Mathematical Model of Magnetic-Geared Motor with Permanent Magnets Only in Stator

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Abstract

A magnetic-geared motor (MGM) with permanent magnets only in its stator is proposed. The MGM can control the maximum transmission torque utilizing DC currents. In addition, low-speed rotor torque due to coil currents is larger compared with conventional MGMs. Therefore, the dynamic characteristics of the proposed MGM are different from that of conventional MGMs. In this paper, firstly, a mathematical model of the proposed MGM is created. Secondary, the electric circuit equation of the proposed MGM is described, and physical quantity maps are introduced. Finally, the simulated relationship between the phase angle difference of the rotors and load is compared with finite element analysis under vector control.

1 Introduction

A magnetic-geared motor (MGM) is focused because of its low-speed and high-torque characteristics. However, the assemblability of the MGM is low due to a large amount of permanent magnets (PMs). In order to solve this problem, an MGM with PMs only in its stator is proposed [1]. The proposed MGM can control the maximum transmission torque by using DC currents. Therefore, the decrease of the maximum transmission torque due to a small amount of PMs can be compensated.

2 Magnetic-geared Motor and Control Diagram

Fig. 1 shows an MGM with PMs only in its stator. The MGM consists of high- and low-speed rotors, and stator. The stator has 2 sets of 3-phase coils. Positive DC currents are applied to a set of 3-phase coils, and negative DC currents are applied to another set of 3-phase coils. In addition, 2 sets of 3-phase AC currents are superimposed on the coils. In this way, the DC currents can control the maximum transmission torque. Furthermore, the proposed MGM can rotate without DC currents because of the stator PMs.

The electrical circuit equation of the proposed MGM is shown in (1).

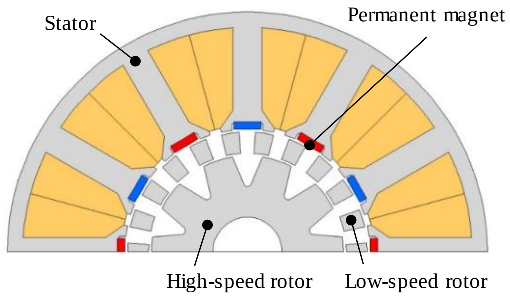

Figure 1: Magnetic-geared motor

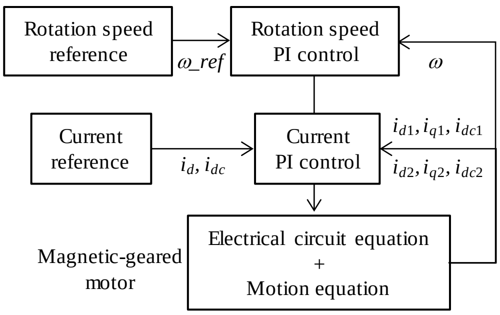

Figure 2: Control diagram

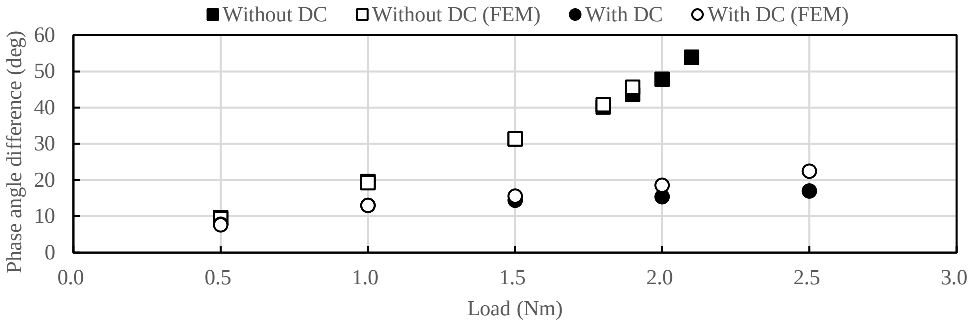

Figure 3: Load vs. phase angle difference

$$\begin{pmatrix} v_d \\ v_q \\ v_\gamma \end{pmatrix} = R\begin{pmatrix} i_d \\ i_q \\ i_\gamma \end{pmatrix} + \omega\begin{pmatrix} 0 & -L_q & 0 \\ L_d & 0 & L_1 \\ 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} i_d \\ i_q \\ i_\gamma \end{pmatrix} + \begin{pmatrix} L_d & 0 & L_1 \\ 0 & L_q & 0 \\ L_1 & 0 & L_2 \end{pmatrix}\begin{pmatrix} \frac{di_d}{dt} \\ \frac{di_q}{dt} \\ \frac{di_\gamma}{dt} \end{pmatrix} + \begin{pmatrix} \sqrt{\frac{3}{2}}\omega\psi_q \\ \sqrt{\frac{3}{2}}\omega\psi_d \\ 0 \end{pmatrix} \quad (1)$$

where v_d, v_q, and v_γ are d-, q-, and γ-axis voltages, respectively, i_d, i_q, and i_γ are d-, q-, and γ-axis currents, respectively, ψ_d and ψ_q are d- and q-axis fluxes, respectively, L_d and L_q are d- and q-axis inductances, respectively, L_1 and L_2 are the AC and DC component of the inductances, respectively, R is the coil resistance, and ω is the rotation speed of the high-speed rotor. The proposed MGM is driven by 2 sets of 3-phase vector control as shown in Fig. 2.

3 Comparison with Finite Element Analysis

In order to verify the mathematical model of the proposed MGM, the relationship between the phase angle difference and load of the mathematical model is compared with that of the finite element analysis model.

Fig. 3 shows the relationship between the phase angle difference and load. The torque when both rotors step out is different from each other. This is because the change ratio of the phase angle difference against load is large just before both rotors step out. Therefore, we can see that Fig. 3 shows a good agreement between the simulated and computed results.

4 Conclusion

In this paper, a mathematical model of an MGM with PMs only in its stator was described. The circuit equation was introduced, and a control model for the proposed MGM was described. Finally, the validity of the mathematical model was confirmed by the finite element analysis model in terms of the relationship between the phase angle difference of both rotors and load.

References

[1] J. Okamoto, N. Niguchi, and K. Hirata, *Proposal of a Magnetic-Geared Motor with Controllable Maximum*, Proceedings of the 2022 International Conference on Electrical Machines and Systems (ICEMS2022), Paper ID:1570815204.