Design of Mechanical Systems for Prototype of a Vehicle with Omnidirectional Traction

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***Abstract*— This article focuses on the design of the mechanical systems for a single-seater vehicle with omnidirectional traction, taking as a reference point the regulations of the SAE formula, based on this criterion, a load analysis was carried out to determine the necessary calculations for the design. From each of the parts of the different systems, starting from these calculations, the selection of the appropriate gearbox was carried out to obtain the ideal revolutions; As main points we have the optimization by topology of the wheel hubs, which consists of reducing the material to use only what is necessary, in it. In the same way as innovation we have the design of the suspension knuckle, fulfilling various functions being a single piece as they are, housing and protecting the electrical components and in turn serving as support to the suspension arms, for each of the designs was It is essential to consider both the longitudinal movement and the lateral movement made by the car and in this way it was possible to identify each effort made in each design, reaching the manufacture of each element and demonstrating through the construction and assembly of the vehicle that each process carried out was efficient because the omnidirectional vehicle worked with total normality and under the appropriate operating parameters.**

Keywords-omnidirectional ;maneuverability ;knuckle; hub; longitudinal; lateral; stress;

I. INTRODUCTION

Today, finite element analysis is becoming a popular tool for design and simulation, taking as reference some studies carried out for static behavior electric karts and using various parameters calculated such as maximum speed, transmission ratio, among others [1, 2]

The need to change the design of conventional transport vehicles, to more efficient models for urban mobility, has forced manufacturers to extend to users a new trend regarding design [3].

In the future, one-person transport is proposed as an efficient mobility alternative, which aims to solve various problems with respect to transit in populated centers.

Vehicles with narrow track gauge can be built with a significant reduction in weight and their frontal area decreased, compared to ordinary ones, in addition to occupy less footprint on the road [4, 5]; because these vehicles need less parking space, less road space and reduced pollution [6].

A new generation of cars is being studied which will be practical and efficient in relation to traffic problems and lack of parking spaces in urban areas [7, 8], with these needs in mind, the use of an omnidirectional system has been considered, among the various types of existing omnidirectional tractions, the one chosen was the Mecanum wheels, which consist of a series of rollers on their circumference and have a 45-degree configuration with respect to the wheel axis [9]. However, it is necessary to connect several mechanical systems that adapt to Mecanum wheels for proper operation; knowing that generally single-seaters or Go-Karts vehicles do not use any suspension system [10]; its design has been developed complying with the requirements of its structure [11]. The design of mechanical systems has been reached according to the type of vehicle that has been designed and achieving synchronization between them allowing an adequate and simple driving.

II. METHODOLOGY

Within the load analysis that has been considered for the design of the mechanical systems, there is the weight of the frame already made previously, which has a weight of 128.92[lb], in the same way the percentile weight of a person has been consider to drive the 150[lb] vehicle, the values delivered by the Jeti Phasor Racer 2035/2100 2D engine must also be examined, which has an engine power of 1400[W] and a torque of 40 [Nm],originally has 70 560 [rpm] but incorporates a rev reducer with which the revolutions would drop to 10 453,33[rpm]; another factor that should be considered is the diameter of the Mecanum wheels which is 10 [inches], and they have a weight of 9[lb] each and are designed to support a load of 400[lb] each ; considering these aspects we proceeded to perform the various calculations shown below to determine what type of traction is going to be used and to develop the design of an efficient suspension system.

$$n = \frac{P*716}{T} \tag{1}$$

Knowing the power and torque offered by the motor, we can calculate the turning speed of each motor using Eq.1, which in this case is 329.47[rpm].

$$a_{x,y} = \frac{V^2}{R} \tag{2}$$

To calculate both the longitudinal and lateral acceleration using the Eq. 2, it is necessary to use the speed which for the first case is 12.5 [m/s] and for the second is 11.11 [m/s] and a distance of 7.5[m], with which we obtain a longitudinal acceleration of 20.83[m/s^2] and a lateral acceleration of 16.46[m/s^2].

$$af_{x,y} = \frac{Ff_{x,y}}{m} \quad (3)$$

For the calculation of the longitudinal and lateral braking we are going to use the braking force and the mass in Eq. 3, In this way, the braking force is obtained by taking the weight and the adhesion coefficient, with which we will have a longitudinal coefficient of 0.80 and a lateral coefficient of 0.60 and from this we can obtain the braking value that for the longitudinal motion will be 2 188.96 [N] and for the lateral motion it will be 1 641,72 [N]; and once we determine these data we can calculate the longitudinal braking of 7.84 [m/s^2] and the lateral braking of 5.88 [m/s^2]; with previously performed calculations, four planetary gearbox with two stages are selected for transmission, with a gear ratio of 12:1 to reduce the rotational speed of the brushless motors to 871 [rpm] according to the design parameters, maximum speed and torque required for a total of 250 [lb] between suspended and unsprung mass, and maximum speed of 40[km/h].

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$$V_{RPMS} = \frac{V*1000*}{3600} * 1000 \quad (4)$$

Using Eq. 4 gives the speed value of 11 111.11[Rpms], with which we proceed to calculate the revolutions per millisecond of the wheel by means of:

$$RPMS_W = \frac{V_{RPMS} *2*30}{W_D*\pi} \quad (5)$$

Once the Eq. 5 is solved, the resulting value for the angular velocity is 835.45[RPMS], and finally this value is used to calculate the gear ratio we need, knowing the value of the revolutions per minute that the Jeti engine has.

$$G_R = \frac{RPM_{ENGINE}}{RPMS_W} \quad (6)$$

Solving Eq. 6 the result obtained is 12 for which it has been decided that the gear ratio necessary for the prototype is 12:1 as can be seen in Fig. 1 and with this justifies obtaining the gear box used in the car with omnidirectional drive.

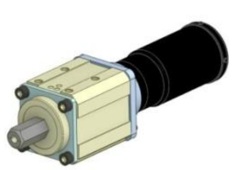

Figure 1. Planetary Gear Box 12:1 with Jeti Phasor Rscer 2035/2100 2D engine

III. Design and simulation

For the design and selection of the suspension system, several parameters were considered that were used in some calculations, these allowed us to develop different decisive and original components that together provide the vehicle with the necessary benefits during its operation, as can be seen in Fig. 2, the main elements of the suspension system are the following:

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- Wheel Hub
- Suspension Knuckle
- Suspension Arms

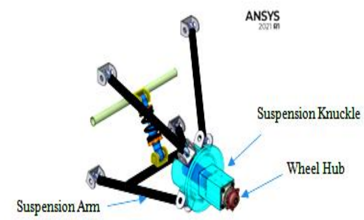
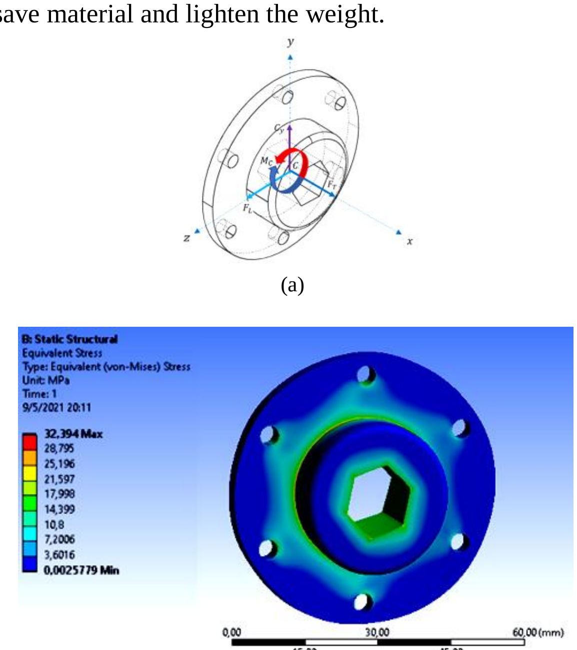


Figure 2. Suspension System and its main parts

A. *Wheel Hub*

The design of this component was made based on the function it must fulfill, which is to transmit the torque generated by the engine through the gearbox to finally reach the wheel and perform the appropriate omnidirectional movement for the vehicle to move, the loads that this element must withstand were also consider and based on that a first geometry was obtained, but it was determined that this design could be optimized to save material and lighten the weight.



(a)

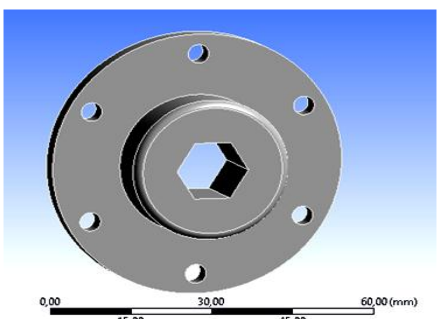
(b)

Figure 3. Wheel Hub Analisis: (a) Force Diagram , (b) Equivalent Stress Simulation

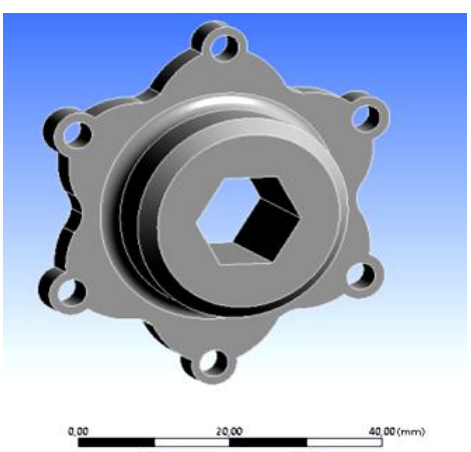
Based on the force analysis in Fig. 3 literal (a) and simulation carried out in Fig. 3 literal (b), we determined that the Wheel Hub designed when subjected to a force of

400 [N], representing the weight that each wheel supports according to the manufacturer ,but considering that by having a longitudinal movement and a lateral one, this element will be subjected to forces in both directions depending on the movement it performs; would become deformed 0.0013 [mm], the deformation is almost zero and in the same way we can observe that the equivalent stress is 32.49 [MPa] which is used to calculate the factor of safety , once the values of Yiel Stength of AISI 1020 that is of 390 [MPa] and from Equivalent Stress that is of 32.49 [MPa], the result is a safety factor of 12.04, which indicates that the component will not present failures during the operation of the vehicle.

1) Wheel Hub Optimized by Topology: It was possible to observe that within the geometry of the component there was excess material in Fig. 4 literal (a) so that**, t**he most feasible way to optimize resources was sought, so a topological study was carried out in Fig. 4 literal (b) that allowed finding a way to optimize the design of the component, in this case, it would be to use only the amount of material necessary to resist the load to which it is going to be subjected without causing any damage or problems in the operation of the single-seater vehicle.



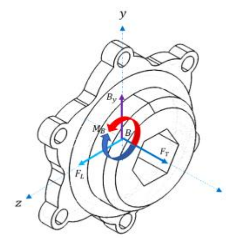
(a)



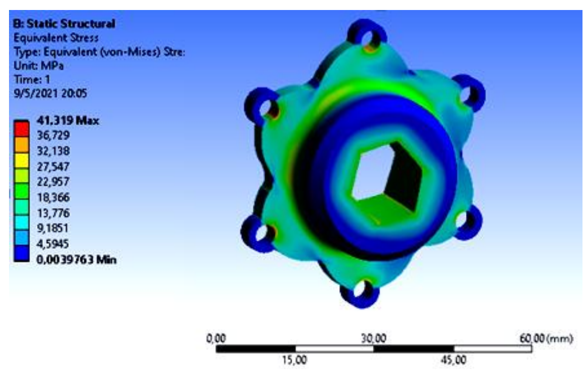
(b)

Figure 4. Topological Analysis of the Wheel Hub: (a) Original part, (b) Optimized part

Based on the force analysis in Fig. 5 literal (a) and simulation carried out in Fig. 5 literal (b) we determined that the Wheel Hub designed when subjected to a force of 400 [N], representing the weight that each wheel supports according to the manufacturer,but considering that by having a longitudinal movement and a lateral one, this element will be subjected to forces in both directions depending on the movement it performs;would become deformed 0.0012 [mm], the deformation is almost zero and in the same way we can observe that the equivalent stress is 41.86 [MPa] which is used to calculate the factor of safety , once the values of Yiel Stength of AISI 1020 that is of 390 [MPa] and from Equivalent Stress that is of 41.86 [MPa], the result is a safety factor of 9.31, which indicates that the component will not present failures during the operation of the vehicle.



(a)

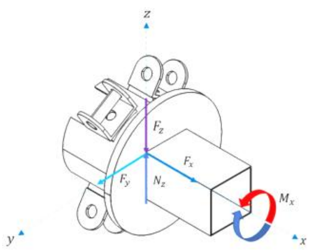


(b)

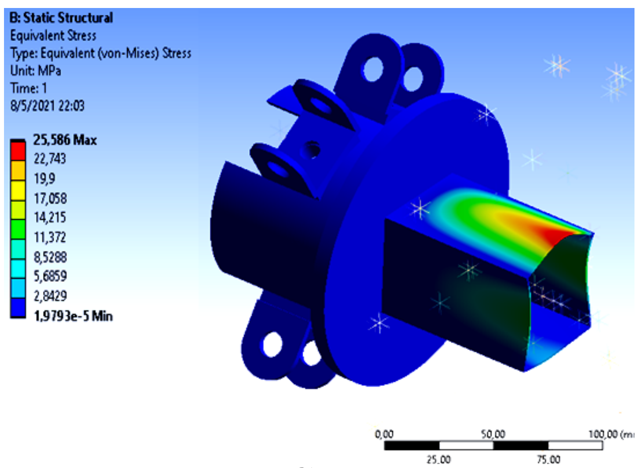
Figure 5. Wheel Hub Optimized Analisis: (a) Force Diagram , (b) Equivalent Stress Simulation

B. Suspension Knuckle

The design and geometry of the Suspension Knuckle was made looking for a new unconventional configuration and easy maintenance, deciding to do it in a circular way consider that it is necessary to provide accommodation for both the motor and the reducer, as these electrical components must be covered by a casing to avoid damage, according to these aspects, it was possible to establish a design that provides both the attachment points required for the suspension and the protection for these fragile elements, this allows us to ensure that omnidirectional movement is carried out efficiently, this Suspension Knuckle configuration is presented as an innovation due to the fact that the new technologies regarding electric vehicles do not present any adaptation in which the engine is incorporated into a spindle, but considering that by having a longitudinal movement and a lateral one, this element will be subjected to forces in both directions depending on the movement it performs; always respecting the basic principles of the dynamics of a single-seater vehicle and allowing omnidirectional movement to flow normally.



(a)



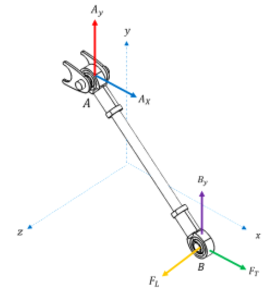
(b)

Figure 6. Suspension knuckle Analisis: (a) Force Diagram , (b) Equivalent Stress Simulation

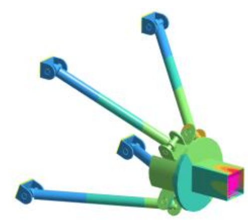
Based on the force analysis in Fig. 6 literal (a) and simulation carried out in Fig. 6 literal (b), it was determined that the Suspension Knuckle designed when subjected to a force of 400 [N], which has components that are presented depending on whether the movement is longitudinal or transverse and an angular moment that also It would have a meaning depending on whether the movement is forward or backward, it would deform 0.026 [mm] that is, the deformation is almost zero and in the same way we can see that the equivalent stress is 25.58 [MPa] which is used to calculate the safety factor together with the Yiel Stength values of AISI 1020 which is 390 [MPa] and Equivalent Stress which is 25.58 [MPa], the result is a safety factor of 15.24, which indicates that the component will not present failures during vehicle operation.

C. Suspension Arms

The design and geometry of the suspension arms is based on the frame and the wheels, which is why this configuration has been chosen, consisting of four bi-articulated bars on each one of the Mecanum wheels, consider that it is essential that the wheels remain at an angle of 90 degrees with respect to the floor and this arrangement fully respects the fundamental concepts of dynamics for a single-seater and guarantees the full development of the omnidirectional movement with total normality.



(a)



(b)

Figure 7. Suspension Arms; (a) Force Diagram, (b) Equivalent Stress Simulation

Based on the force analysis in Fig. 7 literal (a) and simulation carried out in Fig. 7 literal (b), we determined that the Suspension Arms designed when subjected to a force of 400 [N], representing the weight that each wheel supports according to the manufacturer, but considering that by having a longitudinal movement and a lateral one, this elements will be subjected to force; in both directions depending on the movement that they performs ; it should also be mentioned that calculations are made for an upper arm and for a lower one with which we will have that would become deformed 0.032 [mm] for the upper armand 0.075[mm] for the lower arm, that is, the deformation is almost zero and in the same way we can observe that the equivalent stress is 23.84 [MPa] and 29.36 [MPa] respectively which is used to calculate the factor of safety , once the values of Yiel Stength of AISI 1020 that is of 390 [MPa] and from Equivalent Stress that is of 23.84 [MPa]and 29.36 [MPa], the result is a safety factor of 16.35 for the upper arm and 13.28 for the lower arm, which indicates that the components will not present failures during the operation of the vehicle.

IV. TEST AND RESULTS

The tests carried out in Fig. 8 literal (a) for the mechanical systems of the vehicle consist mainly of verifying the correct operation of these elements already in real conditions, the first observation is that the selection of the box was adequate since it allows the engines to rotate and drive the car without any difficulty, in the same way, it was possible to verify that both the design of the apple, as that of the wheel hub and the suspension arms was effective complying with the established parameters as we can seen in Fig. 8 literal (b), mainly supporting the total weight of the car in addition to the weight of the pilot, which together are equivalent to approximate 383 [lb.] without suffering any type of damage or having any problem in the operation in general.

(a) (b)

Figure 8. The Omnidirectional Vehicle: (a) All of Systems, (b) Suspension System

The maneuverability test carried out in Fig. 9 literal (a) consisted of parking the single-seater vehicle in an extremely narrow place in which a normal vehicle would not be able to park, however, the omnidirectional single-seater had no major inconvenience to achieve this maneuver as we can seen in Fig. 9 literal (b), thus demonstrating the efficiency of each of the mechanical systems that allow proper operation without any problem.

(a) (b)

Figure 9. Maneuverability Test: (a) Before Parking,(b) After Parking

TABLE I. TESTS AND DATA

Nª Test	Data					
	V_{MAX} (Long.)	*V_{MAX} (Lateral)*	*Braking Time (Long.)*	*Braking Time (Lateral)*	*T_{Radius}*	*A_{MAX}*
	Km/h	*Km/h*	*s*	*s*	*m*	*m/s^2*
1	39	19	2	1	2,50	19,8
2	43	20	3	2	2,50	18,6
3	41	21	3	2	3	16,5
4	44	17	4	1	2,50	20,5
5	40	18	2	1	2,50	22,3

Finally, five operation and performance tests were carried out as can be seen in Table I, which made it possible to verify if the calculations carried out in an ideal environment resemble those obtained in a real situation and under normal conditions. We can see that the maximum longitudinal and lateral speed is very close to the calculated value and the same happens for the braking and acceleration values, the design of all the mechanical systems allow the omnidirectional vehicle to work with total normality and without presenting any errors or failures. With the data from the tests we can generate graphics to better identify the performance of the car and we can see in Fig. 10 the Maximum Longitudinal Speed in each test, in Fig. 11 the Maximum Lateral Speed in each test, in Fig. 12 the Longitudinal Braking Time in each test, in Fig. 13 the Lateral Braking Time in each test, in Fig. 14 the Turning Radius in each test, and in Fig. 15 the Maximum Acceleration in each test, and by visualizing each of these graphs we can determine that there are no large variations, that is, the operation of the vehicle is in a normal range

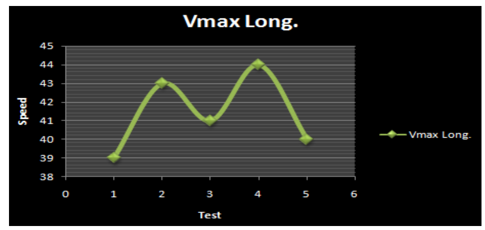


Figure 10. Longitudinal Maximum Speed

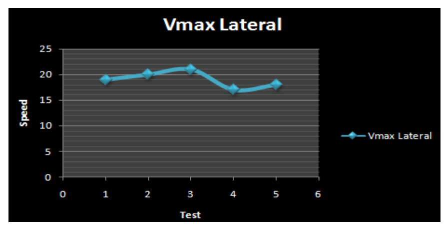


Figure 11. Lateral Maximum Speed

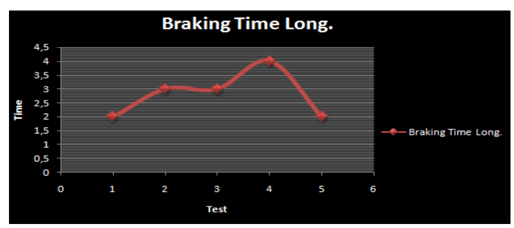


Figure 12. The Longitudinal Braking Time

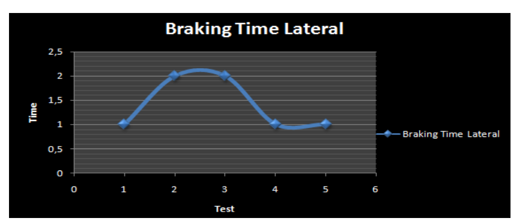


Figure 13. Lateral Braking Time

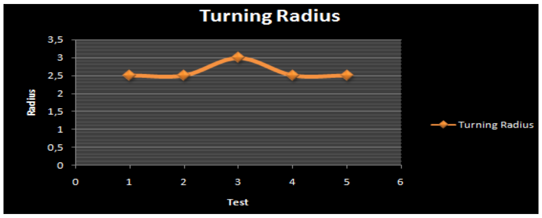


Figure 14. Turning Radius

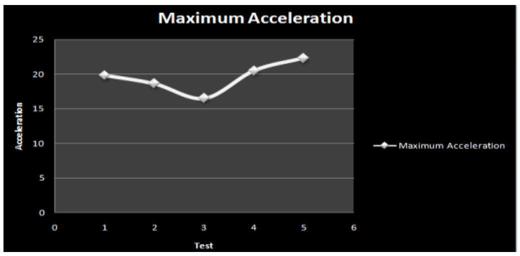


Figure 15. Maximum Acceleration

V. CONCLUSIONS

The mechanical systems of the omnidirectional vehicle comply with the calculated and simulated parameters, providing an adequate operation as a whole, which allows the functional development of the same with total normality.

Both the suspension system and the transmission system were able to support a total load of approximately 383[lb.] weight without presenting any failure or affecting the normal operation of the omnidirectional vehicle.

Through the different simulations carried out, it was possible to establish an optimal and functional design complying with the established parameters and allowing the development of an omnidirectional vehicle prototype capable of improving the maneuverability that a common vehicle presents in confined spaces.

The prototype was innovated by designing a suspension knuckle that fulfills more than one function according to the needs presented by single-seater vehicle with omnidirectional traction and allowing the desired operation to be achieved.

Performing an optimization through topology allows to save material without affecting in the least the correct operation of the piece subjected to this study, presenting us an alternative in terms of optimizing resources and thus avoiding the waste of materials

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