Characteristic Analysis of Claw-pole Generator using Equivalent Magnetic Circuits

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Abstract — Magnetic field analysis of claw-pole type generator using equivalent magnetic circuit is presented in this paper. On the basis of 3D geometry, equivalent magnetic circuit, which consists of permeance and magneto motive-force (MMF) source, is designed and field analysis is performed by solving it. Non-linear characteristic of material is considered for precise analysis results. 3D FEA is performed to verify calculated results and flux densities in rotor and stator regions are compared. Comparing to 3D FEA, presented method gives precise results within instant calculation time. Calculated no-load back-EMF for field input voltage and speed of two models are verified by experiments.

I. INTRODUCTION

Unlike conventional electric rotary machines, the rotor poles of claw-pole type generators are made by mold and their shape is not symmetrical along rotor axis. This structure results in the 3D-dimensional (3D) flux distribution in the machines and requires 3D magnetic field analysis. Therefore, 3D finite element analysis (FEA) can be directly applied to the magnetic field analysis. However, 3D FEA requires huge computation time and memory. Therefore, it is not practical to apply 3D FEA in the initial design stage of claw-pole type machine.

3D FEA is performed to investigate the flux paths in the generator, then, equivalent magnetic circuit (EMC) is constructed considering flux paths in this paper. By applying Kirichoff's current law (KCL), equations on each node are generated and represented in matrix composed of permeance, potentials at nodes, and magneto motive-force (MMF) sources. By solving the matrix, unknown potentials at nodes are calculated, and flux densities are simply calculated from potentials and permeances.

Comparing to 3D FEA, field analysis using EMC provides precise results almost instantly, while 3D FEA requires huge computation time and efforts. Therefore, the EMC method will effective for the initial design of machines having complex flux distributions.

II. CLASSIFICATION

A. Analysis model

Fig. 1 shows the general construction of a claw-pole type generator. The analysis model of 3kW has16 poles in the rotor and 96 slots in the stator 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. However, since rotor structure is not symmetrical along rotor axis, flux distributions are 3D and this leads to the difficulty in design and analysis of the machine.

B. Concept of EMC

In Fig. 2 EMC components are shown, where u_1, u_2, Φ_1, R_1, F_1 is the potentials at nodes, magnetic flux, magnetic resistance, and MMF source respectively. Ohm's law in electric circuit is applied on the basis of analogy between electric and magnetic circuit and represented in (1). The quantity of flux can be represented (2) and (3) in the circuit. Flux continuous condition at each node is applied, then, the MEC is represented in matrix form as shown in (5)

$$F = N \cdot I = R_m \cdot \Phi \tag{1}$$

$$\Phi = \frac{F}{R_m} = P \cdot F \tag{2}$$

$$\Phi_1 = P_1 \cdot (U_1 - U_2 \pm E_2) \tag{3}$$

$$\sum_i \Phi_i = 0 \tag{4}$$

$$[P]\{U\} = \{F\} \tag{5}$$

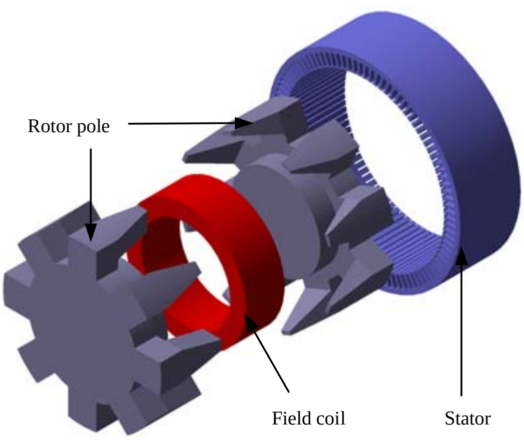

Fig. 1. Configuration of claw-pole generator.

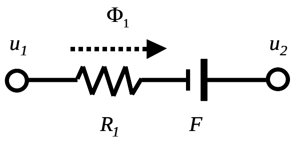

Fig. 2. Configuration of claw-pole generator.

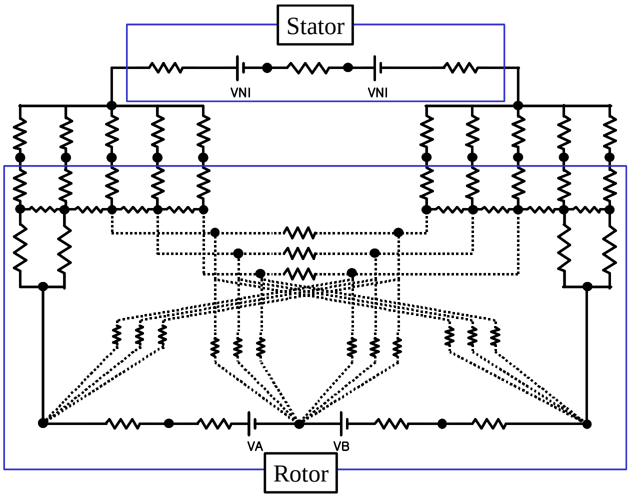

Fig. 3. Equivalent magnetic circuits.

Equivalent magnetic circuit is constructed according to the flux path and shown in Fig. 3, where, VA and VB are half of field MMF, VNI is the armature reaction MMF. Solid lines are flux paths in the iron cores, and dotted lines are that in the air. The equivalent circuit represents half of N-pole and S-pole that corresponds to the 3D FEA model.

Comparing to previous research; [3], the equivalent magnetic circuit in Fig. 3 is very simple. This is due to that not all the leakage flux paths are considered, but only main leakage paths are considered in this paper. From the 3D FEA, it is proved that the quantity of the other leakage flux is negligible.

III. RESULTS AND DISCUSSION

A. Comparison of flux density

To verify presented analysis method, two models (Model-1 Model-2) are selected and tested. Flux densities of Model-1 calculated from EMC in air-gap, rotor surface, and stator tooth are compared with that from 3D FEA in Table I. Comparing to 3D FEA, results from EMC have some errors, however, the errors does not seem to be significant for estimation the flux saturation in the rotor poles and stator teeth. If more accuracy is required, increasing elements in the analysis model will be helpful.

B. Back-EMF under the no-load

No-load back-EMFs of two generators (Model-1 and Model-2) are calculated for field input voltage and speed. The calculated back-EMF compared to experimental measurements and the comparison is shown in Fig. 4.

C. Computation time

Computation time of 3D FEA and EMC required for the field analysis is compared in Table II. Comparing to 3D FEA, EMC method gives precise results almost instantly.

TABLE I
The comparison of flux density 3D FEA and EMC

Element number	Area	|B| (T)	
		3D FEA	3D EMC
2	Rotor	0.25	0.21
10	Air-gap	0.17	0.18
14	Stator teeth	0.36	0.34

TABLE II
The comparison of computation time

	Number of element	Computation time	System
3D FEA	168,488	30 minutes	Pentium IV 2.4 GHz with 1G RAM
3D EMC	54	1 second	

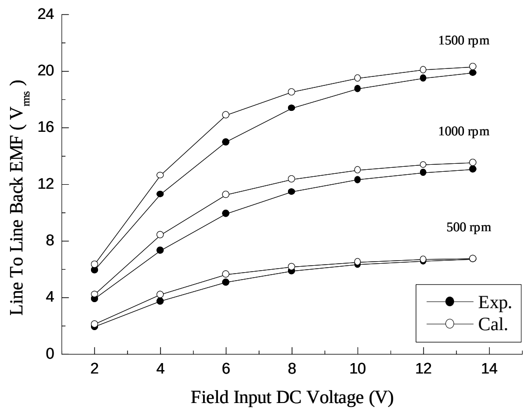

Fig. 4. Line to line back-EMF of Model-1

IV. CONCLUSIONS

Magnetic field analysis of claw-pole type generator using magnetic equivalent circuit is presented in this paper. Detailed calculation method of permeance is presented for the design of magnetic equivalent circuit and analysis result is verified by experimental measurement.

V. REFERENCES

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