 mm
Maximum ramping angle (RMPXFFW)	10.5 deg	Maximum plunge depth (AZ)	1 mm
Usable length (LU)	25.908 mm	Cutting pitch differential (CPDF)	false
Peripheral effective cutting edge count (ZEFP)	2	Adaptive interface machine direction (ADINTMS)	Weldon (DIN6535-HB) -Inch: 3/4
Hand (HAND)	R	Damping property (DPC)	false
Coolant entry style code (CNSC)	1: axial concentric entry	Coolant pressure (CP)	10 bar
Connection diameter (DCON)	19.05 mm	Connection diameter tolerance (TCDCON)	h6
Standard number (STDNO1)	ISO3338-2	Standard letter (STDLET1)	WE
Functional length (LF)	82.55 mm	Torque (TQ)	1.2 Nm
Body material code (BMC)	Steel	Rotational speed maximum (RPMX)	41800 1/min
Weight of item (WT)	0.14 kg	Sensor embedded property (SEP)	0
Life cycle state (LCS)	Released	Release pack id (RELEASEPACK)	98.3

Insert suitable for milling operation.

- ISO QD-NE-0200-0003-CR 1125; ISO QD-NR2E26-25[a]

Specifications presented on Table 4.15 and 4.16.

Table 4.15 Insert specifications.



Generic representation

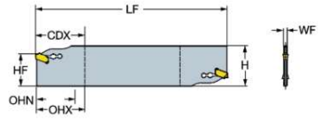
Product data

Material classification level 1 (TMC1ISO) P M K N S	Chip breaker manufacturer's designation (CBMD) **CR**
Insert size and shape (CUTINTSIZESHAPE) **CoroCut QD -size E**	Cutting edge count (CEDC) **1**
Cutting width (CW) **2 mm**	Cutting width lower tolerance (CWTOLL) **-0.05 mm**
Cutting width upper tolerance (CWTOLU) **0.05 mm**	Corner radius left (REL) **0.3 mm**
Corner radius right (RER) **0.3 mm**	Corner radius lower tolerance (RETOLL) **-0.05 mm**
Corner radius upper tolerance (RETOLU) **0.05 mm**	Machine side body angle (BAMS) **0 deg**
Hand (HAND) **N**	Grade (GRADE) **1125**
Coating (COATING) **PVD TIALN**	Clearance angle major (AN) **7 deg**
Weight of item (WT) **0.001 kg**	Sensor embedded property (SEP) **0**
Life cycle state (LCS) **Released**	Release pack id (RELEASEPACK) **13.2**

Start values

P — fnx **0.13 mm/r(0.08-0.28)** vc **160 m/min(210-140)**	M — fnx **0.13 mm/r(0.08-0.28)** vc **130 m/min(170-110)**

Table 4.16. Tool specifications.



Generic representation

Product data

Cutting depth maximum (CDX) **26 mm**	Part 2 of cutting item interface identifiers (CUTINTMASTER) **CoroCut QD -size E (QD-NE-0200-0002-CM)**
Insert seat size code (SSCM) **E**	Adaptive interface machine direction (ADINTMS) **Parting off and grooving blade -size 25**
Workpiece side body angle (BAWS) **0 deg**	Minimum overhang (OHN) **26 mm**
Maximum overhang (OHX) **50 mm**	Hand (HAND) **R**
Coolant entry style code (CNSC) **0: without coolant**	Coolant exit style code (CXSC) **0: no coolant exit**
Shank height (H) **31.9 mm**	Functional length (LF) **150 mm**
Functional width (WF) **2.6 mm**	Functional height (HF) **25 mm**
Weight of item (WT) **0.071 kg**	Sensor embedded property (SEP) **0**
Life cycle state (LCS) **Released**	Release pack id (RELEASEPACK) **13.2**

4.4- **Machining process.**

References: [28], [29].

The machining process begins in the turn machine, following the next steps:

- Face rough of 4 mm.
- Turn rough of 51 mm diameter and 215 mm length.
- Turn finish of 50 mm diameter and 215 mm length.
- 2xGroove of 47 mm diameter and 2,15 mm length.

After using the turn machine, the shaft is finished on the mill machine:

- Groove of the keyways.

Finally, the shaft is part off the stock bar.

4.4.1 **Operation 1: Rough facing.**

First operation is the facing of both sides of the initial stock. In order to choose the rotational speed of the turn machine next formula is used:

$$Vc = \frac{Dm \cdot \pi \cdot n}{1000} \quad \textbf{(4.4.1.)}$$

Where Vc: cutting speed; n:rotational speed.

The cutting speed Vc is obtained from the corresponding insert table. When n is calculated (must be less than the maximum speed of the machine, 4500 rpm in this case), machining time is obtained from next formula:

$$Tc = \frac{l}{fn \cdot n} \quad \textbf{(4.4.2)}$$

Where Tc: machining time; l: machined length; fn:feed per revolution.

Feed per revolution value is also obtained from insert table. Choosing the recommend values of fn and Vc and respecting the maximum value of rotational speed , Table 4.17 is completed for each operation. Where ap is depth of cut in mm.

Table 4.17. Op1: Rough facing.

OPERATION 1:ROUGH FACING						**INSERT**	SNMG 12 04 12-PR 4325
						TOOL	ISO DSSNR 2020K 12
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	4	1500	-	55	0,41	259,05	0,390243902

4.4.2 **Operation 2: Rough turning Ø51x215 .**

Machining parameters presented on Table 4.18.

Table 4.18 .Op2: Rough Turning 51x215.

OPERATION 2:ROUGH TURNING Ø51x215						**INSERT**	SNMG 25 07 24-PR 4325
						TOOL	DSDNN 4040S-25
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	215	1250	2	55	1,04	215,875	9,923076923

4.4.3 **Operation 3: Finishing Ø50x215.**

Machining parameters presented on Table 4.19

Table 4.19 .Op3: Finishing 50x215.

OPERATION 3:FINISIHING Ø50x215						**INSERT**	CP-B1108-M5 4325
						TOOL	CP-25BR-2020-11
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	215	2250	0,5	51	0,59	360,315	9,717514124

4.4.4 **Operation 4: 2xGroove 2,15x1,5.**

Machining parameters presented on Table 4.20.

Table 4.20 .Op4:Groove.

OPERATION 4:2xGROOVE 2,15x1,5.						**INSERT**	N123E2-0200-0002-GM 4325
						TOOL	N123E20-25A 2
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	2	1530	1,5	50	0,07	240,21	1,120448179
2	0,15	1530	1,5	50	0,103	240,21	0,057110223

4.4.5 **Operation5: Milling keyway 16x6x50.**

Machining parameters presented on Table 4.21.

Table 4.21. Milling keyway 16x50.

OPERATION 5:MILLING KEYWAY 16x6x50			**INSERT**	R390-11 T3 12E-PM 1130
			TOOL	RA390-016M19-11L
Pass	n(rpm)	ap(mm)	fz(mm)	Vc(m/min)
1	3910	2,47	0,0992	195
2	3910	4,94	0,124	195
3	4470	0,0625	0,25	200
4	4410	5	0,32	220
5	4470	0,0625	0,312	200

4.4.6 **Operation 6:Milling keyway 16x6x45.**

Machining parameters presented on Table 4.22.

Table 4.22 Milling keyway 16x45.

OPERATION 6:KEYWAY 16x45			**INSERT**	R390-11 T3 12E-PM 1130
			TOOL	RA390-016M19-11L
Pass	n(rpm)	ap(mm)	fz(mm)	Vc(m/min)
1	3910	2,47	0,0992	195
2	3910	4,94	0,124	195
3	4470	0,0625	0,25	200
4	4410	5	0,32	220
5	4470	0,0625	0,312	200

4.4.7 **Operation 7: Parting off .**

Machining parameters presented on Table 4.23.

Table 4.23 Parting off.

OPERATION 7:PARTING OFF						**INSERT**	QD-NE-0200-0003-CR 1125
						TOOL	QD-NR2E26-25A
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	2	1000	25	50	0,13	157	0,923076923

After the machining, a quality control process is carried out.

5. COMPOSING OF THE WORK SAFETY AND ENVIRONMENTAL PROTECTION REQUIREMENTS FOR OBJECT DESIGNED.

5.1- Work safety.

Considering that the system presented in this paper is designed for elderly people or with mobility problems, safety is a crucial part of the design.

- The system is designed to work properly with people until 160 kg.
- The electric motors are programmed to work at constant slow speed, in order to avoid high speed or accelerations, which could be dangerous for the user.
- All parts have been designed with a safety coefficient.
- Back`s Lift cannot rotate more than 90 degrees to prevent possible back injuries or other risk situations.
- All sharp edges have been fillet.
- There are not any electric cables.
- All parts are attached by joints, no free parts.
- Keep out of reach of children.

5.2- Instructions guide.

- Once user is laid on bed , the Back`s Lift can be activated.

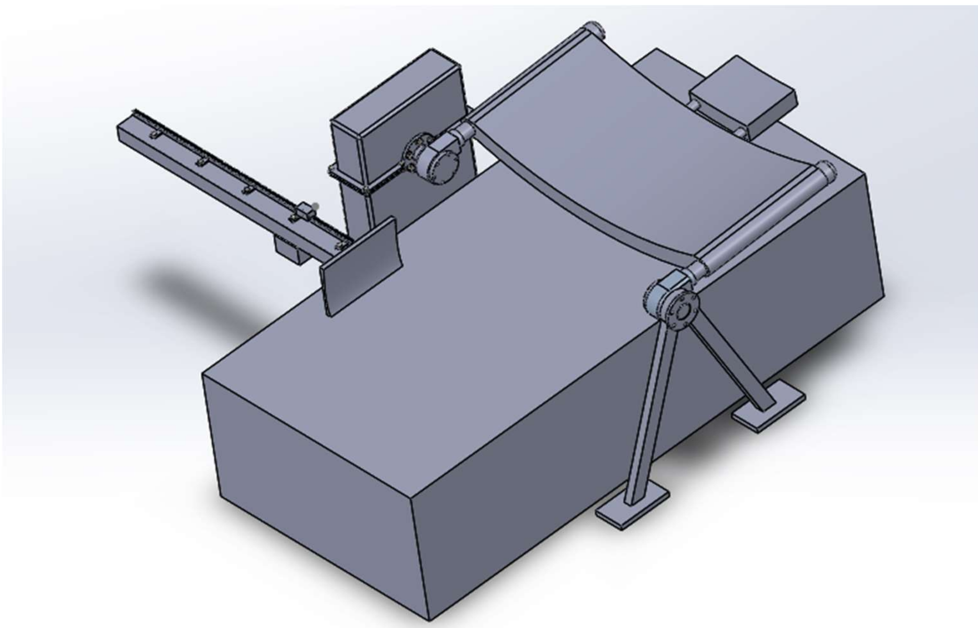


Figure 5.1. Initial position.

- It can rotate any degree until 90. User can get a comfortable position for reading a book, watch television or have lunch while using the system.

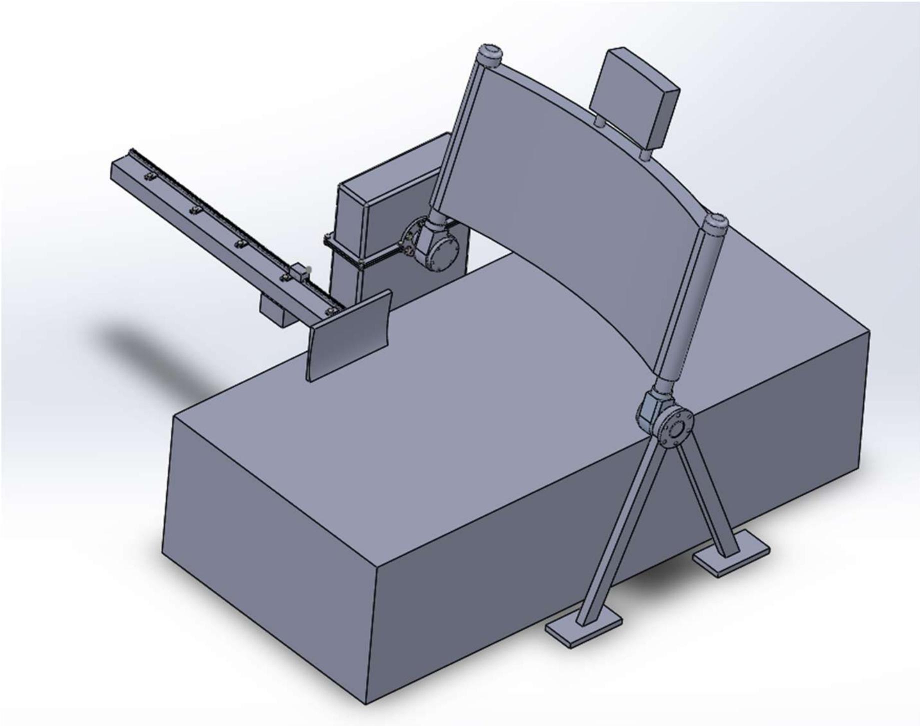


Figure 5.2. Back`s lift can rotate any degree until 90º.

- When the Back`s lift it is in the final position, user can activate the Legs Pusher system.

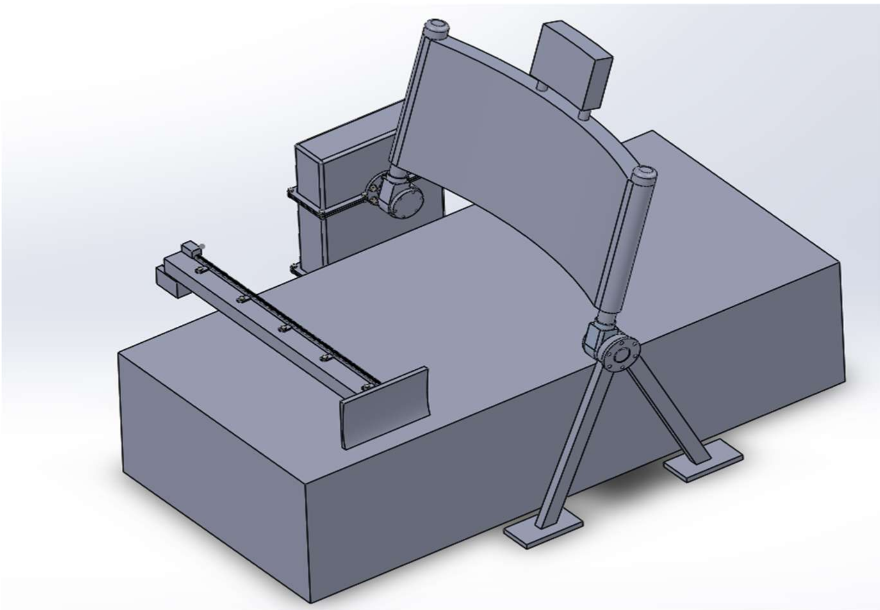


Figure 5.3.Final position.

- When user is sit on the edge of bed, it is possible to get the system back to the initial position in order to be more comfortable and ease next movements.

5.3- **Environmental protection.**

Nowadays, global warming and climate change are common words in the vocabulary, and it is necessary to make changes in daily people live. This complicate situation it has been considered in the design.

- The system designed in this paper does not require of fossil fuels, energy for the electric motors can be obtained from a generator or the user`s house.
- The whole system only needs electricity to work. Shafts are supported by ball bearings and the lubrication of the gear is renewed in the maintenance time. Maintenance is necessary every 2 years.
- The system is designed to by easily assembled and disassembled when needed and get to the components fast and safely.
- Acoustic contamination is minimum. The noise is only produced when the machine is working, but the exposure time is short and harmless for the human body. This noise is produced mainly for the electric motor and the gear system. The system doesn't make noise while it is not been used.
- All components have been obtained with environmentally friendly procedures when possible.
- When the machine or any of its components are broken, worn or have reached the end of their expected lifespan and can no longer be used or repaired, they must be scrapped and disposed of in an appropriate manner.

6. ECONOMICAL ESTIMATION OF THE PROJECT.

6.1- Project cost calculation.

In this section the cos of producing one unit of the system is calculated, including the product design expenses and the means needed for manufacturing and construction.

Table 6.1.Standards parts costs.

Nr	Item	Q.	Price per unit (Eur)	Sum (Eur)
1	DIN EN 24018 - M8 x 25-WC	25	0,11	2,75
2	Hexagon Flange Nut DIN 6923 - M8 - C	25	1,05	26,25
3	KEY A 16X10X50 DIN 6885	2	1,35	2,70
4	Plain Washer M12 ISO 7089	12	0,61	7,32
5	DIN EN 24018 - M12 x 45-WC	12	0,37	4,42
6	Hexagon Flange Nut DIN 6923 - M12 - C	12	2,62	31,44
7	KEY A 16X10X65 DIN 6885	2	1,54	3,08
8	ISO 7046-1 - M6 x 20 - Z - 20N	12	0,52	6,20
9	ISO 7046-1 - M8 x 20 - Z - 20N	6	0,65	3,88
10	ISO 4018 - M10 x 30-WN	2	0,70	1,40
11	ISO - 4034 - M10 - N	2	0,29	0,58
12	KEY A 2X2X20 DIN 6885	1	0,40	0,40
13	Circlip DIN 471 - 6 x 0.7	2	0,12	0,24
14	Plain Washer M8 ISO 7089	25	0,29	7,20
15	Circlip DIN 471 - 50x 2	2	1,92	3,84
16	Circlip DIN 471 - 55x 2	2	2,24	4,48
			Total (eur)	106,18

Table 6.2.Stock parts costs.

Nr	Item	Description	Weight(kg)	Price per kg (Eur)	Sum (Eur)
1	Steel AISI 4130 tempering at 540 °c	55x265	0,51	2,20	1,11
2	Steel AISI 4130 tempering at 540 °c	60x265	0,67	2,20	1,48
3	Steel AISI 1095 HR	10x60	0,00	1,20	0,00
4	ASTM 25 Grey-cast iron		24,00	0,94	22,56
5	PP Copolymer		6,66	0,24	1,60
6	AISI 1015 CD	CHS 50.4 Profile	0,33	0,91	0,30
7	AISI 1015 CD	Square bar 120 mm	0,77	0,91	0,70
				Total (eur)	27,75

Table 6.3. Catalogue parts costs

Nr	Item	Q.	Price per unit (Eur)	Sum (Eur)
1	SKF Ball Bearing 61910	2	46,30	92,60
2	Spur gear 1M 12T	1	7,21	7,21
3	Spur gear 4M 65T	1	92,16	92,16
4	Spur gear 4M 100T	1	131,81	131,81
5	SKF Ball Bearing 61911	2	55,61	111,22
6	SKF Ball Bearing 618/6	2	6,14	12,28
7	Rack	1	39,63	39,63
8	Mellor Electric USBD1106	1	72,22	72,22
9	ZD Motor	1	136,74	136,74
			Total (eur)	695,87

Total cost of the supplies is 829,8 Eur.

Transportation costs can be calculated as the 10% of the supplies costs.

$$Ct = Ps \cdot 0,1 \qquad \textbf{(5.1.1)}$$

Where Ct are the transportation costs, Eur; Ps are the supplies costs, Eur.

Ct=82,98 Eur**.**

Total costs of supplies will be **Cs=912,78 Eur**.

The necessary equipment for manufacturing and construction will be hired for two weeks. Except casting process of the grey cast iron and plastic parts, that will be carried out by sub-contractors. Equipment costs are presented on Table 6.4.

Table 6.4.Equipment costs.

Nr	Equipment (including transportation)	Price (Eur/year)
1	CNC JYOTI AX 200Turn-Mill Center	2000
3	Drill IBARMIA A35	1850
4	Inspection tools	60
5	Tools and consumables	400
	Total(Eur)	4310

The approximate costs of the manufacturing tasks, labour included, for the manufacturing of one unit are shown in Table 6.5.

Table 6.5. Manufacturing costs.

Nr	Task	Price(Eur)
1	Turning	30
2	Milling	80
3	Drilling	50
4	Casting	500
5	Assembling	40
	Total	700

Consumables needed for the system to work properly are in table 6.6. Price for 2 weeks.

Table 6.6. Consumables costs.

Nr	Item	Price (Eur)
1	Gear Lubricants	100
2	Greases for bearings	100

A local is rented in order to manufacture the product. Its costs are shown in Table 6.7.

Table 6.7. Workspace costs.

Nr	Item	Price (Eur/month)
1	Local renting	2000
2	Electricity costs	400
3	Others	300
	Total	2700

Some previous works are carried out on the workspace before manufacturing starts. Costs shown on Table 6.8.

Table 6.8. Previous works costs.

Nr	Item	Price (Eur/year)
1	Coordination costs	200
2	Workshop tuning	600
3	Machines tuning	400
4	Personal protective equipment	200
5	Unanticipated additional costs	1000
	Total(Eur)	2400

The total project cost will be:

$$CT = Cs + Ce + Cm + Cc + Cw + Cwp \qquad \textbf{(6.1.2)}$$

Where Ce are the equipment costs, Eur; Cm are the manufacturing costs per unit, Eur; Cc are the consumables costs, Eur; Cw are the workspace costs,Eur; Cwp, are workspace previous works,Eur.

CT=11222,78 Eur.

The net profit per unit will be approximately the 20% of the unit cost:

$$Np = Cu \cdot 0{,}2 \qquad \textbf{(6.1.3)}$$

Np=2244,55 Eur.

The market price of the product will be **P=13467,33 Eur.**

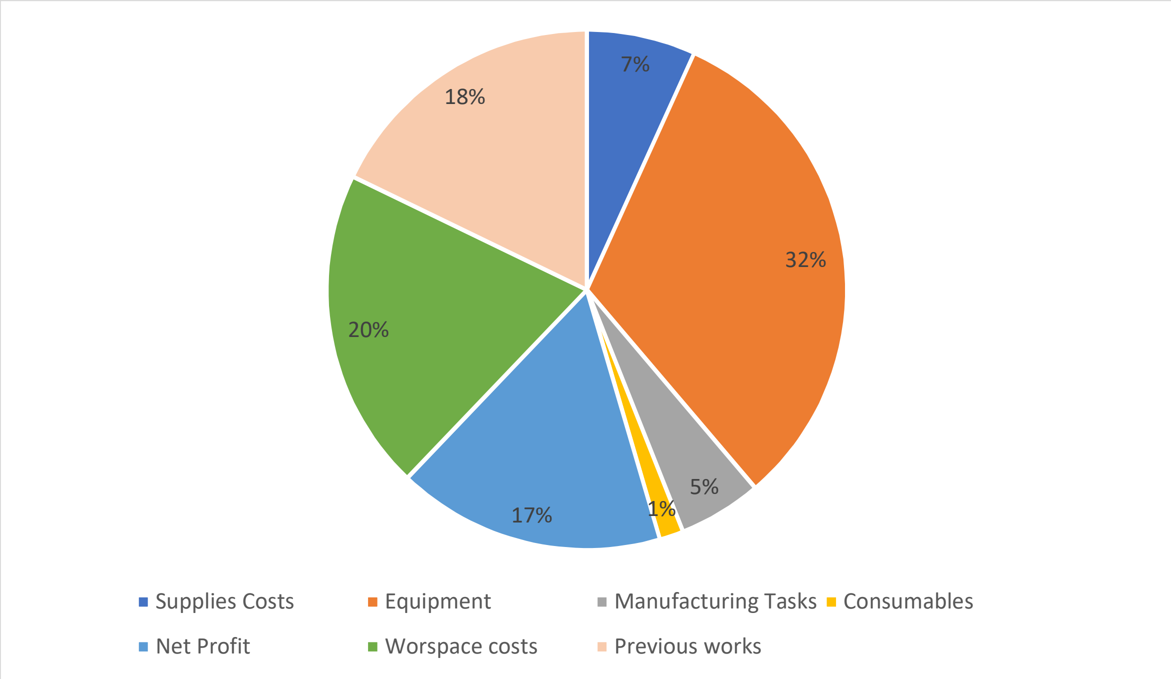


Figure 6.1. Pie chart of costs per unit.

6.2- Break even point calculation.

Firstly, is needed to separate the fixed and variable costs, like shown on Table 6.8. Fixed costs related to equipment is calculated like the depreciation costs related to the equipment.

$$D = \frac{Ce}{t} \quad \textbf{(6.1.4)}$$

Where D is depreciation cost, Eur; t is time of usage, it is supposed t=5 years.

Table 6.9. Fixed and variable costs.

Fixed Costs		Variable Costs	
Depreciation of equipment	862 Eur	Material	912,78 Eur
Consumables	200 Eur	Manufacturing	700 Eur
Workspace total costs	5100 Eur		

Then this formula is used:

$$Op = P \cdot Q - Vc \cdot Q - Total\ Fc \quad \textbf{(6.1.5)}$$

Where Op is the operating profit ,Q is quantity of units; Vc are the variable costs per unit, Eur; Fc are the fixed costs per unit. Eur.

Breakeven point indicates when the product start to be profitable. In order to calculate how many units are needed to be produced and sold in the period specified, two weeks. Operating profit is set to zero and Q is calculated. Providing a value of Q=0,52. In one year is necessary to product **14 units** of the product.

6.3- Payback period.

Initial investment for the project will be of 150.000 Eur (including designing costs, taxes, consultancy, marketing).Payback period is calculated following next formula:

$$Pp = \frac{IV}{Ppr} \quad \textbf{(6.3.1)}$$

Where Pp is payback period, years; IV is initial investment, Eur; Ppp is profit per year, Eur.

To calculate profit per year, first is necessary to calculate EBIT, Earning before interest and taxes, which is calculated by:

$$EBIT = P - Vc - Fc \quad \textbf{(6.3.2)}$$

EBIT=5692,55 Eur. This is the earnings for two weeks. In one year, total profit will be:

$$5692{,}55 \frac{€}{2\ weeks} \cdot 52 \frac{weeks}{year} = 148006{,}3 \frac{Eur}{year} \quad \textbf{(6.3.3)}$$

Replacing on formula 6.3.1 Payback period=1,01 years=**12,16 months.**

Figure 6.2. Payback period`s graphic.

Almost in one year the product becomes profitable.

7. CONCLUSIONS AND RECOMMENDATIONS.

The initial conception of this project comes from the idea of trying to improve dependent people`s life by designing a system that helps them to get up from bed . Like it is mentioned on the literature review, it already exists systems like transfer cranes which help dependant people to move from bed to another place, but always requiring another person`s help to manage the crane.

- System designed can be managed by the patient himself.
- It does not need previous works to be installed.
- It can be adaptable to different beds and person size.
- It can be portable.
- The system can work until 160 kg.
- In 26 seconds can put a person in a sitting position.

These objectives have been achieved by designing two independent machines managed by a remote control.

Some improvements can be done in future projects related:

- Shafts have been studied in a fatigue case, not in a static one like it was done with the arm. Static study could be done to the shafts with a more restrictive criteria than the Von-Misses one, which is more optimistic than others.
- Back's design can be more ergonomic doing a proper anthropometric study.
- Back could move out of bed in order to allow user to sleep more comfortable.
- Protective casing could be lighter improving its design and making it thinner.
- Wheels could be added in order to ease system`s displacement.
- Costs could be reduced by mass production and doing better materials study.

ANNEXES

Format	Zone	Position	Marking	Name	Quantity	Remark
				Documentation		
A1			MBP 20 00 01 00 000 GD	General view		
				Subassemblies		
A1			MBP 20.00.01.01.000 AD	Gear Box		
			MBP 20.00.01.02.000	Back`s Lift		
			MBP 20.00.01.03.000	Pinion system		
			MBP 20.00.01.04.000	Rack system		

MBP 20 00 01 00 000 GD			
General view	Litera	Page	Pages
		1	1
	VGTU MPfuc-16		

Format	Zone	Position	Marking	Name	Quantity	Remark
				Documentation		
A1			MBP 20.00.01.01.000 AD	Assembly drawing		
				Subassemblies		
A1			MBP 20.00.01.01.000 AD	Gear Box		
				Parts		
		1		BOTTOM PROTECTIVE CASING	1	
		2		INPUT SHAFT	1	
		3		MIDDLE PROTECTIVE CASING	1	
		4		OUTPUT SHAFT	1	
		5		TOP PROTECTIVE CASING	1	
A3		10	MBP 20.00.01.01.010	INPUT SHAFT COVER	1	
		11		OUTPUT SHAFT COVER	1	
				Standard parts		
		6		DIN EN 24018 - M8 x 25-WC	16	
		7		HEXAGON FLANGE NUT DIN 6923 - M8 - C	16	
		8		PLAIN WASHER M8 ISO 7089	16	
		9		KEY A 16X10X50 DIN 6885	2	
		12		ISO - SPUR GEAR 4M S65A75H50L50	1	
		13		ISO - SPUR GEAR 4M S100A75H50L55	1	
		14		PLAIN WASHER M12 ISO 7089	16	
		15		DIN EN 24018 - M12 x 45-WC	12	
		16		Hexagon Flange Nut DIN 6923 - M12 - C	12	
		17		ISO 15 RBB - 2250	2	
		18		ISO 15 RBB - 2255	2	
		19		Circlip DIN 471 - 50 x 2	2	
		20		Circlip DIN 471 - 55 x 2	2	
		21		Fill Plug SKF 487016000	1	

MBP 20 00 01 01 000 AD

Asembly drawing	Litera	Page	Pages
		1	1

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List of tables.

List of figures.

LIST OF REFERENCES.

[1] H. P. Barthelt, “HOSPITAL BED WITH ELECTRIC”. United States Patent US 2010/0064441 A1, 18 March 2010.

[2] F. J. Burst and J. S. Adams, “DOUBLE INSULATED ELECTRIC HOSPITAL BED”. United States Patent 3,633,225 , 11 January 1972.

[3] A. Corell Dolz, “Nuevos conceptos en el desarrollo de gruas de transferencia,” *Revista de biomecanica,* pp. 13-15, 2000.

[4] I. Ghersi, M. Mariño and M. T. Miralles, “From Modern Push-Button Hospital-beds to 20th Century Mechatronic Beds: A Review,” *Journal of Physics: Conference Series,* 2016.

[5] C. C. Lo, S. H. Tsai and B. S. Lin, “Novel non-contact control system of electric bed for medical healthcare,” *Medical and Biological Engineering and Computing,* pp. 517-526, 2017.

[6] W. J. Peterson, “ELECTRIC HOSPITAL BED”. United States Patent 3,710,404, 16 January 1973.

[7] TECNUM AGILITY S.L, “tecnum.net,” [Online]. Available: http://www.tecnum.net/gruas.htm. [Accessed 29 March 2020].

[8] H. Tominaga, “HEIGHT ADJUSTING LIFTER FOR”. Japan Patent 4,556,198, 3 December 1985.

[9] H. Yamamoto and M. Kurita, “CONTROL DEVICE FOR A HOSPITAL BED”. Japan Patent 4,609,854, 2 September 1986.

[10] L. Eglitis, “worlddata.info,” [Online]. Available: https://www.worlddata.info/average-bodyheight.php. [Accessed 2020].

[11] S. Camalan, R. Maskeliunas and R. Damasevicius, “GENDER DETECTION USING 3D ANTHROPOMETRIC MEASUREMENTS,” *METROLOGY AND MEASUREMENT SYSTEMS,* vol. 25, no. 2, pp. 253-267, 2018.

[12] F. J. Llaneza Alvarez, Ergonomia y psicosociologia aplicada, Lex Nova, 2006.

[13] J. C. Garcia Prada, Problemas resueltos de Teoría de Maquinas y Mecanismos., Paraninfo, 2007.

[14] M. Herraez y F. Romano, Apuntes de Diseño de Maquinas, Universidad de Valladolid.

[15] R. C. Juvinall, Diseño de elementos de máquinas, Limusa, 2013.

[16] J. E. Shigley y C. R. Mischke, Mechanical Engineering Design, Mc Graw Hill.

[17] S. R. Schmid y B. J. Hamrock, Fundamentals of Machine Elements, CRC Press .

[18] G. Henriot, Traité théorique et pratique des engrenages., Dunod , 2013.

[19] A. Lamadrid, . Cinemática y dinámica de máquinas., Universidad Politécnica de Madrid, 1992.

[20] R. L. Matt, Machine elements design., Pearson-Prentice Hall, 2006.

[21] R. L. Norton, Machine Design: an integrated approach., 5th ed., Prentice Hall, 2014.

[22] S. R. Schmid, Fundamentals of machine elements., CRC Press, 2014.

[23] D. Blanco, J. Cebrian and M. Garcia, “Reto B Portico,” Armeria Eskola, [Online]. Available: https://sites.google.com/site/retobportico/pinon-cremallera. [Accessed 2020].

[24] Cejarosu, “MecanESO,” 2005. [Online]. Available: http://concurso.cnice.mec.es/cnice2006/material107/mecanismos/mec_cremallera-pinon.htm.

[25] P. M. Saenz, “Acabado Superficial,” CCS/ASTIN, 1997.

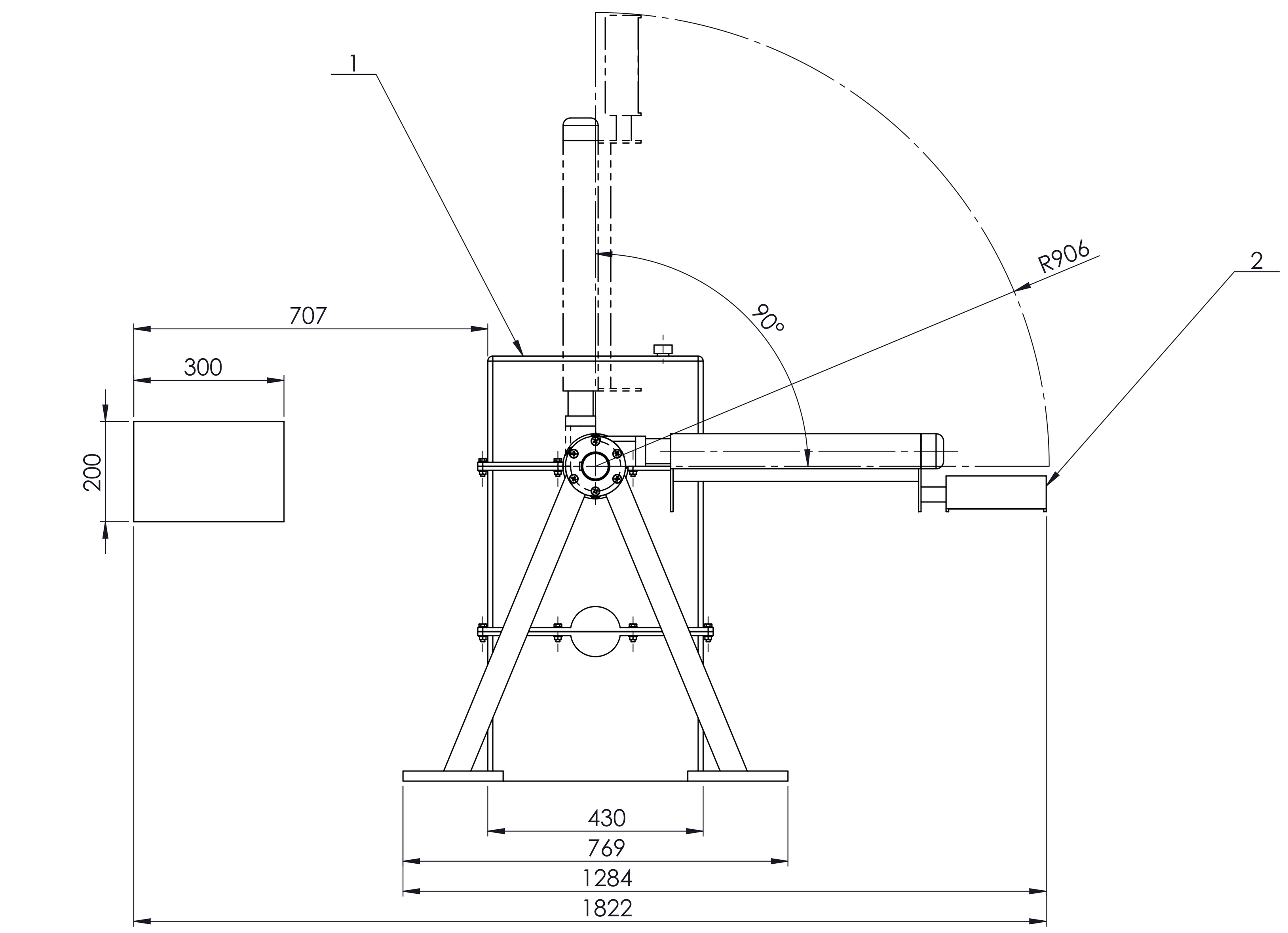
[26] «The World Material,» 2020. [En línea]. Available: https://www.theworldmaterial.com/sae-aisi-4130-chromoly-steel-alloy-material/. [Último acceso: 2020].

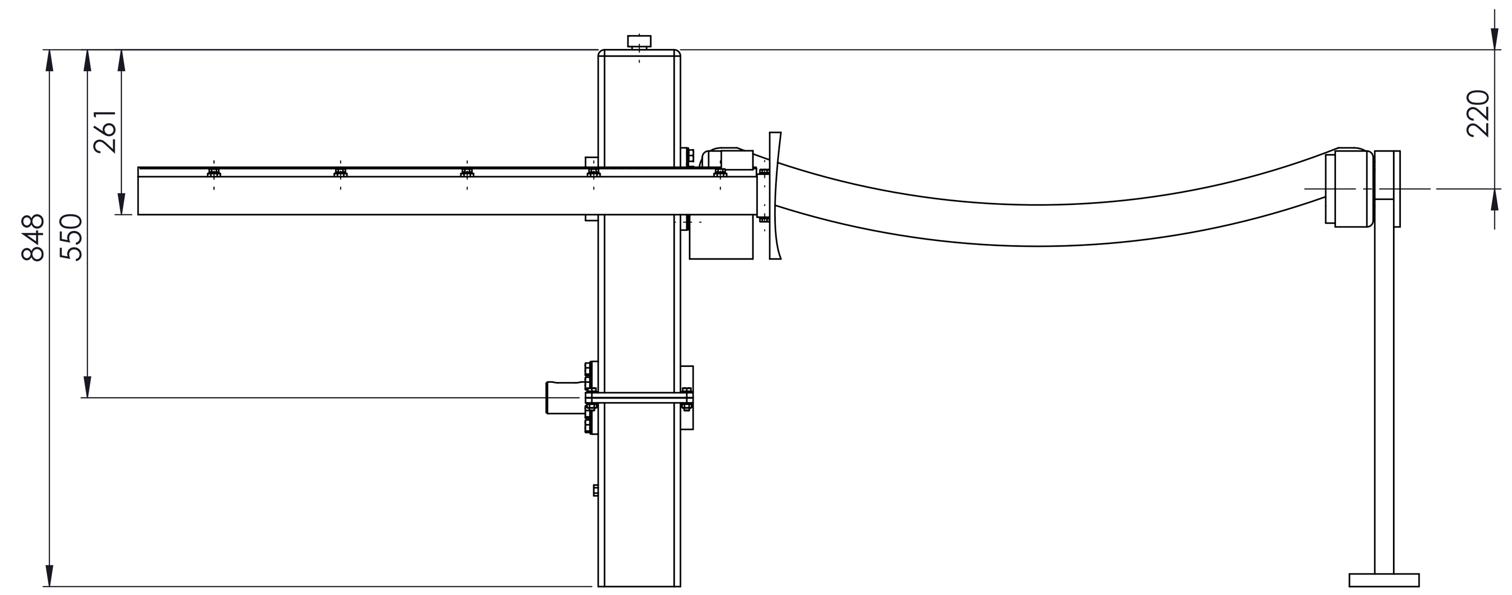
[27] Jyoti, «Jyoti.co,» 2015. [En línea]. Available: http://jyoti.co.in/wp-content/uploads/2015/03/AX%20Series.pdf. [Último acceso: 2020].

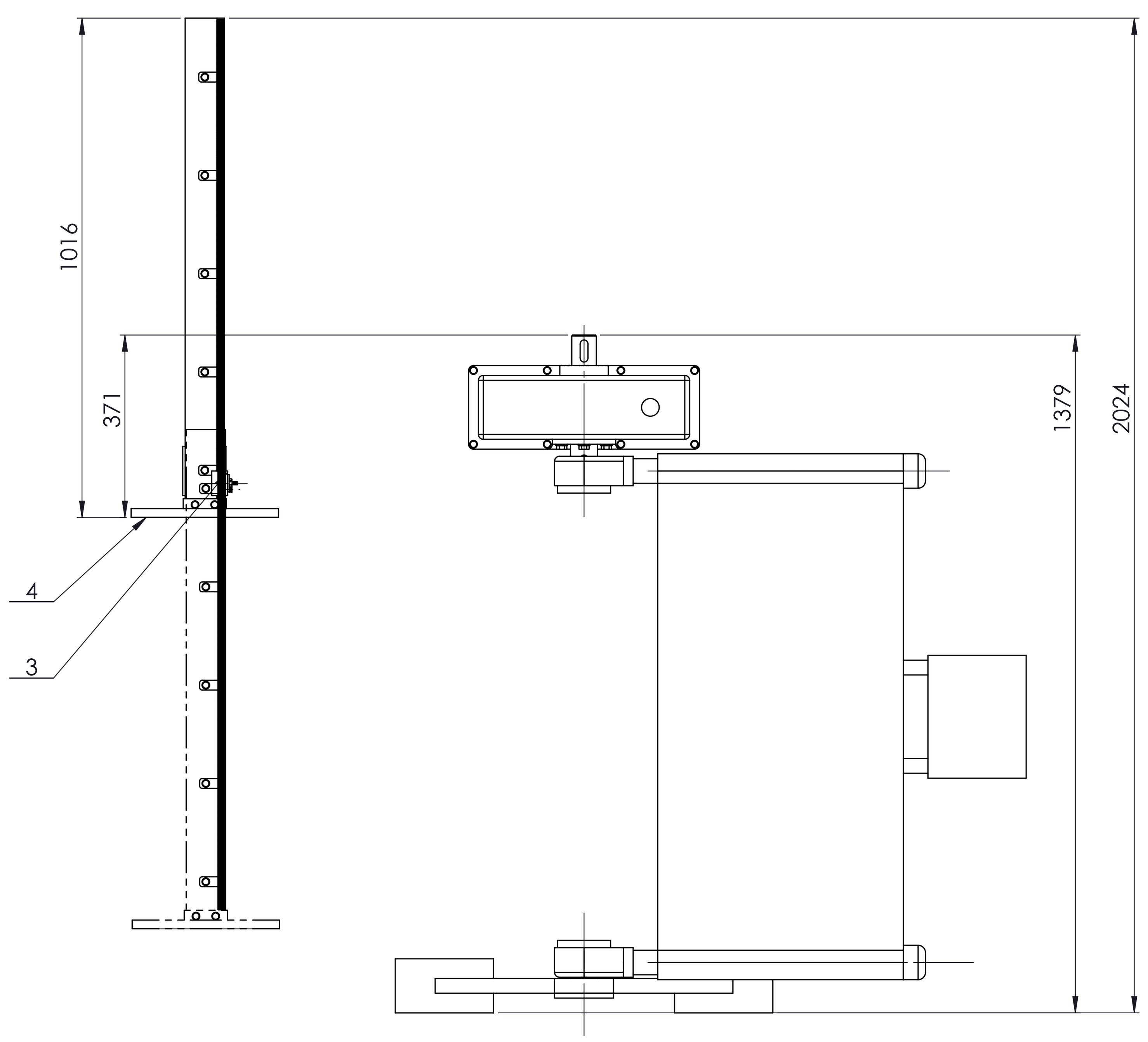
[28] Sandvik Coromant, «sandvik.coromant.com,» [En línea]. Available: https://www.sandvik.coromant.com/es-es/products/pages/toolguide.aspx. [Último acceso: 2020].

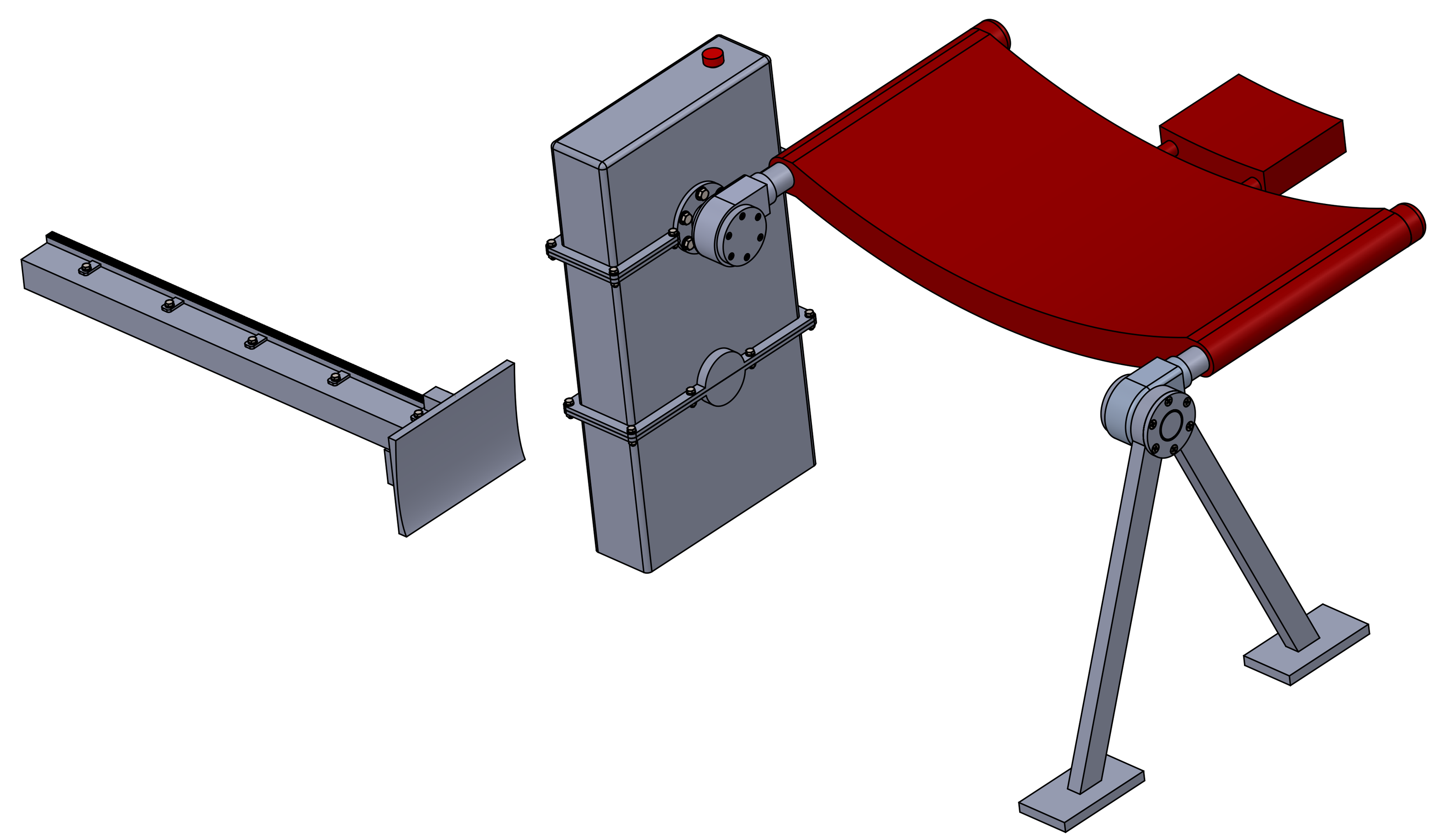
[29] P. Coca and J. Rosique, Tecnología mecánica y metrotecnia., Piramide, 2002.

[30] S. Teruel Pardo, “Diseño y calculo de un reductor de velocidad.,” Universidad Politecnica de Valencia., 2016.









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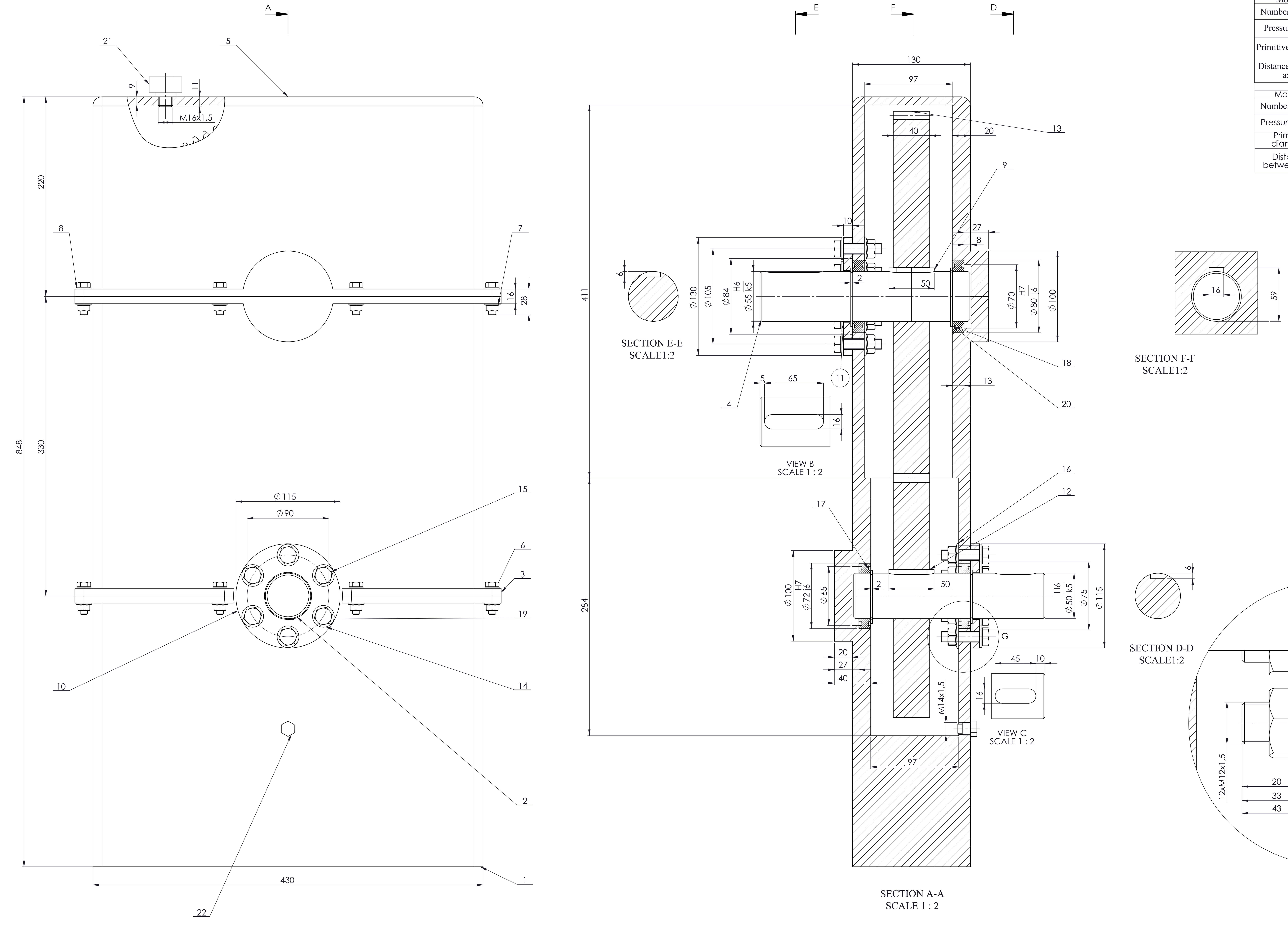
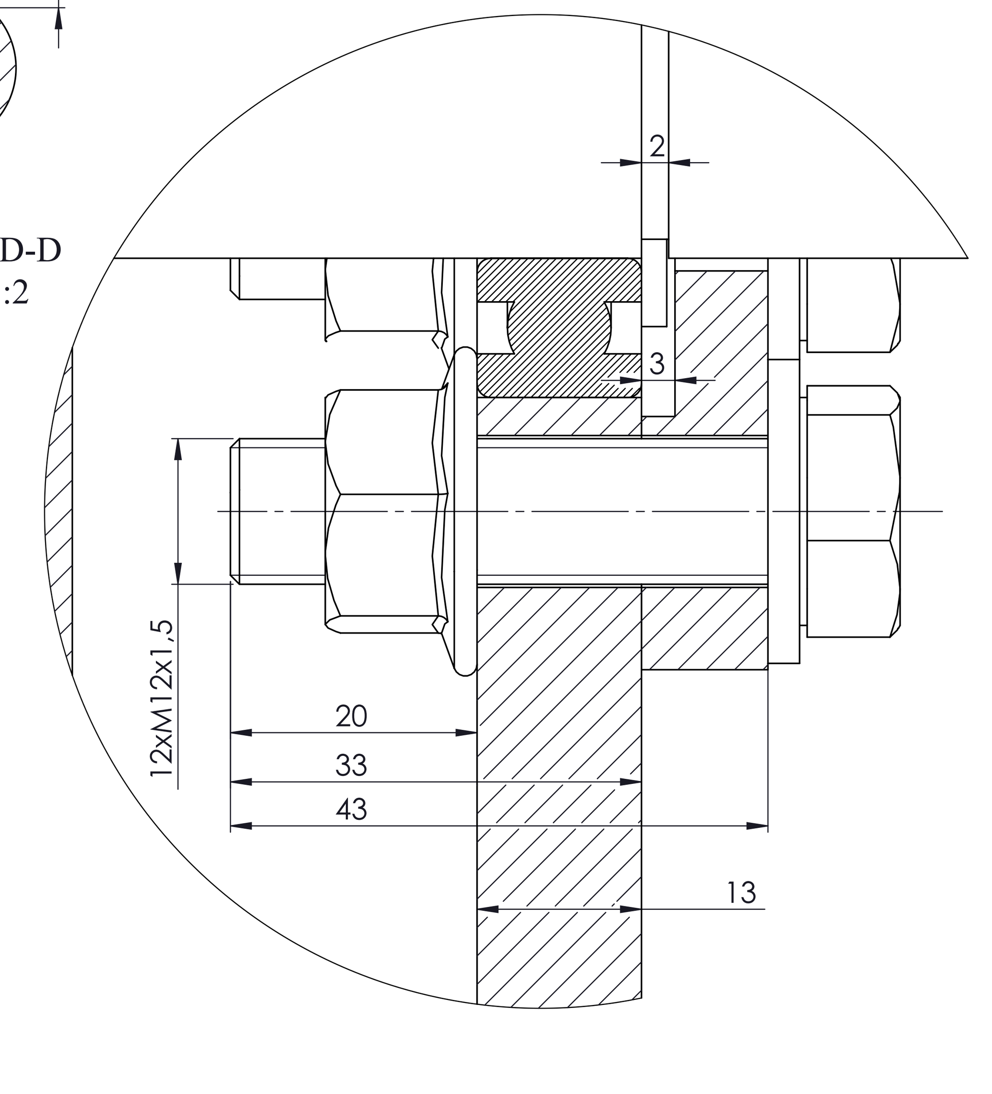
Resp. Dep. Inz. gr. k-dra	Consultant	Document type: General view drawing		Document Status Educational
Owner VGTU Mpfuc-16	Compiled by Carlos Izquierdo Checked Paulius Ragauskas	Title General view		Drawing nr: MBP 20 00 01 00 000 GD Rev A · Date 2020.01.06 · Lan en · Page 1/9

DATA SHEET GEAR ISO 100		
Module	m	4
Number of teeth	Z	100
Pressure angle	a	20º
Primitive diameter	dp	400
Distance between axis	C	330

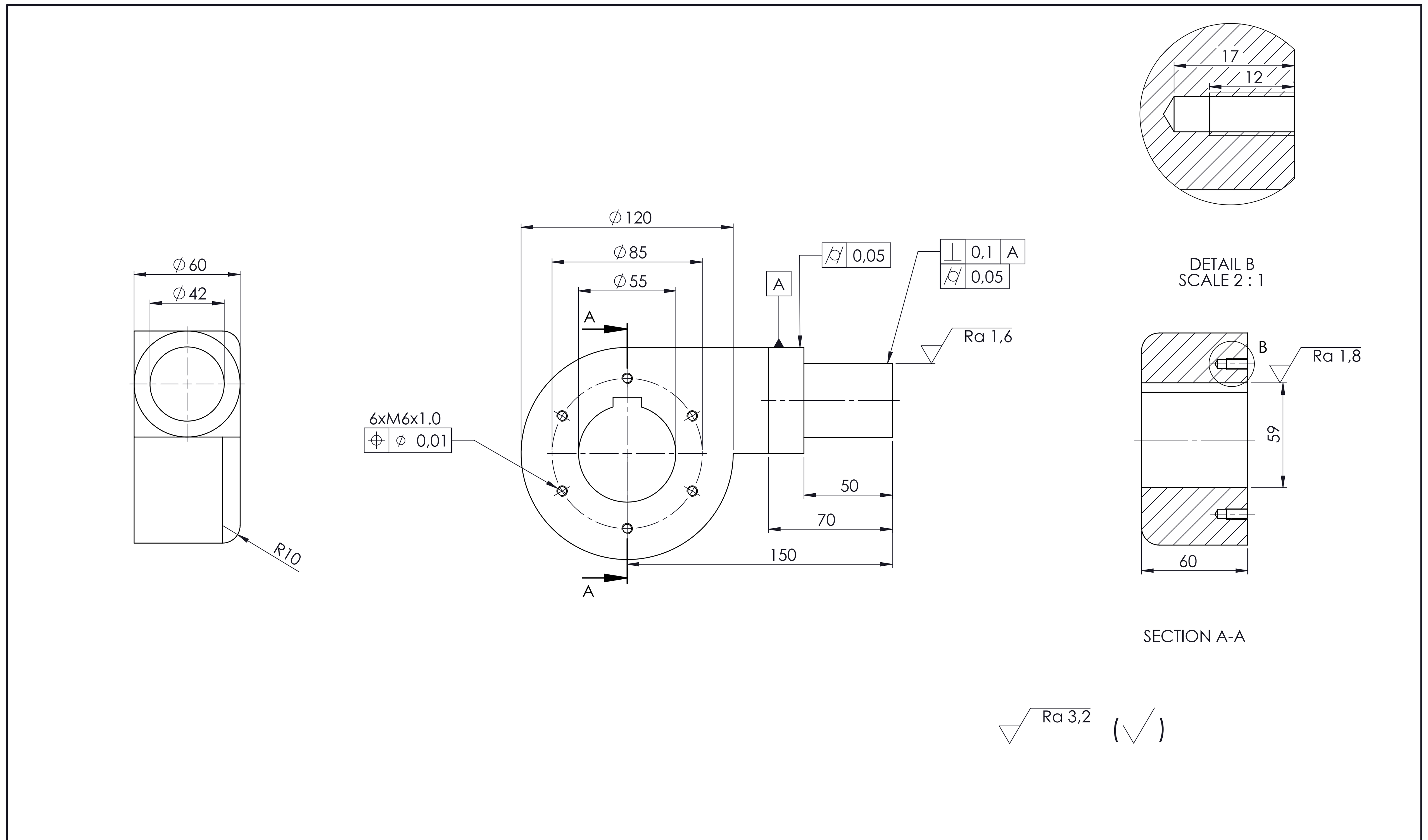
DATA SHEET GEAR ISO 65		
Module	m	4
Number of teeth	Z	65
Pressure angle	α	20º
Primitive diameter	dp	260
Distance between axis	C	330



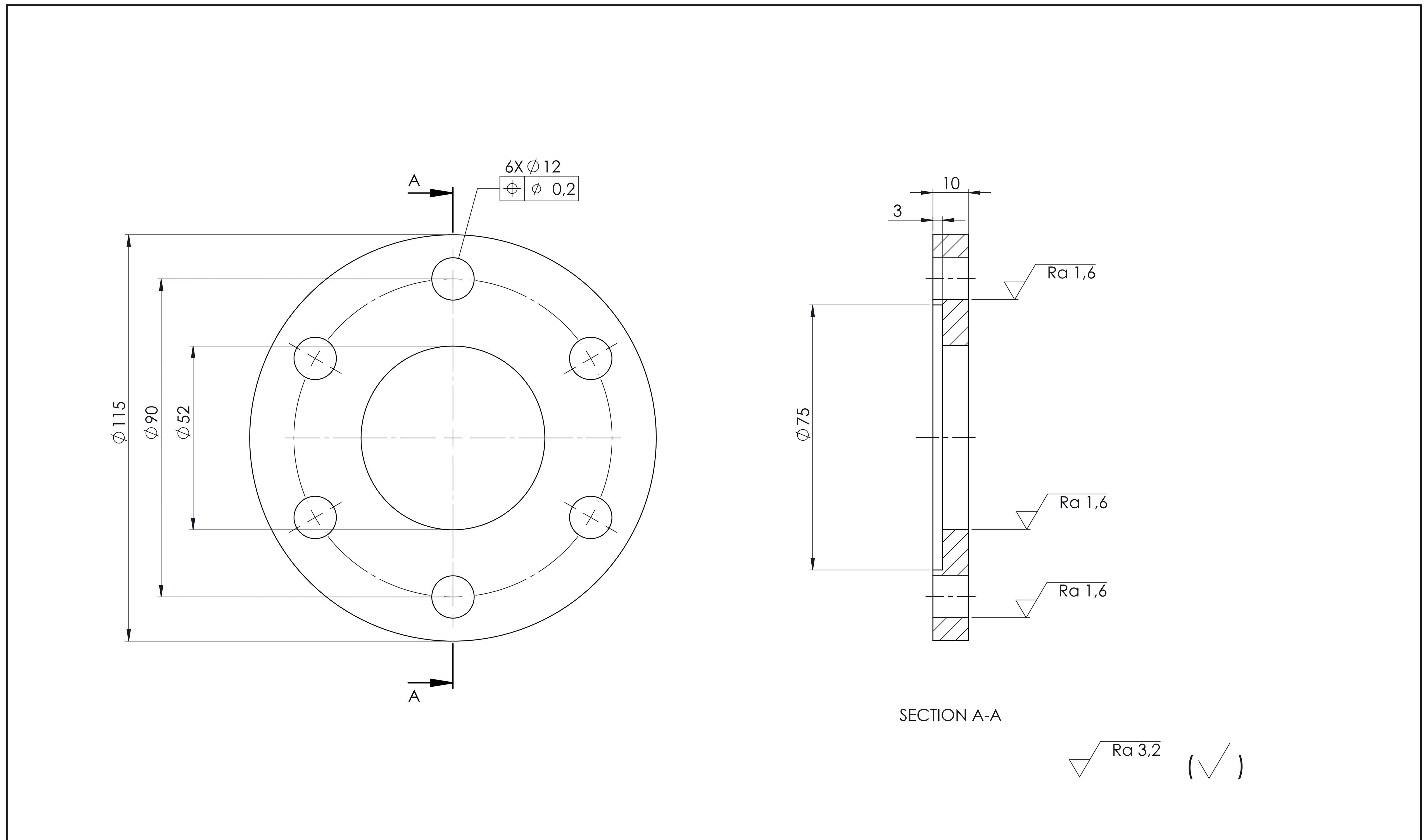


DETAIL G
SCALE 2 : 1

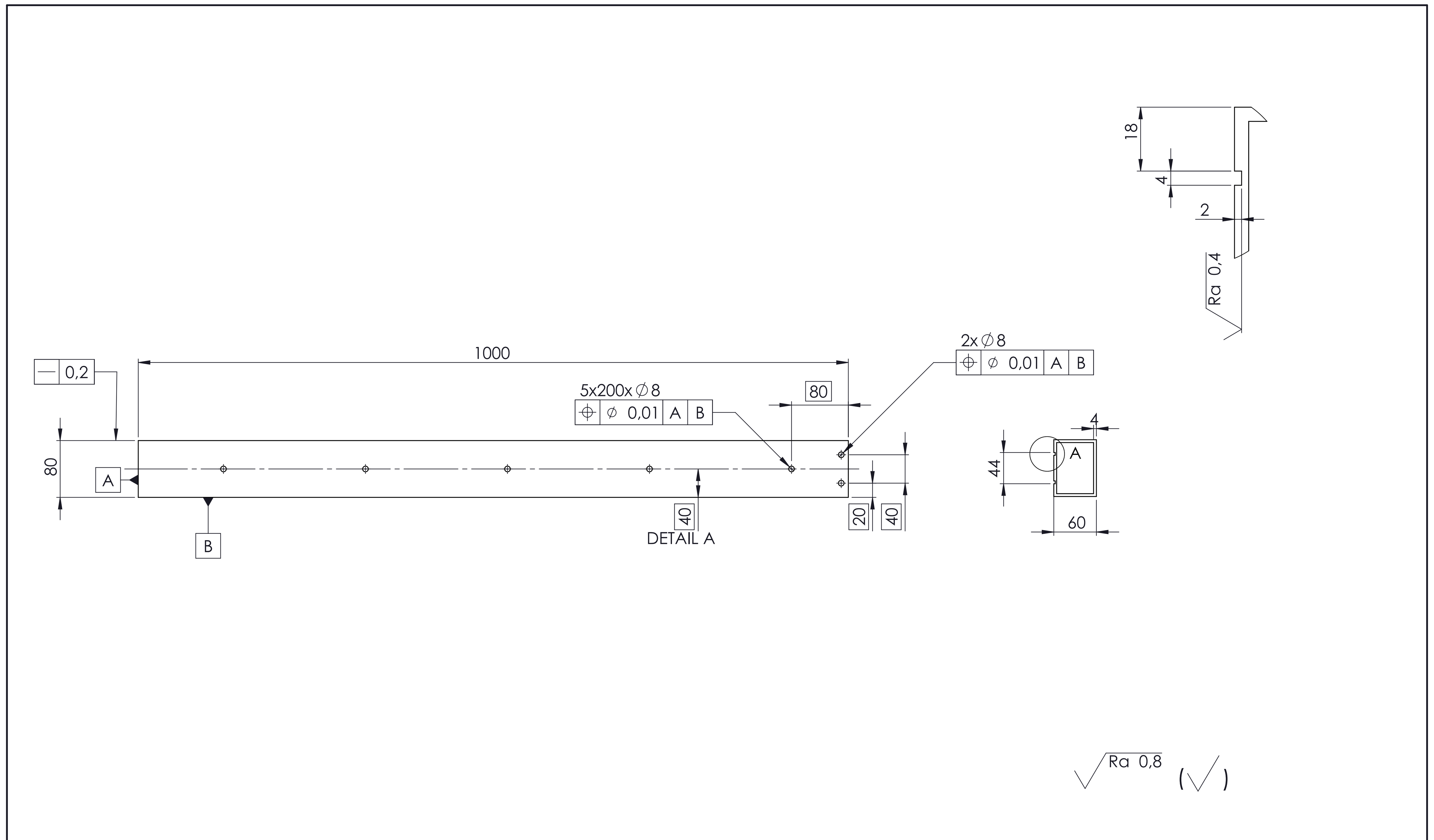
Case No.	Additional Information	Material		Scale 1:2
Resp. Dep. Inž. gr. k-dra	Consultant	Document type Subassembly drawing		Document Status Educational
Owner VGTU Mpfuc-16	Compiled by Carlos Izquierdo	Title Gear box subassembly drawing		Drawing nr: MBP 20.00.01.01.000 AD
	Checked Paulius Ragauskas			Rev A · Date 2020.05.30 · Lan. en · Pag 2/9



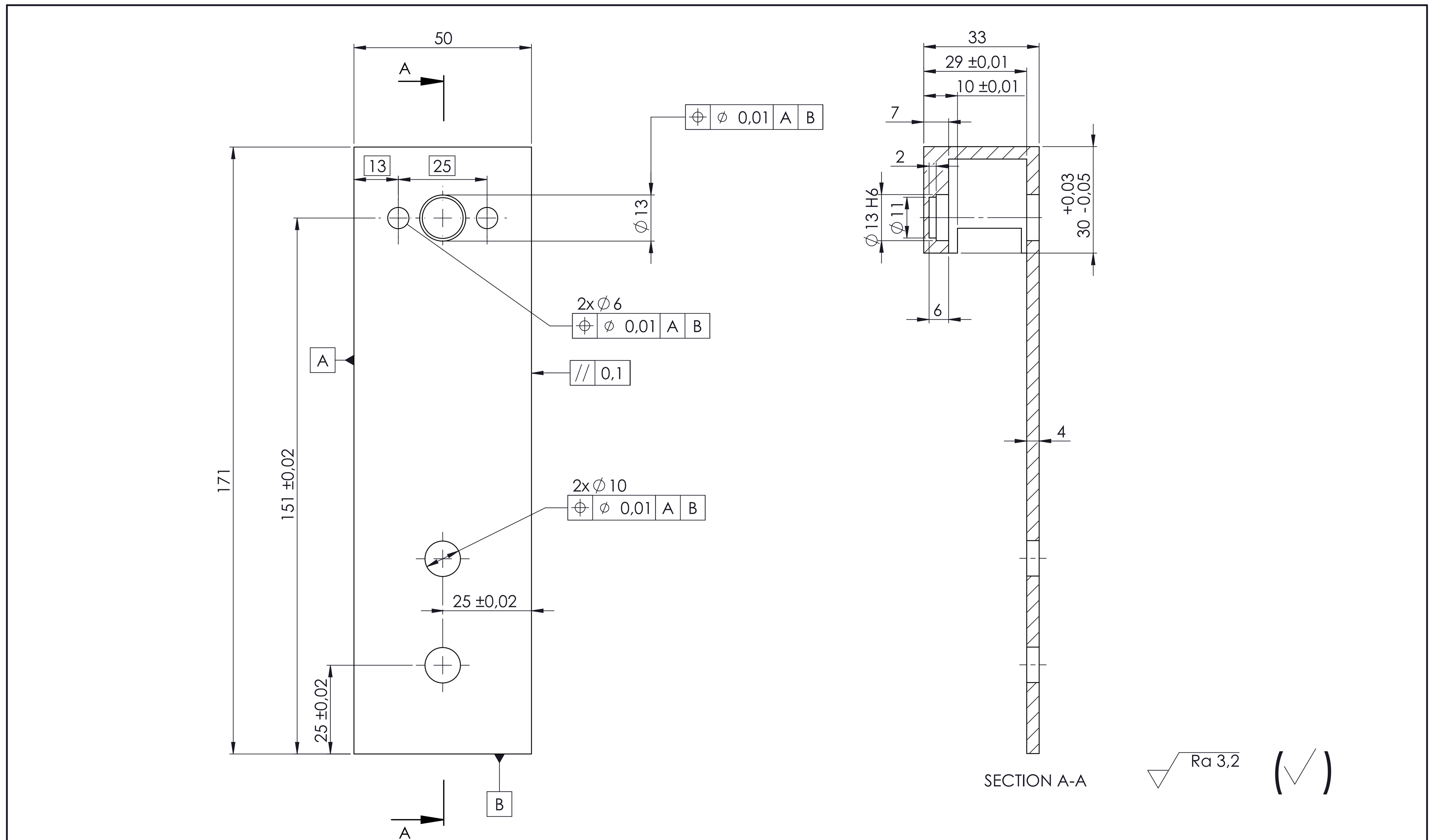
Case No.	Additional Information	Material: Grey cast iron ASTM 25	Scale 1:2
Resp. Dep. Inž. gr. k-dra	Consultant	Document type: Part drawing	Document Status: Educational
Owner: VGTU Mpfuc-16	Compiled by: Carlos Izquierdo; Checked: Paulius Ragauskas	Title: Arm support	Drawing nr: MBP 20.00.01.02.001; Rev A; Date 2020.05.30; Lan en; Page 4/9



Case No.	Additional Information	Material: Grey cast iron ASTM 25	Scale 1:2
Resp. Dep. Inž. gr. k-dra	Consultant	Document type: Part drawing	Document Status: Educational
Owner: VGTU Mpfuc-16	Compiled by: Carlos Izquierdo; Checked: Paulius Ragauskas	Title: Input shaft cover	Drawing nr: MBP 20.00.01.01.010; Rev A; Date 2020.05.30; Lan en; Page 5/9

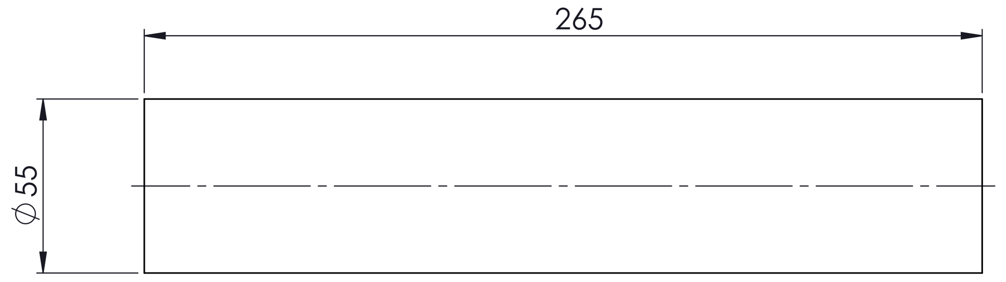


Case No.	Additional Information	Material: PP Copolymer	Scale 1:5
Resp. Dep. Inž. gr. k-dra	Consultant	Document type: Part drawing	Document Status: Educational
Owner: VGTU Mpfuc-16	Compiled by: Carlos Izquierdo; Checked: Paulius Ragauskas	Title: Legs pusher arm	Drawing nr: MBP 20.00.01.03.001; Rev A; Date 2020.05.30; Lan en; Page 6/9

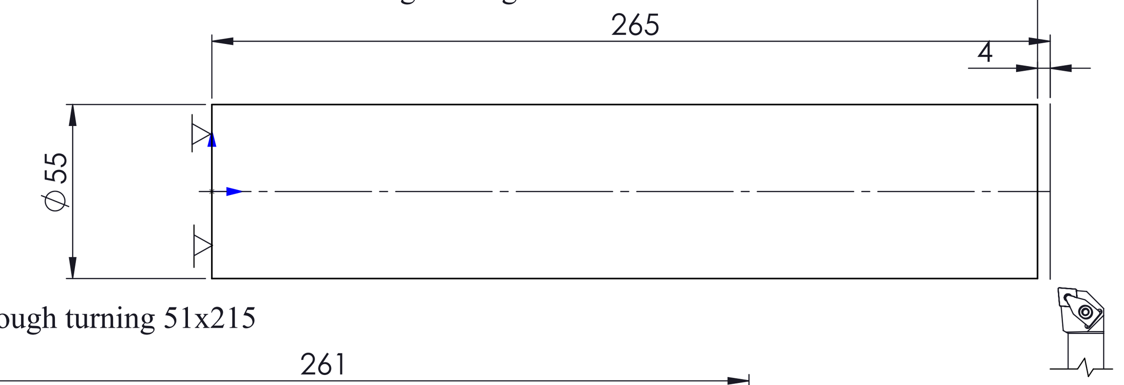


Case No.	Additional Information	Material: PP Copolymer	Scale 1:2
Resp. Dep. Inž. gr. k-dra	Consultant	Document type: Part Drawing	Document Status: Educational
Owner: VGTU Mpfuc-16	Compiled by: Carlos Izquierdo; Checked: Paulius Ragauskas	Title: Pinion support	Drawing nr: MBP 20.00.01.03.002; Rev A; Date 2020.30.05; Lan en; Page 7/9

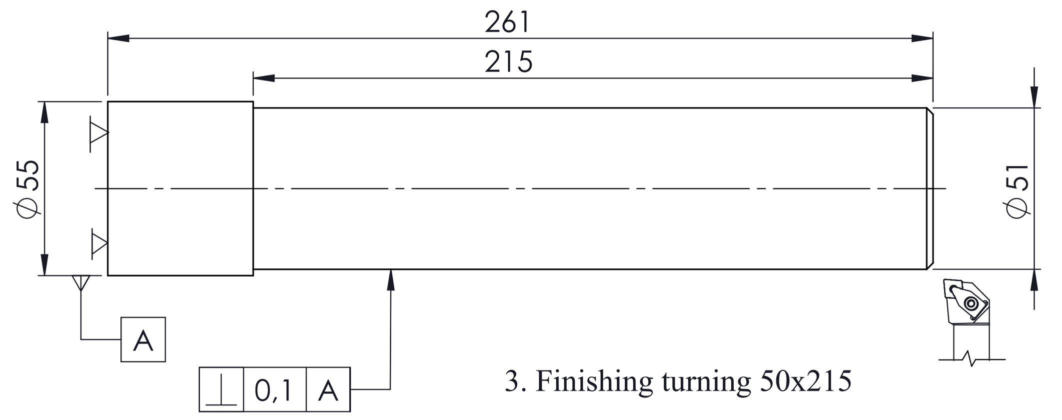
Initial stock



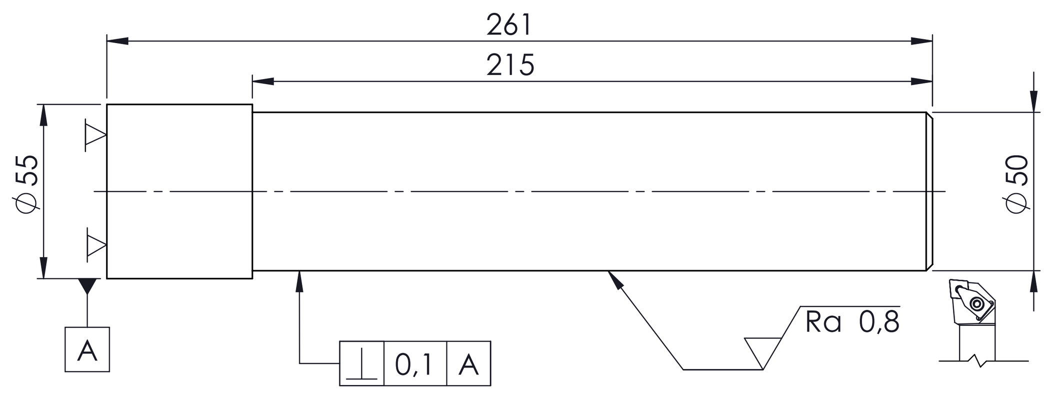
1.Rough facing



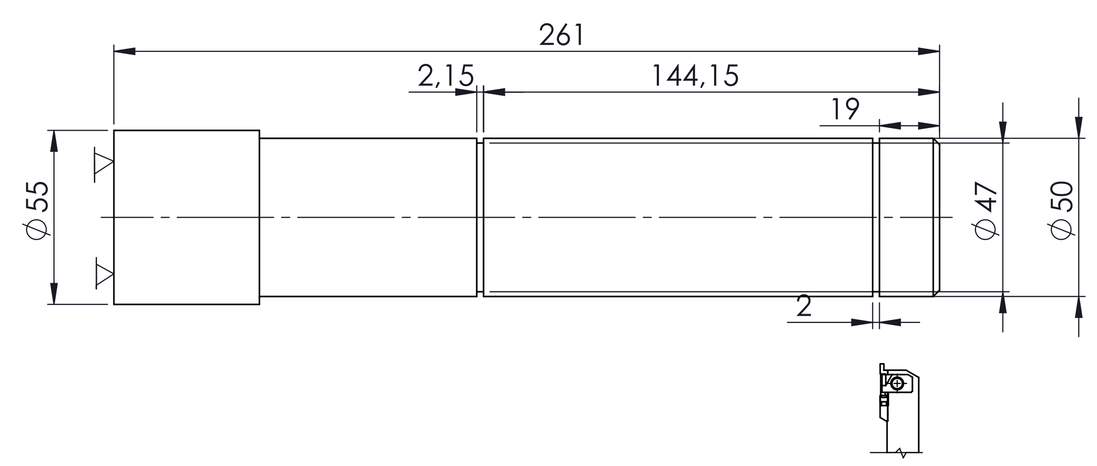
2. Rough turning 51x215



3. Finishing turning 50x215



4. 2xGroove 2,15x1,5



OPERATION 1: ROUGH FACING						INSERT SNMG 12 04 12-PR 4325 TOOL I DSSNR 2020K 12	
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	4	1500	-	55	0,41	259,05	0,390243902

OPERATION 2: ROUGH TURNING 51x215						INSERT SNMG 25 07 24-PR 4325 TOOL DSDNN 4040S-25	
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	215	1250	2	55	1,04	215,875	9,923076923

OPERATION 3: FINISIHING 50x215						INSERT CP-B1108-M5 4325 TOOL CP-25BR-2020-11	
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	215	2250	0,5	51	0,59	360,315	9,717514124

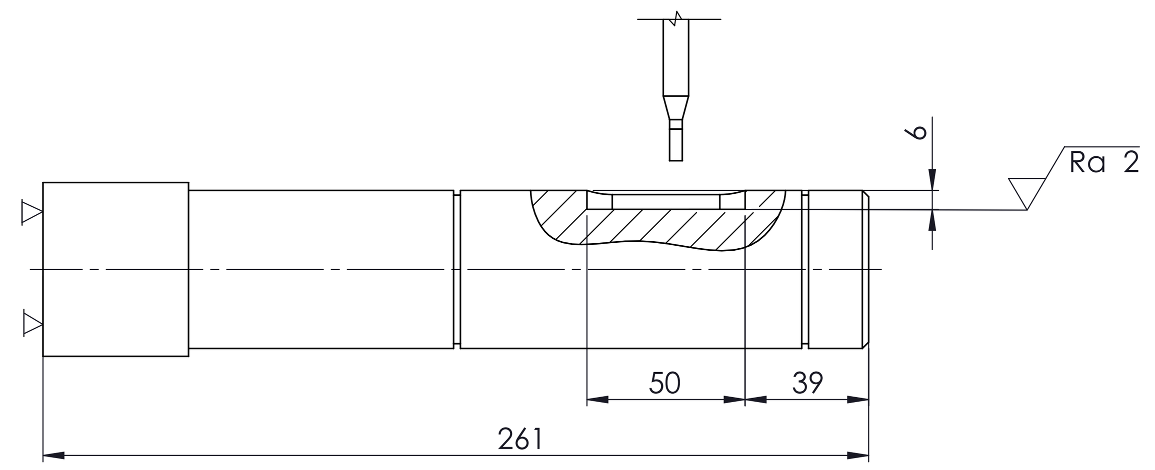
OPERATION 4: 2xGROOVE 2,15x1,5						INSERT N123E2-0200-0002-GM 4325 TOOL N123E20-25A 2	
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	2	1530	1,5	50	0,07	240,21	1,120448179
2	0,15	1530	1,5	50	0,103	240,21	0,057110223

OPERATION 5:KEYWAY 16x50			INSERT R390-11 T3 12E-PM 1130 TOOL RA390-016M19-11L		TOTAL TIME t(s)=9,24
Pass	n(rpm)	ap(mm)	ae(mm)	fz(mm)	Vc(m/min)
1	3910	2,47	15,88	0,0992	195
2	3910	4,94	15,88	0,124	195
3	4470	0,0625	14,24	0,25	200
4	4410	5	0,0625	0,32	220
5	4470	0,0625	14,24	0,312	200

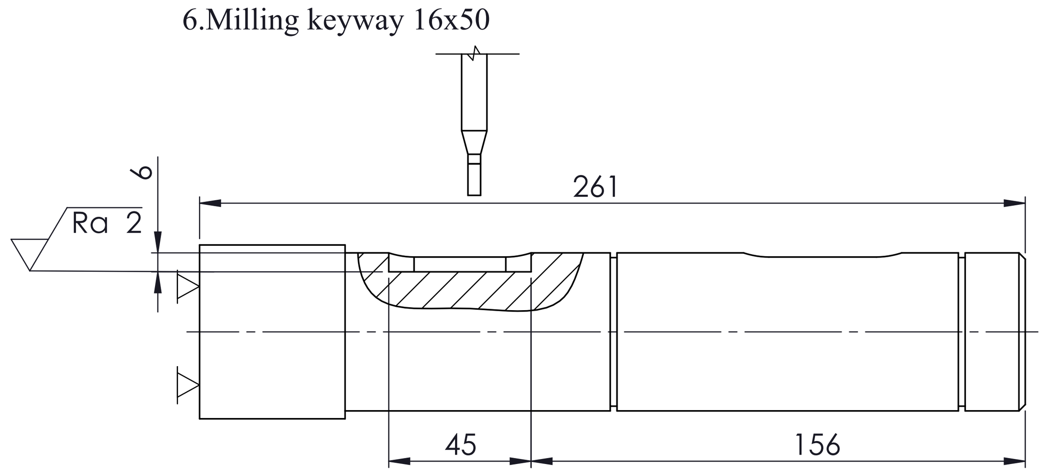
OPERATION 6:KEYWAY 16x45			INSERT R390-11 T3 12E-PM 1130 TOOL RA390-016M19-11L		TOTAL TIME t(s)=8,64
Pass	n(rpm)	ap(mm)	ae(mm)	fz(mm)	Vc(m/min)
1	3910	2,47	15,88	0,0992	195
2	3910	4,94	15,88	0,124	195
3	4470	0,0625	14,24	0,25	200
4	4410	5	0,0625	0,32	220
5	4470	0,0625	14,24	0,312	200

OPERATION 7:PARTING OFF						INSERT QD-NE-0200-0003-CR 1125 TOOL QD-NR2E26-25A	
Pass	l(mm)	n(rpm)	ap(mm)	Dm(mm)	fn(mm/rev)	Vc(m/min)	t(s)
1	2	1000	25	50	0,13	157	0,923076923

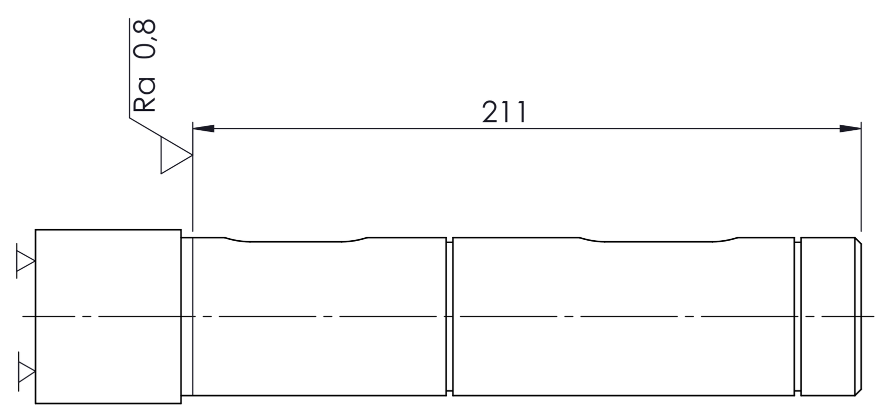
5.Milling Keyway 16x45.



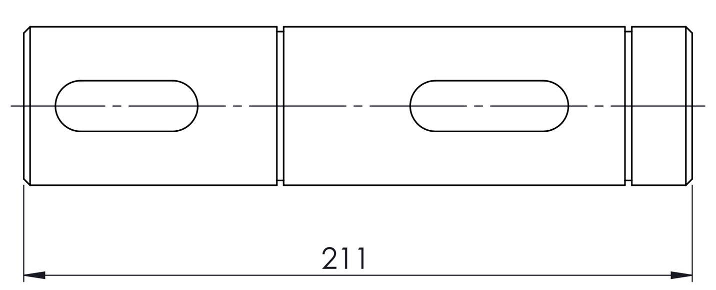
6.Milling keyway 16x50



7.Parting off

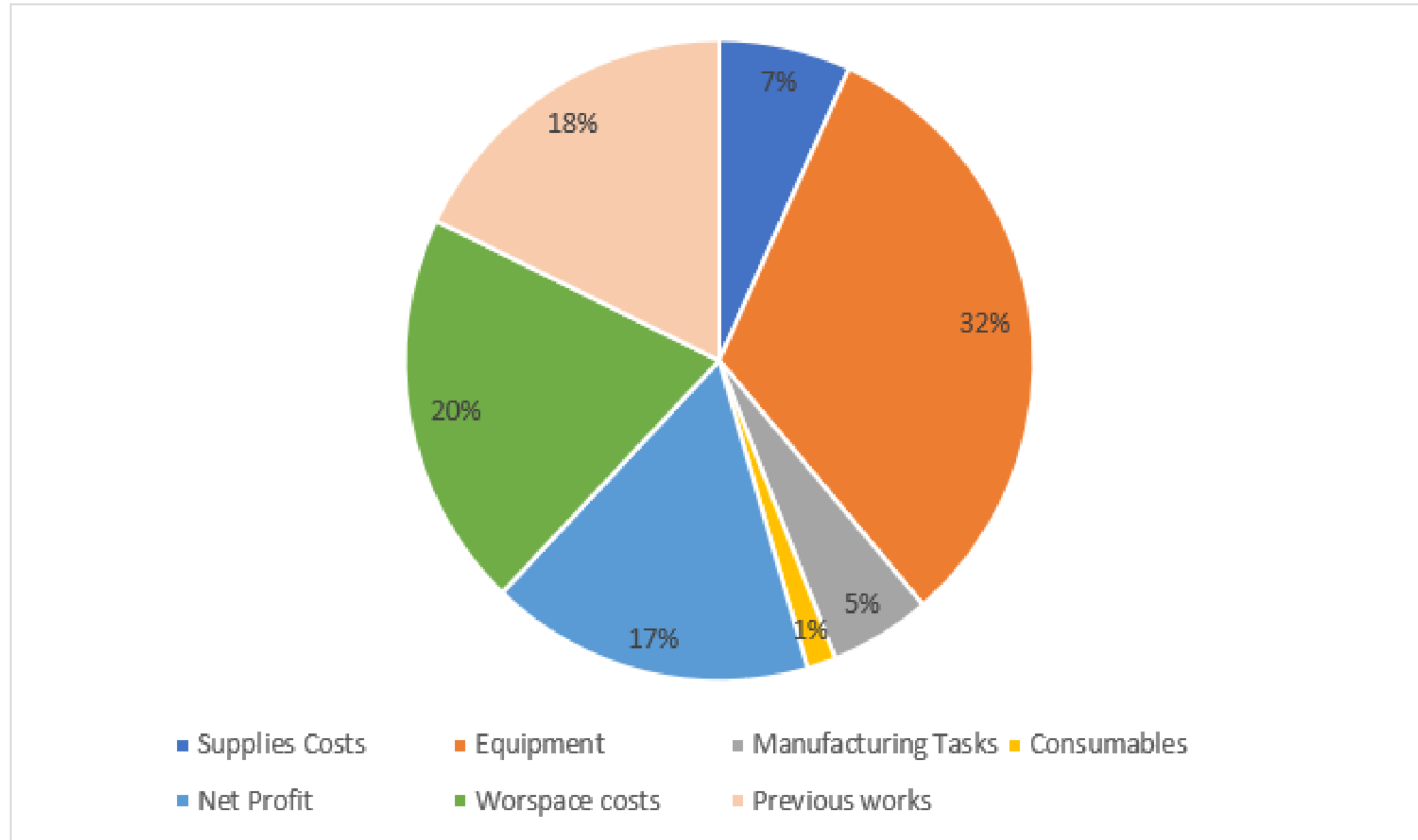


Final Part

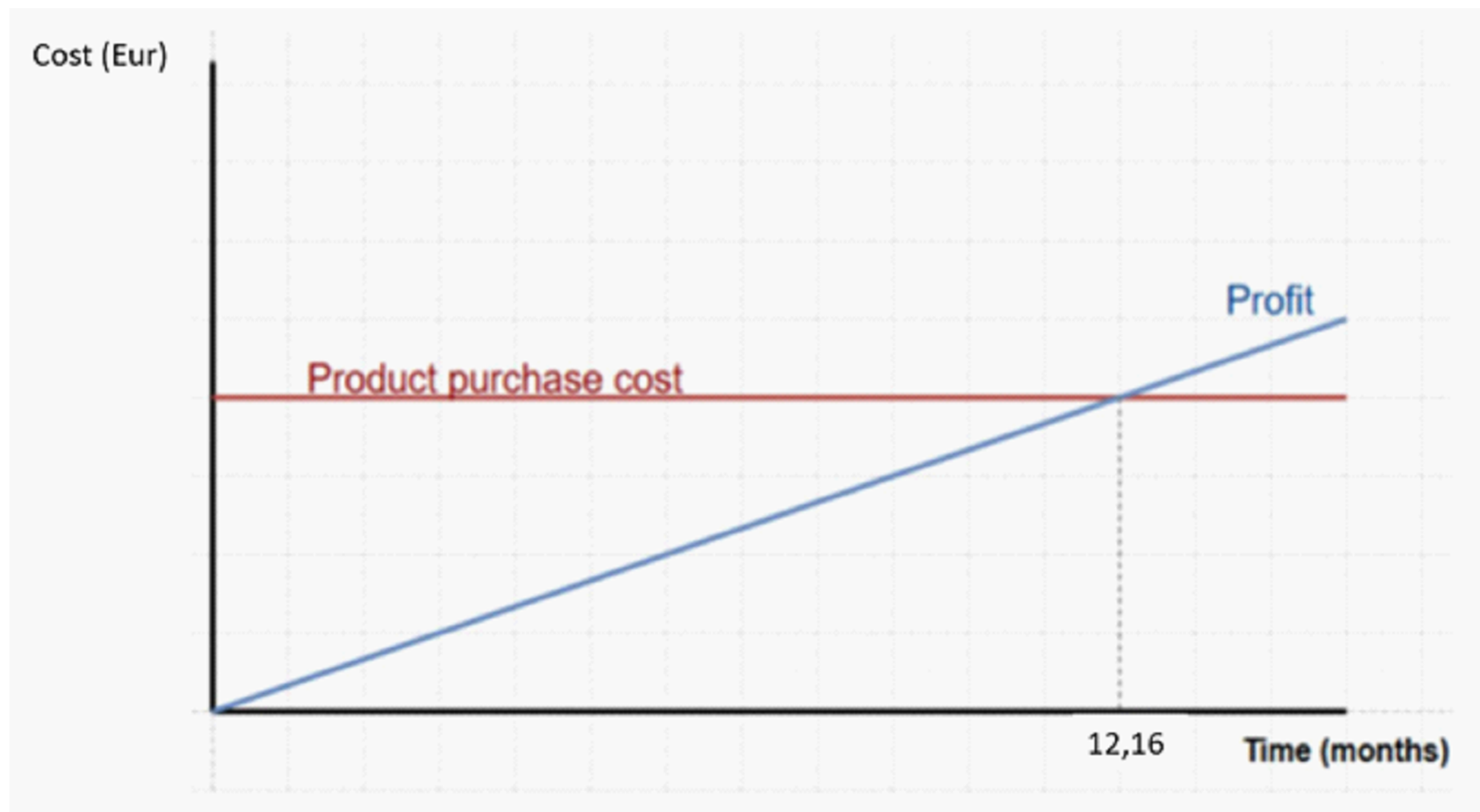


	Case No.	Additional Information	Material AISI 4130 tempering at 540 ºC	Scale 1:5
Resp. Dep. Inž. gr. k-dra	Consultant	Document type: Technological process	Document Status Educational	
Owner VGTU Mpfuc-16	Compiled by Carlos Izquierdo Checked Paulius Ragauskas	Title Machining process of Input Shaft	Drawing nr: MBP 20.00.01.01.002 TD Rev A / Date 2020.01.06 / Lan en / Page 8/9	

Costs pie-chart



Break even point



	Case No.	Additional Information	Material	Scale
Resp. Dep. Inž. gr. k-dra	Consultant	Document type: Economical rates	Document Status Educational	
Owner VGTU Mpfuc-16	Compiled by Carlos Izquierdo Checked Paulius Ragauskas	Title Economical rates	Drawing nr: MBP 20.00.00.00.000 G1 Rev A / Date 2020.01.06 / Lan en / Page 9/9	