

論文 / 著書情報
Article / Book Information

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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
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論文要旨

THESIS SUMMARY

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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

In this thesis, a novel low-speed high-torque electric machine named as swirling actuator is proposed. It is driven by the electromagnetic radial force and has integrated mechanical gears. The principle, design, and experimental tests are presented in the thesis.

Chapter 1 is the introduction. First, the applications of low-speed high-torque electric machines are introduced. Second, the basic principles and characteristics of various speed reducers, direct-drive machines and geared machines are simply described. Finally, the motivation of the swirling actuator is demonstrated. Conventional electric machines do not utilize the electromagnetic radial force. Bearingless motors utilize the electromagnetic radial force to levitate the rotor shaft. In contrast, the swirling actuator aims to investigate that whether the electromagnetic radial force is possible to generate the output torque. The mechanical gears are necessary to convert the translational movements into the low-speed rotation. The gear mechanism is identical to that of cycloidal drives. Therefore, the transmission ratio is essentially high, indicating that the swirling actuator has the potential to achieve a high torque density.

Chapter 2 presents the literature review. First, direct-drive machines including the permanent magnet (PM) servo motor, vernier machines and other special direct-drive machines are picked up from the literature. Second, magnetic gears and magnetic-geared machines developed in recent decades are presented. Third, some high-torque-density mechanical-geared actuators from manufacturers are shown. A summary of the torque densities with machine volumes is presented at the end of this chapter. Moreover, literature about cycloidal machines is also introduced because it serves as a good reference for the mechanical design of the proposed swirling actuator.

Chapter 3 presents the swirling actuator with a surface-permanent-magnet (SPM) type electromagnetic part. The electromagnetic radial force is generated between a 12-slot inner stator and a swirler with 12-pole PMs. The resultant force is decomposed into two perpendicular components. The d -axis force is in the eccentric direction of the swirler. The q -axis force generates the mechanical power. The two force components rotate with the eccentric direction but have constant amplitudes. The double-layer non-overlapping stator windings are designed to generate 10-pole and 14-pole magnetomotive forces to generate the net electromagnetic radial force. The air-gap flux densities are analyzed with the non-uniform air-gap length caused by the circular motion of the swirler. The electromagnetic radial force is calculated analytically by Maxwell's stress tensor method and verified by 3-D finite element analysis (FEA). A simple experiment is also conducted to measure the static radial force. After the radial force verification, a preliminary prototype is designed for the torque measurement. Several moving pins go through the swirler to guide the circular motion with low friction losses. The prototype has an outer diameter of 100 mm, an axial length of 20 mm and a transmission ratio of 113. In the torque measurement, it is found that the d -axis force can improve the torque and gear efficiency, especially at high-torque operation points. The reason is that the d -axis force can enlarge the eccentric radius which is proportional with the mechanical power. The necessary d -axis force increases when the torque increases.

Chapter 4 presents the torque density improvement of the SPM-type swirling actuator with the same dimensions. First, the electromagnetic radial force is enhanced by reducing the nominal air-gap length from 1 mm to 0.6 mm and reducing the PM thickness from 2 mm to 1 mm. As a result, the current force factor is improved from 27.5 N/A to 51.2 N/A analytically. Then, the design of the involute-type gears is investigated. First, the effect of the pressure angle is discussed. When the pressure angle is large, the force on the meshing gear teeth that tries to push the gear to the concentric position is large. This force should be overcome by d -axis electromagnetic force. Thus, the pressure angle should be small. Second, to reach the maximum transmission ratio, the tooth number difference is set as 1, which may lead to gear interference. The gear parameters should be carefully selected to avoid the interference. Compared with the gear in Chapter 3, the new gear reduces the pressure angle from 42 degree to 20 degree and increases the transmission ratio from 113 to 150. The gear efficiency is analyzed by considering the friction loss and the strength analysis is conducted with 3-D FEA. Two prototypes are built to verify the torque density improvement by the radial force enhancement and new gear design, respectively. Considerations of mechanical design, including the load force on the bearings and the configuration of guide pins, are discussed. The peak torque density in the experiments is improved from 27 Nm/L to 64 Nm/L. Due to the thin PMs in the new prototypes, the thermal evaluations is conducted to verify that the PMs are not irreversibly demagnetized under different current densities.

Chapter 5 gives the conclusions. The future work includes the evaluation of the performance criteria related to robotics applications, and other novel topologies that integrated the electric machine and mechanical speed reducer.

備考 : 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

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