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Design Analysis of a Tubular Chassis for an Electric Vehicle using Finite Element Method

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Abstrak.
Pada zaman sekarang, seluruh manusia harus memilih di antara mengubah kendaraan menjadi kendaraan yang menggunakan mesin listrik atau mesin bakar, kita tahu bahwa masyarakat dipaksa untuk mengurangi jejak karbon, dengan menerapkan regulasi baru mengenai pajak karbon pada 2022. Tujuan utama dari penelitian ini adalah membuat rangka untuk kendaraan Listrik dengan suspensi depan *Torsional Bar* dan satu suspensi belakang adalah untuk mengurangi produksi karbon di kemudian hari. Dengan mengembangkan sebuah rangka untuk Gokar, mahasiswa dari President University dapat menjadi satu Langkah lebih dekat untuk mengembangakan kendaraan listrik yang bisa digunakan oleh seluruh kalangan masyarakat dan menjadi pelopor dari pengembangan teknologi terbarukan di Indonesia, Penelitian ini akan menguji kapabilitas dari rangka dalam menahan beban dengan beberapa limitasi, desain 3D akan dilakukan di perangkat lunak *Solidworks* sementara simulasi struktur statis, analisis modal, dan reapon harmonik menggunakan metode elemen hingga. di perangkat lunak *Ansys.* Hasil dari penelitian ini adalah rancangan rangka kendaraan yang aman setelah melalui proses Analisis beban, Analisis factor keamanan, Analisis defleksi rangka, dan frekuensi natural dari rangka.

Kata kunci. Rangka Gokar Listrik, Analisis Struktur Statis, Simulasi Respon Harmonik, Analisis Frekuensi Natural, Metoda Elemen Hingga

Abstract.
In these new eras, human race was stuck between fully converting vehicles using an electric motor or combustion engine. It is a known fact that people were forced by the government to reduce carbon footprint, with the new regulation of Carbon tax that will be implemented in 2022 by the government. The main purpose of this research is to design a chassis for an electric vehicle with a Torsional Bar front suspension and single rear shock breaker is to help reducing carbon production in the future. By developing a chassis for an electric Go-Kart, the students of President University is one step closer to develop an electric vehicle that can be used by everyone and become a leading green technology innovator in Indonesia, this research will test the capability of the chassis to endure certain loads with a few limitations, the 3D design will be performed in software called Solidworks while the static structural, modal analysis, and Harmonic Response Simulation will be performed in Ansys using the finite element method. The results from this research is a sufficient design of electric go-kart through a stress analysis, safety factor analysis, chassis deflection analysis, and chassis natural frequency analysis.

Keywords: *Electric Go-kart Chassis, Static Structural analysis, Harmonic Response Simulation, Natural Frequency analysis, Finite Element method.*

Introduction

Indonesia is the Fourth biggest Greenhouse Gas Emitter in 2015, one of the reasons is the massive use of fossil fuel [1], but starting from 2016 Indonesia is making serious effort to reduce its Greenhouse Gas emission and Carbon Footprint, they reduced almost 31 Metric Ton per year, Indonesia is planning to go Zero Greenhouse Gas emissions in 2060 [2].

One of the problems that occurred in Indonesia is the massive increase of Fossil Fuel Transportation such as Cars, Motorcycle, & Truck for Industries, this is why Indonesia starting from April 2022 will implement a carbon tax of 30 Rupiah per every Kilogram Carbon produced [3]. Because of this Indonesian Government also pushed the development of electric car and set the goal that 20% of the car manufactured in Indonesia is Electric Vehicle by the year 2025 [4].

There is a research by Sutisna & Akbar (2019) that are trying to design a chassis for an electric vehicle, this first one is a research about Torsional Bar Technology [5] to increase the rigidity on the chassis by connecting the right and left front tires to make a front rigid suspension.

There is also Razak et al. [6], research that is using Topology Optimization to reduce the weight of the chassis because according to their study by reducing 10% of the vehicle weight it could increase 5% – 8% of Energy efficiency.

Abdullah et al. [7] who make research about the effect of light chassis, it can cause a resonance to the chassis when it is driven and induced by the road inconsistency, engine vibration and uneven load position, which can lead to discomfort when driving the Go-kart.

There is another paper that is written by Patil et al. [8] that analyze a Go-kart chassis design with FEM Software and make a Chassis to perform under the load of Driver and the machine, the location of the deflection is the same when it is calculated using simple beam theory.

With this development there is not any research that has a significance increase of Electric Vehicle related Study in Indonesia, this is why this research goal is to make a design for an electric Go-kart to start contributing in the development of a better future in Indonesia.

This research studied the development of Go-kart Chassis that used a Torsional Bar and Single Shock absorber in a split Tubular chassis to reduce the chassis vibration and increase the driving comfort. The model of this go-kart is exhibited in Fig. 1.

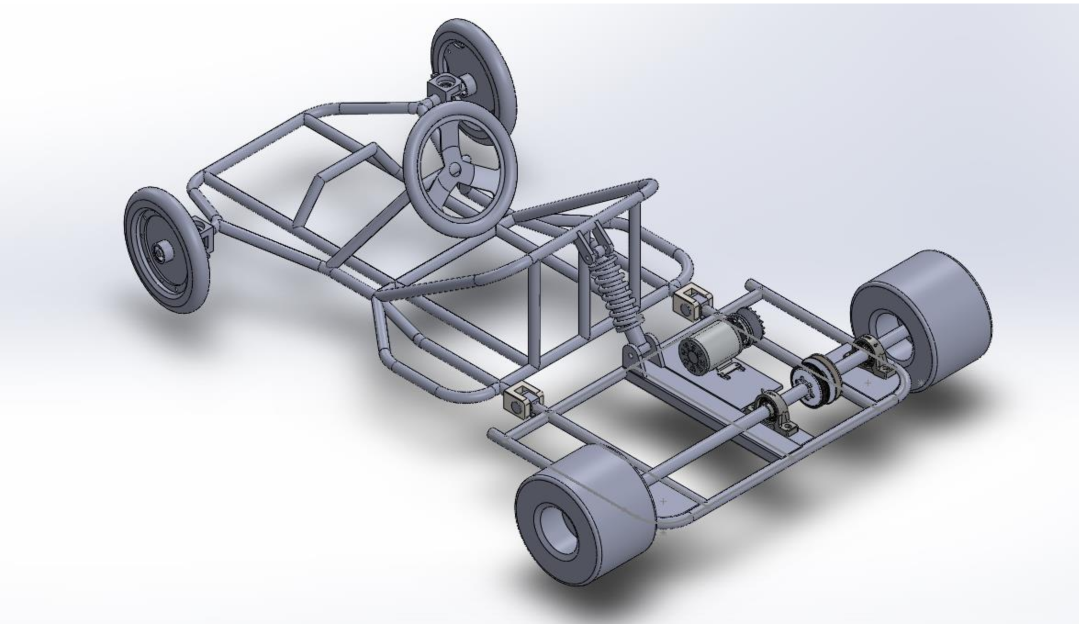


Fig. 1 Electric Go-kart Chasis Design

This Go-kart will use a Tubular Chassis because it has the best weight to structural rigidity Ratio, and it is the most safety Chassis that can be used for prototyping. It mainly uses pipe or a hollow tube as it structure, this is why it is lightweight because every structural piece is calculated before [5].

Method

Finite Element Method

Finite Element Method or F.E.M is a system that was developed by engineer since the 1950's it is used to reduce the complexity of a calculation by dividing it into smaller problems. This smaller problem is called finite elements analysis, this method is used to reduce the time and cost of solving a design problem, which will be use to calculate the maximum stress and displacement of the Go-kart Chassis [13].

Finite element method uses a mathematical formulation to reduce engineering mechanic problems into smaller ones, this problem it can be calculated using a differential equation to get an approximation on the stress and strain of the chassis, but one thing to keep in mind is that finite element method can only give an estimation or an approximate of solution [14].

Finite Element can be solved using Matrix, it depends on the element types, from a single line into Cube that has 8 points on every corner, every one of this point has 3 Degree of freedom, this means a single Cube (Hexahedron) has 24 Degree of Freedom and a single Parts can contain upward of thousands Element, which makes it impossible to calculate it manually, Fig. 2 shows a Linear Spring formula as an Example for element matrix [15]:

$$f = k \cdot d \tag{2.1}$$

f = Element Force Vector (Known)

k = Element Spring Stiffness Matrix (Coefficient)

d = Element Nodal Displacement (Unknown)

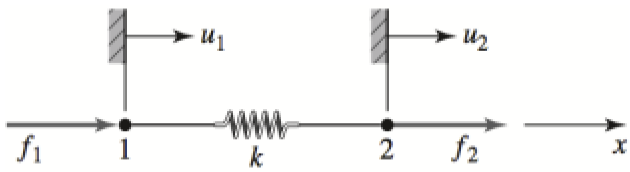


Fig. 2 Linear Spring [15]

$d = u_2 - u_1$

$f = k(u_2 - u_1)$

for zero deflection it must be assumed that

$f_1 + f_2 = 0 \rightarrow f_1 = -f_2$

then it can be formulated it into 2 equations:

$f_1 = -k(u_2-u_1)$

$f_2 = k(u_2-u_1)$

in matrix form:

$$\begin{bmatrix} k & -k \\ -k & k \end{bmatrix} . \begin{Bmatrix} u1 \\ u2 \end{Bmatrix} = \begin{Bmatrix} f1 \\ f2 \end{Bmatrix} \qquad (2.2)$$

$$[Kc] . \begin{Bmatrix} u1 \\ u2 \end{Bmatrix} = \begin{Bmatrix} f1 \\ f2 \end{Bmatrix} \qquad (2.3)$$

From this matrix, the displacement of the Spring can be calculated using Inverse matrix to change the position and to find out the stress and strain of the system, using this formula:

$$\begin{Bmatrix} u1 \\ u2 \end{Bmatrix} = \begin{Bmatrix} f1 \\ f2 \end{Bmatrix} . [Kc]^{-1} \qquad (2.4)$$

Strain: : $\delta = \frac{\Delta u}{L}$

Stress: $\sigma = E \,.\, \varepsilon$

Meshing

Meshing is a simplification of 3D object into lines or shapes and used to calculate Finite Elements. There are many types of 3D mesh from the simplest Tetrahedron to Hexahedron or prism shaped Mesh as it is shown in Fig.3. It is used for different purposes, Tetrahedron is used for a more complex shape and Hexahedron is used for more simple Form, while there are other shapes that is used as a transition between Tetrahedron and Hexahedron shape [16].

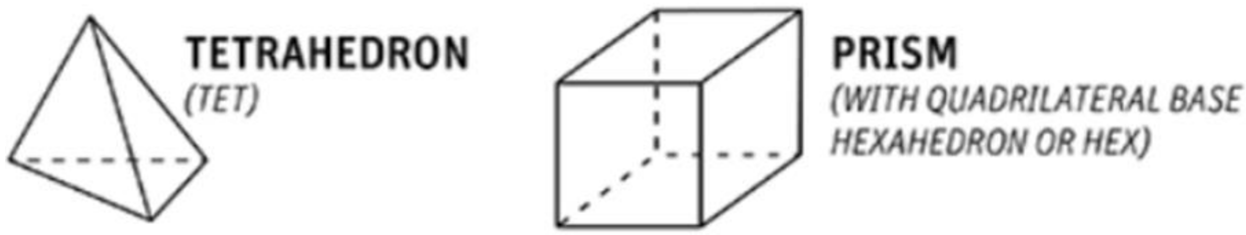


Fig. 3 Meshing Shape[16]

Finite element can be costly if not done properly, it could add cost in time and money, using the wrong mesh type and size could increase the simulation time exponentially as it is a 3d object and as shown in Fig. 4 downsizing mesh size into unnecessary size would not give any advantage [14].

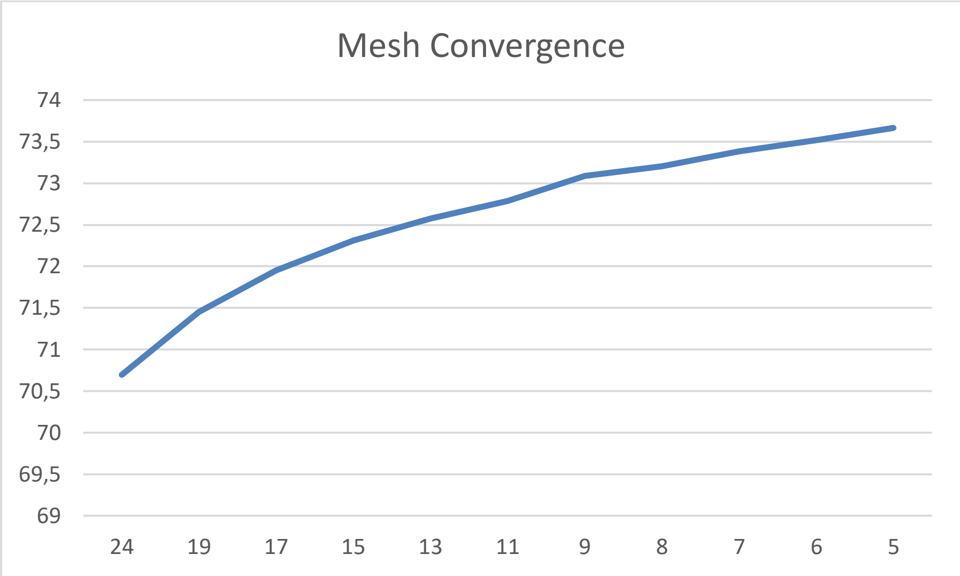


Fig. 4 Mesh Convergence

From the Meshing Chart above, concluded that the mesh size is steadying after 7 mm and can be used as it is the most efficient and there would not be a significance difference after the 7 mm mesh point.

Boundary Condition

Boundary Condition is used to add a more realistic simulation on how the project will take form in Real world when using finite element Simulation Software. Many things can be added to reduce the differences between the simulation and real-world comparison like a contact for loads and fixed or movable supports [17].

- Used a Pipe Profile with an Outer Diameter of 30.5 mm an Inner Diameter of 27.2 mm
- add Gravity Acceleration of 9.81 m/s$^{2]}$ (see Fig. 5)

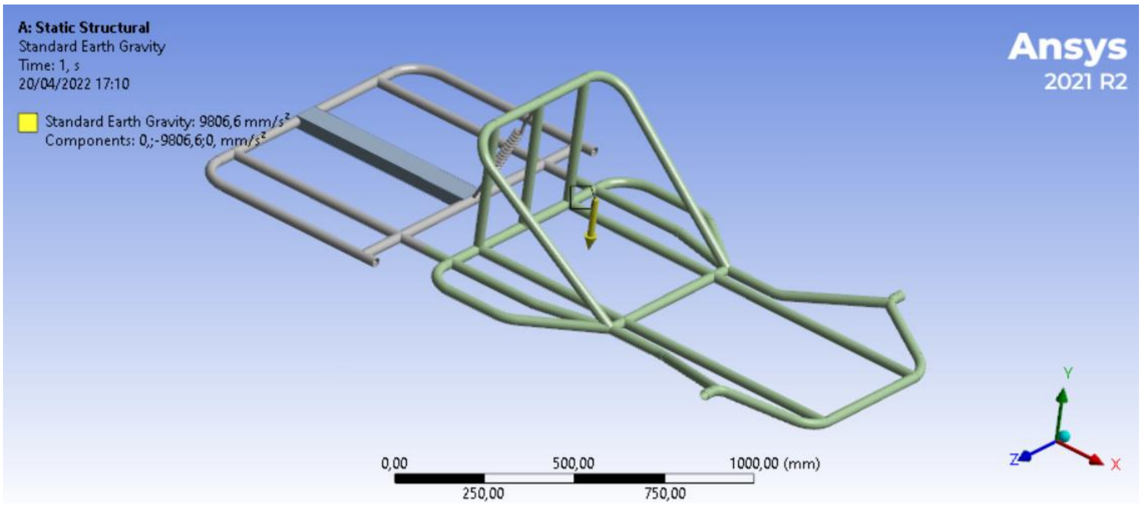


Fig. 5 Adding Gravitational Load

- add a Remote Force of the driver in the amount of 100 kg (see Fig. 6)

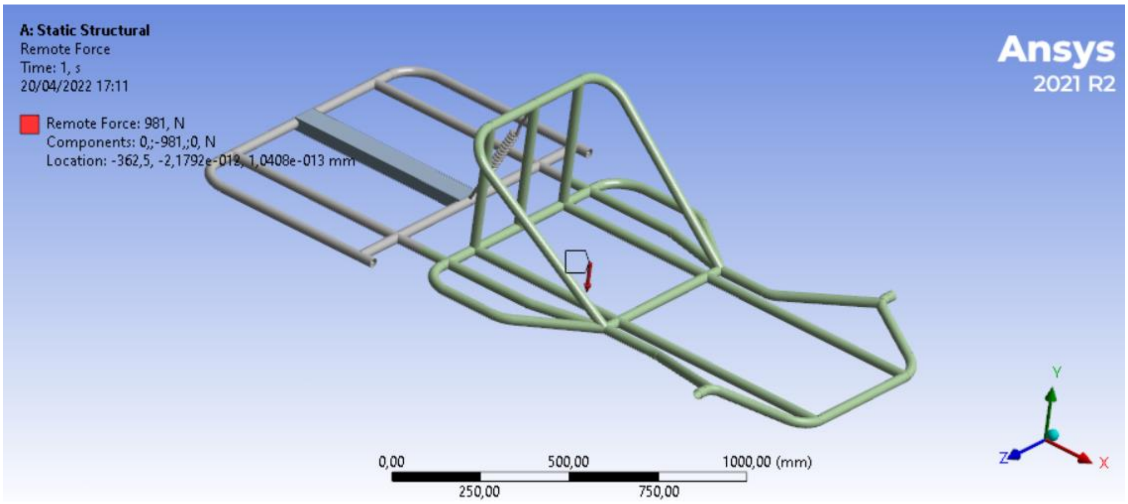
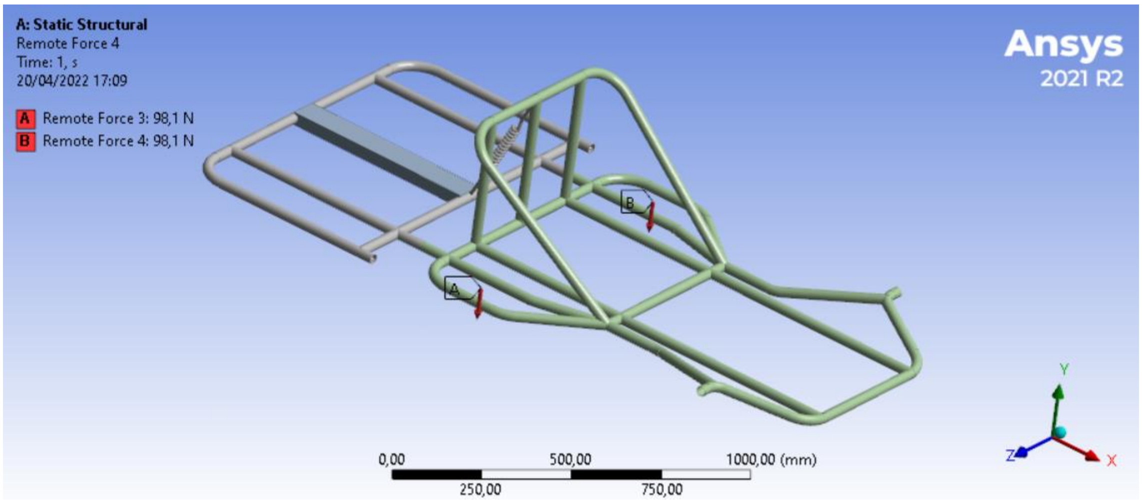


Fig. 6 Adding Driver Load

- add a Remote Force of the Battery in the amount of 20 kg (see Fig. 7)



- **Fig. 7 Adding Battery Load**

- add a Remote Force of the Electric Motor & CVT in the amount of 30 kg (Fig. 8)

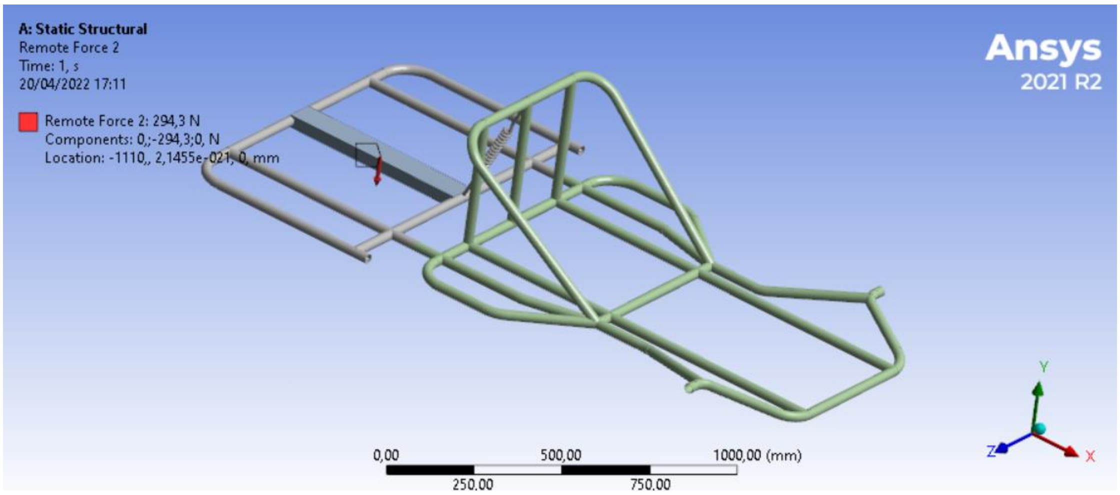


Fig. 8 Adding Motor & CVT Load

− add Rear Fixed Support (see Fig. 9)

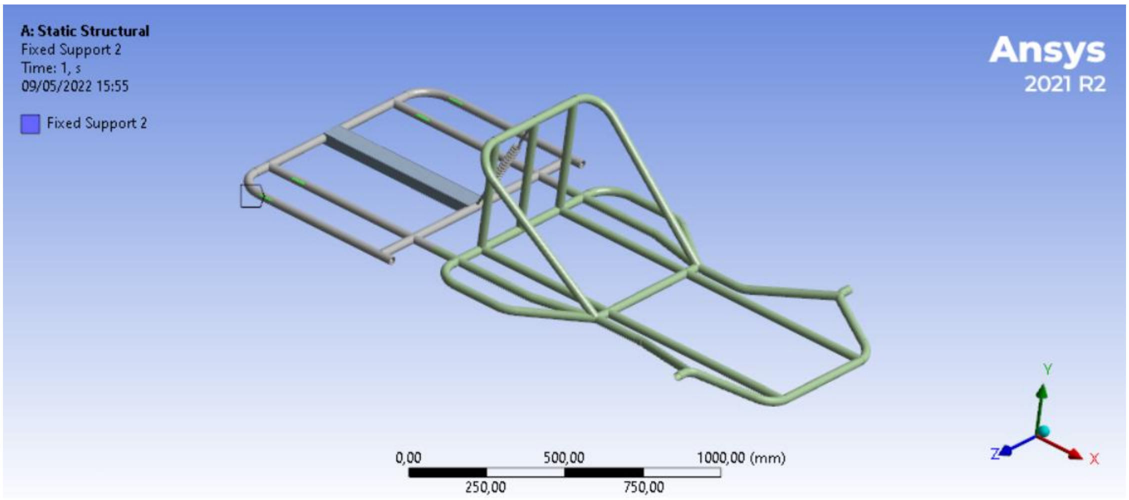


Fig. 9 Adding Rear Support

− add Front Fixed Support (see Fig. 10)

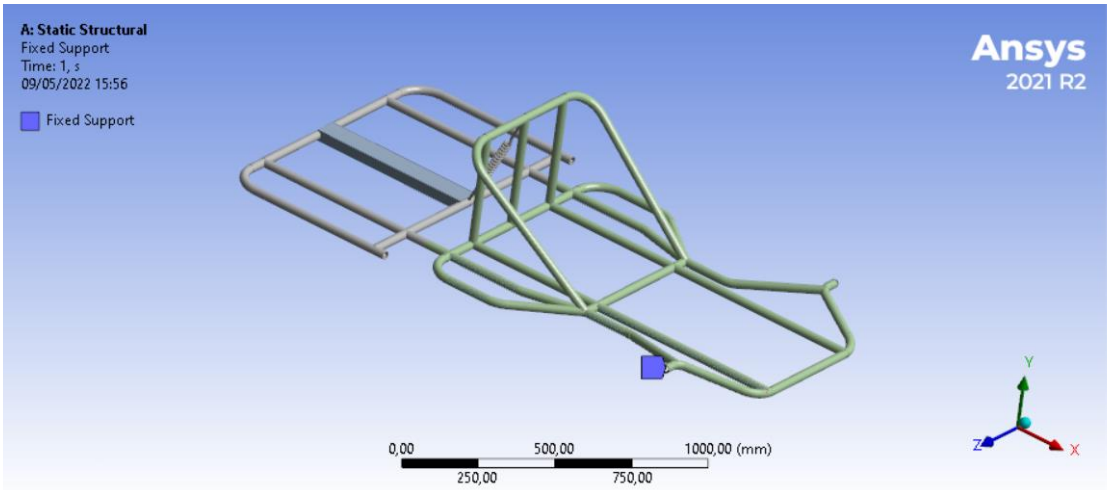


Fig. 10 Adding Front Support

− set the Material to fit the specification of ASTM A106B and change the Tensile strength to 60.000 Psi (413.69 MPa) and the Yield Strength to 35000 Psi (241.32 MPa) [19]. (see Fig. 11)

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7850	kg m^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
12	Strain-Life Parameters				
20	S-N Curve	Tabular			
24	Tensile Yield Strength	60000	psi		
25	Compressive Yield Strength	35000	psi		
26	Tensile Ultimate Strength	4,6E+08	Pa		
27	Compressive Ultimate Strength	0	Pa		

Fig. 11 Material Specification

– add 2 Connection on the point between Front and Rear Suspension to act as a Joint connection. (see Fig. 12)

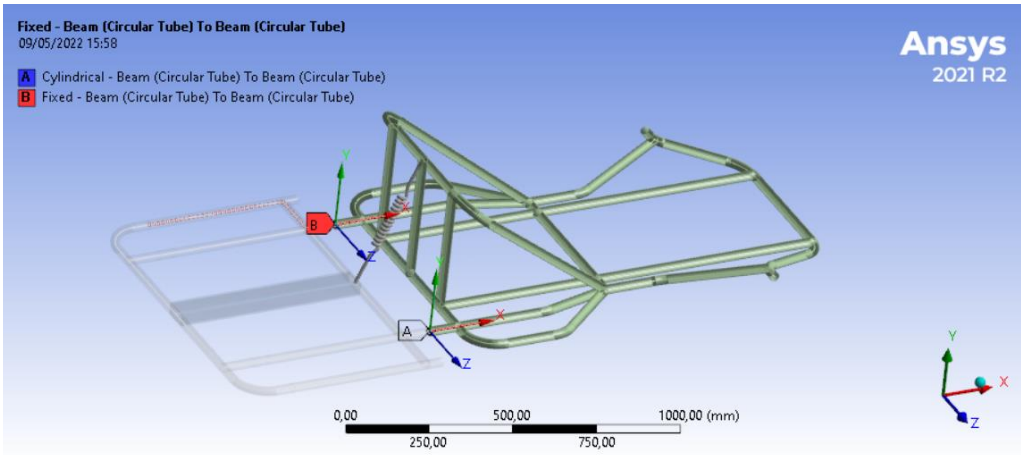


Fig. 12 Adding Joint Connection

– add a Spring Connection with value of 72.7 N/mm to resist the Chassis movement while driving. (see Fig. 13)

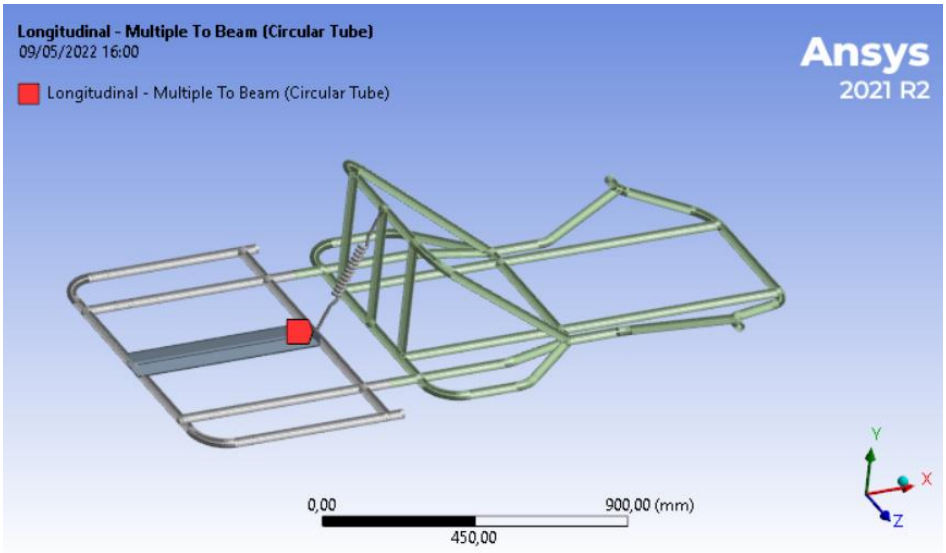


Fig. 13 Adding Spring Dampener

Spring Coefficient

For the spring because there is no Material Data Sheet, to Calculate an estimation for the Spring Coefficient that is used for the Shock Breaker, The Formula for the spring coefficient calculation is [12]:

$$K = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n} \tag{2.5}$$

$$K = \frac{78600 \cdot 13^4}{8 \cdot 82^3 \cdot 7}$$

$$K = 72.7\ N/mm$$

K = Spring Coefficient [N/mm]

G = Modulus of elasticity [MPa] = 78.600 [18]

d = Spring wire diameter [mm] = 13

D = Spring outer Diameter [mm] = 82

n = number of coil = 7

From the calculation above assumed that the Spring Coefficient for the Shock breaker is 72.7 N/mm.

Natural Frequency

Natural frequency or usually called eigenfrequency is a frequency which every object has, it is happening when there is a natural vibration at an object that does not have any damping or external force. An additional force can be applied to the system with the same frequency as the natural frequency and it would create resonance, this resonance will create an oscillation and increasing the deflection of the structure, this is why finding the natural frequency of an object is a must [23].

A natural frequency can occur in many points, it isn't just going to happen at certain frequency, this is the formula for natural frequency:

$$f = \frac{\omega}{2\pi} \quad (2.6)$$

f = Natural Frequency

ω = Angular Frequency in rad/s

$$\omega = \sqrt{\frac{K}{m}} \quad (2.7)$$

K = Stiffness of the Spring [N/m]

m = mass of an object that oscillates [kg]

$$f = \frac{\sqrt{\frac{K}{m}}}{2\pi} \quad (2.8)$$

Results

From the previous design, this research designs a new type of go-kart chassis, using a torsional bar and a single point suspension that connect front and rear chassis which going to dampen the vibration of the chassis when faced with road irregularity.

This type of chassis as shown in Fig. 14 is developed to withstand the weight of the driver, the weight of the electric motor, and the weight of the battery. The weight is reduced by reducing the thickness of the pipe, a go-kart usually builds using a Scheduled pipe [5], that according to ANSI B36.10 for Schedule 40 1 Inch pipe has a thickness of 3.38 mm, while this research used a pipe that has a thickness of 1.65 mm.

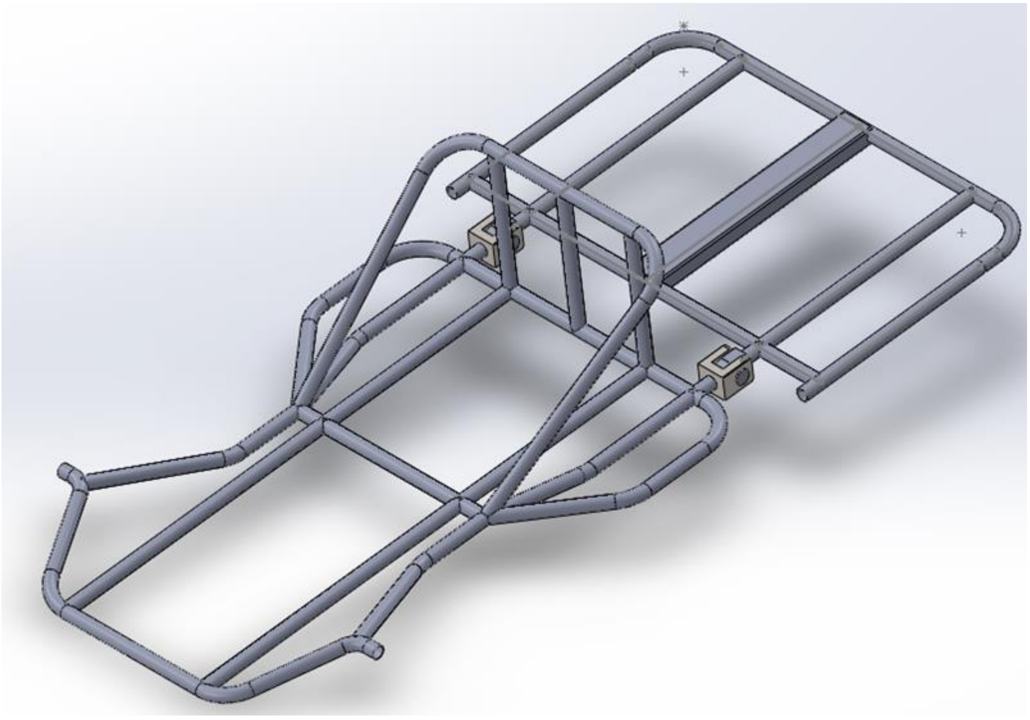


Fig. 14 Chassis Design

Table 1. Weight Comparison

Material Profile	Weight
Schedule 40 1-inch Pipe	51.742 kg
OD30.5 mm, ID27.2 mm Pipe	30.618 kg

According to software calculation this research found out that the weight is reduced from 51.7 kg to 30.6 kg by reducing the pipe thickness, this is used because according to a study [6] that weight reduction could increase the energy efficiency.

After the designing process this research continue to the Simulation phase as shown in Fig. 15 and found out the result of how much is the Deflection and Maximum Stress on the Chassis, it can be seen that the maximum stress on the chassis is 73.38 Mpa this means the chassis can withstand the maximum force that are exerted onto it.

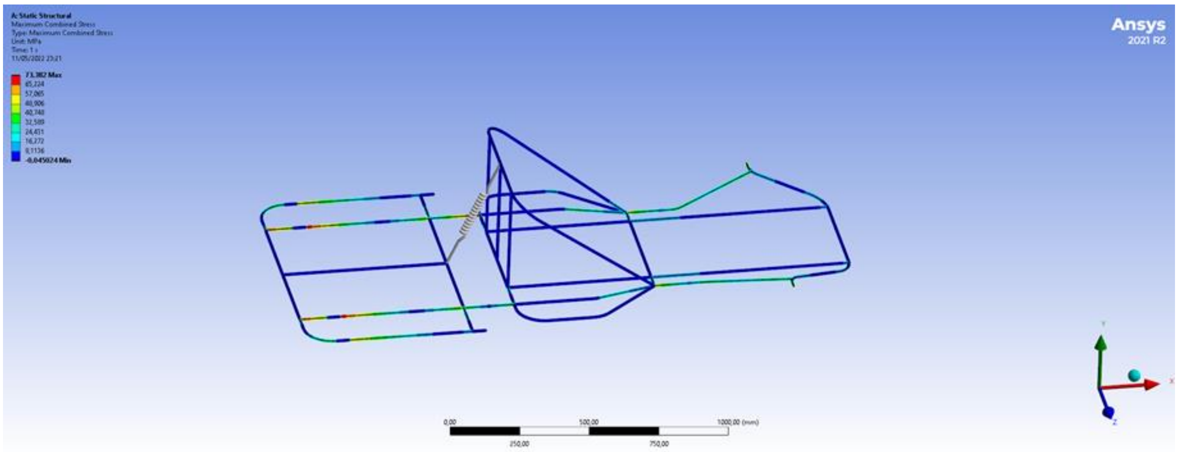


Fig. 15 Chassis Load Simulation

From this Result it can be calculated that the Safety Factor of the chassis, this reasearch calculates the safety factor using this formula because the material is Ductile [20]:

$$Safety\ Factor = \frac{Yield\ Strength}{Maximum\ working\ Stress}$$

$$Safety\ Factor = \frac{241.31\ [Mpa]}{73.38\ [Mpa]}$$

$$Safety\ Factor = \mathbf{3.288}$$

After analyzing the load on the Go-kart Chassis, this research tested it in Modal Analysis simulation, this simulation is used to test the natural frequency of an object, this is the results of the simulation for the Past design [5] and the new design chassis (Fig. 16 & 17):

Table 2. Natural Frequency Comparison

No	Past Design [Hz]	New Design [Hz]
1	58.138	35.042
2	77.141	46.743
3	88.74	76.48
4	144.91	78.508
5	166.92	115.62
6	171.94	127.21

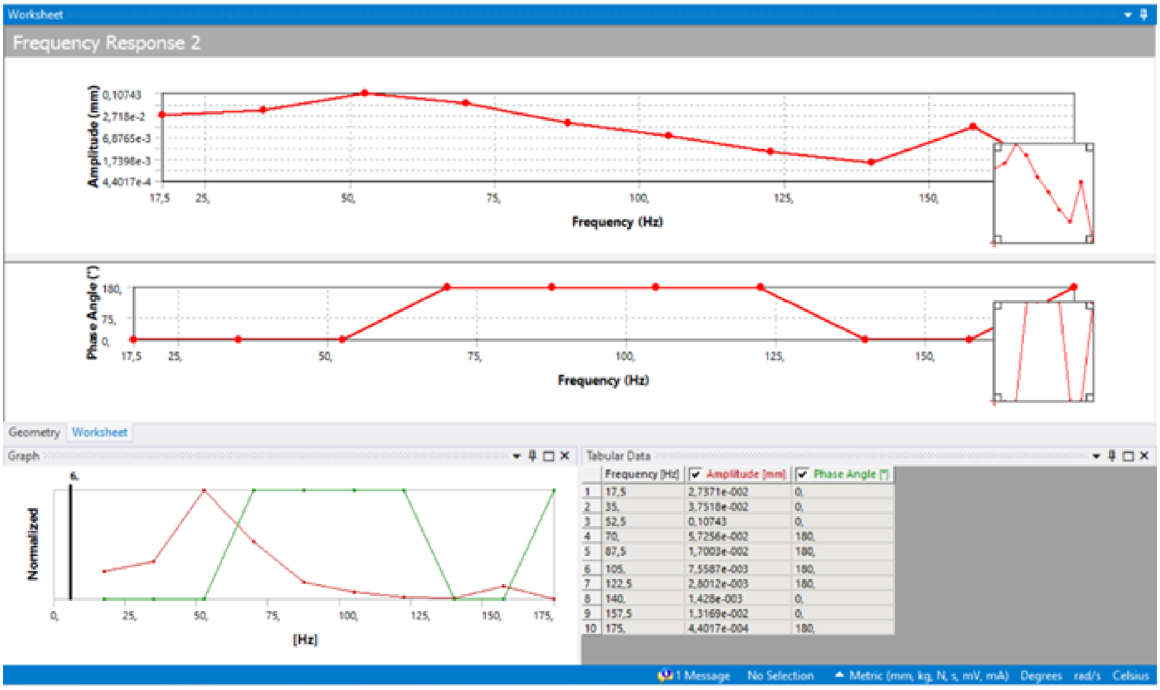


Fig. 16 Past Chassis Harmonic Response Simulation

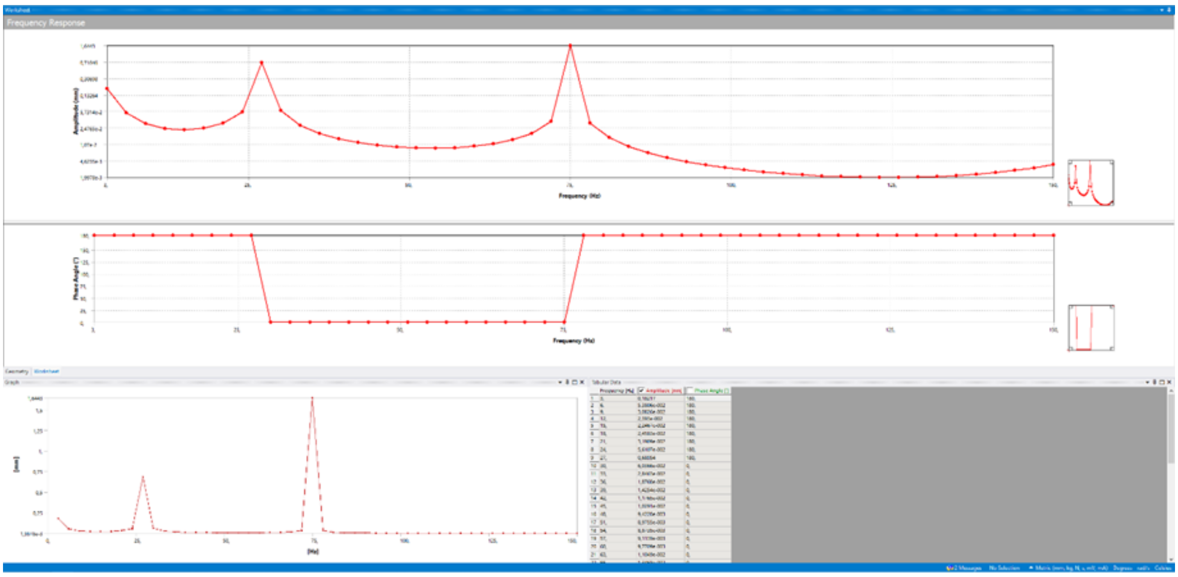


Fig. 17 New Chassis Harmonic Response Simulation

From these results it can be seen that this research found out that the new design had a smaller Natural frequency compared with the past designs, as pointed out in Table 2 that the smallest natural frequency is 35.042 Hz while the past design smallest natural frequency is 58.138 Hz and the amplitude of the new design is bigger than the past designs, it is supposed that the chassis design that use two separate chassis with a joint connection and added suspension is responsible of this huge amplitude of 1.6443 mm while the past design has a maximum amplitude of 0.10743 mm.

This single Suspension Chassis is designed to increase the comfortability of the rider because it differentiates itself from the normal Go-kart by adding a Shock breaker suspension between Front and rear Chassis to dampen it. The Decrease in Weight also increasing the energy efficiency according to a study that happened in Malaysia [6].

From the static load analysis. It is found that the Chassis receive a maximum principal load of 73.38 MPa, if the tensile strength of the material is divided by the maximum load, it can be calculated that the load that can be endured by the chassis is 3.288 times more than what is happening right now. From this discussion if reader want to use a better material to develop a heavy-duty electric vehicle, this research can be used as a base to understanding the calculation of maximum load that chassis could suffer before reach a plastic deformation point.

After analyzing the modal analysis and harmonic response simulation of this chassis and the past design [5] this research found that this type of chassis has a smaller natural frequency and bigger amplitude, suppose that this result is relevant with the chassis type, with a suspension in place the chassis will oscillate a higher amplitude but slower frequency which will become more comfortable for the driver.

Conclusion

In conclusion This design is a success, it is a more advanced design than a Normal Go-kart, it could increase riding comfort, without increasing too much of a cost for building it, if compared with a Formula SAE which have 4-point suspension in every tire, this design only uses one suspension between the two chassis.

This research also conclude, that in designing go-kart chassis, the need of knowledge to understand that the chassis weight needs to be calculated and made to become as light as possible because weight reduction will increase the energy efficiency of the electric vehicle.

When calculating the load of the chassis it is found that the safety factor of the chassis is more than enough, this can be used to increase the load that will happened in the chassis for future projects that will be done with the chassis.

In modal analysis and harmonic response simulation it is found that the chassis have a maximum deflection of 1.6 mm at 75 Hz point, this could be further reduced with adding dampener in the chassis(ex: rubber mounting).

While doing a software simulation is cheaper, reader need to understand that the real-world condition cannot be replicated 100 [%] into the software and there are many limitations in the software to replicate it, this means that the thesis results cannot be trusted 100 [%] reader must still do a prototyping process and re-test it before using this design.

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Comments from the reviewer:

1. **Abstract:** Since this research has been completed, please write down the "**Result**" obtained from this research, and not only the "**Expected result".**
2. **Content:**
    - Please check the citation, many citation symbol were located inappropriately, the citation symbol should be placed before the full-stop i.e "**[1].**" and not "**.[1]**" and give a space after the previous word. (See highlight in the manuscript.)
    - There is no need to write units using parentheses. (See highlight in the manuscript.)
    - Figure 15 needs to be enlarged (focus on the whole structure) so that the fringe/stress distribution is clearly visible on all parts of the structure.
    - It is also necessary to add a figure of the simulation results showing the displacement/deformation of the entire structure.
    - The design, the simulations and the analysis have been carried out very well, however, it is necessary to show how/what methods are used to validate and ensure that the FE model made is correct and represents the actual physical model in terms of boundary conditions, constraints, selection of elements according to with a geometric design etc