A study of Asymmetric Magnetic Field for Surfaced Permanent Magnet Spherical Motor

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Abstract — In this paper, study on having asymmetry magnetic field and research on improvement through compare core materials in surfaced permanent magnet spherical motor. And compare the data of experiments and 3D FEM simulations, verified an authenticity of the results. Surfaced permanent magnet spherical motor proposed to realize three degrees of freedom and is the focus of attention in the field of electrical applications.

I. INTRODUCTION

The surfaced permanent magnet spherical motor drive a simplification of the needed more than two degree of freedom system which can be placed in army vehicle, joints of the robot, and eyes of robot, this research is rapidly increasing in this field. Result of research of spherical motor of few years is small about the requirement of the average torque and efficiency range, so future research is needed to improve both of them. In this regard, possible to raise the level of permanent magnets or replace the stator core, in particularly suggest the stator core to powder forming core with soft magnet composite that is major role in improvement motor's output characteristics and production flexibility.

Permanent magnet of spherical motor's operating method is rotating as well as special driving as tilting, unlike conventional rotary motor is just rotating along rotating axis, in this paper analysis the torque characteristics through each tilting angle. This analysis concludes the source of torque ripple that need to know how the spherical motor can be operate in stable state. And in this paper verify improvement of average torque and efficiency and also reduction of eddy current loss by the simulation data and experiment data. Step of verification is 3D-FEM simulation based on Labview and Maxwell and experiment by real prototype, and shows the improve properties.

II. SURFACED PERMANENT MAGNET MOTOR

Since several years ago, spherical motor research has been studied continuously. And research of spherical motor is promising field of study; it is no wonder that the possibility of future growth is almost infinite. In figure 1 is modeling of Surfaced permanent magnet spherical motor. As can see in figure, driving three degree of freedom; yaw, pitch, and roll; with one motor. Existing method to drive three degree of freedom those need three motors that are connected by gears and belts. The problems with this system using the gears and belts which will be too large size and high loss at gears and belts. Compensate for all problems will be a degree of freedom of spherical motor.

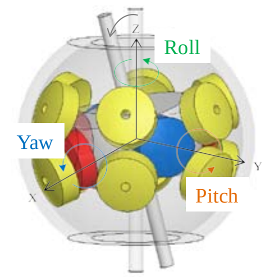
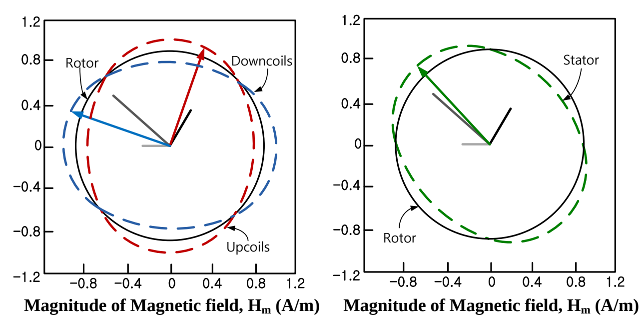


Fig. 1 Modeling the three degree freedom of spherical motor

III. SOURCE OF TORQUE RIPPLE

In surfaced permanent magnet spherical motor, the input current that flowing into the upper six coils is the parallel three phase current like a general rotating motors when tilting angle is zero. However the tilting angle is not zero, input current that flowing into the upper six coils is not unbalanced waveform of different current magnitude according to each tilting angles. In other words unbalanced three phase current of different magnitude occur torque ripple of rotating axis and X-, Y-axis torque.

X-, Y-axis torque, torque ripple, is disturb the stable driving in the steady-state. Figure 2(a) shows the separate of magnetic field by flowing into the upper 6 coils and magnetic field by flowing into the lower 6 coils using the trajectory of rotating magnetic field by MATLAB. As can be seen in the figure, magnetic field by upcoils and downcoils do not match each other. So two magnetic fields occurs the power and that is ingredient of torque ripple.



(a) (b)

Fig. 2(a)Magnetic field by upcoils and downcoils,
(b)Magnetic field by permanent magnet and stator coils

In figure 2 (b) show the stator rotating magnetic field by separating the previously synthesized and a magnetic field by permanent magnet. Magnetic field of a permanent magnet is always circle based on the rotor, but magnetic field of stator is ellipse that can be seen in the figure 2 based on the orthographic form to rotor. Harmonics by mismatch of the two magnetic fields will be served in a torque ripple. And figure 3 shows three phase stator magnetic field through each tilting angle. As can see in the figure, if the tilting angle is zero the magnetic field consistent with the permanent magnet, but if the tilting angle is not zero the ellipse of the stator by a rotating magnetic field is in the form of an ellipse along the long axis of the tilting angle increases, the shorter length of the oval shape is not.

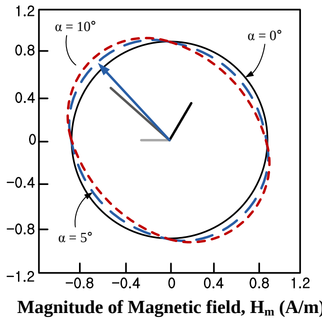


Fig. 3 Magnetic field by stator coils according to tilting angle

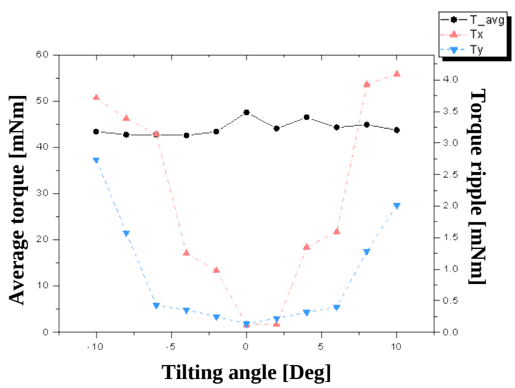


Fig. 4 X, Y and Z torque through tilting angle

If the rotational axis is tilted by the z-axis, rotating magnetic field by permanent magnet of the rotor change the current magnitude that occurs tilting about one pole of permanent magnet by two or four coils on up and down. And also flowing in the coil side like a current magnitude that produce the rotation changed again. These changes create the stator rotating magnetic field as ellipse form, not a circle.

The state of tilting angle is not zero, airgap flux by permanent magnet along X- and Y-axis to orthographic projection, not a cosine function, non-sinusoidal waveform.

In constant speed drive for each tilting angle has a nearly constant average torque values. But interfering with stable driving torque ripple is increase to space and time harmonics. That torque ripple is value of X- and Y-axis, not rotating axis.

And figure 4 shows the torque about each axis according to the actually changing each tilting angle. is X-axis torque, is Y-axis torque, and is Z-axis torque. Torque for rotating axis about each tilting angle is almost constant value, but, is increase with tilting angle grows. This EMF of the permanent magnet flux and tilting angle of the waveform with increasing space and time harmonics to the X and Y axes will be increase in torque. Through this fact, any tilting angle, X and Y axes torque for torque ripple component do not affect the rotary shaft torque and efficiency. So in this paper, research the improvement of torque and efficiency state of just considers about tilting angle is zero.

IV. SELECTION THE CORE MATERIALS

In this paper proposed the powder forming core for improving efficiencies. Presented material of stator core is powder forming core of Somaloy 550 steel and addition of 0.5% Kenolube. And conventional pure iron processing core is difficult to improve the eddy current losses in high frequency, but powder forming core is easily to improve efficiency and that will be expected big help in research of the spherical motor. Also mentioned what makes reduce the eddy current loss in powder forming core.

	200rpm (Low Speed)		1000rpm (High Speed)	
	Model 1	Model 2	Model 1	Model 2
Average Torque [mNm]	63.53	69.78	69.25	75.84
Eddy Current Loss [W]	0.016	0.015	2.55	0.39
Efficiency [%]	8.95	9.83	38.4	42.06

(a) (b)

Fig. 5 (a)Powder forming core, (b)Comparison characteristics of powder forming core and pure iron processing core

As a result, average torque is approximately 9% higher than the case of powder forming core than pure iron processing core. Eddy current loss is approximately 84% lower than pure iron processing core, so efficiency can be increased. And compared high speed range with low speed range, increase rate of eddy current loss is small in case of using powder forming core. In other words, increased efficiency in high speed range is greater than low speed range. Figure 5(b) is showing the results. So in this paper suggested the powder forming core can reduce eddy current loss problem and enhance efficiency with regard to characteristics could be an alternative.

V. REFERENCES

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