Journal of Solid and Fluid Mechanics (JSFM), 15(4): 1-3, 2025

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: **10.22044/jsfm.2025.16182.3973**

Manufacturing Engineering of Iran

Multi objective Optimization of an L6e-Class Electric Vehicle Body Structure using the MOPSO Method

Mina Maghsoudi Nejad[1], Abolfazl Khalkhali[2]

[1]M.s, Automotive Simulation and Optimal Design Research laboratory, Iran University of Science and Technology, Tehran.
[2]Assoc. Prof., Automotive Simulation and Optimal Design Research laboratory, Iran University of Science and Technology, Tehran.
*Corresponding author: ab_khalkhali@iust.ac.ir

Received: 05/12/2025 Revised: 07/11/2025 Accepted: 09/02/2025

Abstract

Given the increasing demand for electric vehicles, optimizing their structural design is a key engineering challenge. In this research, with the aim of achieving an optimal design for the body structure of an L6e class electric vehicle, the Multi-Objective Particle Swarm Optimization (MOPSO) algorithm has been utilized. In this optimization problem, the main objective is to increase the torsional and bending stiffness of the vehicle's body structure. The dimensions of the structural beams were considered as design variables. Since the complete body structure model in Catia was not suitable for optimization due to the multiplicity of design variables, especially in connections, a simplified model was first created in Abaqus software. This model was constructed using beam elements and rigid connections to facilitate the optimization process. To validate the reliability of the simplified model, torsion and bending tests were performed on both the simplified Abaqus model and the complete Catia model, showing that the difference in stiffness was less than 4%. This result fully confirmed the reliability of the simplified model for use in the optimization process. Finally, Abaqus scripting capability allowed for the parameterization of profile dimensions, which enabled the automatic link of the model to the MOPSO optimization code in MATLAB and the generation of new structures. The results of this research showed that by utilizing MOPSO multi-objective optimization, a significant simultaneous increase in the torsional stiffness (32.10%) and bending stiffness (33.79%) of the structure could be achieved, compared to the initial model before optimization.

Keywords: Multi-Objective Particle Swarm Optimization, Simplified model, Torsional stiffness, Bending stiffness.

1. Introduction

Due to environmental concerns, four-wheeled electric vehicles have been welcomed as a green and efficient alternative to fossil fuel-powered cars [1]. The stiffness of the vehicle body, as a fundamental characteristic, directly impacts handling and occupant comfort [2]. Full finite element modeling is not suitable for early-stage design and optimization due to the multiplicity of design variables; hence the use of simplified models is common [3].

In previous research, simplified models were utilized by replacing structural members with beam elements [4, 5] and modeling joints with thin elastic layers [6]. Furthermore, multi objective optimization algorithms like MOPSO [7, 8] and NSGA-II [9] have been employed to optimize vehicle structures.

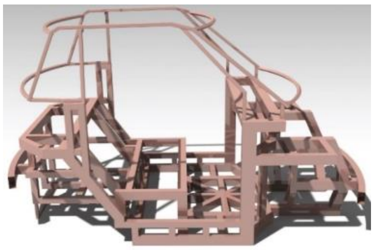
In this study, with the aim of simultaneously increasing the torsional and bending stiffness of an L6e-class electric vehicle body, the Multi-Objective Particle Swarm Optimization (MOPSO) algorithm was used. First, a simplified model of the body was created with beam elements in Abaqus software and validated by comparing its results with a full Catia model, showing a stiffness difference of less than 4%. The main innovation of this research lies in creating an automated optimization loop that connects the Abaqus model to the MOPSO code in MATLAB via scripting. The results showed that this approach could increase the torsional and bending stiffness by 32.10% and 33.79%, respectively, which demonstrates the effectiveness of this method.

2. Methodology

The EQ10 is a four-wheeled electric vehicle in the L6e class. It's being developed in the Vehicle Optimal Design and Simulation Lab at the Iran University of Science and Technology, as shown in Figure 1.

To evaluate the performance of the body structure, a full finite element model was created in CATIA and then meshed in Hypermesh. Through mesh convergence studies, an optimal element size of 10 mm was determined. The number of elements and nodes for this mesh size are presented in Table 1.

a



b

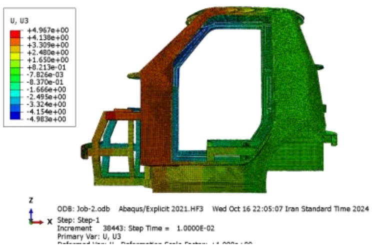
Figure 1. (a) EQ10 vehicle (b) EQ10 body structure

Table 1. The number of elements and nodes of the model with optimal mesh.

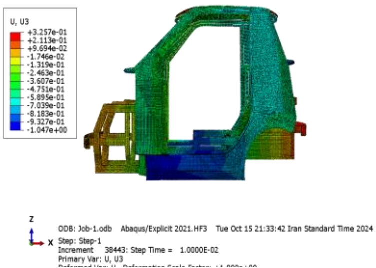
Mesh size (mm)	Number of elements	Number of nodes
10	82670	84822

RBE2 elements were used to simulate the behavior of connections between different structural components. After creating the geometric model in CATIA, the torsional and bending loads were applied in Abaqus.

In the torsional test, a torque of 3000 Nm was applied to the front suspension system, while in the bending test, a force of 2000 N was applied to the vehicle's rocker panels. The displacement of the body structure along the Z-axis after these two tests is shown in Figure 2.



a



b

Figure 2. Z-axis displacement (in mm) for the (A) torsional and (B) bending tests.

To eliminate local effects at the load application and support points, correction formulas (1) to (4) for bending and (5) to (8) for torsion were used. After correcting the displacements and angles, the bending stiffness was calculated as 6030.253 N/mm, and the torsional stiffness was 5358.128 Nm/degree.

$$\delta = \frac{|\delta_L| + |\delta_R|}{2} \quad (1)$$

$$\delta_F^a = \frac{|\delta_{Ff}| + |\delta_{Fr}|}{2} \quad (2)$$

$$\delta_R^a = \frac{|\delta_{Rf}| + |\delta_{Rr}|}{2} \quad (3)$$

$$\delta^a = \delta - \delta_F^a - X * \frac{|\delta_R^a| - |\delta_F^a|}{L} \quad (4)$$

$$\varphi = \tan^{-1}\left(\frac{|\delta_R| + |\delta_L|}{w}\right) \quad (5)$$

$$\varphi_F = \varphi_{Fr} + (X_F - X_{Lf}) * \frac{(\varphi_{Fr} - \varphi_{Ff})}{(X_{Lr} - X_{Lf})} \quad (6)$$

$$\varphi_{Ff} = \tan^{-1}\left(\frac{|\delta_{Lf}| + |\delta_{Rf}|}{w}\right) \quad (7)$$

$$\varphi_{Fr} = \tan^{-1}\left(\frac{|\delta_{Lr}| + |\delta_{Rr}|}{w}\right) \quad (8)$$

To accelerate the optimization process, a simplified model of the structure was fully created in Abaqus. This model was then validated by comparing its bending and torsional stiffnesses with the full model's results, showing an acceptable difference of 2.78% and 2.12%, respectively.

3. Results and Discussion

In this study, the multi-objective optimization of the EQ10 vehicle's body structure was investigated using the MOPSO algorithm. The goal was to simultaneously maximize both torsional and bending stiffness. The dimensions of the cross-sections of 10 unique beams—including width, height, and thickness—were considered as 30 design variables. A specific range of variation was defined for each variable: width and height from 30 to 60 mm, and thickness from 1 to 2 mm.

The MOPSO algorithm successfully generated a diverse set of optimal designs, each of which lies on a point of the Pareto front. This set is called the Pareto front, where improving one objective comes at the cost of decreasing another. In this study, 14 optimal solutions were identified and are shown in Figure 3.

To select the best design, three representative designs were chosen: Design A (highest torsional stiffness), Design B (highest bending stiffness), and Design C (the optimal design using the TOPSIS method). In the TOPSIS method, due to the greater importance of torsional stiffness for vehicle stability, a weight of 0.9 was assigned to it, and a weight of 0.1 was assigned to bending stiffness. The exact dimensions of each design are provided in Table 2.

The final optimization results showed that the torsional stiffness of the structure increased by up to 32.10% and its bending stiffness increased by up to

33.79% compared to the initial pre-optimization model.

Table 1. The number of elements and nodes of the model with optimal mesh.

Design variables	Plan A,C	Plan B
t1	1.6	1.8
w1	56	42
h1	45	58
t2	1.7	1.4
w2	52	44
h2	48	50
t3	1.4	1.8
w3	39	43
h3	51	49
t4	1.5	1.7
w4	47	52
h4	51	50
t5	1.3	1.6
w5	43	47
h5	58	60
t6	1.6	1.5
w6	52	46
h6	57	56
t7	1.8	1.6
w7	48	59
h7	51	43
t8	1.4	1.9
w8	53	44
h8	50	56
t9	1.7	1.8
w9	55	54
h9	46	48
t10	1.8	1.5
w10	43	52
h10	57	59
Torsional stiffness	7251.252	7219.563
Bending stiffness	8216.835	8250.132

4. Conclusions

This study presents an efficient method for the multi-objective optimization of the EQ10 electric vehicle's body structure. By using a simplified model, the computational load was significantly reduced, and the validation of this model with the full model confirmed its accuracy.

The use of the MOPSO algorithm led to a notable and simultaneous improvement in both the torsional and bending stiffness of the structure. This approach paves the way for designing the next generation of electric vehicles with lighter and more robust frames, which can significantly help increase their range and safety.

5. References

[1] Ahmadi, S. A., Khalkhali, A., Mohammadi, M., & Abasi, M. (2024). Static and dynamic stiffness optimization on the body structure of an electric quadricycle. *Mechanics Based Design of Structures and Machines*, 1-26.

[2] Danielsson, O., & Cocana, A. G. (2015). Influence of body stiffness on vehicle dynamics characteristics in passenger cars.

[3] Prater Jr, G., Shahhosseini, A. M., Kuo, E. Y., Mehta, P. R., & Furman, V. T. (2005). Finite element concept models for vehicle architecture assessment and optimization. *SAE transactions*, 1667-1675.

[4] Mundo, D., Hadjit, R., Donders, S., Brughmans, M., Mas, P., & Desmet, W. (2009). Simplified modelling of joints and beam-like structures for BIW optimization in a concept phase of the vehicle design process. *Finite Elements in Analysis and Design*, 45(6-7), 456-462.

[5] Doke, P., Fard, M., & Jazar, R. (2012). Advanced concept modelling method for automotive structural optimization. In Sustainable Automotive Technologies 2012: Proceedings of the 4th International Conference (pp. 91-96). *Springer Berlin Heidelberg*.

[6] Nguyen, N. L., & Jang, G. W. (2021). Joint modeling using nonrigid cross-sections for beam-based analysis of a car body. *Computers & Structures*, 257, 106648.

[7] Xiong, F., Zou, X., Zhang, Z., & Shi, X. (2020). A systematic approach for multi-objective lightweight and stiffness optimization of a car body. *Structural and Multidisciplinary Optimization*, 62, 3229-3248.

[8] Lotfi, M., & Masoumi, A. (2024). Multi-objective crashworthiness optimization for a newly developed 3D re-entrant auxetic structure using response surface method and MOPSO algorithm. Proceedings of the Institution of Mechanical Engineers, Part D: *Journal of Automobile Engineering*, 09544070231221015.

[9] Khalkhali, A., Mostafapour, M., Tabatabaie, S. M., & Ansari, B. (2016). Multi-objective crashworthiness optimization of perforated square tubes using modified NSGAII and MOPSO. *Structural and Multidisciplinary Optimization*, 54, 45-61.