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Research Article

Static Analysis of Tubular Space Frame Chassis of an Electric Racing Car Made of ASTM A106 Grade B

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ABSTRACT

The chassis is a vital component in electric vehicles, which can keep the car rigid and robust to support the load on it. In this research, the chassis is designed for electric vehicles with sufficient strength and rigidity, as well as light in weight and safety according to KMLI regulations, to be used in student racing competitions. The design process is begun with chassis space frame determination and weight and position definition of all components to be installed on the chassis. Then calculate the center of gravity and the reaction force at the mounting supports on each wheel. The chassis design has a length of 2300mm, a width of 1100mm, and a height of 1100 mm. This chassis is made using ASTM A106 Grade B steel pipe with a diameter of 1 inch, and the total weight is 76.5 kg. The analysis was carried out statically using Solidwork. The static study showed maximum stress of 22.06 MPa, a maximum deflection of 0.346 mm, and a minimum safety factor of 10.9. All the parameters show promising results, strength, stiffness, and safety in compliance with KMLI regulations

1. INTRODUCTION

In the era of rapidly developing technology, various alternative energy sources have emerged to generate power in vehicles, including electrical energy. An electric car is a vehicle without emission (clean transportation) that can reduce air pollution due to carbon dioxide and sulfur dioxide emissions caused by combustion engines [1]. The electric car also has higher efficiency, and the engine sound is smoother, odorless, and free of smoke compared to fuel cars [2].

The development of electric vehicles has reached an advanced level, used for daily use and competitions such as competitions to create fast and efficient electric vehicles. At the college student level, there are various levels of electric car competitions, the Indonesian Electric Car Competition (KMLI = Kompetisi Mobil Listrik Indonesia) for the national level and the SAE Formula for the international level. KMLI is a competition that is participated by college students in Indonesia, which is not only competing for speed (racing) but also for the efficiency of electric cars.

One of the essential parts of all vehicles is the chassis. The chassis is the part located at the car's underside that supports and carries all the components placed on it, such as the engine, the

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steering system, the suspension system, the braking system, the seats, and loads. The chassis must not only provide strength and thus withstand shock and twist but also have the stability to dampen vibration. Chassis can be used in various vehicles, such as backbone chassis frame, ladder chassis, tubular space frame, and monocoque [3],[4]. Regarding its function and performance, the chassis has a vital role; thus, it needs more attention, especially in racing cars [5]. Failure of the chassis will fail to support the load and damage to other components and can endanger the driver's safety.

The tubular space frame chassis has the advantage that it is easy to design adds components, and is also light in weight. All struts made of pipes or tubes were arranged in good triangulated joints to obtain maximum stiffness in bending, torsion, and impact load [6]. Triangulation is the simplest structure that is formed to obtain high stiffness. Triangular frames will always construct a structure and not a mechanism. Then to get a high rigidity of the chassis, the triangular frame should be shaped in the chassis at the most [7].

The tubular space frame is also easy to be manufactured, repair, and modify at a minimal expense without compromising the safety of the driver [5], [8], [9]. That is the reason why the tubular space frame chassis has become the favorite choice for race cars and has been established as an essential requirement for racing competitions in general [3], including KMLI competitions

To fulfill all requirements, such as: gaining a chassis that has strong, lightweight, and safe according to the KMLI regulations, it is necessary to carry out the design and static analysis of the electric vehicle chassis correctly. The chassis is a tubular space frame arranged by welded pipes to form a rigid structure. This chassis generally uses a square tube shape for easy connection, although the circular pipe shape has greater strength.

2. METHODOLOGY

There are limitations in designing a tubular space frame electric racing car chassis in the KMLI competition. The primary regulation of KMLI is developed based on Formula SAE regulation. KMLI regulations for the design and chassis development for the racing car are seen in Table 1.

Table 1. KMLI Regulation [10]

KMLI	
Width of electric car	120 – 140 cm
Minimum weight	125 kg (without driver)
Construction	Safety for driver

(Source: KMLI, 2019)

The FORMULA SAE regulation determines the limitation for designing and developing chassis for the racing car that is not stated in the KMLI regulation. These regulations will accomplish the safety requirements of the racing car chassis design so it would be safe for the driver. Table 2 shows the details of Formula SAE regulations.

Table 2. Formula SAE Regulations

Formula SAE		
Wheelbase	Minimum length	1525 mm
Chassis	Structure	Triangular
Chassis material	Steel material properties	a. Non-welded material E = 200 GPa σ_y = 305 MPa σ_u = 365 MPa b. Welded material σ_y = 180 Mpa σ_u = 300 Mpa
	Other material properties	Equal or better than the minimum steel requirement

(Source: SAE, 2018)

The chassis designed is a tubular space frame type chassis arranged with welded struts to form a rigid structure. Several hollow rods are used as struts in space frame chassis, such as square and round hollow bars (pipes). Square tubes were generally used for easy connection, while circular pipes had greater strength. The space frame chassis was made using round hollow bars (pipes).

The design of the KMLI car chassis starts with determining the ergonomic shape and size that fits the driver's body. These ergonomic shapes and sizes are defined based on anthropometric data references to the 95th percentile male ergonomics data, complying with the general regulations of the SAE Formula [11].

The driver's ergonomics model is developed by manually drawing a rough sketch of the chassis frame structure concept, as shown in Figure 1. Using the Solidworks software, the rough sketch is then defined into a 3D illustration of the chassis frame structure. The concept drawing of the chassis frame structure is shown in Figure 2.

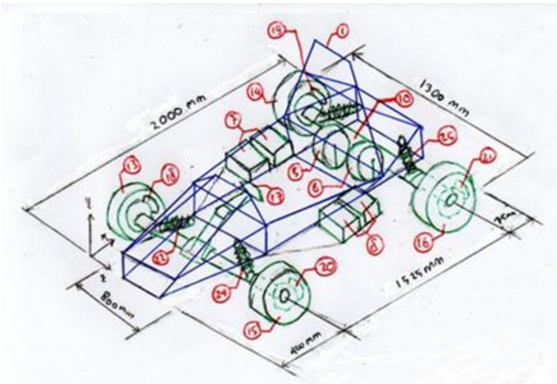

Figure 1. Rough sketch concept

The shape and size of the chassis frame structure concept are carried out by considering the position of all components installed on the chassis.

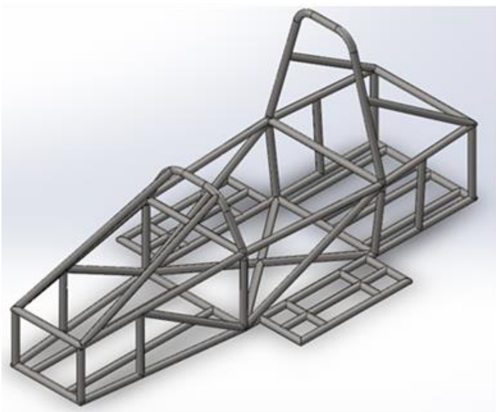

Figure 2. Drawing concept

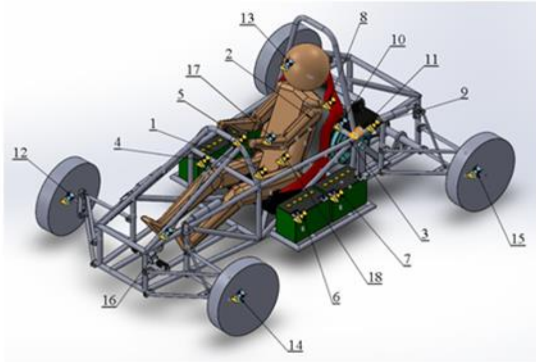

Figure 3. Detailed drawing concept

All components installed and their size and position will determine the shape and size of the frame structure of the chassis. The application of all parts on the chassis will produce a detailed chassis concept, as shown in the picture. Since all components have been applied to the chassis, it will result in a complex idea, as shown in Figure 3.

Adjustments were made to get the shape and dimensions that match the components assembled on the chassis and also fit the driver ergonomically. The dimension of the chassis can be determined, as seen in Figure 4.

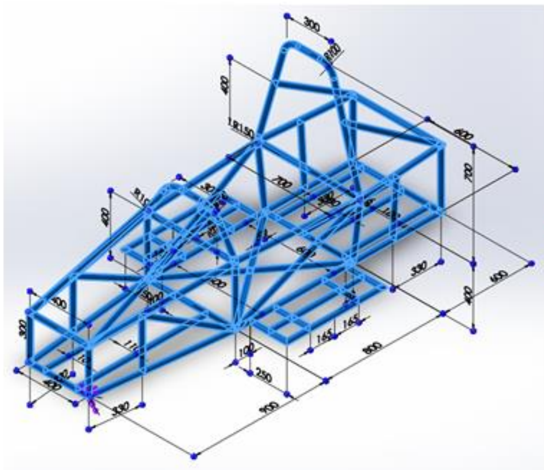

Figure 4. Chassis dimension

Since the chassis frame structure shape is determined, the components to be installed, their weight, and position are defined in the x, y, and z-axis, as shown in Table 3.

Table 3. Components on chassis

No	Component	Mass (kg)	Position (mm)		
			X-axis	Y-axis	Z-axis
1	*Chassis*	76.5	1244.61	203.34	896.78
2	BLDCmotor (R-wheel)	15	1833.27	226.7	732.03
3	BLDCmotor (L-wheel)	15	1833.27	226.7	1061.43
4	Battery-1 (R)	4	1165.39	117.53	467.7
5	Battery-2 (R)	4	1486.38	117.53	467.7
6	Battery-1 (L)	4	1165.39	117.53	1321.22
7	Battery-2 (L)	4	1486.38	117.53	1321.22
8	*Drive Inverter*	4	1836.63	448.06	906.67
9	*Drive Shaft*	5	2222.65	81.7	903.56
10	Transmission (R)	3	2015.97	158.57	829.34
11	Transmission (L)	3	2015.97	158.57	963.55
12	Suspension, brake and wheel [F-R]	7	292.28	105.98	147.96
13	Suspension, brake and wheel [R-R]	7	2292.59	98.46	70.99
14	Suspension, brake and wheel [F-L]	7	292.28	105.98	1650.3
15	Suspension, brake and wheel [R-L]	7	2292.59	98.46	1727.28
16	Steering system	8	412.05	153.36	897.68
17	Driver	70	1323.3	418.79	890.52
18	Driver seat	10	1437.51	213.65	896.83
19	*Body* (front)	3	412.05	203.34	896.78
20	*Body* (right)	1	1355	117.53	467.7
21	*Body* (left)	1	1355	117.53	1321.22
Total mass (kg)		256.5			

Note: F-R Front-Right; R-R Rear Right; F-L Front Left; R-L Rear Left

Based on masses and the position of each component in the chassis, calculations are then carried out to determine the combined center of gravity. The total system chassis weight and combined center of gravity positions obtained W_{total} =2516.265 N at position X = 1358.228 mm, Y = 247.34 mm, and Z = 895.47 mm.

The support reaction force determines the value of the constraint on the chassis. All the support reaction forces, in this case, are statically indeterminacy cases; thus, the calculation was carried out with three-moment equations.

The free-body diagram of the chassis system was configured based on the modeling with the position of the center of gravity, as shown in Figure 5.

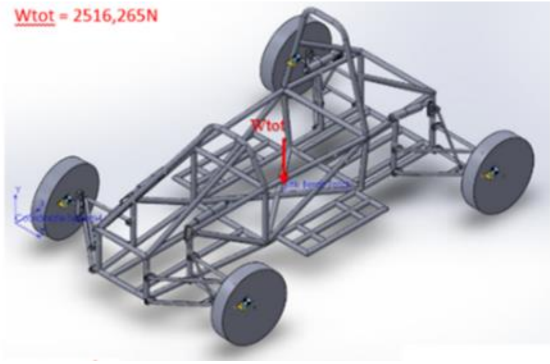

Figure 5. Chassis total center gravity position,

The simplified configuration of the free body diagram is carried out to find a model close to realistic. The simplified configuration is carried out in two ways: three-link bar simplification, as shown in Figure 6, and 9-link bar simplification, as shown in Figure 7.

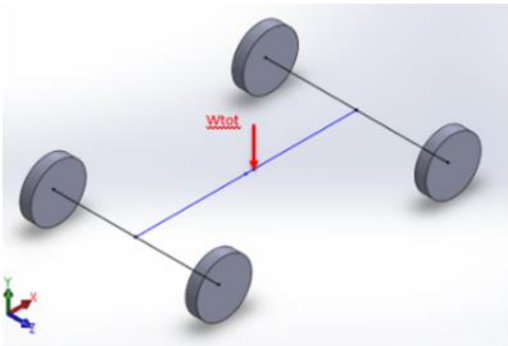

Figure 6. 3-link bar simplification.

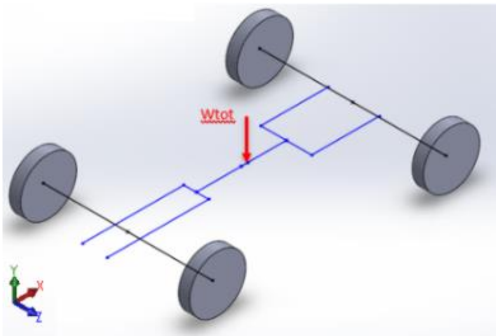

Figure 7. 9-link bar simplification.

The chassis system's free body diagram, simplified in 3-link bars and 9-link bars, is shown in Figure 8 and Figure 9.

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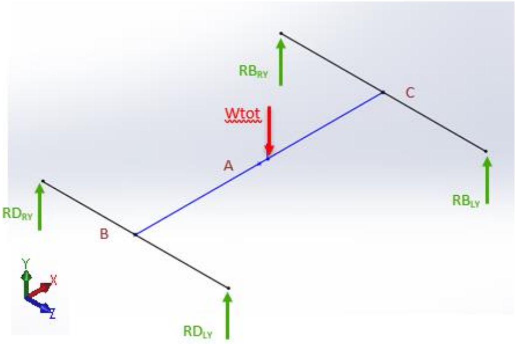

Figure 8. Free body diagram of 3-link bars simplification.

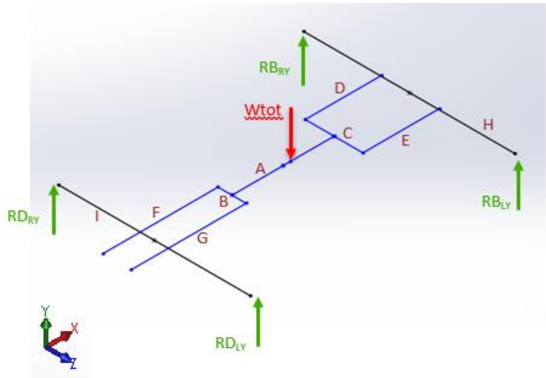

Figure 9. Free body diagram of 9-link bars simplification.

By performing calculations using the three-moment equation for each rod in each simplification configuration of the chassis system free body diagram, the following results are obtained as follow:

- by simplification of 3 link bars, the result is RDRY = 608,285N and RDLY = 608,285N on the front wheel, RBRY = 649,8475N and RBLY = 649,8475N on the rear wheel,
- by simplification of 9 link bars, the result is RDRY = 583,852N and RDLY = 583,852N on the front wheel, RBRY = 674,2805N and RBLY = 674,2805N on the rear wheel.

Comparing both links' bar system simplification shows that the calculations on simplifying 9-link bars give better results. This calculation provides results closer to realistic, and errors in calculations are pretty minimized.

The data obtained through previous definitions and calculations are used to conduct a static strength analysis and ensure that the chassis design has adequate (sufficient) strength, is lightweight, and safety for the driver. And also important is appropriate to regulations.

The initial step to perform a static strength analysis is modeling the chassis frame shape in 3 dimensions using solid work software. This modeling aims to define the shape of the chassis to be simulated based on its constraint parameters. The modeling stage has been carried out since the beginning when determining the shape of the chassis frame. The results of modeling using SolidWorks software are shown in Figure 10. At this stage, the details of the mounting position of each component on the chassis have also been determined. This stage is vital for defining loading positions and determining constraints for static strength analysis.

After the modeling stage, the chassis material to be used is selected. Strength and weight are two critical things to consider when selecting a material for the chassis. The chassis should have the lightest weight to minimize energy consumption and obtain better maneuverability. Higher strength is required for passenger safety [8], [12]. Other important things are its physical, chemical, and mechanical properties related to its manufacture and durability. By considering the two essential things above, steel became the first choice. Although aluminum is lighter and has better corrosion resistance, its modulus of elasticity is low and cannot match steel. Using aluminum to make the chassis requires re-engineering to achieve the same mechanical strength as steel [12].

To comply with KMLI regulations, SAE Formula regulations and the availability of materials in the local market, the ASTM A106 Grade B seamless carbon steel pipe was selected. The specifications and properties of the material are shown in Table 4.

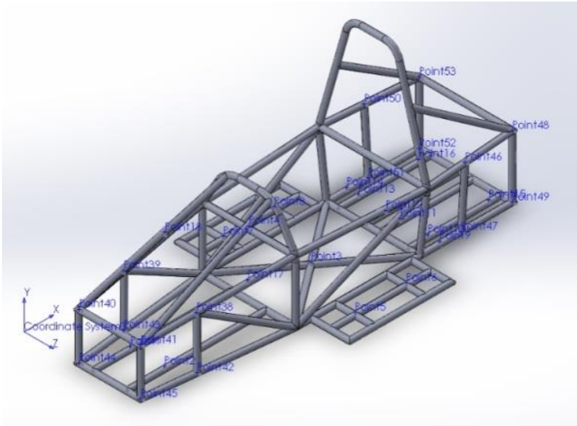

Figure 10. Chassis modelling.

Table 4. ASTM A106 Grade B Specification.

Properties	Value	Units
Model Type	Linear Elastic Isotropic	N/A
Default failure criterion	Max von Mises Stress	N/A
Elastic Modulus	2e+011 – 2,15e+011	N/m^2
Poisson's Ratio	0.29	N/A
Shear Modulus	7,5e+010 – 8e+010	N/m^2
Mass Density	7800 - 7900	kg/m^3
Tensile Strength	4,15e+08	N/m^2
Yield Strength	2,4e+08	N/m^2
Thermal Expansion Coefficient	1,32e-05	$/K$

The definition of loads applied on the chassis is the next stage after selecting the material. The load was defined and applied based on each component's mass and data position, as in Table 3. The load distribution from the driver and seat is assumed to be divided into four equal seat support points. Loading points are shown in Figure 11.

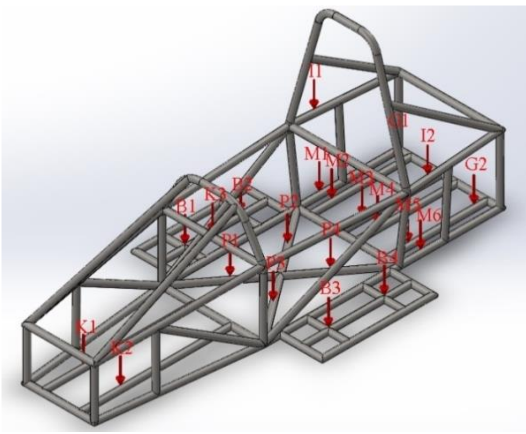

Figure 11. Chassis Loads.

Table 5. Chassis loads.

Force component	No.	Mass (kg)	Force (N)
Front Steering system (left & right)	K1 = K2	3	29.43
Rear Steering system	K3	2	19.62
Battery (right)	B1 = B2	4	39.24
Battery (left)	B3 = B4	4	39.24
Drive Inverter	I1 = I2	2	19.62
Driver & Seat	P1 = P2 = P3 = P4	20	196.2
BLDC Motor (right)	M1 = M2	3.75	36.7875
BLDC Motor & Transmission	M3 = M4	9.5	93.195
BLDC Motor (left)	M5 = M6	3.75	36.7875
axle & transmission	G1 = G2	3.5	34.335

As all the loads were defined, the constraint must also be determined. Determining the constraint means determining the type and position of the support on the chassis. This support value has been determined through the previous calculation process separately.

The determination of the constraint begins with the combined center of gravity. The combined center of gravity is already determined, which can be seen in Figure 5. Then the position of the constraint is also determined at the mounting support point on the chassis. The mounting supports welded to the chassis will then connect the chassis to the suspension system mechanism.

The type of support or constraint was defined as fixed geometry. Fixed geometry was determined with the assumption that the support connection is fixed support as it is joined by welding. It was also assumed that all the RF (Reaction Force) at the suspension mounting system have equal values for each singular wheel. The constraints determined at the mounting support point on the chassis can be seen in Figure 12, and the values of each constraint (RF) are listed in Table 6.

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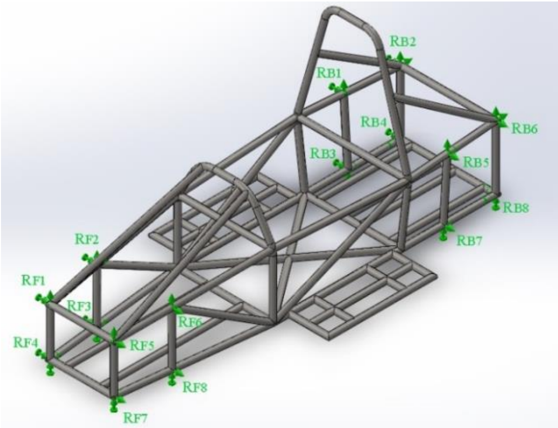

Figure 12. Chassis constrain

Table 6. Constrain applied on the chassis

Force component	No.	Force (N)
Wheel reaction force (Front-Right)	RF1 = RF2 = RF3 = RF4	145.9625
Wheel reaction force (Front-Left)	RF5 = RF6 = RF7 = RF8	145.9625
Wheel reaction force (Rear-Right)	RB1 = RB2 = RB3 = RB4	168.7051
Wheel reaction force (Rear-Left)	RB5 = RB6 = RB7 = RB8	168.7051

The meshing process is the final stage of the static strength analysis modeling on the SolidWorks application before the simulation can be run. The steps of the meshing process were aimed at determining the number of elements, the number of node points, and coordinate points so that high accuracy can be achieved in the results.

Table 7. Details Meshing on Chassis

Study name	Static 2 (-Default<As Machined>-)
Mesh type	Beam Mesh
Mesh control	Defined
Total nodes	299707
Total elements	293909
Time to complete mesh (hh:mm:ss)	00:14:47
Entities	Mm
Size	0.128

At the meshing step, the shape of the elements must be determined to obtain modeling results based on the weldment features. The parameter that must be set, namely the element's size, is made as small as possible (smooth) to get accurate simulation results.

3. RESULT AND DISCUSSION

The simulation is run to perform calculations and analysis using software to obtain the parameters of the result, such as σ_{max}, δ_{max}, and SF.

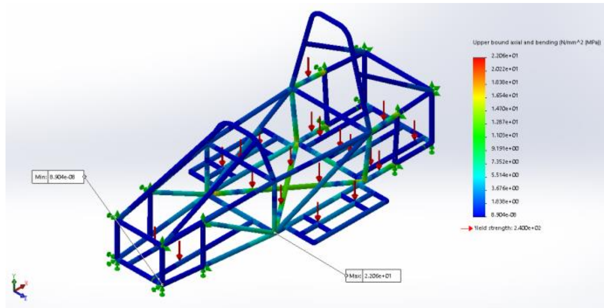

Figure 13. Stress occurs on the chassis

The maximum stress in the chassis is 22.06 MPa on element no.63216, and the minimum stress is 8.904×10-8 MPa on element no.143255. These results show that the chassis is solid and safe because the maximum stress occurs below the material yield stress. The ASTM A106 Grade B material yield stress is 240 MPa.

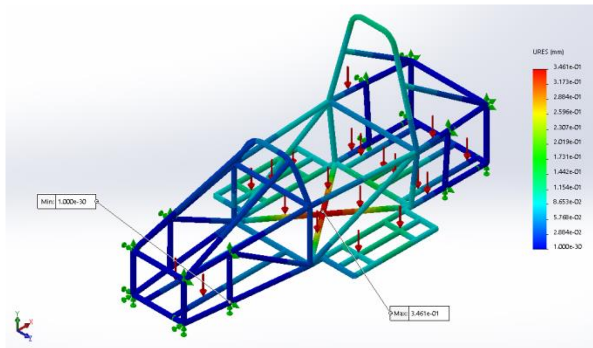

Figure 14. Deflection occurs on the chassis

The maximum deflection on the chassis is 0.346 mm at node 66970, while the minimum deflection is 1×10^{-30}mm at node 38928. The recommended maximum deflection limit for medium precision is at a minimum limit of 0.000254 mm/mm pipe length. The maximum allowable deflection recommended at the medium precision level is at the minimum limit of 0,000254 mm/mm pipe length [13]. The maximum permissible deflection limit can be calculated by considering the wheelbase as a distance between chassis support of 2000 mm.

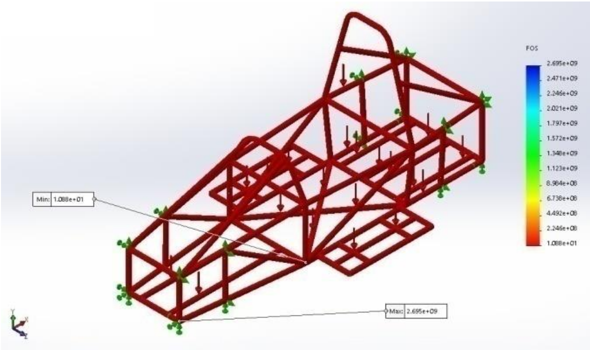

Figure 15. Safety factor on chassis

Assuming that the electric vehicle's speed is not so high, it is assumed that it is still a normal vehicle chassis and is selected. Considering the electric vehicle's speed is not so fast, the designed chassis is believed to be a standard vehicle chassis and carried out on structures that are considered static. Engine elements that receive dynamic loads with uncertainties in load, material properties, stress and environment, so the minimum safety factor required is selected are 3. Compared to the required minimum of the safety factor of 3, the simulation results obtained a safety factor of 10.9, which means that the chassis has good strength and safety to comply with KMLI regulations.

The maximum safety factor on the chassis is 2.695×10^9 at node 143272, while the minimum safety factor is 1.088×10 at node 63231.

4. CONCLUSION

The static simulation design of the KMLI car chassis made of steel pipe size of 1-inch schedule 10 ASTM A106 Grade B with 2300 mm length, 1100 mm width, 1100 mm height, with a wheelbase of 2000 mm has been done. At a track of 1400 mm gives the result that the maximum stress that occurs in the chassis is 22.06 MPa, the maximum deflection is 0.346 mm, and the minimum safety factor is 10.9. The simulation results of stress analysis, deflection, and safety characteristics gave good results, namely strength, stiffness, and safety in compliance with KMLI regulations.

REFERENCES

[1] M. Muratori *et al.*, "The rise of electric vehicles-2020 status and future expectations," *Progress in Energy*, vol. 3, no. 2. Institute of Physics, Apr. 01, 2021. doi: 10.1088/2516-1083/abe0ad.

[2] A. Efendi and A. R. Fahmi, "Design and build of electric car frame SULA evolution," *VANOS Journal Of Mechanical Engineering Education*, vol. 6, no. 1, pp. 11–21, May 2021, [Online]. Available: https://jurnal.untirta.ac.id/index.php/vanos

[3] I. U. Onyenanu, O. N. K. Swift, and P. N. Atanmo, "Design and Analysis of a Tubular Space Frame Chassis for FSAE Application," *Journal of Emerging Technologies and Innovative Research (JETIR)*, vol. 2, no. 10, pp. 134–140, 2015, [Online]. Available: www.jetir.org

[4] Mgbemena C.O, M. O. Okongwu, and Ibhadode. A.O.A, "Design Considerations for Ladder Chassis of a Lightweight Vehicle," *FUPRE Journal of Scientific and Industrial Research*, vol. 3, no. 1, 2019.

[5] R. Nain and R. Sharma, "Design and Analysis of Space Frame Tubular Chassis to be used in Formula SAE," *International Journal of Aerospace and Mechanical Engineering*, vol. 2, no. 6, pp. 22–25, 2015.

[6] T. Shantika, E. T. Firmansjah, and I. Naufan, "PERANCANGAN CHASSIS TYPE TUBULAR SPACE FRAME UNTUK KENDARAAN LISTRIK," *POROS*, vol. 15, no. 1, pp. 9–17, 2017.

[7] Y. Sahu, N. Ramachandran, and S. Manvatkar, "DESIGN AND ANALYSIS OF TUBULAR SPACE FRAME CHASSIS FOR STUDENT FORMULA RACE CAR," 2018.

[8] A. More, C. Chavan, N. Patil, and Prof. R. K, "Design, Analysis and Optimization of Space Frame Chassis," *Int J Eng Technol*, vol. 9, no. 2, pp. 1411–1422, Apr. 2017, doi: 10.21817/ijet/2017/v9i2/170902216.

[9] P. Kumar, V. Muralidharan, and G. Madhusudhana, "Design and Analysis of a Tubular Space Frame Chassis of a High Performance Race Car," *IJRET: International Journal of Research in Engineering and Technology*, vol. 3, no. 2, pp. 497–7501308, 2014, [Online]. Available: https://www.researchgate.net/publication/262946277

[10] Polban, *KOMPETISI MOBIL LISTRIK INDONESIA XI POLITEKNIK NEGERI BANDUNG KMLI XI*. Bandung: Politeknik Negeri Bandung, 2019.

[11] S. Sayovitz, "Formula SAE Rules 2019," 2018.

[12] C. J. Bulgu, "Design a Space Frame Chassis for Light Weight Automobiles for Improved Safety and Reliability," *Mechanical Engineering Research*, vol. 9, no. 2, pp. 36–50, Jan. 2019, doi: 10.5539/mer.v9n2p36.

[13] R. L. Mott, E. M. Vavrek, and J. Wang, *Machine elements in mechanical design*, 6th ed. New York: Pearson, 2018.