Transmission Torque Analysis of a Novel Magnetic Planetary Gear Employing 3-D FEM

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Abstract — This paper describes the transmission torque characteristics of a novel magnetic planetary gear. A hybrid-type magnetic planetary gear is proposed, and the operational principle is shown when it is operated as a star-, planetary-, and solar-type magnetic planetary gear. Then the dynamic transmission torque characteristics are computed by employing 3-D finite element method, and lastly verified by carrying out measurements on a prototype.

I. INTRODUCTION

Magnetic gears have some advantages such as low mechanical loss and maintenance-free operation that are not observed in mechanical gears. In addition, magnetic gears have an inherent overload protection. Therefore, a variety of magnetic gears have been proposed, and some studies have been focusing on magnetic planetary gears. However, they are not practical due to the requirement of a lot of permanent magnets and the complex shapes of the rotors and stators [1]-[6].

This paper proposes a novel hybrid-type (HB-type) magnetic planetary gear. The operational principle of this gear is shown when it is operated as a star-, planetary-, and solar-type magnetic planetary gear. The transmission torque characteristics of this gear are computed by employing dynamic analysis with 3-D finite element method, and lastly verified by carrying out measurements on a prototype.

II. HYBRID-TYPE MAGNETIC PLANETARY GEAR

Fig. 1 shows the novel HB-type magnetic planetary gear proposed in this study. This gear consists of a sun gear, four planetary gears, and a ring gear. The four planetary gears are connected with each other by a carrier (which is not shown in Fig. 1). Each gear has an axially magnetized permanent magnet between two yokes which are made of SUYP. These two yokes have a phase difference of half a pole-pitch as shown in Fig. 1(b). This configuration works as a conventional gear with multipole magnets.

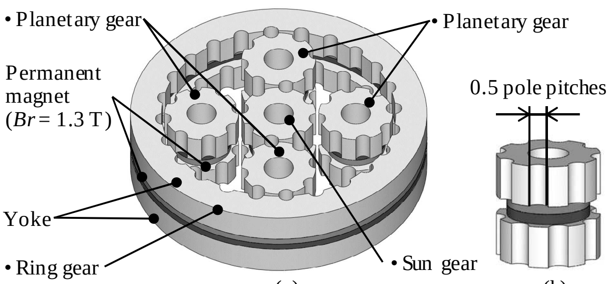


Fig. 1. HB-type magnetic planetary gear

III. OPERATIONAL PRINCIPLE

The number of poles in the gear must satisfy (1).

$$Z_c = Z_a + 2Z_b \tag{1}$$

where Z_a, Z_b, and Z_c are the number of poles of the sun, planetary, and ring gear, respectively. In this study, Z_a = 16, Z_b = 16, and Z_c = 48, and the gear ratios are obtained according to the gear combinations shown in Table I.

IV. ANALYSIS METHOD AND CONDITION

In order to compute the dynamic transmission torque of the HB-type magnetic planetary gear, the Ω method is employed. In this study, eddy currents are ignored because this gear is designed for the low operational speed range.

In the Ω method, (2) is satisfied.

$$\mathrm{div}\{\mu(\boldsymbol{T_m} - \mathrm{grad}\Omega)\} = 0 \tag{2}$$

where $\boldsymbol{T_m}$ is the current vector potential of the equivalent magnetizing current density $\boldsymbol{J_m}$ shown in (3), Ω is the magnetic scalar potential, μ is the permeability.

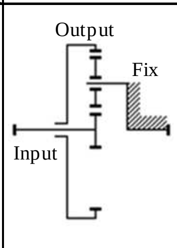
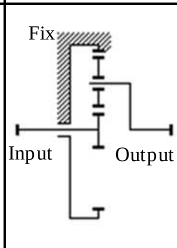
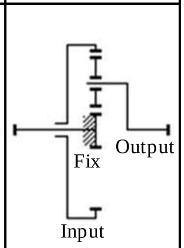
$$\boldsymbol{J_m} = \mathrm{rot}\boldsymbol{T_m} \tag{3}$$

In this analysis, the input gear is rotated at 1 rpm, and the output gear rotates according to the following motion equation. The time step is 5 ms.

$$J\frac{d^2\theta}{dt^2} = T_r - T_f \tag{4}$$

where J is the moment of inertia, θ is the rotation angle, T_r is the torque transferred to the output gear, T_f is the friction torque(In this analysis, 0.003 Nm was given to each gear).

TABLE I
THREE TYPES OF COMBINATIONS

	Star-type	Planetary-type	Solar-type
Schematic view			
Sun gear	Input	Input	Fix
Planetary gear	Rotation	Rotation+Revolution (Output)	Rotation+Revolution (Output)
Ring gear	Output	Fix	Input
Gear ratio	$-\frac{Z_c}{Z_a} = -3$	$\frac{Z_c}{Z_a} + 1 = 4$	$\frac{Z_a}{Z_c} + 1 = \frac{4}{3}$

V. ANALYSIS RESULTS

The computed transmission torque of the star- and planetary-types without load is shown in Fig. 2.

In the star-type, the maximum transmission torque of the sun and ring gear is 0.039 Nm and 0.113 Nm, respectively, and the gear ratio –2.9 is obtained. In the solar-type, the maximum transmission torque of the ring gear and carrier is 0.127 Nm and 0.165 Nm, respectively, and the gear ratio 1.29 is obtained. These results are slightly smaller compared to the theoretical ones shown in Table I due to the friction torque.

Next, the transmission torque and the rotation angle of the output gear are computed with a constant load on the output gear. The results of the solar-type are shown in Fig. 3.

The gear ratio calculated using the average transmission torque is 1.20, which is slightly different from the theoretical value due to the friction torque and the noise of the torque waveform. This noise is thought to be computation errors of the mesh distortion, CG method, and non-linear iterations. On the other hand, the gear ratio calculated using the average rotation angle is 1.34, showing a good agreement with the theoretical one.

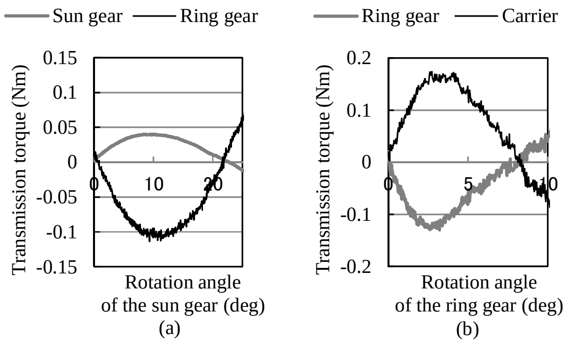


Fig. 2. Transmission torque of (a) star- and (b) solar-types

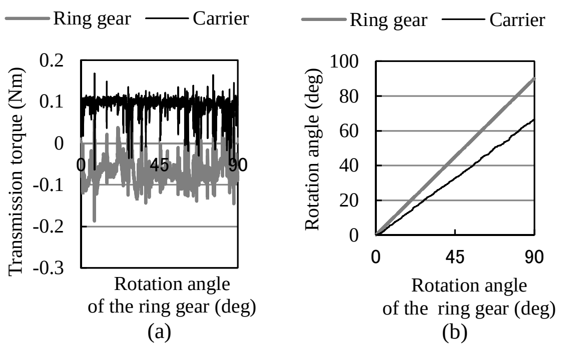


Fig. 3. (a) Transmission torque and (b) rotation angle of the-solar type

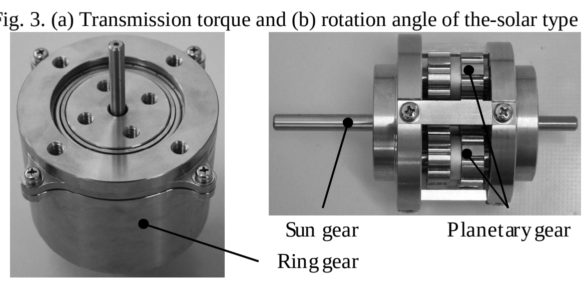


Fig. 4. Prototype of the HB-type magnetic planetary gear

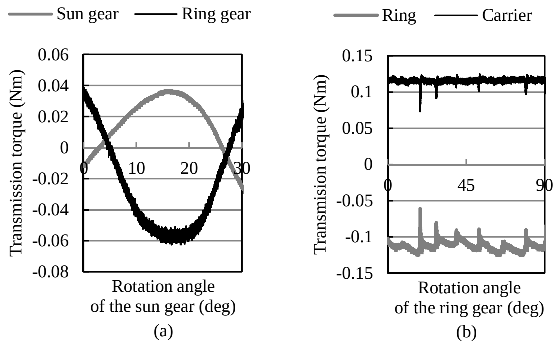


Fig. 5. (a) Transmission torque of the star-type without load and (b) transmission torque of the solar-type with load.

VI. VERIFICATION BY A PROTOTYPE

In order to verify the analyzed results, the transmission torque of a prototype (shown in Fig. 4) is measured, and the results shown in Fig. 5. Fig. 5(a) shows the transmission torque of the star-type without load, and Fig. 5(b) that of the solar-type with load. As can be seen, the gear ratio of the star-type calculated using the maximum transmission torque without load is –1.58, which is about 50% of the theoretical one. And the maximum transmission torque of the solar-type calculated using the average transmission torque with load is 1.04. These are due to the friction torque of the measuring system and the hysteresis loss.

Thus, the transmission torque of this gear is very small, and greatly influenced by the mechanical and magnetic loss.

VII. CONCLUSION

A novel HB-type magnetic planetary gear was proposed, and the transmission torque characteristics of star-, planetary-, and solar-type combinations were computed by employing 3-D FEM. The validity of the computation was verified by the measurement of a prototype.

Furthermore the gear ratio of each combination was evaluated by measuring the rotation speed for each combination using an encoder. These results will be discussed in the final paper.

VIII. REFERENCES

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