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Optimization of bus frame with bending moment and torsion constraints using finite element method

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Optimization of bus frame with bending moment and torsion constraints using finite element method

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Abstract. This paper presented the optimization of bus frame to obtain the optimum weight of bus frame. Failure of the frame can be caused by bending loads and torque experienced by the structure in the conditions of two wheel bumped and one wheel bumped. The optimization process applied is structural size optimization. The method used includes solver deck input and element criteria, input material used, making load collector and load step, running program, convergence test. Then a static linear analysis is performed using the finite element method to see the maximum stress that occurs in the frame, the magnitude of the Von-mises stress value is 1,303 × 10^3 MPa under static bending conditions and 1,305 × 10^3 MPa under static torsion conditions. The next step is size optimization which results in a mass reduction of 0.236 tons under static torsion conditions and 0.46 tons under static bending conditions.

1. Introduction

The transportation is a backbone of development in developing countries. It supports the mobility of human and goods from one region to another region within the country. The transportation increases the development significantly since with the smooth, safe, fast and cheap transportation system the mobility of human and goods growth rapidly. The price of goods and material become cheaper due to the reducing of delivery cost.

Bus is an important vehicle in public transportation due to its capacity for brings a passenger and the affordable price of ticket. The reducing weight of vehicles became a current issue for reducing fuel consumption [1]–[6]. Bus frame plays as a critical component in order to keep bus in a stable condition. Therefore bus frame must be strong enough and for the reason of efficiency it must as light as possible. The light weight of bus frame can reduce the production cost and improve energy efficiency [7]. Many researchers have carried out work for optimization of the vehicles frame by considering important parameter such as stress and displacement as constraints [8]–[15][16], [17].

The present work deals with the analyzing and optimizing bus frame with bending moment and torsion constrains using Finite Element Method (FEM). Bending moment and torsion stiffness are the important parameters that affect the dynamic performance of vehicles [17]–[19]. FEM was used for the analysis in order to reduce the cost of product development in the early stage of design. Many researchers have been investigated the performance of vehicle's frame using FEM [8], [9], [16], [17], [20]–[22].

2. Methods

2.1. Material Identification

In this study, the determination of the frame material used refers to the material data from the bus body builder company. The data was used in the optimization of bus frame. The properties of materials were shown in Table 1 and Table 2.

Table 1. Material specification STALATUBE.EN.1.4003 (FERRTIC)

Properties	**STALATUBE.EN.1.4003 (FERRITIC)**	
Density	7.7	g/cm³
Poisson ratio	0.3	
Yield Strenght	327	Mpa
Tensile Strenght	400	Mpa
Modulus Young	200	Gpa

Tabel 2. Material specification STALATUBE.EN.1.4162 (DUPLEX)

Properties	**STALATUBE.EN.1.4162 (DUPLEX)**	
Density	7.85	g/cm³
Poisson ratio	0.3	
Yield Strenght	610	Mpa
Tensile Strenght	800	Mpa
Modulus Young	450	GPa

2.2. Bus Frame Modeling

The aim of the optimization is to minimize the weight of the vehicle with the bending stiffness and torsion as constraints. The model of bus frame was built in Solid works software and then to be imported to the Altair software. Figure 1 displayed the CAD software bus frame model for simulation in Altair 2019.

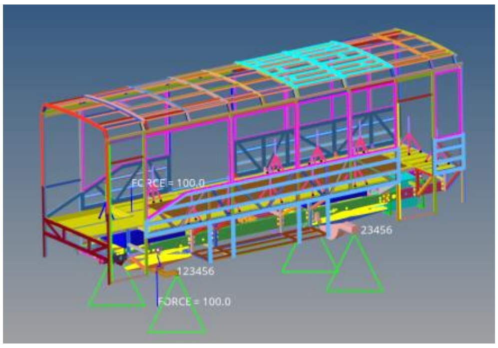


Figure 1. Frame Bus Design

2.3. Static linear modelling

The simulation of the static structure loading analysis on the bus frame is carried out to determine the maximum stress and deflection of a bus frame model under certain conditions. The result of simulation namely maximum stress and deflection will be used in the optimization simulation.

2.4. Optimization Process

In this study, the optimization of the bus frame structure uses a type of size optimization, where the thickness of the bus frame structure is a parameter in the optimization. With the maximum stress limitation and maximum deflection from the results of the analysis of the conditions of one wheel bumped (torque loading) and two wheels bumped (bending loading) so as to get the lightest structure. The following are the steps for determining a size optimization strategy:

1) Determine the design variable
   Design variables are numerical inputs that are allowed to change during design optimization. In this research, the thickness of the frame structure will be changed so that it is a design variable. The definition of design variables in Altair 2019 software is shown in Figure 2.

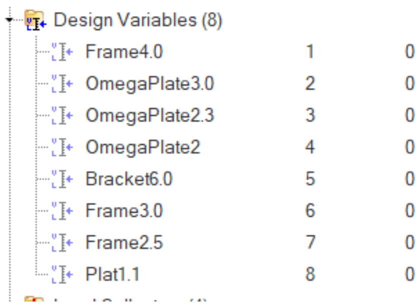


Figure 2. Design variable

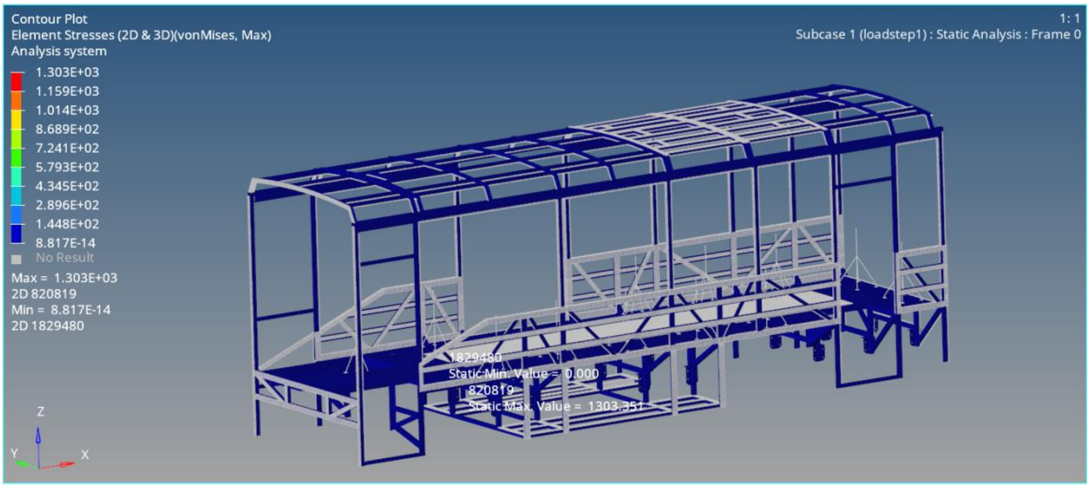
2) Determining *Constraint*
   Optimization constraint is a variable that optimizes an objective function with respect to several variables with constraints on these variables. In this study, there are 2 constraints, namely displacement and stress.
3) Determining the Response Structure
   Response optimization helps identify combinations of variable settings that together optimize a single response or series of responses. This is useful when it is necessary to evaluate the impact of multiple variables on a response. In this study, there are 3 responses used, namely mass, displacement, and stress.
4) Determining *Objective*

Objective is the goal of each response function to be optimized, the response is a variable of the design. In this study, the mass of the electric bus frame structure is an objective function, so that the mass of the bus frame will be minimized in optimization.

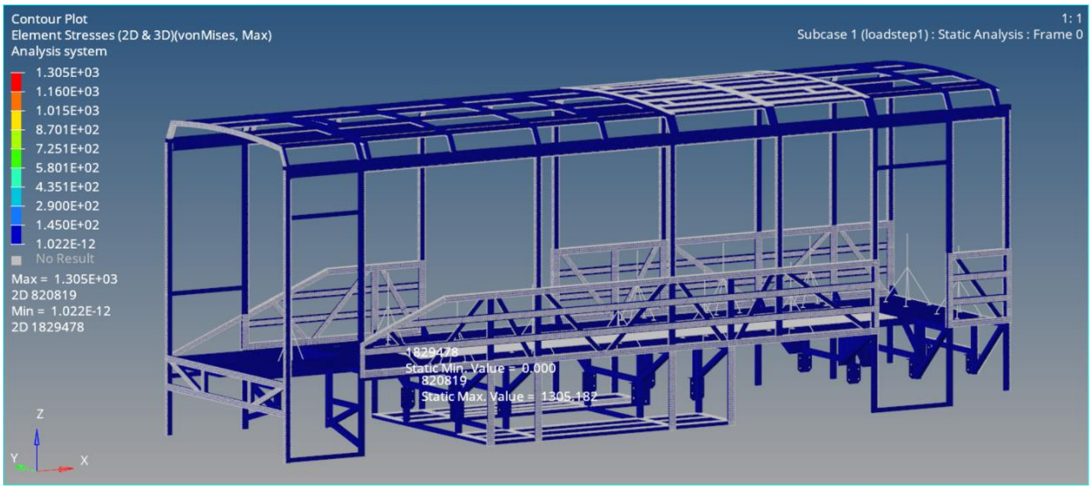
3 Results and Discussion

3.1. Results of Static Linear Simulation

Static load analysis is carried out for a vehicle that is at rest. In this study, there are 2 loading conditions, namely static bending (Two Wheels Bumped) and static torsion (One Wheels Bumped). The loading variation is intended to obtain the deflection value of the bus frame which represents the bending stiffness and torsional stiffness of the bus frame structure. The results of linear static analysis can be seen in Figure 3. Based on the results of the linear static simulation, the Von-mises stress value is 1.303 × 10^3 MPa in static bending conditions and 1.305 × 10^3 MPa in static torsion conditions.



(a)



(b)

Figure 3. Von-mises value under loading conditions (a) static bending, (b) static torsion

3.2. Convergence Test Results

To determine the appropriate number of elements to be continued with the optimization process, a convergence test is carried out which can be seen in Table 3 until convergent results are obtained for each increase in elements by making mesh improvements gradually and in certain areas.

Table 3. The maximum von misses stress value for each element

Number of Elements	**Stress(Mpa)**
28322	1323
246203	1299
328737	1305
428603	1310
725793	1312

Based on the variation of the increase in elements in Table 3 above, the more the elements increase, the stress that occurs remains the same, so it can be concluded that these elements show that they have converged. This study uses the results of the 3rd convergence test, which is 328737.The following is a picture of the stress distribution that occurs in the frame

3.3. Optimization Result

The optimization results are illustrated in Figure 4 and Figure 5 where in this optimization the design variable that is determined is the thickness of the frame structure. Then selected the optimization constraint (constraint) displacement and stress (stress). Constraint displacement is related to both bending stiffness and torsional stiffness, while constraint stress is chosen so that the optimization result stress does not exceed the stress before optimization. The objective function of this optimization is to reduce the overall mass of the frame structure. In the optimization result, the variable design has a slight increase in the maximum von-mises stress but it is still acceptable.

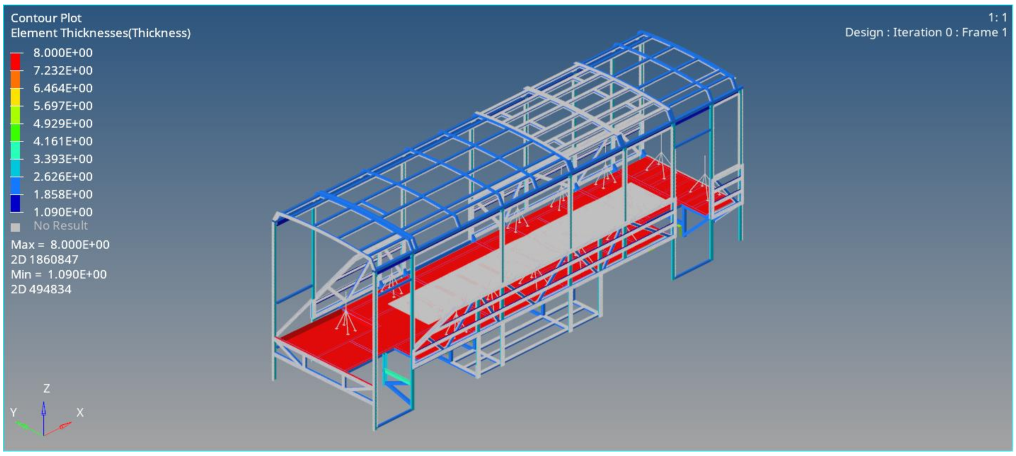


Figure 4. The result of size optimization in static torsion .

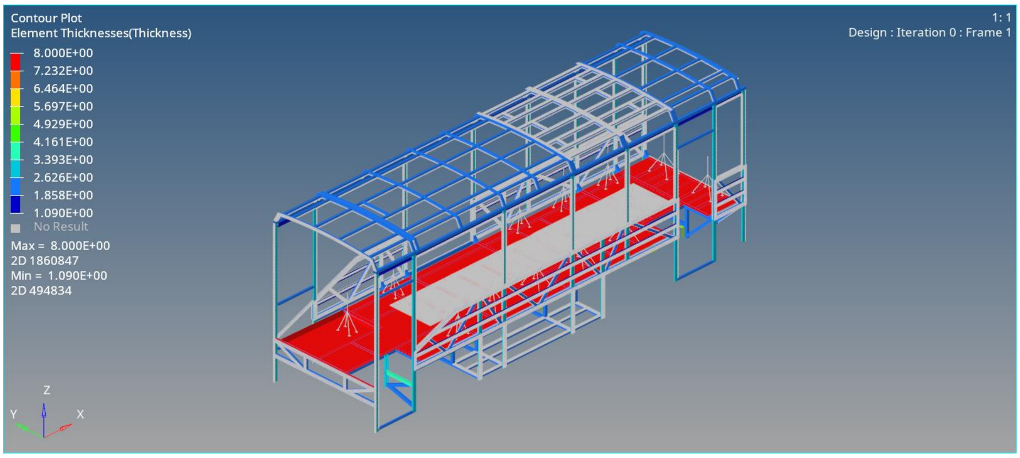


Figure 5. The result of size optimization in static bending

3.4. Topology Optimization Results

Size optimization is a form of optimization that is often applied to a structure. The application of size optimization in this study aims to change the thickness of the frame structure into a lighter design. This is shown by the comparison of the results of the design optimization between the initial design and the design after optimization in Table 4 below.

Table 4. Comparison of initial design and after optimization.

	Static bending	Static torsion
Initial Mass	2.968 Ton	2.968 Ton
After optimization mass	2.58	2.732 Ton
Initial maximum stress	1.303×10^3 MPa	1.305×10^3 MPa
After optimization stress	1.416×10^3 MPa	1.436×10^3 MPa

4. Conclusion

Linear-static simulation resulted, the Von-mises stress value of 1,303 × 10^3 MPa in static bending condition and 1,305 × 10^3 MPa in static torsion condition. These values were used as constraints for the size optimization of bus frame thickness. Furthermore, the size optimization is carried out which results in a mass reduction of 0.236 tonnes in static torsion conditions and 0.46 tonnes in static bending conditions.

Acknowledgement

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