Practical Analysis Method for Claw-pole type Generator using 2-Dimensional Equivalent Model

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***Abstract*- The design of 2-dimensional equivalent model for claw-pole type generator is presented in this paper. On the basis of 3D geometry, 2D equivalent model is designed and 2D FEA is performed. Comparing to other analysis method for claw-pole type machine, such as 3D FEA and MEC, presented method can be more practically used and directly applied to industry. Flux distribution in the air-gap and flux density at rotor and stator are verified by 3D FEA, and no-load back EMFs for field input voltages are verified by measurement.**

I. INTRODUCTION

Large numbers of claw-pole type generators are used in vehicles because the production process is simple and their structure is robust. However, the machines have high saturation and leakage flux due to their unique structure of rotor. Moreover, the flux distributions are purely 3-dimensional (3D). Accordingly, 3D Finite Element analysis (FEA) can be directly used to accurately predict the electrical and mechanical behavior of the machines [1]. However, it is not recommended using 3D FEA in the initial design because it requires much computation time and memory, and it is hard to model claw-poles.

Another approach using MEC (Magnetic Equivalent Circuit) method is introduced in [2]. MEC method gives precise analysis results by considering 3D geometry and non-linear characteristics with instant calculation. However MEC requires complex process such as design of equivalent magnetic circuit, permeance calculation of each element considering the shape of element, and building matrix of potential, permeance, and source.

The method using 2D equivalent model for claw-pole type servomotor is proposed and analysis results are verified by measurements in [3] and [4], however, 2D equivalent model considers only rotor pole part and the effect of saturation in the other part of rotor is not considered. Therefore, the analysis results roughly agree to measurements. In this paper, 2D equivalent model of claw-pole type machine is developed by considering the saturation of the entire rotor part. For the design of 2D equivalent model, 3D flux distribution and flux paths are understood then 2D equivalent model for entire region of rotor and stator part is designed.

3D FEA is firstly performed to identify 3D flux distribution. Then, on the basis of 3D geometry and material information, 2D equivalent model is designed and 2D FEA is performed. Air gap flux density distribution and flux densities in rotor and stator from 2D FEA are compared to 3D FEA [4]. Finally no-load back EMFs for field input voltages are calculated by 2D FEA and compared to measurements, and comparison verifies presented analysis method.

II. ANALYSIS MODEL

Fig. 1 shows the general construction of a claw-pole type generator, and Fig. 2 shows the analysis model of 3kW. The rotor has16 poles with double layer structure, and the stator has 96 slots with laminations. Axial length of stator is shorter than rotor for the space of armature windings and field coils fed by DC currents through brushes are wound in rotor. Since the rotor is manufactured by molding, its structure is robust and manufacturing process can be simple comparing to the laminated structure. Therefore, these aspects are suitable for the mass productions such as the applications of automobile. However, since rotor structure is not symmetrical along rotor axis, flux distributions are 3D and this leads to the difficulty in design and analysis.

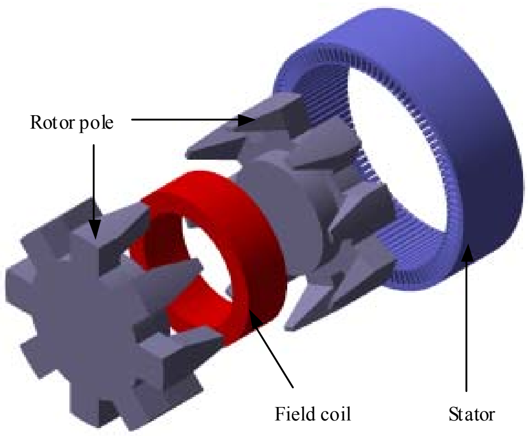

Fig. 1 Claw-pole type generator

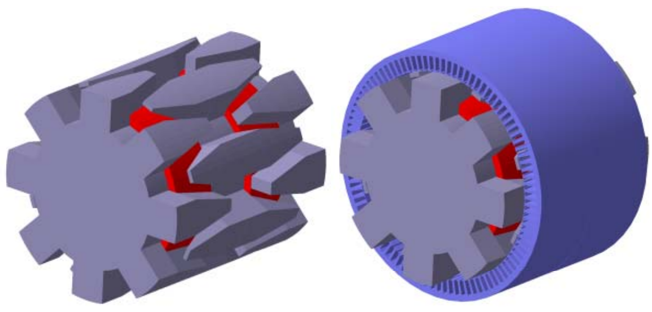

Fig. 2 Analysis model (Double Layer)

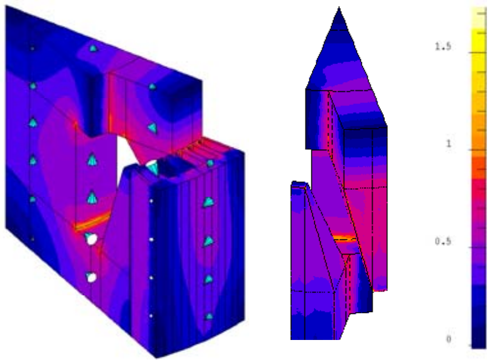

Fig. 3. 3D FEA result (flux distribution and paths on rotor)

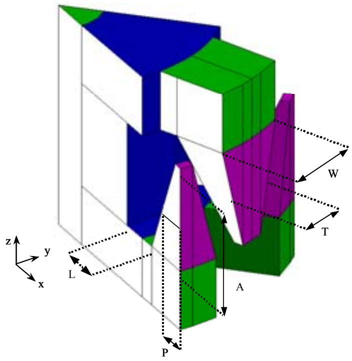

Fig. 4 Parameterized dimensions for 2D equivalent model

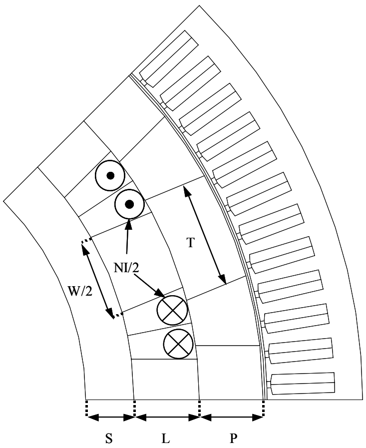

Fig. 5 Complete 2D Equivalent model

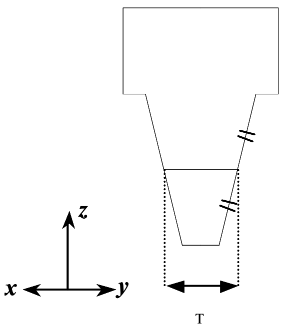

Fig. 6 3D geometry for 2D model – T

III. 3D FEA

For static 3D FEA, commercial software, Flux-3D is used. With the help of periodicity and symmetry, it is possible to use 1/32 model instead of full 3D model. Fig. 3 shows the 3D FEA result. The flux distributions are purely 3D almost in everywhere in the rotor and stator. 168,488 of tetrahedral elements are used. 3D FEA is performed only for the flux distribution in static field and verification of 2D FEA.

IV. 2D EQUIVALENT MODEL

In designing 2D equivalent model, only rotor part is considered. Since the structure of stator is symmetrical along rotor axis stator part is modeled as general 2D analysis model.

In Fig. 4 and 5, parameterized dimensions of 3D model and their corresponding 2D equivalent model are shown respectively. The design of 2D equivalent model is focused on the design of the 2D magnetic paths from that of 3D, by doing this, 2D equivalent model have the close magnetic resistance with 3D model. “L” is maintained and the other parameters for 2D equivalent model are determined as follow.

a. A (Axial Length) – In the analysis model, total axial length of rotor does not directly contributes to the output as conventional laminated machine, because axial length of pole and total axial length of rotor are not equal. Axial length contributing to output is determined by overlapped length of upper and lower pole.

b. T (Pole width) and P – To determine rotor pole width, it should be assumed that flux density on pole surface is uniform. The assumption does not seem to cause significant error, since 3D FEA result shows almost uniform flux density distribution in one pole as shown in Fig. 3. Pole shape facing stator side along axial direction is shown in Fig. 6 and the shape is trapezoidal. Therefore, “T” is determined to be an average value and “P” is determined by the same manner.

c. NI/2 (Magneto motive force of field coil) – As a homo-polar type machine, claw-pole type generator has the same MMF in all poles with one field winding and this feature is one of the advantages of claw-pole type machine. To consider this unique characteristic, a half of total field MMF (NI/2) is applied to both side of one rotor pole. Consequently, total MMF of one rotor pole in 2D equivalent model becomes NI.

d. S (Rotor yoke thickness) – The flux produced by field coil first flows axially through the area in Fig. 7. Therefore, 3D magnetic resistance, which can be represented by the ratio of magnetic circuit length and section area, is considered in 2D equivalent model. Fig. 7 shows the relation between 3D model and 2D equivalent model and “S” is determined by (1).

$$\frac{l}{SS_{3D}\cdot\mu_0\mu_r} = \frac{l}{SS_{2D}\cdot\mu_0\cdot\mu_r} \quad \text{and} \quad SS_{2D} = S\cdot A \qquad (1)$$

where μ_0, μ_r is relative permeance of air and rotor respectively.

V. Analysis Results and Verificaton

Equi-potential lines of 2D FEA results are shown in Fig. 8, and flux density from 3D FEA and 2D FEA are shown in Fig. 9 and compared in Table 1. In the comparisons, flux densities from 2D FEA at a, c, d well agree with 3D FEA results, however, at b, there is huge difference and this is caused by the fact axial component of flux density can not be considered in 2D FEA. Air gap flux densities are compared in Fig. 10. As shown in Fig.10, the positive flux density from 2D and 3D FEA agree well, however, in the negative part, there is large difference. This difference is caused by that the effective pole area of positive and negative of 3D are not identical, and this cannot be considered in 2D equivalent model. However, the total flux of positive and negative pole should are identical.

No-load back EMFs from analysis and measurements at 500rpm are compared in Fig. 11. From the comparison it is shown that back EMF waveform from 2D analysis contains many harmonics unlike measurement result. This difference is caused by the fact 2D equivalent model does not consider the skew effect due to the shape of claw-pole and this problem can be solved by removing the harmonic component of slot. The line to line rms back EMF from analysis is 3.94 V and that of measurement is 3.78V. Back EMF for various speed and field input voltages are compared in Fig. 12, and comparison show good agreements.

From the comparison to 3D FEA and experimental results, 2D equivalent model and analysis are verified. In Table 2, other aspects of 2D and 3D analysis for claw-pole generator performed in this paper are compared.

VI. Conclusions

Practical analysis method for claw-pole type generator is developed in this paper. 2D equivalent model for claw-pole type generator is designed and 2D FEA is performed. The design process is described in detail and analysis results of 2D FEA are verified by 3D FEA and measurements. With simple modeling and much less computation time comparing to 3D FEA, presented analysis method can be directly applied to the analysis and design of claw-pole type machine.

Acknowledgment

This work was partially supported by MOCIE through IERC and K-MEM R&D Cluster

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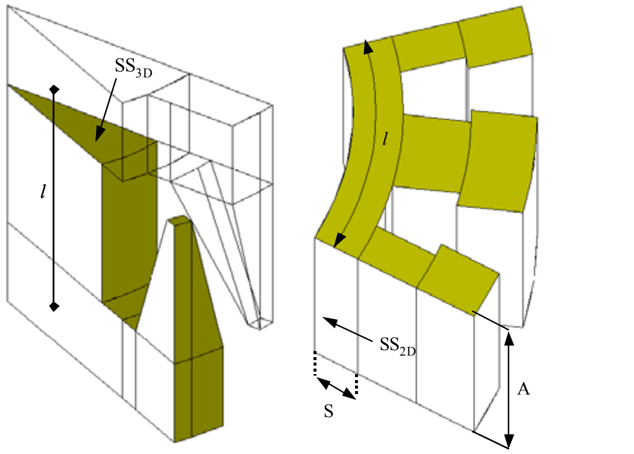


a. 3D geometry to determine "S"   b. Conceptual 2D equivalent model and determination of "S"

Fig. 7 Determination of "S"

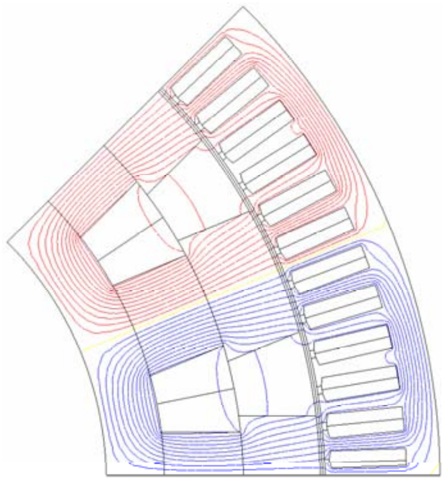
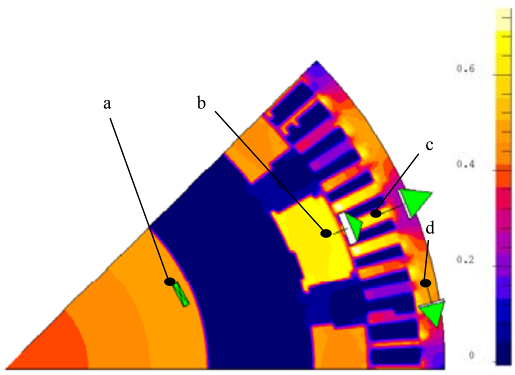
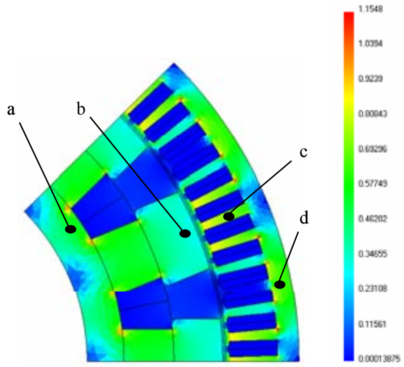


Fig. 8 Equi-potential lines from 2D FEA



a. Flux density from 3D FEA



b. Flux density from 2D FEA

Fig. 9 Comparisons of flux density at rotor and stator part

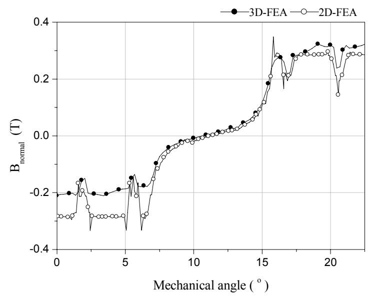
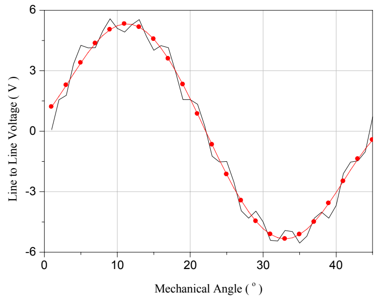
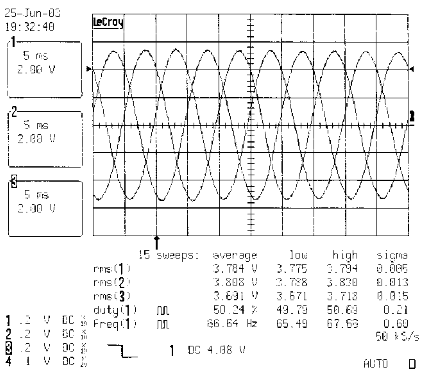


Fig. 10 Air gap flux density from 2D and 3D FEA



a. Back EMF waveform from 2D FEA



b. Back EMF waveform from measurement

Fig. 11 Line to line back EMF waveform from 2D FEA and measurement

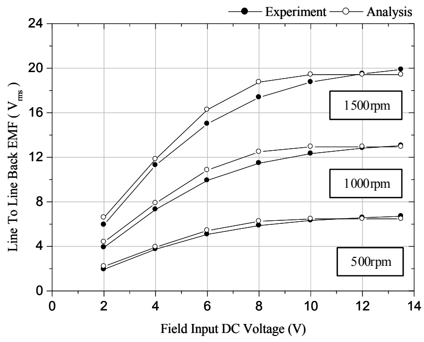


Fig. 12 Comparison of back EMF according to the input voltage and speed obtained by 2D analysis and measurements

TABLE I

FLUX DENSITY OF 3D FEA AND 2D FEA

Position	3D FEA	2D FEA
a	0.484 T	0.400 T
b	0.648 T	0.275 T
c	0.623 T	0.592 T
d	0.523 T	0.523 T

TABLE II

COMPARISON OF 3D FEA AND 2D FEA

	Number of elements	Computation time for single step	Modeling	System
3D FEA	168,488 tetrahedral	30 min.	Hard	Pentium IV 2.4 GHz with 1G RAM
2D FEA	14,000 triangular	30 sec.	Easy	