Model simulation of a battery pack for an electric vehicle using simulation tools Ansys with structural optimization techniques incorporation

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***Abstract*: The research work presented in this paper discusses on "*Model simulation of a battery pack for a electric vehicle using simulation tools Ansys with structural optimization techniques incorporation*" with simulated results. The battery tray is one of the important components to protect batteries in electric vehicles, the dynamic and static performance of the battery tray is closely related to the safety of the whole vehicle. Therefore, it is very important to study the stress and displacement distribution of the battery tray under specific working conditions to optimize the design of the weak parts of the battery box's stiffness and strength. Due to the advantages of high energy density and long cycle life, Li-ion batteries are being widely studied and proverbially used as power sources for electric vehicles. Simulations are carried out in Ansys & the results are observed, which shows the effectiveness of the methodology that is being demonstrated via the simulated results.**

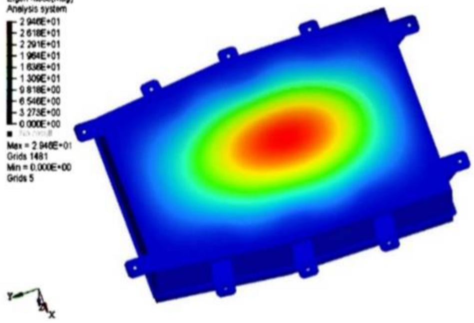
Keywords: Electric Vehicles, Lithium-ion batteries, cells, materials, dynamic loads, vibrations, Dynamic simulation battery charging, batteries technology, EV charging Finite element, Uncertainties, Mechanical strength, Stress, Strain, Optimization, Simulation.

Model simulation of the battery pack

The modal simulation is also carried out on the basis of processing of the finite element model [23]. The goals are two, one is to check whether the battery structure has a bug or abnormal vibration caused by an unreasonable design, the other one is to see whether it overlaps with the natural frequency of the frame to avoid accidents caused by a long-term internal resonance of the battery, and also to improve the interior comfort. The different mode shapes when the battery pack is subjected to vibrations are shown in the Figs. 1 to 10 respectively where the 10 modal shapes are displayed [1] [20].

Based on the constrained modal analysis, the finite element model bas been imported into the modal simulation in ANSYS to calculate the first 10-order natural frequencies. Since the battery is installed on the chassis, the box and the groove on the chassis are connected by bolts with lifting lugs, so the selected constrained mode will be closer to the real vibration environment of the battery pack than the free mode, the prerequisite condition of 6 DOF cannot be omitted in the modal link as shown in Figs. 1 to 10 [2] [19].

According to the results of modal simulation, the natural frequency of the first-order vibration mode is relatively low and may resonate with the frame. During the driving process of the vehicle, it is inevitable that there will be violent vibrations due to the unbalance of the wheels. When driving at high speed, the natural frequency of the frame is generally maintained at about 15 Hz [18]. Based on the vibration requirements of high-speed driving, the first vibration mode of this battery pack is completely within the vibration frequency range of the frame, and the natural vibration frequency of the human organs is also between 5-15 Hz, so except for the first-order problem, the other vibration modes are basically within the safe frequency ranges [3] [21].



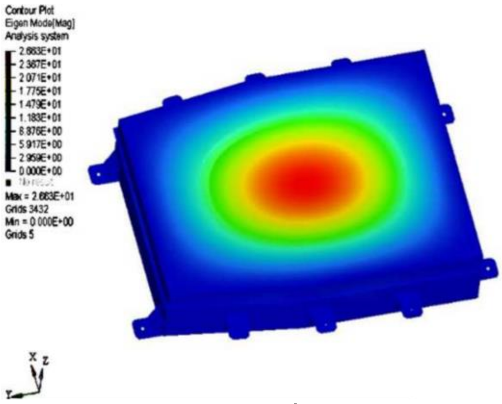


Fig. 1 : (a) The 1st-order and (b) the 2nd order mode of the battery pack

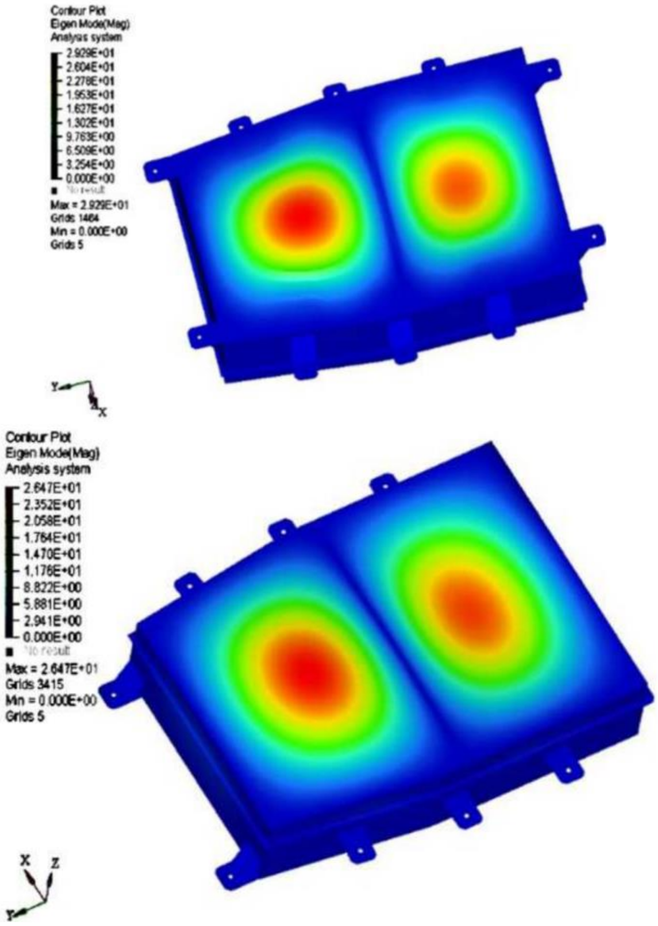


Fig. 2 : (a) The 3rd order and (b) the 4th order mode of the battery pack

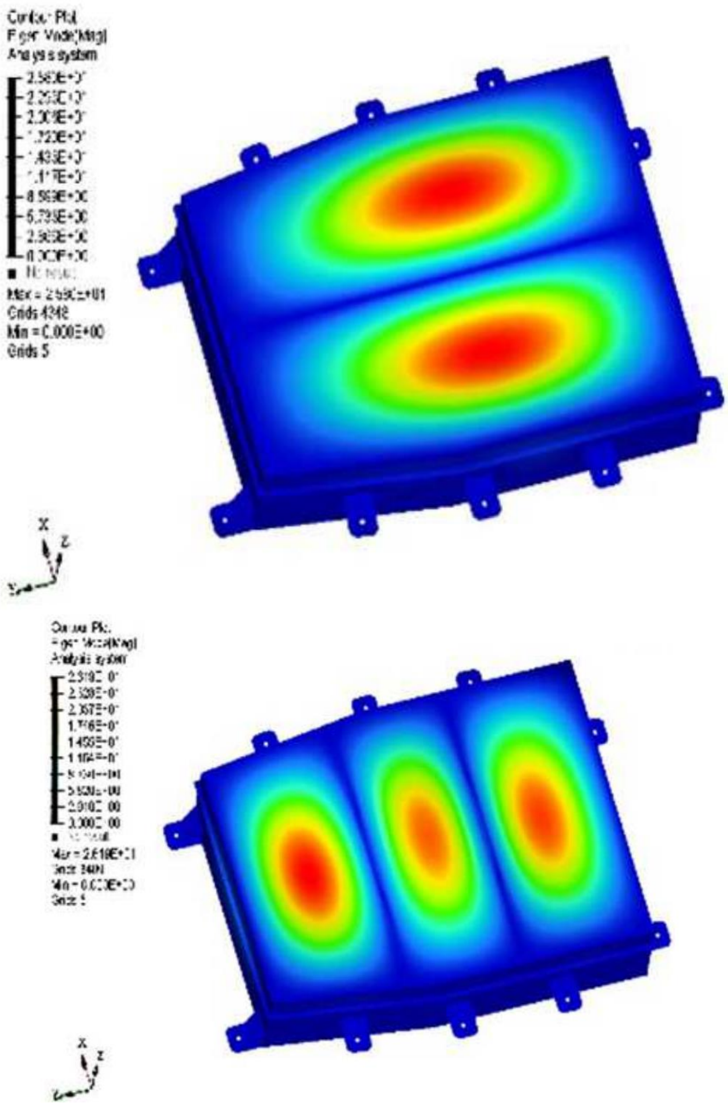
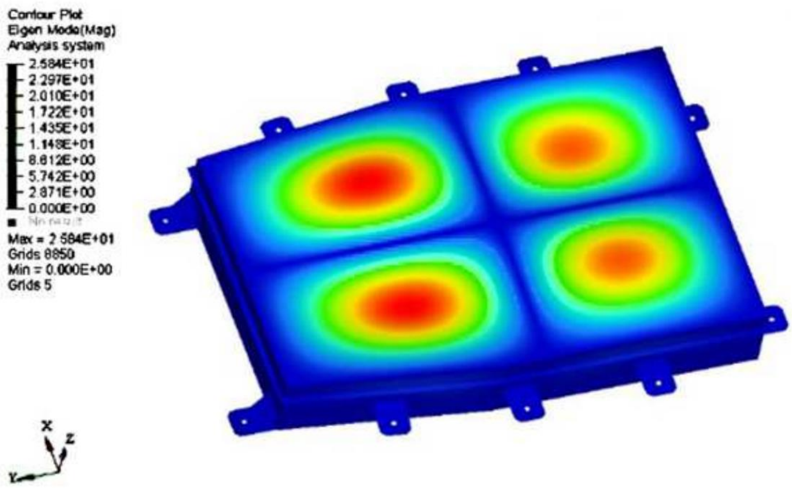


Fig. 3 : (a) The 5th order and (b) the 6th order mode of the battery pack



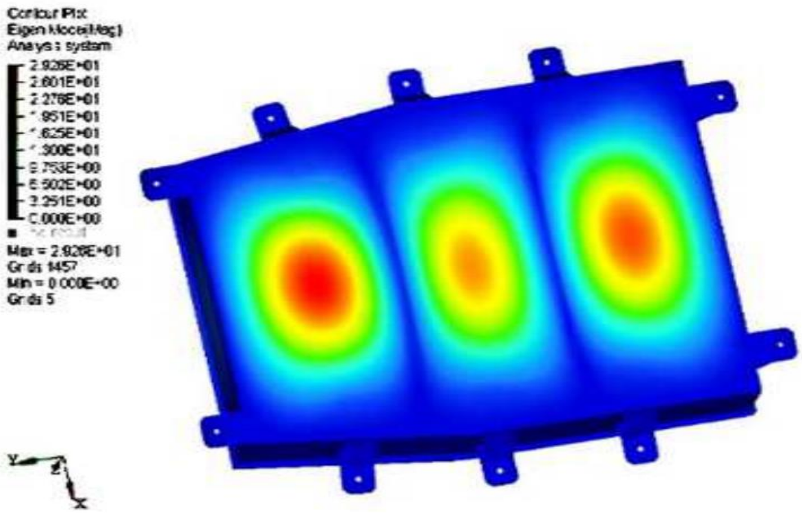
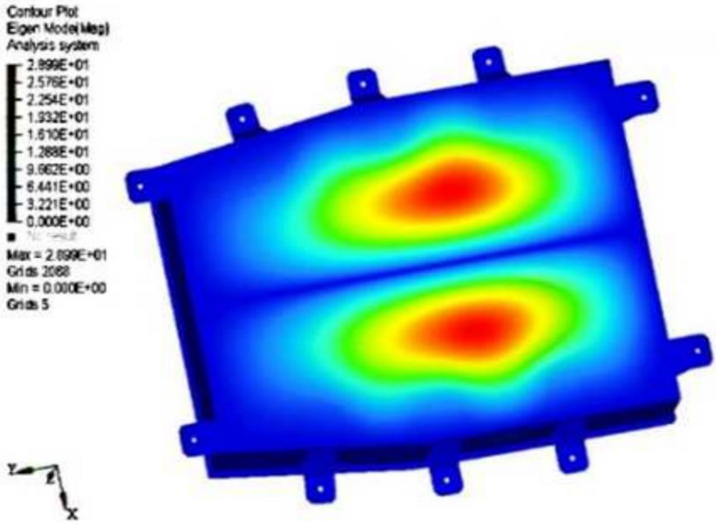


Fig. 4 : (a) The 7th order and (b) the 8th order mode of the battery pack



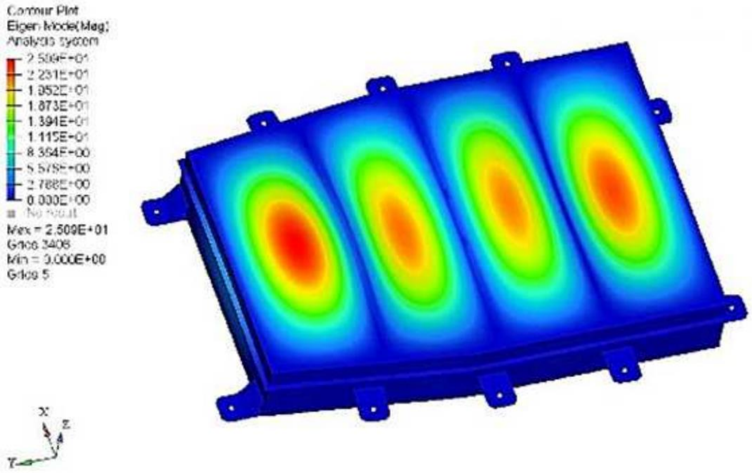


Fig. 5 : (a) The 9th order and (b) the 10th order mode of the battery pack

Order	Frequency	Order	Frequency
1	17.08	6	33.67
2	18.05	7	37.99
3	21.39	8	41.17
4	25.66	9	43.74
5	32.70	10	51.63

Table 1 : Constraint modal analysis of battery pack results

Structural optimization verification

According to the above structural changes, the improvement of the optimized structural performance is analyzed again from the perspective of static stiffness and modal examination. First the static strength. Working condition 1 is bumpy and sharp turning [24]. The result shows that the maximum stress is 140.8 MPa after optimization, and its location is distributed near the edge line of the added rib and the box cover (Fig. 1a) [17] . The maximum deformation is 37.1 mm, which appears in the front, middle and rear of the box cover (Fig. 1b). Compared with the previous static simulation, the stress and maximum deformation are reduced by 30.09% and 54.59%, respectively. Working condition 2 is bumpy and rapid acceleration [5].

The maximum stress on the structure is 143.6 MPa, and its location is similar to the previous working condition (Fig. 1a). The maximum deformation is 38.2 mm, which is also distributed in the front and middle and rear positions of the box cover (Fig. 1b). Compared with the previous model, the maximum stress and the maximum deformation decreased by 29.2% and 54.3%, respectively [16]. Through optimization, the stress and deformation of each working condition are successfully reduced and the thickness of the battery pack body is reduced, the material is saved, and the overall weight of the battery goes down a lot. It is concluded that the optimized battery pack meets the use of security and structural reliability under these three load conditions [6].

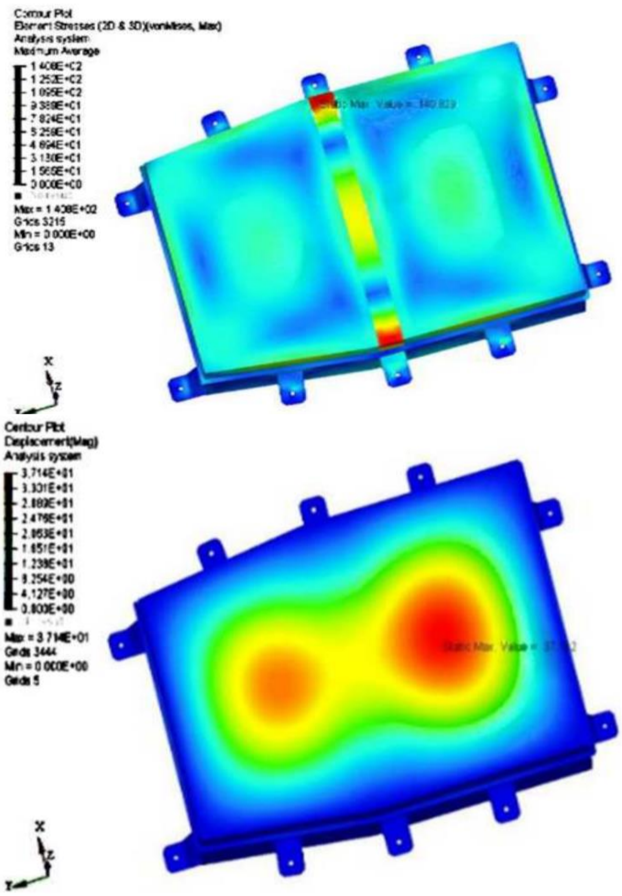


Fig. 6 : (a) Stress and (b) strain of working condition 1 after optimization

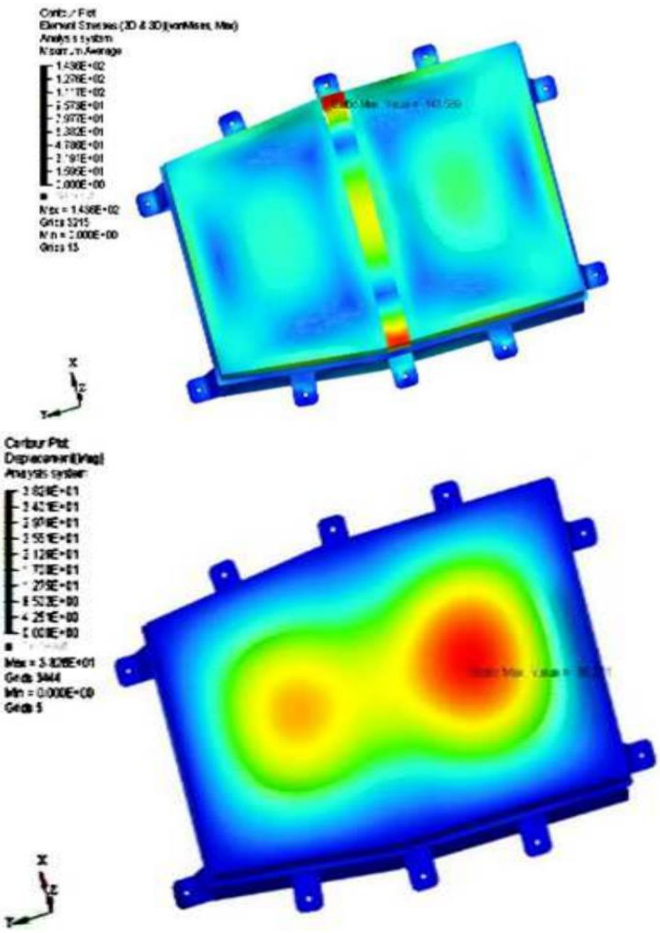
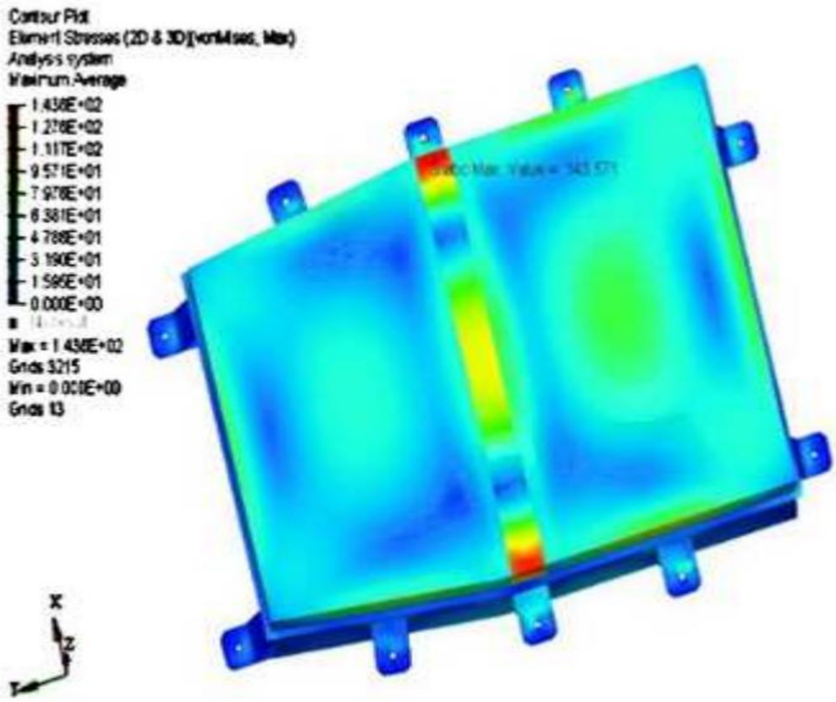


Fig. 7 : (a) Stress and (b) strain of working condition 2 after optimization

Working condition 3 is bumpy, emergency braking and turning. According to the analysis, it is concluded that the maximum stress of the battery pack under this working condition is 142.6 MPa (Fig. 6a). Its location is still on the two sides where the ribs are in contact with the edge of the box cover [15]. The maximum deformation in the middle rear position of the box is 40.0 mm (Fig. 6b). Compared with the original, the maximum stress and maximum deformation have been reduced by about 29% and 52%, respectively [7].



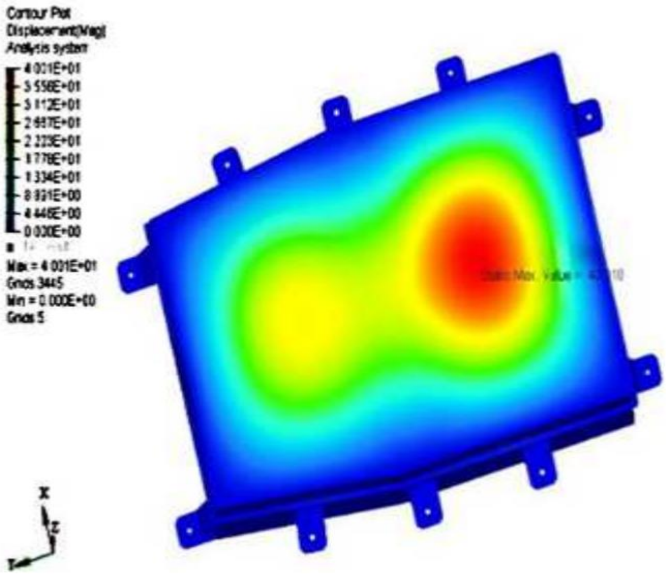


Fig. 8 : (a) Stress and (b) strain of working condition 3 after optimization

Benefits - Summary

In this section, some of the benefits of the carried-out simulation in the project work done is presented. New product development time is getting reduced by taking the advantage of the existing design of the components and necessary modifications are conducted. CAE analyses all the possible load cases since there is no physical part available [14]. This drastically saved the development time and testing material. The FE analysis gives a real insight into the critical stress areas by which it leads to conducting optimization of components in near future. This analysis gives a clear picture of the stresses and displacements developed during the real-time working condition of the components. The Table 1 gives the comparison of optimization results under various working conditions [8] [25].

Working condition	Stress calculation result			Displacement calculation result		
	Before optimization [MPa]	Optimized [MPa]	Decrease percentage [%]	Before optimization [MPa]	Optimized [MPa]	Decrease percentage [%]
1	199.7	140.8	30.09	83.4	37.1	54.59
2	202.9	143.6	29.22	83.6	38.2	54.30
3	204.2	143.6	29.00	83.9	40.0	52.00

Table 1 : Comparison of optimization results under various working conditions

Structural analysis

The battery pack studied in this article is a lithium battery pack, which is located in the center of a car chassis. Its total power is 22 kWh, the battery capacity is 60 Ah, and the total voltage of the battery is 353 V. The battery element material is an aluminum structure made by ATL Pride with characteristics of large temperature difference withstand, higher peak value of electric heating, over 120 Wh/kg specific energy of the battery element, and 150-kilometers driving mileage [10].

The battery pack is 1700 mm long, 1200 mm wide, and 210 mm high. The cover and the box are formed by stamping and die-casting aluminum steel, respectively. The entire box is fixed to the frame by 10 fixing bolts through connectors (Fig. 5.49a). Above, the weight of the entire box is about 235 kg. The main components of the battery pack have six parts [12]. The outside is composed of the housing upper cover, the housing base and the lug connecting pieces. The upper cover and the base are connected by bolts, and the inside is composed of battery modules, fixing plates of battery modules and high liquid cooling plates, etc [13]. The entire battery pack is fixed in the special groove with 10 bolts through the lug connection piece, and the groove is surrounded by the groove sheet on all sides. The finite element mesh model of the box can be seen in Fig. 8b [9] [11].

Overall conclusive remarks

Finally, to conclude, the static & dynamic analysis of the lithium-ion battery packs were conducted using the simulation tools and the results were analyzed and found to be more effective compared to the work done by the others in this field. The conclusions and scope for future works is presented in this section, which throws a highlight into what are the things that have been done in this paper. Project was successfully completed with the conduction of static & dynamic analysis of the battery tray for the electric vehicles. Different types of stress plots were plotted to check the stress levels at different parts of the battery tray when it is subjected to dynamic forces when the vehicle is moving. The displacement plots are also observed which occurs because of the vibration patterns that takes place when the vehicle moves over bumpy roads or pot-hole ridden surface. The different mode shapes are also studies from which we can come to a conclusion that which mode is the more dominant one as it has to be suppressed else the system may go into the resonance mode or reliability of the EV goes on decreasing. The design of the battery pack mounting is also taken care of and seen to it that space is well optimized and left for cooling purposes also. Ansys, Hypermesh was used for the simulation purposes. Models are developed and the analysis is carried out to observe the overall performance of the designed system. All the set objectives are solved herewith and arrived at excellent results in comparision to the works done by other researchers. A design for the tray to hold the battery of an EV has been proposed in order to reduce the maximum deformation as much as possible, while raising the minimum frequency as much as possible. In other words, both the responses - maximum-deformation and base-frequency - are treated and taken care of with. One should be minimized while the other should be maximized. Also, static analysis is conducted when the EV is stationary. The work that is being simulated could be implemented in the real time (RT) sense by using the hardware of the system, which could be treated as a case of future work that could be done by the next post-graduation students.

References

[1]. Inside-EVs. EV Battery Makers 2016: Panasonic and BYD Combine to Hold Majority of Market. 2017.
[2]. Schweiger, H.G.; Obeidi, O.; Komesker, O.; Raschke, A.; Schiemann, M.; Zehner, C.; Gehnen, M.; Keller, M.; Birke, P. Comparison of several methods for determining the internal resistance of lithium ion cells. Sensors 2010, 10, 5604–5625.
[3]. Institute of Transport Economics, Norwegian Centre for Transport Research. Available online: https://www.toi.no/ (accessed on 21 February 2021).
[4]. Electric Car Use by Country.
[5]. European Alternative Fuels Observatory. Available online: http://www.eafo.eu/ (accessed on 21 February 2021).
[6]. Electric Car Use by Country. The Electric Vehicles world Sales Database.
[7]. Statista. Electric Vehicles Worldwide.
[8]. Hong Kong Bussiness. EV Dossier.
[9]. EVAdoption.com. Analyzing Key Factors That Will Drive Mass Adoption of Electric Vehicles. 2019. Available online:
[10]. Zhao, H.W., Chen, X.K., L, Y. (2009) Topology optimization of power battery packs for electric vehicles. Journal of Jilin University, 39: 846-850.
[11]. Yang, S.J. (2012) Dynamic and static characteristics analysis and structural optimization design of battery box for electric vehicle. Hunan University, Changsha.
[12]. Sun, X.M. (2013) Structure analysis and improvement design of battery pack of a certain electric vehicle. Hunan University, Changsha.
[13]. Zhang, H.B. (2013) Study on optimization of stiffener structure of battery box of electric vehicle based on dynamic and static characteristics. Hunan University, Changsha.
[14]. Kazuo, O., Takamasa, O. (2006) Thermal behavior of small lithium-ion battery during rapid charge and discharge cycle. Journal of power source, 158: 535-542.
[15]. Hartmann, M., Roschitz, M., Khalil, Z. (2013) Enhanced Battery Pack for Electric Vehicle: Noise
[16]. Reduction and Increased Stiffiness. Materials System Forum, 765: 21-23.
[17]. Klaus, H., Hirtz, E. (2013) With System Integration and Lightweight Design to Highest Energy Densities. Advanced Microsystems for Automotive Applications,56-57.
[18]. Castano, S., Gauchia, L. (2012) Dynamical modeling procedure of a Li-ion battery pack suitable for real-time applications. Energy Conversion and Management, 92:396-405.
[19]. Vaidya., Parthasrathy., Serrano. (2006) Design and process simulation of long fiber thermoplastic battery box door for mass transit application. Composites: Part A, 33-34.
[20]. Dynamic and static analysis of the battery box structure of an electric vehicle Na Yang et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 688 033082
[21]. Yoon Cheol Jeon, Gun Goo LEE, Tae Yong KIM, Sang Won BYUN, Choong Ho LEE, Kyeong Beom CHEONG, Han Yong LEE, Soo Seok CHOI, KiHo KIM, and Jun SONU. Development of battery pack design for high power li-ion battery pack of hev. World Electric Vehicle Journal, 1(1):94–99, 2007.
[22]. Kristel Coronado, John Lyons, Randy Curtis, and Thomas Wang. High volt- age hybrid battery tray design optimization. Technical report, SAE Technical Paper, 2011.
[23]. Li Shui, Fangyuan Chen, Akhil Garg, Xiongbin Peng, Nengsheng Bao, and Jian Zhang. Design optimization of battery pack enclosure for electric vehicle. Structural and Multidisciplinary Optimization, 58(1):331–347, 2018.
[24]. Adrian Mahlen. Shape optimizing sheet structures with respect to buckling. Technical report, Linkoping university, 2016.
[25]. Yang, Na & Fang, Rui & Li, Hongliang & Xie, Hui. (2019). Dynamic and static analysis of the battery box structure of an electric vehicle. IOP Conference Series: Materials Science and Engineering. 688.