

Progress on Electric Motor Noise Modeling

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T-Motor U13



4kW peak power
4,000 RPM maximum

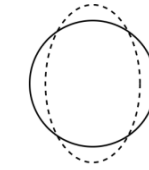


Accelerometers being installed on rotor
for static modal analysis

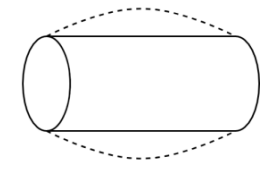
Mode Shape Qualitative Comparison



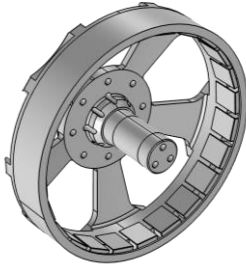
Azimuthal Mode 2



Azimuthal Mode
Number M

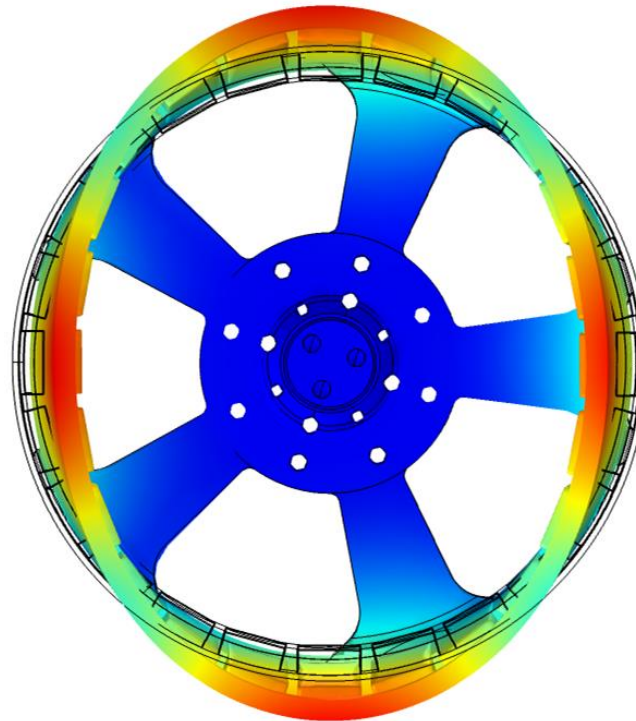


Axial Mode
Number N



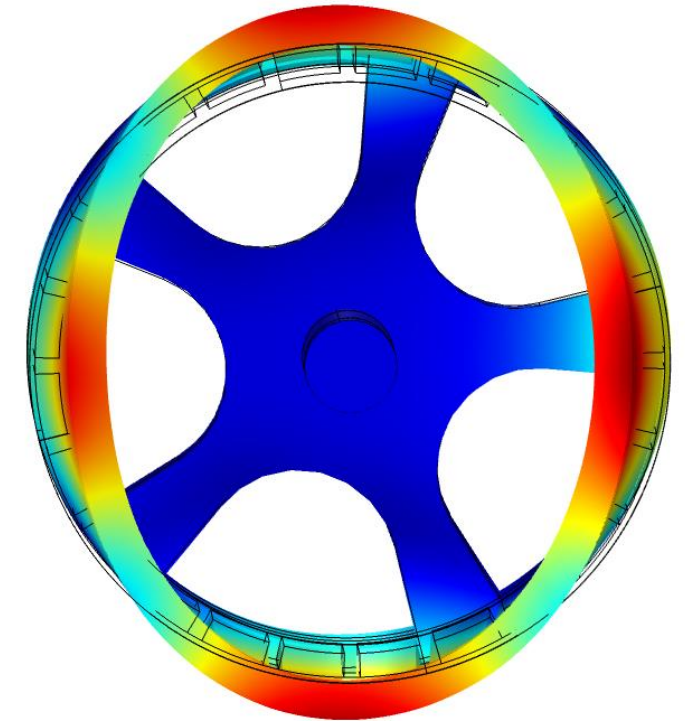
1400 Hz

Experimental Modal Analysis



1354 Hz

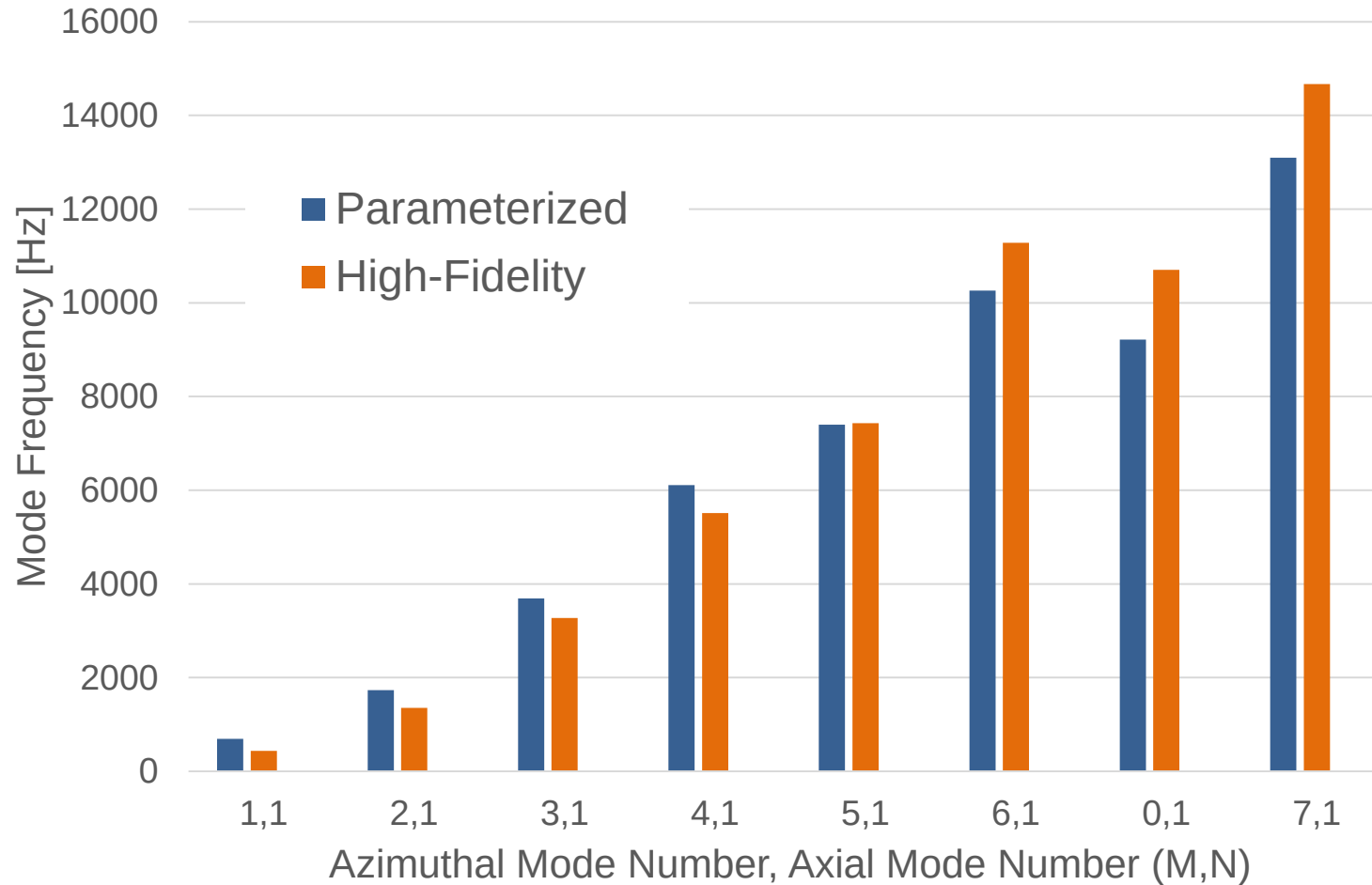
FEA- High-Fidelity Model



1730 Hz

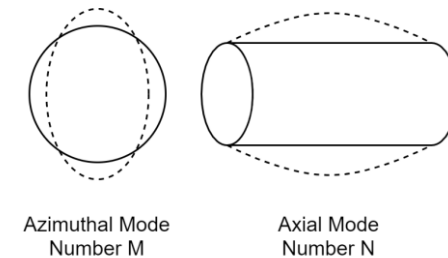
FEA- Parameterized Model

Mode Frequency Comparisons

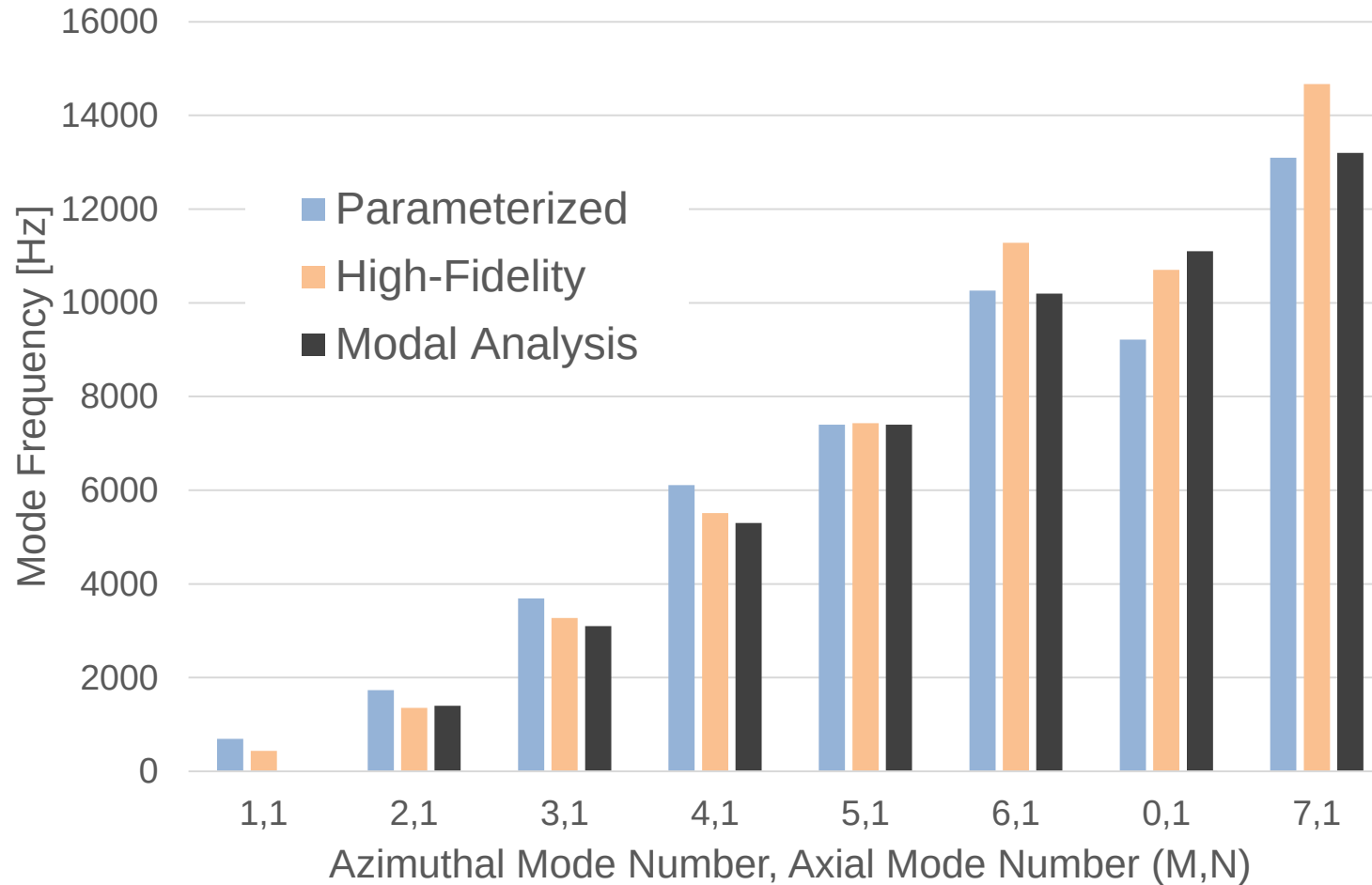


- COMSOL used for FEA
- More complex modes that are predicted by the models are not compared here

High-fidelity and parameterized models compare reasonably well

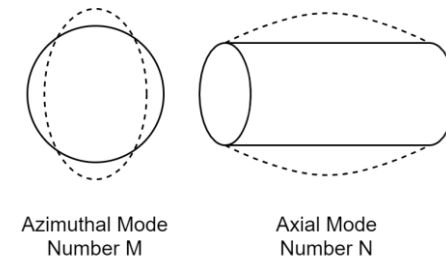


Mode Frequency Comparisons

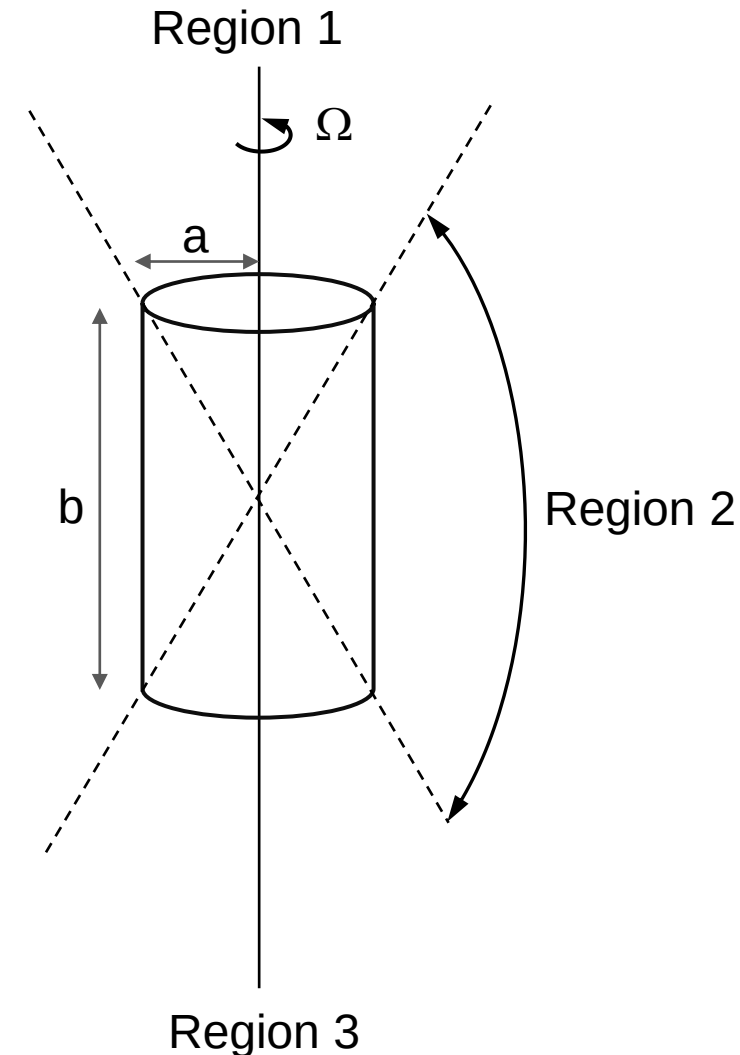


- Further studies are planned for the modes that involve the top surface spokes
- Modal analysis did not detect a 1,1 mode

Experimental measured mode frequencies agree with FEA predictions



- Divide radiation into three regions
 - Simplify problem by ignoring longitudinal modes (for now)
 - Simplify problem by assuming boundary conditions in Regions 1 and 3 are the same
 - Start with rigid boundary conditions in regions 1 and 3 (will change in the future for axial flux motors)
- Use solution approach of Williams, Parke, Moran and Sherman
 - Solution was for non-rotating cylinder
 - Series coefficients obtained by minimizing square error on cylinder boundaries
- Use problem formulation of Farhadi
 - Problem formulation for rotating cylinders
 - Galerkin approach for solutions (resulted in volume integrals)



Williams, Parke, Moran, Sherman, 1964, JASA 36, pp. 2316 – 2322.
Farhadi, 2018, JSV 428, pp. 59 – 71.

- On the cylindrical surface, the normal displacement is (cylindrical coordinates)
 - $w(\varphi, z, t) = \{[(-A \cos(n\varphi) + B \sin(n\varphi)) \sin(n\Omega t)] + [(A \sin(n\varphi) + B \cos(n\varphi)) * \cos(n\Omega t)]\} \Psi(z) e^{i\omega t}$
- The acoustic field is a **solution of the wave equation in spherical coordinates** (ϕ = **velocity potential**)
 - $\phi = [\tilde{\phi}_1 \sin(n\Omega t) + \tilde{\phi}_2 \cos(n\Omega t)] e^{i\omega t}$
 - $\tilde{\phi}_1 = \sum_{i=1}^p \sum_{j=1}^q a_{ij} h_i(kr) P_i^j(\cos \theta) \sin(j\varphi) + \sum_{i=1}^p \sum_{j=1}^q b_{ij} h_i(kr) P_i^j(\cos \theta) \cos(j\varphi)$
 - $\tilde{\phi}_2 = \sum_{i=1}^p \sum_{j=1}^q c_{ij} h_i(kr) P_i^j(\cos \theta) \sin(j\varphi) + \sum_{i=1}^p \sum_{j=1}^q d_{ij} h_i(kr) P_i^j(\cos \theta) \cos(j\varphi)$
 - Problem is simplified by orthogonality of trigonometric functions ($j = n$)
- **Minimize square error on cylinder boundaries**
 - Results in surface integrals in Regions 1, 2, 3
 - Equate $\sin(n\varphi)$ and $\cos(n\varphi)$ terms
 - Integration in one variable can be performed analytically
 - Final solution will require numerical integration over one variable
 - Geometrical symmetry reduces range of integration
- Number of terms included in series can be determined by residual at observation location(s)

Upcoming Work



- Experimental modal and FEA analyses are planned for additional 2-4kW motors
- Modal analysis of an EMRAX[®] motor of the type used in the Moog SureFly[®] vehicle will be performed
- Acoustic model equations will be implemented in software