Characteristic Comparison of Various SynRMs according to the Geometric Structure by Experimental Verification

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This paper presents the loss and efficiency evaluations for synchronous reluctance motors (SynRM) with permanent magnet assisted (PMA), non-PMA and concentrated winding (CW), distributed winding (DW) by finite element method (FEM) and experiment. In this paper, the performance characteristic is compared according to the stator and rotor types in SynRM. In addition, the efficiency evaluation is also compared including iron loss, copper loss, other loss on the basis of rated load condition. Computer simulation and experimental result for the efficiency, losses evaluations using dynamometer show the characteristics of each SynRMs and enable to select a proper industrial application field.

***Index Terms*— Synchronous reluctance motor (SynRM), Torque ripple, Permanent magnet assisted (PMA), Concentrated winding (CW), Distributed winding (DW).**

I. Introduction

A DRIVING POWER SOURCE of the actuator is distinguished by hydraulic, pneumatic and electric. In the past, actuator widely used hydraulic and pneumatic valve. However, it is replaced by electric valve because easy installation and control and management. Consequently, the induction motor has been used in the electric valve actuator. This motor in terms of operation and maintenance is simple, and hence, it is popular in the industries due to low maintenance cost. On the other hand, it is low efficiency in low speed. In addition, slip caused by losses has a bad effect on torque in low speeds [1]-[4].

Therefore, the feasibility of adopting an optimal design method and fabrication of an electric-actuator-driving synchronous reluctance motor (SynRM) was studied, as presented in this paper, with specific targets of high efficiency and high torque. Four types of synchronous reluctance motors are shown in Fig. 1. Concentrated type has advantages that production cost is cheap due to the simplification of winding in factory. It is called concentrated winding synchronous reluctance motor (CW-SynRM). Distributed type has advantages that the torque ripple is decreased. It is called distributed winding synchronous reluctance motor (DW-SynRM). By adding a proper quantity of permanent magnets to the SynRM, the torque density and power factor of SynRM can be greatly increased. It is called permanent magnet assisted synchronous reluctance motor (PMA-SynRM). However, the torque ripple of the SynRMs is larger than that of induction motor and thus generates large differences in magnetic reluctance on the air gap. This torque ripple causes noise and vibration.

To solve this problem, we studied the proportion of rotor structure relative to torque characteristic, efficiency, etc. on the basis of the configurations of stator and rotor in order to select a proper SynRM. In order to verify that the performance of the comparison models is in accordance with the FEM design, an experiment was carried out using prototype motors.

II. Characteristic Analysis of SynRMs

The application of the SynRMs is the driving motor for electric-actuator.

A. Design Parameters

Main design factors that affect the L_d and L_q in optimum design are the thicknesses of the flux barrier and the rotor core layers

$$K_w = \sum(W_i) / \sum(W_c) \quad (1)$$

Here,

$\sum(W_i)$: The total flux barrier width

$\sum(W_c)$: The width of the overall core region

Therefore, the design parameters of the rotor are the thickness of the iron core and the thickness of the flux barrier. These parameters are designed considering the saturation of the iron core as well as the manufacturability. In this paper, the K_w of initial model is determined K_w = 1 in consideration of previous research result. When K_w = 1 the configuration of the rotor is constructed of alternate position in which the iron core and flux barrier are equal.

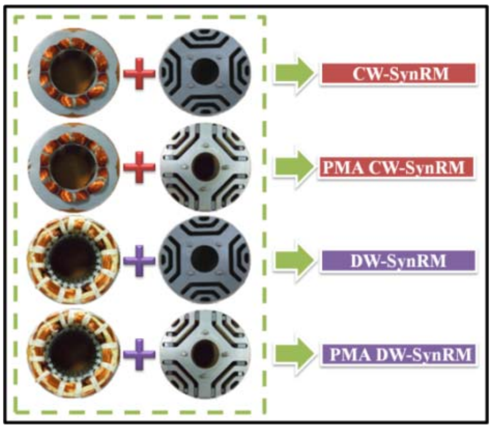

Fig. 1. Combination of SynRMs.

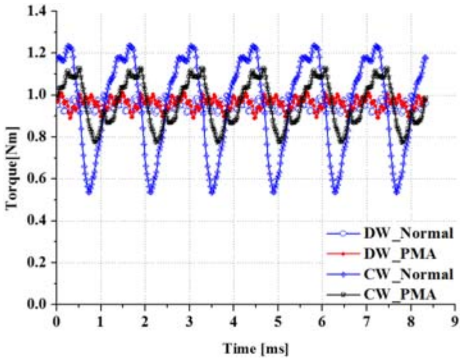

Fig. 2. Comparison of torque curves of each model. (@ rated speed: 3600rpm, output torque: 0.9Nm).

TABLE I
CHARACTERISTIC COMPARISON OF VARIABLE SYNRMS

	Irms (A)	No. of turns	Beta angle (deg)	Torque (Nm)	Torque ripple(%)	EMF (V)	K_w ratio
CW-SynRM	3.11	72	45	0.9046	73.58	117.2	0.56
CW-PMA SynRM	2.70	72	42	0.9185	37.01	103.4	0.56
DW-SynRM	3.05	36	45	0.9144	14.56	89.92	0.55
DW-PMA SynRM	2.61	36	41	0.9115	12.91	73.27	0.56

III. ANALYSIS OF THE PROPOSED MODELS

A. Results of the analysis Model

Fig. 2 shows the torque ripple characteristics of four-type SynRMs on same load condition (approximately 0.9Nm) at the rated speed. It is confirmed that the torque ripple of CW types are more fluctuated than those of DW types.

In this case of SynRM, by adding the proper amount of the PM to the rotor, the value of the torque ripple can be reduced. According to Table I, compared to the value of the torque ripple of normal type that of PMA type is reduced from 73.6% to 37.0 % and 14.6 % to 12.9 % respectively.

In addition, one should notice that the PMA type can be obtained a lower current than those that predicted by the normal type for the same torque density as shown in Table I.

IV. EXPERIMENTAL VERIFICATION

To validate the performance of the proposed design model, an experiment was carried out using prototype motor in accordance with the design model. Experimental set up consisted of dynamometer, torque sensors, power quality analyzers, power supplies, and vector control inverters and the appearance of the rotor fully assembled, as shown in Fig. 3.

It is confirmed that the input current and torque result of each SynRM in simulation closely match the experimental results, as shown in Fig. 4.

Even if the stator iron loss of the CW type is increased by a lower power factor, due to the simplification of winding carried out in the factory, this still ensures a decrease in both the quantity of copper used (by a half) and in the production costs.

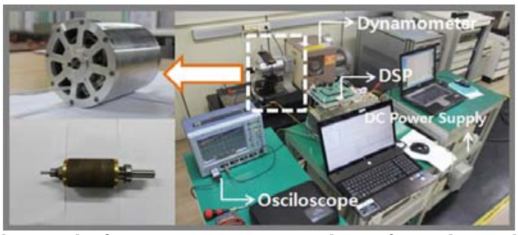

Fig. 3. Photograph of experiment equipment and manufactured rotor shape.

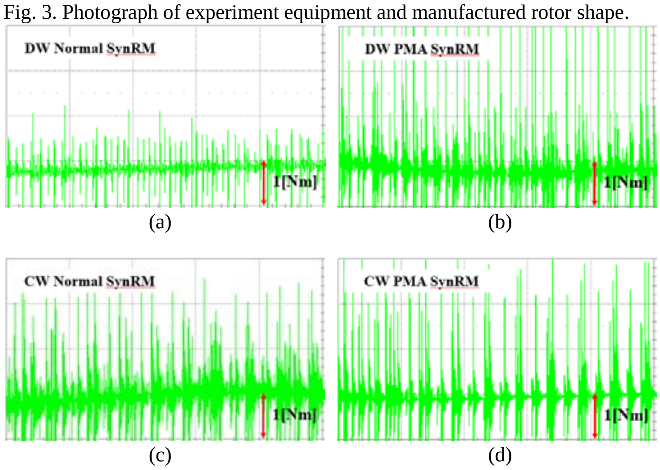

Fig. 4. Comparison of torque result of each model by experiment.

V. CONCLUSIONS

This paper deals with that the loss and efficiency of four type SynRMs is analyzed according to the winding and rotor structure by FEM and experiment verification. The four type SynRMs have been simulated and examined to obtain the efficiency and losses at same load condition.

In case of PMA rotor type, it is confirmed that the torque density is increased compared that of non PMA rotor type because L_d is reduced by inserting the permanent magnets in the direction of counteracting q-axis flux. Therefore, it is confirmed that the PMA-SynRMs have the high output power and efficiency through experimental verification. And CW-SynRMs have a lower copper loss compared to DW-SynRM. Also, DW-SynRMs have an advantage of the production cost reduction due to the simplification of winding in factory. These points have competitive power in industrial field.

Consequently, these four types of SynRM have the merits in applying for any industrial field, respectively. In the near future, SynRM is expected to be generalization in terms of energy-saving, environmental issues and industrial competitiveness.

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