송풍기용 고속 2상 6/5 SRM의 설계 및 특성해석

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Design and Characteristics of High Speed 2-Phase 6/5 Switched Reluctance Motor for Air-blower Application

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Abstract – This paper presents a design of a high speed 2-phase 6/5 switched reluctance motor (SRM) for an air-blower application. This type of motor is suitable for the applications that require high speed and only one directional rotation as air-blower. The desired air-blower is unidirectional application, and requires a wide positive torque region without torque dead-zone. In order to get a wide positive torque region without torque dead-zone during phase commutation, asymmetric inductance characteristic with non-uniform air-gap is considered. The proposed motor can be operated at any rotor position. The proposed 6/5 SRM uses short flux path technique that achieved by means of winding configuration and lamination geometry. The purpose of short flux path is to reduce the core loss and the absorption MMF in the stator. The proposed 2-phase 6/5 SRM is verified by finite element method (FEM) analysis and Matlab-Simulink. In order to verify the design, a prototype of the proposed motor was manufactured for practical system.

1. Introduction

In recent, high speed motor drives are much interested in the practical applications to reduce the system size with an increased efficiency. Especially, blowers, compressors, pump and spindle drives are suitable for the high speed motor drives. The demand for the high speed motor system is much increased according tothe industrial market. For a practical system, various electric machines are researched to apply for the high speed application such as DC motors, permanent magnet machines and SRMs.

SRM has simple structure and inherent mechanical strength without rotor winding or permanent magnet. These mechanical structures are suitable for harsh environments and high temperature and high speed applications [1-4]. This paper presents of a 2-phase 6/5 SRM for an air-blower. In this application, the impeller rotates only one direction, and it requires a wide positive torque without torque dead-zone. The proposed 6/5 SRM has self-starting ability without torque dead-zone. The 6/5 SRM is designed with 6-stator and 5-rotor poles. In order to get a wide positive torque region without torque dead-zone during phase commutation, asymmetric inductance characteristic with non-uniform air-gap is considered. The desired motor is employed short flux path [5-7]. This is an advantage of 6/5 SRM. The advantages of short flux path are to increase the efficiency and torque production while decrease the core loses.

2. Proposed 6/5 SRM

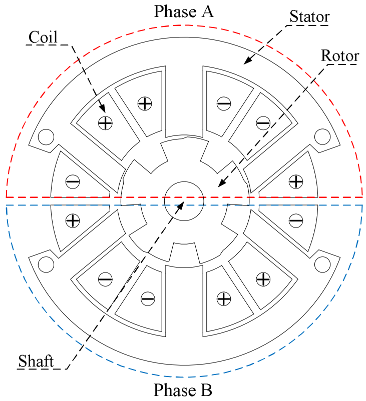
Table I shows the specifications of the proposed 6/5 SRM.

<TABLE I> Specifications of The Proposed 6/5 SRM

Parameters	Value	Parameters	Value
Output power	420[W]	Average Torque	0.2[Nm]
Stator Poles	6	Rotor Poles	5
Bore Diameter	32[mm]	Stator Outer Dia.	90[mm]
Stack Length	30[mm]	Air-gap	0.3[mm]
Stator Pole Arc	22-32[°]	Rotor Pole Arc	44[°]

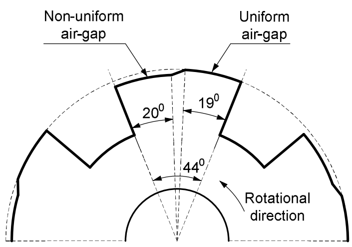
2.1 Basic principles of the 6/5 SRM

Fig. 1 shows the 2-phase 6/5 SRM structure. The proposed motor has 6 stator poles and 5 rotor poles. The stator core is separated into two e-cores with three poles each, and between these cores have no steel lamination. The stator cores are fixed by a plate. Each phase consists of windings on three poles of the e-core, and these windings are connected in serial. With this structure, the magnetic flux flows through the stator core are to be shortest.



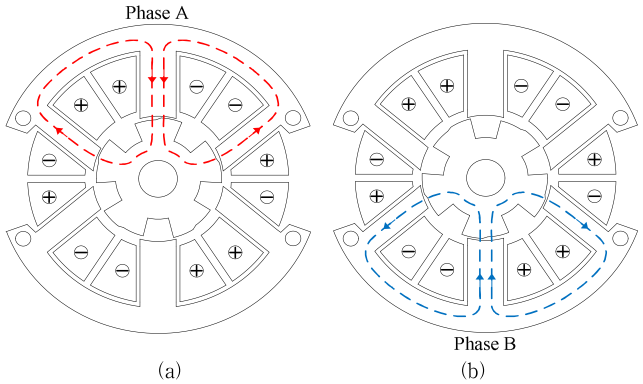
<Fig. 1> The 2-phase 6/5 SRM structure

The stator poles of the 6/5 SRM are placed at an angle of 72 degree that is equal to the rotor pole pitch. And two e-cores are shifted with rotation of 180 degree. The major problem of the one-phase and 2-phase motor is self-starting ability, and the 6/5 SRM is not an exception. To overcome this problem, a wider rotor pole arc with non-uniform shape is used. This type of rotor shape is suitable for the applications which require only one rotational direction as air-blowers in this research. The proposed rotor pole arc is 44 degree. The non-uniform shape is applied for the first 25 degree of the rotor poles as shown in Fig.2.



<Fig. 2> The rotor shape

The effects of this rotor shape like as the stepper rotor shape. With geometric structure, the inductance in the motor depends on the air-gap length and overlap area between rotor and stator poles. When the rotor and stator pole are at first overlap region, increasing overlap area results increasing inductance. Otherwise, when the rotor and stator poles are at full aligned position, the overlap area is constant, reducing of average air-gap between rotor and stator pole results increasing inductance. So, the motor can produce positive torque during 44 degree of rotor poles.



<Fig. 3> Magnetic flux path (a) Phase A; (b) Phase B

Fig. 3 shows the magnetic flux path in the proposed 6/5 SRM at the aligned position. Because of separating of these cores, the magnetic flux flows only through the respective excited poles, it can't flow through the other. To keep the rotor poles do not touch into the stator poles, the stator core is fixed by an aluminum plate. The plate has no influences on flux distribution of the proposed motor.

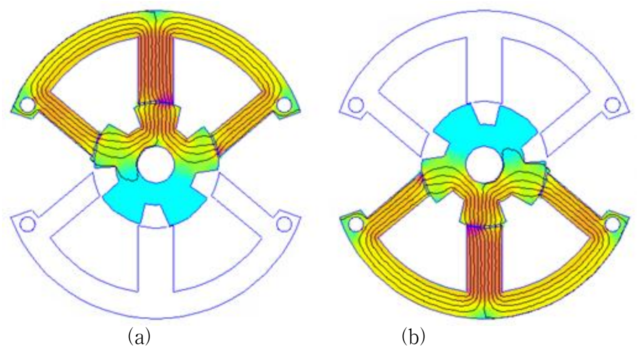
2.2 FEM analysis

Fig. 4 shows the flux distribution of the proposed motor. In this paper, the characteristic of the flux distribution that influences the performance and characteristic of the motor is analyzed by 2D FEM analysis. As shown in Fig. 4, the magnetic flux only flows through the respective phase excitation.

Torque is one of the important parameters. The designers try to increases torque with efficiency. The higher torque density that means the motor size and the cost can be reduced. Compared with the others motor which have a uniform rotor shape, the proposed motor has lower torque production. Torque characteristics depend on the relationship between flux linkages and rotor position as a function of phase current. Torque varies with rotor position and phase current. The torque production can be estimated by (1).

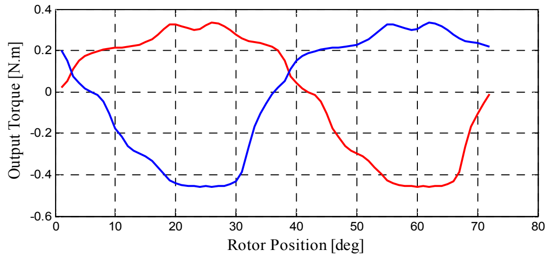
$$T_e = \frac{1}{2} i^2 \frac{dL(\theta, i)}{d\theta} \qquad (1)$$

where T_e is the electromagnetic torque, i is the excited current, and $L(\theta, i)$ is the inductance dependent on the rotor position and phase current.



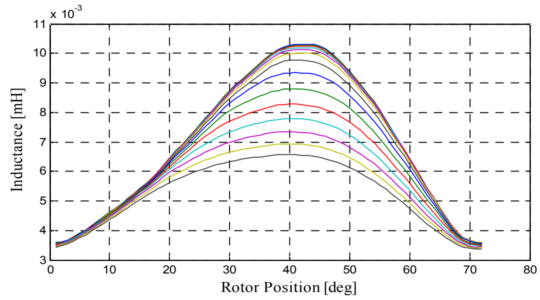
<Fig. 4> Flux distribution (a) Phase A; (b) Phase B

By using the 2D FEA, the inductance and torque characteristics are analyzed. Fig. 5 shows the torque profile of the proposed motor. As shown, the overlap torque is about 10 degree. This overlap torque ensures that the motor can be operated without the torque dead-zone and has self-starting ability.



<Fig. 5> Torque profile

Fig. 6 shows the inductance profile of the proposed motor. Because of uniform rotor shape, so the 6/5 SRM has torque and inductance profile are asymmetric shapes.

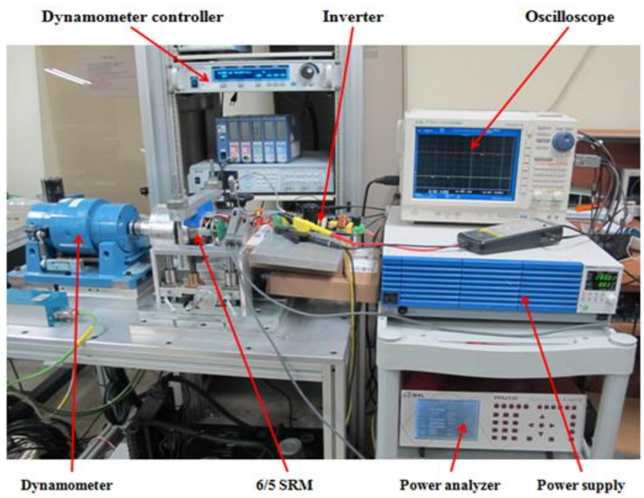


<Fig. 6> Inductance profile

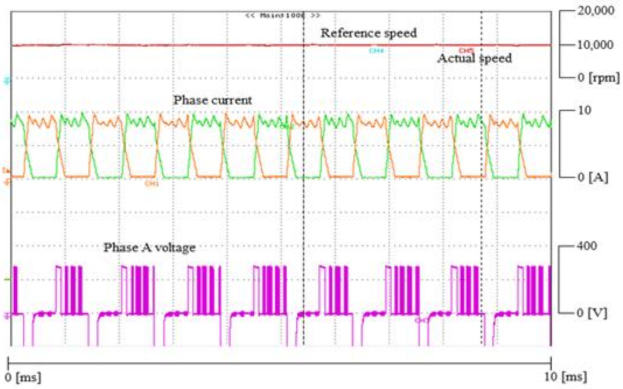
3. Experimental verification


<Fig. 7> Proposed 4/3 SRM prototype

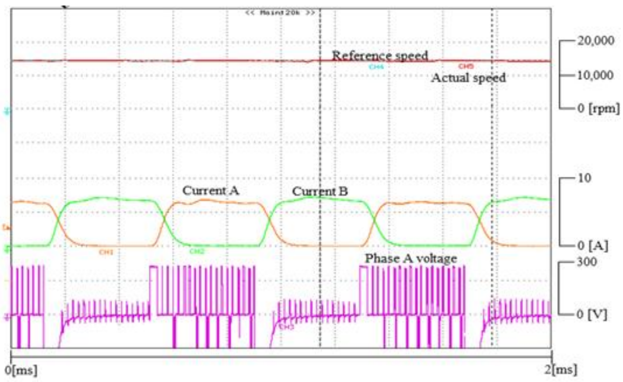
In order to verify the proposed design, a prototype was manufactured for practical system. Fig. 7 shows the prototype of the proposed 6/5 SRM. The prototype was manufactured with specifications as shown in Table 1. Fig. 8 shows the experimental setup of the 6/5 SRM drive system. The load is supplied by the dynamometer and the output power is measured by high-speed dynamometer 2WB43. The input power is measured by the power analyzer PPA2530.



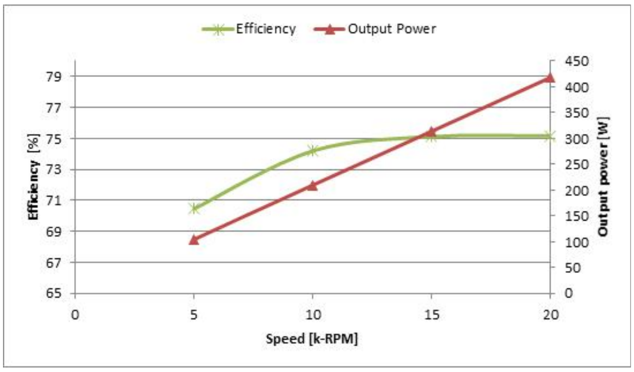
<Fig. 8> Experimental setup



<Fig. 9> Experimental results of the 6/5 SRM with the air-blower at 10,000[rpm]



<Fig. 10> Experimental results of the 6/5 SRM with the air-blower at 15,000[rpm]



<Fig. 11> Efficiency and output power characteristics with rated torque

Fig. 9 and 10 show the experimental results of the proposed motor with air-blower at 10,000[rpm] and 15,000[rpm], respectively. The output and input power are mesured by high speed dynamometer 2WB43 and power analyzer PPA2530, respectively. The total efficiency of the motor driver system at rated value, including the power converter and motor is 75.3% as shown in Fig. 11.

4. Conclusion

This paper presents a novel 2-phase 6/5 SRM which has short flux path to reduce core losses and increase torque production. In order to produce a continuous output torque, the positive torque region is extended with asymmetric inductance characteristic. The proposed motor is suitable for applications that require unidirectional rotation.

Acknowledgment

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