Bachelor Degree Project

UNIVERSITY OF SKÖVDE

CAR DOOR OPENING GEOMETRY FOR ENHANCED ENTRY/EXIT

Bachelor Degree Project in Automation Engineering Mechanical
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Certification of authenticity

This thesis work is submitted by Nieves Alonso and Endika Fernández to the University of Skövde as a bachelor degree project at the School of Technology and Society.

We certified that all the material in this Bachelor Degree Project is our own work and the parts which are not, have been identified. It is significant to emphasize that our own work is mostly based on the knowledge acquired during the courses at our home Universities and it is also based on the notes collected from those courses.

ABSTRACT

This project is developed in collaboration with the University of Skövde, especially with the Mechanical Department. The report is also elaborated making use of several technical notes from the University of Málaga in Spain.

The aim of this project is to design a new concept of car doors opening mechanism which has remarkable advantage with comparison to existing mechanisms.

The first step in this report and after analysing the defined problem cautiously a market analysis has been made in order to decide the best option. Regarding all possible solutions to design the door, a new mechanism which is similar to some that already exist on the market has been decided upon.

The system is mainly concerned with a rail located in the middle of the chassis where the door can move freely through it. Moreover, a guide is fixed with screws at the bottom of the door and it works as an axle in which a piston moves along the guide making possible the opening and the locking of the door. The piston has a translational movement due to a rod in which there are two bearings that provide the rod with a rotating movement. In this manner, the rotating movement of the rod makes possible the translational movement of the piston along the guide. There is another part that completes the mechanism which is the base; this part supports the pin that connects the piston and the rod. The base is also fixed at the bottom of the door with screws, making easier the maintenance and a possible change in the mechanism if the user wants.

Before the assembly of the 3D model, the most critical zones in the mechanism are studied. The 3D model is performed with the software called SolidWorks and the FEM (Finite Element Method) simulation is carried out by SolidWorks Simulation.

The material selection is arranged to obtain the most suitable system for the requirements that have to be satisfied.

Finally, all the results are presented to the University of Skövde for possible future works.

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1. INTRODUCTION

This project evaluates a new car door opening mechanism. The design has to meet several requirements and to achieve this aim with a satisfactory result; different tests have to be performed.

The information search is the first step in any project thesis. Accordingly, after an accurate and an intensive process of researching, a great database for car doors was obtained from several sources. There are two major areas where information can be checked: the internet and books. This thesis is based on these sites to acquire a variety of different designs of car doors, as well as additional information about cars.

Organizing the information is the next step in the progress of the process which is not as important as the searching, but is still decisive for a successful result. In this case, a market analysis becomes crucial for a correct understanding of the door mechanism. The analysis covers different car doors which are provided by the automobile industry nowadays. All the outcomes are arranged by means of a simple comparison between the different existing products. As a consequence, the door mechanism chosen for this project comes out taking into account all of these doors that a user can find in the industry. Besides, thanks to this study it has been possible to achieve a system that will improve this market with the main objective of creating a user-friendly door for unconventional people (old people, physically handicapped people, children…).

The system design will be defined below, in the specific section that is used for this purpose. Moreover, different parameters are considered and calculated to make possible the process of design. This process will also be explained in detail at the same time than the material selected for the door and the accurate kinematic study will be described. They are needed for a real and a favorable design of the mechanism. It is also needed to consider the force that affects the door mechanism, and for this reason, a finite element method is used to obtain the results. Regarding these results, the design could be modified because it may be needed to be reinforced. Furthermore, depending on the material the forces will affect in a different way to the mechanism under study such as the weight, the strength or the design. But also, the result for future users can be affected because these facts influence the petrol consumption for example.

1.1 Objectives

This project aims to find a solution for most of the difficulties that a conventional car door causes in several situations such as parking space between cars or car and obstacles (columns, walls, etc…), difficulties for disabled people when they get in/off the car.

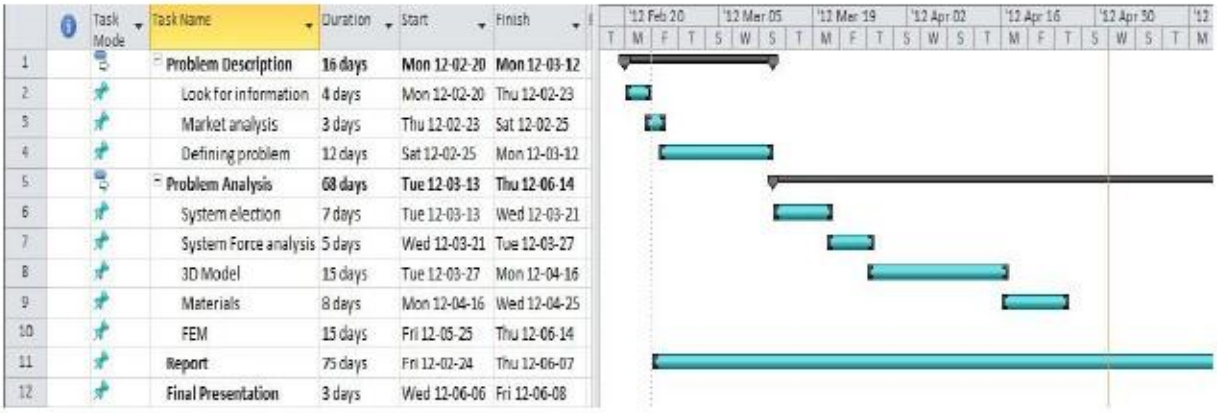
The selected mechanism is a sliding door, vertical door or disappeared door. All of them have the same functions although their design differs. Firstly, we will study the most suitable door to solve the problem of the parking space, which is the most important aim in this project. With one of those kinds of doors we will see the difficulties that people normally have when they park their cars, as it is usual to have problems of space when you get off the car in places where the parking space is very narrow. Regulations relating to parking spaces do not really consider the necessity of enough space when opening a car door. Therefore, the solution for this limitation is the main goal of the door design.

Secondly, another reason to study one of those doors is to facilitate the entrance for disabled people. Regarding the available space, if a person without mobility problems have some difficulties to get into a car, for an old or disabled person it will be more problematic indeed. The door which is designed provides these kinds of people with an easy entrance to the car. This door will not be limited in its opening ratio as it can be opened completely wherever place the car is parked, making more comfortable its use. Besides, in this project materials and manufacture methods will be considered to be available for a general car market, which means, that the mechanism is accessible to all kinds of users with different necessities.

Finally, the design process is focused on creating a new concept of door. This is not the most important objective but we want the product to be at the same time, elegant, smart, fashionable, comfortable, economical and manoeuvrable.

1.2 Project Planning

In this part how the project was planned and structured is explained. The project was planned to be able to finish in 3 month and 15 days (from end of February until end of May). The Gantt diagram can be seen in picture 1. The project was divided into different tasks. One deadline was assigned for each task. The deadline is an approximation to beginnings and endings datelines to handle the project.



	Task Name	Duration	Start	Finish
1	Problem Description	16 days	Mon 12-02-20	Mon 12-03-12
2	Look for information	4 days	Mon 12-02-20	Thu 12-02-23
3	Market analysis	3 days	Thu 12-02-23	Sat 12-02-25
4	Defining problem	12 days	Sat 12-02-25	Mon 12-03-12
5	Problem Analysis	68 days	Tue 12-03-13	Thu 12-06-14
6	System election	7 days	Tue 12-03-13	Wed 12-03-21
7	System Force analysis	5 days	Wed 12-03-21	Tue 12-03-27
8	3D Model	15 days	Tue 12-03-27	Mon 12-04-16
9	Materials	8 days	Mon 12-04-16	Wed 12-04-25
10	FEM	15 days	Fri 12-05-25	Thu 12-06-14
11	Report	75 days	Fri 12-02-24	Thu 12-06-07
12	Final Presentation	3 days	Wed 12-06-06	Fri 12-06-08

Figure 1: Gantt Diagram

1.3 Foreword

These lines explain all the procedures that have been followed in this project in order to carry it out successfully. In this way, the reader knows which objectives this project is based on and which tools have been used to get them. Besides, the reader could decide before start the reading if this project is under his/her interest.

- In this project, suitable methods and relevant scientific foundations besides current research for the work have been applied.
- The problem has been delimited by a complete description and goals to reach the solution.
- The project provides a great connection between the problem, the goals, the results and the conclusions that are presented in this part.
- In order to make it real, a realistic plan for each task regarding such as time, activities, and deliverables has been followed with reasonable and relevant adaptations to the prevailing situation as it is shown in the Gantt Chart.
- Moreover, it is shown the ability to identify and apply knowledge in the field of the project by relevant methods, predict and assess processes.
- The ability to design and handle products is proved by the 3D part in the project, also the sustainable development has been considered.
- In addition, possible risks and consequences associated with the present work are presented in this project.
- It has also sought additional complements and systems to complete the present project in a possible future work.
- Studying all the possible solutions the best one has been applied to satisfy the targets for economically, socially and sustainable development.
- This project has been developed by dividing it to tasks. Each members of the group has not only been focused on his/her tasks but also on the tasks of each other for a better understanding of the mechanism achieved. They have tried to gain the most suitable product as far as possible.

- The project shows the ability of the member of the group to examine and show their knowledge related to mechanical engineering. This is demonstrated in different parts of this project such as: Market analysis, FEM analysis, Design of 3D model, sustainable study, etc.

- In the sustainability study in this project it is explained the process and the materials used for the system which have been chosen according to an attempt of reducing costs and being environmentally friendly. Additionally, disabled people can take advantage of this mechanism as it makes easier the entrance into a car in comparison with the existing ones. Therefore, it can be assorted that social sustainability has been also taken into account in this project. On the other hand, a better solution in this term can be found.
- As in lines above has been said, this project can be better developed in a future as far as sustainability process can be improved. Besides, two additional mechanisms; suspension system and an electric motor for the opening and the locking of the door could be implemented. The mechanism presented in this work would then be improved in a great way. The mechanism design can be improved because all the calculations presented in this work shows that it is oversize due to the loads applied. In future works, the dimensions of the parts that form the mechanism could be smaller or made of different kind of material (in that case the dimensions could be modified too) in order to save money, space and to improve the sustainability.

2. PROBLEM DESCRIPTION

2.1 Market Analysis

Actually, in any project in which a new product is being developed, a market analysis becomes a necessary part of the work. All the new ideas that an engineer has to consider are based on it. The door, that this project is focused on, is not really a new concept. There is a vast market where a customer can look for his/her most suitable commodity to be satisfied. Therefore, the goal of this study is to investigate all the existing options related to this product. In order to satisfy a solution a new door mechanism is chosen based the selection on this analysis. Consequently, the new product becomes more comfortable and exciting for future consumers.

2.1.1 Kinds of Doors

The most common door which can be found in cars market is the classic door. It is the most common door used, it is well known to everyone because it opens like the typical door in a conventional house. Being very common, the assembly becomes fitting, cheap and also simple although it has a disadvantage because a huge lateral space is needed for its manipulation. The same disadvantage can be found in a gull wing door although this door makes easier the entrance as its opening is in the upper side of the car.

Figure 2: Classic Door

To continue, the scissor door should be mentioned as a very similar kind of door. This one has also a vertical opening and it is fixed in the area near the end of the windshield. Its look is very pleasing but it needs a considerable height to work properly

.

Figure 3: Scissor Door

Nowadays, there is another fantastic door in the cars market, although not very usual, appreciated by vintage drivers who love cars. It is called the suicide door. This sort of door is opened by the opposite direction to the conventional. It is hinged on the trailing edge. Additionally, the edge is closer to the rear of the vehicle. It becomes very comfortable and aesthetically as it provides a wide and easy entry at the time when the car is converted into a very sophisticated one, totally different to the rest. As a result, the space is very limited between the front edge of the rear and the rear edge of the front door and it is also more dangerous than any other door due to its special way of being opened.

Figure 4: Suicide Door

A very strange door can be found in the market, called the doom door. It is placed in the top of the car and it can be opened by many different ways. The hinges can be placed on the front, side or backwards. It provides an aesthetically pleasing look but it has a great complex and expensive system.

Figure 5: Doom Door

Furthermore, being unrelated to the previous gates, the sliding door appears in the car world. This door is opened by sliding out on rails so that small lateral space is needed for its handling. With these features the entrance and the exit are facilitated but the bodywork must be modified. Close to this concept of door is the disappearing door which works by using a window lift button to be opened and closed. In this way, the door goes inside the bodywork of the car. The best characteristic of this concept is that no space is needed but an ordinary customer cannot afford it because it is extremely expensive as the system becomes deeply complex. An easy and cheap construction system is one which consists of slides where the door is placed on rails located on the bodywork. But, in this case the bodywork must be changed, taking into account that the space is limited by the rear wheel.

Figure 6: Sliding Door

Figure 7: Disappearing Door

In the next table, a summary of the kinds of door is shown:

Table 1: Kinds of Doors

Style	Characteristics	Advantages	Disadvantages
Classic door	• Standard use • Houses doors	• Fitting assembly • Cheap assembly • Simple	• A vast lateral space is needed
Gull wing door	• Upper opening	• Entrance ease	• A vast lateral space is needed
Scissor door	• Vertical opening • Fixation in the area near the end of the windshield	• Aesthetically pleasing	• Aconsiderable height is needed
Suicide door	• Opposite opening to the normal one • Hinged on the trailing edge • Edge closer to the rear of the vehicle	• Wide and easy entry	• Limitedspace between the front edge of the rear door and the rear edge of the front door

			• More dangerous than any other door due to its special way of being opened
Doom door	• Placed in the top of the car • There are no rules for the opening. • The hinges can be placed in the front, side or backwards	• Aesthetically pleasing	• Complexand expensive system
Sliding door	• It is opened by sliding out rails	• Small lateral space needed • It facilitates the entrance and the exit	• Thebodywork must be modified
Disappearing door	• Thedooris openedand closed using a window lift button and the door goes insidethe bodywork of the car	• Almost no space is needed	• Complexand expensive system

2.1.2 Mechanical System

Concerning the mechanical system of the door, there are two great different options: slide system and spindle screw inside door. In the table below, the most important features and advantages/disadvantages of each system are shown:

Table 2: Mechanical System

Style	Characteristics	Advantages	Disadvantages
Slides system	• The door is placed on rails located on the bodywork	• Easy construction • Cheap	• Bodywork needs to be modified • Limited by the rear wheal
Guide inside door	• The Guide is inside the door • It opens opposite to the normal direction	• Bodywork is not affected	• Limitedby stability
Combination of the two previous	• On the top, a rail is placed to allow the movement of the door • At the bottom, a spindleguideis located inside the door	• Almostno significant changes have to be made on the bodywork • Stable	• Bodywork needs to be modified

There is a similar system that adopts a guide inside the door so that the bodywork is not affected because the guide inside. However, this system is bounded by the stability. It is not popular as its entrance takes place opposite to the normal direction.

2.1.3 Access System

The access system is another issue to be taken into account. This is an optional complement. Several options are studied: a ramp system and a suspension system. They are explained in detail in the next table. It has to be mentioned that they are possible aims in future works but they are not the object of study in the present project.

Table 3: Access System

Style	Characteristics	Advantages	Disadvantages
Ramp	• Itgoesbya compartment • Once it is activated the ramp goes down	• Easy to assembly • Easy to maintain	• A great space is needed for the assembly • A great space is needed to use it • Expensive
Suspension system	• It is an adjustable system for the height of the car	• It is integrated in the mechanics of the car • No lateral space is needed	

2.2 Mechanism Selection

The decision for the new product is made after an accurate and an intensive analysis previously made. At that point, the advantages and disadvantages of existing mechanisms are known. Due to that, the new concept is defined: a combination of slide and spindle guide door mechanism.

This mechanism lies in a rail placed on the middle of the chassis of the car allowing the door to move freely. At the bottom, a guide with a piston that moves through it is located inside the door, in this way almost no changes have to be made on the chassis and it resolves into a very stable solution to achieve all the requirements that the preceding doors could not solve.

3. PROBLEM ANALYSIS

3.1 3D Model

3.1.1 Introduction

In this section, the construction of the 3D model is described in steps. The door of the car and its opening mechanism are the parts to be designed. It is not necessary to build the entire car in 3D because the mechanism is based on a Volvo car but any vehicle can take advantage of this device. Instead of only the door, the opening mechanism is also constructed. In the picture below the area marked in red which becomes the aim of the study for the 3D model design is shown:

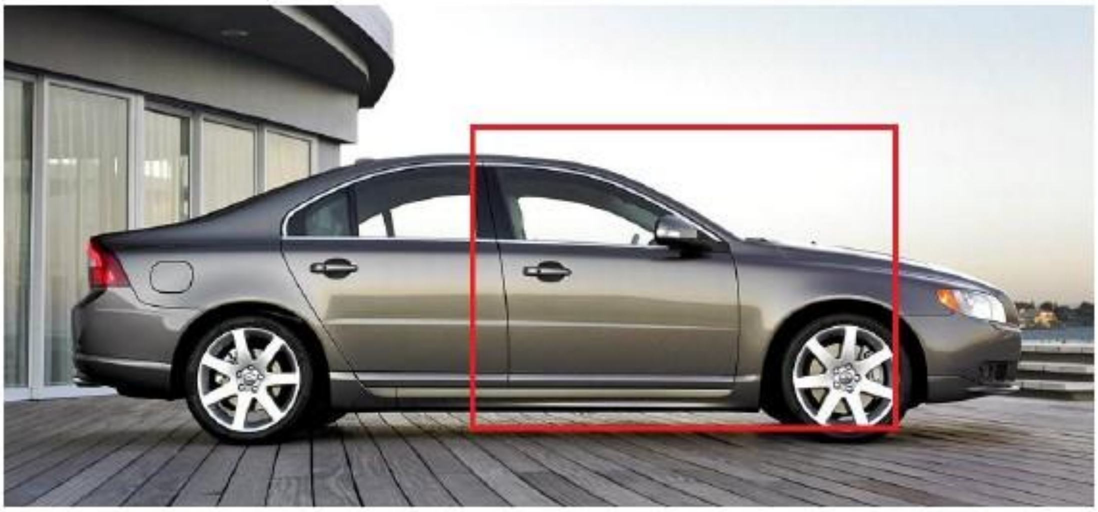


Figure 8: The part to design

Once the parts for the analysis are located the creation of them in 3D starts using the software called Solid Work 3D. Different parameters must be defined in order to achieve a satisfying solution.

The dimensions of the car are needed. A Volvo S80 is used for this issue, because it is a Sedan model which is the most common car and it is easy to carry out all the modifications on it. The Volvo Company authorized a dealer in Skövde to provide the dimensions needed for this project. Besides, Högskolan i Skövde facilitated this process because there is a real model in the facilities of the University which was lent for this purpose. Once the dimensions are taken, the system is ready to be created in 3D. The important parts for the design of the car are the door (picture 9) and the chassis (picture 10). Those are the basic parts for the 3D model that will be useful for the following levels in the process.

As soon as the basic parts for the mechanism are designed, the model, which the complete analysis is focused on, is obtained. The mechanism is divided into two parts that also have to be constructed in 3D for later reviews. The first one is the top part composed of one rail in the chassis of the car, one small wheel and two bars that connect the door with the chassis of the vehicle. The bottom part is more complex than the top part because new parts with specific characteristics and dimensions are required, and they must obey all the calculations made previously.

3.1.2 The Parts

Following, a brief description of the elements is made:

The door and chassis

The car, which the analysis is based on, is a Volvo S80. Some changes are made in order to apply correctly the mechanism created for this project.

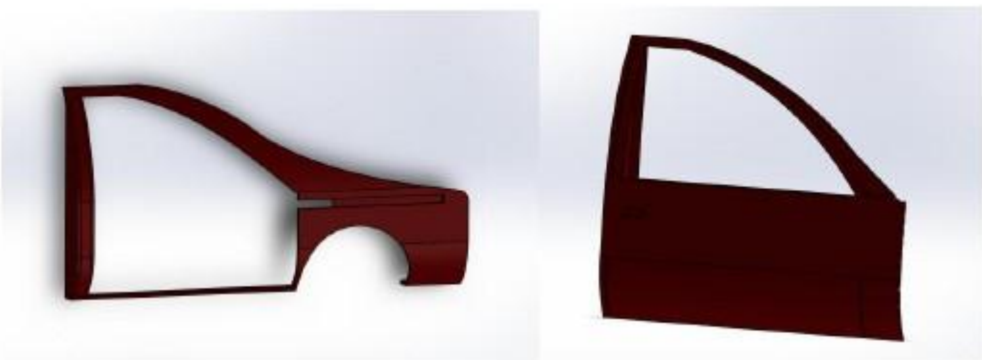


Figure 9: Chassis and Door

Guide bar

The length of the bar is adapted to the door. The diameter of the bar is 20 mm. There are normalized bars of this steel on the market.

The bar is installed in the door through screws.

Figure 10: Guide Bar

Piston

The piston slides on the guide bar and it is connected through the rod to the bearings. Axial bearings are used to resist rotations and loads applied on the system.

When the door is opened, the piston resists the whole weight of the door. The design is created using real dimensions and commercial and standard elements. Considering this, the model is carried out; displacements and stresses are calculated by FEM analysis (see FEM apart). Consequently, it is certified that one piston is enough to resist the whole weight of the door (only 15kg without considering the windows glasses).

Figure 11: Piston

Rod

The rod is installed between the piston and the base. It is connected through bearings because they are the best option to resist the rotations. The dimensions of the rod are based on the door and chassis dimensions. The length of the rod is chosen to minimize the ratio of the rail and it has also to go out to the chassis. There are standard sheet for the rod on the market.

Figure 12: Rod

Base

The base is installed in the chassis through screws which resist well the torque. The most important load in the base is the torque. The base is connected to the rod through bearings in order to resist the movement that the base has.

All the parts are optimized to obtain more space into the chassis. Besides, economic materials are used to obtain cost reductions.

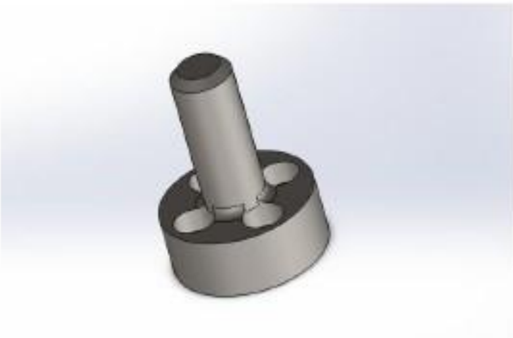


Figure 13: Base

Wheel

The wheel is settled into the rail. The function of the wheel consists in sliding on the rail; it also resists the weight of the door. The dimension of the wheel is adapted to the rail to avoid displacements. The material which the wheel is made of is Nylon because this material has low friction; this means that it does not put too much resistance when the door slides. Additionally, it has also a high level of strength. These two characteristic are important for an appropriate function.

Figure 14: Wheel

Top guide

This part is connected to the door through screws. The wheel is connected through this to the door. The shape is designed to avoid the contact to the rail when the door slides on it.

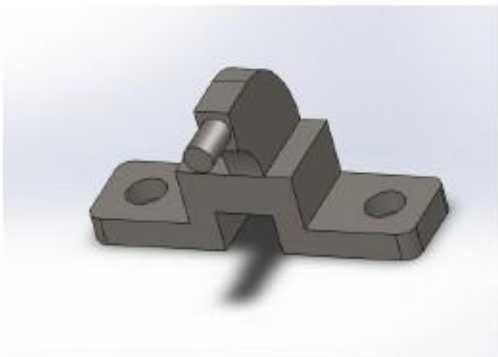


Figure 15: Top Guide

Rail

The rail is assembled into the chassis. It is installed by screws so that, the installation becomes easy. The shape is adapted to the chassis.

Figure 16: Rail

3.1.3 Part Modeling

Firstly, the rail with the correct dimension to avoid problems in the assembly is created. The rail is longer than the door so the design has to be precise. The wheel does not need great treatment as it can be formed by a simple operation; only a rounded shape becomes necessary. After that, the next part to create is the connection element between the door and the pin. This part has an exact angle and length (explained in the previous part) because it is the most important part of the mechanism. If the angle or the length is wrong, the system will not work properly. The system is connected to the door through some screws. The last part that is designed is the pin which is located between the wheel and the part that connects the door with the car.

In these lines, the construction of the parts at the bottom of the mechanism is explained. It is composed of a bar connected to a base, one rod, a guide bar and a piston bar. First, it is important to know the behavior of the mechanism. The guide bar is fitted into the door. The piston bar slides on it to open or close the door. Also, the piston bar is connected to the rod in order to rotate and to make possible the sliding of the piston bar. The rotation of the rod is limited 90 degrees. The bar with the base is connected to the car through screws and it is fixed without movement, however, the complete mechanism turns around it. The mechanism is showed in the next two pictures:

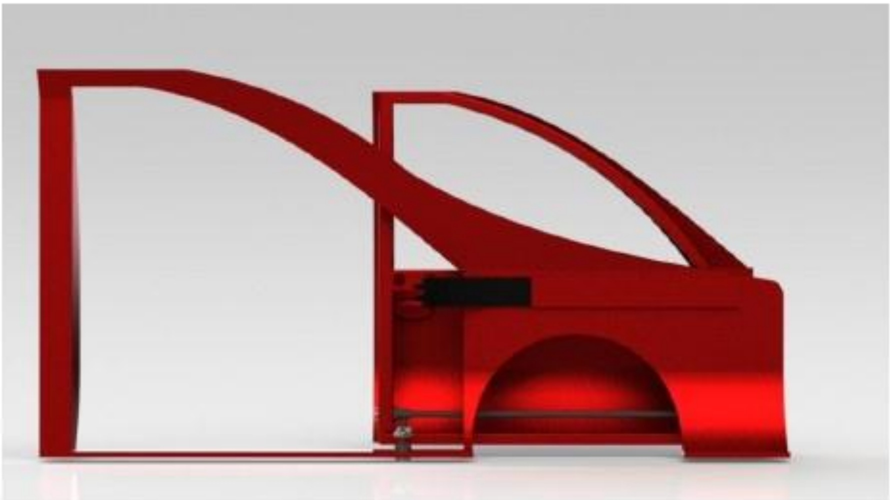


Figure 17: Door Opened position

Figure 18: Door Closed Position

3.1.4 Commercial Aspects

After designing all the parts in 3D, it becomes essential to find the necessary commercial elements. It is important to study the requirements in all the connections when assembling a system. It is known that some elements have to avoid different problems. Besides, they should reduce the final cost. Therefore, in this project these elements are the bearings, screws and the piston cap.

Piston Cap

A great important element is the piston cap. This element is a mechanical element capable to resist the movement of the rotary axes. It is characterized by its reduction of friction coefficient. Another feature of this element is the material which it is made of, this material must be softer than the material of the axes to avoid damage of the axes.

Normally, the material that is selected for the piston cap is an antifriction material.

Concerning this, a bronze alloy is selected, more specifically a phosphor bronze alloy. The reason for this selection is that this kind of alloy has a really high resistance to corrosion and also to fatigue. In terms of wear resistance it is also economical as its use is very common in the industry.

The bronze alloy selected is Bronze AISI 62. It is an alloy for general uses with antifriction properties that can resist high loads. Its tensile strength is 289.58MPa and its hardness varies between 75 and 85 Brinell.

Figure 19: Bronze Cap

Bearings

The selection of the bearings is based on products that the company SKF offers. This company has a wide catalogue of bearings with different properties according to the applications they are going to be used for. This company also provides all the data needed to make a good selection. Therefore, and after analysing the effects that the bearings in the mechanism under study present, the selected bearings are 7204BE.

Before explaining the properties of this specific bearing, 7204BE, it is important to make a brief analysis concerning the general operation of these elements. In that way it is easier to understand how they work.

A bearing is an element which is located between two components that are placed into the same axis. The bearing prevents possible glide between both components. In that case, the power absorbed by rolling is much lower than by gliding. A bearing is normally formed from four pieces: an inner ring, an outer ring, the rolling elements and a cage. The inner ring and the outer ring are fixed to the two components that connect the bearing. Both rings have rails through which the rolling elements move (balls, needles, rollers). These rolling elements revolve around their own axles causing a rolling in the rails making the turn possible. There are different kinds of bearing:

- Ball bearings
    - Angular contact ball bearings: they have the raceways of the inner and outer rings offset from each other in the direction of the bearing axes. This means they are designed to support combined loads, i.e., radial and axial loads simultaneously.

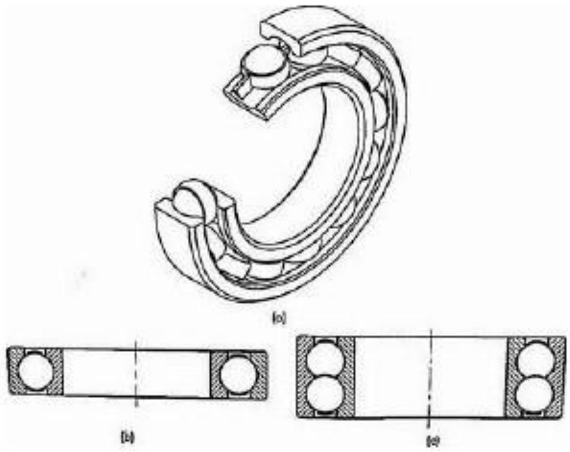


Figure 20: Ball Bearing (Single & Double) [2]

- Roller bearings (cylindrical, spherical, conical, etc…)

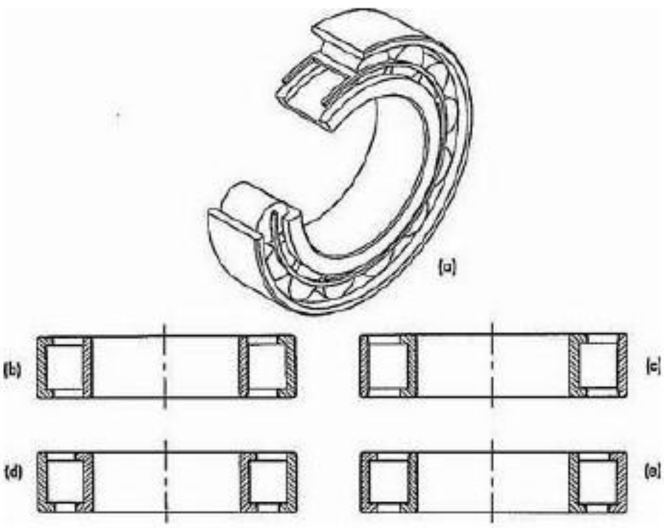


Figure 21: Roller Bearing (Different distribution of the bearings) [2]

The main reason to select one or another is the direction of the loads that they support. These loads can be axial or radial. In the table below the differences between these bearings are explained to understand the reason of the selected bearing in this project.

Table 4: Bearing Types

	Ball Bearings	Rolling Bearings
Line	Point contact The contact surface is oval when the load is applied	Line contact The contact surface is rectangular when the load is applied
Characteristics	Low resistance due to the contact between points. They work properly at high speed.	High resistance due to the line points. They resist the torque better although the stiffness is higher.
Capacity of loads	Support loads in both radial and axial direction	Support loads in axial direction, i.e. in one direction, because in the other one loading can cause their dismantlement

According to that, it can proceed to detail the characteristics of 7204BE selected bearings.

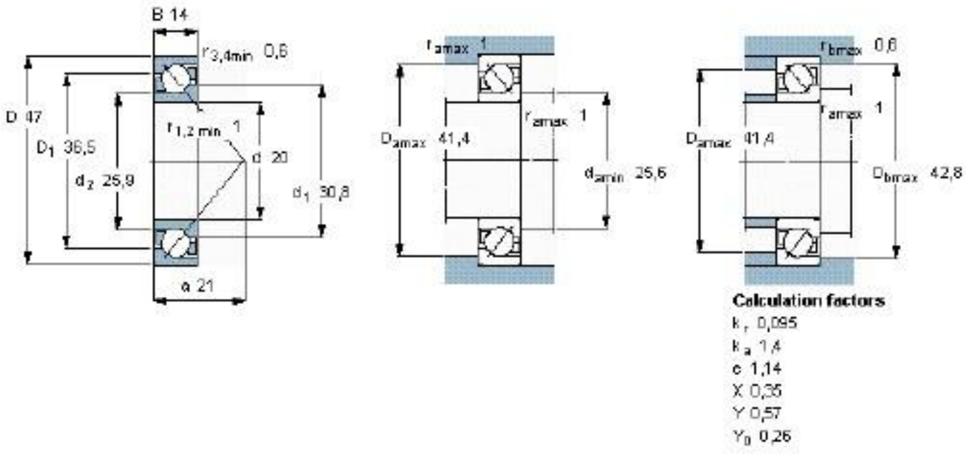


Figure 22: Bearing 7204 BE [2]

3.1.5 Closed and Opened Position

The door has two main positions: closed and opened position. The different systems to keep the door in each position are explained in this section. Additionally, the systems are economized as far as possible. The closed position uses the system of a serial car. Therefore, the final cost is reduced as it is easy to find it in the market. The system is explained with a picture below:

Figure 23: Close System

Concerning the opened position, the system has a simple function. At the end of the rail there is a small hole where the guide wheel is introduced. A slot is located there to avoid the door close by its own weight, but at the same time this slot is designed in order to make the handle of the door safer to the user as the door is stopped into it.

3.1.6 Assembly

Finally, all the elements are just designed in 3D (main parts and commercial elements). Next step is to assemble the system. First, the assembly starts with the fixed parts: the base in the chassis with the correct nuts and screws; the bar in the door; the rail in the chassis; and the top guide in the door. During the assembly, some dimensions of the parts were changed to adapt them correctly to the system. After that, parts with movement are assembled. The first one is the rod which has 90 º of rotation. This limitation is decided with advanced options. The next moving part is the bottom guide which slides on the bar with two limitations. The last moving but not less important element is the door. The door movement is a combination of all moving parts. The next step to develop is the wheel in the top guide to follow the rail. Finally, the final 3D model is achieved. The pictures below show the result:

Figure 24: 3D Model

Figure 25: 3D Model

This 3D model is created to represent the behavior of the mechanism and to find the critical zones. The Finite Element Method (FEM) is used to analyze it.

3.2 Material Selection

3.2.1 Introduction

The material selection is an important decision within the mechanical design process of a new product to make. It is of great importance to determine correctly the material for a mechanical element because the material not only affects in the calculation process but the manufacturing also depends on it. In general, the selection of the material limits the dimensions of the element according to all the requirements for the element behaviour. In the design process, an expression, that relates the dimensions of the element to the existing effects on it, is obtained. This expression relies on the dimension, and the stress that the element can support which depends basically on the material chosen for it. As a result, the selection of one of the two parameters defines another. Moreover, it is necessary to study all the factors that condition the behaviour of the element: possible impact loads, operating temperature, corrosion, etc…

3.2.2 Properties

The features of a material are characterized by several aspects which help to clarify the behaviour of the material, which generally is rather complex. The following properties define the behaviour of a material in a general way:

1. Homogeneity: A material is homogenous if its properties are the same in all points. Homogeneity is an ideal state that does not appear in real materials. However, the difference is so small that the current material is supposed to be homogenous.
2. Elasticity is the property of a material that after being exposed to an external load can recover its original shape.
3. Isotropy: A material is isotropic if it has the same elastic properties in all directions.
4. Plasticity is the property of a material that after being exposed to an external load cannot recover its original shape. It is the opposite of elasticity.

5. Ductility is the property of a material that permits it to be deformed without fracturing. Frequently, the ductility is expressed as a percentage of lengthening. Consequently, if the lengthening is over 5% the material is considered to be ductile, if the lengthening is under this quantity the material is considered to be brittle. Sometimes, the ductility is underestimated. For example, two materials with identity resistance and hardness, but one of them more ductile than another, this last one will resist a higher load. The ductility is measured by the resilience test using for it the Charpy´s pendulum. This test consists of a test tube which is notched and flexed. A pendulum falls down the test tube causing its fracture. The difference of height between the initial of the pendulum and the final height after the crash can be used to measure the energy absorbed in the fracture process.
6. Strength: The resistance σ_u is the uniaxial tension applied on a material that causes the fracture of it. [1]

Most of the data that is used in the design process is obtained by the traction test of the material. This test concerns a test bar, with normalized diameter d_0 and length l_0, which is subjected to a pure tensile load. This load is applied in stages on the material in order to capture many values of the load applied and to discover where the deformation is originated.

The result from the tensile test is represented in a graph, the stress-strain diagram. The stress= F/A_0, according to the unit deformation i= $(l_i-l_0) / l_0$, is plotted below:

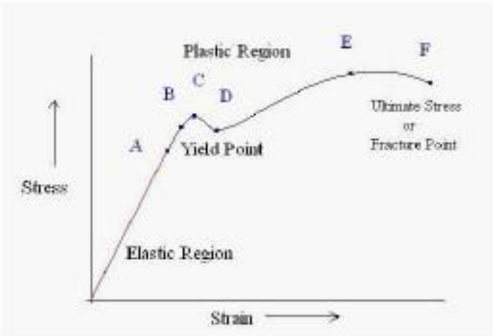


Figure 26: Stress Strain Diagram

The diagram in figure 26 shows the usual behaviour of a ductile material. Some representative points and regions can be distinguished. The material works elastically until point A is reached, this point is called the proportionality limit. At that point, the curve diverts from the straight line nearer to point B, which is called the elasticity limit, due to the fact that the material at that point would return to its original shape if the load that was supporting disappeared, although the stretch A-B is not a straight line. As it can be observed in the diagram, only the stretch until point A is strictly straight. Another important data taken from the diagram is the elasticity modulus, E, which is the slope of the line up to point A.

If the load is increased, many materials present a region called the fluency region, in which the deformation is increased without increasing the load. The point, where this starts, is called the yield point, D, and the value that causes the deformation, the yield strength, σ_y

There are materials in which this point is not easy to identify. Therefore, the yield point can be defined as the value that causes a permanent deformation of 0.2%.

Increasing the load, point E is reached as the ultimate stress, σ_u, or tensile stress, which is the maximum value of the effort reached although it is not the fracture effort that is achieved in the point F.

In the design process, sometimes the value of the fracture limit σ_u is used and otherwise the yield limit σ_y as limiting values of the effective stresses.

An important concept is the security factor, n. It can be defined as the ratio between the resistance of the material and the load that the material is subjected to.

$$n = \text{Strength } (\sigma_u \text{ or } \sigma_y) / \text{Max.stress}$$

It can also be defined as the safety margin between the stress that the element supports and the strength of the material that the element is made of. It is interesting to mention that the first only depends on the geometry and the load supports, while the second depends exclusively on the material chosen for the design. The safety factor should be increased if unknown parameters exist in the process.

Some of the parameters to consider in the design process are:

- Material: sort of, guaranteed by the data used, treatment, etc.
- Size effect: the material composition
- Grade of the load definition
- Accuracy of the method used
- Others: environment, final inspection, risk of accidents, etc.

7. Hardness: The resistance against various shape changes when a force is applied.

There are different methods to measure the hardness:

- Rockwell (HRC, HRB). It measures the depth of a bradawl in the element. There are two different methods depending on the tool used for the measure, Rockwell C if the bradawl is a cone or Rockwell B if the bradawl is a ball.
- Vickers (VHN). It uses a diamond pyramid which leaves a small footprint in the element. The grade of hardness is obtained by the ratio between the load applied and the footprint area.
- Brinell (BHN). This is one of the best methods for obtaining the hardness. It consists of a ball made of steel with a diameter of 10mm. This ball is pressed in a tube test with a load applied of 3,000kg for steel and 500kg for soft metals. [1]

3.2.3 Selection

In this project, after an intensive study of the materials that the market provides the industry with, steel has been chosen for all the pieces that form the mechanism except for the bearings and the piston cap.

The steel is an alloy of iron and carbon and additional materials which can be seen as impurities or simply as part of the composition of the steel.

Basically there are three kinds of steel: carbon steel, which apart from iron and carbon, has small quantities of manganese, silicon, sulphur and phosphorus. Alloy steel contains one or more chemical substances modifying the properties, improving them or /and affecting the heat treatments too. Finally, stainless steel which must contain at least 12% of chrome that provides this steel with peculiar properties is the last group.

According to this and after an intensive analysis about the possible materials that could meet the requirements of the system under study, it has been chosen for all the elements, except for the bearings, a High Strength Low Allow steel (HSLA steel). The reason for that election is that this kind of steel provides better mechanical properties and large resistance to atmospheric corrosion than conventional carbon steels. This steel has developed a significant importance along the automotive industry because of its hardness in comparison with the conventional steels. This steel can be used for thinner sections fulfilling the same mechanical works required. It is also attractive for the transportation equipment in which the weight reduction takes considerable relevance. This steel is designed to offer better mechanical properties and its chemical composition does not matter at all. Its composition is basically low carbon contents and several micro alloy particles such as: Mn, Mo, B, Ni, Cr, Al, Si, P, etc. In fact, the chemical composition can vary depending on the element and the efforts that it has to support. [1]

Furthermore, there is a decisive point when HSLA steel is chosen in a design process: the cost. As a result of the advantages that this steel presents, relating to the ease of its manufacturing, the improvement of its mechanical properties and the facility to transport it, its cost in the market of industry is really competitive comparing with the rest of steels.

In this project, the specific HSLA steel to satisfy the properties expected from the elements in the system is the HSLA steel 1045 AISI. The HSLA steel 1045 is really well known in the industry because of its good quality that combines high toughness-ductility with a great capacity of hardness by deformation and high resistance. This material assures the service of the elements as it is a material easy to form and it has a low cost. In addition, it offers good work wear conditions considering its tendency for plastic deformation hardening. This steel is usually used for elements such as: gears, pinions, screws, pipes, axles, cranks, etc. Depending on the heat treatment that this steel receives, the fluency limit, the yield limit and the fracture limit differ from each other. In the following table it can be observed these values.

Table 5: AISI 1045

AISI	Heat Treatment	Su (MPa)	Sy (Mpa)	Lengthening % Hardness (HB)
1045	Lamination 1200/850ºC	685	460	24212
	Normalizing 850/875ºC	700	450	25207
	Annealing 810/860ºC	620	380	27183
	Quenching 815/840ºC	710	610	15269

3.3 Finite Element Analysis

In this chapter, all the technical aspects and the calculations used on the simulation are described. The method used in this project to analyse the technical aspects and to make a structural analysis in mechanical engineering is the Finite Element Method (FEM). This method is based on the creation of a mesh of a continuous domain into smaller subdomains called elements. These elements are joined together in points called nodes. FEM is a very common tool used in mechanical engineering. This method provides stiffness and stress visualizations. Besides, it helps to optimize weight, material and cost as a result of these optimizations. It shows structures submitted to loads, stresses and their distributions. FEM is a powerful tool that, once it provides the user with the results, it procures the user with a better understanding of the results so that he/she can manage them in the best way to solve the initial problem.

In this project, the software used for the design of the 3D model and the calculations is SolidWorks Simulation 2012. This software uses FEM for the analysis. The software formulates different equations that express the behaviour of the elements in the mesh. These equations consider the connections between each element and they make reference to the response of loads, restrictions and known material properties. The steps to work properly with this method are the following:

1. Design of the 3D model
2. Insure the model is correct in geometry to start with its analysis using FEM.
3. Specify the kind of study under analysis.
4. FEM inputs. They are boundary conditions such as connections and external loads, materials used in each element of the construction, fixing points, and selection of the mesh.
5. Simulation is fulfilled by the software.
6. Evaluate the results provided by the analysis of the software.

It is important to make these steps cautiously, especially the FEM inputs step as this directly affect the model and the calculations.

3.3.1 Simulation Process in Solid Works Simulation 2012

In this part, it is explained the process followed to achieve a proper simulation for the mechanism under study. It is intended to clarify all the steps for a better understanding to the reader.

3.3.2 Parts

The mechanism presented in this project is composed mainly of 4 parts: a bar, a piston, a rod and a base. These parts are assembled together creating the mechanism. There are some commercial elements like the bearings or the screws that make possible the joint of these parts and their movements. The commercial elements do not appear physically. They are replaced by their effects in the mechanism. SolidWorks Simulation allows these joint elements to simulate the behavior of the mechanism without creating a detailed geometry.

3.3.3 Mesh

The mesh generating is a crucial step in the analysis of the model. The software uses an automatic mesh generation according to the size of the global element, the tolerance and the local specification of the control of the mesh. The software estimates a global element size for the model. In this case, the mesh used for the calculations in FEM is formed by parabolic tetrahedral element with high quality. This kind of element of the mesh is defined by 4 angular nodes, 6 central nodes and 6 edges. This kind of element provides better solutions than any other because it represents curves shapes with a high precision. Besides, it provides accurate mathematical solutions. In consequence, the elements selected for the mesh gives an analysis with results close to reality.

3.3.4 Von Mises Failure Criteria.

With SolidWorks Simulation the stresses can be presented as the effective stresses due to von Mises.

These stresses are related to a criteria known as the "Theory of maximum distortion energy".

Considering principle stresses in the element as: σ_1, σ_2 and σ_3, the von Mises´ stress is defined:

$$\sigma_{VM} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}} \geq \sigma_Y$$

This theory says that a ductile material starts distorting when von Mises´ tension reaches the tension limit. Most of the cases, the tension limit is considered as the yield limit. If this expression is fulfilled, the material will break. Von Mises´ tension must have a lower value than the tension limit. The yield limit depends on the material. Besides, it is of great importance to consider a safety factor in the design. This factor is a function of the design stress and yield strength. It can be defined in terms of von Mises´ tension and tension limit as:

$$SF = \frac{\sigma_{\text{limit}}}{\sigma_{\text{VonMisses}}}$$

3.3.5 Dynamic Analysis

In this section, the behavior of the door in movement is analyzed. Tension stress is indicated when the door is moving. So, it is possible to certify that the new model is correct. Moreover, the stress analysis of the system is started by a static study. The Finite Element Method is used for this analysis and the program SolidWorks Simulation is used.

Boundary Conditions

In this part, the different boundary conditions in the system are defined. There are two boundary conditions: connections and forces/pressure.

Connections

The mechanism has different connected points. The first point is the top guide. The wheel slides along the rail and this is considered as a support because the wheel can move only in one direction. Friction is neglected. After that, the guide bar is fixed to the door through screws. There is a rigid connection between the edges to the door. It can be concluded that the door and the bar can be considered as the same piece.

The piston has two different systems connection. The first connected point is to the guide bar. This connected point is a support because it can slide in one direction (on the guide bar). The last connected point is the base of the piston. It is connected to the rod through rigid connection.

Force

In this mechanism, there is only one external force which is the force that the user applies. This force is applied on the handle. The maximum force is 490 N for a normal person. This value is the average value of force that a normal person can apply. The direction of the force is in the bar direction because the door is opened in this way.

Mesh

The mesh is very important in FEM. The result can change depending on it. It is chosen the smallest measure for the mesh. An accurate result is obtained because the parts are divided into many small parts increasing in this manner the number of nodes. Therefore, the analysis of the parts is better and an accurate result is reached.

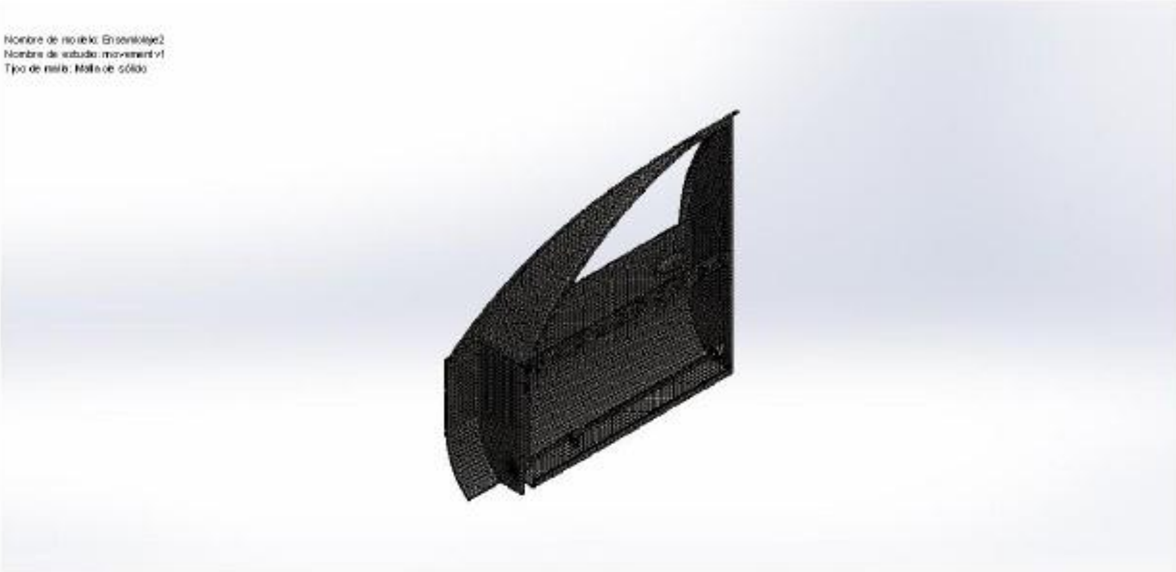


Figure 27: Door System with Mesh

Result and interpretation

Once, all the conditions are established, the computer carries out the analysis. The results are plotted in the image below which is illustrated in different colors. The colors help to understand the results better.

The picture 28 shows the Von-misses stress:

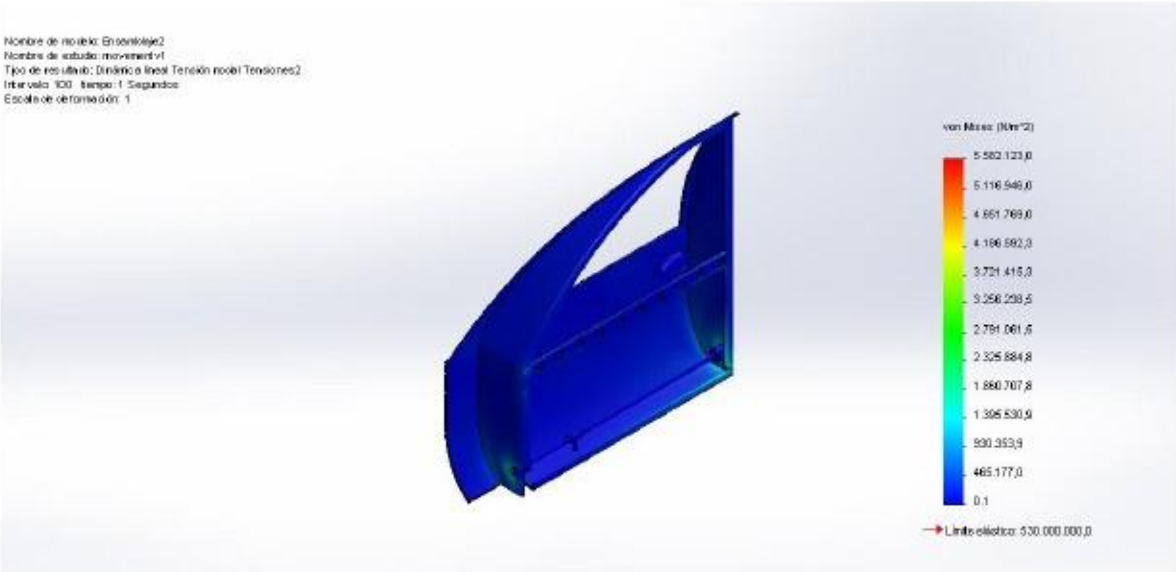


Figure 28: Stress

The system has some stress concentrations at the edges. But this phenomenon occurs in all the parts. The maximum stress is 6 MPa and the limit is 530 MPa. To conclude, the mechanism configuration and materials are correct.

3.3.6 Static Analysis

In this section, each part is studied in different position. The most important characteristic is that the analysis is carried out in stationary conditions.

Bar-Piston

Figure 29: Bar Piston

This assembly is compounded by the bar and the piston. The bar and the piston have a rigid connection in the assembly. The piston has a translational movement along the bar and it is connected to the rod. On the rod the bearings are installed to allow a rotational movement of the bottom part of the piston in the rod. The software needs to define the connectors and the loads to start with the analysis.

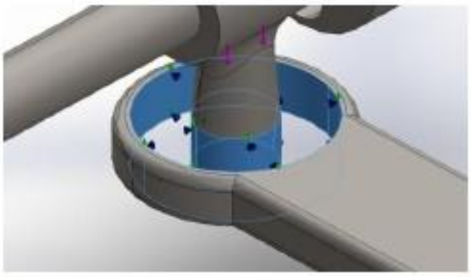


Figure 30: Piston-Rod Fixed Hinge

In figure 30 connection between the piston and the rod is plotted as “fixed hinge”.

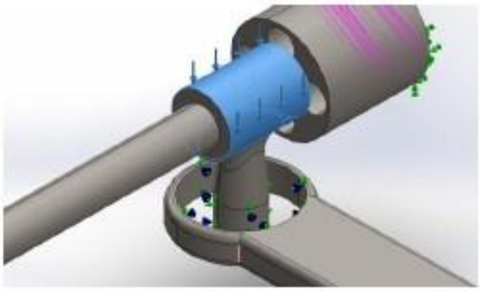


Figure 31: Load in the Piston

A load of approximately 150N is considered on the piston according to the weight of the door as it is the only force this part resists. It is supposed to be perfectly lubricated so any friction resistance can be rejected.

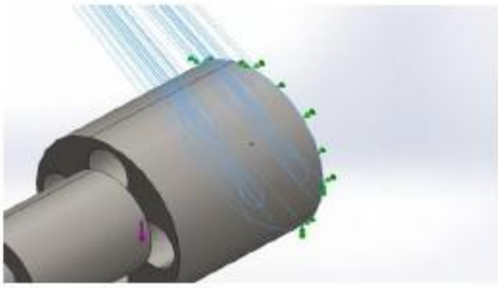


Figure 32: Remote Force in the Bar

Moreover, in this assembly the force that a user applies to open the door is studied in the bar as it is supposed to be the element that is most affected by this force. This is proved by the analysis provided by SolidWorks Simulation. This force is close to 490N. It is defined as a remote load because it is not applied directly on the bar but on the handle of the door so it has to be moved to the bar, as shown in figure 32.

Mesh

Two different analyses are done. They are based on the size of the element in the mesh have been used. The shapes of the elements are the same in all the studies made in this project: quadratic element. The reason of using this kind of element is that this gives a result close to experiment that provides. This shape has three degrees of freedom in each of the nodes; as a consequence the analysis becomes more exact.

The shape of elements does not change but the size does. Therefore, the study of each part assembled of the mechanism is focused on demonstrating the importance of choosing different elements sizes and the consequences of the selection in the final result.

Figure 33: Big Size of the Element of the Mesh

In the figure 33 a larger size of the element is considered. The number of elements as a consequence of the size is 9861 and the number of nodes is 17131.

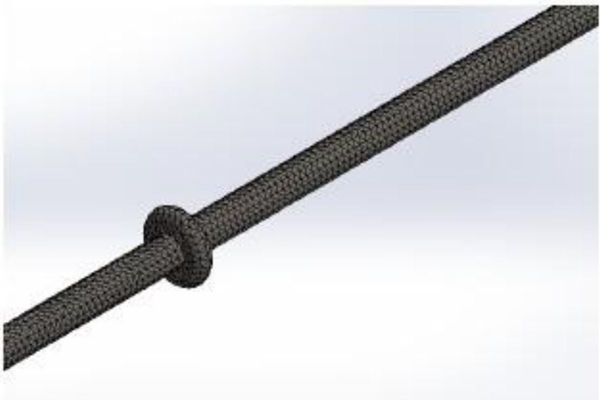


Figure 34: Small Size of the Element of the Mesh

On the contrary, as it is shown in the figure 34, a small size of the element of the mesh increases the number of them and the nodes, which improves the result. In this case, the number of elements is 62107 and the number of nodes is 96432. With this comparison it is proved that a smaller size of the element of the mesh is better to reach a result for the analysis similar to experiment. Considering this study, it is proceeded to show the deformation due to the stress in the presented assembly using the last mesh exposed.

Stress according to von Mises´criteria

The stress study of the bar piston is plotted in figure 35.

Table 6: Stress

Name	Type	Min.	Max.
Stress	VON: Von Mises´stress	6.88298 N/m^2 Node: 59881	1.10451e+006 N/m^2 Node: 5301

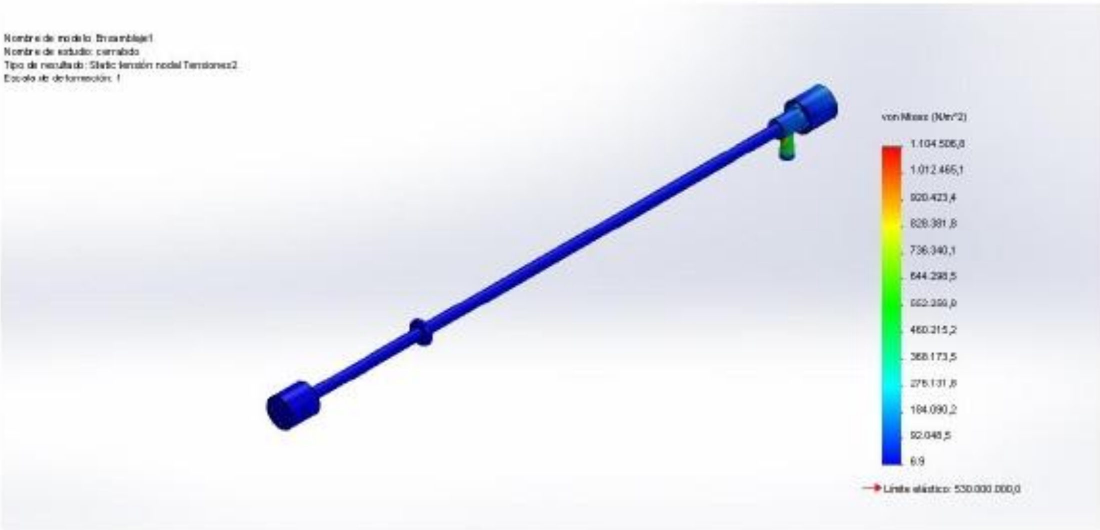


Figure 35: Stress in the piston bar

Blue color covers most of the assembly and the maximum stress is in the piston which is represented by green color. However, the stress is not high and it does not produce a considerable deformation to be considered for a possible change of design.

Rod

Figure 36: Rod

The figure 36 represents the rod. This part has a rotational movement that allows the translational movement of the piston along the bar.

The rod is settled over the bearings which are placed in each end of the rod.

The connectors are defined as “fixed hinges”. Translational motion is rejected but it can rotate.

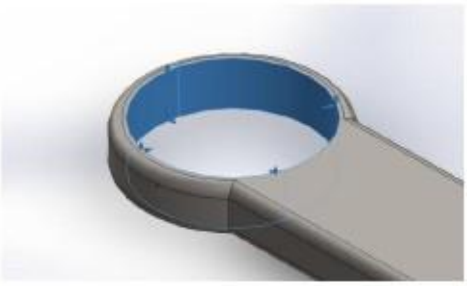


Figure 37: Fixed Hinge Connection of the Rod

The load which is applied in the rod is 150N that represents the weight of the door. This force is plotted in figure 38.

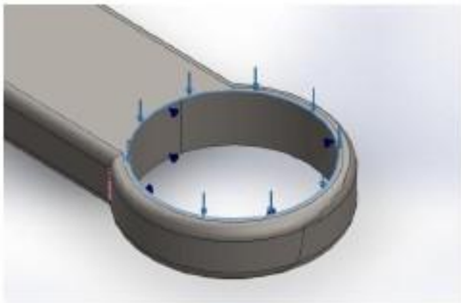


Figure 38: Force Applied in the Rod

Besides, it is considered the stress that the rod suffers because of the bearings. This is simulated in figure 39.

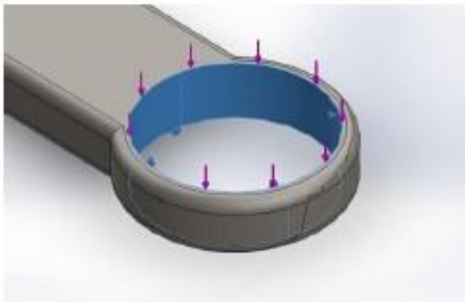


Figure 39: Stress due to Bearing

Mesh

Figures plotted below show the mesh used for the calculation. Figure 40 represents a mesh that has larger elements than in the mesh represented in figure 41. Consequently, calculations are based on the mesh with smaller size of the elements because satisfies results closer to reality. The number of elements in figure 40 is 8453, and the number of nodes is 14430. On the other hand, the number of the elements in figure 41 is 50673, and the number of nodes is 77860.

Figure 40: Large Size of the Element of the Mesh

Figure 41: Small Size of the Element of the Mesh

Using the last mesh, the stresses caused in the rod are calculated.

Stress according to Von Misses criteria

Due to the load the maximum stress is located in the end of the rod. In addition, it is significant to look at its low value because as shown in the legend this can be neglected. It does not have any effect in the rod. The previous design has not to be changed.

Table 7: Stress

Name	Type	Min.	Max.
Stress	VON: Von Mises´ stress	0.258996 N/m^2 Node: 45996	50771.9 N/m^2 Node: 417

Figure 42: Stress

Figure 42 exposes the tension stress in the rod. It verifies the low value of it, so it can be assorted that the design works properly. A redesign is not necessary.

Base

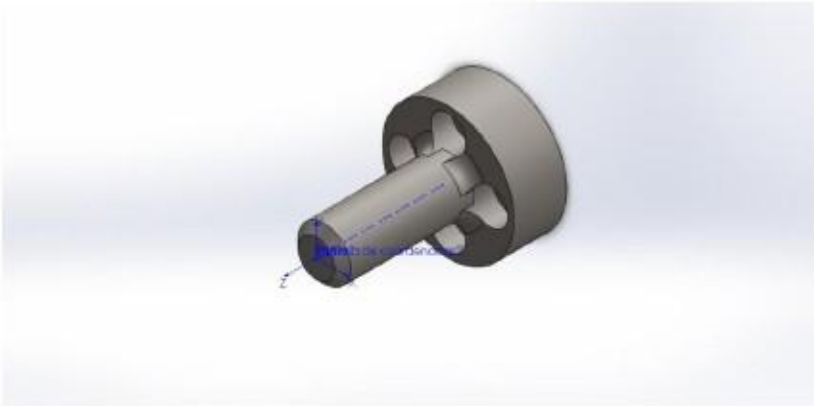


Figure 43: Base

The base is fixed to the bottom of the chassis. It has a rigid connection with one of the end of the rod in which there is a bearing settled in it to allow its rotating movement and to reduce the possible stresses caused in the base.

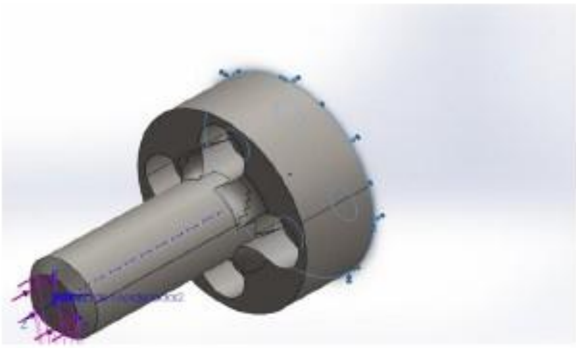


Figure 44: Rigid Connection

There is only a loaded region but two different loads are applied in it.

Figure 45 simulates a load of 150N due to the weight of the door and figure 46 a load of 490N caused by the opening movement in the handling. This last one is treated as a remote load in the software.

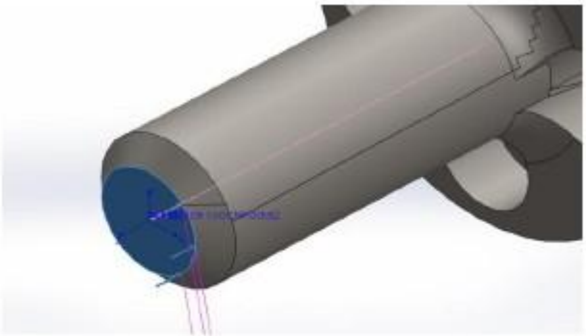


Figure 45: Load of 150 N

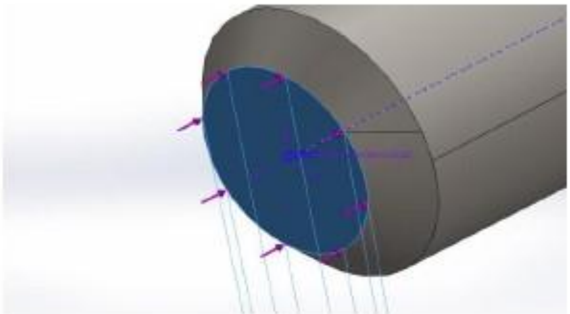


Figure 46: Remote Load of 490 N

Mesh

In this part, as it has been made with the previous assembly, it is shown two different representations of the mesh used for the calculation. It is justified the utilization of the mesh with a small size of the elements that compound it. The reason is the same as for the rest of the assemblies, its similarity to reality.

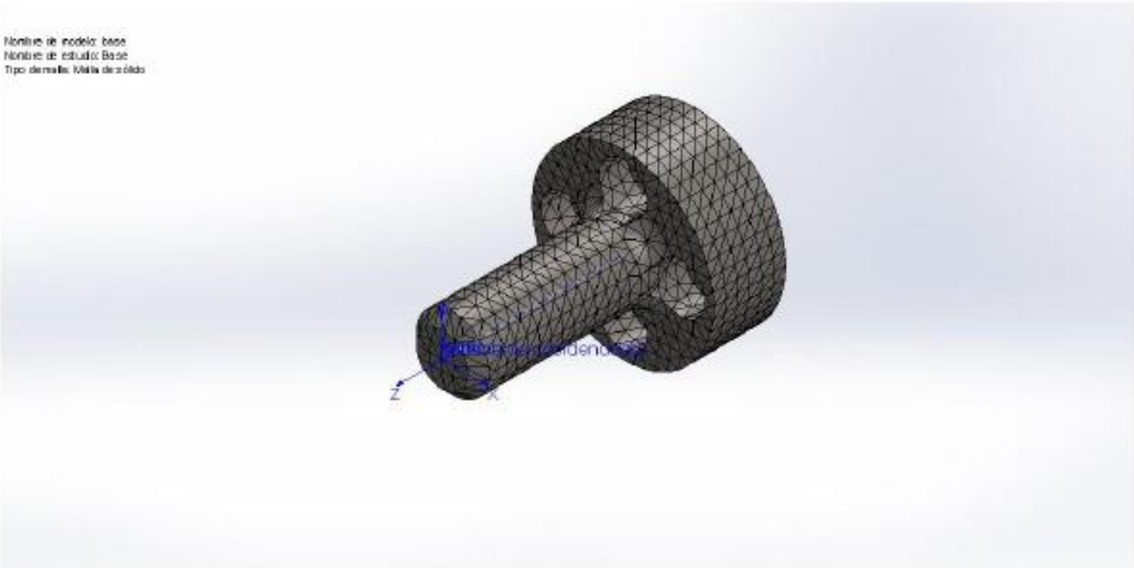


Figure 47: Mesh with Small Size of the Element

The number of elements is 11037, and the number of nodes is 17200.

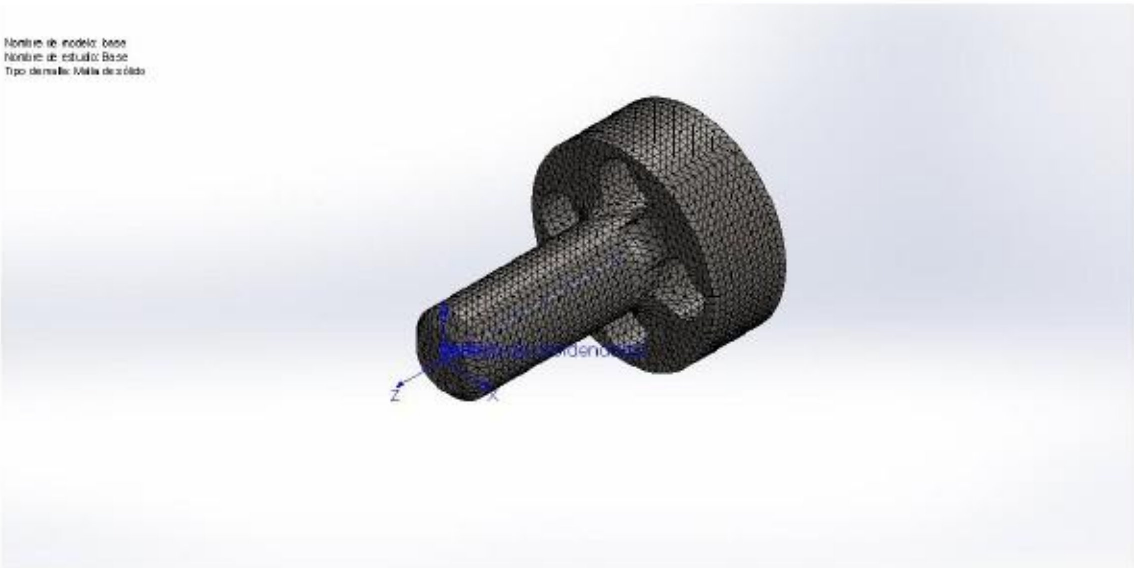


Figure 48: Mesh with Large Size of Element

The number of elements in figure 48 is 53142, and the number of nodes is 78403.

Stress according to Von Mises´criteria

Table 8: Stress

Name	Type	Min.	Max.
Stress	VON: Von Mises´ stress	267548 N/m^2 Node: 3113	1.12909e+009 N/m^2 Node: 2520

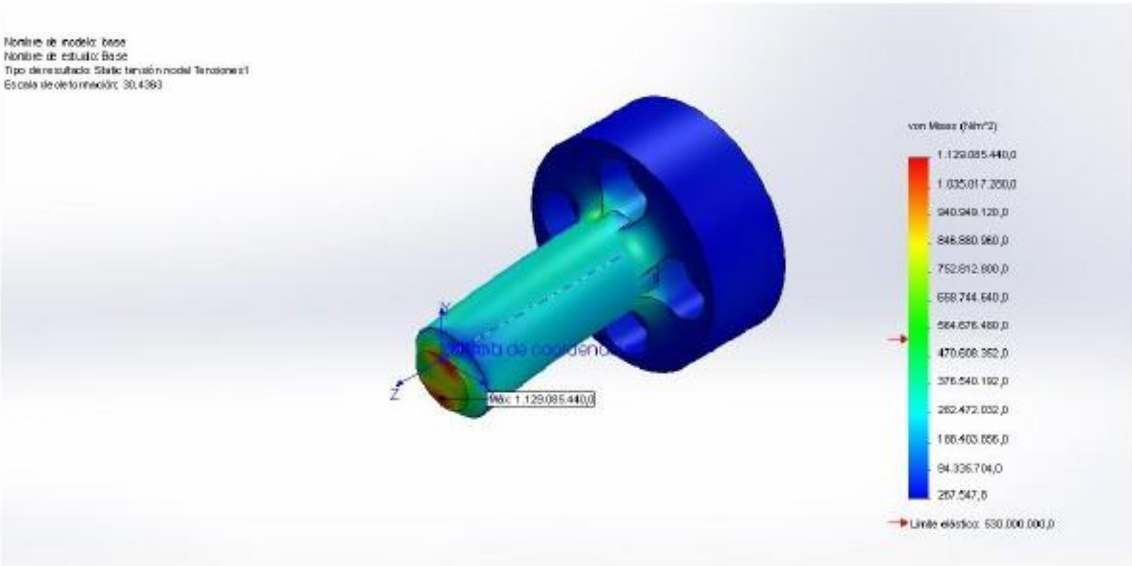


Figure 49: Stress in the base

Figure 49 showes the maximum stress in the end of the base which is connected to the rod. This stress can be reduced redesigning the edges of the base making them more rounded, but as the value of the tension demonstrates that is not necessary as the part can support the load.

Complete assembly

In this section, the intention is to demonstrate the behaviour that the complete mechanism exposes.

The mechanism works in different positions so its behaviour is studied to recognize a possible critical reaction in any of those positions. In that way it can be reconsidered a redesign to avoid problem in the real system.

There are three positions:

- The door is completely opened. (Figure 50)

Figure 50: Opened Position

- Half opened position (Figure 51)

Figure 51: Half Opened Position

- Closed position (Figure 52)

Figure 52: Closed position

Next step convers the stress analysis in each position. For that, it is used a mesh with small size of the elements as results obtained by this way are near to reality so it is easy to imagine how the elements could behave in each situations studied.

The number of elements in the mesh is 56403, and the number of nodes is 91281.

Figures 53, 54 and 55 show the stresses.

Table 9: Opened Position Stress

Name	Type	Min.	Max.
Stress	VON: Von Mises´ stress	0 N/m^2 Node: 81895	1.03628e+006 N/m^2 Node: 20423

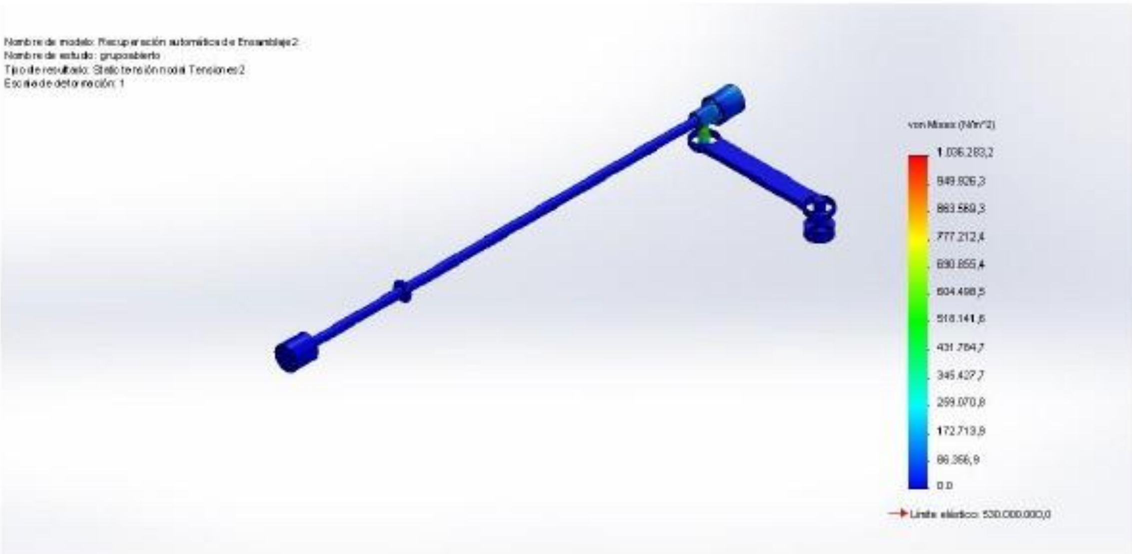


Figure 53: Stress. Opened Position

Table 10: Half Opened Position Stress

Name	Type	Min.	Max.
Stress	VON: Von Mises´ stress	0 N/m^2 Node: 82004	910176 N/m^2 Node: 24118

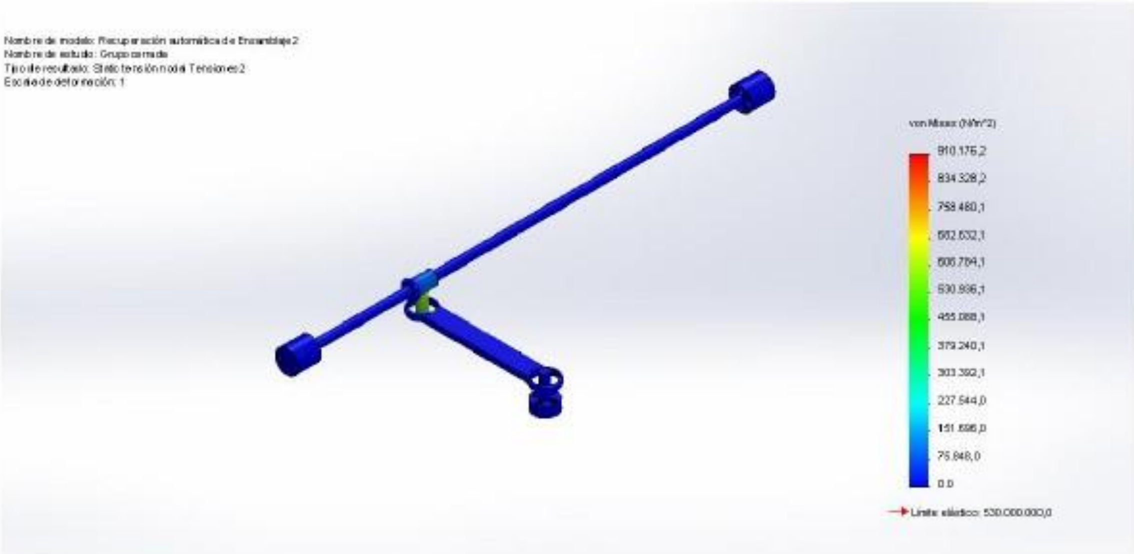


Figure 54: Stress. Half Opened position

Table 11: Closed Position Stress

Name	Type	Min.	Max.
Stress	VON: Von Mises´stress	0 N/m^2 Node: 81976	910176 N/m^2 Node: 24090

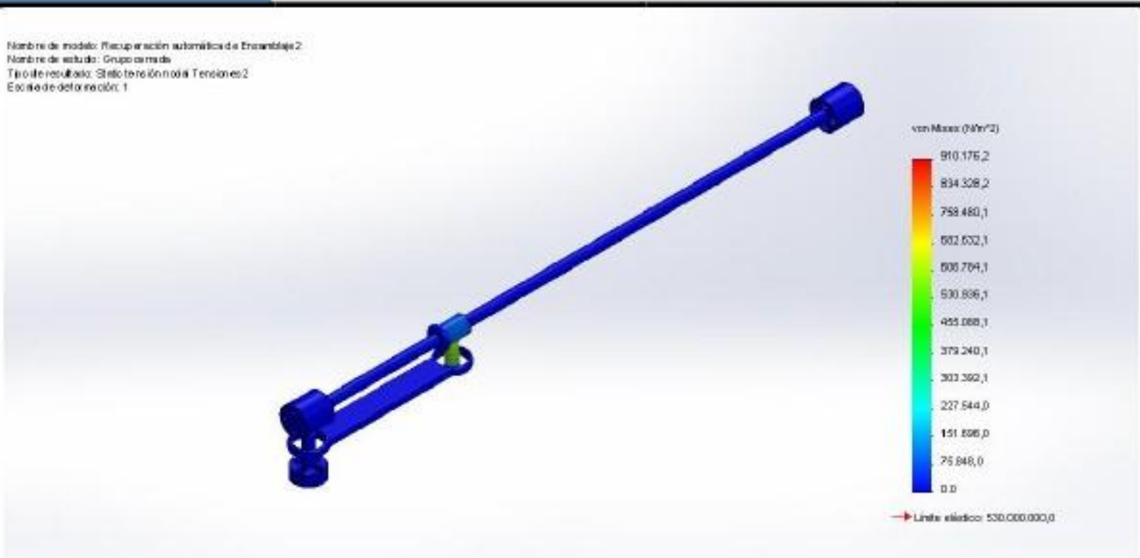


Figure 55: Stress. Closed Position

The stress analysis clarifies where the maximum stress is placed in each position. In all of them, this stress is largest in the piston but it has a low value so that a redesign of the mechanism is not necessary.

3.4 Manufacture

The mechanism has 5 parts to be provided. All parts are made of steel AISI 1045. This material has been selected because it is the most common one used for components in the automotive industry. This material is great to use in industrial production. The parts have standard dimensions. The base and the guide bar are cylindrical elements. A turnstile is used to remove material in order to obtain the final shape. Once the spare material is removed, the holes of the screws are made by a drill. Finally, the correct dimension is obtained.

Figure 56: AISI 1045 Cylindrical Shape

The rod has the base made of one sheet of steel AISI 1045. The first step is to obtain the shape of the rod by using an electric saw. When the shape is obtained, the holes for the bearings are created. They are created by milling cutter because a great finish is needed to install the bearings properly. The next piece in the manufacture process is the top guide. It is made of the same material as the previous parts. A block of the current material is used to obtain the shape that is wanted; this block has to be treated. A milling cutter is used for this objective. Finally, the holes for the screws have to be created and for this issue the drill is also used. The last part is the piston. It is composed by two elements. The first element is the base that is obtained from a solid cylinder block. It is processed by a turnstile. The second element is the guide and it is obtained from an empty cylinder which is cut considering the length needed. Once, both elements are fabricated they are welded together.

3.5 Material Cost Estimation

In this step, an approximated study of the price of each part is done. The price differs depending on the company. The number of elements is indicated in the 3D part. Moreover, the steel quantity for the manufacture of each part is estimated. This estimation is shown in the table below:

Table 12: Prices table

Element	Unitary price	Total
14 Screw Din 912	0.08 €/unit	1.12 €
14 Nut ISO 4034	0.02 €/unit	0.28
2 Bearing SKF 7204 Be	18.53 €/unit	37.06 €
1 Bronze cap	0.22 €/unit	0.22 €
≈ 5kg Steel AISI 1045	0.78 €/unit	3.88 €
TOTAL		**42.56€**

These prices can vary depending on the suppliers. Consequently, the final price presented above is a guidance price.

In the manufacturing of this door, there are several factors to be considered apart from materials. These factors are related to manufacturing work and the installation system process. It is difficult to provide a price, because it changes in each country. An example could be the average price in Spain which is approximately 25€/h which includes the salary of the workers, the expense of light, the amortization…

3.6 Sustainable Development

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brutland Commission, 1987)

Sustainable Manufacturing is defined as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound". [3]

In this project the minimization of the number of parts for the assembly of the system has been strongly followed. The system consists basically of 5 parts and the rest of them are the connected elements which are mainly screws. The numbers of screws is the fewest one to be able to assemble the system correctly. Moreover, the mechanism is made of recyclable materials. In this project it has been tried to achieve the most environmental and sustainable solution as far as it has been possible by using these recyclable materials, by choosing the least energy waster process, or by reducing the number of pieces and their volume in the assembly. These factors directly affect the cost, which is reduced. A better solution for the environment can be found.

Social sustainability is applied in this project, as one of the main goals is to make easier the entrance into a car for disable people. They can take advantage of it because the mechanism improves the difficulties that these people can find when using a conventional entrance into a car. The mechanism is not expensive at all so it can be applied easily in any car because no great changes have to be made in the chassis and the material used is very common so the cost is reduced.

3.7 Comparison of Initial Model vs. Final Model

In this section, a comparison between the initial model and the new model is carried out. This section tries to explain the main differences between them. In the next figures, the two models are shown:

Figure 57: Original Door

Figure 58: New Model

The most important difference is the opened position. In the initial model, it has been presented a "classic door" which needs more space for the opening which is a disadvantage. Besides, the way of opening it can cause the door to hit another door of other cars.

In the new model, the door slides. It prevents the disadvantages mentioned above. The door saves space when it is opened. This difference is the most important. It can be seen clearer with numbers. The initial door needs around 1.1 m and the new model needs 0.4 m of lateral space.

The lock system is the same in both models because it is tried to minimize the cost. Therefore, in the new model, the system of the serial car is kept. Furthermore, in the new model, the users apply the force right to left or opposite. This means that they can use all their body force. In the new model, there is a rail. This rail has one wheel into it, which is connected to the door. Good sliding is obtained due to the material of the wheel which is Nylon.

4. CONCLUSIONS

As conclusions, it can be assorted that:

- The mechanism is simple and easy to assembly.
- The material selection is adequate to support the loads applied into the mechanism.
- The manufacturing process is simple.
- The mechanism satisfies economically, socially and sustainable development.

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