Improvement of Torque Characteristic of Flux-Concentration-Type Surface Permanent Magnet Motors

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Abstract — This paper presents results of torque characteristic analysis of magnetic flux concentration type surface permanent magnet synchronous motors (CSPMSMs). Firstly we optimized the stator structure suitable for the conventional 12-pole CSPM rotor construction by using the finite element method. Then the rotor permanent magnet arrangements were examined in order to improve the torque characteristic. In the optimized model, we achieved larger average torque and small cogging torque.

I. INTRODUCTION

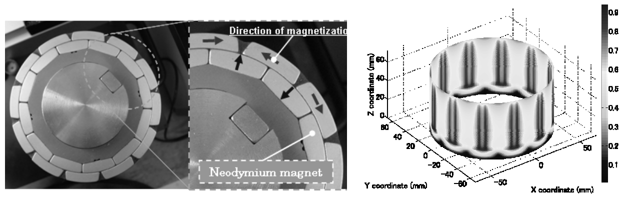
Recently, demands for development of small size, high torque, and high efficiency motors are increasing more and more. However there is a limitation in the current motor design technique to achieve all the requirements [1]. We have also aimed to develop a high torque permanent magnet motor and developed a concentration surface permanent magnet (CSPM) synchronous motor by applying the CSPM arrangement. The CSPM arrangement structure contributes to concentrated magnetic flux distribution and increase of the maximum flux density in the air gap. As a result, higher torque in proportional to the magnetic flux density in the air gap can be obtained [2].

We have investigated firstly the stator structure suitable for the conventional 12-pole CSPM rotor construction by using the finite element method (FEM). After that, we tried to improve the rotor construction by changing the permanent magnet arrangement in order to improve the torque characteristic. In the optimized model, the average torque was about 10% improved in comparison with that of the conventional model.

II. CSPM ARRANGEMENT AND MODELS

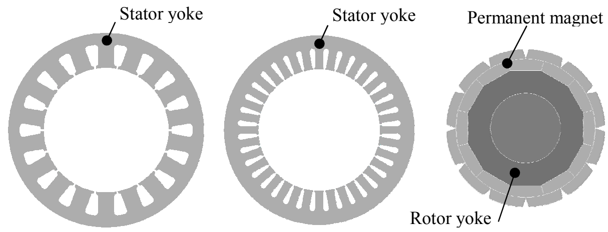
Fig.1 (a) shows the CSPM arrangement used in the rotor structure. A high magnetic flux density in comparison with that of the remanence of the permanent magnets (PMs) can be generated by facing the same poles of PMs to each other. Fig. 1 (b) shows the measured magnetic flux density distribution around the rotor surface. As shown in this figure, the magnetic flux distribution is salient around the V-shaped slots and it is possible to generate locally strong magnetic fields with the CSPM arrangement.

Fig.2 (a) shows the conventional 18-slot stator structure, which has the concentrated windings and Fig. 2 (b) shows the optimized stator structure, which has 36-slots and the distributed winding. The number of turns of the stator winding per phase was kept to be 252 turns in the both models. In addition, Fig.2 (c) shows the conventional 12-pole rotor structure of the CSPM arrangement. The magnetizations of the PMs were assumed to be 1.33T. Table I shows the specification of the analyzed model.



(a) CSPM rotor structure (b) Distribution of magnetic flux density

Fig.1.CSPM arrangement and the flux distribution



(a) Conventional (b) Optimized (c) CSPM rotor model

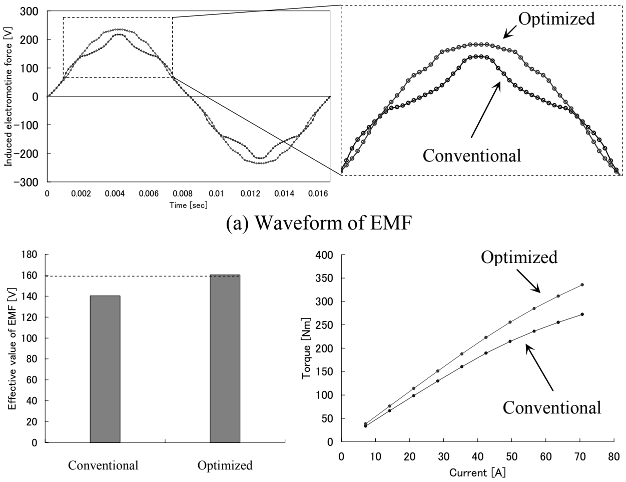
Fig.2. Analyzed models

TABLE I
SPECIFICATION OF THE ANALYZED MODEL

	Conventional	Optimized
Number of slot	18	36
Number of pole	12	
Number of turns [turn/phase]	252	
Residual magnetization [T]	Neodymium 1.33	
Winding	Concentrated	Distributed

III. OPTIMIZED RESULTS OF THE STATOR CONSTRUCTION

Figs. 3 (a) and (b) show comparison of the induced electromotive force (EMF) waveforms and the effective values of EMF for the each model, respectively. The EMF waveform of the optimized 36-slot model was closer to a sinusoidal waveform in comparison with that of the conventional model, because the conventional model was the concentrated winding and the optimized model was the distributed winding. Generally the effective value of EMF decreases by eliminating the harmonic content in the induced EMF waveform and EMF waveform approaches to a sinusoidal waveform by means of the distributed winding [3]. However the effective value of EMF of the optimized model was larger than that of the conventional one. This is a result of elimination of the leakage flux. Fig.3 (c) shows the torque characteristics as a function of the load current. The torque increased with increasing the load current in each model and the optimized one was superior in magnitude and linearity.



(a) Waveform of EMF

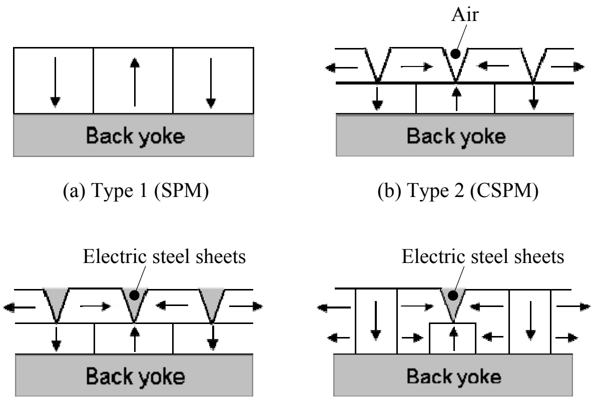
(b) Effective value of EMF (c) T-I characteristics

Fig.3. Analyzed results

IV. ANALYZED MODELS OF PERMANENT MAGNET ARRANGMENT

Figs. 4 (a) through (d) show the arrangement of the permanent magnets. Type 1 is the common SPM structure and Type 2 is the conventional CSPM arrangement. Type 3 is a CSPM structure that the V-shaped slots are filled with stacked electric steel sheets (ESS). Type 4 is a new hybrid one. The numbers of the stator slots and the rotor poles were assumed to be 36 and 12, respectively.

The outer diameter of the stator core was assumed to be 180 mm, and the inner diameter of the rotor core was assumed to be 113 mm. The number of turns of the stator winding per phase was kept to be 372 turns in all the models. Table II shows the specification of the analyzed model.



(a) Type 1 (SPM) (b) Type 2 (CSPM)

(c) Type 3 (CSPM with ESS) (d) Type 4 (HCSPM)

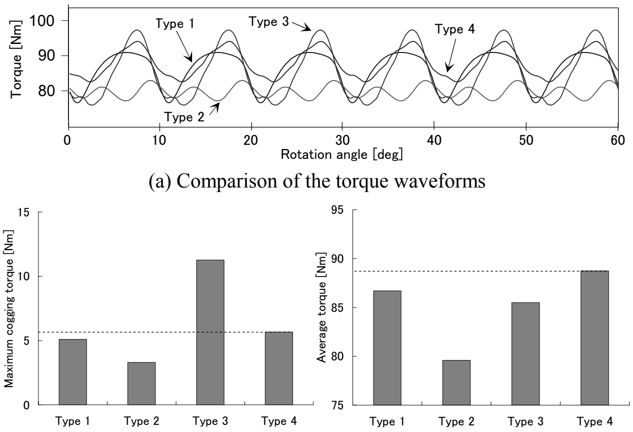
Fig.4. Analyzed permanent magnet arrangements

TABLE II
SPECIFICATION OF THE ANALYZED MODEL

Number of slot	36
Number of pole	12
Number of turns [turn/phase]	372
Residual magnetization [T]	Neodymium 1.33
Winding	Distributed

V. ANALYZED RESULTS

Figs. 5 (a) and (b) show comparisons of the torque waveforms and the maximum cogging torque. The torque ripple of Type 3 was the largest and one of Type 2 was very small. The cogging torque is generated alternatively by changing the magnetic energy due to variation of the magnetic flux of the permanent magnets, because of the permeance changes according to the rotor position. In the other word, the variation of the magnetic flux density in the air gap influences greatly on the cogging torque characteristic. The maximum cogging torque of Type 3 was the largest and one of Type 2 was the smallest. Ones of Type 1 and Type 4 became almost similar value. Fig. 5 (c) shows the average torque. The largest average torque was obtained in the Type 4.



(a) Comparison of the torque waveforms

(a) Maximum cogging torque (c) Average torque

Fig.5. Torque characteristics

VI. CONCLUSIONS

In this paper, the stator structure suitable for the CSPM arrangement and the influence of CSPM arrangements on the torque characteristic were investigated with the FEM. The obtained results can be summarized as follows;

(1) The reduction of the leakage flux was able to be achieved in the optimized 36-slot stator structure for the conventional 12-pole CSPM rotor structure. The EMF waveform become nearly sinusoidal and the torque characteristic also improved.

(2) In comparison of the torque characteristics of the analyzed models, Type 4 (HCSPM) had the largest average torque and the cogging torque was kept in the similar low level of the common SPM (Type 1).

VII. REFERENCES

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