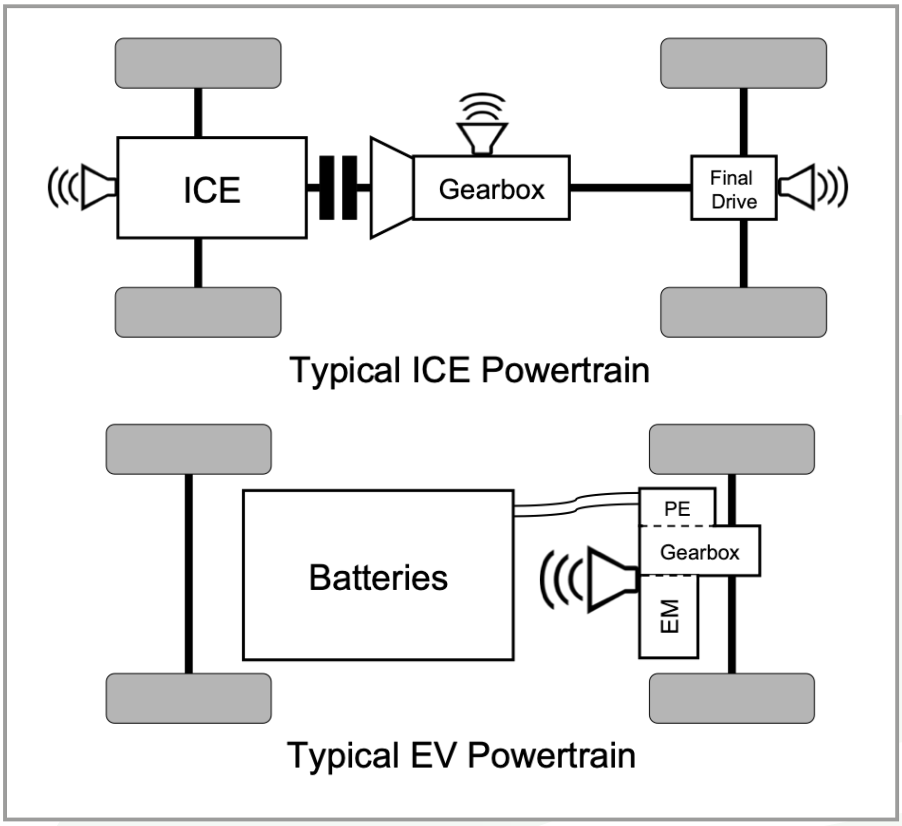
# Silencing the Future – A System Level Approach to NVH Reduction

Authored by Michael Furness

Without a combustion engine to mask unwanted noise, electric vehicles (EVs) require greater emphasis on the design of powertrain components and subsystems for low noise emissions. Despite growing industrywide understanding of vehicle NVH (Noise, Vibration and Harshness), issues continue to arise for manufacturers and suppliers alike as they pursue greater powertrain efficiency as a remedy for consumer range anxiety.



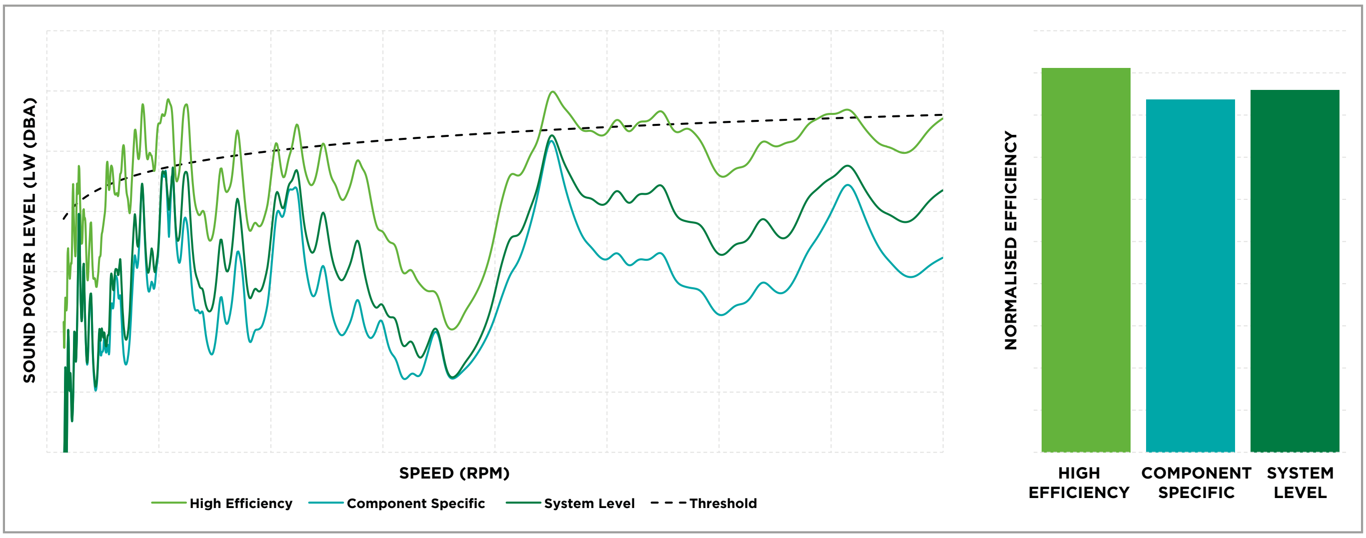

Efficiency and NVH typically compete in the same design space. Rotor skew, gear tooth geometry, motor control and even fundamental ratio and slot/pole combinations are all driven by design trade-offs between NVH and efficiency. Demands for increased torque density and mass reduction add to the challenges.

Even if the individual component systems of a vehicle have been designed for low excitation and response, issues can arise when they are brought together. For example, when the motor, inverter and drivetrain perform together for the first time, the combination of their characteristics can cause an unexpected response in the powertrain structure as well as other chassis components.

To prevent such issues arising late in a vehicle program, when rectification costs are at their highest, at Drive System Design we have developed a system level approach to evaluate the effects of interactions between the sub-systems of an EV powertrain at the concept design stage. Our methods enable the design to be optimized for NVH and efficiency as a complex system rather than as individual components throughout the development process. This increased control over NVH at a powertrain system level enables a more informed attribute trade-off, creating opportunities to improve efficiency rather than compromise it.

In a recent study we evaluated the system level effects of the sub-system sensitivities by modelling a complete EV powertrain for a C-segment vehicle. The powertrain included an 8-pole 48-slot interior permanent magnet synchronous motor (IPMSM), a 13:1 two-stage single-speed transmission and a conventional insulated gate bipolar transistor (IGBT) power inverter.

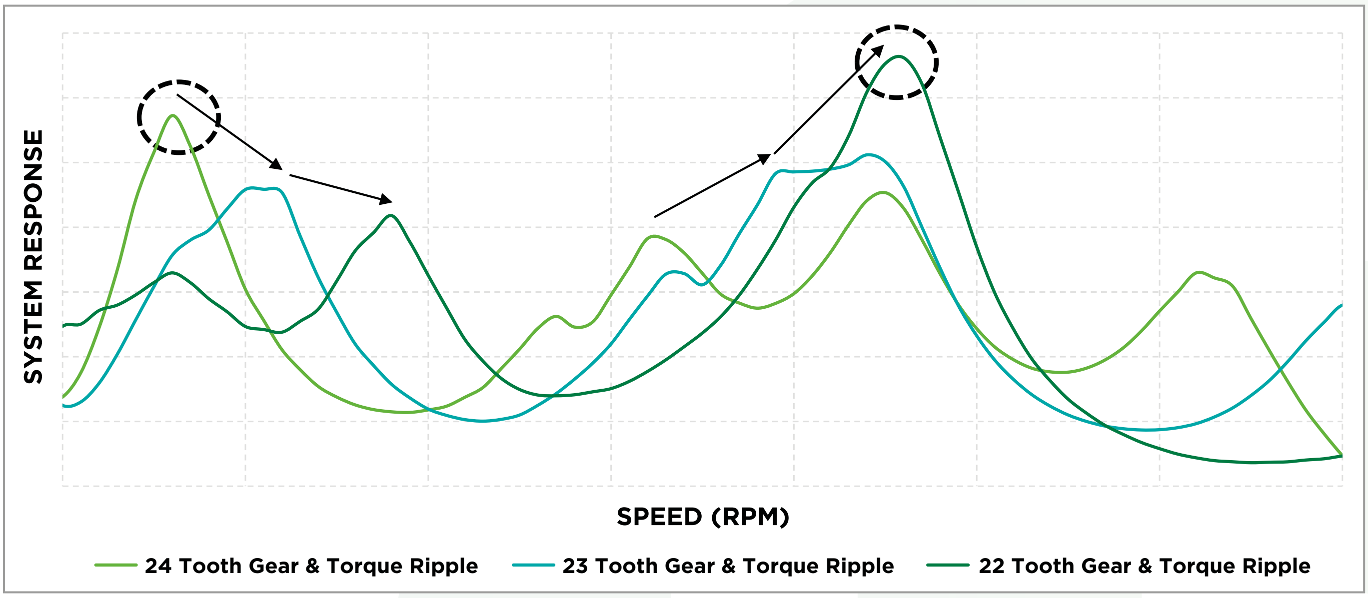
Finite element (FE) models of complex geometries such as the housing, differential and large gear blanks were included, as were non-linear stiffness models for components such as bearings and mounting bushes, with anisotropic material properties used for the rotor and stator lamination stack.



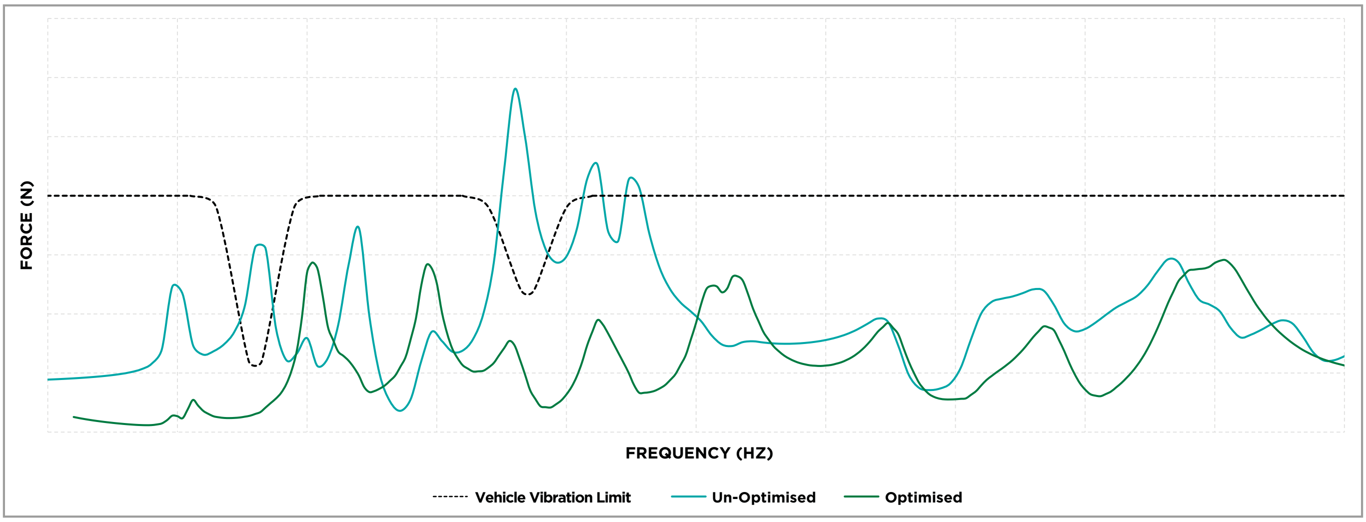

Three variants of the powertrain were created by changing the sub-system design variables, gear geometry, motor skew and switching frequency: a ‘High Efficiency’ model, focused on maximizing the efficiency of each sub-system; a ‘Sub-system’ model, focused on reducing the NVH performance of each sub-system to meet typical sub-system targets; and finally an ‘Optimized’ model, in which the NVH performance was optimized within the system NVH thresholds while reducing unnecessary efficiency losses. This latter option yielded efficiency benefits that could be taken as increased range or reduced battery cost.

A potential risk, when designing powertrain sub-systems in isolation, is the generation of excitations that share a common harmonic order. This may lead to issues when the sub-systems are integrated within the same structure as common harmonics will excite the same structural resonances at the same speed resulting in an unexpected, elevated NVH risk, despite meeting sub-system targets.

An example of this can occur between a transmission input pinion and electric motor. The fundamental torque ripple harmonic of a PMSM 4-pole pair machine over one rotation of the input shaft is of the 24th order. The fundamental TE (transmission error) harmonic for a 24-tooth gear is also of the 24th order. By changing the number of gear teeth, and hence the harmonic order of the fundamental gear TE excitation, this constructive interference can be avoided. However, this approach can often only move the potential NVH risk to another speed where a significant peak in total sound power is also observed using a 22-tooth gear, generating a response greater than that observed when using a 24-tooth gear.




Another aspect of powertrain NVH that is historically difficult to validate in the design and development phase of a program is the interaction between the powertrain and the vehicle. By understanding the response of the powertrain at a system level, the force of vibration can be calculated at the powertrain mounts and evaluated against vehicle limits established at each one. Structure-borne vibrations can excite resonances in other vehicle systems which often have very sensitive and specific frequencies, for example a steering column bending mode, a characteristic completely unrelated to the powertrain. Our system approach enables such interactions to be identified and eliminated at the concept design stage.




While we accept that up-front design activity is increased by the system approach, the downstream benefits massively outweigh any potential delay in the 'design freeze' milestone. If implemented effectively and correlated with physical performance, early stage system analysis can greatly reduce the duration of hardware testing and the occurrence of late development issues, cutting overall engineering costs and time-to-market.

Our long term goal is a full system approach that ultimately requires the characterization of any objectionable noise in the vehicle cabin, then the effective correlation of everything this includes, back to powertrain excitation and response. This represents an enormous expansion of today's analysis environment; the matrix of interactions and dependencies is several orders of magnitude greater than a traditional sub-system approach.

Keeping control of the trade-offs will become a task that can no longer be controlled by the human intellect alone; the future for the optimization of electrified powertrains will rely heavily on tools and methods that can generate and process large amounts of data then present the output in a readily interpreted form that can be used to make decisions. Our work so far has taken us the first few steps towards this goal and we look forward to sharing our future progress.



Drive System Design, Berrington Road, Leamington Spa, UK
WWW.DRIVESYSTEMDESIGN.COM