Analysis of Static Eccentricity Faults in Double Stator Single Rotor Axial Flux Surface-mounted Permanent Magnet Motors

Shuvajit Das & Md Tawhid Bin Tarek

ECE Department
The University of Akron
Akron, USA

The University of Akron
College of Engineering

Presentation outline

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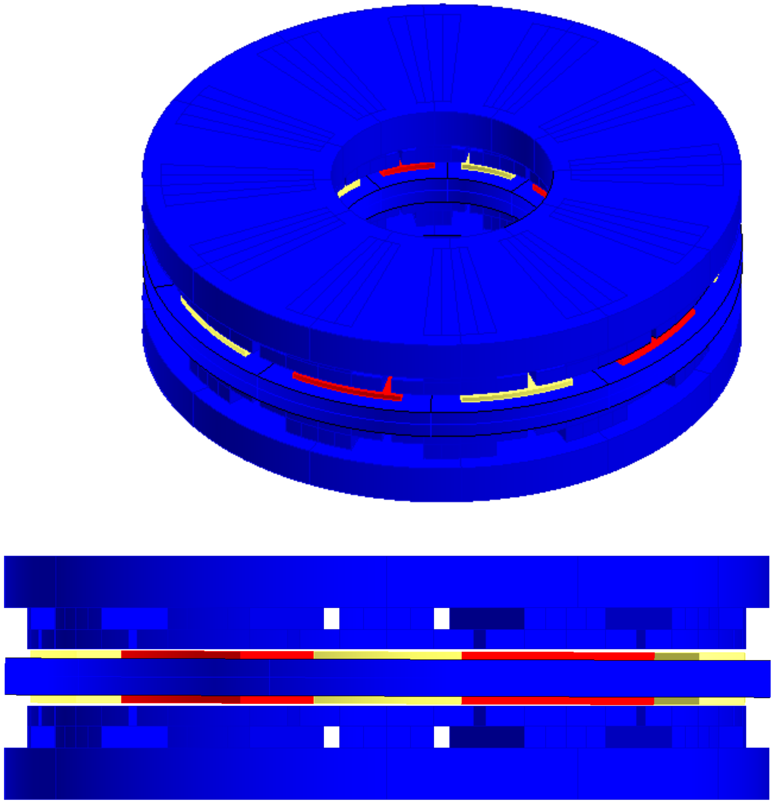
- Static Eccentricity in AFM.
- Studied Machine.
- Simulation Setup.
- Eccentricity Simulation Issues.
- Mesh Structure for Simulation.
- Simulation Results.
- Conclusion & Future Works.



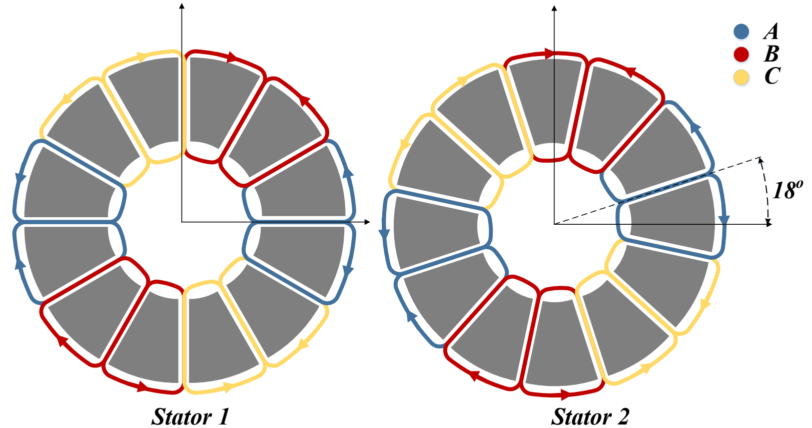
Axial Flux Machine (AFM)

Motivation

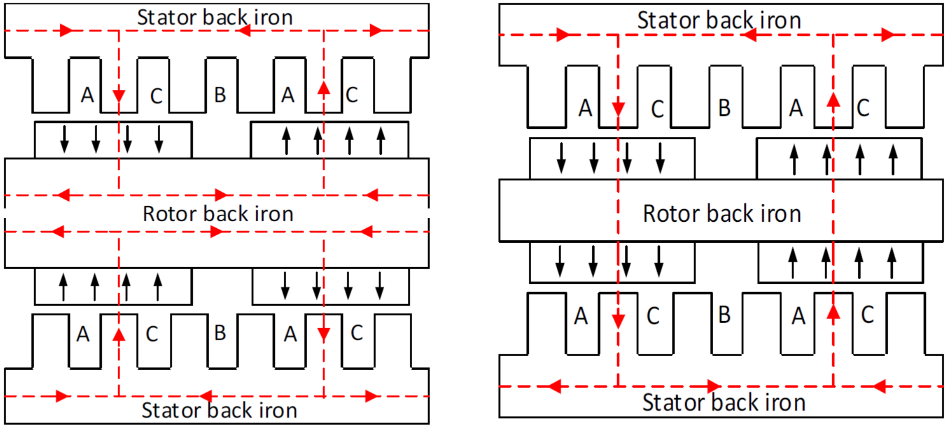
- Axial Flux Machines (AFM) are ideal for compact applications with large diameters.
- High performance in pancake-shaped applications.
- High power and torque density.
- However, low contact area between the rotor and shaft makes AFM more susceptible to mechanical defects like eccentricity.
- Eccentricity can generate vibration and unbalanced magnetic force (UMF) which affect the performance and lifetime of the motor.
- So, analysis of eccentricity is important for AFM.

Axial Flux Machine

- Better utilization of rotor volume.
- Double layer concentrated winding structure.
- Lower weight and winding resistance compared to distributed winding structure.
- Double stator single rotor (DSSR) structure has benefits of higher torque density and balanced axial force.
- NS magnet type can increase torque density further.



Winding distribution

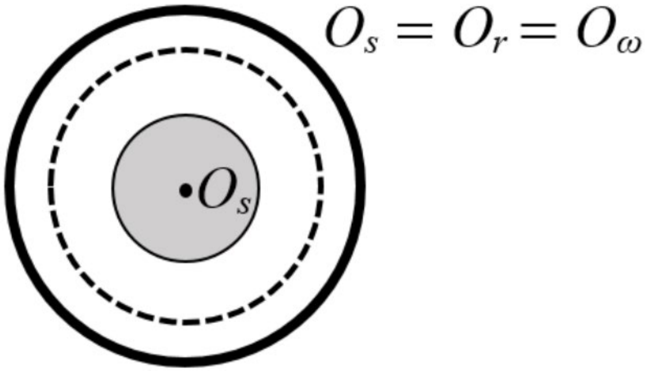


NN Structure **NS Structure**

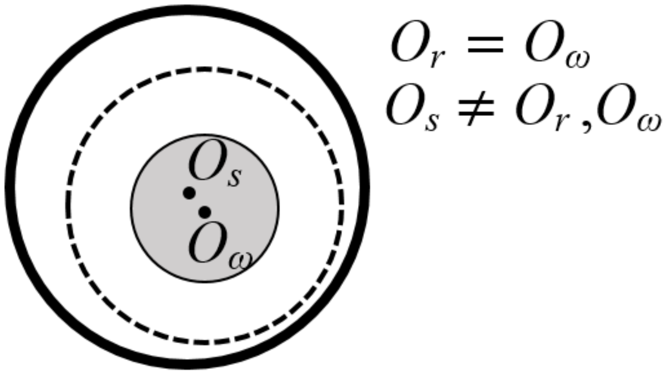
Flux directions of the proposed machine

Static Eccentricity in the Motor

- Eccentricity exists when rotor geometric axis and stator geometric axis are not aligned.
- Due to eccentricity , the airgap in the motor becomes non-uniform.
- Among the types of eccentricities, static eccentricity is the simplest one.
- In the static eccentricity, the airgap becomes non-uniform whereas the points of maximum and minimum airgap are fixed.

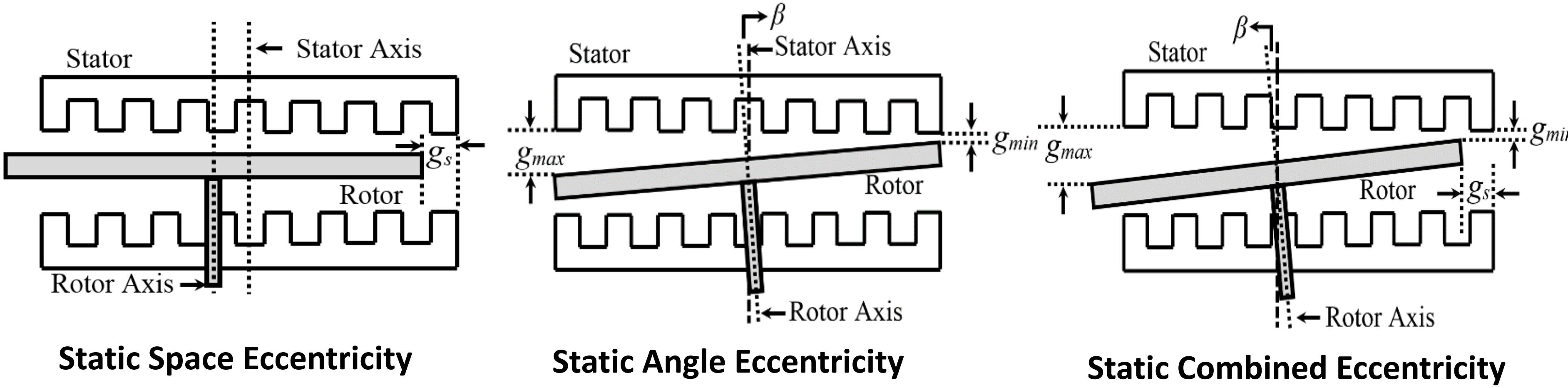


Healthy Radial Flux Motor



Static Eccentricity in Radial Flux Motor

Static Eccentricity in AFM



- However, the concept of eccentricity is different for AFM.
- Static space eccentricity can be defined as [1] : $\%ECC = \frac{g_s}{g_o} \times 100\%$
- Static angle eccentricity can be measured as [2] : $\%SEF = \frac{g_{\max} - g_{\min}}{2g_o} \times 100\% = \frac{R_{mid} \times \sin\beta}{g_o} \times 100\%$
- Combined eccentricity can be generated by applying both space and angle eccentricity.

[1] Y. Huang, B. Guo, Y. Guo, J. Zhu, A. Hemeida and P. Sergeant, "Analytical modeling of axial flux PM machines with eccentricities", *International Journal of Applied Electromagnetics and Mechanics*, vol. 53, no. 4, pp. 757-777, 2017.
[2] S. M. Mirimani, A. Vahedi, F. Marignetti and R. Di Stefano, "An Online Method for Static Eccentricity Fault Detection in Axial Flux Machines," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 3, pp. 1931-1942, March 2015.

Studied machine

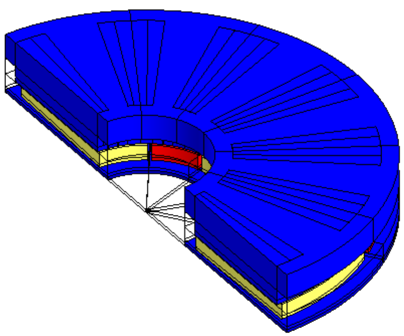
- 12 Slot 10 Pole (12s/10p) AFM with NS configured permanent magnets.
- NS configuration is used to improve the volumetric torque density.
- High airgap flux density.
- Lower cogging torque.

Case study machine

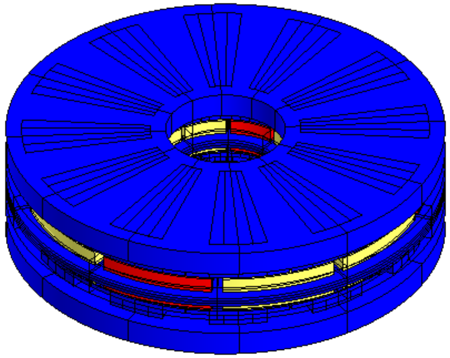
- Automotive application
- Double stator single rotor structure
- 58 KW continuous power
- 70 kW peak power for 20 seconds

Simulation setup

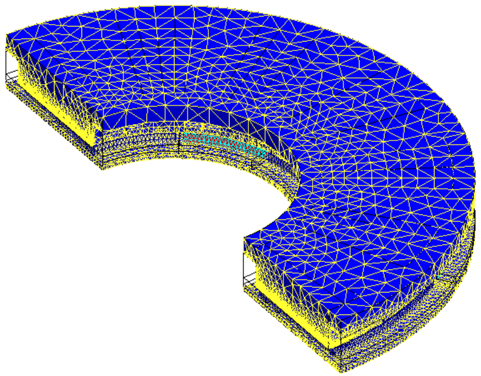
- Usual modeling of electric machines are done with periodicity and symmetry.
- 12s/10p can be drawn using an odd periodicity of 2 about the Z-axis and a symmetry about the x-y plane.
- Flux mesher is used for automatic volume mesh generation.
- Simulation time for a full electrical cycle is reasonable.



Part of the full machine drawn in flux



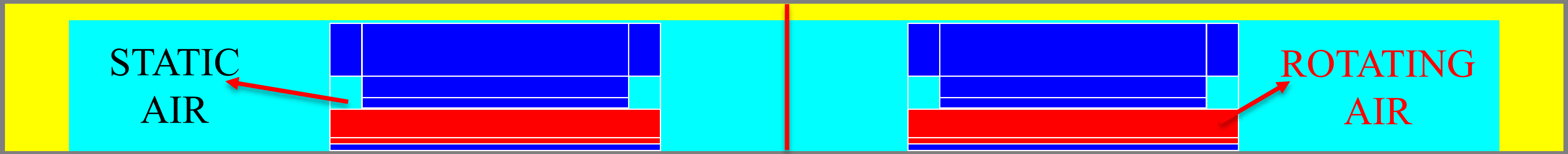
Full machine: odd periodicity about Z- axis and symmetry vs. the x-y plane



High mesh density

Eccentricity Simulation Issues

- Periodicity can not be used about z axis for angular eccentricity.
  - Linked mesh generator application on symmetric faces can be done.
  - Problem occurs during assigning rotation about Z-axis.
- Symmetry about x-y plane can not be used as well for a double stator single rotor configuration.
- Unlike the usual case, static and rotating air regions need to separated for eccentricity simulation.



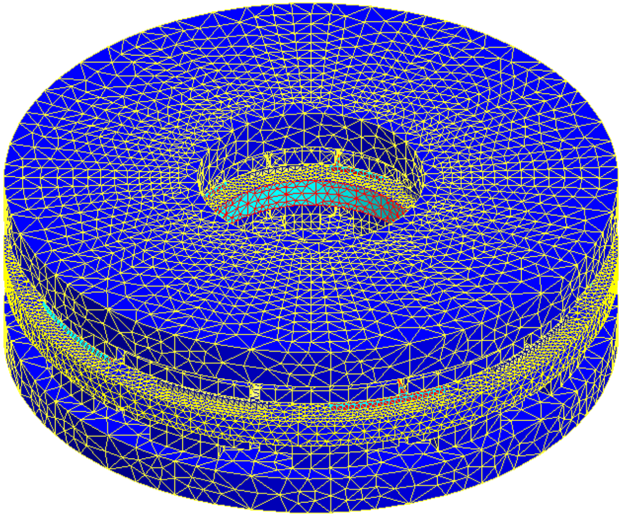
Generic 12s10p geometry (x-z plane view)

- ➢ Left and right half about the center red line is symmetric.
- ➢ Linked mesh generator with a rotating transformation of 180° can be applied.
- ➢ Static (turquoise) and rotating air (red) regions are connected.

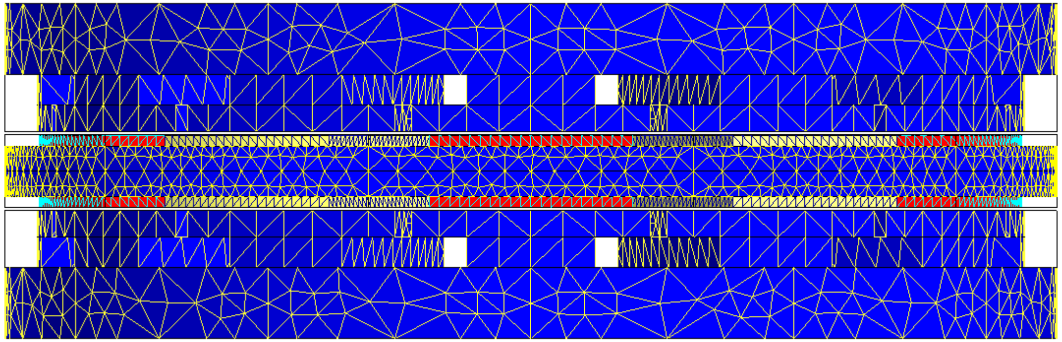
Take away: For eccentricity simulation full machine needs to be drawn and static and rotating air needs to be separated to accommodate angular eccentricity

Mesh Structure for Simulation

- Full machine geometry with high density mesh lengthens the simulation time.
- MeshGems mesher is used to reduce the simulation time.
- Half electrical cycle simulation takes about 3hrs on 16 core Intel Xeon 2.40 GHz CPU with 32.0 GB of RAM.
- The following mesh of the full machine is obtained using MeshGems mesher.

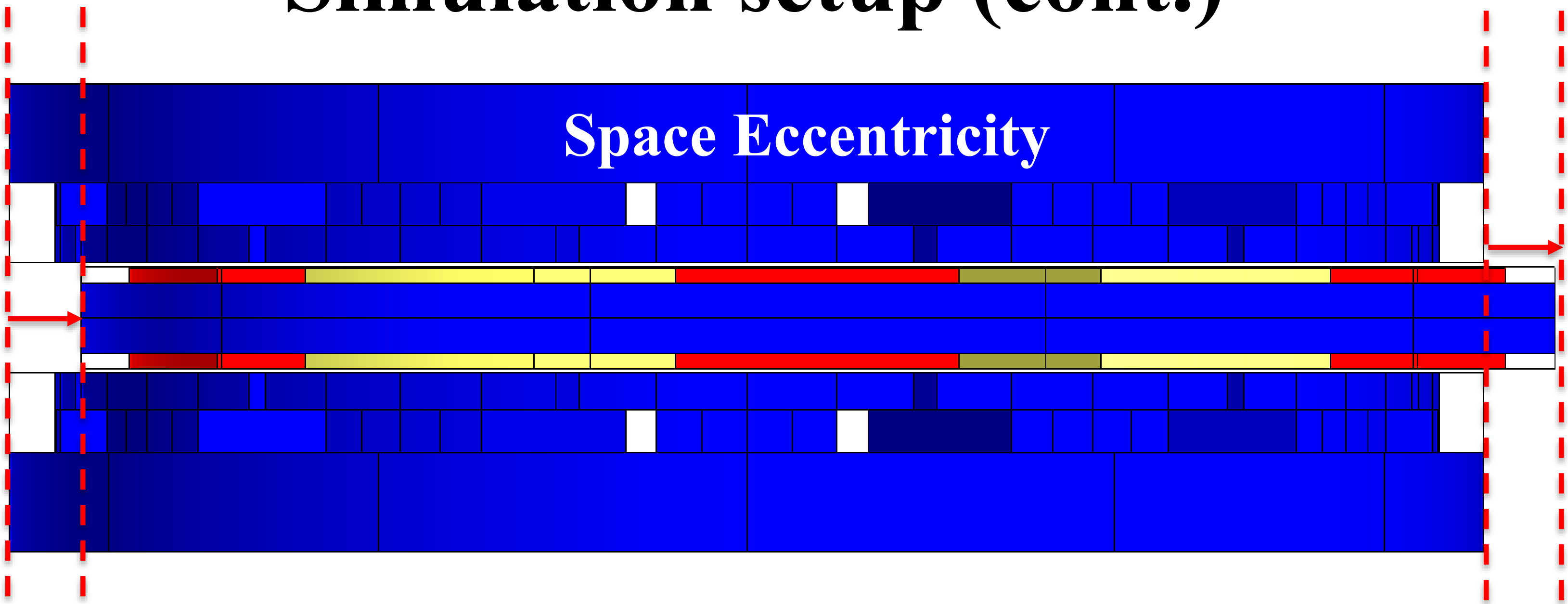


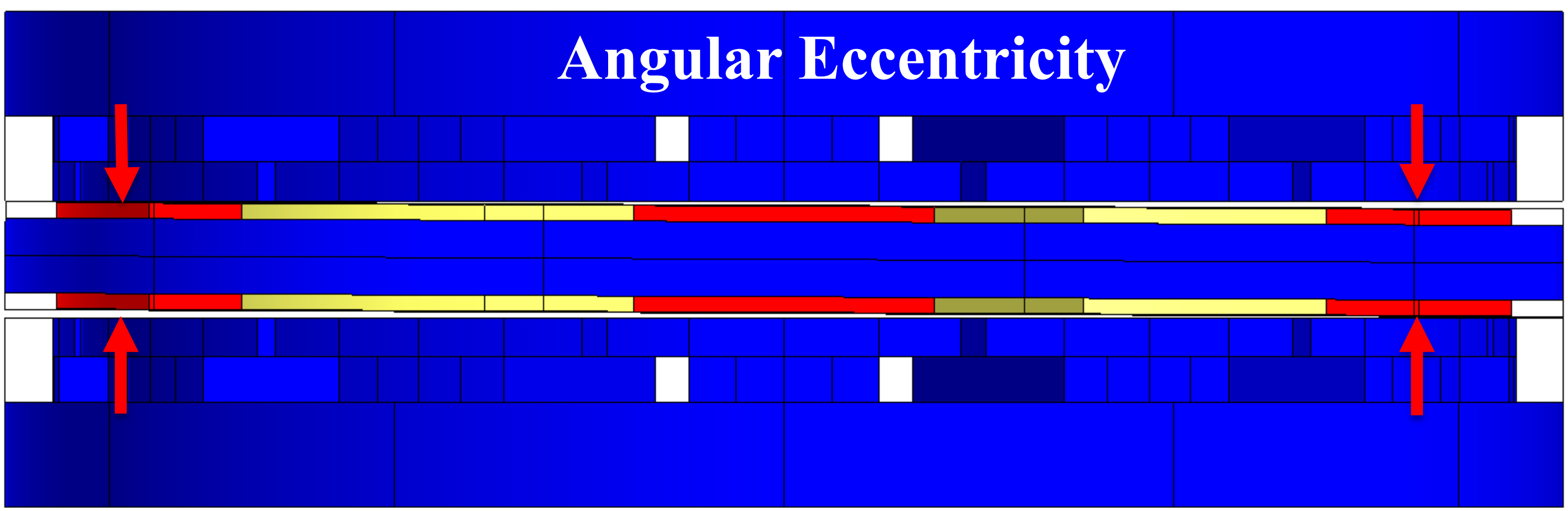
Mesh of AFM: Top View



Mesh of AFM: Side View

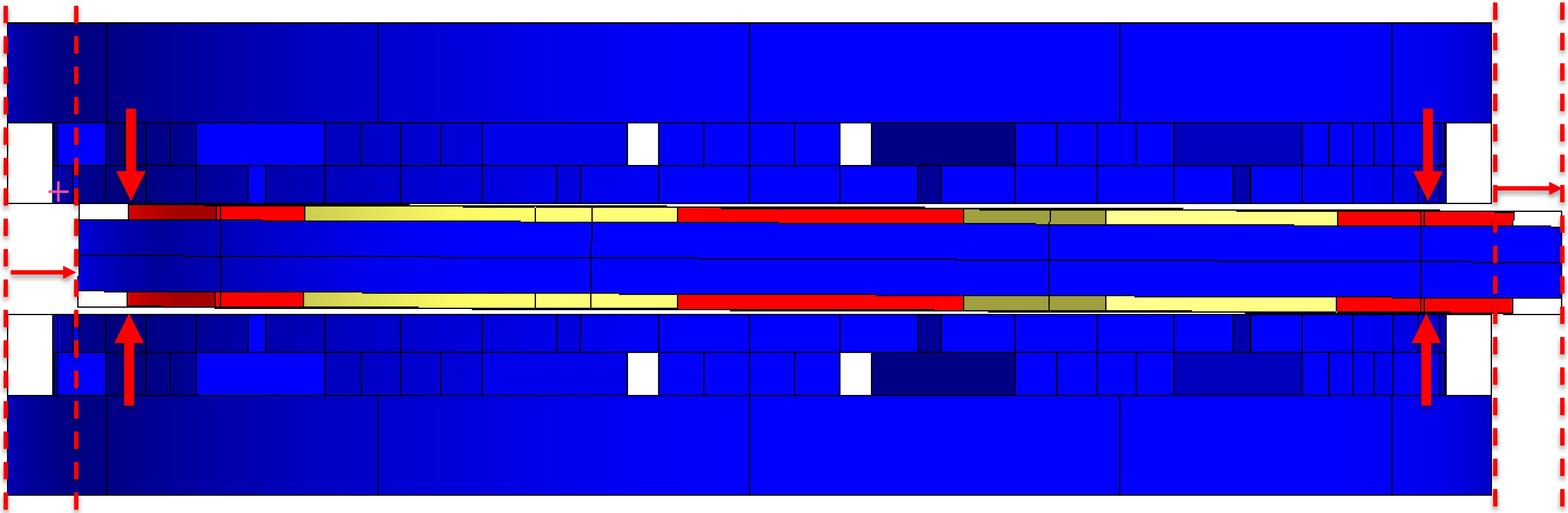
Simulation setup (cont.)





Simulation setup (cont.)

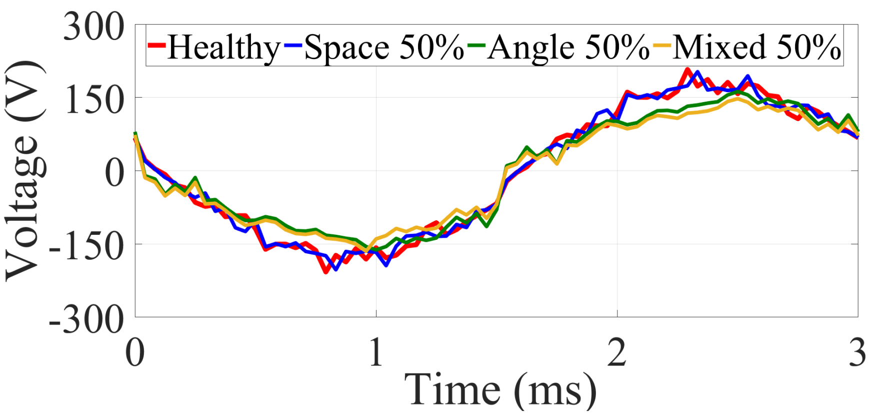
Combination of space and angular eccentricity



Simulation Results

- Static Eccentricities have been implemented in AFM from 0% to 50% in seven steps.
- Following parameters have been used for eccentricity implementation in AFM.

% Eccentricity	Shift Distance (g_s)	Shift Angle (β)
0.00%	0.00mm	0.00 degree
14.29%	0.10mm	0.08 degree
21.43%	0.15mm	0.12 degree
28.57%	0.20mm	0.16 degree
35.71%	0.25mm	0.20 degree
42.86%	0.30mm	0.24 degree
50.00%	0.35mm	0.28 degree



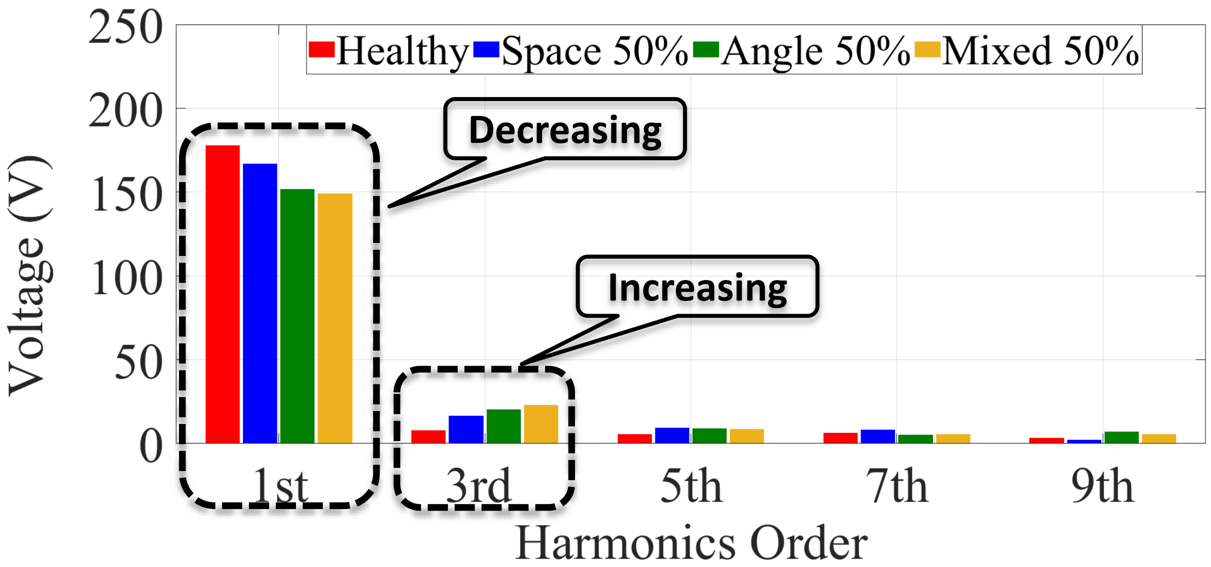
No-load BEMF Curve of Phase A

- Back EMF curve of Phase A of AFM shows distortion due to eccentricities.

Simulation Results (Cntd.)

- To understand the difference between the eccentricities, Fast Fourier Transform (FFT) of no-load BEMF has been done for all eccentricity conditions.

- FFT has been done for one cycle.



- Harmonic analysis of no-load BEMF shows that:

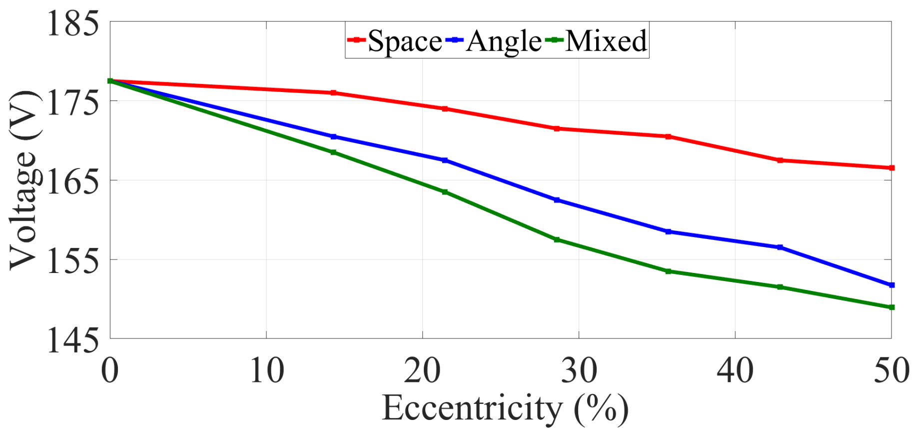
  1) Value of fundamental component is highest for healthy condition.

  2) Value of 3rd harmonics component is highest for combined eccentricity condition.

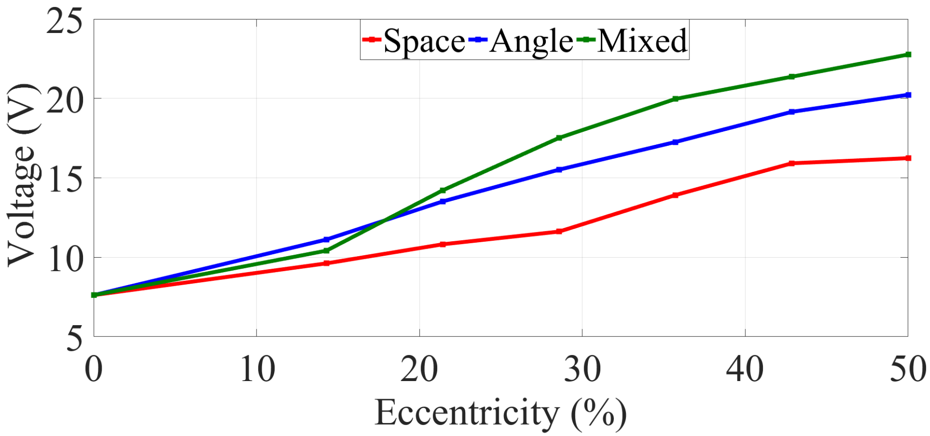
Simulation Results (Cntd.)

- Furthermore , the change of fundamental and 3rd harmonic components of no-load BEMF has been analyzed for all three types of eccentricities.

Fundamental



3rd Harmonic



- From the curves, it can be seen that for fundamental component, rate of decrease is highest for combined eccentricity.
- For 3rd Harmonics, rate of increase is highest for angle eccentricity up to 20% eccentricity.
- After 20% eccentricity, rate of increase is highest for combined eccentricity.

Conclusion & Future Work

- Analysis of static eccentricity in AFM.
- Introduction of static combined eccentricity.
- No-load BEMF analysis in different eccentricity types.
- Fundamental and 3rd harmonic analysis for different eccentricity levels.
- It has been found that, combined eccentricity shows highest deviation in terms of no-load BEMF analysis.
- Following parameters will be analyzed in future studies:
  - ✓ Cogging torque.
  - ✓ Airgap flux density.
  - ✓ Axial force.

QUESTIONS ?

Email:

Shuvajit Das : sd178@zips.uakron.edu
Md Tawhid Bin Tarek : mt106@zips.uakron.edu
Yilmaz Sozer: ys@uakron.edu