How does magnet segmentation affect cogging torque in PMSMs?

PMSMs

Permanent Magnet Synchronous Machines (PMSMs) are essential in electric vehicles and traction applications for their steady-state operation, high efficiency, and torque density, exemplified by models like the Toyota Prius. This application note presents the computation and validation of cogging torque in a Surface-Mounted PMSM using EMWorks2D, as shown in Figure 1. It further explores the effect of permanent magnet segmentation on cogging torque utilizing the "multi-configuration" feature.

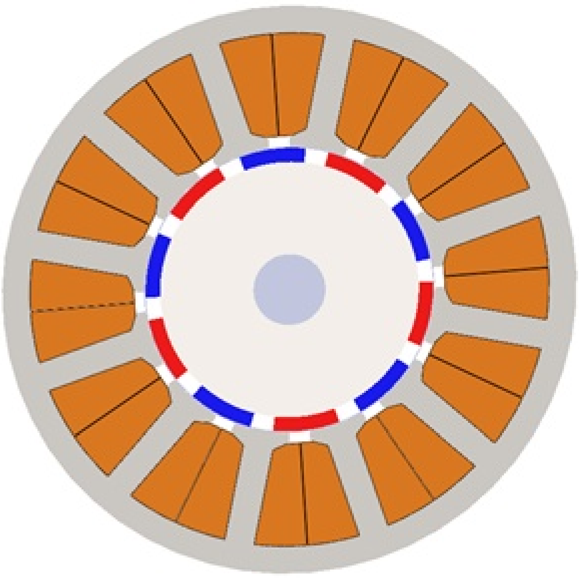

Figure 1 *- a 2D cross-section of the original SMPMSM.*

Simulation and results

1- No-Load analysis of the original model

The magnetic field mapping for the original surface-mounted PMSM motor at an initial 0-degree angular position is simulated using EMWorks2D, as depicted in Figure 2.

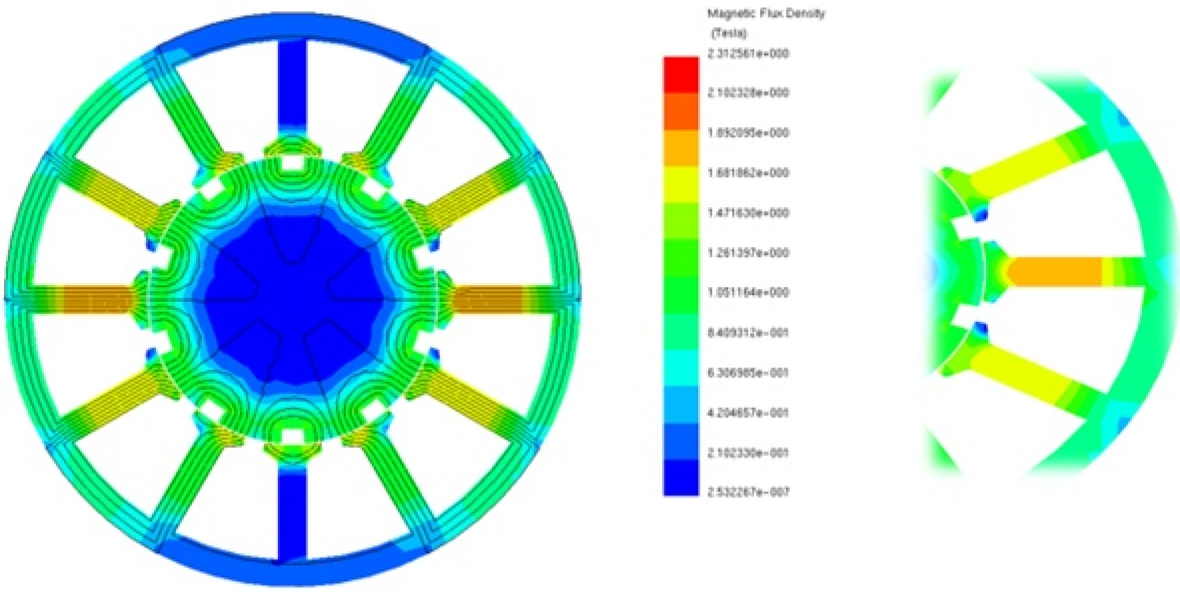

Figure 2 *- Magnetic field of the original PMSM using EM2D.*

The magnetic field reaches its maximum when the stator tooth aligns fully with the pole. The cogging torque of the original PMSM, plotted against angular position over one period, is computed and validated using EMWorks2D, as demonstrated in Figure 4.

Figure 4 *- Cogging torque of the original PMSM versus the angular position.*

The original PMSM's cogging torque exhibits a peak-to-peak value of 5.58N.m and an average value of -0.0185N.m.

2- Effect of magnet segmentation on the cogging torque of the PMSM

Two case studies using EMWorks2D investigated the effect of magnet segmentation on no-load torque, with permanent magnets segmented into two and then three blocks each, as shown in Figure 5.

Figure 5 *- a 2D cross-section of the segmented SM-PMSMs. (a) Case of one segmentation, (b) Case of two segmentations.*

The magnetic field mappings for the PMSMs with one and two segmentations of the permanent magnets are depicted in Figures 6 and 7, respectively.

Figure 6 *- Magnetic field mapping of the PMSM having 2 PMs per pole. (a) 2D model, (b) zoom.*

Figure 7 *- Magnetic field mapping of the PMSM having 3 PMs per pole. (a) 2D model, (b) zoom.*

The cogging torque for different segmentation cases of the PMSMs was computed using EMWorks2D, with results presented in Figure 8. To emphasize the impact of permanent magnet segmentation on cogging torque, both peak-to-peak and average values are detailed in Table 1.

Figure 8 *- Cogging torque for different PMs' segmentations.*

Table 1 *- Cogging torque for different PMs' segmentations.*

Cogging torque	1 PM per pole	2 PMs per pole	3 PMs per pole
Peak-to-peak value (N.m)	5.4629	3.355	3.99478
Average value (N.m)	0.01486	0.011802	0.029759

From Table 1, it's apparent that the average cogging torque across the configurations is nearly zero, suggesting any differences might be attributed to computational errors. Notably, in the second configuration with two PMs per pole, the peak-to-peak cogging torque significantly decreases, while it slightly increases in the third configuration.

Conclusion

The application note delves into Permanent Magnet Synchronous Machines (PMSMs), vital components in electric vehicles and traction systems due to their efficiency and torque density. Focused on a Surface-Mounted PMSM, it investigates cogging torque using EMWorks2D simulations and examines the impact of magnet segmentation. Initial analysis of the original model reveals cogging torque patterns, with subsequent studies exploring the effect of permanent magnet segmentation. Results showcase variations in cogging torque values across different magnet segmentation configurations. Notably, while average cogging torque remains minimal across configurations, significant changes are observed in peak-to-peak values. The note concludes by noting the potential computational errors affecting results and highlighting the significance of magnet segmentation in mitigating cogging torque.

References

[1] A. Frikha, "Contribution to the Multiphysics Modelling of Permanent Magnet Synchronous Machines", Master Thesis, National Engineering School of Sfax, Tunisia, 2019.