Universidad de Valladolid

ESCUELA DE INGENIERÍAS INDUSTRIALES

UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

Design of agricultural terrain robot for real time soil and plant health inspection
"Diseño de un robot de terreno agrícola para la inspección en tiempo real de suelos y plantas"

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Vilnius Gediminas Technical University

Valladolid, Junio 2020.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Design of agricultural terrain robot for real time soil and plant health inspection

ALUMNO: Sara Lorenzo Pinto

FECHA: 17/06/2020

CENTRO: Faculty of Mechanics

UNIVERSIDAD: Vilnius Gediminas Technical University

TUTOR: Andrius Gedvila

Resumen

Este TFG consiste en el diseño de un robot autómata agrícola que controle el estado de diferentes partes del terreno gracias a un sistema autónomo, analizando su humedad y nutrientes con diferentes sensores que serán insertados en la tierra gracias a unos brazos plegables incluidos en el interior del vehículo. La información recogida será enviada a un sistema local que analizará los datos y tomará las decisiones necesarias para el uso adecuado de riego y fertilizantes individualmente en cada parte del terreno para así obtener mejores cosechas.

El vehículo contará con 4 motores eléctricos conectados a cada par de ruedas de tracción, y una batería que proporcionará la energía necesaria para cada uno de ellos.

Palabras clave

Autómata, vehículo, grandes superficies agrícolas, ruedas de oruga, brazo plegable.

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY[1]
FACULTY OF MECHANICS
DEPARTMENT OF MECHANICAL AND MATERIAL ENGINEERING

Sara Lorenzo Pinto

Design of agricultural terrain robot for real time soil and plant health inspection

Bachelor ‘s degree final work

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

Vilnius, 2020

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY[2]

FACULTY OF MECHANICS

DEPARTMENT OF MECHANICAL ENGINEERING

APPROVED BY
Head of Department

(Signature)

Prof. Dr. Mindaugas Jurevičius
(Name, Surname)
2020-06-11
(Date)

Sara, Lorenzo

DESIGN OF AGRICULTURAL TERRAIN ROBOT FOR REAL TIME SOIL AND PLANT HEALTH INSPECTION

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Supervisor Andrius Gedvila ____________ 5
(Title, Name, Surname) (Signature) (Date)

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VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
DEPARTMENT OF MECHANICAL AND MATERIAL ENGINEERING

APPROVED BY
Head of Department
____
(Signature)
Mindaugas Jurevičius
2020.03.12
(Date)

Mechanical Engineering study field
Mechanical Engineering study programme, State Code 612H33001
Machine Design specialisation

OBJECTIVES FOR BACHELOR THESIS

2020.03.12 No. 28
Vilnius

For student **Sara Lorenzo Pinto**

Final work (project) title: **Design of agricultural terrain robot for real time soil and plant health inspection**

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

The Final work has to be completed by 27 May, 2020

THE OBJECTIVES:

The design of a small electric wheel robot acting as mobile real time laboratory for agricultural terrain, equipped with sensors and probes to inspect soil humidity, temperature, ph and optical chlorophyll level meter of the plants.

Initial data:
Probe insertion depth: 100 mm
Electric arm length: 300 mm

Explanatory note:
Introduction; Analysis of soil and plant health inspection techniques; Analysis of similar robotic machines and conciderations on main working principles; Construction decisions and basic calculations; Technological design and calculation of one part; Operation instructions, safety and environmental requirements; calculations and economical part; Final conclusions; Biography.

Drawings:
General view (1 sheet of A1); Robot assembly drawing (1 sheet of A1); Working drawings of parts (1 sheet of A1); Technological drafts of the part processing (0.5 sheet of A1); Economic indicator diagrams (0.5 sheet of A1).

Academic Supervisor .... (Signature) Lect. Andrius Gevila

Objectives accepted as a quidance for my Final work
....
(Student's signature)
...... Sara Lorenzo Pinto ....
(Student's Name, Surname)
.........10.03.2020...........
(Date)

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

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Sara, Lorenzo,

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

Faculty of Mechanics

(Faculty)

Mechanics Engineering, MPfu-16

(Study programme, academic group no.)

DECLARATION OF AUTHORSHIP IN THE FINAL DEGREE PROJECT

2020-06-01

(Date)

I declare that my Final Degree Project entitled “Design of agricultural terrain robot for real time soil and plant health inspection” is entirely my own work. The title was confirmed on 2020-06-01 by Faculty Dean’s order No. 60. 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: Andrius Gedvila.

The academic supervisor of my Final Degree Project is Andrius Gedvila .

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

(Signature)	SARA, LORENZO (Given name, family name)

Vilnius, 2020

Vilnius Gediminas Technical University
Mechanics faculty
Department of Machine Engineering

ISBN ISSN
Copies No. 1
Date 2020-06-01

Bachelor Degree Studies Mechanics Engineering study programme Bachelor Graduation Thesis
Title: Design of agricultural terrain robot for real time soil and plant health inspection

Author **Sara Lorenzo** Academic supervisor **Andrius Gedvila**

Thesis language

☐ Lithuanian

☒ Foreign (English)

Annotation

In this bachelor‘s degree final work was designed an agricultural terrain robot for real time soil and plant health inspection. The main aim of this project is to improve crops in large agricultural terrains focusing on the state of the ground. It will analyse the humidity and nutrients of the land by different sensors which will be located by the vehicle thanks to an automated system in pre-determined areas. The information collected will be sent to a local computer which will analyse it.

The vehicle will move all around the terrain thanks to 4 engines connected each one to two pairs of gearwheels, one bigger than the other, and the small one, will be able to go up and down to get more stability in the ground when needed in each situation.

Theoretical part reviews the popularity of large agricultural terrains, mainly growing for the wine sector, and also the need to look for a system that improves the quality of the land and the fair expenditure of water and fertilizers to not to do a big waste of it. Moreover, it is explained the functioning of the automated vehicle, the technological process of a part of the vehicle, and safety and environmental requirements

Calculations part focus on the power needed for the engines, and the resistance of the different materiales used for some parts of the designed vehicle. And economical calculations of the product.

Structure: introduction, references review, grounding of taken decisions, costruction decisions and calculations, functioning, description of the technological process of machining of the arm wrist, safety of work, economic calculation, conclusions and suggestions, references.

Thesis consist of: 64 p. text without appendixes, 33 pictures, 27 tables, 28 bibliographical entries.

Appendixes included.

Keywords: automated vehicle, large agricultural terrains, gearwheels, folding arm

Table of Contents

1. INTRODUCTION

[References: 1,2]

Nowadays, agricultural areas are the main source of humans´ life, that is why better innovations must be taken to get better crops with the aim to lose the less the better and obtain the maximum good harvest.

All around the world, vineyards are getting more popular because wine's trade are increasing significantly in the past years *(Figure 1-1).*

In Spain, for example, the planted area of this kind of surface is the biggest one, having the 15% of the world, and being the 3rd worldwide after Italy and France in the production of wine.

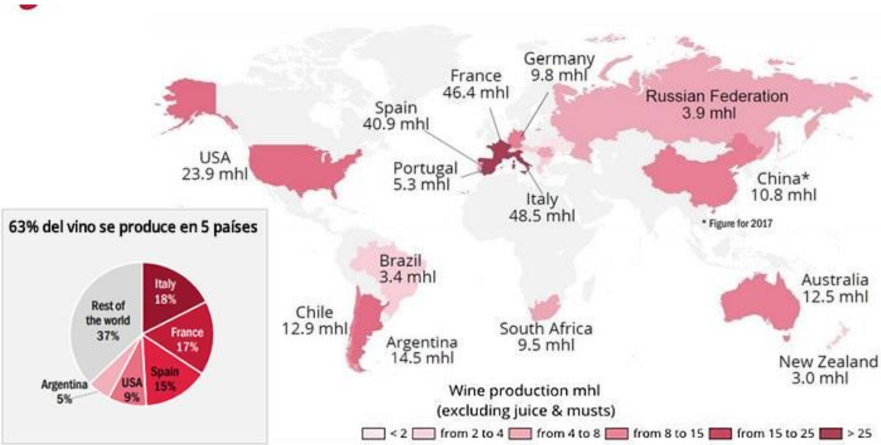


Figure 1-1*: Global wine production*[1]

This popularity makes companies look for better innovations and technologies to get better production so that they can compete in the wine trade all around the world and make their wine as much competitive as they can, with the better qualities.

Moreover, the waste of water is so big in this kind of agricultural areas, so solutions have to be taken to reduce it, and the best way to do it is to know the water demand of each part of the area to supply the exact quantity of water and no waste it *(Figure 1-2).*

We are growing up so quickly and the environment is not prepared for that speed, so that, we need new technology to help it grow in a healthy way, something that will also have positive repercussions in our society and in our health.

Figure 1-2: Water waste [2]

2. REFERENCES REVIEW, GROUNDING OF TAKEN DECISIONS

2.1 Agricultural areas

[References: 3]

In the middle of the last century, the engineer Norman Borlaug and another group of agronomies, stablished the basis of the "Green Revolution", introducing highly productive cereal crops, pesticides and fertilizers, and new techniques which allow multiply the harvests and extend the crops, helping to save people from famine.

Actually, thanks that, the number of hectares has increase beating the 4.000 million of hectares, being the 34% of the all skilful flooring *(Figure 2.1-1).*

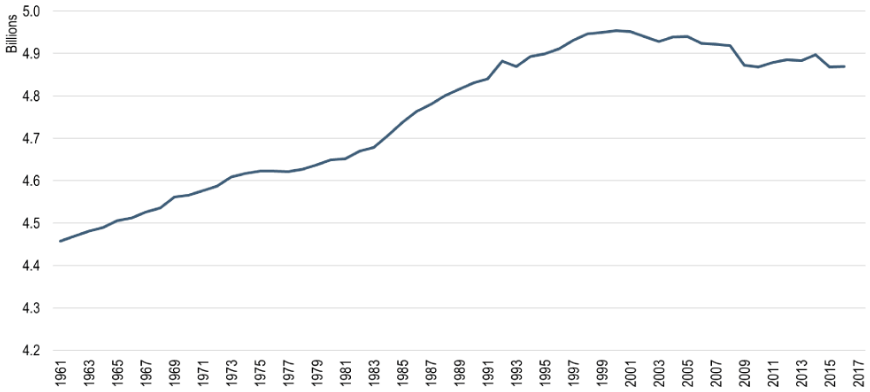


Figure 2. 1-1: World agricultural area (1961-2016)[3]

The agriculture is the basis of our life, and it keeps continuingly growing up, that is why new technologies must be developed to help people to make it happen.

2.2 The use of water in agriculture

The water is a natural resource, and a need for human's life, from generating electricity, feed people, clean, or irrigate the land. To be a natural resource, climate change and life habits are making the water reserves decrease so fast.

Something to have be considered, is that only the 2,5% of water worldwide is sweet, being most of its part of glaciers, so the water for the consume is minimum.

The more extended use for water is the agriculture, it consumes the 70% of usable water worldwide. The field need water to water the crops and make it grow in a proper way. The 20% of the cultivated lands are irrigated, what involves the 40% of the total food production. It is needed between 2000 and 5000 litres of water to produce the nourishment consumed by a person in only one day.

The worldwide population is increasing so fast, and with that the water consumption, estimating a demand by 2050 of 50% more than nowadays. Moreover, a lot of that water is wasted, and being a good makes it more valuable, so that, we must look for an efficient use of it.

Our goal is to find new technologies that improves the water use, looking for the exact quantity of water needed for each application or needs, reducing the wastewater.

2.3 Static nutrient sensors and controllers

[References: 4,5]

Nowadays, the ways more used to know all the characteristics of the soil, are different appliances that need to be used to take samples by a person *(Figure 2.3-1)*, going this person all around different parts of the terrain and doing the stablished guidelines to get the correct information.

This system works with a portable central compounded by humidity sensors, nutrients, anemometer, or even flowmeter, that will identify the status of the soil.

Figure 2.3- 1 A man taking simples[4]

Another system used are remote sensors interconnected *(Figure 2.3-2)*, located in a fixed place, that get information about the status of the soil, and send this information to a control centre that could be a computer or another communication point, that evaluates and show the information to the user.

Figure 2.3- 2: Remote sensors[5]

2.4 Automaton vehicles

[References: 6,7,8,9]

For this study, it is considered different kind of automaton vehicles from military to agricultural use, to have both characteristics such as stability and agronomy issues.

Pioneer 3-AT

Is an automated robot for all-purpose outdoor base. Its uses include mapping, navigation, monitoring, reconnaissance and more for research and prototyping applications.

The Pioneer 3-AT comes with one battery, emergency stop switch, wheel encoders and a microcontroller with ARCOS firmware.

It is a 4-wheel vehicle *(Figure 2.4-1)*, of 12kg and a maximum speed of 0.7 m/s. Its autonomy is 2-4 hours with 3 batteries and needs 12 hours to get charged with a standard charger, or 2 hours with a high-capacity charger.

Figure 2.4-1: Pioneer 3-AT [6]

UGV "Testudo"

This is a controlled vehicle *(Figure 2.4-2)* developed by DCD Protected Mobility and CMTI, two African companies, designed to detect and desactivate mines and improvised explosive dispositives, or to do reconnaissances.

Its weight is about 260kg, but it can transport even 150kg.

The robot uses two pairs of caterpillar transporters of 17.2 cm wide from caterpillar commercial vehicles, what assures a more economic production and maintenance.

The charge of the standard batteries let it develop a velocity of 6 km/h and a 6h operativity.

Figure 2.4- 2: Testudo[7]

FENDT'S TRACTOR VARIOGUIDE

This trade name is one of the most technological advanced in what means autonomy, their best tractors use a technology called "VarioGuide" *(Figure 2.4-3)* with which it can be controlled remotely with big precision.

“VarioGuide” is an automated guidance system which uses highly accurate technology to work to a precision of +/-2 cm, even at night or in poor visibility. This achieves a more economical and therefore efficient utilisation of expensive farm inputs.

The receiver systems used are NovAtel® or Trimble®

Figure 2.4- 3: Fendt VarioGuide[8]

GNSS and correction signal

GNSS (Global Navigation Satelite System) is a global navigation satellite system to determine position and navigation thanks to satellites and pseudo satellites.

- They communicate position and exactly hour through radio
- It is needed at least 4 satellites to determine position
- Stationary reception stations calculate the actual position due to the 4 signals and get better thanks to correction signals (DGPS), from geostationary satellites (European EGNOS, American WAAS, …) and base station or RTK net.

Satellite reception

GNSS reception and correction signal can be obstructed by:

- Presence of dense trees, forest, high buildings, high-voltage network
- The loose of correction signal when the satellite is in less than 5/8 grades over the antenna level (The satellite for this kind of use is geostationary positioned over the Ecuador)

- Have to be careful with slopes so that the vehicle may goes out from the reception zone of the antenna

What could be stablish

(Figure 2.4-4)

- The working width mark of the tire tracks
- The calibration of the gyroscopic system, direction angle, deviation compensation of the GPS
- The Limits compound by contour segments
- Reference lines
- Obstacles during the path
- Header adjustment (field limit) (decimetric precision DM or centimetric CM): It calculates the GNSS distance till the header limit of activation of the sequence TI (optionally): manual or by GNSS position

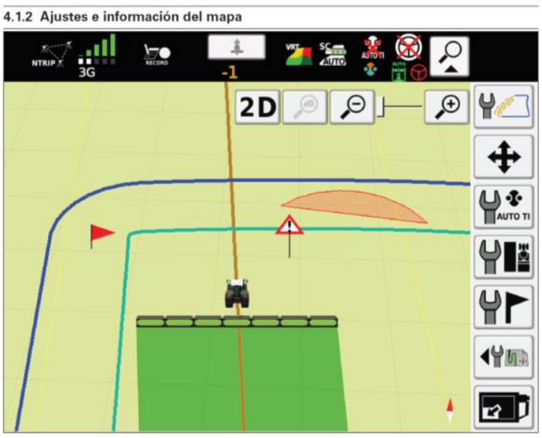


Figure 2.4- 4: Configuration and information of the map[9]

2.5 Justification of the decision taken

What it is looked for with this study, is to find a better and efficiently way to improve the land's state and so, the quality of the crops and an efficient use of water, with an automotive vehicle capable of going by its own all around the terrain and to a specific geolocation, to take samples of the land and collect all this information in different parts. With this, we will be able to know the necessities of each part of the field and solve it in a more efficiently way, using the exact amount of fertilizers or water for each part.

The most commonly ways to take the samples at present, are manually or by sensors located in a specific location and sending information to a local centre. With this kind of technology, it will be needed the use of a greater number of devices and taking always samples from the same place. That is why it has been decided a design of an automated vehicle to go all around, needing only one kind of each item, and without the variability of the different calibrations of each of them. Moreover, it will give more autonomy and knowledge of all the different hectares of our land, not only a specific one.

3. CONSTRUCTION DECISIONS AND CALCULATIONS

3.1 Global Positioning System

What I have chosen for the vehicle, it is the NovAtel® system *(Figure 3.1-1)* for the automated guidance. This will help it to go around the land in a pre-set way to not to harm in its way the crops. This will give our vehicle a completely autonomy.

Figure 3.1- 1: Novatel GNSS System[10]

3.2 Wheels

[References: 11,12]

The wheels that we will use have been decided taking into account the kind of wheels used in the UGV "Testudo" *(Figure 3.2-1)*, because this kind of caterpillar transporters, divided into 4, will give us more stability in the worst conditions of the land, and also in the process of collecting the samples of the different parts of the land.

Figure 3.2- 1: Testudo's caterpillar wheels[11]

But the wheels will not be the same as this one, I have designed other ones similar *(Figure 3.2-2)*.

Figure 3.2- 2: Wheel of the designed vehicle[12]

This Wheel is formed by two gearwheels interconnected by a timing belt.

3.3 Ground Shaker and calculation of the force needed to make the hole

[References: 13]

It will be used a standard electric ground shaker located in the inside of the vehicle, and connected to an extension arm, that will perforate the ground with the aim of later, introduce the sensors and get better results from more inside of the ground, not only superficial samples. It will give us more accurate results.

It will be like in *(Figure 3.3-1)*.

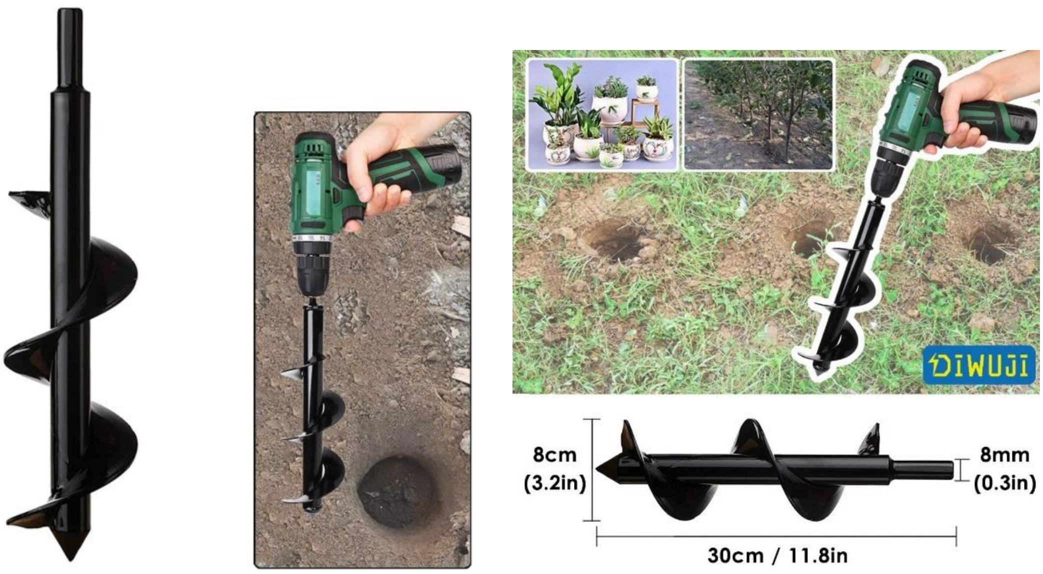


Figure 3.3- 1: Ground Shaker[13]

It is manufactured of high-quality steel (Heavy Duty steel), which main characteristics are:

- Diameter: 8 cm
- Length: 30 cm

Calculation of the force to make the hole into de ground

To calculate the force needed, it will be used the shear stress equation:

$$F = A * \tau \qquad (3.3\text{- }1)$$

Where:

- **F** = force [N]
- **A** = applied area [m^2]
- $\boldsymbol{\tau}$ = ultimate shear stress [Pa]

The applied area will be determined by the characteristics of the ground shaker:

$$A = \pi * D * h \qquad (3.3\text{- }2)$$

In our case:

D = Diameter [m] → **D = 0,08 m**
h = depth [m] → **h = 0,3 m**

So, substituting into Equation (3.3-2), the applied area will be: **A = 7,54x10^{-2} m^{2}**

For The ultimate shear stress of the ground, it will be used the value for the clay, because it is a very compact earth, and even our ground may have less shear stress, it is better to calculate it in a more critic operation, so that, it will be used the mean ultimate shear stress of the clay of the approximation of: $\boldsymbol{\tau = 25\ MPa}$

Now having all the information, it will be got the force needed with Equation (3.3-1):

$$\boldsymbol{F} = (7{,}54 * 10^{-2}) * (25 * 10^{6}) = 1885000\ N = \mathbf{1885\ kN}$$

3.4 Soil sensor

[References: 14]

It will be used a soil T/H/CE sensor *(Figure 3.4-1)* which measure the temperature, the humidity, the electrical conductivity of the soil, the dielectric permittivity and the electrical conductivity of the water pores contents on the hole of the ground.

Figure 3.4- 1:Soil sensor[14]

Like the ground shaker, it will be located inside the vehicle, connected to an extension arm that will put it inside the hole made before.

The specifications of the sensor are in *(Table 3.4-1, 3.4-2)*.

Table 3.4- 1: Specifications of the sensor

	Volume of water	**Electrical Conductivity**	**Temperature**
Accuracy	+/-1 units (unitless) from 1 to 40 (soil range), +/-20% from 40 to 80 (VWC) • Using Top equation: 0:03 m3=m3(3% VWC) typical in mineral soils that have solution electrical conductivity < 10 dS/m • Using medium specific calibration, 0:01 to 0:02 m3=m3(1to 2% WC) in any porous medium.	10% from 0 to 10 dS/m, user calibration required above 10 dS/m.	+/-1 ^{o}C
Range	Apparent dielectric permittivity: 1 (air) to 80 (water)	0 to 25 dS/m (bulk)	-40 to 60 ^{o}C
Resolution	0.1 units (unitless) from 1 to 20, < 0.75 (unitless) from 20 to 80	0.01 dS/m from 0 to 10 dS/m, 0.05 dS/m from 10 to 25 dS/m	0,1 ^{o}C

Table 3.4- 2: General specifications of the sensor

	General
Frequency of the dielectric measurement	50 MHz
Measurement's time	1s (seconds)
Energy requirements	7 to 25 VDC
Exit	RS 485
Working's temperature	-40 to 60 ^{o}C

3.5 Selection of the electric engine

[References: 15, 16]

To find the best option for the vehicle, it is looked for and calculated the maximum power that it will be needed to move it in the most unfavourable situation (higher land resistance and higher slope), so that it will be the minimum power needed for the engine of our vehicle.

To calculate the power, it will be used the formula:

$$P = F * v \quad [kW] \tag{3.5- 1}$$

- **F** = force needed to move the vehicle [N]
- **v** = maximum velocity of the vehicle [m/s]

The maximum velocity stablished for the robot is 20 km/h or 5,55 m/s, the mass is 20kg, and the force needed will be calculated by the formula:

$$F = F_R + F_A + F_P + F_A \quad [N] \tag{3.5- 2}$$

F_R= rolling resistance → $F_R = m * g * C_{\mu}$ *(3.5- 3)*

In which **m** (mass of the vehicle [kg]), **g** (gravity acceleration[m/s^2]) and $\boldsymbol{C_{\mu}}$ (coefficient of rolling resistance)

It is considered a high rolling resistance's coefficient to simulate the worst condition: loose sand ($C_{\mu} = 0{,}3$). So, the result:

$$F_R = 300 * 9{,}8 * 0{,}3 = 882\ N$$

F_A= aerodynamic resistance → $F_A = \frac{1}{2} * C_x * A * \rho * v^2$ (3.5- 4)

This factor is to consider the aerodynamic of the vehicle, in which:

$\boldsymbol{C_x}$ is the aerodynamic resistance coefficient, considered $C_x = 0{,}387$ because of its shape.

A is the frontal surface of the vehicle, and it can be calculated by the approximation: $A = 1{,}6 + 0{,}00056 * (m - 765)$ (3.5- 5)

$$A = 1{,}6 + 0{,}00056 * (300 - 765) = 1{,}3396\ m^2$$

$\boldsymbol{\rho}$ is the density of the air, which is: $\rho = 1{,}225\ kg/m^3$

$\boldsymbol{v}$ is the velocity of the vehicle, which is $\boldsymbol{v} = 5{,}55\ m/s$

$$F_A = \frac{1}{2} * 0{,}387 * 1{,}3396 * 1{,}225 * 5{,}55^2 = 9{,}78\ N$$

$\boldsymbol{F_p}$**= slope resistance** → $F_p = m * g * sen\ \alpha$ *(3.5-6)*

$\boldsymbol{\alpha}$ is the angle of inclination of the road, and we consider the maximum slope angle of $\alpha = 45°$

$$F_p = 300 * 9{,}8 * sen\ 45° = 2078\ N$$

$\boldsymbol{F_a}$**= acceleration force** → $F_a = m * a$ *(3.5- 7)*

It will go from 0 to 20 km/h in 20 seconds, so that, the acceleration is:

$\boldsymbol{a} = \frac{v}{t} = \frac{5{,}55}{20} = 0{,}277\frac{m}{s^2}$ *(3.5- 8)*

So: $F_a = 300 * 0{,}277 = 83{,}1\ N$

Finally, the force needed is calculated with the Equation (3.5-2):

$$F = 882 + 9{,}78 + 2078 + 83{,}1 = 3053\ N$$

And the power is calculated with the Equation (3.5-3):

$$P = 3053 * 5{,}55 = 16944{,}15\ W = 16{,}94\ kW$$

It is needing an electric motor of at least 16,94 Kw.

But instead of choosing only one motor, it will be chosen 4 motors, one for each pair of wheels, to supply the power needed in each wheel and occasion.

The chosen one of 4,5 kW called "**W22 Carcasa de Hierro Gris - Premium Efficiency - IE3"** with the characteristics shown in *(Table 3.5-1, 3.5-2, 3.5-3).*

Table: 3.5- 1: Engine's characteristics

Case	112M	**Insulation class**	F
Power	4,5 Kw	**Temperature raise**	80 K
Frequency	60 hZ	**Locked rotor time**	12 s (hot)
Poles	2	**Service's factor**	1,25
Nominal rotation	3500	**Service regime**	S1
Glissade	2,78%	**Room temperature**	-20ºC - +40ºC
Nominal Voltaje	208-230/460 V	**Height**	1000 m
Nominal current	15,9-14,4/7,18 A	**Protection**	IPW55
Starting current	108/53,9 A	**Approximate mass**	30 Kg
Ip/In	7,5	**Moment of inertia**	0,00803 kgm^2
Current in vaccum	5,36/2,68 A	**Noise level**	66 db(A)
Nominal torque	12,3 N	**Maximum torque**	310%
Starting torque	250%		

Table: 3.5- 2: Efficiency and Power's factor

Efficiency			**Power's Factor**		
50%	75%	100%	50%	75%	100%
87,7	89,0	89,4	0,74	0,84	0,88

It can be seen the electric engine in *(Figure 3.5-1)* and his measurements in *(Table 3.5-3):*

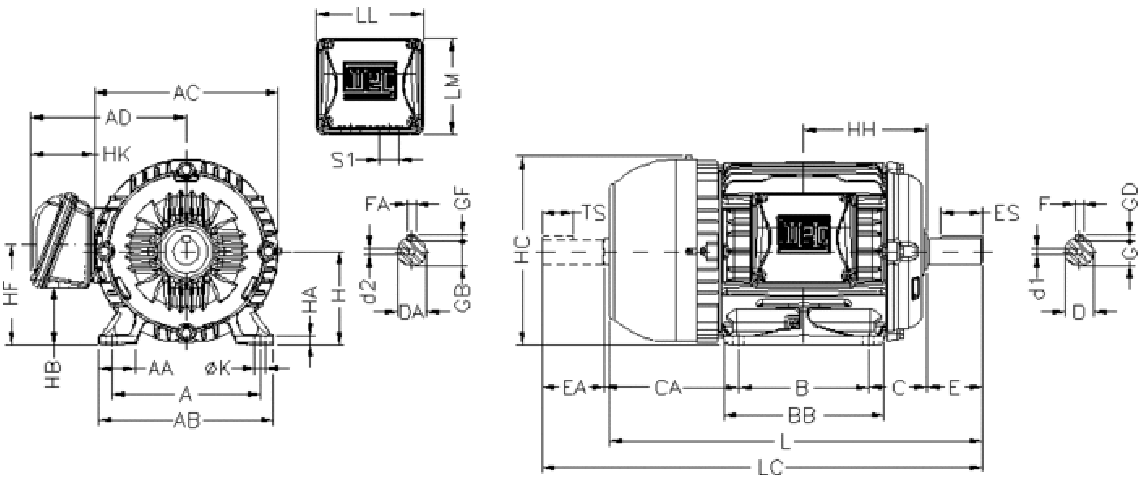
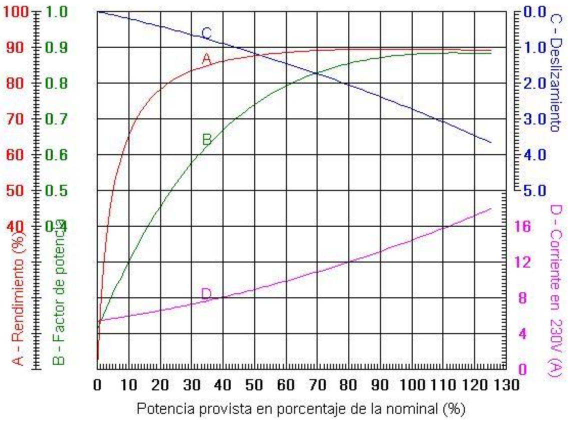


Figure 3.5- 1: Engine's measurements[15]

Table: 3.5- 3: Measurements of the electric engine

A	**AA**	**AB**	**AC**	**AD**	**B**	**BB**	**C**	**CA**	**D**	**E**
190	40,5	220	226	192	140	177	70	128	28j6	60
ES	**F**	**G**	**GD**	**DA**	**EA**	**TS**	**FA**	**GB**	**GF**	**H**
45	8	24	7	24j6	50	36	8	20	7	112
HA	**HB**	**HC**	**HD**	**HF**	**HH**	**HK**	**K**	**L**	**LC**	**LL**
10	54,5	226	280	112	140	80	12	394	448	140
LM		**S1**				**d1**		**d2**		
133		2xM32x1,5				DM10		DM8		

The performance curves are shown on *(Figure 3.5-2):*



Eficiency	**A**	
Power factor	**B**	
Glide	**C**	
Electric Current	**D**	

Figure 3.5- 2: Performance Curves of the engine[16]

Selection of the material of the axis

To overcome the hard conditions that could have the land like high slopes or shifting ground, it is needed a material for the axis strong enough, so that it doesn't broke at any circumstance and endure with the requirements of the engine and land conditions.

The material chosen is the **AISI SAE 4140 Standardized (cold drawn) Steel,** whose main characteristics are:

- It is a low alloy steel from the Cr-Mo series
- High strength and hardenability
- Good toughness
- Little deformation during fast cooling
- High fluence resistant
- Lasting resistance at high temperature

The data sheet is given in *[Table 3.5-4, 3.5-5, 3.5-6, 3.5-7, 3.5-8, 3.5-9, 3.5-10]:*

Table: 3.5- 4: AISI 4140 Chemical composition

Chemical Composition (%) of Steel AISI 4140

Steel	**C**	**Si (≤)**	**Mn (≤)**	**P (≤)**	**S (≤)**	**Cr**	**Mo**
4140	0,38-0,43	0,15-0,35	0,75-1,00	0,035	0,040	0,80-1,10	0,15-0,25

Table: 3.5- 5: AISI 4140 Linear Expansion Coefficient

Physic properties of Steel SAE 4140: SAE 4140 Steel Linear Expansion Coefficient

Value (10^{-6}/K)	**Temperature (°C)**	**Processing or condition**
12,3	20-100	Hardened oil, tempered
12,7	20-200	
13,7	20-400	
14,5	20-600	

Table: 3.5- 6: AISI 4140 Mechanic Properties

Mechanic Properties in thermic treatment conditions or cold worked

Steel	**Tensile strength (MPa), ≥**	**Creep stress (MPa), ≥**	**Elongation in 50 mm, %, ≥**	**Area reduction, %, ≥**	**Hardness (HB)**	**Sample diameter**	**Conditions**
AISI SAE 4140	1020	655	17,7	46,8	302	25,4 mm (1 inch)	Standardized at 870°C (1600°F)
	655	414	25,7	56,9	197		Annealing at 815°C (1500°F)
	1075	986	15,5	56,9	311		Cooled water from 845°C (1550°F) and temperate at 540°C (1000°F)

Table: 3.5- 7: AISI 4140 Thermic Conductivity Coefficient

SAE 4140 Steel Thermic Conductivity Coefficient

Value (W/m*K)	Temperature (°C)	Processing or condition
42,7	100	Hardened and tempered
42,3	200	
37,7	400	
33,1	600	

Table: 3.5- 8: AISI 4140 Specific Heat

SAE 4140 Steel Specific Heat (specific heat capacity)

Value (J/Kg*K)	Temperature (°C)	Processing or condition
473	20-200	Hardened and tempered
519	20-400	
561	20-600	

Table: 3.5- 9: Electric Resistance

SAE 4140 Steel Electric Resistance

Value (μΩ*m)	Temperature (°C)	Processing or condition
0,22	20	Hardened and tempered
0,26	100	
0,33	200	
0,48	400	
0,65	600	

Table: 3.5- 10: Thermic Treatment

SAE 4140 Steel Thermic Treatment

Treatment	Temperature (°C)	Hardness	Cooling/Agent
Standardized	870	302 HB	Air

Once chosen the material, it will be checked if it will endure in the working conditions.

3.5.1 Material Resistance Calculation

[References: 16,17, 18, 19,20, 21, 22, 23]

It is considered the axis that link with the wheel and considered both like just one solid rigid. So that, the biggest section break is in the linking part as we see in *(Figure 3.5.1-1).*

The axis is supported by bearings and then with the wheel. It is supposed that in the critical case, all the weight is supported by one wheel, and this is the study that will be considered.

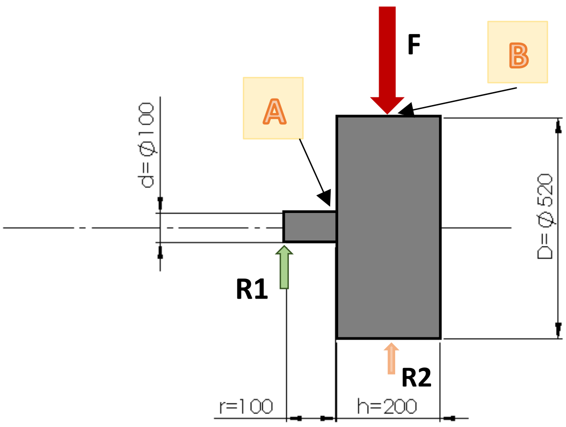


Figure 3.5.1- 1: Disposition of the Wheel elements[16]

It is considered a force F which is: $F = m * g$ (3.5.1- 1)

Where **m** (vehicle mass) = 450 Kg and **g** (gravity force) = 9,8m/s^2

→ $F = 450 * 9{,}8 = 4410\ N$

The material chosen is: **<u>AISI 4140 STANDARDIZED (cold drawn).</u>**

The **calculation to fatigue**: it tours with variable load in time, rotary flex, whose medium load is 0 (σ_m=0) as seen in *(Figure 3.5.1-2).*

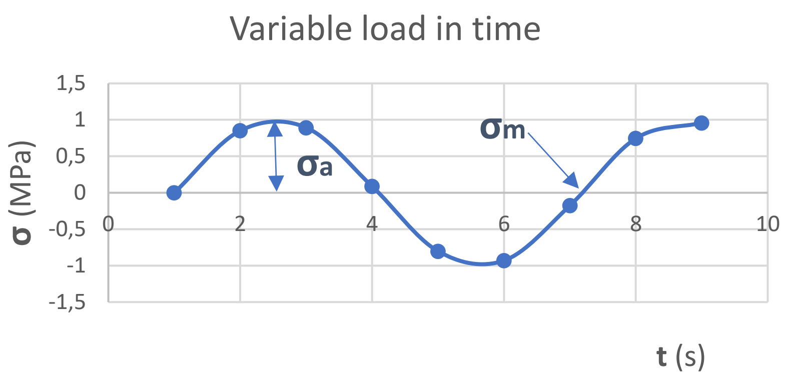


Figure 3.5.1- 2: Variable load in time[17]

It is a Ductile material, so it will be used **<u>"Goodman Criteria"</u>** *(Figure 3.5.1-3) and* equation *(3.5.1-2):*

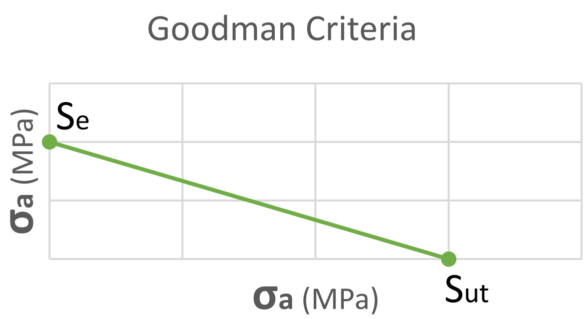


Figure 3.5.1- 3: Goodman Criteria[18]

$$\frac{\sigma_m}{S_{ut}} + \frac{\sigma_a}{S_e} = \frac{1}{n_f} \qquad (3.5.1\text{-}2)$$

$\mathbf{S_{ut}}$ = ultimate resistance to stress

$\mathbf{S_e}$ = fatigue resistance limit

The critic section is the **"A"**, because of being the biggest section break.

It works by flexion, so: $\sigma_a = \frac{32*M_A}{\pi*d^3}$ (3.5.1- 3)

$\mathbf{M_A}$ = moment in section A

d = diameter of the axis

Piece resistance shown in *(Figure 3.5.1-4):*

AISI N.	Treatment	Temperature ˚C	Tensile strenght MPa	Creep resistance Mpa	Elongation %	Area reduction %	Brinell hardness
4140	Normalized	870	1020	655	18	58	285

Figure 3.5.1- 4: Mechanical properties of heat treated AISI 4140 steel.

From the (Figure 3.5.1-4), it is obtained the ultimate resistance to stress **S_{ut}** = 1020 MPa.

The fatigue resistance limit does not appear, so it is used the approximation:

$$S_e' = 0{,}504 * S_{ut} \quad (3.5.1\text{- }4)$$

So → $S_e' = 0{,}504 * 1020 = 514{,}08\ MPa$

Now, it is applied the correction factors to get a better approximation of the S_e with the equation:

$$S_e = S_e' * k_a * k_b * k_c * k_d * k_e \quad (3.5.1\text{- }5)$$

K_a = Surface factor → Calculated with *equation (3.5.1-6)* and *(Figure 3.5.1-5):*

$$k_a = aS_{ut}^b \quad (3.5.1\text{- }6)$$

Surface finish	a factor S_{ut} Mpa	b exponent
Frosted	1,58	-0,085
Cold rolled	4,51	-0,265
Hot rolled	57,7	-0,718
As it comes out of the forge	272	-0,995

Figure 3.5.1- 5: Allowable Working Stresses

So: $k_a = 4{,}51 * 1020^{-0{,}265} = 0{,}7192$

K_b = Size factor → Calculated with equation:

$$k_b = \begin{cases} (d/0.3)^{-0.107} = 0.879d^{-0.107} & 0.11 \leq d \leq 2 \text{ pulg} \\ 0.91d^{-0.157} & 2 < d \leq 10 \text{ pulg} \\ (d/7.62)^{-0.107} = 1.24d^{-0.107} & 2.79 \leq d \leq 51 \text{ mm} \\ 1.51d^{-0.157} & 51 < d \leq 254 \text{ mm} \end{cases} \quad (3.5.1\text{- }7)$$

As d= 100 mm, $k_b = 1{,}51 * 100^{-0{,}157} = 0{,}7327$

K_c = reliability factor → determined thanks to *(Figure 3.5.1-6).*

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

Figure 3.5.1- 6: Reliability factor

The reliability chosen is of 99%, so k_c = 0,814

K_d = temperature factor → I consider K_c = 1 because we don't consider any extreme case of temperature.

K_e = concentration of efforts factor → calculated thanks to the next equation:

$$k_e = 1/k_f \quad (3.5.1\text{- }8)$$

Where **K_f** is the concentration of fatigue efforts factor, which can be calculated by:

$$k_f = 1 + [k_T - 1] * q \tag{3.5.1- 9}$$

$\boldsymbol{k_T}$ = theorical concentration of efforts factor, which can be determined by *(Figure 3.5.1-7):*

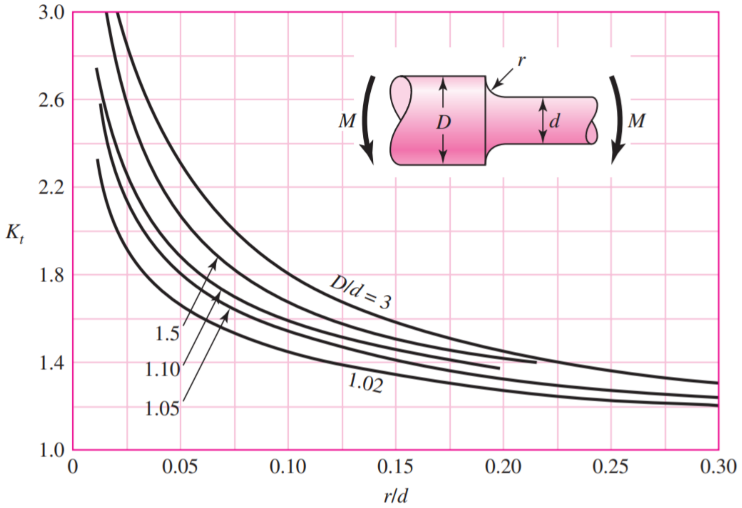


Figure 3.5.1- 7: Theorical concentration of efforts factor.

Knowing that: $\begin{cases} \frac{r}{d} = \frac{10}{100} = 0{,}1 \\ \frac{D}{d} = \frac{520}{100} = 5{,}2 \end{cases}$ → $k_T = 2$

q = notch sensitivity, calculated with *(Figure 3.5.1-8).*

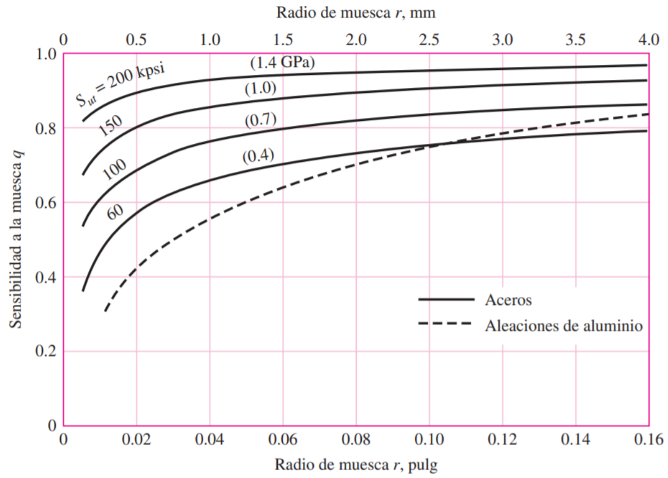


Figure 3.5.1- 8: Notch sensitivity in case of steels and forged aluminium alloys UNS A92024-T, reverse bended of reverse axial charged.

So → q = 1

Now, it can be determined with *Equation (3.5.1-9)* that: $k_f = 1 + [2 - 1] * 1 = 2$

And with *Equation (3.5.1-8)* → $k_e = \frac{1}{2} = 0{,}5$

To sum up, it can be finally determined with *Equation (3.5.1-5)* that:

$$S_e = 514{,}08 * 0{,}7192 * 0{,}7327 * 0{,}814 * 1 * 0{,}5 = 110{,}255\ MPa$$

The charge: previously, it was determined that $\begin{cases} \sigma_m = 0 \\ \sigma_a = \frac{32 * M_A}{\pi * d^3} \end{cases}$

Doing balance of power, it could be said: $\begin{cases} \sum F_v = 0 \rightarrow R1 + R2 = 0 \\ \sum M_B = 0 \rightarrow R1 = 0 \rightarrow R2 = F = 4410N \end{cases}$

So that: $M_A = R2 * \frac{h}{2} = 4410 * \frac{0{,}2}{2} = 441\ Nm$

And with *Equation (3.5.1-3)* → $\sigma_a = \frac{32 * 441}{\pi * (0{,}1)^3} = 4491989\ Pa \cong 4{,}49\ MPa$

Failure criteria → it is applied **"Goodman criteria"** with *Equation (3.5.1-2):*

$$\frac{0}{1020} + \frac{4{,}49}{110{,}255} = \frac{1}{n_f} \rightarrow \boldsymbol{n_f = 24{,}5}$$

It is a big factor, so that, it won't fail, and the axis will resist.
The chosen material is suitable for the application.

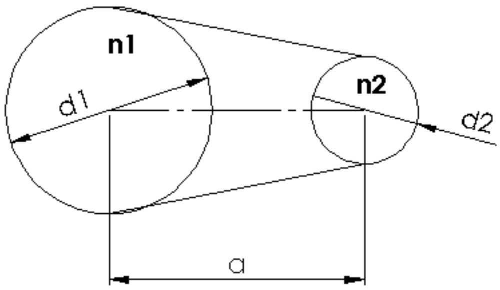
3.6 Selection of the material of the gearwheels

For the selection of the material for the gearwheels, it must be chosen a material that will have enough resistance for the applications required and the power administered by the electric engine. So that, some calculations have been done to know the minimum ultimate resistance to stress.

3.6.1 Calculations of the minimum ultimate resistance to stress

[References 24, 25, 26]

The wheels consist in a timing belt compounded by two gearwheels set like the schematics and the dimensions shown in the *(Figure 3.6.1-1):*



d1	500 mm
d2	300 mm
a	370 mm

Figure 3.6.1- 1: Timing belt scheme [24]

The transmission ratio (**i**) is by:

$$\boldsymbol{i} = \frac{d2}{d1} = \frac{n1}{n2} = \frac{300}{500} = \mathbf{0,6} \quad (3.6.1\text{- }1)$$

The maximum speed of the vehicle is: **v = 20 Km/h = 5,55 m/s**

To know n1, it is transformed the velocity in m/s to rpm by:

$$n1 = \frac{60}{2\pi} * \frac{v}{r} = \frac{60}{2\pi} * \frac{5,55}{0,25} \cong 212\ rpm \quad (3.6.1\text{- }2)$$

And using the transmission ratio, it is calculated n2:

$$\boldsymbol{i} = \frac{n1}{n2} \rightarrow n2 = \frac{n1}{i} = \frac{212}{0,6} \cong 353\ rpm$$

The gearwheel is a cylindrical-straight gear with surround profile, in general zipper finish *(Figure 3.6.1-2)*, with the next measurements:

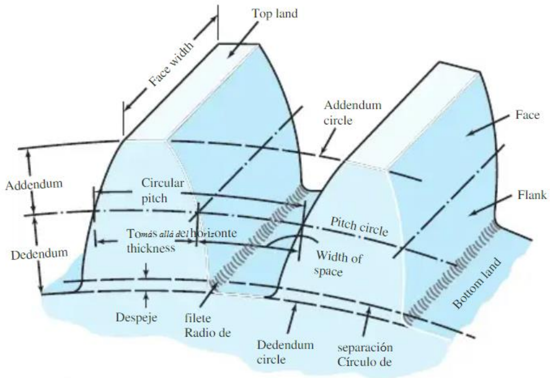


Figure 3.6.1- 2: Tooth nomenclature spur gears [25]

Primitive diameter (Dp): **Dp= 500 mm**

Number of teeth (Z1): **Z1 = 50**

Modulus (m): $m = \frac{Dp}{m} = \frac{500}{50} = 10$ *Equation 1. Modulus*

Transmission ratio (i): **i =0,6** (calculated with *Equation (3.6.1-1)*)

Velocity (n1): **n1 = 212 rpm** (calculated with *Equation (3.6.1-2)*)

Pressure angle (α): **α = 20º**

Teeth width (b): **b = 22,5 mm**

Circular pitch (p): $\boldsymbol{p} = \frac{Dp*\pi}{Z} = \frac{500*\pi}{50} \cong \mathbf{31,416\ mm}$ (3.6.1- 3)

Addendum (Ad): $Ad = m = 10\ mm$ (3.6.1- 4)

Dedendum (Dd): $Dd = 1,25 * m = 1,25 * 10 = 12,5\ mm$ (3.6.1- 5)

Clearance (C): $C = Dd - Ad = 12,5 - 10,5 = 2\ mm$ (3.6.1- 6)

Basic circle diameter (Db):

$Db = Dp * cos\alpha = 500 * \cos(20°) = 469,85\ mm$ (3.6.1- 7)

Other aspects that have to be taken into account are:

Power to be transmitted: **P = 18,5 kW**

What It will be used to determine the ultimate resistance to stress, is the **"Failure criteria for breakage":**

$$\sigma_{lim} = \frac{S_{10^7}}{Y_{Sa} * Cs} \qquad (3.6.1\text{- }8)$$

$\boldsymbol{\sigma_{lim}}$ = bending limit stress [daN/mm^2]

$\boldsymbol{S_{10^7}}$ = breaking strength [daN/mm^2]

$\boldsymbol{Y_{Sa}}$= stress factor concentration

$\boldsymbol{Cs}$ = safety coefficient

What have to be found, is the $\boldsymbol{S_{10^7}}$**,** because it determines which material must be chosen, one with a breaking strength equal or bigger than the calculated one, that is also why **Cs = 1**, it is being calculated the minimum.

$\boldsymbol{Y_{Sa}}$ will be determined thanks to the *(Figure 3.6.1-3):*

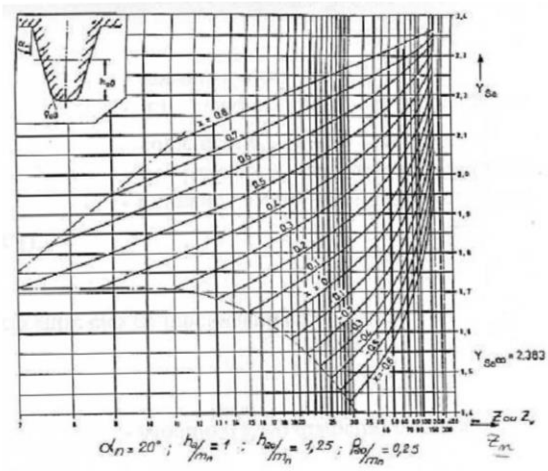


Figure 3.6.1- 3: Stress factor concentration[26]

$$\boldsymbol{Y_{Sa} = 2,1}$$

Now, to find $\boldsymbol{\sigma_{lim}}$, it will be used the formula for the managed power, which is:

$$P_{adm} = \frac{10^{-6}}{1{,}96} * \sigma_{lim} * b * \frac{m_n^2}{cos\beta} * \frac{n_1 * z_1}{Y_{Fa1} * Y_\varepsilon * Y_\beta} * \frac{K_v * K_{bl1}}{K_A * K_m * K_R} \quad (3.6.1\text{- }9)$$

It is a spur gear, so: $\begin{cases} \boldsymbol{\beta = 0 \rightarrow cos\beta = 1} \\ \boldsymbol{Y_\beta = 1} \\ \boldsymbol{m_n = m = 10} \end{cases}$

$\boldsymbol{P_{adm} = 18{,}5\ kW}$

Tooth width: **b = 22,5 mm**

Sprocket turning speed: $\boldsymbol{n_1 = 212\ rpm}$

Number of teeth: $\boldsymbol{Z_1 = 50}$

Y_{Fa1}= form factor, that could be found thanks to the *(Figure 3.6.1-4):*

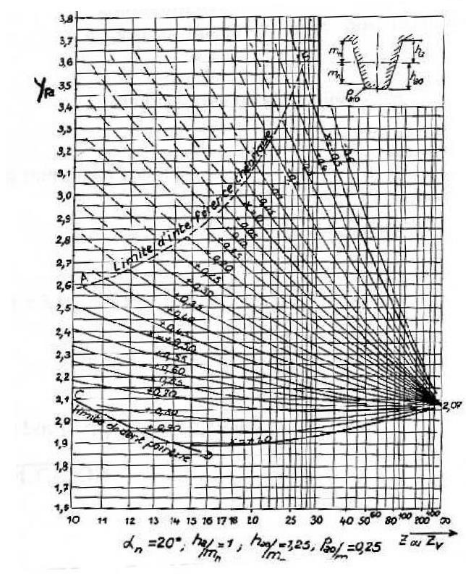


Figure 3.6.1- 4: Form factor [27]

$$\begin{cases} Z1 = 50 \\ x = 0{,}37 \end{cases} \rightarrow \boldsymbol{Y_{Fa1} = 2{,}15}$$

Y_ε = driving factor → $Y_\varepsilon = 0{,}25 + \frac{0{,}75}{\varepsilon_\alpha}$ (3.6.1- 10)

ε_α is the driving relationship, which can be calculated thanks to*:* (3.6.1- 11)

$$\varepsilon_\alpha = \frac{1}{\pi * cos\alpha_1} * \left[\sqrt{\frac{Z1^2}{4} * sen\alpha_a{}^2 + Y1^2 + Z1 * Y1} + \right.$$

$$\left. \sqrt{\frac{Z2^2}{4} * sen\alpha_a{}^2 + Y2^2 + Z2 * Y2} - \left(\frac{Z1+Z2}{2}\right) * sen\alpha_a \right]$$

Z1 = 50 y Z2 = 30

$$\boldsymbol{\alpha_a} = arctg\left(\frac{tg\alpha}{cos\beta}\right) = arctg\left(\frac{tg20°}{cos0°}\right) = \mathbf{20°} \quad (3.6.1\text{- }12)$$

$$Y1 = Y2 = cos20° = 0{,}94 \quad (3.6.1\text{- }13)$$

Substituting in the *Equation (3.6.1-11)*, it is obtained the next result:

$$\boldsymbol{\varepsilon_\alpha = 1,61}$$

And now it can be obtained the driving factor thanks to *Equation (3.6.1-10)*:

$$\boldsymbol{Y_\varepsilon = 0,7158}$$

$\boldsymbol{K_A}$ = application factor determined thanks to (Table 3.6.1-5).

Table 3.6.1- 1: Application factor

Characteristics of the drive machine	Characteristics of the working machine		
	Uniform	**Medium shocks**	**Strong shocks**
Uniform	1,00	1,25	1,75
Medium shocks	1,25	1,50	2 or more
Strong shocks	1,5	1,75	2,25 or more

$$\begin{cases} Drive\ machine \rightarrow uniform\ (electric\ engine) \\ Work\ machine \rightarrow medium\ shocks \end{cases} \rightarrow \boldsymbol{K_A = 1,25}$$

$\boldsymbol{K_v}$ = dynamic factor

Is general zipper finished (v ≤ 20 m/s), so:

$$\boldsymbol{K_V} = \frac{6}{6+\sqrt{v}} = \frac{6}{6+\sqrt{5,55}} = \mathbf{0,718} \qquad (3.6.1\text{- }14)$$

$\boldsymbol{K_m}$ = load distribution determined with (Table 3.6.1-2).

Table 3.6.1- 2: Load distribution

SUPPORT CONDITION	**FACE WIDTH (mm)**			
	≤ 50	**150**	**225**	**400**
Exact mounting,	1,2	1,4	1,5	1,8
Less rigid mounts	1,6	1,7	1,8	2,0
Accuracy and assembly so that there is incomplete contact with the face	>2,0			

$$\begin{cases} Exact\ mounting \\ b = 22,5 \end{cases} \rightarrow \boldsymbol{K_m = 1,2}$$

$$\boldsymbol{K_{bl}} = \text{duration} \rightarrow K_{bl} = \left(\frac{10^7}{N}\right)^{exp} \qquad (3.6.1\text{- }15)$$

It is supposed endless life, so N=10^7, and $\boldsymbol{K_{bl} = 1}$

$\boldsymbol{K_R}$ = fiability, determined by *(Figure 3.6.1-8):*

Table 3.6.1- 3: Fiability factor

Fiability	**K_R (Y_Z)**
0,9999	1,50
0,999	1,25
0,99	1,00
0,90	0,85
0,50	0,70

It is supposed a fiability of 99%, so → $\boldsymbol{K_R = 1}$

Once having all the terms of the *Equation (3.6.1-9)*, they are substituted, and obtained:

$$\boldsymbol{\sigma_{lim} = 4,89\ daN/mm^2}$$

Now, it can be used the failure criteria for breakage with *Equation (3.6.1-8)*, and obtain breaking strength:

$$\boldsymbol{S_{10^7} = 10,26\frac{daN}{mm^2} = 102,6\ MPa}$$

With this value, it is obtained the minimum breaking strength that must have the material to endure in the most demanding situations.

Almost every steel or foundry have this minimum value, so that, any could be chosen for this application. The chosen one is ASTM360 60HB.

3.7 Arm designed for the application of the soil sensor and ground shaker

For the application into the soil of the soil sensor and the ground shaker, the designe into solid works of the articulated arm is show in *(Figure 3.7-1):*

Figure 3.7- 1: Articulated Arm

The arm will be connected into the vehicle as is shown in drawing MPfu 16.02.001.

In the extreme part of the arm (the black part), it will be connected the items for the applications needed.

It will be an electric arm controlled by an automated control connected into a controller situated inside of the vehicle, and which contains all the data programme for its determined job.

The motion will be simplified by movements parallel or perpendicular to the ground to make it easier and not disturb the other components of the vehicle.

4. FUNCTIONING

In this part, it will be explained the main functions of the designed vehicle.

This vehicle has been designed to move autonomously all around the terrain but in a clever way, following a previously established pattern into the control system, thanks to the dispositive NovAtel® system for the automated guidance. The path followed by the vehicle could be changed depending on the actions demanded in each moment.

In some preselected areas, it will be stablished some stops to take the samples. When the vehicle reaches that stand, it will stop and start with the sample collection action:

- First, the lower folding door will be open to let the indoor devices go out to the exterior.
- Second, the articulated arm holding the ground shaker will go down into the ground and it will be powered starting the action to be inserted into the ground as much as it has been designed.
  This is a fundamental action for our process of taken samples, because if it is taken them from very shallow earth, they will not be very precise and won't tell the real state of the ground. To be more precise, it must be inserted the sensor into an enough depth to get accurate information.

- Now it is time for the sensors. For this action, the previous articulated arm will have to pick itself up into the initial position. Then, the vehicle will be programme to move straight the necessary distance to stablish the next arm with the sensor in the precise position where the hole was done by the ground shaker, so that the arm will go down across the hole till position the item into the end of the hole. It will be located there the time enough needed to get all the information. It will depend on the kind of sensor chosen.
- To facilitate the different actions of the arms, they will only move perpendicular to the ground. That is because the vehicle will have only to move straight the exact distance of the difference of the positions of the arms in the vehicle, something that is factory set, so that it is always the same distance.
- After that, all the collected information will be stored into a computer integrated in the vehicle, which will send all the information remotely into a local centre where the owner could see it and analyse it.
- Then, the arms will be collected themselves into the vehicle again, the lower folding door will be closed, and the automated vehicle will reach the next stablished stop to do the same actions as mentioned before.
- Moreover, if necessary, if it is wanted to collect samples, it could be an option in which one of the arms collect them and introduce them into the vehicle.
- The vehicle will be able to move thanks to 4 engines connected for each track wheel, that will give it the power needed for each one in every operation. Apart from that, the small gearwheels will be able to go up and down when needed thanks to a pulley system connected to the motor, so that they could move independently the other gearwheels for each occasion.

5. DESCRIPTION OF THE TECHNOLOGICAL PROCESS OF THE MACHINING OF THE ARM WRIST

In this part of the report, it will be shown briefly the machining process of the arm wrist, with their parameters and tools used.

The part which be machined, is part of the folding arm, and it will help to guide correctly the tools which will be inserted into the ground.

The material used for the product is ASTM360 60HB, and the initial rectangular block will be of 54x59x26 mm.

The machine used is a Multitask 01 – Medium (8-12" chuck), whose main characteristics are shown in (Table 5-1).

The machining process with all the characteristics are shown in drawing MPfu 16.04.003.

Table 5- 1: Multitask machine characteristics

N min	1 rpm
N max	5000 rpm
P max	22 kW
T max	500 Nm

The operation of the machining of the part will be divided into 3 steps, placing the block in each step in 6 points, depending on the faces to be milled in each one.

The tools used are shown in (Table 5-2, 5-3, 5-4, 5-5, 5-6).

Table 5- 2: Main characteristics of tool 1

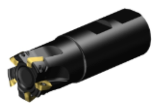
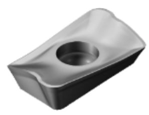
<table>
<tr><td rowspan="12">TOOL 1</td><td rowspan="6">Tool holder: RA390-032M32-11H</td><td>Cutting diameter</td><td>32 mm</td><td rowspan="6"></td></tr>
<tr><td>Max. depth of cut</td><td>10 mm</td></tr>
<tr><td>Usable length</td><td>40 mm</td></tr>
<tr><td>Functional length</td><td>100 mm</td></tr>
<tr><td>Diameter of connexion</td><td>32</td></tr>
<tr><td>Maximum cutting depth</td><td>5,5 mm</td></tr>
<tr><td rowspan="6">Insert tool: R390-11 T3 31E-NL H13A</td><td>Tip radius</td><td>3,1 mm</td><td rowspan="6"></td></tr>
<tr><td>Width</td><td>6,8</td></tr>
<tr><td>Efective length</td><td>10 mm</td></tr>
<tr><td>Mayor cutting angle</td><td>90 deg</td></tr>
<tr><td>Thickness</td><td>3,59 mm</td></tr>
<tr><td>Maximum cutting depth</td><td>10 mm</td></tr>
</table>

Table 5- 3: Main characteristics of tool 2

<table>
<tr><td rowspan="8">TOOL 2: 1P231-0200-XA 1630</td><td>Tip radius</td><td>0 mm</td><td rowspan="8"></td></tr>
<tr><td>Max. depth of cut</td><td>6,5 mm</td></tr>
<tr><td>Usable length</td><td>6,5 mm</td></tr>
<tr><td>Functional length</td><td>57 mm</td></tr>
<tr><td>Diameter of the body</td><td>2 mm</td></tr>
<tr><td>Diameter tolerance</td><td>h6</td></tr>
<tr><td>Shear angle</td><td>5,5 deg</td></tr>
<tr><td>Max. turning speed</td><td>80000 rpm</td></tr>
</table>

Table 5- 4: Main characteristics of tool 3

TOOL 3: 860.1-0800-024A1-NM H10F	**Cutting diameter**	8 mm	
	Max. depth of cut	6,5 mm	
	Usable length	25,1 mm	
	Functional length	77,9 mm	
	Tip length	1,1 mm	
	Total length	79 mm	
	Diameter tolerance	H7	
	Tip angle	130 deg	
	Max. turning speed	19099 rpm	

Table 5- 5: Main characteristics of tool 4

TOOL 4: R216.32-00630-AJ06G 1620	**Cutting diameter**	0,6 mm	
	Max. depth of cut	0,6 mm	
	Usable length	6 mm	
	Functional length	57 mm	
	Diameter tolerance	H6	
	Helix angle	30 deg	
	Max. turning speed	80000 rpm	

Table 5- 6: Main characteristics of tool 5

TOOL 5: RA215.26-4050HAL45L 1620	**Cutting diameter**	15,875 mm	
	Max. depth of cut	71,438 mm	
	Usable length	71,438 mm	
	Functional length	139,7 mm	
	Diameter tolerance	H6	
	Helix angle	50 deg	
	Max. turning speed	80000 rpm	

5.1 Operations and tools

Once it is stablished the tools to be used, the operation steps will be:

Step 1

In this step it will be machined one of the faces of the initial block.

At first, it will be pre-machined the face 2mm, to prepare it for the machining, with Tool 1.

Then, it will be done the straight slot hole with Tool 2, the big Ø8 mm hole with Tool 3, and the small Ø1 mm holes around the big one with Tool 4.

Except the Ø8 mm hole, which will be a trough hole, the other ones will have a depth of 4,5 mm.

The result is like shown in (Figure 5.1-1).

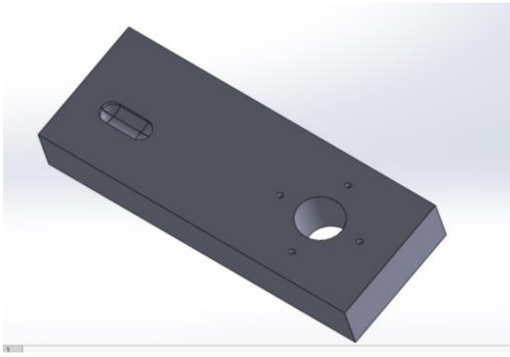


Figure 5.1- 1: Step 1

Step 2

Now, the orientation of the piece is changed to mill the opposite face of the face milled before.

In this step it will also be pre-machined the face with Tool 1 for 2 mm, and then the straight slot hole with Tool 2, the Ø1mm holes with Tool 4, and to finish, the shape of the piece with tool 5.

The result is like shown in (Figure 5.1-2).

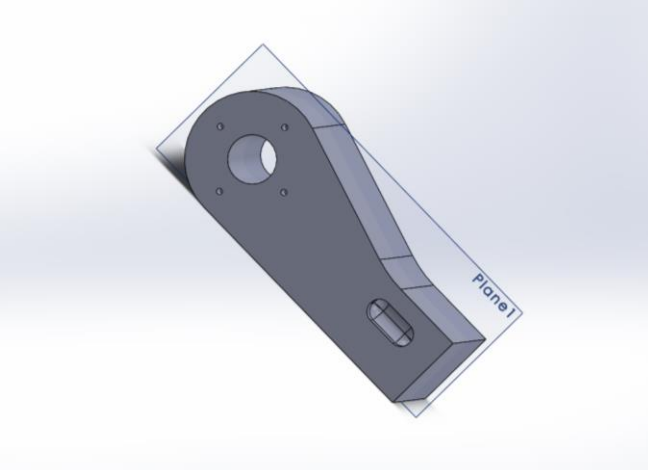


Figure 5.1- 2: Step2

Step 3

To finish up with the piece, the orientation of the piece is changed again to mill the inside.

It will be milled the inside with Tool 5, letting 4mm of thickness from the faces milled before, and till letting 4,5 mm of thickness from the bottom. Then, It will be milled completely the inside 27mm of length from the part of the drills with Tool 1.

The piece is now finished, as it is seen in (Figure 5.1-3).

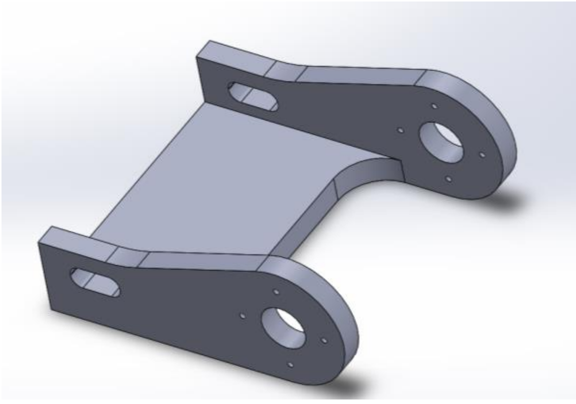


Figure 5.1- 3. Step 3

6. SAFETY OF WORK: SAFETY REQUIREMENTS DURING WORKING WITH THE DESIGNED CONSTRUCTION

6.1 Use

Automated vehicles refer to that of whose aspects of a safety control function (e.g., brake, speed up or turn) happen without direct driver input.

This automated vehicle could be provided by cameras, GPS, board sensors or other items to get information of the environment in order to take decisions into the safety-critical situations and act in a proper way by controlling their mechanisms.

While the vehicle is working, signalling lights must be installed in order to show its presence and that it is switched on.

Do not use the vehicle in extreme situations of which is not prepared to face such as extreme weather situations, extreme steep places or ravine or glare areas.

6.2 Breakdown signs

If some of the lights that show breakdown of any of the components are switched on, disconnect immediately the vehicle and take it to repair. Do not use it unless no emergency light is on.

6.3 Emergency shutdown

The vehicle must have an emergency shutdown that stops the action of the actuators (steering wheel, brake, throttle, and gearbox) if any breakdown signal is on or runs into an obstacle that cannot be overcome.

6.4 Electronic Control Systems Safety. Sensors

For the safety of the vehicle, it must have installed an Electronic Sensor System that allows it to know all the obstacles around him, identifying and recognising what kind of obstacle is, and make it take decisions about the action to take depending on the type it is, braking, turning, requesting more power, accelerating or whatever the situation requires it.

6.5 Maintenance

For all the maintenance operations, the vehicle must be switched off and resting on the ground.

Lubrication

The lubrication level must be checked regularly to assure that they are in the correct ones, with the right amount of oil and grease.

Before any lubrication operation, all the lubricated areas must be cleaned properly to avoid any impurities that may cause a bad operation of the parts.

Moreover, it must to be checked if there are any oil leaks.

Checking the condition of the wheels

To assure the smooth running of the wheels, it must be checked its condition, and look if the tire condition of the timing belt has no cracks, or if its wear is uniform. In the event that the minimum failure is detected, it must be immediately exchanged for another in good condition.

Storage

For the storage of the vehicle, it must be sought a good place that do not expose it to bad environmental conditions that could damage it.

6.6 Environmental requirements

Manufacturing

To reduce pollution in this part of the process, more environmentally friendly equipment should be use, predominating renewable energy, and avoiding manufacturing multipoint , trying to manufacture as much components as possible in the same factory so that the pollution produced by the transport of that components to each place get reduced.

Use

This is an electric vehicle, so that, the pollution coming from the combustion of the fuels are completely removed.

What it must be control, is the disposal of the lubricants to the waste points established by law.

Disposal

Once one of the components or the hole vehicle is broken or has reached its life cycle, and cannot be repaired, it must be disposed in the correct waste points depending on the kind of component, and check if any of them can be recycled.

Do not leave any of that components into the environment, because the damage it can cause could be very damaging for the eco-system.

7. ECONOMIC CALCULATION

7.1 Project cost calculation

In this part of the project it is roughly calculated the cost of the product, including the materials needed for its construction and the designs expenses. It can be seen the different costs in (Table 7.1-1, 7.1-2).

Table 7.1- 1: Standard Items

Nr.	Item	Standard	Quantity	Price (€)	Sum (€)
1	M10x25 steel grade a hexagon head bolt	DIN-933 A2	12	0,16 €/u.	1,92
2	A 10 Packing ring	DIN-125 A4	12	0,03 €/u.	0,36
3	Key 28x16x140 Form A	DIN 6885	8	6,79 €/u.	54,32
4	Circlip 100x3	DIN 471	16	1,63 €/u.	26,08
5	Circlip 80x2,5	DIN 471	16	0,97 €/u.	15,52
					Sum: 98,2

Table 7.1- 2: Catalogue items

Nr.	Item	Quantity	Price (€)	Sum (€)
1	NovAtel	1	16.283,00	16.283,00
2	Soil sensor T/H/CE	1	199,79	199,79
3	Ground shaker	1	149,95	149,95
4	Electric engine	4	313,00	967
5	Roller bearing: SFK481800 6216	8	66,09	528,72
				Sum: 18.128,46

Table 7.1- 3: Stock items

Nr.	**Item**	**Material**	**Note**	**Quantity**	**Price (€)**	**Sum (€)**
1	Bar	Steel AISI 4140 Norm	Ø102 mm	5 m	12 €/m	60
2	Bar	Steel ASTM A360	Ø550 mm	1 m	50 €/m	50
3	Bar	Steel ASTM A360	Ø350 mm	1 m	22 €/m	22
4	Plate	Steel AISI 316L	t = 4 mm	0,25 m^2	12 €/m^2	3
5	Plate	Aluminium 3003 alloy	t =15 mm	3 m^2	20 €/m^2	60
6	Plate	Polypropylene		0,15 kg	1,35 €/kg	0,21
						Sum: 195,21

The total cost of the supplies is: 18.421,87 €.

Now it has to be sum up the transport, stablishing it as 10% of the supplies cost:

$$C_T = C_S * 0{,}1 = 1.842{,}19\ € \qquad (7.1\text{- }1)$$

Where C_T is the cost of transport and C_S is the cost of the supplies.

So that, the total cost (C) will be:

$$C = C_S + C_T = 20.264{,}06\ € \qquad (7.1\text{- }2)$$

Once stablished the cost of the supplies, it is set the approximation of hired equipment costs for a month in *(Table 7.1-4)*. Tools and consumables are purchased, and the depreciation period is about 2 years, but as we are only using the tools for a month, the depreciation cost will be:

$$Dt = \frac{Pt}{2years*12\frac{months}{year}} = 18{,}75\ € \qquad (7.1\text{- }3)$$

Dt is the depreciation cost and Pt is the purchased cost.

Table 7.1- 4: Hired equipment

Nr.	**Hired equipment (including transportation)**	**Price (€/year)**
1	CNC multitask machine: Mazak i-20027	2000,00
2	Cutting centre: ESAB Hydrocut LX 400029	3000,00
3	Instruments for inspection	800,00
	Equipment purchasing (including transportation)	
4	Tools and consumables	450,00
5	Tools depreciation	18,75
		Sum: 6268,75

For the operations to be done, it is stablished the cost approximation for the manufacturing of the parts in *(Table 7.1-5)*.

Table 7.1- 5: Manufacturing costs

Nr.	**Task**	**Price (€)**
1	Turning	1000
2	Milling	1000
3	Cutting	2000
4	Drilling	300
5	Painting	200
		Sum: 4500

For the power systems and gear and greases lubricants, it could be stablished an approximation cost of 1500 €

The design and assembly of the vehicle also needs of the work of people who get salaries, and this cost for a period of a month is set in the *(Table 7.1-6)*.

Table 7.1- 6: Cost of salaries

Nr.	**Worker**	**Salary hour (€)**	**Daily working hours (h)**	**Monthly salary (€)**
1	Designer	20	8	3200
2	Manager	16	8	2560
3	Promoter	16	8	2560
4	Engineer	12	8	1920
5	Technical	10	8	1600
			Total:	*11840*
			Tax 21%:	*2486*
			Sum:	*14326,4*

Now it is stablished the different costs which are:

1. Cost of the supplies (Table 6.1-1, table 6.1-2, table 6.1-3) → 20.264,06 €
2. Hired equipment (table 6.1-4) → 6268,75 €
3. Operation costs (table 6.1-5) → 4500 €
4. Power systems and lubrication → 1500 €
5. Salaries → 14326,4 €

The total cost of the project will be:

$$C_{TOTAL} = 20.264,06 + 6268,75 + 4500 + 1500 + 14326,4 = 46.859,21\ € \quad (7.1\text{- }4)$$

It could be stablished the net profit of about the 20% of the total cost of the project:

$$Net\ profit = 0,2 * C_{TOTAL} = 9.371,84\ € \quad (7.1\text{- }5)$$

Accordingly, the total cost of the product on the market would be:

$$Market\ price = C_{TOTAL} + Net\ profit = 56.231,05\ € \quad (7.1\text{- }6)$$

To see it graphically, it can be seen in (Figure 7.1-1).

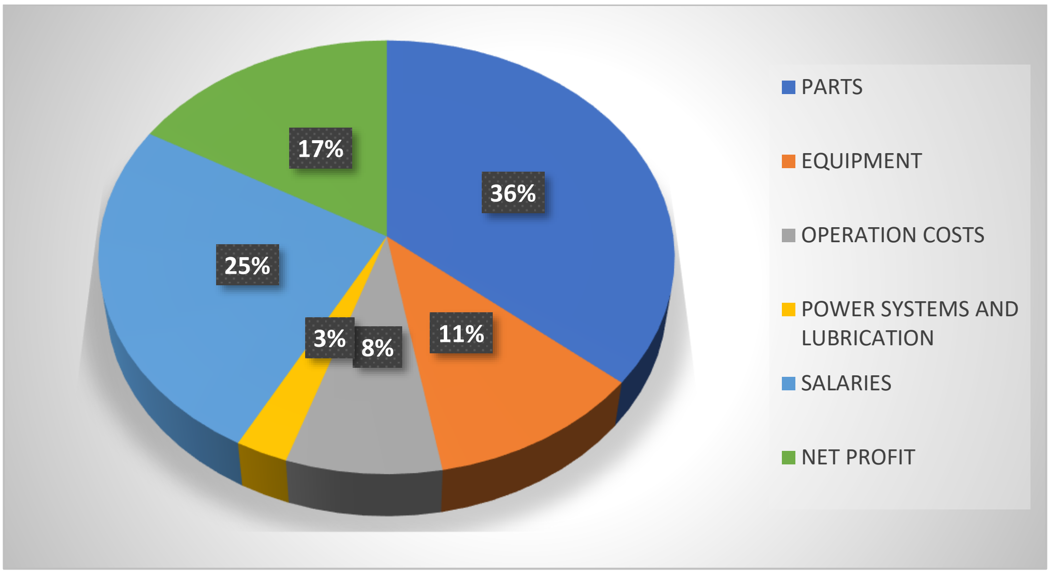


Figure 7.1- 1: Costs

7.2 Break-even point calculation

The break-even point is the one in which the total cost of the product and the total amount of incomes are equal.

To calculate it, it will be used equation (7.2-1).

$$Break - even\ Point = \frac{Fixed\ costs}{Market\ price - variable\ costs} \qquad (7.2\text{- }1)$$

$$Break - even\ Point = \frac{6.268{,}75 + 14.326{,}4}{56.231{,}05 - (20.264{,}06 + 4500 + 1500)} = 0{,}68$$

Therefore, in 1 month, less than 1 vehicle has to be produced, so that, at least 8 products have to be produced in a year.

7.3 Payback period

In this part, to calculate the payback period, it must be estimated the initial investment to produce the vehicle, it means the place used for the manufacturing, or the machines to be used.

It is estimated an initial investment of around 200.000 €.

Besides, the Earning Before Interest and Taxes (EBIT) is needed, so that it is calculated thanks to equation (7.3-1).

$$EBIT = Market\ Price - Variable\ costs - Fixed\ costs \qquad (7.3\text{-}\ 1)$$

$$EBIT = 56231{,}05 - (20264{,}06 - 4.500 + 1.500) - (6.268{,}75 + 14.326{,}4) = 9.371{,}84 \frac{€}{month}$$

So that, the profit of the first year will be:

$$9.371{,}84 \frac{€}{month} * 12 \frac{months}{year} = 112.462{,}08\ €/año \qquad (7.3\text{-}\ 2)$$

And the payback period will be:

$$\frac{200.000\ €}{112.462{,}08 \frac{€}{year}} = 1{,}77\ years = 1\ year\ and\ 9{,}24\ months \qquad (7.3\text{-}\ 3)$$

It can be seen the break-even point in (figure 7.2-1):

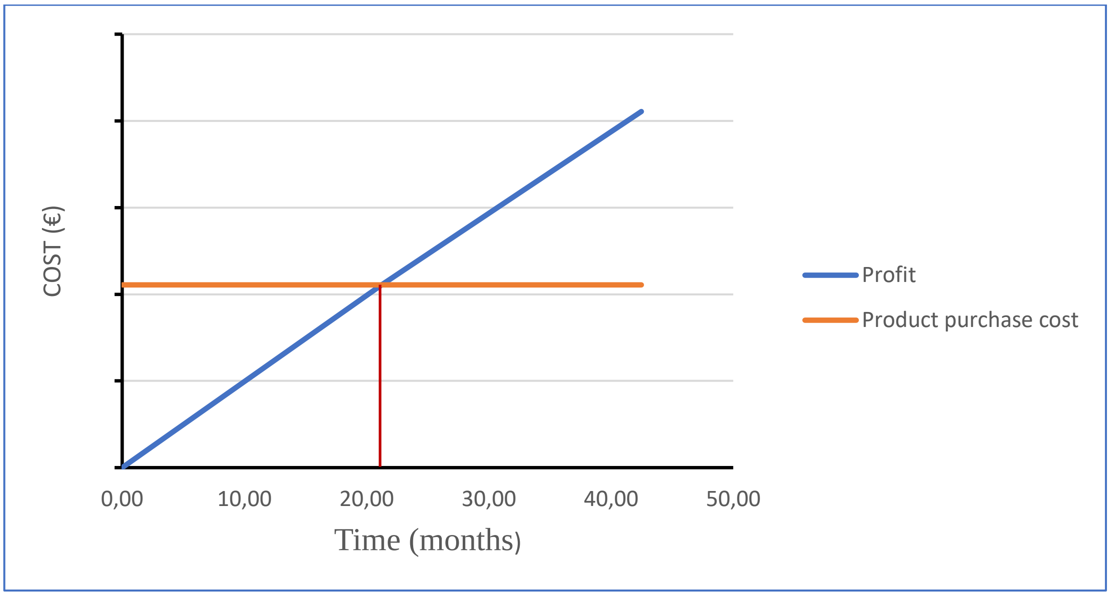


Figure 7.2-1: Payback period

This is an approximation of the payback period, because the price of the itmess could change during the time and production. However, an idea of it can be stablished, giving us a general view of the profitable time.

CONCLUSIONS

The popularity of large agricultural areas, mainly the ones dedicated to vineyards in countries like Spain, France, Italy or the EEUU, are growing in a high level. Accordingly, the demand of water and fertilizers are increasing too, and with that, the cost of them.

Moreover, many of them are being wasted, making grow the cost for squander them, that is why this vehicle will help the landowners to look for the right quantity of resources needed. This will not only help on the production costs or the waste made, but also it will help to obtain better crops, and control the necessities of each part of their terrain.

The designed gearwheels connected to 4 different engines helps the automated vehicle to move around any type of terrain, from big slopes to difficult stony grounds with mounds or loose earth.

Besides, the use of an electric engine, makes the automatic vehicle eco-friendlier.

After making the design and calculations, any other improvements have appeared, such as a chlorophyll sensor for the health of the plants or the insertion of a camera for a real time view of the environment, to visually determine the places where it is moving. Moreover, it could be improved by the installation of some solar panels to recharge the batteries and save energy.

As to the economical part, the payback period is so little, so that it could be a good inversion for farmers although the increase of the cost of land or the crops values.

TABLE LIST

Table 7.1- 1: Standard Items

Table 7.1- 2: Catalogue items

Table 7.1- 3: Stock items

Table 7.1- 4: Hired equipment

Table 7.1- 5: Manufacturing costs

Table 7.1- 6: Cost of salaries

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Approoved:
Andrius Gedvila

/FORMAT	/ZONE	/POSITION	/MARKING	NAME	QUANTITY	/REMARK
				DOCUMENTATION		
A1			MBP 20.60.01.00.000 AD	ASSEMBLY DRAWING		
				PARTS		
		1		BODY	1	
A3		2	MBP 20.60.01.02.002	LARGE GEARWHEEL	4	
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		10		MOTOR	4	
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		13		AC TO DC CONVERTER	1	
		14		3 PHASE MOTOR INVERTER	4	
		15		REMOTE CONTROL	1	
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		19		ROLLER BEARING SFK481800 6216	8	
		20		BOLT M10X25 STEEL GRADE A HEXAGON HEAD DIN-933 A2	12	

Reference Nº.	Other information:	Material:	Scale:

Responsibility: Dprt. of Mech.	Consulted by:	Document type: Part list	Document status: Educational
Owner: VGTU MPFu-17	Drawn by: Sara Lorenzo Pinto Checked by: Andrius Gedvila	Title: Assembly parts of the autonomous vehicle	Drawing Nº. MBP 20.60.01.00.000 Rev.: B · Date: 2020.05.22 · Lang.: En · Sheet: