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A Comparative Study of Source Vibration Between the Electric Motor and Internal Combustion Engine Application for Passenger Vehicles

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Abstract

In an electric vehicle, internal combustion engines are replaced by the electric motor. As a result, the signature of source vibration changes. The noise, vibration and harshness (NVH) issues are entirely different in electric vehicle (EV) compared to internal combustion engine (ICE) due to the change in source vibration. The outline of this paper is a comparative study of source vibration, the challenges to address various noise issues related to source vibration and the isolation methodology. A case study is presented to show the different methods of treatment required to mitigate source vibration issues during the electric vehicle development program.

Keywords

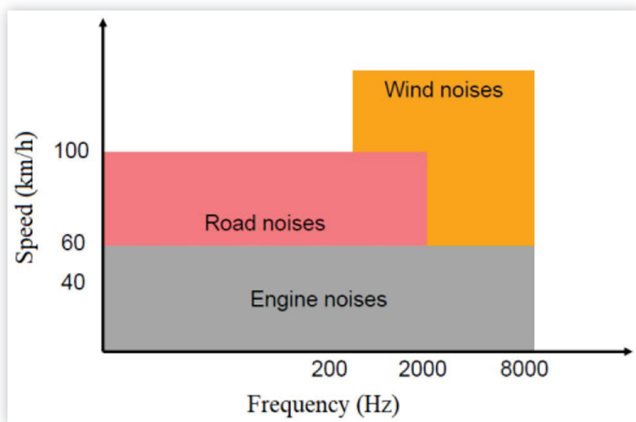
Engine, Motor, vibration

Introduction

The automotive industry has various challenges for safety, fuel economy and environmental norms. One of such challenges is to reduce pollution and improve carbon footprints. For minimization of the carbon footprint, there is an increasing trend of electric vehicle introduction. More and more original equipment manufacturers(OEM's) are focussing on their product portfolio for the development of EVs and faster launch in the market. The shortest lead-time adopted by almost all OEM are modified EV. An electric powertrain replaces the current Internal combustion engine (ICE), and a battery replaces the exhaust and fuel system. We all know the noise, vibration and harshness(NVH) is a mechanism of interaction among source, transfer path and receiver. Here, the transfer path is the same, but the source is getting changed as we are replacing ICE with EV. The customer comfort requirement is also getting changed due to the increased quietness of EV compared to gasoline or diesel engine.

A typical representation of the Noise profile of EV and ICE are shown in Figure 1a) and 1b: The engine noise in ICE would be replaced by ancillary noise and motor noise in EV. The aerodynamic and road noise in EV is more than ICE as there is no masking effect in EV compared to ICE. So, a little noise is experienced by a user called buzz, squeak and rattle (BSR) noise in a quiet an objectionable in EV car.

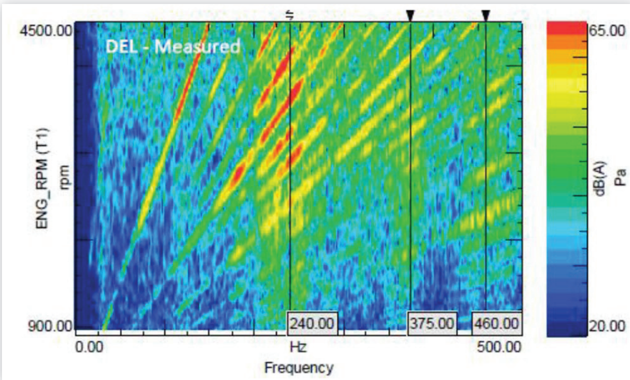
FIGURE 1A The noise profile of an ICE vehicle



The identification and treatment of each noise source are essential for EV. Due to motor resonance in high frequency, sometimes, EV has a high-frequency resonance issue not present in ICE. So, it is essential to understand the source noise difference between ICE and EV to further work on the treatment mechanism of various noise issues during development.

There is a significant difference in forcing function between ICE and EV powertrains. In ICE, the engine's sound masks many other noises and is shown in Figure 1a: Due to

FIGURE 12 Driver Ear level measurement- A typical plot



Contribution of LHS mount (forcing function from LHS mount structural resonance) at 240Hz, which correlates with the resonance observed at DEL as shown in Figure 12.LHS mount resonance frequency is tested through hammer test and observed that LHS mount structure have 1st mode as 250Hz which is close to ICE engine orders. It means the LHS mount housing mode contributes to the driver ear level for ICE due to its resonance with powertrain source vibration. This was not present in EV due to the absence of source vibration. Hence the treatment of modal frequency of mounts structure would be different from ICE to EV.

Receiver The occupant sound pressure level is shown in Figure 12 over an engine rpm ranging from 900 to 4500. The resonance at 240Hz in color plot is due to the resonance of B mount structural mode, and as a result, the noise level increased.

From the above case study of source, transfer path and receiver analysis, it is observed that the approach would be different due to change in source vibration of EV and ICE vehicle. However, in EV, the high-frequency motor vibration is another area in ICE that needs special attention through powertrain mount design optimization. The detailed discussion outlines source vibration and their possible treatment to address them for EV compared to ICE.

Methods to Address Source Vibration The various mount characteristics are outlined in Table 2 between the ICE and EV powertrain mounting system. For example, EV is more sensitive in BSR due to the absence of powertrain presence, whereas ICE is less sensitive. Due to sudden torque reaction in EV, the powertrain roll for a 3-point pendulum mounting system is more than ICE requires a bigger envelope to achieve dynamic clearance. As there is no engine firing order in EV, the 6 degrees of freedom (DOF) powertrain modal alignment are not restricted by engine firing order like in ICE.

So, keeping all requirements together, various system simulation approach generally adopted in EV. The system layout, 6 DOF analysis and dynamic force transfer, the powertrain mounting position and dynamic stiffness are defined together. Then based on overall load transfer, the layout is optimized to minimize the load during an extreme braking event in EV. As the powertrain forcing is minimum in EV, that results in dealing with various other noises which are not there in ICE.

TABLE 2 Main requirements in EV and ICE mounts

Requirements	EV mount properties	ICE mount properties
No noise, vibration during key on/off	Not applicable	Soft in transverse direction
No Engine shake	Not applicable	High damping
No idle vibration	Soft mount	Soft mount
No judder in Tip in/out	Not applicable	Hard in travel direction
Roll movement during braking	High articulation/bigger envelop	Less articulation/ smaller envelope
Good Crash performance	High strength	High strength
No metallic contact during Cornering	Hard in transverse	Hard in transverse
No high frequency resonance	Mount internal structure should be free from resonance	No such issue
Modal span in 6DOF	Big	Small
No BSR noise	Highly sensible	Less sensible

Conclusion

Interior noise is mainly the combination of structure-borne and airborne noise. The engine structure-borne noise transfer through the powertrain mounting system, whereas airborne noise directly enters the passenger cabin through insulation.

This paper first identifies the source vibration between EV and ICE and then compares the structure-borne noise profile between the electric motor and the internal combustion engine. ICE has low-frequency noise, whereas EV motor has high-frequency noise. Through Engine mount optimization, the structure-borne noise, either low frequency or high frequency, are addressed. A proper selection of the powertrain mounting system is the key to resolving any powertrain source vibrations issues based on the motor or engine vibration profile. The scope for future work is to study in detail the structure-borne contribution from auxiliary parts in EV, which is more dominant than ICE. All such external factors act as a forcing function that needs special attention during vehicle development.

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Definitions/Abbreviations

CoG - Center of gravity

DSR - Driver's seat rail

DOF - Degrees of freedom

DEL - Driver ear level

EV - Electric vehicle

ICE - Internal combustion engine

LHS - Left Hand mount

NVH - Noise vibration and harshness

NTF - Noise transfer function

OEM - Original equipment manufacturer

PT - Powertrain

RHS - Right Hand Side

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