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Challenges and Approaches of Electric Vehicles Powertrain Mount System Optimization for NVH, Buzz Squeak Rattle and Durability

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Abstract

In electric vehicles, the powertrain mounting system design has challenges different from conventional internal combustion engine (ICE) powertrains. Due to the absence of source noise, the customer predominantly experiences the buzz, squeak and rattle (BSR) noise. The 6 degrees of freedom (DOF) modal frequency target is less stringent than a three-cylinder or four-cylinder ICE powertrain. The durability loads in EV also differ due to less powertrain weight. In this paper, a study has been carried out about balancing all three main performance parameters of modal decoupling, BSR and durability through powertrain mount design optimization. The article shows that a carryover ICE powertrain mount has typical issues in Electric Vehicle (EV). A case study has discussed in detail how to manage those issues. Finally, it is concluded that a particular focus is required during an early stage of mount design to address these challenges for an EV.

Keywords

EV, BSR, NVH, Durability

Introduction

Powertrain mounting system optimization for ICE has been studied, refined and applied for many years with numerous applications. Whether in ICE or EV, the engine mounting system has similar input, control, and noise factors as mentioned in Figure 1 to achieve expected NVH, BSR and durability targets. The input signal for EV's is different than ICE as EV powertrain has a quieter engine presence compared to ICE's. The main differences are the absence of idle load case, engine start/stop load cases, higher excitation frequencies, lighter mass moment of inertias in EV compared to an ICE. The high torque and fast change in torque during acceleration and deceleration require a stiff and progressive load-deflection curve in the non-linear zone of engine mounting. Also, the 6 degrees of freedom (DOF) modal frequency targets in ICE are quite relaxed in EV. As a result, the 6 DOF modes are comparatively easier to place in the EV modal map. The BSR noise issue is more prominent in EVs than ICE because of the difference in powertrain masking effect. Failure in addressing BSR issues is often the biggest challenge faced by car manufacturers during the EV development stage. Even perfectly optimized powertrain mounts for EV's fail to deliver the best NVH due to BSR noise. The next challenge is to meet durability targets. In EV's, the powertrain is lighter than the similar ICE class, so the durability load cases are also different.

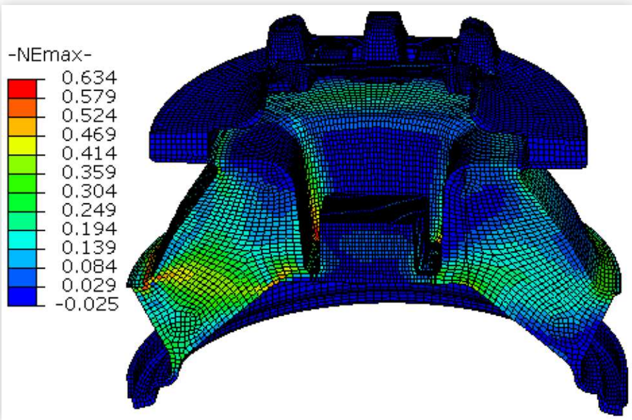
However, as the torque rise is quick in EV, which leads to a higher engine roll in EV than an ICE engine. In this paper, a 6 DOF optimization for the mounting system is carried out. BSR issues are discussed. After that, the mount progression curve correction is done to balance BSR and NVH aspects through stopper gap optimization. Finally, the RLDA based durability load cases are checked on revised progression curves to estimate the corresponding rubber strain. The simulated durability cycles are calculated from the Wohler curve of the rubber compound. The ratio of estimated cycles (N1) and the total target cycles (N) is called relative damage. The total damage is calculated for each block cycles for final life estimation. Focus is given to balancing the engine mounting progression curve through optimization. So, a 6 DOF study is not enough for overall NVH, BSR and durability target balancing. Proper attention is required to choose all performance aspects and system-level noise factor to achieve the overall target as per customer expectation.

The powertrain mounting system in EV is quite similar in layout as compared to ICE. Depending on packaging space, load transfer and type of electric vehicle, the powertrain mounting system can be classified as shown in Table 1 for EV. Mainly two types of EV, namely modified and dedicated with the transverse or longitudinal powertrain. Mounting systems

TABLE 3 Durability load on right side mount

Mount	X dir. (N)	Y Dir. (N)	Z Dir (N)	Total damage
Right side mount	-3200 to +1000	-320 to +250	-4230N to +3025	
Calculated Total Damage	0.26	0.15	0.40	0.81

FIGURE 15 CAE with strain rate



and the strain levels are plotted as shown in Figure 15. The value of 0.634 indicates the strain level as 63.4% in the color plot.

The corresponding strain values are picked from loading on rubber and fed back from the Wohler curve for the estimated no of the cycle. The estimated and required no of cycles are called damage for that particular block. Generally, the cumulative damage should be <1 to have a durable design. The calculated cumulative damage was 0.81 for right side mount, which is <1 and satisfies the damage criteria.

This study shows how to design a stopper gap for the BSR noise issue and the corresponding strain rate to achieve the durability cycle. Here every step, a proper balancing of design parameters to meet the performance target is required. Otherwise, some of the other parameters will become not OK in terms of meeting overall performance requirements.

Results and Discussion

The study of attribute balancing is done for the powertrain mounting system. A powertrain mount suitable for ICE for BSR noise becomes worse due to the absence of a powertrain masking effect. Mount load-deflection characteristics, BSR issues resolution through progression curve adjustment is made. The simulated load is evaluated for overall damage.

A similar type of load measurement/analysis was done for all three mounts in all three directions. Block cycles were created based on force-deflection characteristics, and then CAE is done based on Wohler's curve, as mentioned in Figure 9. Total damage for durability was estimated. In this particular study, the BSR issue was observed from the right side mount. Hence, load-deflection characteristics adjustment done only in right side mount and overall modal alignment, durability and BSR impact shown in the case study.

Accordingly, the stopper gap was designed to address BSR and durability together. As the primary linear stiffness was not changed, there was no change in dynamic stiffness at 15Hz, which corresponds to no change in modal separation targets in 6 DOF. The transient characteristics were designed through the stopper gap and non-linear progression.

Overall, balancing all three primary targets has been discussed in this paper in detail for the electric vehicle powertrain mounting system.

Conclusions

The requirement matrix during a vehicle-level system development has been discussed. The forward and backward interaction among various performance nodes plays a critical role while optimizing the system to meet overall performance.

Conflicts of various performance targets can be resolved by finding a solution space rather than optimizing individual system-level targets like optimizing kinetic energy coupling. Solution spaces are regions in the design space where all requirements are considered satisfactory.

Here firstly, a 6 DOF optimization is done through optimization for modal alignment and decoupling of modes. Then the stopper gaps are designed to take care of the BSR noise issue. While doing that, durability loads are calculated and checked to ensure that the rubber strain rate met the cumulative damage. Finally, this paper presents the approach to have a proper balance among NVH, BSR and durability while meeting attribute targets.

The significant aspects of BSR, durability and NVH are covered in this paper. However, more complex system-level interaction during engine mount development in EV is the future scope of the study. There is various potential risk associated with the application of traditional ICE powertrain mount design process in EV. The shift of focus is also needed to include the impact of driveshaft integration, engine roll movement during sudden braking in EV, which can also cause various types of noises in EV.

References

1. Königs, S. and Zimmermann, M., "New Chassis Systems and Methods- Resolving Conflicts of Goals in Complex Design Processes - Application to the Design of Engine Mount Systems," in *7th International Munich Chassis Symposium 2016*, 125-141, 2017, doi:10.1007/978-3-658-14219-3_14.
2. Hazra, S., "Engine Mounting System Design Approach for Electric Vehicles," SAE Technical Paper 2019-26-0116 (2019). https://doi.org/10.4271/2019-26-0116.
3. Kim, W., "Fatigue Life Estimation of an Engine Rubber Mount," *International Journal of Fatigue* 26, no. 5 (2004): 553-560, doi:10.1016/j.ijfatigue.2003.08.025.

4. Woo, C. and Park, H., "Useful Lifetime Prediction of the Rubber Component," *Engineering Failure Analysis* 18, no. 7 (2011): 1645-1651, doi:10.1016/j.engfailanal.2011.01.003.
5. Hazra, S. and Deshmukh, S., "Engine Mount Stopper Design Techniques to Balance Vehicle Level Buzz, Squeak, Rattle and Durability," SAE Technical Paper 2020-01-0401 (2020). https://doi.org/10.4271/2020-01-0401.
6. Hazra, S. and Gupta, I., "Engine Mount Design Technique to Address Vehicle Level Buzz, Squeak & Rattle," in *IEEE Transportation Electrification Conference (ITEC-India)*, 2017, doi:10.1109/ITEC-India.2017.8333721.
7. Hazra, S. and K, J., "Impact of Powertrain Dimensional Variation on Buzz, Squeak and Rattle Noise for Cradle Type Electric Vehicle," SAE Technical Paper 2021-01-0836 (2021). https://doi.org/10.4271/2021-01-0836.
8. Chen, D., Shangguan, W., and Zhang, W., "The Design Strategies and Calculation Methods for Powertrain Mounting System with Multi-Powertrain," *International Journal of Vehicle Design* 60, no. 1/2 (2012): 3, doi:10.1504/IJVD.2012.049155.
9. Zhou, B., "Optimization Design of Engine Mounting System," *Applied Mechanics and Materials* 543-547 (2014): 168-172, doi:10.4028/www.scientific.net/amm.543-547.168.
10. Zhou, H., Liu, H., Gao, P., and Xiang, C., "Optimization Design and Performance Analysis of Vehicle Powertrain Mounting System," *Chinese Journal of Mechanical Engineering* 31, no. 1 (2018), doi:10.1186/s10033-018-0237-2.
11. Rane, G. and Deshmukh, S., "Development of Mount for Electric Powertrains - A Multi Degree of Freedom Optimization Approach," SAE Technical Paper 2020-01-0417 (2020). https://doi.org/10.4271/2020-01-0417.
12. Zhu, D., Pritchard, E.G.D., and Silverberg, L.M., "A New System Development Framework Driven by a Model-Based Testing Approach Bridged by Information Flow," *IEEE Systems Journal* 12, no. 3 (2018, Sept. 2018): 2917-2924, doi:10.1109/JSYST.2016.2631142.

Definitions/Abbreviations

Mount 1,2,3 - Right, Left and Rear Mount
BSR - Buzz, Squeak and Rattle
CoG - Centre of Gravity
DOF - Degree of Freedom
EPDM - ethylene propylene diene monomer
EV - Electric Vehicle
ICE - Internal Combustion Engine
KE - Kinetic Energy
MRE - Main rubber element
NVH - Noise Vibration and Harshness
NR - Natural rubber
NBR - Nitrile-butadiene rubber
OEM - Original Equipment Manufacturer
RLDA - Road load data acquisition
RPN - Risk priority number