CAE Study on Electric Motor Whine Radiated from Hybrid Vehicle Transmission

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Introduction to E-Motor Noise and Presentation Outline

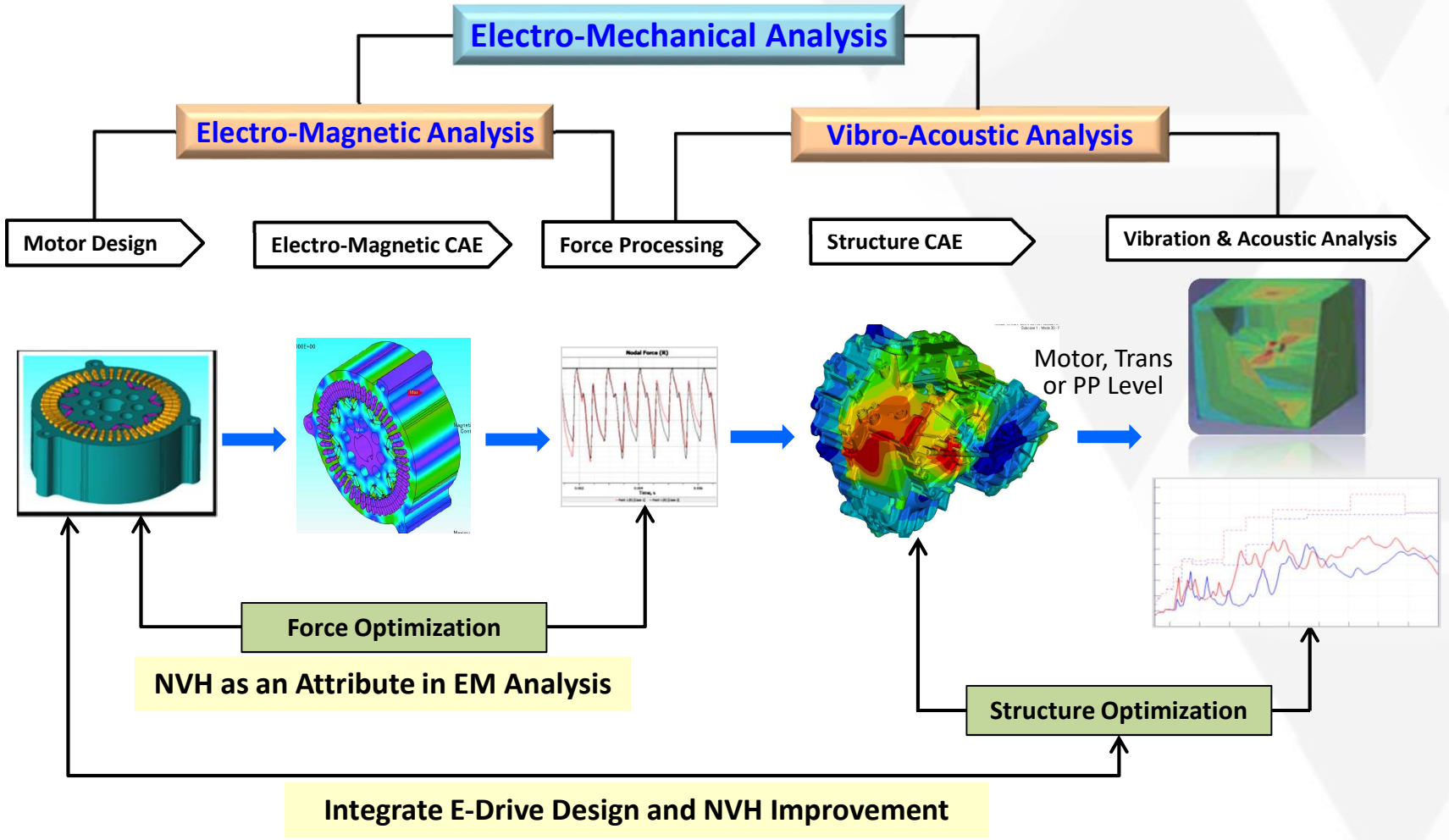
Challenge

- Hybrid and electric (HEV/BEV) powertrains bring additional challenges to NVH development.
- Noise from transmissions of HEV/BEV vehicles is more prominent.
- E-motor whine noise becomes a primary concern.
- **E-motor noise analysis, especially with the motor as installed in the HEV transmission is still relatively new area for CAE.**

Presentation Outline

- The process established for using CAE in HEV transmission development for e-motor whine noise prediction and reduction.
- E-motor modeling and correlation.
- Transmission e-motor noise prediction and correlation.
- E-motor whine characteristics and sensitivities to certain factors.
- Examples of countermeasures evaluated for reducing the noise.

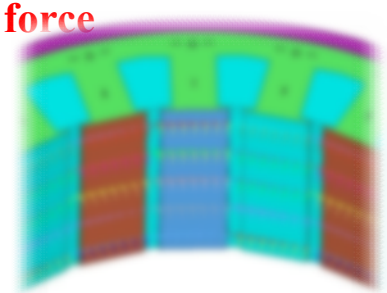
Electro-Mechanical CAE for HEV/BEV Powertrain NVH



Electro-Magnetic and Vibro-Acoustic CAE Process

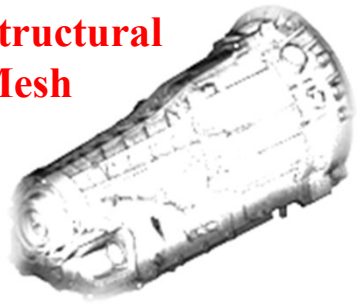
E-Motor Radiated Noise CAE

Electromagnetic force



BEM Mesh

Structural Mesh



Motor as Installed in Transmission

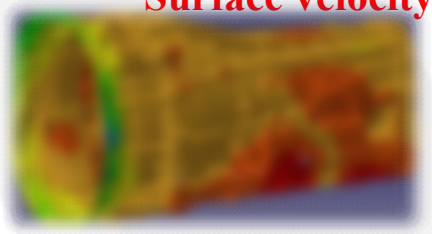
Transmission Surface Vibration

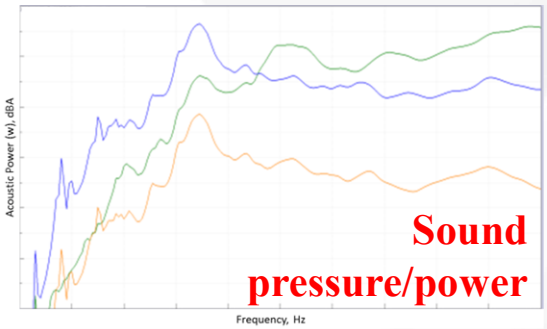
Vibro-Acoustic Analysis

Radiated Sound Pressure/Power

FE Model

Surface velocity



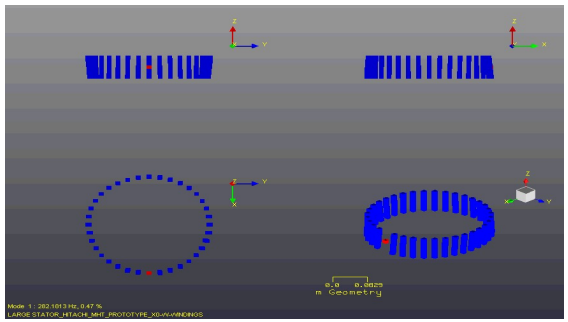


Sound pressure/power

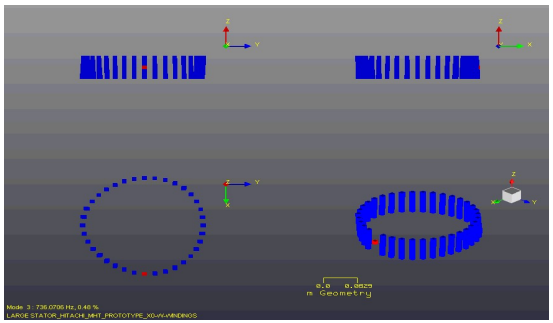
Motor Structural Modeling and Correlation

Mode		1	2	3	4	5
Test	Frequency (Hz)	282	353	736	897	1339
	Mode Shape	Elliptical (m=2)	Elliptical bending	Triangular (m=3)	Triangular bending	Quadrilateral (m=4)
FEA	Frequency (Hz)	289	355	768	957	1382
	Mode Shape	Elliptical (m=2)	Elliptical bending	Triangular (m=3)	Triangular bending	Quadrilateral (m=4)
Freq. Diff.		2.4%	0.6%	4.3%	6.6%	3.2%

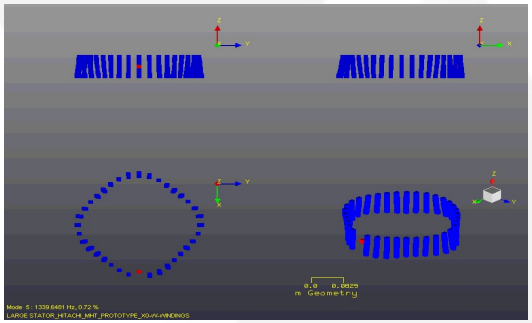
Sample Stator



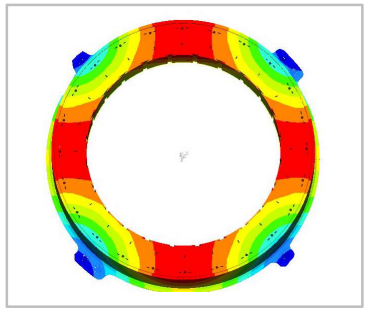
m=2 mode

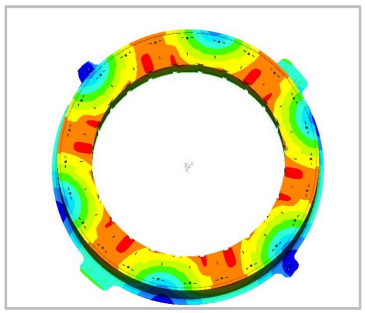


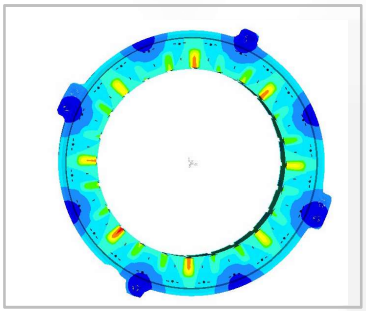
m=3 mode



m=4 mode

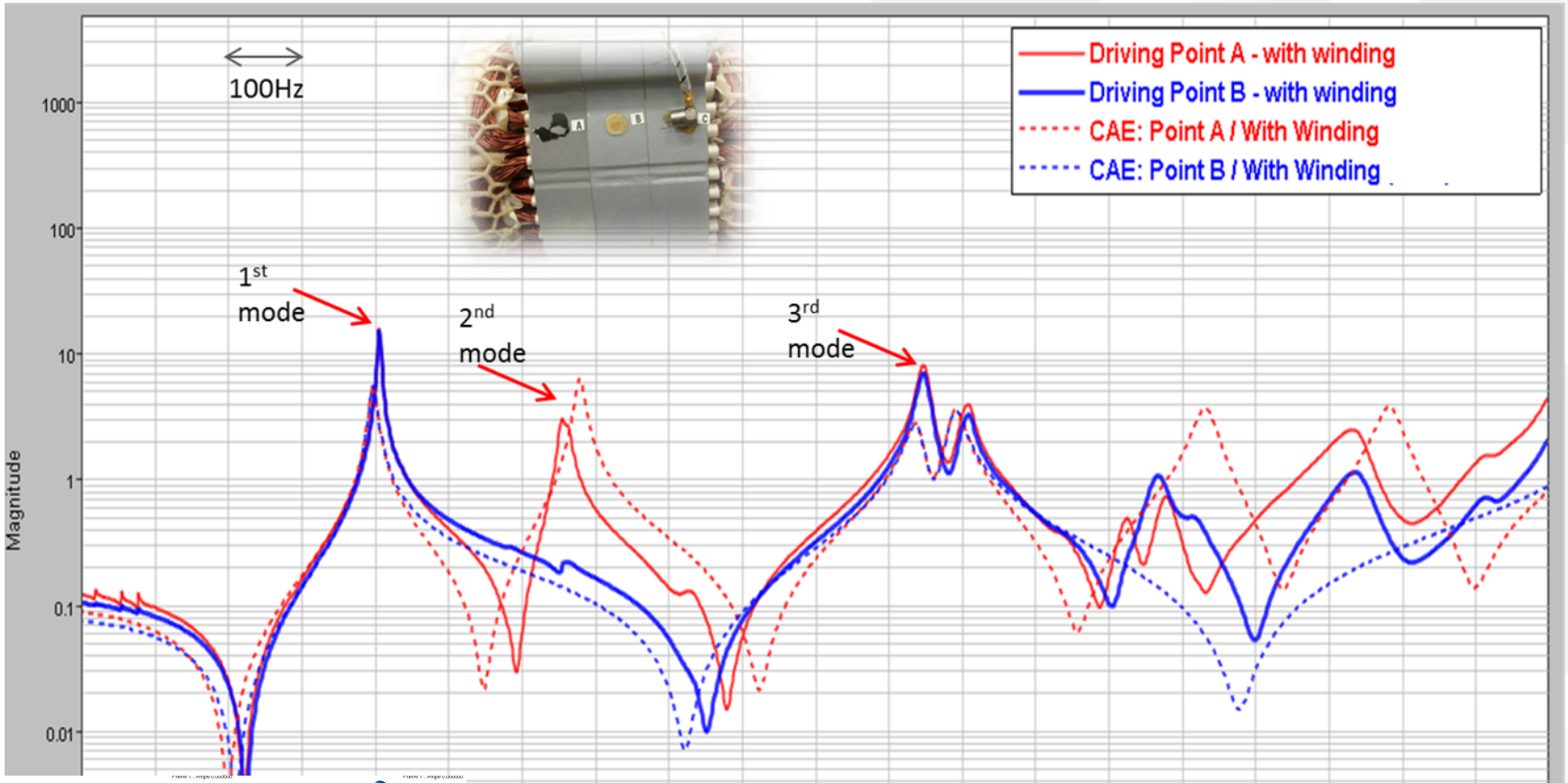


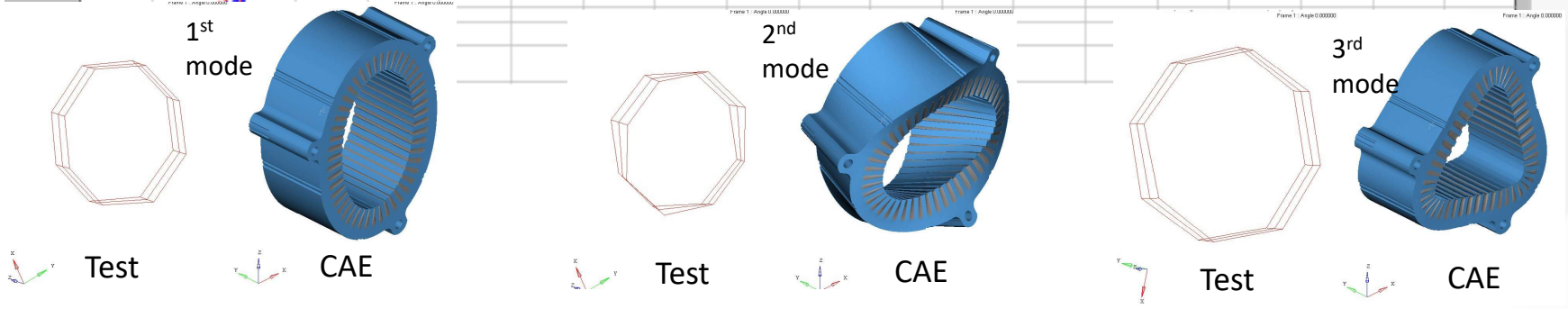




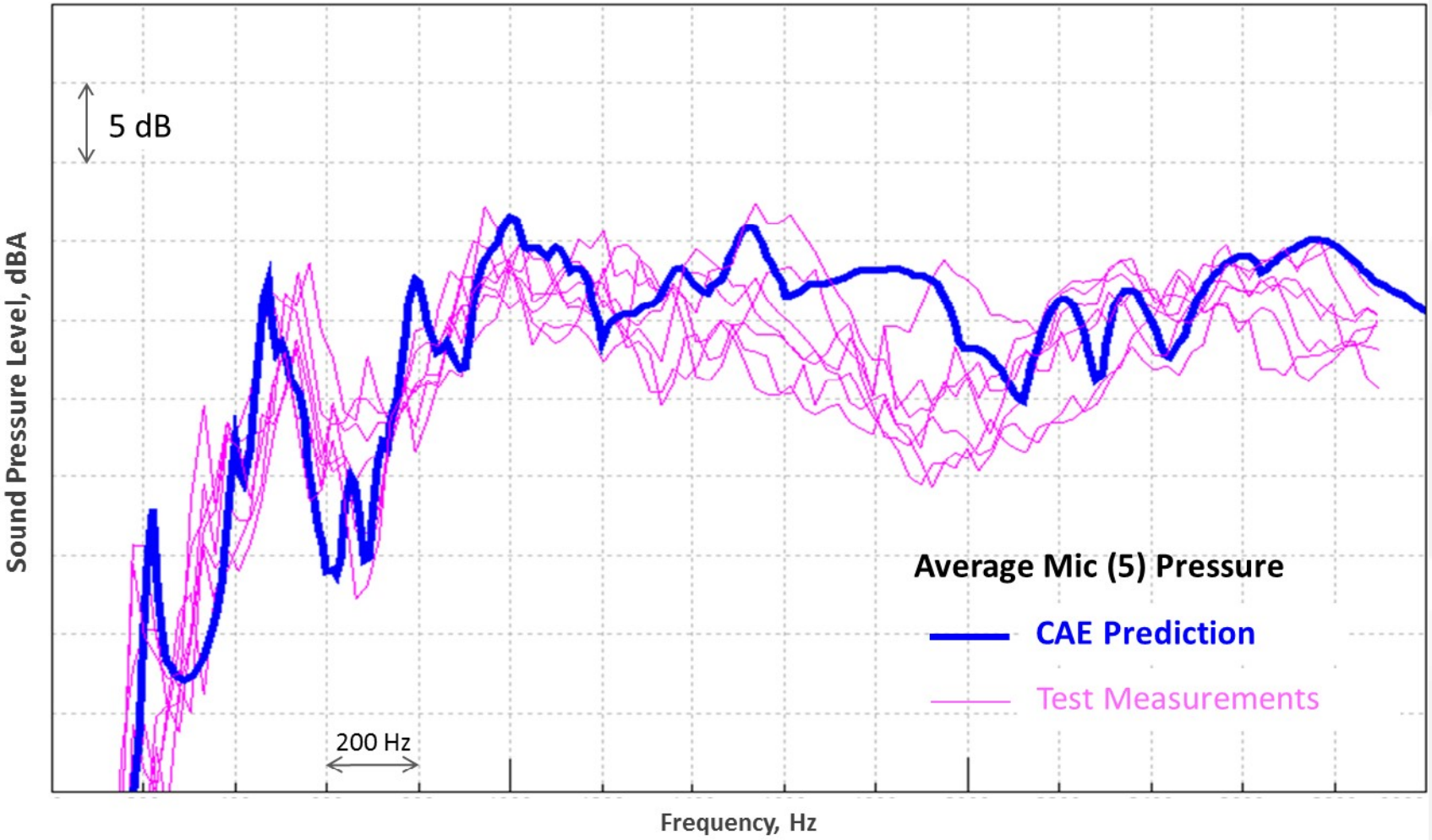
Laminated motor structure compounded by winding makes CAE modeling more challenging, but it is critical to get it right.

Motor Structural Modeling and Correlation



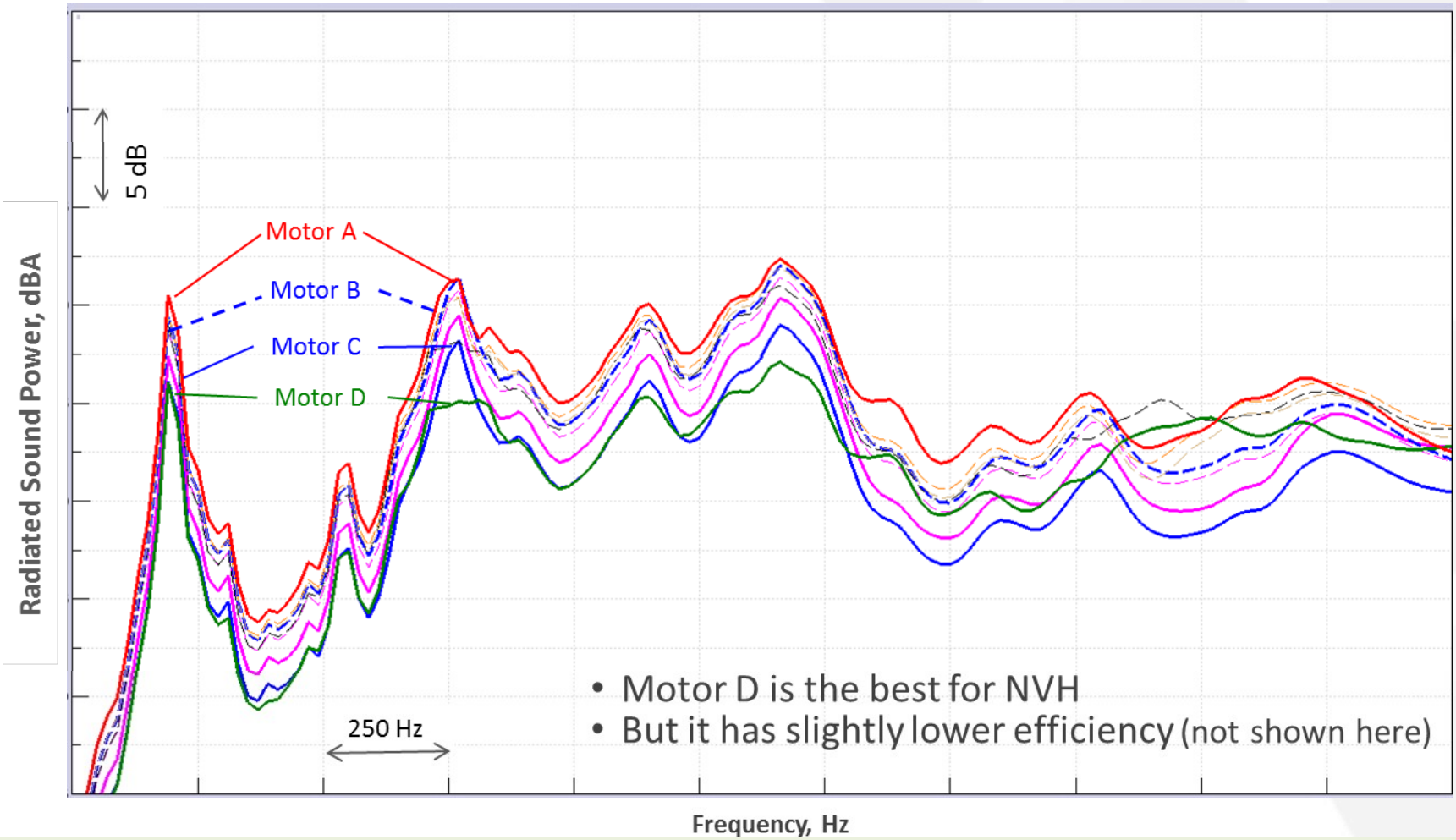


Transmission Radiated Motor Noise Prediction and Correlation



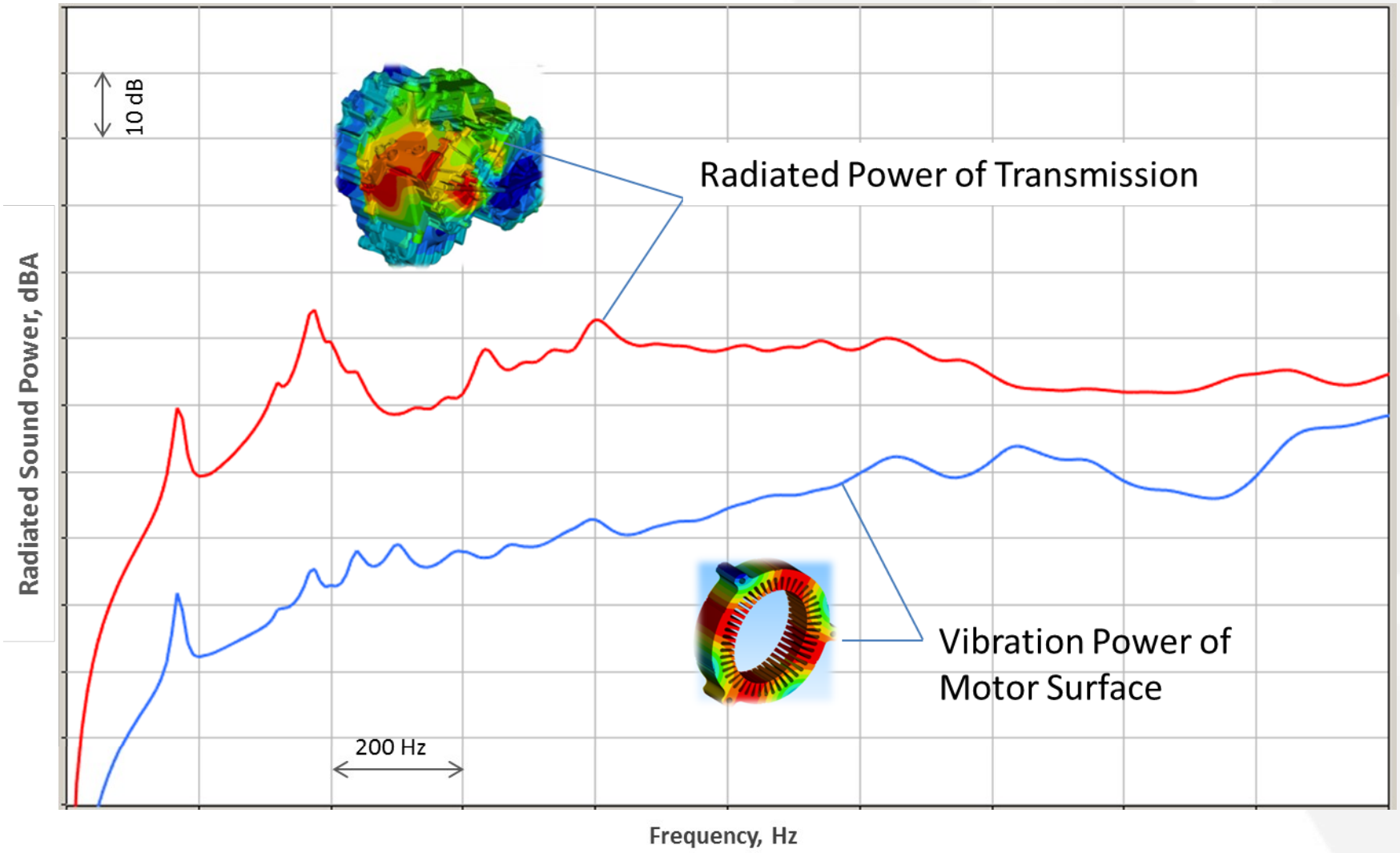
CAE prediction for motor radiated noise of a transmission showed reasonably good correlation with tests

CAE Motor Noise Assessment for Motor Design Selection



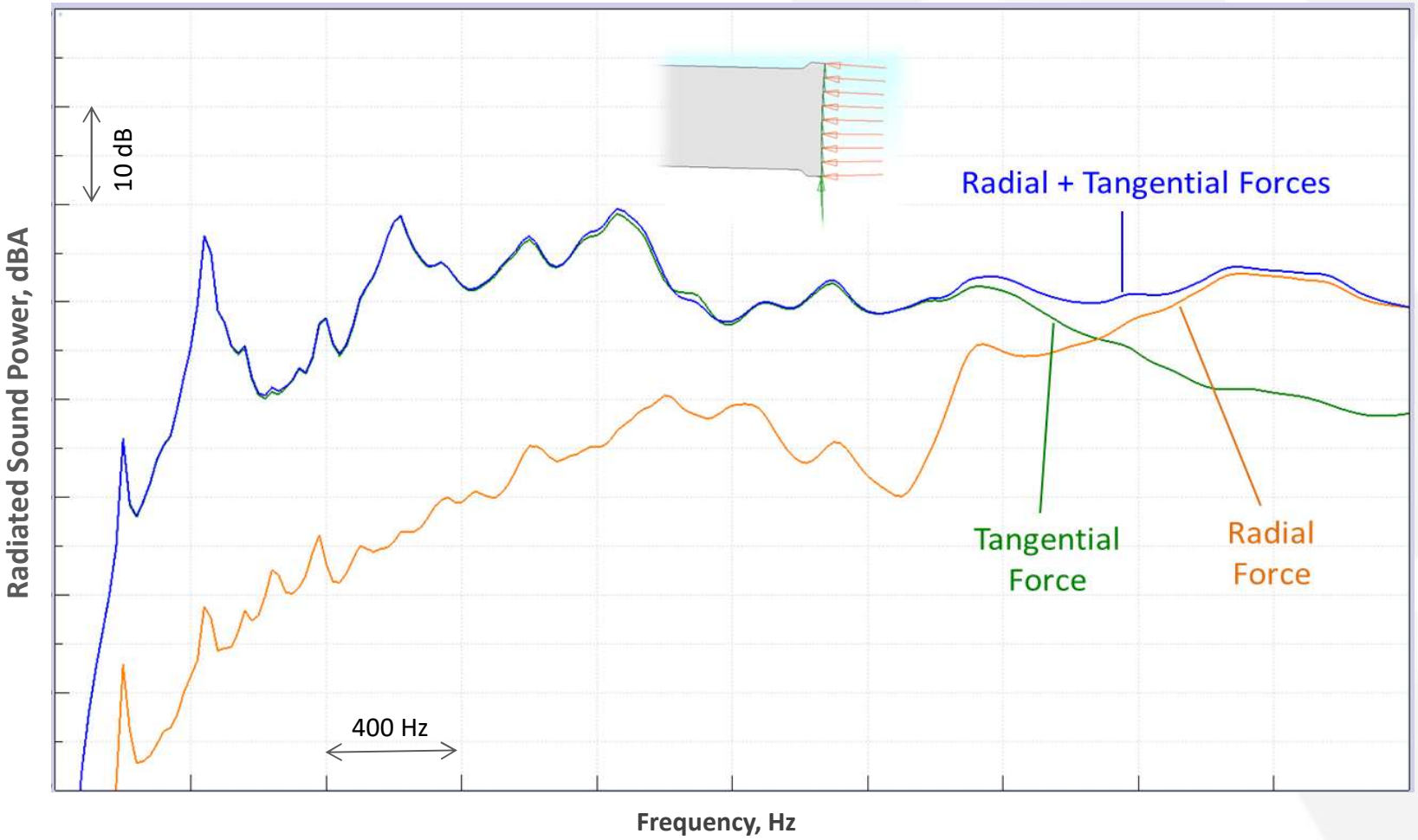
CAE analysis was utilized to guide motor design selection for NVH in addition to other motor performance measures, such as efficiency and thermal evaluations.

Role of Transmission Case to Motor Noise



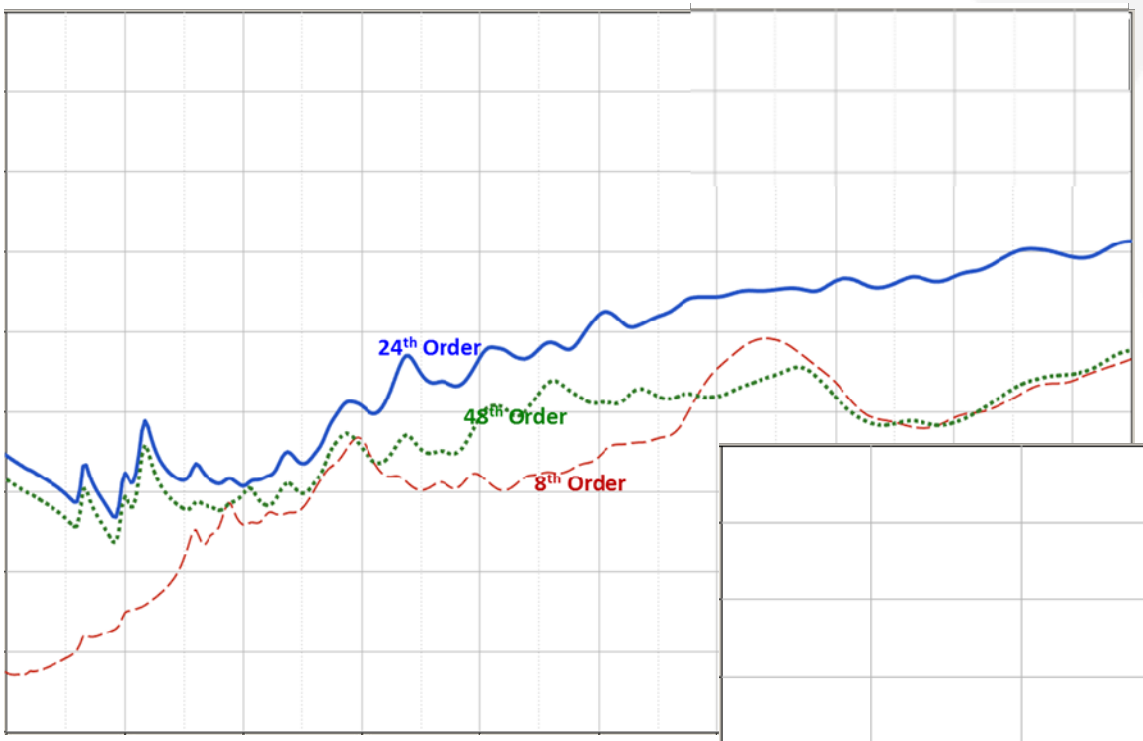
Transmission case has speaker effect in amplifying motor noise.

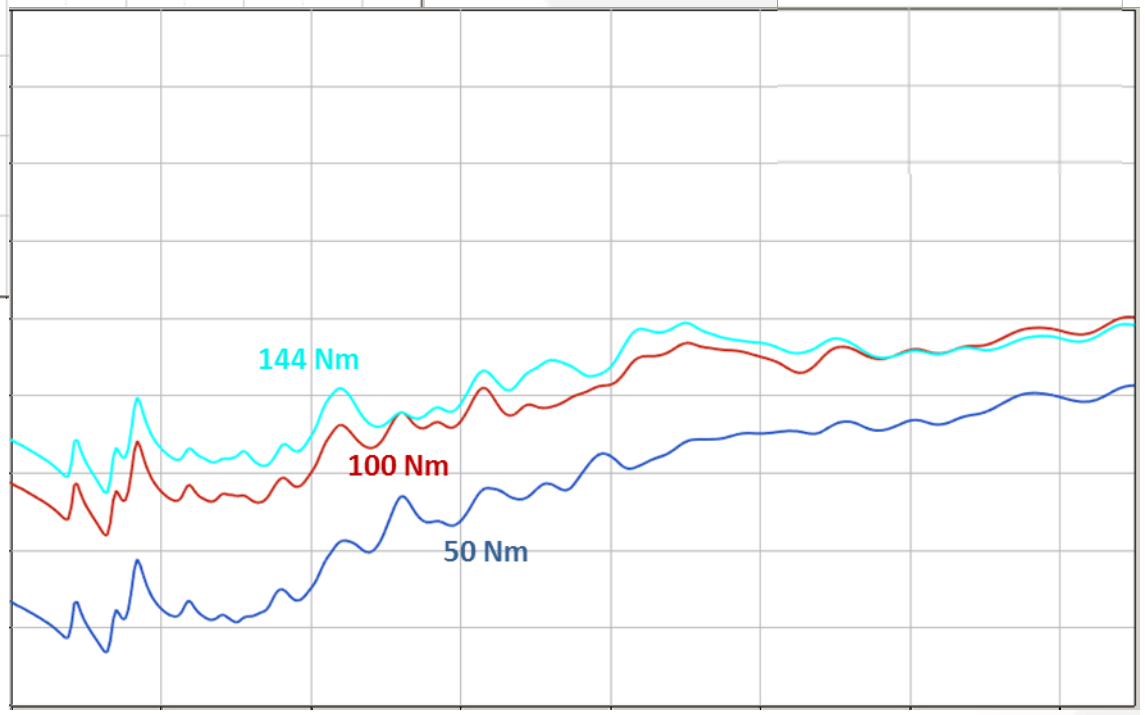
Tangential vs. Radial Motor Force Contribution to Motor Noise



A transmission design may have different level of sensitivity to radial and tangential motor force components.

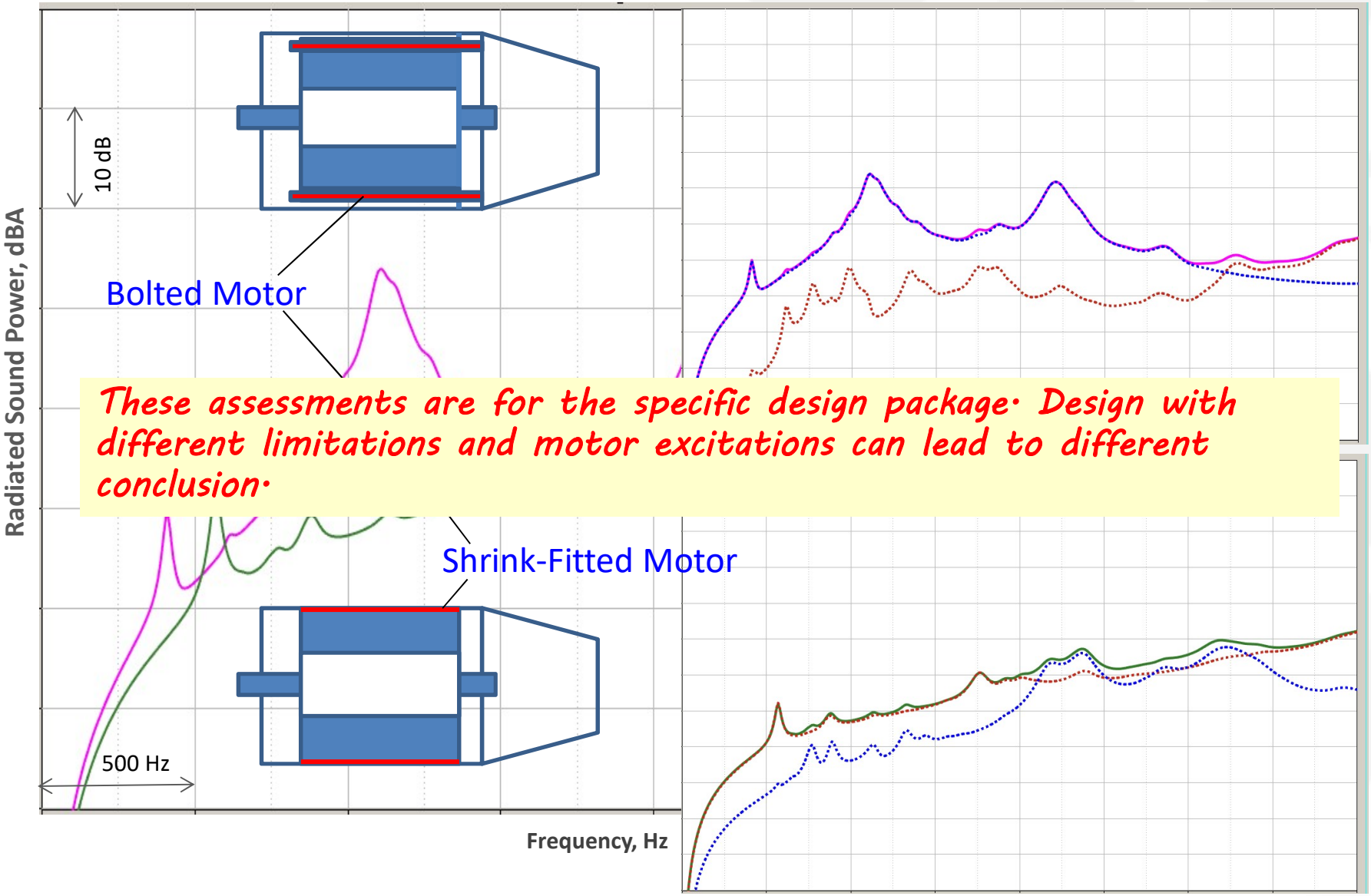
Motor Critical Motor Order and Torque Sensitivity





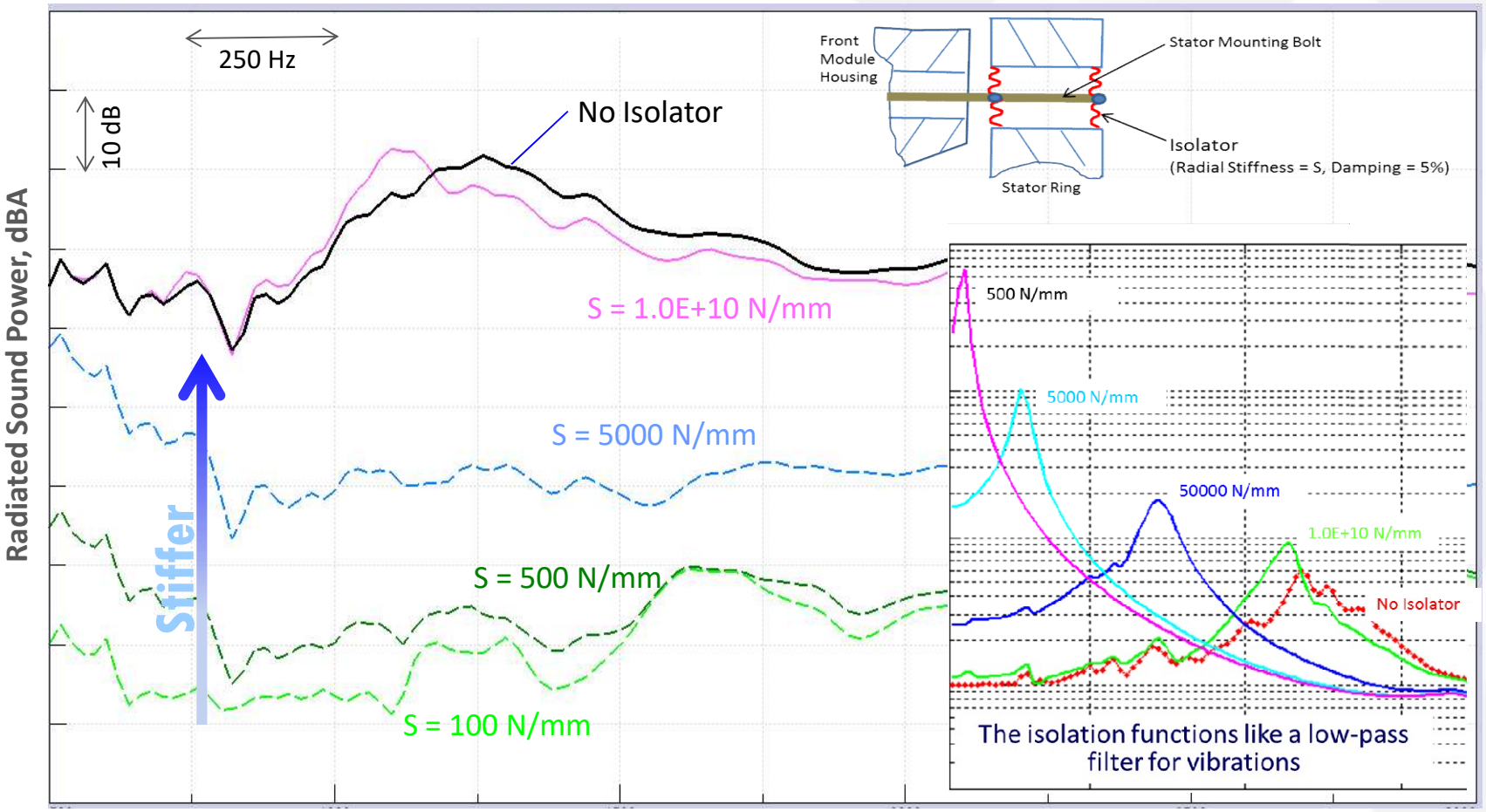
Analysis can help to identify and compare critical orders, and to determine sensitivity to different levels of torque

Effect of Motor Installation on Motor Noise



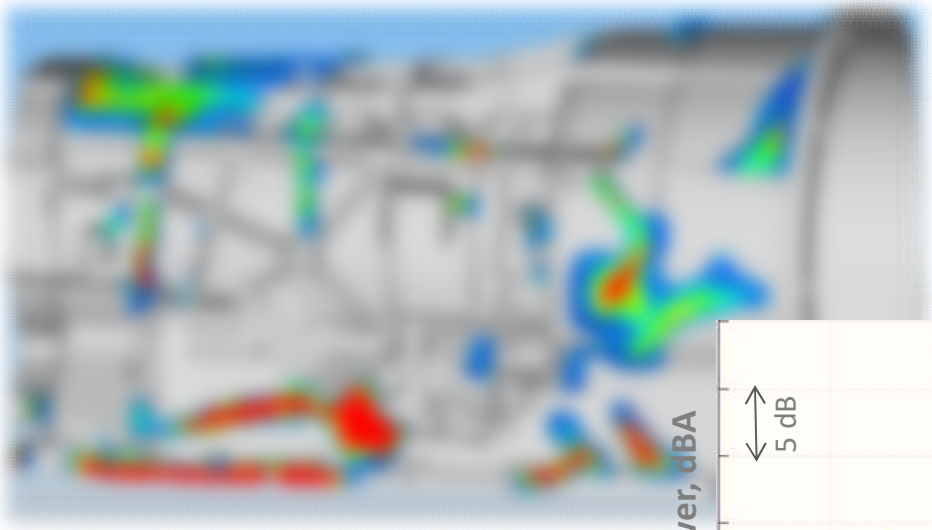
These assessments are for the specific design package. Design with different limitations and motor excitations can lead to different conclusion.

Effect of Motor Installation Isolation on Motor Noise



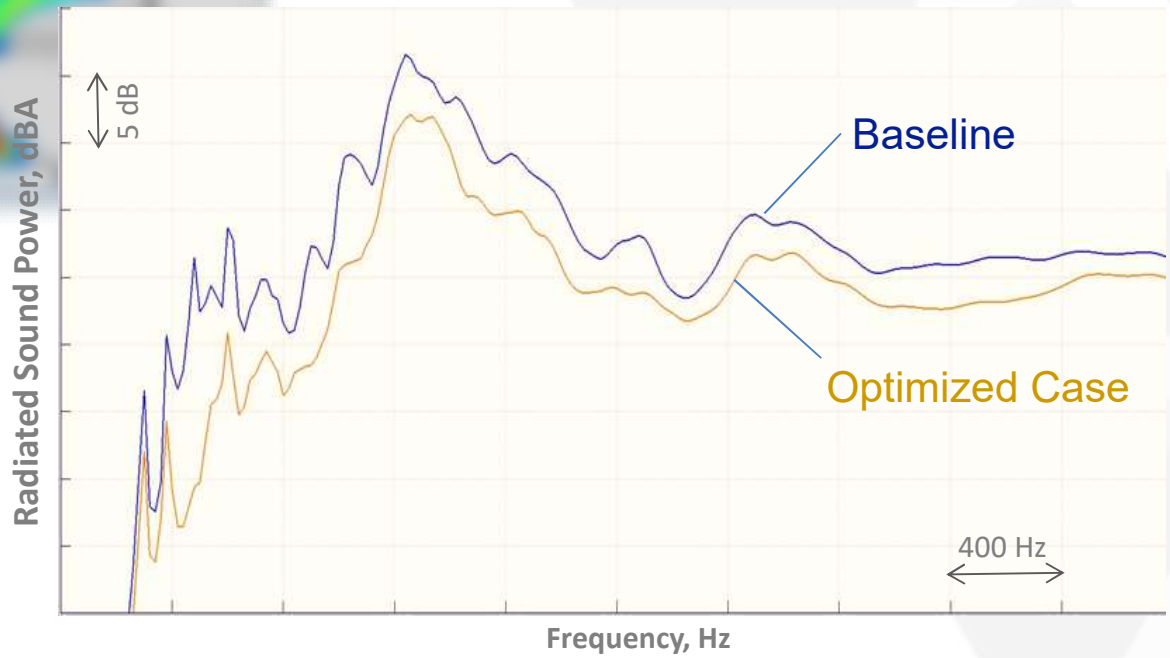
The analyses show bolt isolation would reduce the noise, though difficulty is to practically achieve the desired isolation without adverse effects.

Structural Optimization for Reducing Motor Noise Radiation



GRAY: Current S650 5L 10R80 Case

HOT Colors indicating CRITICAL area to add material for reducing noise radiation.



Structural optimization, such as topology optimization, was performed for the transmission case to reduce motor noise.

Conclusion and Acknowledgement

Conclusions

- A CAE process which incorporates electro-magnetic and vibro-acoustic analyses is established and applied to e-motor whine noise prediction and reduction in HEV/BEV powertrain NVH development.
- The correlations and samples of countermeasures demonstrated the capability of the process.
- The CAE analysis aided in comprehending the sensitivities and effects of certain design and excitation factors.
- The process can be used in optimization for reducing e-motor whine noise.

Acknowledgements

The authors would like to thank the transmission NVH development team and motor design team in Ford Motor Company, and all others who have contributed to and assisted in the work.

Thank You!

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