Improvement Project of an AGV's Suspension System in order to Reduce Manufacturing Costs

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November 2019

Abstract

The manufacturing time of a component is closely linked to its manufacturing cost . Thus, it is necessary to manipulate the geometry of the components, leading to a reduction in manufacturing time and, consequently, its cost. Within this scope, the need arises for a project to improve the suspension system of a high-load (2 ton) Automated Guided Vehicle (AGV), for pallet transport, with the goal of reducing its manufacturing cost. This suspension system consists of electrical components (traction system), spring and mechanical components. Most mechanical components are manufactured by machining. Therefore, simulations were made using CAM (Computer Aided Machining) software. Iteratively , it was possible to obtain a new geometry that met the same specifications and had a shorter production time. The following topics are present in this dissertation: the description of the original suspension system, relevant patent research, the development of the proposed solution and CAD / CAM models as a decision-support tool, manufacturing and assembly of the suspension system, and a simplified cost analysis. In addition, a dynamic analysis of the suspension system (quarter-car analysis) was made and the main structural components and bolted connections were analysed. Possible future developments of the project are also presented. The tests performed and technical drawings can be found in the appendices. The project objectives were fulfilled with an expected 38% reduction in manufacturing time and a 23% cost reduction. A new suspension system is presented that meets the specified requirements and constraints of the project.

Keywords: Suspension system, AGV, Structural Project, Quarter-car Analysis, Machining Time, Manufacturing Cost.

1. Introduction

An Automated Guided Vehicle (AGV) is an automated vehicle capable of navigating wide area surfaces through a set of sensors such as magnets, lasers, vision cameras and more. The main application of this type of vehicle is the transportation of cargo in large factory floors. The use of this equipment allows the transport of parts in the manufacturing area, mainly between warehouses, or between warehouses and the production line [9].

The company ActiveSpace Automation develops AGVs of various dimensions, suitable for different types of loads. Currently, it has started the development of a Heavy Load AGV, which can carry a maximum load of 2000 Kg, represented in Figure 1. This AGV is bi-directional and has a turning angle of 360º, reaching a top speed of 0.8 m/s. Its navigation is controlled by magnetic tapes placed on the floor or by natural navigation.

Figure 1: AGV ActiveOne XL, by ActiveSpace Automation, source: [3]

During the prototyping phase of the AGV ActiveOne XL, the costs of manufacturing the suspension system were high, taking into account the company's expectations. This was due to a high number of machining hours. The production of the prototype, consisting of two suspension systems, had a cost of 2010€, which translated into 27 hours of machining.

The main objective of this work is to improve upon the project of this AGV's suspension system, in order to reduce its production time, without altering the specifications of the vehicle.

2. Background

2.1. Description of the AGV and Original Suspension System

The AGV has six wheels, and only the two center ones are drive wheels. This vehicle is bi-directional and can manoeuvrer in small spaces as it has a low turning radius and the ability to turn on its own axis. For this reason, it uses a differential traction system. That is, the vehicle rotation occurs by imposing different speeds on the two driving wheels of the vehicle. The other four wheels, positioned at each corner of the vehicle, are swivel wheels, fixed on a caster that attaches the wheel to the chassis, providing stability to the vehicle and maintaining its steering, as it is shown in Figure 2 [4].

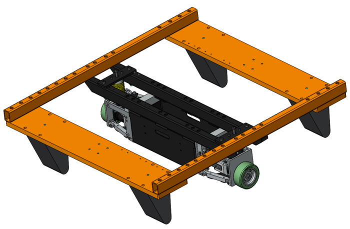

Figure 2: Suspension systems positioned in the AGV ActiveOne XL, source: [4]

A suspension system consists of springs, shock absorbers and articulations that connect a vehicle to its wheels and allow relative movement between the two. The suspension system designed by ActiveSpace Automation for AGV ActiveOne XL is shown in Figure 3.

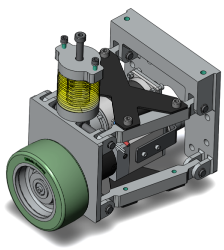

Figure 3: Original Suspension system of the AGV ActiveOne XL

Usually, a suspension system consists of a spring and a shock absorber. The spring has the function of filtering the ground profile and reducing the range of motion of the chassis. However, if the energy in the spring is not dissipated, it continues to transmit motion to the chassis indefinitely. A damper then serves to absorb the spring's energy, causing the vehicle to return to its the original position.

In the studied suspension, there is no damper. This option was taken since the vehicle is designed to ride on flat profile floors without any major obstacles. Since there are also dimensional constraints, the company chose not to include a damper and use the suspension arms to dissipate the spring's energy.

The suspension consists of four parallel arms two by two, joining two plates. A rear plate connecting the suspension to the chassis and a front plate connecting the wheel to the suspension and differential. The spring is connected to the front plate and chassis, thus allowing the absorption of changes in the floor profile. To make these connections, there are two parts that hold the spring and a pin that goes through it, thus ensuring its positioning. The arms are connected to the plates by a trapezoidal eye and pin system, with an angle of 8^circ.

In order to produce and control the vehicle's movement, there is a traction system connected to the suspension, that consists of a motor, differential, encoder and pulleys. This components were previously chosen by the company and will not be altered in this project.

2.2. Requirements and Constraints

2.2.1 Requirements

1. Each suspension shall have a maximum load of 1666.67 Kg.
2. The geometries selected for the mechanical components of the suspension shall be simple in order to shorten manufacturing times.
3. Components such as bolts, nuts, washers and bushings shall be standardized, as well as other components required for the project.
4. The suspension shall be designed so that there is easy access to electrical components, for maintenance.
5. All components must be designed with a safety factor of 2 ($\mathbf{n} = 2$).

2.2.2 Constraints

1. The connection points between the chassis and suspension shall remain unchanged.
2. The Electrical components shall not be changed.
3. The tilt angle of the suspension arms shall remain as 8°.
4. The manufacturing cost of the new suspension must be lower than the production cost of the original suspension, that cost 1200€.
5. The materials of the mechanical components will not be altered.

3. Development of the Proposed Solution

3.1. Identification of critical components

It is crucial to analyse the components of the original suspension designed by the company. This is the only way to comprehend how the proposed changes can have the biggest impact.

With that in mind, for components were identified for their improvement potential. Those were: The back and front plate, the arms, and the arm reinforcement:

3.1.1 Front and Rear Plate

For the manufacture of the front and back plate, shown in Figure 4, it is necessary to remove a large volume of material in order to obtain the eyes and they also have a great level of detail. This means that smaller diameter tools will have to be used, which increases the manufacturing time of the parts.

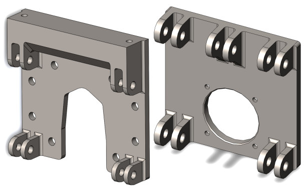

Figure 4: Rear and front plate, respectively

3.1.2 Arm and Reinforcement

The arms, shown in Figure 5, are narrower in the plate connection zone and are thicker in the central area, allowing the arm reinforcement to be bolted.This change in thickness in the arm profile means that a large volume of material must be removed to achieve the projected geometry. For this reason, the arms and, consequently, the reinforcements will be the object of alterations.

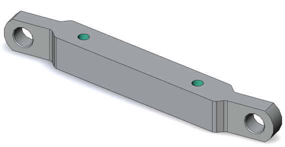

Figure 5: Arm of the suspension system

3.2. Concept Generation

3.2.1 Housing System

In order to reduce the manufacturing time of the front and rear suspension plate, the possibility of implementing a housing system for the plate eyes has been studied.

This system would allow the individual production of the different components and, consequently, this times would decrease, since it would not be necessary to remove such a large volume of material from the plates.

However, this option has as a constraint the need for a system that provides correct alignment between the eyes, so that the arms maintain the same relative position.

This possibility makes the assembly of the suspension system more complex, as it will be necessary to fit and secure the position of all eyes. In these circumstances it will be necessary to ensure that this new system is advantageous compared to the manufacture of the plates already with the eyes.

3.2.2 Arm Geometry

Three different scenarios were considered:

- **Tilted configuration:**

  The first scenario to consider is to tilt the eyes relative to the front and rear plates. This way the arms would become straight and there would be only a thickness variation to accommodate the reinforcement of the arms. This solution is represented in Figure 6.

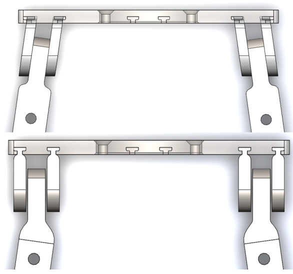

Figure 6: Tilted versus straight configuration

- **Division of the arms into different parts**
  In order to decrease the volume of material to be removed, it was also considered possible to split the original arms into two tops and a centrepiece, which would be assembled with the screws joining the arm reinforcements to them. This solution is shown in Figure 7.

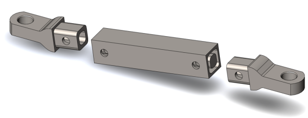

Figure 7: Representative scheme of a quarter car model analysis,

- **Decrease on the thickness of the arms**

  By uniformizing the thickness of the arms it is possible to decrease the volume of material to be removed. This solution is represented in

Figure 8. However, it is necessary to decrease the size of the bolt joining the reinforcement to the arm and therefore ensure that this change meets the design requirements.

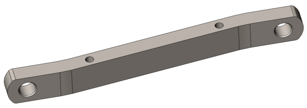

Figure 8: Arm of the suspension with a reduced thickness

3.2.3 Arm reinforcements

Arm reinforcement serves to provide rigidity to the system and to ensure synchronous movement between the two arms. In order to reduce the manufacturing time of this part, it was proposed the reduction of the size of the tears in this part, keeping only the openings that ensure access to the electrical components, without having to remove this part. The proposed concept is represented in Figure REF.

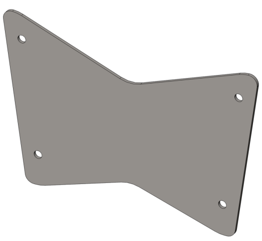

Figure 9: Arm of the suspension with a reduced thickness

4. Relevant Patent Research

Since this project is an improvement project, it has as its starting point an existing product. Patent research is important since it provides knowledge regarding different systems with similar requirements.

From the search for patent registrations, some relevant results were obtained, which correspond to suspension systems used in AGVs. Which are presented bellow:

4.1. **US5199524A**

Th patent no. US5199524A, issued in April 6, 1993, by Milan E. Ivancic, refers to an AGV with a maximum load of $100ton$, 4 wheels, one at each end of the vehicle. The suspension system of this vehicle is designed to hold the vehicle against unwanted forces applied to the wheels during loading [6].

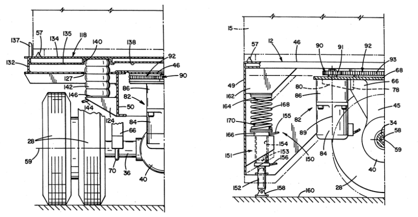

Figure 10: Schemes of the suspension system for a heavy-load AGV, source: [6]

4.2. **JP2007283958A**

Patent no. JP2007283958A ("Suspension device for automated guided vehicle"), published on 28/10/2009, by Akira Kaihara and Noria Oka, refers to the suspension system of an AGV.

This suspension system consists of a pair of arms that are mounted vertically to the chassis (14), where the drive wheels (7) with electric motors (6) are mounted. The spring is also mounted on these arms. This system aims to reduce the space used by the suspension and simplify its assembly. [2] (Figure 11)

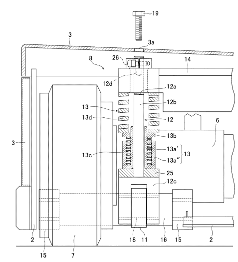

Figure 11: Schemes of the suspension system of an AGV with the goal of minimizing space, source: [2]

4.3. **JP3157948U**

Patent no. JP3157948U ("Automatic guided vehicle of the suspension device"), issued April 3rd, 2010, by Atsushi Saito, also refers to the suspension system of a AGV

This suspension system is designed to relieve impact when load is transferred to the platform by suppressing the AGV's range of motion in the vertical direction. Contrary to the models of the other patents previously described, this system includes a shock absorber [7] (Figure 12).

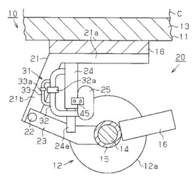

Figure 12: Schemes of the suspension system of an AGV with an hydraulic shock absorber, source: [7]

5. CAD/CAM Models for the proposed solution

In order to validate the concepts proposed in the section 3, SOLIDWORKS 2018 software [5] was used to perform geometric modeling (CAD - Computer Aided Design) and later simulation of machining time, with CAM (Computer Aided Machining).

CAM software generates the code used on CNC machines for tool control, defining the entire machining process, including the tool path. It is then possible to extract valuable information from this simulations, such as manufacturing times.

CAD / CAM software, when used in a factory context, should have a setup as similar as possible to the CNC machine that will be used to produce the parts. That is, all tools that are used on the machine must be present in the software as well as all other machine settings.

Considering that for this project it is only necessary to establish a comparative point between the various proposed concepts, it is not necessary to simulate the scenario of a real CNC machine. It is, however, imperative to ensure that the same conditions are met between all simulations.

5.1. Software Specifications

As mentioned earlier, the software used was SOLIDWORKS 2018 [5]. This program already has a CAM package, which allows to simulate its production in the same CAD file. This way, it is possible to iteratively change the geometry of the component, considering the production simulations.

5.2. Procedure

5.2.1 Tool Crib

Tool Crib refers to the set of tools available to the software that can therefore be used to manufacture the part. Since there isn't any information regarding what tools will be available for the CNC that will produce the components, it is only necessary to ensure that the same tools are available for all simulations.

5.2.2 Stock Manager

The stock manager configuration allows us to define and characterize the material block that will originate the component to be manufactured. It is necessary to define the material class from which the component is made. However, it is also crucial to configure the original block dimensions.

Although other configurations are possible, for all simulations the option "bounding box" was selected, which assumes an initial block with the maximum dimensions of the component to be machined.

5.2.3 Coordinate System

When defining the coordinate system it is important to ensure that the z coordinate has a direction perpendicular to the plane on which the component is constructed.

The coordinate system origin for all simulations has been selected using the Part bounding box vertex option, which allows you to select a vertex from the original block defined in the stock manager.

5.2.4 Simulation

Since the CAM software runs within the component's CAD file, it is able to recognize the part's characteristics and automatically define the operating plan and toolpath for each component.

However, this process is not infallible, so it is necessary to check through graphical simulation, if all of the material is removed and if the tool path is adequate. This implies that sometimes it is necessary to manually add machining operations to part features that are not automatically recognized by the program.

The verification of the success of the simulation is made visually, through the video that simulates the machining process.

5.2.5 Estimated Machining Time

After the program has determined all of the tool paths, the estimated machining time can be extracted.

The simulated time not only contemplates the time it takes the tool to make its course and remove material, but also takes into account the change of setup and tool. These values could also be changed taking into account the actual situation of a CNC machine, but since the purpose is only to compare values, such a change has not been taken into account.

5.3. Method Validation

In order to ensure that the method used and described above is sufficient to evaluate the impact of the changes in the geometry of the part, the following test was performed. It consist in dividing the front and rear plate into its different components and simulating the production time of each one.

Figure 13 shows the plates divided in its components, properly identified.

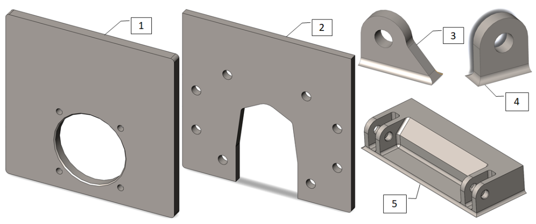

Figure 13: 1 - Simple Front Plate; 2 - Simple Rear Plate; 3 - Simple eyelet; 4 - Spring eyelet; 5 - Chassis eyelet

Table 1 and Table 2 summarizes the results obtained from the CAM simulations.

Table 1: Results for the Front Plate - Method Validation

	Front Plate		
t [min]	268,323		
Part	F Plate	S Eyelet	Sp Eyelet
Qt.	1	8	2
t [min]	9,584	12,416	12,488
TOTAL	133,91 min		

Table 2: Results for the Rear Plate - Method Validation

	Rear Plate		
t [min]	444,055		
Part	R Plate	S Eyelet	C. Eyelet
Qt.	1	4	1
t [min]	24,801	12,416	119,662
TOTAL	194,127 min		

As can be seen, the production time of the sum of the various components that make up the two plates is shorter than the production time of the complete board.

Thus, it is thus possible to verify that it is possible to establish a fair comparison between the production times of the components.

5.4. Simulations to support the decision making process

5.4.1 Tilted versus straight configuration

The results obtained are presented in Table 3.

Table 3: Results for the tilted vs straight configuration

	Straight		**Tilted**	
Part	Arm	Eyelet	Arm	Eyelet
Qt.	4	16	4	16
t [min]	72,969	5,163	49,111	8,608
TOTAL	374,585 min		334,172 min	

The manufacturing times for both configurations are quite similar, having only a deviation of 10%. Thus, production time simulations are not sufficient to make an informed decision as to which configuration to select for the final concept.

Since the tilted configuration leads to non-preferential dimension, the lack of possibility to produce the eyelets in series and makes it hard to use normalized components, such as the self-lubricated caskets, it was decided to go with the straight configuration for final concept.

5.4.2 Division of the arms into different parts

The results obtained are presented in Table 4.

Table 4: Results for the tilted vs straight configuration

	Solid	**Splitted**	
Part	-	Top	Center
Qt.	1	2	1
t [min]	72,969	28,795	14,805
TOTAL	72,969 min	72,395 min	

The time difference between the two hypotheses is practically nil: 0.574 min. The configuration of the arm divided into separate parts provides less rigidity to the component and may lead to greater wear of the arm, in the connections of the different parts. For this reason and since the time differences are not significant, it was decided to opt for only one rigid arm.

5.4.3 Decrease on the thickness of the arms and Arm Reinforcement

The results obtained are presented in Table 5.

Table 5: Results for the tilted vs straight configuration

	Arm		**Arm Reinf.**	
Part	**Og.**	**New**	**Og.**	**New**
Qt.	4	4	2	2
t [min]	72,969	46,979	37	23,248
TOTAL	291,876	187,916	74	46,496

This results validate the new geometry for both components.

5.4.4 Housing System

The components that will undergo geometry changes are the front and rear plates that will split into support plates and eyelets. It will be necessary to consider three different types of eyes, namely:

simple, spring, and chassis. These three eyes fulfil different functions, thus justifying the differences between them.

The simple eyes allow only the arms to be attached to the plates. The spring unloading eyes are coupled to the front plate and the lower spring interface. They are therefore the eyes that undergo the biggest load and thus need a different geometry that gives them greater robustness. Finally, the chassis connection eyes are attached to the rear plate and allow the suspension to be connected to the chassis.

In order for the housing system to be robust, it was necessary to increase the thickness of the eyes. In addition, bevelling the sharp edges had to be included to reduce the potential wear of the fitting. The eyelets are fixed to the plates by means of an M4 screw which is placed in the center of each socket.

The housing system has been sized taking into account two different adjustment classes: one for where the eyelet fits into the plate rail and one for the depth of the rail. Dimensions and adjustment classes are shown in Figure 14.

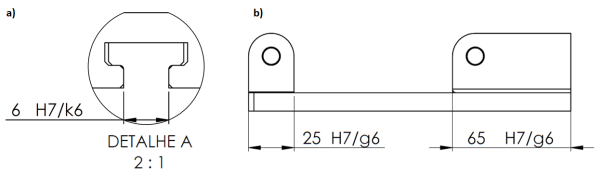

Figure 14: a) Cross-sectional adjustment class for the housing system b) Longitudinal adjustment class for the housing system on the Rear Plate

The selected dimensions for the housing system are shown in Figure 15. However, each type of eyelet has systems with different lengths. In regard to geometric tolerance, it is necessary to ensure perpendicularity and parallelism between the edges of the housing system, where there is contact between the components.

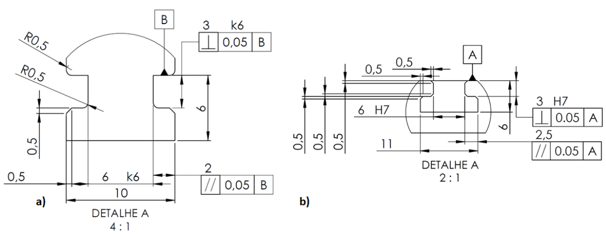

Figure 15: Dimensions and geometric tolerance of the a) simple eyelet b) rear plate

Table 6: Results for implementation of the housing system

	Rear Plate		
t [min]	444,055		
Part	R Plate	S Eyelet	C. Eyelet
Qt.	1	4	1
t/p [min]	63,974	7,051	142,467
TOTAL	210,41 min		
	Front Plate		
t [min]	268,323		
Part	F Plate	S Eyelet	Sp. Eyelet
Qt.	1	8	2
t/p [min]	117,738	7,051	12,365
TOTAL	198,876		

From the results it can be concluded that the implementation of the housing system is truly advantageous for the suspension system, in regard to manufacturing times.

5.5. Final results and Description of the final concept

With the implementation of the alterations previously described, it is possible to estimate a decrease of 411.321 min (6.85h) in manufacturing time, representing a relative difference of 38%.

In Figure 16 the new concept for the suspension of the AGV ActiveOne XL is represented, as well as the identification of all components to be produced. In Table 7 the components are identified, as well as a description of the main alterations that each component has undergone.

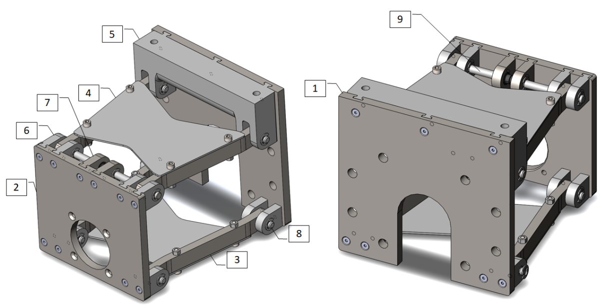

Figure 16: Dimensions and geometric tolerance of the a) simple eyelet b) rear plate

Table 7: Description of the components and main alterations

1	**Rear Plate**: Alteration of the rear tear; Decoupling of the eyelets; Implementation of the housing system
2	**Front Plate**: Increased width due to increased eyelet thickness; Decoupling of the eyelets; Implementation of the housing system.
3	**Arm**: Decrease in thickness; Decrease in the diameter of the whole for the connection to the reinforcement; Decrease in the diameter of the whole for the pin.
4	**Reinforcement**: Alteration of the geometry; Decrease in thickness
5	**Chassis Eyelet**: Increase in thickness; Implementation of the housing system.
6	**Simple Eyelet**: Increase in thickness; Height standardization; Implementation of the housing system.
7	**Spring Eyelet**: Increase in thickness; Implementation of the housing system.
8	**Short pin**: Decrease in diameter
9	**Long pin**: Decrease in diameter

6. Dynamic Response of the Suspension System

A suspension system acts as a mechanical filter, with the main purpose of maintaining the vehicle's stability.

For a vehicle such as an AGV travel comfort is not an important parameter, but it must be ensured that the load is stabilized so that it can be safely transported.

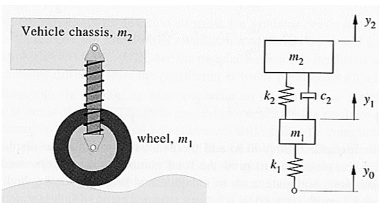

Figure 17: Arm of the suspension system divided into three parts, [1]

It was considered necessary to carry out a dynamic suspension analysis through a MATLAB simulation using a quarte-car model, in order to evaluate the suspension responsiveness to different types of floor, ensuring that the load will not be affected.

The assumptions considered in the implementation of this model are as follows [8]:

- The tire, is shaped like a linear spring without damping.
- There is no rotational movement on the wheel or body.
- The wheel is always in contact with the floor.
- The effect of friction is neglected so that residual damping is not considered in the vehicle model.

By applying a Newton's laws it is possible to obtain the following system of equations, where k and c are the linear coefficients of the spring and damper, respectively, and $y_0(t)$ is the input, corresponding to the changes of the floor profile:

$$\begin{cases} m_1 y_1''(t) + c_2(y_1'(t) - y_2'(t)) + k_2(y_1(t) \\ -y_2(t)) + k_1 y_1(t) = k_1 y_0(t) \\ m_2 y_2''(t) - c_2(y_1'(t) - y_2'(t)) - k_2(y_1(t) \\ -y_2(t)) = 0 \end{cases} \tag{1}$$

6.1. Implementation

For this analysis to be conducted it was necessary to achieve the suspension model that is represented in Figure 19.

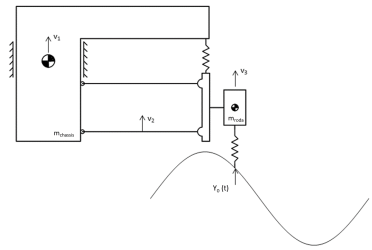

Figure 18: Suspension system model

Through this model, it is possible to achieve a simpler one, similar to the models studied in this type of analysis. We also find that although the arms and the entire metal structure absorb part of the spring energy, in this study this phenomenon is neglected, and therefore it is considered that the suspension studied has no damping effect.

The simplified suspension diagram used to analyse a quarter of a car is shown in Figure

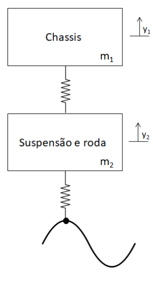

Figure 19: Suspension system model

Chassis and wheel mass values were obtained using Solidworks tools; the spring elasticity constant value was taken from the catalogue and the wheel elasticity constant was retrieved by the means of a compression test. Two different floor profiles were used: one sinusoidal and one step, both with an amplitude of 3.5mm, equal to the maximum step defined in the project specifications.

6.2. Results

Simulation results using the sinusoidal and step function are shown in Figures 20 and 21, respectively.

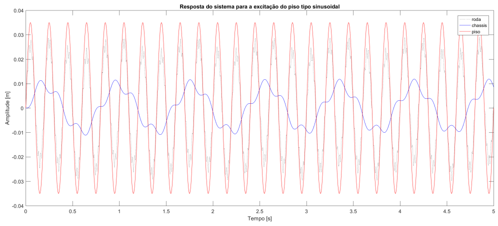

Figure 20: Simulated Floor Profile - Sinusoidal

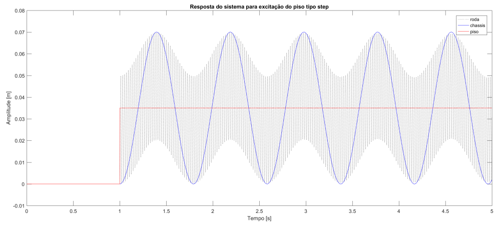

Figure 21: Simulated Floor Profile - Step

These results show that the range of chassis movements is smaller than the range of wheel movements.

In the case of the sinusoidal profile, we observe that the range of chassis movements is substantially smaller than the range of wheel movements. For the step profile, although the range of wheel and chassis movements is equal, the frequency of movement is smaller. It is also possible to verify that the movement of both the wheel and the chassis does not dissipate due to the absence of shock absorber.

7. Manufacturing of the Suspension System

7.1. Mechanical Components

The mechanical components of the designed suspension system are manufactured using machining, milling and turning techniques.

Although there are advantages to the use of mass production techniques and the use of easy-to-purchase standard components, machining technologies have been chosen as the number of AGVs produced by the company is relatively low.

The manufacturing technologies used in each component were mostly 3-axis milling and turning for cylindrical components such as pins.

For the smallest or most detailed components, an overall IT 7 tolerance was selected and for the others an IT 8 tolerance following ISO 286-1.

For finishes, a roughness class N10 or N9 was selected for the components with the highest degree of detail according to ISO 1302.

7.2. Electrical Components

All electrical components are purchased from various manufacturers, selected by ActiveSpace Automation.

Mechanical components that serve as coupling and connection between electrical components are also standardized and purchased from manufacturers.

8. Simplified Cost Estimation

Since this project is an improvement project, with the goal of reducing the manufacturing costs of this suspension system, a simplified cost analysis is required. This analysis will make it possible to conclude whether the reduction in production time has a significant monetary impact.

In this analysis the production cost of the original system will be compared to the cost of manufacturing the new system. Although ActiveSpace Automation has indicated a reference value of 2010€ for the cost of producing two suspensions. This value cannot be taken into account for comparison purposes, because the simulations of machining times, using CAM, do not provide exact values to the productive reality of the CNC machine used by the company. Since the simulations do not use the same parameters nor tools as the CNC used by the company.

For the electrical and complementary components, the manufacturer's catalogues were consulted and the total cost of acquiring these parts was of 662.5€.

To calculate the cost of manufacturing the mechanical suspension components, the cost of machining per hour provided by ActiveSpace Automation was 40 €/h.

The table 8 shows the costs for machining the original suspension system components and the proposed one:

Table 8: Machining cost estimation for the original and proposed suspensions

	Original	Proposed
Production t	17.30 h	11.07 h
Total cost	692€	441.6€

The original total cost of 1354.5€ for the original system contrasts with a cost of 1104.1€ for the proposed system.

It should be noted that this estimate does not take into account the labor costs of mounting and installing the suspension, as well as the costs of purchasing the raw material as these are included in the machining price value.

It is expected a 23% approximated reduction in manufacturing cost.

9. Final Remarks and Future Work

9.1. Final Remarks

This project arose from the need to reduce the time and, consequently, the production cost of an AGV suspension system, originally designed by ActiveSpace Automation.

Throughout the work developed we present the description of the original system, the development of the proposed solution, with the support of production time simulations, manufacturing and a simplified cost analysis.

Since the purpose of this dissertation is to reduce the production cost of the suspension, it was necessary to establish a methodology that would allow the calculation of production times, since these are directly related to costs, since all mechanical components of the system are machined.

Initially, components were identified that could be altered and have a reduction in their manufacturing time. Subsequently, the proposed changes to the identified components were presented.

In order to quantify the production times we used the CAM package SOLIDWORKS 2018 software. This tool allowed the production times of the original and altered components to be obtained. Thus, it was possible to evaluate the impact of component geometry changes.

This way, a final geometry was achieved, similar to the original, but with fundamental changes to reduce the manufacturing time. The most meaningful measures were the separation of the two plates, front and rear, in several components, as well as the alteration of the geometry of the arms.

It was also necessary to perform a dynamic suspension analysis in order to understand the system response to various changes in the floor profile. This analysis, using a quarter-car model, revealed that the system response is adequate to the expected floor changes.

Finally, through simplified cost analysis, it was found that the reduction in component production time resulted in a cost reduction of about 25%. This decrease will have a significant impact on the production cost of the suspension and, consequently, of the AGV.

9.2. Future Work

In future studies, CAM simulations should be optimized to obtain more realistic values. This optimization involves characterizing the software tool crib with the same tools to be used by the company in charge of machining the components. As well as setting stock manager within normalized values. These changes will allow better control over the impact of geometric changes on manufacturing time. Another option is to study other manufacturing methods, which may have a lower cost.

Studying other geometries and shapes of suspension systems may prove to be advantageous. In this project, it was opted to work with the original geometry and format, designed by the company ActiveSpace Automation. However, there may be other types of suspension that have the same level of performance but with a lower production cost.

Another element that may also be considered is the use of different electrical components. Through the estimated cost analysis, it is observed that the acquisition of electrical and complementary components is equivalent to 50% - 60% of the total cost. Conducting a market study that would result in a reduction in the acquisition costs of these components could be particularly beneficial for this project and its economic impact.

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