COMSOL CONFERENCE
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Prediction of Noise Generated by Electromagnetic Forces in Induction Motors

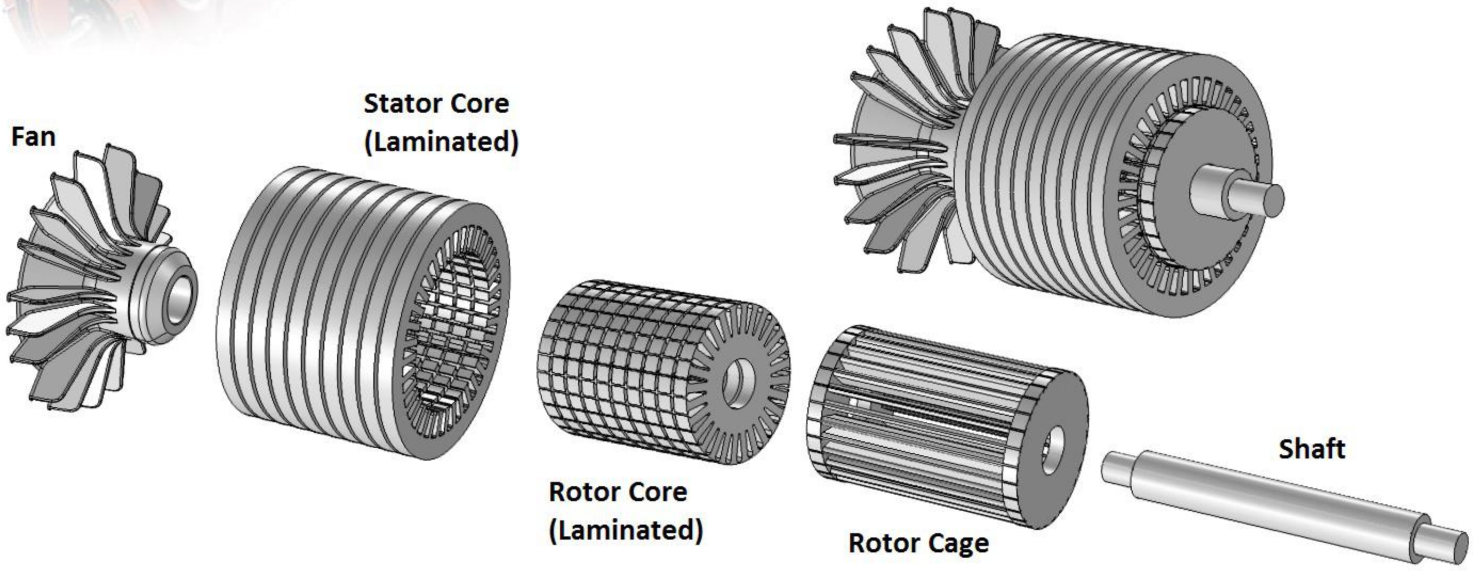
Presentation Outline

- Introduction and Background
- Motor Components
- Model development for magnetic noise
  - Electromagnetic Model
  - Mechanical and Acoustic Models
  - Prediction Results
- Conclusion

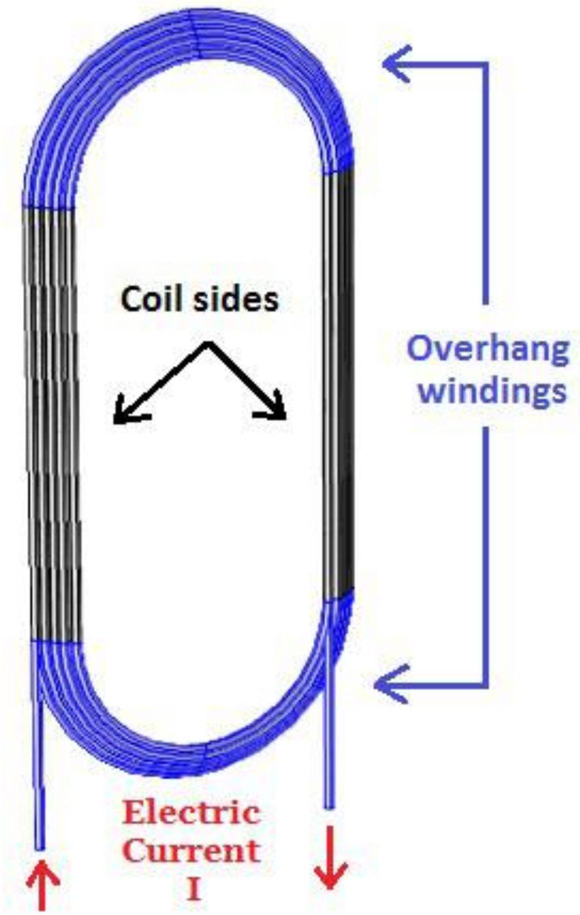
Product and System Examples

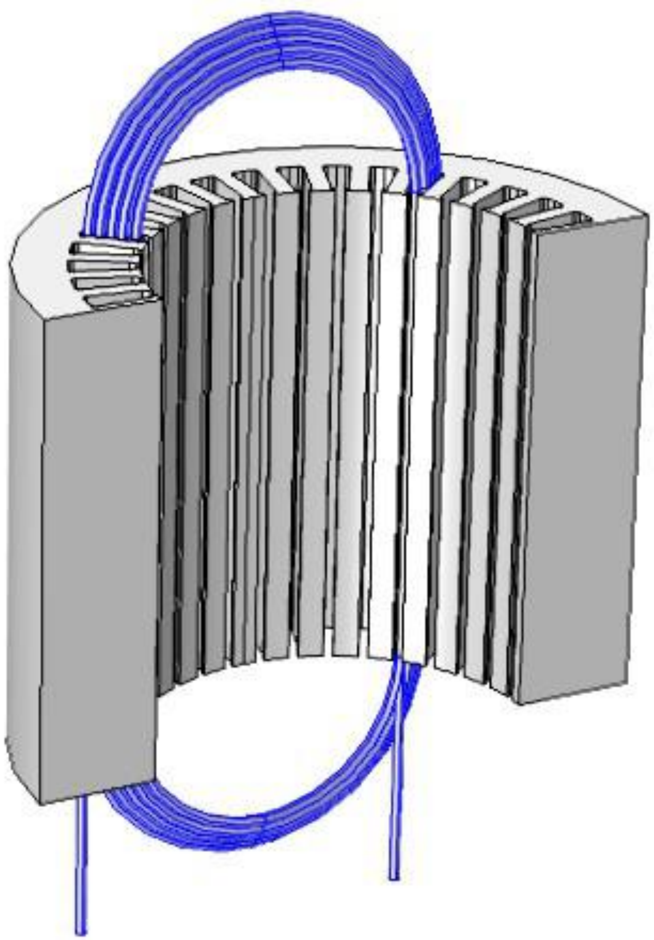
Main Components in Induction Motors

Squirrel cage motor with straight bars



Motor Windings or Coils



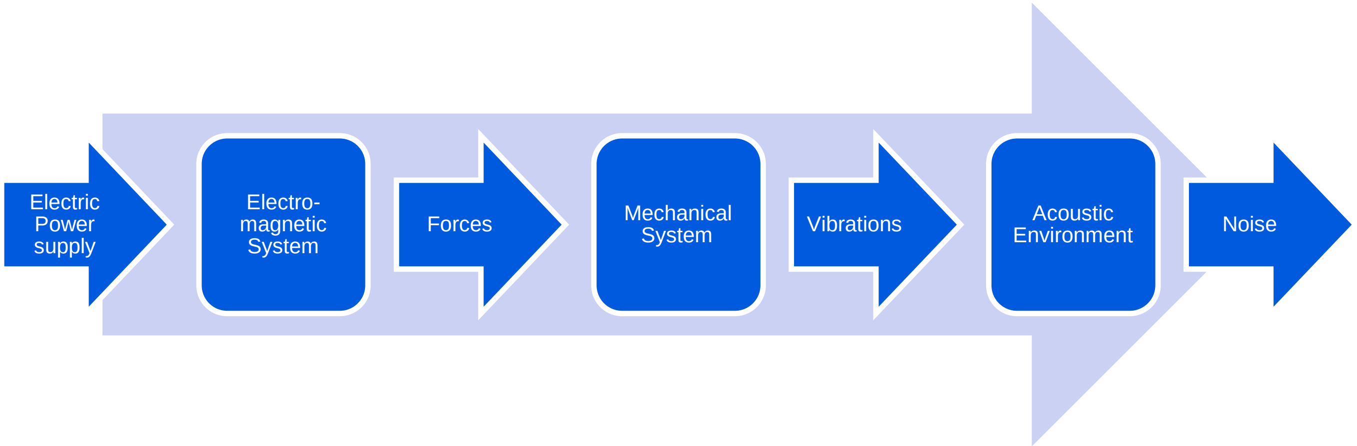


Motor Acoustics

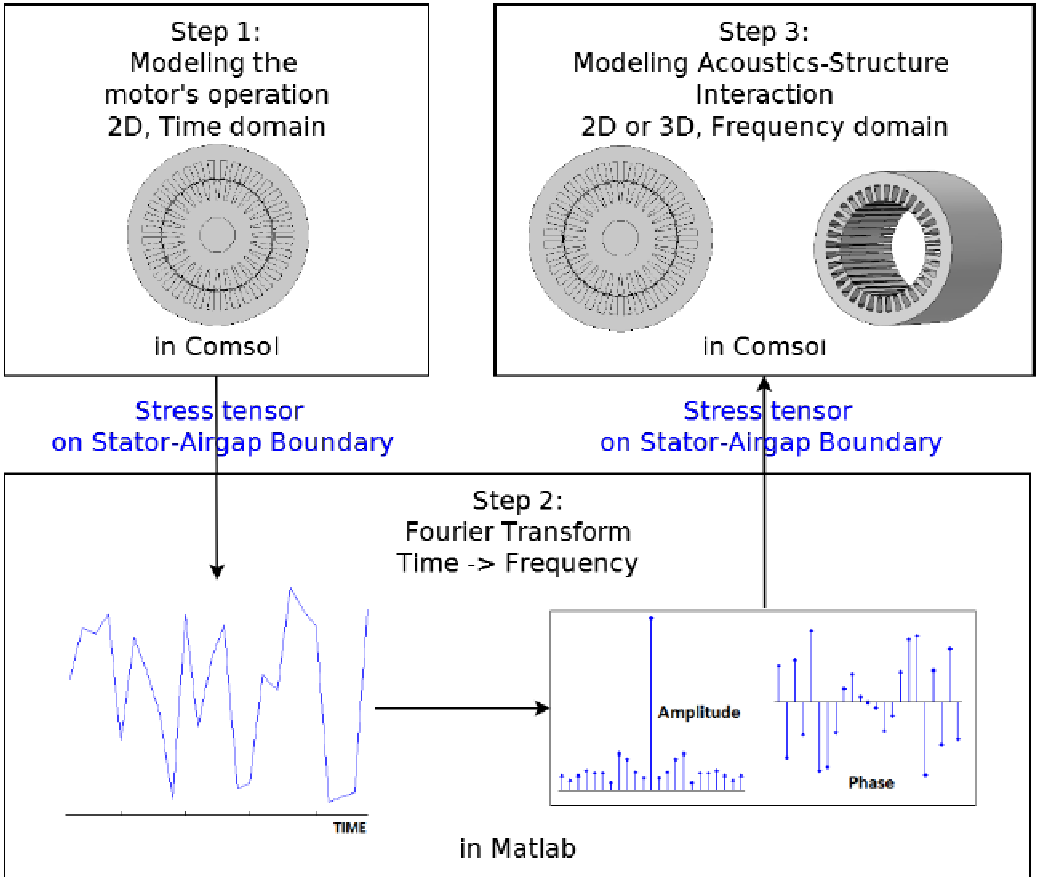
Noise Sources

1) Magnetic Noise
2) Fan Noise
3) Mechanical Noise

Energy Conversion Chain from electric supply to noise

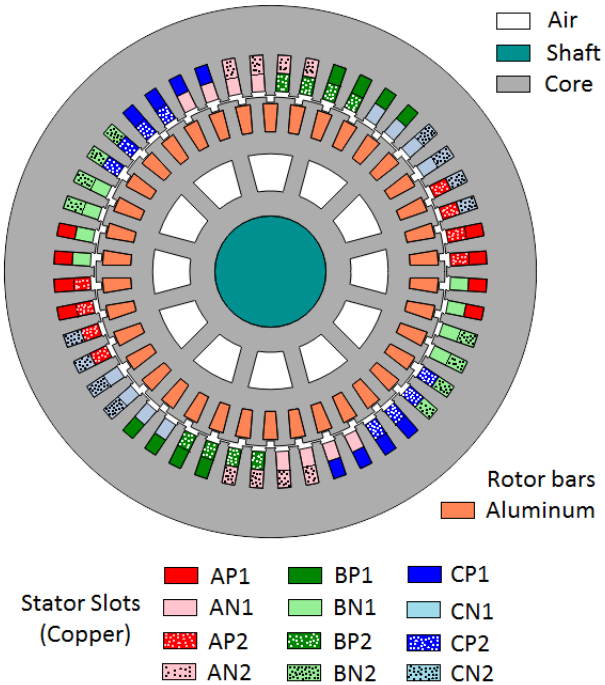


Model Building Procedure

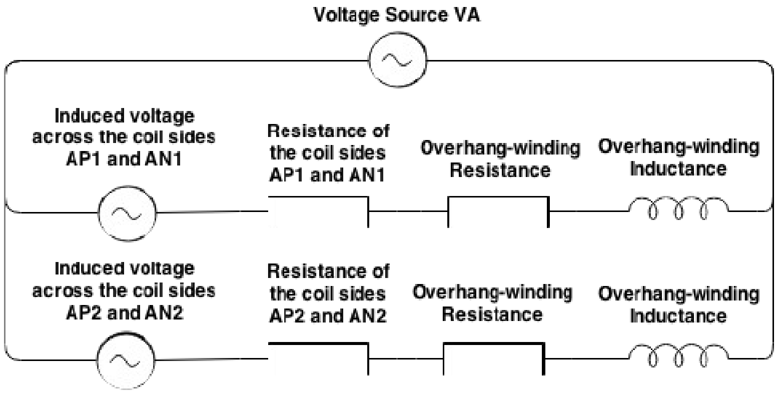


Stator Winding and Equivalent Circuit

The equivalent circuit: <u>Lumped Model</u>



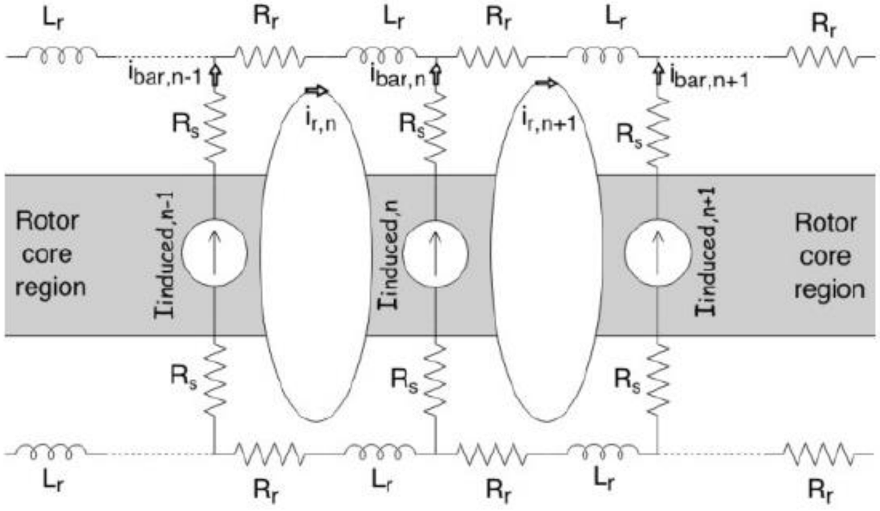
The stator circuit for one phase

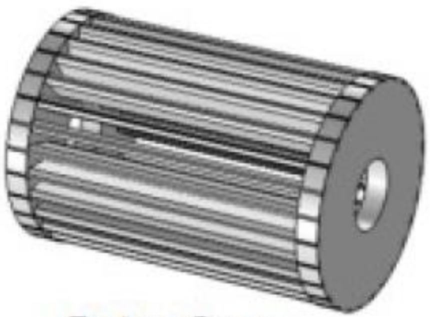


- 48 slots
- 38 bars
- 2 branches for each phase circuit

Equivalent Circuit for Rotor

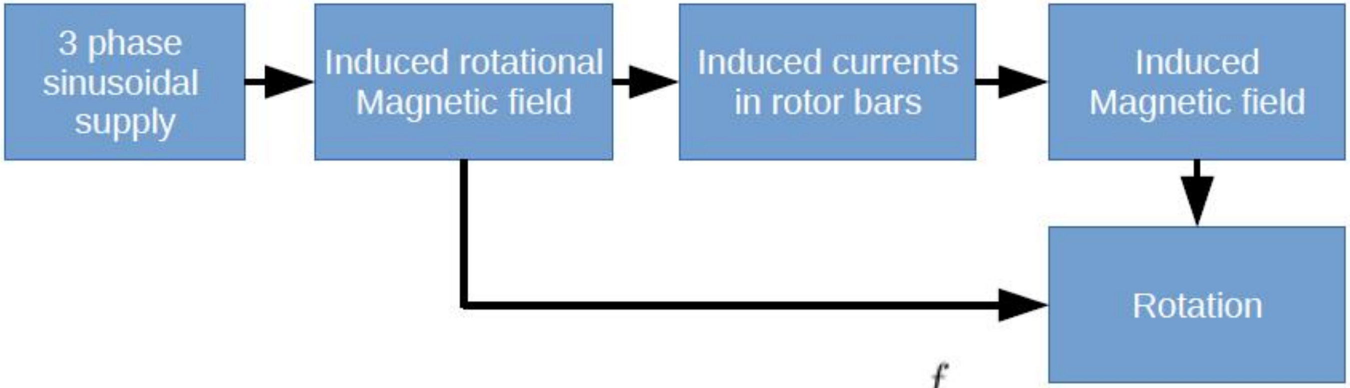
The equivalent circuit: <u>Lumped Model</u>





Rotor Cage

Induction Motor in Operation



- Synchronous speed $n_{ss} = 120 \times \frac{f}{n_P}$
- Slip $s = \frac{n_{ss} - n_{rs}}{n_{ss}} \times 100$

$$Motor1 \quad f = 50Hz, n_p = 4 \rightarrow 1500rpm$$

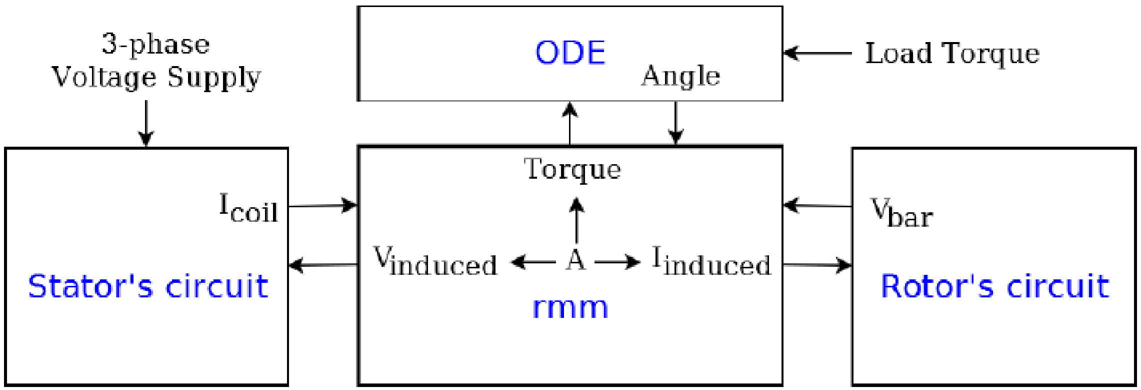
$f : supply\ frequency\ (Hz)$

$n_P : number\ of\ poles$

$n_{ss} : synchronous\ speed\ (rpm)$

$n_{rs} : rotational\ speed\ of\ the\ rotor\ (rpm)$

Step 1: Electromagnetic Model



Solve for:

A, Icoil,
Vbar, Angle

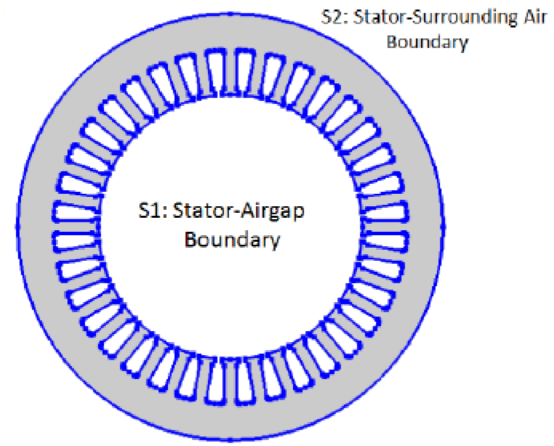
- Lamination is perfect → no eddy current loss
- Coils are made of thin wires and perfectly insulated from one another

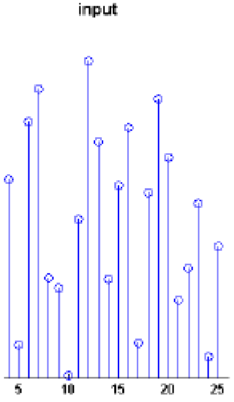
$$\nabla \times (\nu \nabla \times \mathbf{A}) = \begin{cases} N_w I_w \mathbf{e_z} / S_w & \text{in stator slots} \\ -\sigma \frac{\partial \mathbf{A}}{\partial t} + \sigma V_b \mathbf{e_z} / l_b & \text{in rotor bars} \\ -\sigma \frac{\partial \mathbf{A}}{\partial t} & \text{in shaft} \\ 0 & \text{elsewhere (cores, airgap)} \end{cases} \tag{3.17}$$

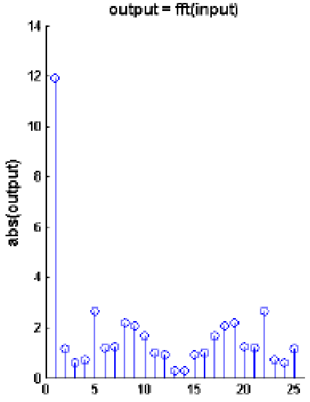
$$J \frac{d^2 \boldsymbol{\alpha}}{dt^2} = \mathbf{T_{rotor}} - \mathbf{T_{load}} \tag{3.29}$$

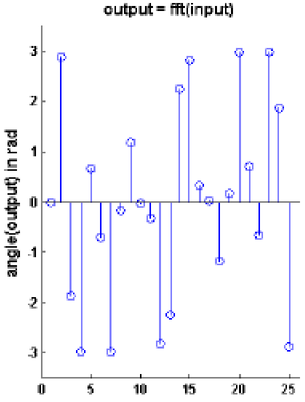
Step 2: Transformation from Time to Freq. Domain

- Extract Maxwell stress tensor along the Stator-Airgap Boundary during the steady state
- Transform from time to frequency domain using Fast Fourier transform in Matlab
- Save the results in text files for next step

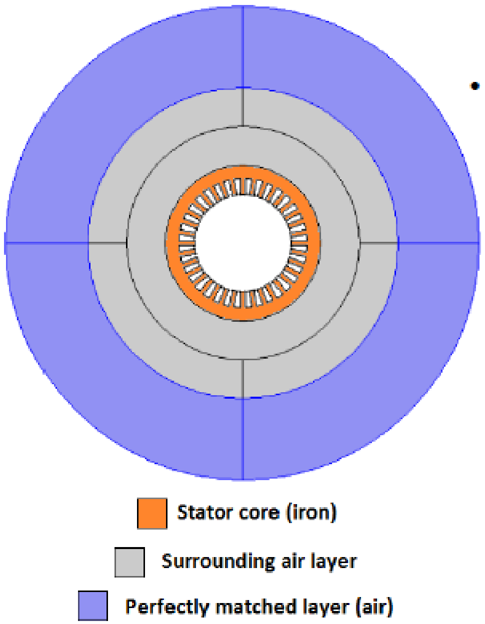








Step 3: Acoustics and Mechanical Models



- Stator + Surrounding air + PML (air)
- The air density is unchanged in time & space

$$\rho_S \ddot{\mathbf{u}} = \nabla \cdot \sigma + \mathbf{F}_V \quad \text{in stator}$$

$$\ddot{p} - c^2 \nabla \cdot (\nabla p) = 0 \quad \text{in air}$$

$$\frac{1}{\rho_A} \mathbf{n} \cdot (\nabla p) = -\mathbf{n} \cdot \ddot{\mathbf{u}} \quad \text{in Stator-Air boundary}$$

$$\sigma \cdot \mathbf{n} = p\, \mathbf{n} \quad \text{in Stator-Air boundary}$$

$$-\rho_S \omega^2 \mathbf{u} = \nabla \cdot \sigma + \mathbf{F}_V \quad \text{in stator}$$

$$-\omega^2 p - c^2 \nabla \cdot (\nabla p) = 0 \quad \text{in air}$$

$$\frac{1}{\rho_A} \mathbf{n} \cdot (\nabla p) = -\omega^2 \mathbf{n} \cdot \mathbf{u} \quad \text{in Stator-Air boundary}$$

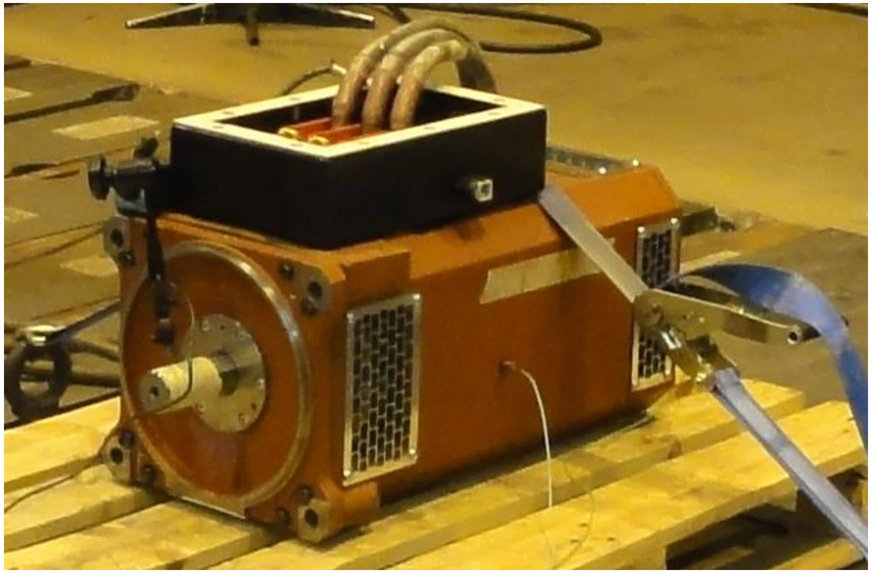
$$\sigma \cdot \mathbf{n} = p\, \mathbf{n} \quad \text{in Stator-Air boundary}$$

$\omega (= 2\pi f)$ is the angular frequency (in rad/s)

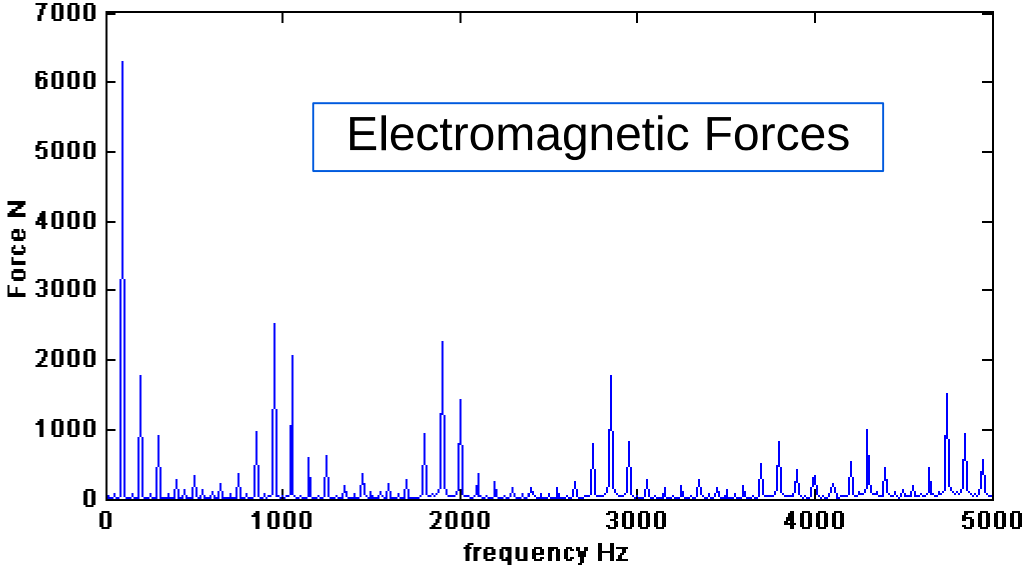
- Young modulus: stress-strain
- Poisson ratio: strain-strain

Motor Parameters

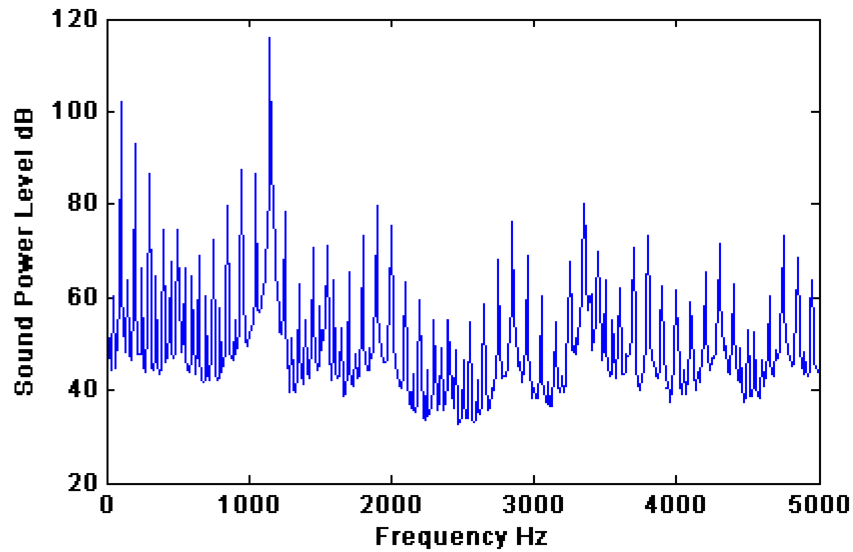
Power supply	3 phase, 388V (nominal)
Number of poles	4 poles
Stator	48 slots
Rotor	Squirrel cage, 38 straight bars
Load	No load



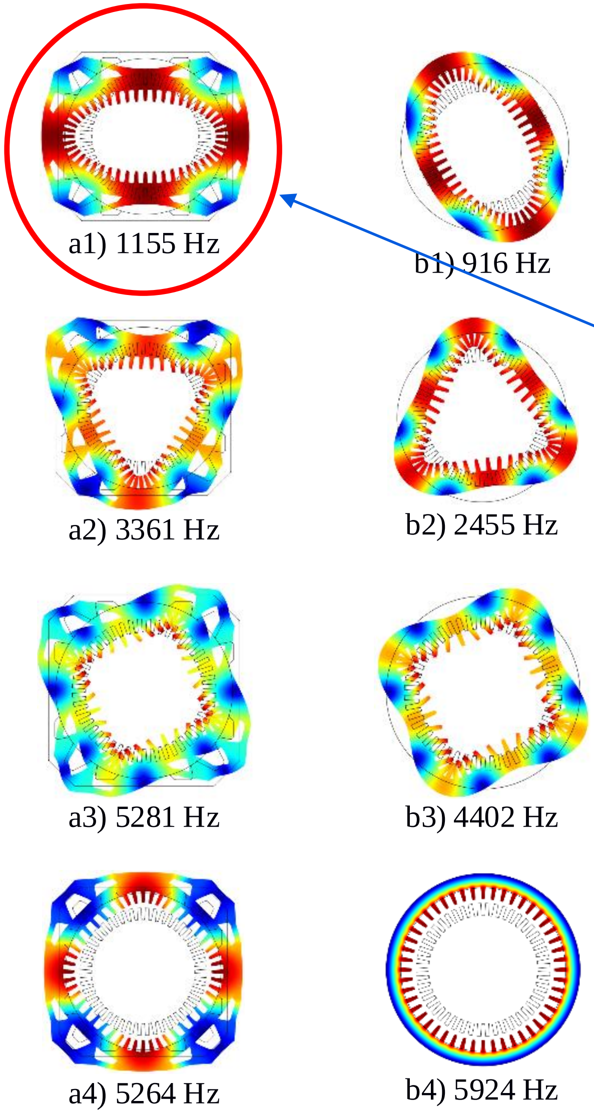
Prediction Results



Sound Power Level



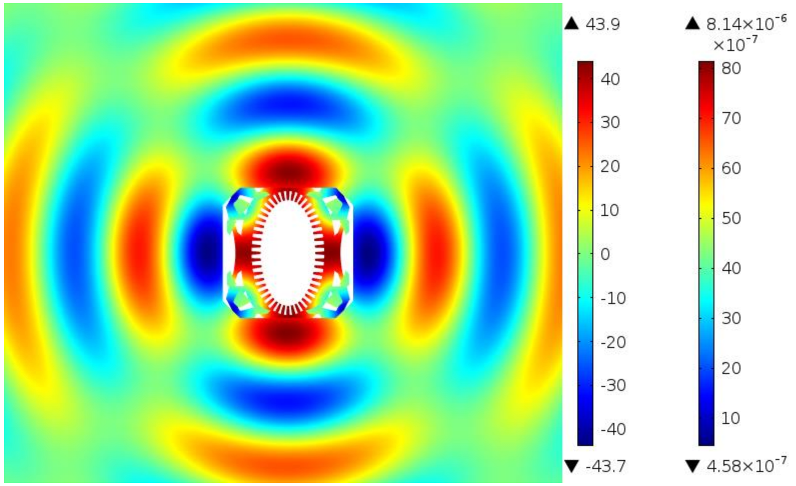
Structural Resonances



Mode Shapes of stator with housing

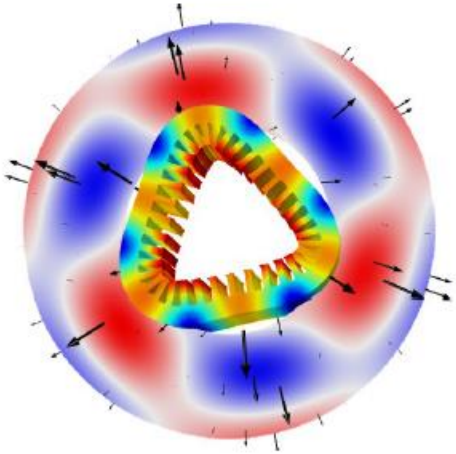
Particular resonance interacting with the electromagnetic excitation

Sound Radiation Pattern at 1155 Hz



Conclusion

- A multiphysic model to predict magnetic noise was built in COMSOL
- The electromagnetic model of the motor in 2D is solved in time domain
- The resulting electromagnetic forces are used in the frequency domain to perform the mechanical and acoustic analysis in 2D
- Future work on a 3D structural model and implementation of BEM for sound propagation



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