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Structural Design and Analysis of Electric Car Engine Mount

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Abstract

In this paper, the analysis of engine mounting structures that will be applied to electric vehicles is conducted. The engine mounting structure will be subjected to static loading from the mounted components assembly, including the assembly of the gearbox, electric motor, and corresponding brackets. In the structure arrangement, HSLA material is mostly used and general structural steel such as AISI 4130 is also used. This study aims to evaluate the existing design so that further optimization steps can be carried out. Simulations and analysis with a static approach were performed using SOLIDWORKS. The stress and displacement contours are then created, and the location of the critical points of maximum stress and maximum deflection can be obtained so that the safety factor of the design can be evaluated. Based on the simulation results, the current safety factor value is very high when compared to using materials with lower physical properties. In addition, it is necessary to develop further studies involving dynamic loading so that it can also be considered to reduce production costs and increase production efficiency.

Keywords

Engine mounting; Structural analysis; Static simulation; Safety factor

1 Introduction

Nowadays, energy efficiency in automotive applications is being considered. In some applications which implicate inefficient acceleration and deceleration of internal combustion vehicles, such as mining, an electric vehicle can be used in a very efficient way [1]. Electric vehicles have components that are more delicate than regular combustion vehicles, such as batteries and other high voltage electrical components. These components are usually directly mounted on the chassis. Therefore, the chassis of the electric vehicle must be able to endure static and dynamic loads to minimize the displacement of each component [2].

The chassis consists of an assembly of frames which are considered one of the substantial structures in the automobile. These frames support most parts of the vehicle, including the engine, powertrain, suspension systems, electrical components, steering assemblies, the body of the vehicle, etc. Mechanical components supported by the chassis usually have typical fasteners such as bolts and rivets. The chassis itself provides the necessary strength to support a variety of vehicle components and payloads to maintain the stiffness and rigidity of the vehicle [3-6]. In automotive applications, several types of chassis are commonly used: ladder chassis and monocoque chassis. Ladder chassis is the oldest configuration of vehicle chassis and is usually applied in most SUVs, trucks, and buses. This chassis contains two longitudinal rails associated with several cross-members [7]. In monocoque chassis, the overall form of the vehicle consists of a one-piece structure. Most present vehicles utilized steel-plated monocoque chassis since it's cost-effective and convenient for automated production [8]. Regarding the chassis configuration type, each different type of chassis will determine the handling performance of the vehicle [9, 10]

Apart from the strength of the chassis, the handling characteristic of the vehicle is determined by the bending and torsional stiffness of the chassis. The higher the torsional stiffness, the better the handling performance and the vehicle has a smoother ride. A. Sorniotti in [11] conducted that a lack of torsional stiffness generally makes the understeering vehicle more prone to understeer and the oversteering vehicle more prone to oversteer, while a higher value of the associated parameter will overcome these problems. In ladder frame chassis, bending stiffness is higher but lacks torsional stiffness, resulting in poor handling in hilly terrain areas [12]. Therefore, designing cross-members in ladder chassis is critical. The cross-section of the cross-member is one parameter to determine the chassis's stiffness. In addition, to have high strength to withstand the attached component's loads, the stiffness of the cross-member also need to be considered. Kamlesh and Eknath [13] performed the optimization of bus chassis using several cross-member types such as

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rectangular box, C, and I beam. Deflection and shear stress were determined at maximum load and used as optimization criteria. It was concluded that a hollow rectangular is the most suitable cross-section.

Considering the previous research, in this paper, a hollow rectangular cross-section is selected to make the chassis cross-member. The respected cross-member is then joined with brackets to mount the electric motor. For these brackets, it is recommended to consider several critical factors. One of the factors to be considered is that the bracket is intended to damp the vibration wave transmission from the electric motor to the suspension. As stated by Mohanachari et al. [14], the bracket must have the capacity to control the movement caused by load conditions and the ability to softly damp the vibration for a little plentifulness excitation over the higher recurrence run. Design optimization is also another important factor that needs to be considered. Typically, optimization in engine bracket can be done using topology optimization and material selection. Topology optimization is done to reduce the mass of the component with the consideration of the stress flow to obtain the component's optimum mass [15]. Based on these previous studies, this paper focuses on designing the engine mount for the recent electric car development and performs several analyses regarding the stress distribution to obtain the optimum design.

2 Methodology

2.1 Modeling

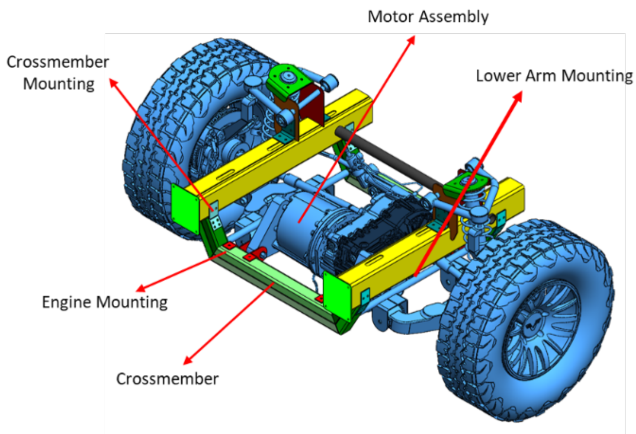
The cross-member type design model that is often used in conventional vehicles is the I beam, C beam, and a rectangular box. After conducting a comparative study through previous research, in this research, a cross-sectioned rectangular box cross-member was used. As shown in Figure 1a, these cross-members are mounted on the main frame with bolted connections. In addition, there are several mountings to support the electric motor assembly. The mountings are welded together with the cross-member, and their position is adjusted according to the position of the bolt holder of the electric motor assembly. In the model design, two cross members hold the motor and gearbox assembly. These two cross-members are also connected to a steel pipe that functions as lower arm mounting as shown in Figure 1b. In the simulation that will be carried out, the simulation will cover the connection between the frame and the cross-member up to the lower arm mounting pipe. This is done because, in terms of the structure being evaluated, the assembly structure of these components will have the most influence when loading conditions are carried out.

2.2 Material

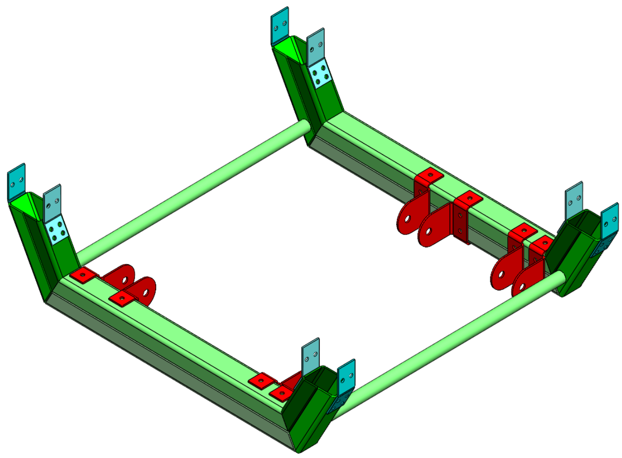
Various materials commonly used for vehicle chassis today are DP 600, BSK 46, AISI 4130, and HSLA [16]. In this electric vehicle design, most components with high loading conditions are made using HSLA steel plates. In the design of the electric motor assembly mounting structure being evaluated, two different materials were used, namely AISI 4130 and HSLA steel. The distribution of the use of this material can be seen in Figure 2, and the properties of each material can be seen in Table 1.

Table 1 Material properties for AISI 4130 and HLSA steel

Material	AISI 4130	HSLA Steel
Density (kg/m^3)	7800	7800
Yield Strength (MPa)	250	700
Tensile Strength (MPa)	400	750
Elongation (%)	21	12
Young's Modulus (GPa)	200	200



(a)



(b)

Figure 1 Front assembly of the vehicle chassis (a) and evaluated cross-member structures (b)

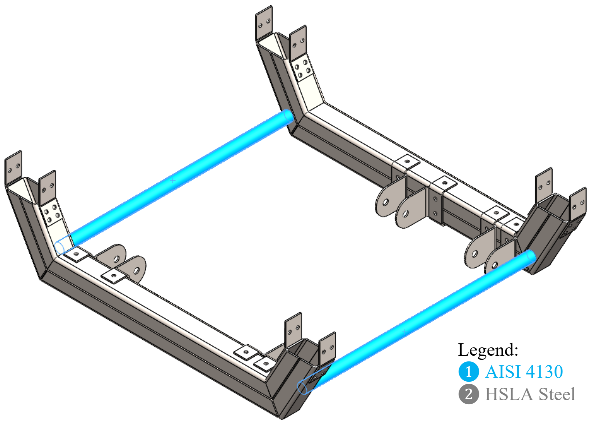


Figure 2 Distribution of material within the structures

2.3 Meshing

The meshing process was done using SolidWorks. The element of the structure should have the capability of deflection, plasticity, elasticity, stress stiffening, creep, and strains. Mesh was generated using blended curvature-based mesh to cover the geometry complexity within the bent steel plate. For some components that utilize bending plates, the meshing process is carried out using the mid-surface of sheet metal components. This is done to drastically reduce the number of mesh while maintaining a good surface mesh fidelity. The maximum element size is set to be 20 mm while the minimum element size is 5 mm. Figure 3 shows the detailed mesh of the structure.

2.4 Boundary and loading condition

Simulations were carried out to determine the strong performance of the structure when it was given a load in the form of motor and gearbox assembly placing. To determine the static analysis, it was simply supported on the 4 sides of the bolt connection between the main frame and the cross-member bracket. One side of the connection is fixed in all directions while the other three sides are only fixed in the vertical direction so that the horizontal shifting possibility of each mounting can be seen as well.

To determine the loading conditions within the structure, each force that occurs on each mounting can be calculated based on the static equilibrium method which is formulated as follows.

$$\Sigma M_0 = 0 \tag{1}$$

The load consists of the total weight of each component that is part of the motor and gearbox assembly, including the electric motor, gearbox assembly, and motor brackets, including the bushings. These loads occur within the assembly's center of gravity (COG). The data for each component weight can be seen in Table 2.

Table 2 Cohesive element mechanical properties

Component	Weight (kg)	Quantity (pcs)	Total Weight (kg)
Electric Motor	43.50	1	43.50
Gearbox Assembly	45.00	1	45.00
Motor Bracket 1	0.89	2	1.68
Motor Bracket 2	2.68	1	2.68
Motor Bracket 3	2.11	1	2.11
Motor Bracket Bushings	0.26	4	1.04
Total			106.1

In calculating the force that occurs, the dimensions of each mounting concerning the COG (Figure 5) are used based on the moment equilibrium formula. Thus, the following formulation for the occurred force for each point is obtained.

$$(F_1 + F_2) = \frac{WF}{E+F} \tag{2}$$

$$(F_3 + F_4) = \frac{WE}{E+F} \tag{3}$$

$$F_1 = \frac{(F_1 + F_2)B}{A+B} \tag{4}$$

$$F_2 = \frac{(F_1 + F_2)A}{A+B} \tag{5}$$

$$F_3 = \frac{(F_3 + F_4)D}{C+D} \tag{6}$$

$$F_4 = \frac{(F_3 + F_4)C}{C+D} \tag{7}$$

Using the given formula, the acting force can be determined as can be seen in Table 3. These respective forces are then applied to the structure as detailed in Figure 5.

Table 3 Force magnitude for each mounting

Force Component	Force Value (N)
$F_1 + F_2$	584
$F_3 + F_4$	455
F_1	295
F_2	289
F_3	21
F_4	453

3 Results and Discussion

Based on the results of the current design simulations (using combination materials of HSLA and AISI 4130) that have been carried out, the maximum stress that occurs reaches 25.98 MPa, and the maximum stress point is at the connection between the main frame and the cross-member.

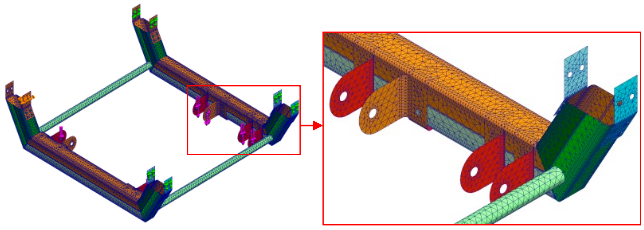


Figure 3 Mesh model of the engine frame and mounting

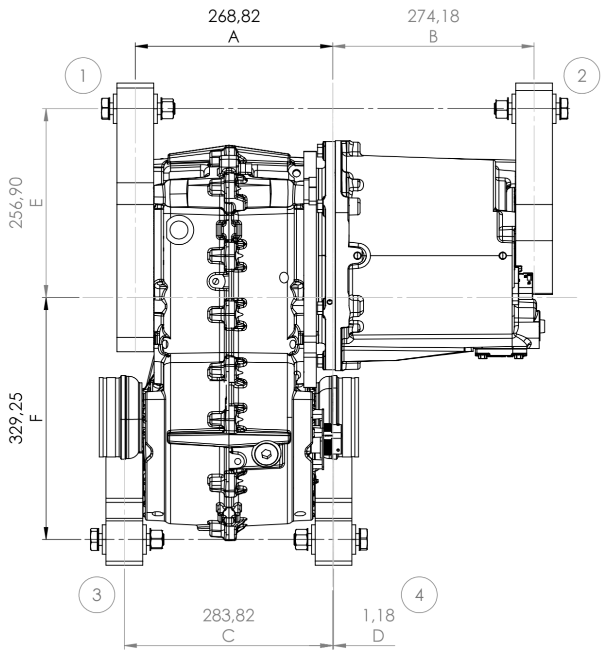


Figure 4 Dimension of the electric motor bracket assembly (unit in mm)

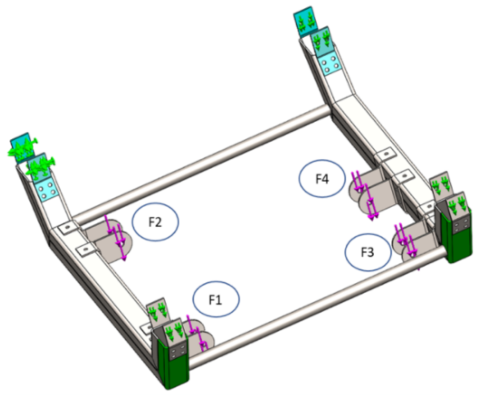


Figure 5 Loading conditions of the structure

There is a small deviation within the simulation results if AISI 4130 material is applied for all components. The result shows that the maximum von mises stress is 28.39 MPa and the location of the maximum stress is also at adjacent points as shown in Figure 6 and Figure 7.

In terms of displacement, the application of combined materials (current real-time condition) has the largest displacement of 86.09 µm. Compared to the application of uniform material using AISI 4130, the maximum displacement value that occurred was slightly larger, which is 97.90 µm. The displacement distribution that occurs for each case can be seen in Figure 8 and Figure 9. The results of both simulations are then compared using the safety factor for each different material application and the results can be seen in Figure 10.

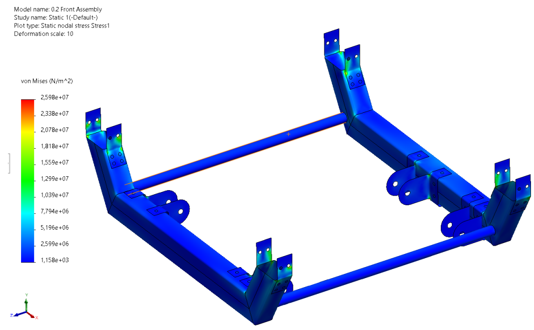


Figure 6 Maximum von mises stress distribution using a combination of HSLA and AISI 4130

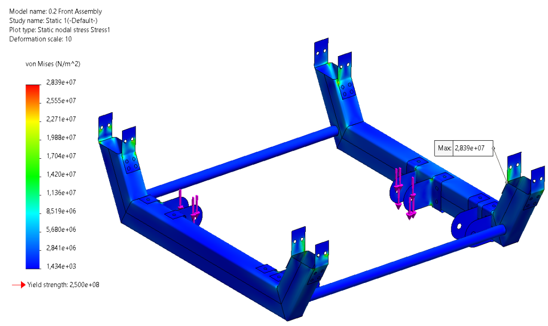


Figure 7 Maximum von mises stress distribution using only AISI 4130

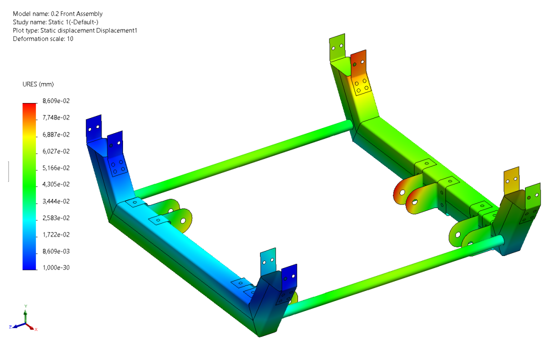


Figure 8 Maximum displacement distribution using a combination of HSLA and AISI 4130

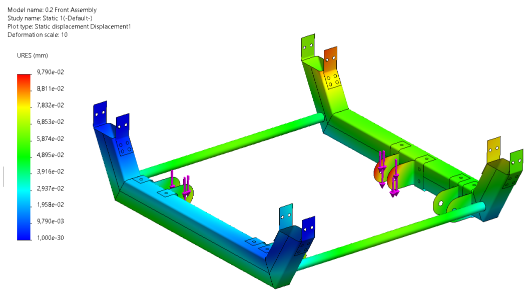


Figure 9 Maximum displacement distribution using only AISI 4130

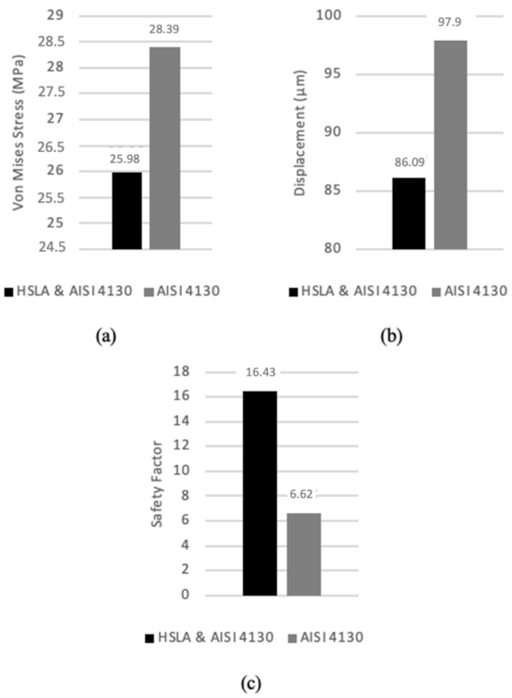


Figure 10 Maximum displacement distribution using only AISI 4130

The value of the safety factor obtained shows that the current cross-member design is statically safe. Even so, in its application in real conditions, there will be dynamic loads whose value is much greater than the static loads. With this dynamic load, it is expected that a drastic decrease in the safety factor will occur. In this study, all loads applied to the simulation process are static loads which are given additional overloads to provide more conservative simulation results.

Previously, research that deliberated on bracket engine optimization was conducted by Xiao-Yong Pan et al. [15]. In that mentioned research, the maximum von Mises stress that occurs due to dynamic loading is 201.1 MPa and the material used is ZG 270-500 which has a Yield Strength of 270 MPa. If further analysis is conducted, the safety factor for this case has a value of about 1.34 under dynamic loading conditions. Referring to this research, the safety factor of the engine mounting design in this paper may decrease when dynamic loading is applied. Therefore, it is necessary to conduct further studies that discuss the addition of dynamic loads in this design simulation. In addition, it is necessary to pay attention to the selection of materials used to reduce costs and production efficiency.

4 Conclusion

Structural analysis has been carried out to determine the current engine mounting structure's maximum stress, deflection, and safety factor. Based on the simulation, the result shows that the current design's maximum stress condition still has a high safety factor, which is 16.43. Compared to the application of materials that tend to have lower physical properties, the safety factor value is still in the safe zone, which is 6.62, so it is possible to optimize in terms of reducing production costs by replacing materials.

Nevertheless, the simulation carried out in this paper merely considers static loading and the addition of an overload factor. It is necessary to conduct further studies by adding dynamic loading simulations so that further optimization steps can be carried out. That way, reducing costs and increasing production efficiency are still possible.

References

[1] P. Luque et al., "Multi-objective evolutionary design of an electric vehicle chassis," *Sensors*, vol. 20, no. 13, p. 3633, 2020.

[2] A. H. Kumar and V. Deepanjali, "Design & analysis of automobile chassis," *Int. J. Eng. Innov. Technol*, vol. 5, no. 1, pp. 187-196, 2016.

[3] R. Y. Garud and A. Pandey, "Structural Analysis of Automotive Chassis, Design Modification, and Optimization," *Int. J. Appl. Eng. Res*, vol. 13, no. 11, pp. 9887-9892, 2018.

[4] V. V. Patel and R. Patel, "Structural analysis of a ladder chassis frame," *World J. Sci. Technol.*, vol. 2, no. 4, pp. 05-08, 2012.

[5] Arifurrahman, F., Indrawanto, I., Budiman, B. A., Sambegoro, P. L., & Santosa, S. P., "Frame modal analysis for an electric three-wheel vehicle," *In MATEC Web of Conferences*, vol. 197, pp. 08001, 2018.

[6] Arifurrahman, F., Budiman, B. A., & Santosa, S. P., "Static analysis of an electric three-wheel vehicle", *in 2018 5th International Conference on Electric Vehicular Technology (ICEVT 2018)*, pp. 218-223, 2018

[7] A. Singh, V. Soni, and A. Singh, "Structural analysis of ladder chassis for higher strength," *Int. J. Emerging Technol. Adv. Eng.*, vol. 4, no. 2, pp. 253-259, 2014.

[8] M. R. Chandra, S. Sreenivasulu, and S. A. Hussain, "Modeling and Structural analysis of heavy vehicle chassis made of polymeric composite material by three different cross-sections," *Int. J. Mod. Eng. Res. Technol.*, vol. 2, no. 4, pp. 2594-2600, 2012.

[9] D. A. Bircan, K. Selvi, A. Ertaş, And A. Yaltirik, "Design and Analyis of Electrically Operated Golf Cart Chassis Using FEA," *Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, vol. 30, no. 1, pp. 87-94, 2015.

[10] S. Padmanabhan, H. V. Reddy, and S. C. Undamatla, "Design and structural analysis of truck frame," *in IOP Conference Series: Materials Science and Engineering*, vol. 923, no. 1, p. 012012, 2020.

[11] A. Sorniotti and A. Crocombe, "Chassis torsional stiffness: analysis of the influence on vehicle dynamics," *SAE Tech. Pap.*, 0148-7191, 2010.

[12] O. Kurdi, R. A. Rahman, and P. M. Samin, "Optimization of heavy-duty truck chassis design by considering torsional stiffness and mass of the structure," *Appl. Mech. Mater*., vol. 554, pp. 459-463, 2014.

[13] K. Y. Patil and E. R. Deore, "Stress analysis of ladder chassis with various cross-sections," *IOSR J. Mech. Civ. Eng*., vol. 12, no. 4, pp. 111-116, 2015.

[14] [J. Mohanachari, D. P. Reddy, S. V. Rao, U. Surendra, and G. Rao, "Analysis Over Engine Mount Vibrational," *J. Sci. Technol.*, vol. 2, no. 02, pp. 28-33, 2017.

[15] X.-Y. Pan, D. Zonni, G.-Z. Chai, Y.-Q. Zhao, and C.-C. Jiang, "Structural optimization for engine mount bracket," *SAE Tech. Pap.*, 0148-7191, 2007.

[16] W. Afzal and R. A. Mufti, "Optimal Cross-section of Cross Member for Increased Torsional and Bending Stiffness of Ladder Frame Chassis," *in 2019 16th International Bhurban Conference on Applied Sciences and Technology (IBCAST): IEEE*, pp. 218-228, 2019.