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4상 16/12극 SRM의 특성해석

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A Characteristic Analysis of Four-Phase 16/12 SRM

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Abstract - In the paper, a four-phase 16/12 structure Switched Reluctance motor drive is presented. The construction of the stator and the rotor in the motor, the scheme of the rotor position detector and the main circuit of the power converter are described. The comparison of the four-phase 16/12 motor and the four-phase 8/6 motor and the comparison of the four-phase 16/12 motor and the three-phase 12/8 motor are made. In the controller, the PWM control variable-speed control, the commutation control, the four quadrants control, the overvoltage protection, the overcurrent protection and the under voltage protection could be achieved. Tested results of the developed prototype are made.

1. INTRODUCTION

The traditional four-phase Switched Reluctance motor is the type of 8/6 structure, that there is eight poles in the stator and six poles in the rotor. There is a novel structure of the four-phase Switched Reluctance motor, that there are sixteen poles in the stator and twelve poles in the rotor. It is called four-phase 16/12 structure motor. In the paper, a four-phase 16/12 structure Switched Reluctance motor drive is presented. The comparison of the two types of the four-phase Switched Reluctance motor drives is made.

2. CONFIGURATION OF THE MOTORS

In the four- phase 16/12 structure motor, the two coils on the diametrically opposite stator poles could be connected to make up a winding, the two vertical windings could be connected to become one phase winding. There are no brush, no magnet and no windings on the rotor of the 16/12 structure motor. The cross section of the four-phase 16/12 Switched Reluctance motors are shown in Fig.1.

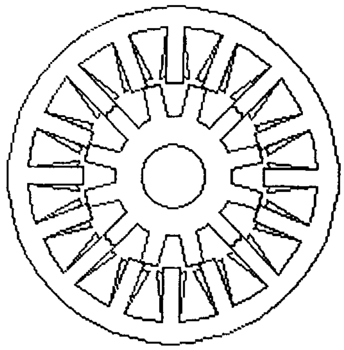


Fig.1. Cross section of the Switched Reluctance motors

The rotor position detector of the motor comprises the slotted disk coaxial with the rotor and two photoelectric transducers fixed to the case of the motor. There are twelve teeth with 150 width per tooth and twelve slots with 150width per slot in the 16/12 structure motor, and the two photoelectric transducers are installed with a (7.50 + θ_r)) interval.

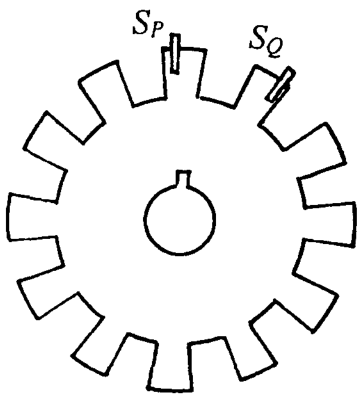


Fig.2. Schematic diagram of the rotor position detector

The schematic diagram of the rotor position detector of the four-phase 16/12 structure Switched Reluctance motor is shown in Fig.2. The two photoelectric transducers are fixed to the case of the motor that is to be installed with a 37.50 interval.

3. PRINCIPLES OF THE OPERATION

The rotor period is as follows,

$$\theta_r = 360^\circ \ / Z_r \tag{1}$$

where, Zr is the numbers of rotor poles. In 16/12 structure motor, Zr = 12, so that θ_r = 300. In the paper, θ = 00is the position that the axis of the rotor slot is aligned with the axis of the stator pole of the conducted phase, where there is the minimum value of the phase inductance.

The drive consists of the motor, the power converter and the controller. In the drives, the four-phase bifilar winding power converter supply to the motors, respectively. The one phase main circuit of the power converter is shown in Fig. 3.

While the rotor is rotated, the output signals of the two photoelectric transducers could be acted as the basic information of the rotor position. Based on the basic information of the rotor position, the main switches of the per phase in the power converter could be conducted at the certain turn-on angle, θ_1, and could be closed at the certain turn-off angle, θ_2.

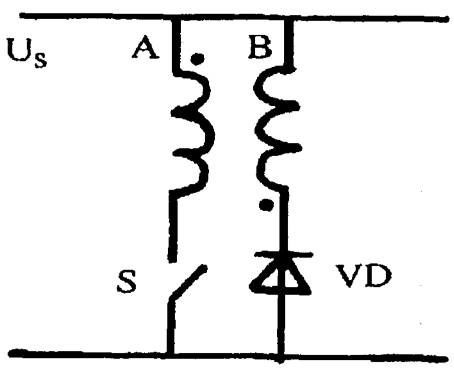


Fig.3. Main circuit of the power converter

The step angle of the two types of the motors is as follows,

$$\alpha_p = \theta_r / 4 \tag{2}$$

So that, the phase difference of the 16/12 structure motor is 7.50.

The basic output frequency of the power converter, f, is synchronism with the rotor speed, n, as follows,

$$f = \frac{Z_r}{60} n \tag{3}$$

So that, the relationship between f and n in the 16/12 structure motor is as follows,

$$f_{16/12} = \frac{n}{5} \tag{4}$$

4. COMPARISON

A. The Comparison of the Four-Phase Motors

The comparison of the two types of the four-phase motorsis made at the condition of the same outer diameter of the stator, the same bore diameter of the stator, the same length of air gap, the same bore diameter of the rotor, the same effective length of iron core, the same stator pole arc factor and the same rotor pole arc factor. With a current-source supply, a current generator, i, forces pulse into the motors at the certain rotor position from θ_1 to θ_2, which could be shown in Fig.4 with the phase inductance $L(\theta)$. θ a and θ b are related to the stator pole arc factor and the rotor pole arc factor.Based on those, the average electromagnetic torque of the m-phase motors could be expressed as follows,

$$T_{av} = \frac{m}{\theta_r} \int_0^{\theta_r} \frac{1}{2} i^2 \frac{\Delta L}{\Delta \theta} d\theta \tag{5}$$

and,

$$\Delta L = L_{max} - L_{min}$$

$$L_{min} = \frac{1}{K_1} L_{max}$$

$$\Delta \theta = \theta_a - \theta_b \tag{6}$$

where, $Lmax$ is the maximum value of the phase inductance, $Lmin$ is the minimum value of the phase inductance, and $K1$ is proportion of $Lmax$ to $Lmin$. So that

$$T_{av} = \frac{m(K_1 - 1) i^2}{2 K_1 \theta_r} L_{max} \tag{7}$$

In the 8/6 structure motor, the maximum value of the phase inductance is as follows,

$$L_{max8/6} = 2 N_{8/6}^2 \frac{\mu_0 l b_{8/6}}{\delta} \tag{8}$$

where, μ_0 is the permeability of air, l is the effective length of iron core, δ is the length of air gap, *N8/6* is the turn numbers of per stator pole coil, *b8/6* is the effective width of the stator poles and the rotor poles. Thus,

$$T_{av8/6} = \frac{m(K_1 - 1)\mu_0 li^2 N_{8/6}^2 b_{8/6}}{K_1 \delta \theta_{r8/6}} \quad (9)$$

where, θ_r 8/6is one rotor period of the 8/6 structure motor.

In the 16/12 structure motor, the maximum value of the phase inductance is as follows,

$$L_{\max 16/12} = 4N_{16/12}^2 \frac{\mu_0 l b_{16/12}}{\delta} \quad (10)$$

where, *N16/12* is the turn numbers of per stator pole coil, *b16/12* is the effective width of the stator poles and the rotor poles. Thus,

$$T_{av16/12} = \frac{2m(K_1 - 1)\mu_0 li^2 N_{16/12}^2 b_{16/12}}{K_1 \delta \theta_{r16/12}} \quad (11)$$

where, θ r 16/12is one rotor period of the 16/12 structure motor.

Because,

$$\theta_{r8/6} = 2\theta_{r16/12}$$

$$b_{8/6} = 2b_{16/12} \quad (12)$$

So,

$$\frac{T_{av8/6}}{T_{av16/12}} = \frac{N_{8/6}^2 b_{8/6} \theta_{r16/12}}{2N_{16/12}^2 b_{16/12} \theta_{r8/6}} = \frac{N_{8/6}^2}{2N_{16/12}^2} \quad (13)$$

At the same average electromagnetic torque, the turn numbers of per stator pole coil in the 16/12 structure motor and the turn numbers of per stator pole coil in the 8/6 structure motor have the relationship, which is based on (13), as follows,

$$N_{16/12} = \frac{\sqrt{2}}{2} N_{8/6} \quad (14)$$

The basic output frequency of the power converter for the 16/12 structure motor, *f16/12*, and the basic output frequency of the power converter for the 8/6 structure motor, *f8/6*, have the relationship at the same rotor speeds as follows,

$$f_{16/12} = 2f_{8/6} \quad (15)$$

So that the switch loss of the power converter and the core loss of the motor in the 16/12 structure motor are bigger than those in the 8/6 structure motor.

B. The Comparison of the Four-Phase 16/12 Motor and the Three-Phase 12/8 Motor

There are 12 stator poles and 8 rotor poles in the three-phase 12/8 structure motor. The comparison of the four-phase 16/12 motor and the three-phase 12/8 motor is also made at the condition of the same outer diameter of the stator, the same bore diameter of the stator, the same length of air gap, the same bore diameter of the rotor, the same effective length of iron core, the same stator pole arc factor and the same rotor pole arc factor. The average electromagnetic torque of the three-phase 12/8 structure motor could be expressed as follows,

$$T_{av12/8} = \frac{2m(K_1 - 1)\mu_0 li^2 N_{12/8}^2 b_{12/8}}{K_1 \delta \theta_{r12/8}} \quad (16)$$

where, *N12/8* is the turn numbers of per stator pole coil, *b12/8* is the effective width of the stator poles and the rotor poles, θ_r 12/8 is one rotor period of the 12/8 structure motor, *m=3*, and,

$$\frac{\theta_{12/8}}{\theta_{16/12}} = \frac{3}{2} \quad (17)$$

$$\frac{b_{12/8}}{b_{16/12}} = \frac{4}{3} \quad (18)$$

So,

$$\frac{T_{av12/8}}{T_{av16/12}} = \frac{3N_{12/8}^2 b_{12/8} \theta_{r16/12}}{4N_{16/12}^2 b_{16/12} \theta_{r12/8}} = \frac{2N_{12/8}^2}{3N_{16/12}^2} \quad (19)$$

At the same average electromagnetic torque, the turn numbers of per stator pole coil in the 16/12 structure motor and the turn numbers of per stator pole coil in the 12/8 structure motor have the relationship, which is based on (19), as follows,

$$N_{16/12} = \sqrt{\frac{2}{3}} N_{12/8} \quad (20)$$

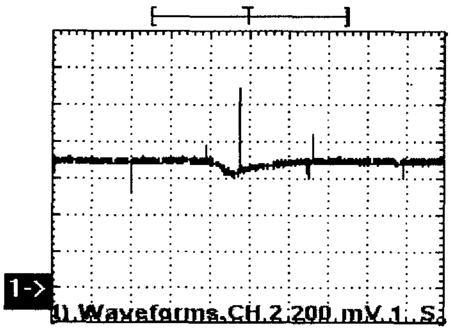
The basic output frequency of the power converter for the 16/12 structure motor, *f16/12*, and the basic output frequency of the power converter for the 12/8 structure motor, *f12/8*, have the relationship at the same rotor speeds as follows,

$$f_{16/12} = \frac{3}{2} f_{12/8} \quad (21)$$

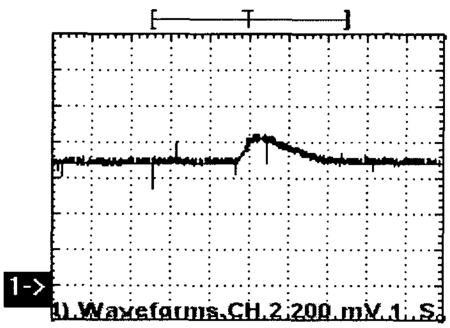
So that the switch loss of the power converter and the core loss of the motor in the 16/12 structure motor are bigger than those in the 12/8 structure motor.

5. TESTS

In the prototype, the IGBTs could be used as the main switches and the fast recovery diodes could be selected as the flywheel diodes. The closed-loop speed control with the PWM control could be adopted.

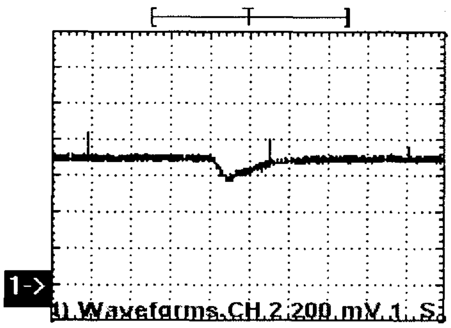


a) loading



b) unloading

Fig.4 Rotor speed curves at normal condition



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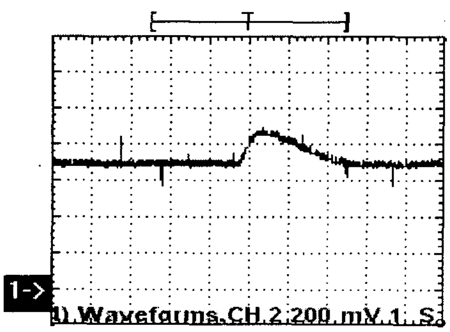

b) unloading

Fig.5 Rotor speed curves at lacking one phase condition

The controller based on the microprocessor or the hardware without the microprocessor is also suitable for the drive.

In the controller, the variable-speed control, the commutation control, the four quadrants control, the overvoltage protection, the overcurrent protection and the under voltage protection could be achieved. The DC supplied voltage is *100 V*. Fig. 4 gives the rotor speed curves, while the given rotor speed is 1*200r/min* at normal condition, and, a) the torque of the load, *1.0N.m*, is loading suddenly, b) the torque of the load, *1.0N.m*, is unloading suddenly. Fig. 5 gives the rotor speed curves, while the given rotor speed is 1*200r/min* at lacking one phase condition, and, a) the torque of the load, *1.0N.m*, is loading suddenly, b) the torque of the load, *1.0N.m*, is unloading suddenly.

6. CONCLUSIONS

The four-phase 16/12 structure Switched Reluctance motor drive are introduced in the paper. The four-phase 16/12 structure Switched Reluctance motor drive system with the four-phase bifilar winding power converter and the closed-loop speed control is the one of the choice for implementing the fault tolerant control.

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