Characteristic Analysis of Claw-Pole Type Motor using 2-dimensional Finite Element Method

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Abstract

This paper presents a rapid and simplified characteristic analysis method for claw-pole type motor using 2-dimensional Finite Element Method (2D FEM) with an equivalent model. The dimensions of the 2D equivalent model are decided by considering geometric mean distance of 3D model. With proposed 2D equivalent model, less calculation time and computer memory are required comparing to 3D anlaysis. For the validity of 2D analysis results, the flux distribution in the air-gap is compared to average flux distribution from 3D static analysis, and the emf (electromotive force) is compared with measurements.

1. Introduction

Large numbers of claw-pole type rotary machines are used as generators in vehicles because the production process can be simpler and the structure can be solid. However, the machines can have high saturation level and leakage flux easily due to their unique shape of poles. Accordingly, Finite Element Methods (FEMs) are used to accurately predict the electrical and mechanical behavior of the machines [1-3]. 3-dimensional (3D) FEM can be used to the analysis of the machines by modeling them as the shapes are [2]. However, it is not recommended to use 3D FEM in the initial design because 3D FEM analysis requires much computation time and computer memory, and it is hard to model claw-poles. Therefore, 2D equivalent analysis models for 2D FEM are presented in several researches as substitution for or auxiliary to 3D FEM [3-5].

In this paper, 2D equivalent model is introduced for rapid and simplified characteristic analysis of claw-pole type motor. The process of transforming the 3D model to 2D equivalent model considering geometric mean distances is presented in detail. 3D FEM is used to check whether 2D equivalent model follows overall trend of flux distribution with 3D analysis. For that reason, the flux density in the air-gap is obtained from the 2D equivalent model, and compared with 3D analysis results. With this comparison, the validity of the 2D equivalent model can be obtained or modified to have more precise analysis results. The analysis results are verified by comparing back emf to measurements.

2. Analysis Model

Fig. 1 shows the construction of a claw-pole type motor of 3kW. The rotor has16 poles with double layer, the stator has 96 slots. Field coils fed by DC current are wound in rotor. Equivalent 2D model is designed considering the 3D dimensions [3].

3. 3D analysis

For static 3D FEM analysis, commercial software, Flux-3D, is used. On the basis of the periodicity and symmetry, it is possible to use 1/16 model instead of full 3D model; cyclic boundary condition is applied to the periodic face and field tangential condition is applied to the symmetry plane. Fig. 2 shows the flux distributions in rotor. As shown in Fig.2, the flux distributions are 3-dimensional in almost everywhere of the rotor. Therefore, for more precise analysis results with 2D equivalent model, the average flux distribution in the air gap along rotor axis can be considered. The flux distribution in the air gap along z-direction is shown in Fig. 3.

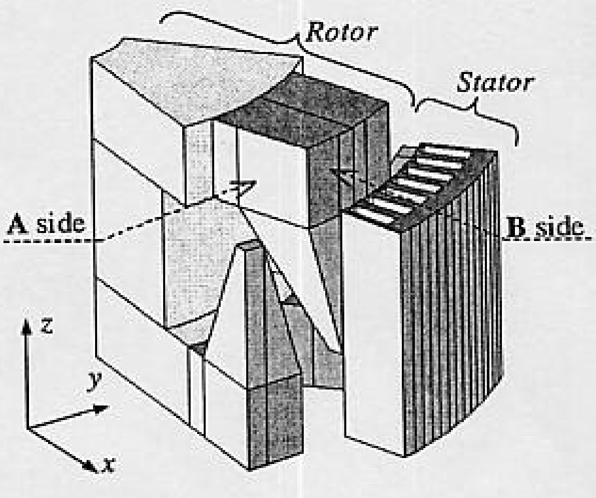


Fig. 1 1/16 Construction of claw-pole type DC motor(rotor coils are hidden for visibility of the entire model)

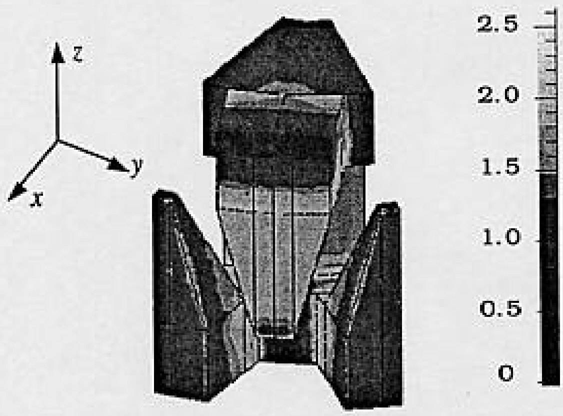


Fig. 2 3D flux distribution from 3D analysis

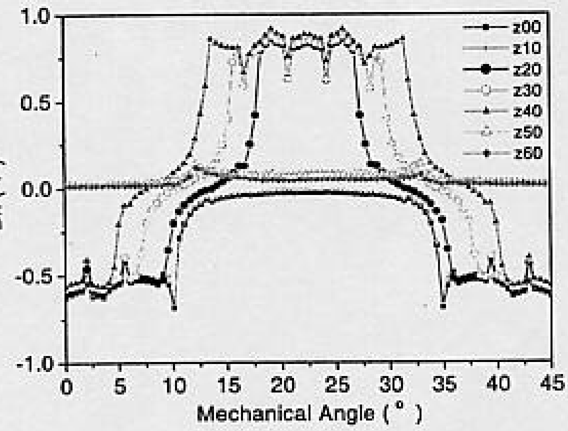


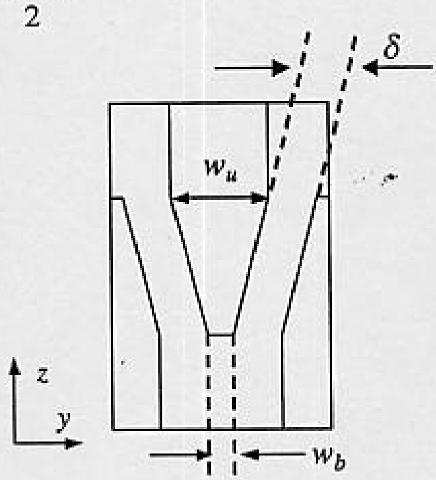
Fig. 3 Normal component of flux density in air gap along z- axis (z denotes z-axis and number does axial position in legend)

4. Designing 2D equivalent model by 3D dimensions

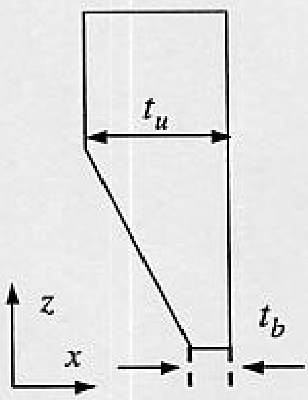
In designing 2D equivalent model, only rotor part is considered, and stator is modeled as general 2D analysis of motor. Slot open width (δ) of the equivalent model is decided and this width is maintained from 3D model, because it is expected that this gap can represent the leakage flux between two poles both of 2D and 3D model. As shown in Fig. 4, the rotor pole width and thickness have variation along z-axis. The tooth width (w) and thickness (t) in Fig. 4 are chosen to be the average width of overlapped pole part, and this is represented in (1) and (2) respectively.

$$w = \frac{w_u + w_b}{2} \quad (1)$$

$$t = \frac{t_u + t_b}{2} \quad (2)$$



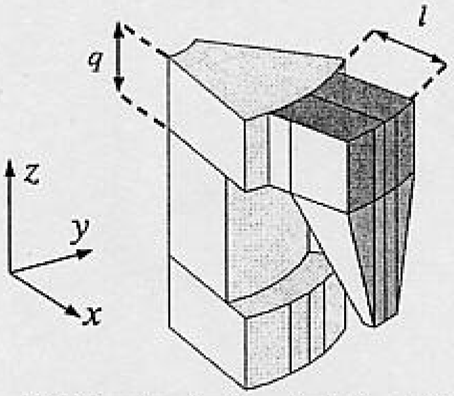
(a) Tooth width and slot open width from A side view in Fig. 1



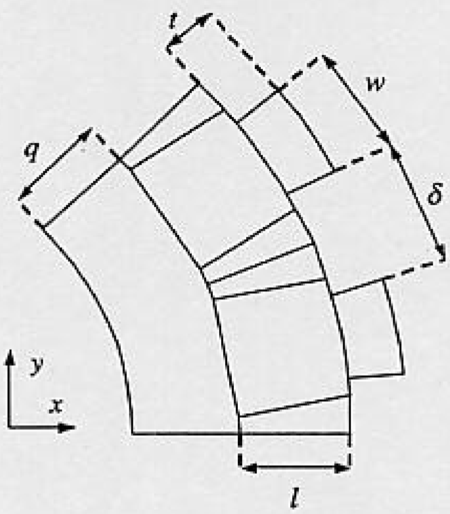
(b) Tooth thickness from B side view in Fig. 1

Fig. 4 Dimensions for 2D equivalent model I

Other factors to be considered are shown in Fig.5 (a), the complete 2D equivalent model of the rotor is shown in Fig. 5 (b), and the complete 2D equivalent model for 2D FEM is shown in Fig. 6, where, F (magnetomotive force) is the source of the entire rotor, N is number of turns, I_A is exciting current. The accuracy of the 2D analysis is mainly affected by magnetomotive force and δ [3]. And these can be modified for more precise results. Flux distribution in air gap of the 2D equivalent model is compared to the average flux distribution from 3D analysis in Fig. 7.



(a) Dimensions for 2D equivalent model II



(b) Equivalent rotor model
(c)
Fig. 5 3D geometry and its corresponding 2D geometry

As shown in Fig.7, the difference between 2D equivalent model and 3D model is small that the difference can be neglected in the initial design stage. Therefore, it is clear that designing 2D equivalent model only by 3D dimension is reasonable and quite accurate. Therefore, this equivalent model is used for the characteristic analysis of the machine. In addition, for 2D FEM analysis with 5,000 nodes, it took only 30 seconds per a step. Meanwhile, for 3D static analysis with 250,000 nodes, it took 30 minutes per a step. This can be varied according to the computer system and analysis model, but it is evident that 3D analysis requires much more time than 2D FEM. And this becomes worse if the analysis is about dynamic characteristics of the machine.

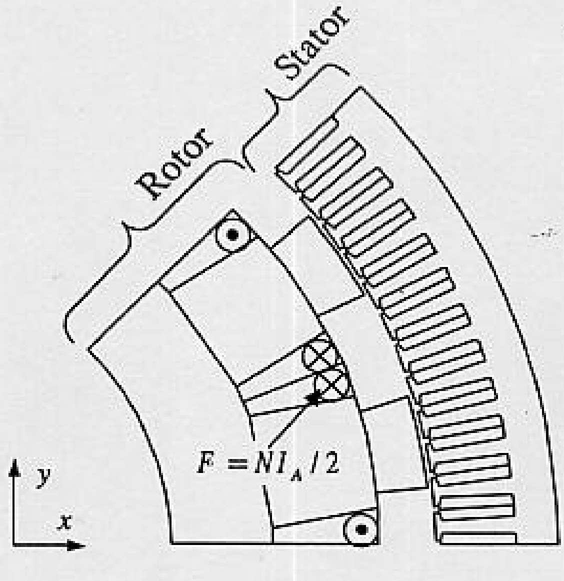


Fig. 6 Complete 2D equivalent model

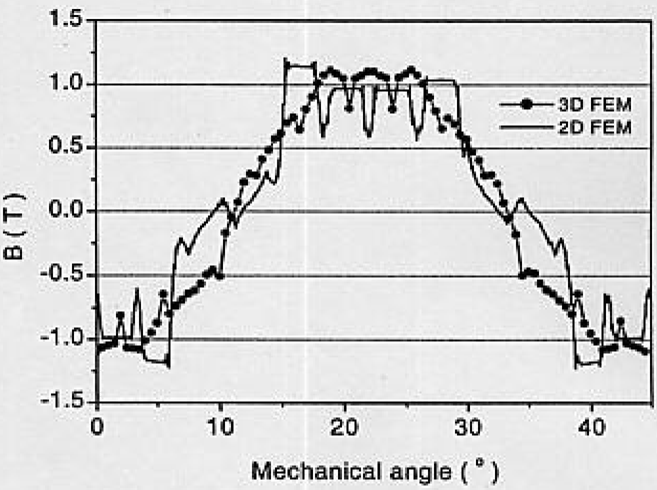


Fig. 7 Comparison between the normal component of average flux density from 3D analysis and 2D analysis

5. Analysis results and measurement

Back EMF by measurements and 2D FEM analysis results according to exciting current at 500 rpm are compared in Fig. 8. From the comparison, it can be said that the 2D equivalent model represents the actual characteristics of the machine very well and can be applied for further characteristic analysis, such as dynamic analysis of the machines easily.

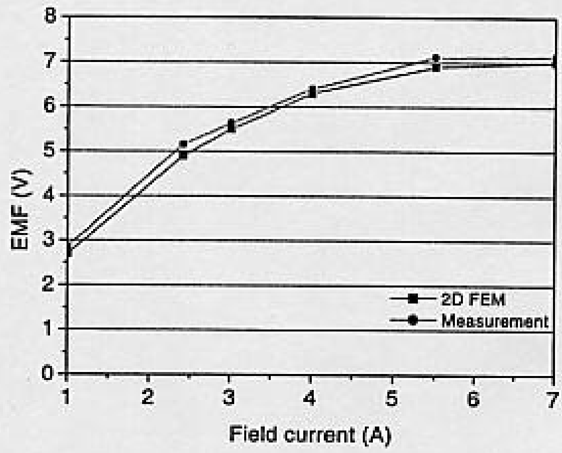


Fig. 8 Comparison of EMFs obtained by 2D analysis and measurements at 500rpm.

6. Conclusions

The method designing 2D equivalent model of claw pole type motor by geometry is verified by comparing analysis results of 2D FEM and measurements. 2D equivalent model is used for the characteristic analysis of the machine and the analysis result shows good agreement with the measurements. With this method the analysis of claw-pole type machines would be easy and fast in the initial design stage of the machine and further characteristic analysis, such as dynamic analysis, can be performed.

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