Magnetothermal Coupling Analysis of Claw Pole Machine using Combined Magnetic and Thermal Network Method

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➢1. Introduction

- For the traditional electrical machine, iron core are made of silicon steel sheets, and the main magnetic fluxes are worked in the 2D plane. However, for the claw pole machine (CPM), the accuracy rate of the 2D electromagnetic analysis is not effective due to the exists of 3D magnetic flux path. The model of CPM is shown in Fig.1

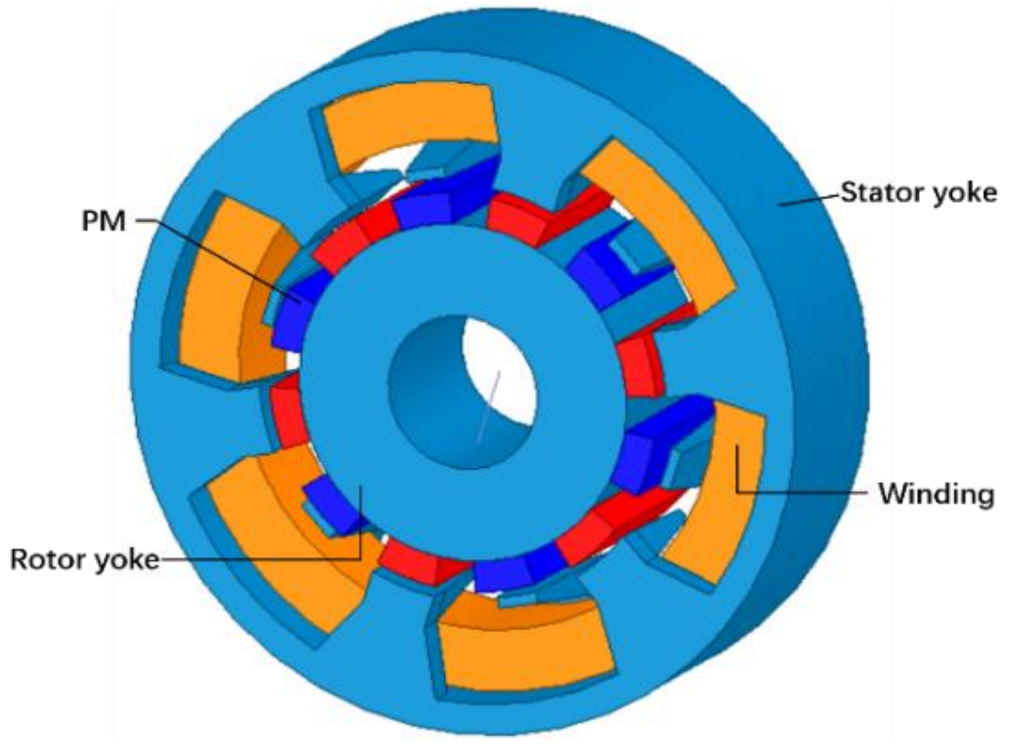

Fig. 1. CPM model

- The most used method in electric machine magnetic analysis is finite element method(FEM), however it's time consuming in the 3D analysis which are needed by CPM [1].
- The MCM is used to make a quick analysis of CPM. And a more precision magnetic network model(MNM) is established [2]. The magnetic and thermal network coupling model is proposed based on the MNM.

➢2.Magnetic network model

One-sixth model is adopted to reduce the model dimension. A mesh-based MNM model is used. Three main steps are needed to calculate magnetic field by MNM:

- In the first step we create the mesh of the PMCPM as shown in Fig. 2 the mesh of stator. The rotor and air gap is also modeled by similar way. Each element is modeled and shown in Fig. 3.

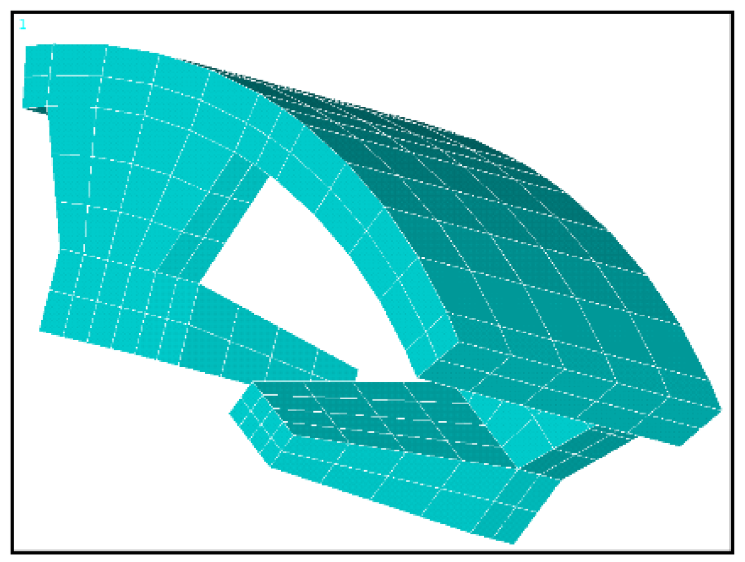

Fig. 2. Mesh of stator core

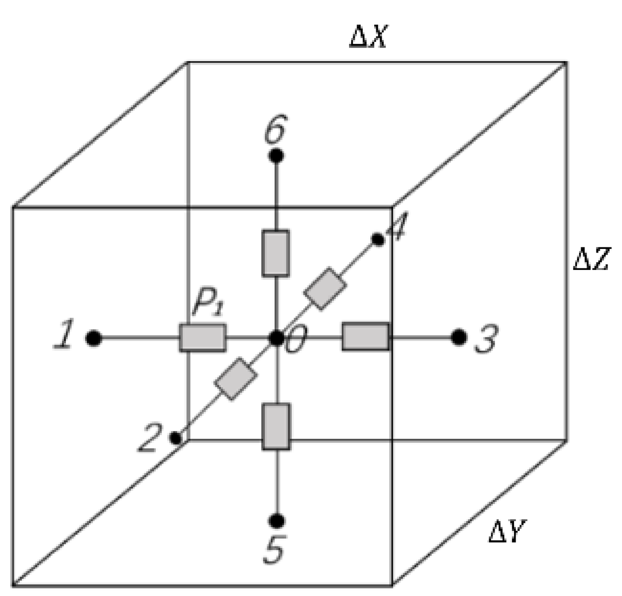

Fig. 3. Single element model.

- Then, the MNM model and the equation are established. According to Ampere's law, the algebra equation can be formed by formular (2).

$$\sum_{1}^{6} P_i(u_0 - u_i) = \sum_{1}^{6} \Phi_i$$

- In the last step, the equation was solved iteratively with in one electrical period. Deal with the solved magnetic scalar u can obtain the motor electromagnetic performance such as torque and flux linkage.

➢3. Stator core loss calculation

Stator core loss is calculated by elliptical rotation loss [3]. Fig. 4 and Fig. 5 show the magnetic density trajectory at particular position of clow pole and stotar yoke. The trajectory coincides with an approximate ellipse.

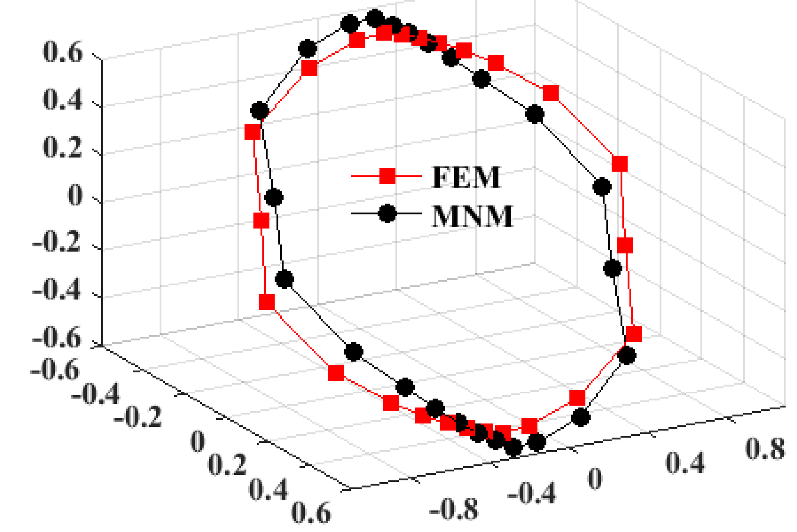

Fig. 4. Magnetic density trajectory at clow pole.

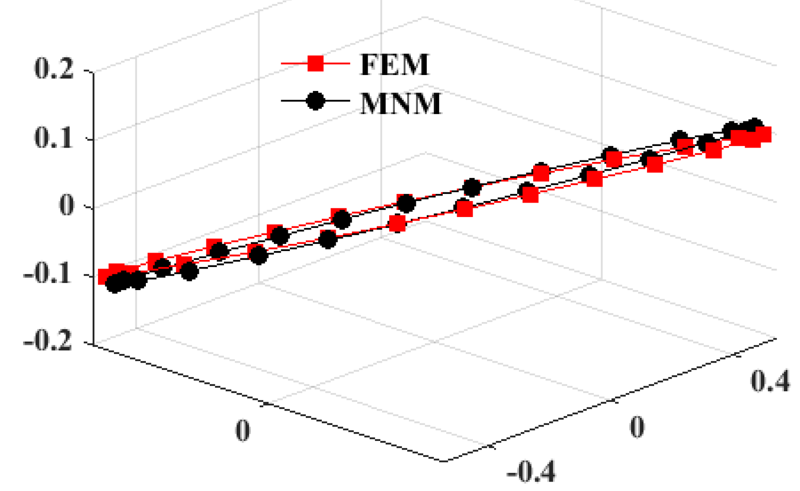

Fig. 5. Magnetic density trajectory at stator yoke.

In order to calculate the elliptical rotation loss, Fourier decomposition(Fig. 4 as example) is performed to obtain the elliptical waveform of each harmonic.

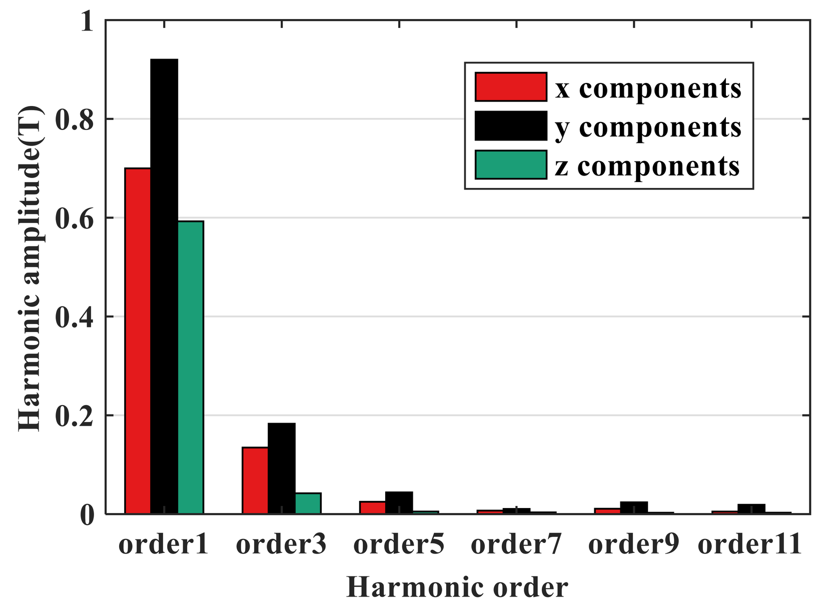

Fig. 6. Harmonic components in three directions.

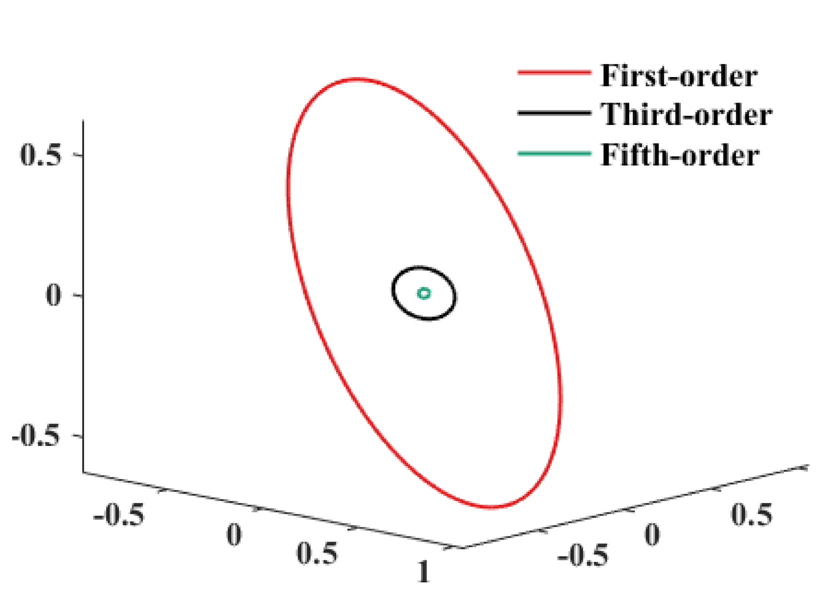

Fig. 7. Harmonic ellipse.

➢3. Coupling model

The thermal network model(TNM) is established with the same structure as the magnetic network, and add the calculation loss of the magnetic network to the thermal network as excitation source. Coupling model calculation process is as follows:

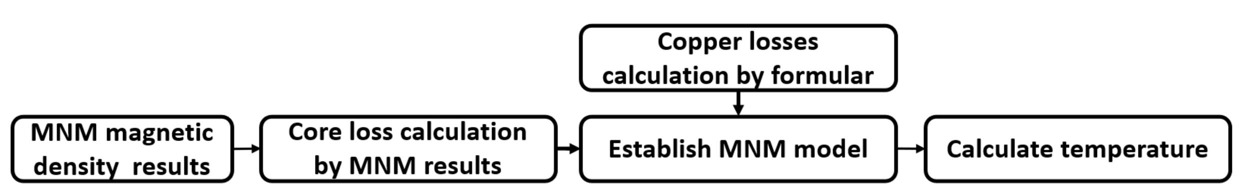

Fig. 8. Coupling model calculation process .

➢5. Results

The coupling model results are compared with FEM.

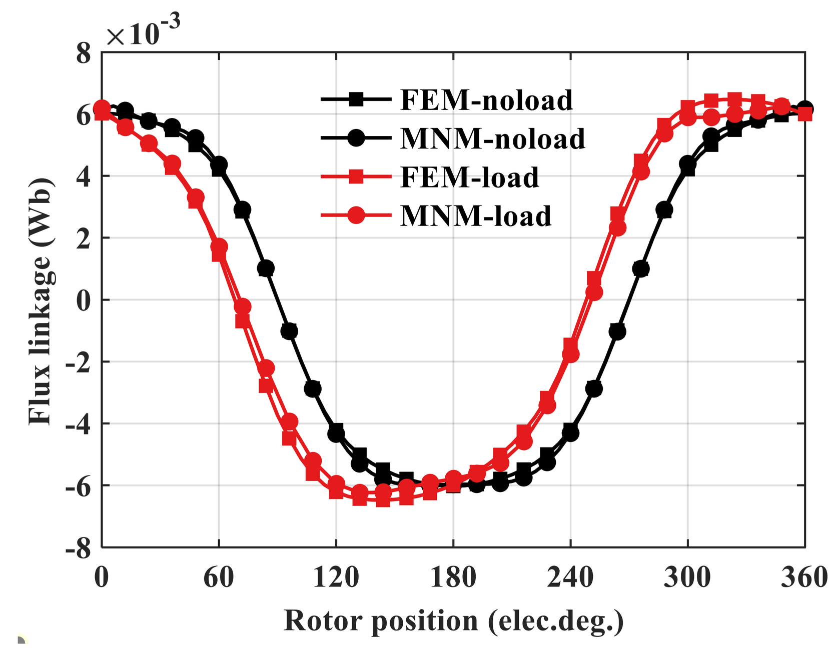

Fig. 9. Flux linkage results.

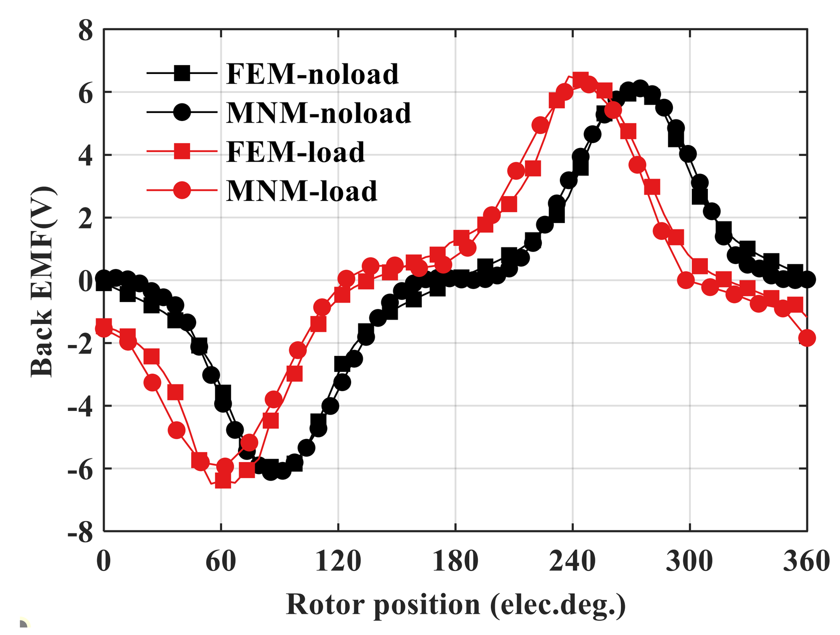

Fig. 10. Back EMF results.

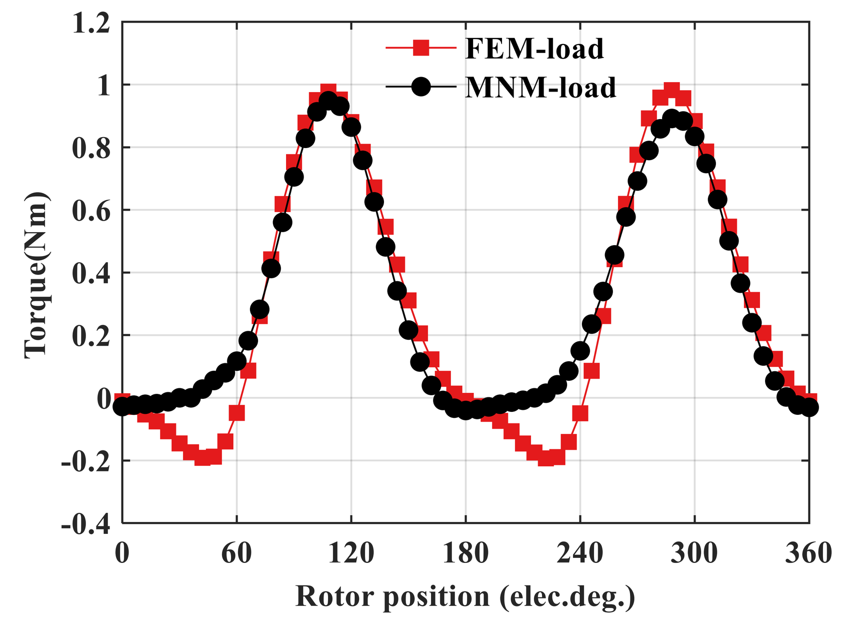

Fig. 11. Torque results.

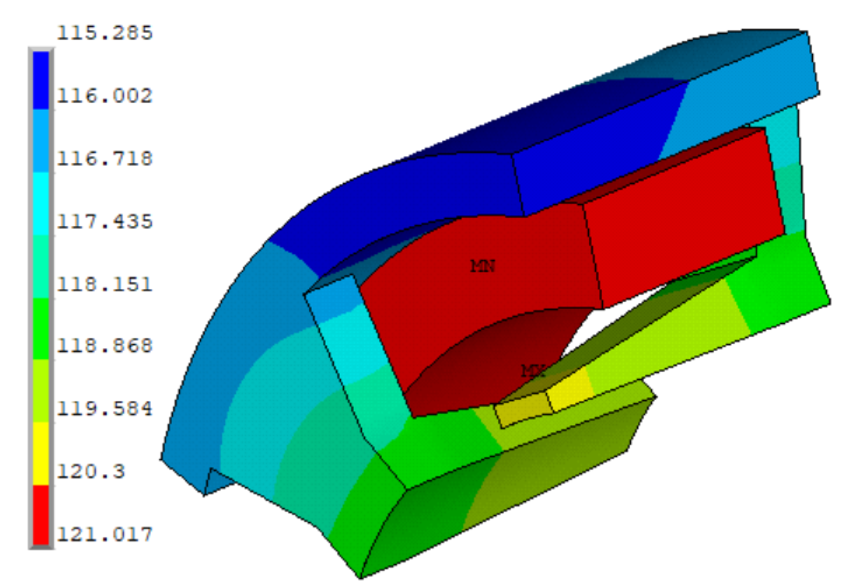

Fig. 12. Thermal results of FEM.

The average temperature rise calculation results of each part is given as Tab.1

Tab.1. Thermal results of coupling model and FEM

position	Stator core	Stator winding	PM	Rotor core
FEM(°C)	116	121	115	115
Coupling model(°C)	115	120	115	114

➢5. Conclusion

1) A mesh-based magnetic network model is proposed for claw pole machine.
2) Then the rotational core loss instead of alternating loss of stator core is calculated to rise the core loss accuracy.
3) A magnetic network and thermal network coupling model is proposed. The MNM and TNM share the same topology to ensure the coupling process.
4)The coupling model is verified by FEM. The proposed coupling model hold the advantages of high calculating speed and coupling convenience.

[1] Alipour-Sarabi, R., Nasiri-Gheidari, Z., & Oraee, H. "Development of a three-dimensional magnetic equivalent circuit model for axial flux machines," IEEE Trans. Ind. Electron., vol.67 no.7, pp. 5758-5767.
[2] N. Li, J. Zhu, M. Lin, G. Yang, Y. Kong and L. Hao, "Analysis of Axial Field Flux-Switching Memory Machine Based on 3-D Magnetic Equivalent Circuit Network Considering Magnetic Hysteresis," IEEE Trans. Magn., vol. 55, no. 6, pp. 1-4, Jun. 2019 [3] Guo, Y., Zhu, J., Lu, H., Lin, Z., & Li, Y. "Core loss calculation for soft magnetic composite electrical machines," IEEE Trans. Magn., vol. 48, no. 11, pp. 3112-3115, 2012.