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A Coreless film shape induction motor for the application to small devices

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Abstract
In the present paper, we propose a coreless film shape axial type induction motor for the application to small devices. In accordance with the developments of modern large scale integrated circuits, the smaller mechanical devices, i.e. micromachines, are intensively exploiting for the medical applications. Because of their physical dimensions, the small devices essentially require the the small current but high voltage type actuators. Our new induction motor proposed here has a possibility to realizing the magnetic induction type actuators by employing a large number of magnetic poles and high frequency excitation, even though most of the existing actuators are the electric field types. As an initial test motor, we constructed an axial type induction motor having 7cm diameter and 5mm width. Examination of this trial motor reveals that our induction motor may be applicable to the micromachines.

1. INTRODUCTION

As an application of the technologies associated with the developments of modern large scale integrated (LSI) electronic circuits, the smaller mechanical devices, i.e. micromachines, are now intensively exploiting for the medical applications. Because of their physical dimensions, their electric circuits consists of the extremely small size electric conductors. This means that the mechanical power source of micromachines must be driven by the low current but high voltage source, e.g. piezoelectric actuator and electric motor utilizing electric field energy [1,2]. The electric motor utilizing electric field energy does not require a large currents but its speed and torque control technologies have not been yet established. On the other side, the control technologies concerning with the electric motors utilizing magnetic field energy, i.e. conventional DC and AC electric motors, are well established because they have been used over 100 years. Among the various conventional electric motors, the polyphase induction motor is one of the most reliable and widely used electric motors. With the developments and widespreads of power electronics technologies, continuous speed and torque control of the induction motors are quite easily carried out by means of the power LSI inverters. This replaces a large number of DC motors by the polyphase induction motors. However, conventional polyphase induction motor is always composed of the iron core to control the magnetic flux flows in the machine. In principle, application of the high frequency excitation to the machines equipping a large number of magnetic poles reduces the operation current into small value but increases an iron loss. Furthermore, it is difficult to reduce their size and weight, because their mechanical structure and coil arrangement are too complex.

In the present paper, we propose a coreless film shape axial type induction motor for the application to small devices. Our coreless film shape induction motor can be constructed by a large number of magnetic poles with a

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high frequency excitation so that it does not require a large operation current. Further, application of the high frequency excitation to our motor does not increase an iron loss because our motor does not have any iron core to control the magnetic flux flow. Our new induction motor proposed here has a possibility to realizing the magnetic induction type actuators by employing a large number of magnetic poles and high frequency excitation. One of the key ideas of our motor utilizes a low magnetic resistance comprising small air gap along the flux path and large area normal to the flux path in the film shape axial type motor. The other key idea is that the rotor is installed on the both sides of the stator coils. This rotor arrangement removes a stator yoke and realizes a light weight motor. Furthermore, the coils of stator as well as rotor can be constructed by the chemical etching processes. This make it possible to realize a short air gap, light weight and cheaper producing cost. Also, in order to fit the micromachines, the size of this new motor can be minimized by means of the lithograph techniques. As an initial test motor, we constructed an axial type induction motor having 7cm diameter and 5mm width. Examination of this trial motor reveals that our induction motor may be applicable to the micromachines.

2. A coreless film shape axial type induction motor

2.1 Basic principle and structure

Figure 1(a) shows a schematic diagram of the new motor. The stator is composed of the lamination of polyphase coils. Each of the polyphase coils is located at $2\pi/3$ different positions in electrical angle. Figure 1(b) shows one of the 2 poles stator coil patterns. Application of the balanced polyphase currents to the stator exciting coils yields the rotating magnetic fields on both sides on the stator. These rotating magnetic fields induce the currents on the rotors. In order to reduce the induced currents on the rotors, the rotors themselves rotate toward the same direction of the stator rotating magnetic fields. Because of the rotor enclosing stator, it is not necessary to install a stator yoke. The stator as well as rotor are constructed by the film shape conductors so that the air gaps along the flux path can be minimized also the surface areas normal to the flux path can be maximized. Thereby, the magnetic resistances in the direction of axis can be reduced to take a small in value. Thus, it is possible to realize our coreless film shape axial type induction motor.

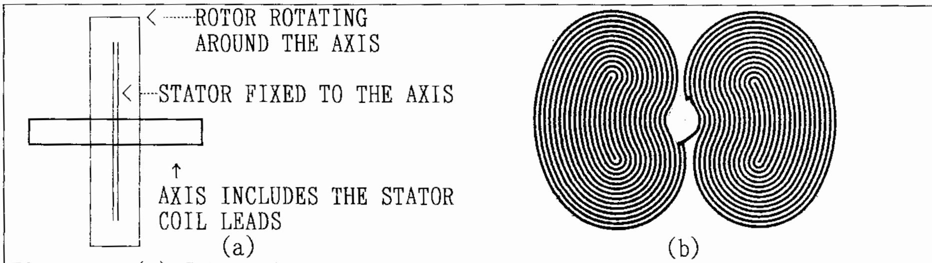


Figure 1. (a) Schematic diagram of a film shape axial type induction motor. Stator polyphase coils are fixed to the axis and their leads are taken out to the external circuit through the axis. Rotor encloses the stator coils and rotates around the axis. (b) One of the 2 poles stator coil patterns.

2.2 System equation and parameter determination

By means of the method of symmetrical coordinate, it is possible to write a following system equation of the positive phase circuit [3].

$$\begin{vmatrix} E \\ 0 \end{vmatrix} = \begin{vmatrix} R_1 + jX_1 & jX_m \\ jsX_m & R_2 + jsX_2 \end{vmatrix} \cdot \begin{vmatrix} I_1 \\ I_2 \end{vmatrix}, \tag{1}$$

where $E, I_1, I_2, R_1, R_2, X_1, X_2$, X_m and j are the stator phase voltage, stator current, rotor current, stator resistance, rotor resistance, stator reactance, rotor reactance, mutual reactance and imaginary unit $\sqrt{-1}$, respectively. Also, the slip s in (1) is defined by

$$s = (\omega - \omega_m)/\omega, \tag{2}$$

where ω and ω_m are the angular frequency of the exciting current and mechanical angular velocity referred to the electrical angular velocity, respectively.

Defining a transforming matrix

$$A = \begin{vmatrix} 1 & \\ & a \end{vmatrix}, \tag{3}$$

(1) is transformed by

$$A \cdot \begin{vmatrix} E \\ 0 \end{vmatrix} = \left[A \cdot \begin{vmatrix} R_1 + jX_1 & jX_m \\ jsX_m & R_2 + jsX_2 \end{vmatrix} \cdot A^{-1} \right] \cdot A \cdot \begin{vmatrix} I_1 \\ I_2 \end{vmatrix}$$

$$= \begin{vmatrix} R_1 + jX_1 & jX_m/a \\ jsaX_m & R_2 + jsX_2 \end{vmatrix} \cdot \begin{vmatrix} I_1 \\ aI_2 \end{vmatrix}$$

or dividing the second column by a^2

$$= \begin{vmatrix} R_1 + jX_1 & jX_m/a \\ jsX_m/a & (R_2 + jsX_2)/a^2 \end{vmatrix} \cdot \begin{vmatrix} I_1 \\ I_2' \end{vmatrix}. \tag{4}$$

When we select $a = \sqrt{R_2}$, (4) reduces to

$$\begin{vmatrix} E \\ 0 \end{vmatrix} = \begin{vmatrix} R_1 + jX_1 & jX_m/\sqrt{R_2} \\ jsX_m/\sqrt{R_2} & 1 + jsX_2/R_2 \end{vmatrix} \cdot \begin{vmatrix} I_1 \\ I_2' \end{vmatrix}. \tag{5}$$

Let consider the no load condition, i.e. $s \simeq 0$ and $I_2' \simeq 0$, in (5), then the primal resistance R_1 and reactance X_1 can be obtained by

$$R_1 = P_0/(3 \cdot I_1{}^2) \text{ and } X_1 = \sqrt{(E/I_1)^2 - R_1{}^2}, \tag{6a}$$

where P_0 is the total input power at no load. Also, let consider the lock condition, i.e. $s = 1$, in (5), then following relationships can be derived as

$$\begin{aligned} \alpha_1 &= P_l/(3 \cdot I_1{}^2) - R_1 \\ &= [X_m{}^2/R_2]/[1 + (X_2/R_2)^2], \end{aligned} \tag{6b}$$

$$\begin{aligned} \alpha_2 &= X_1 - \sqrt{(E/I_1)^2 - (\alpha_1 + R_1)} \\ &= [X_m{}^2 \cdot X_2/R_2{}^2]/[1 + (X_2/R_2)^2], \end{aligned} \tag{6c}$$

where P_l is the total input power at lock condition. By means of (6b) and (6c), the other parameters in (5) can be obtained by

$$X_2/R_2 = \alpha_2/\alpha_1 \text{ and } X_m/\sqrt{R_2} = \sqrt{\alpha_1[1+(\alpha_2/\alpha_1)^2]}. \qquad (6d)$$

Thus, we can evaluate the parameters by means of the no load and lock tests [4]. Using these parameters, the output mechanical power P_m and torque T_m are respectively calculated by

$$P_m = 3[(1-s)/s]I_{2s}'^2 \quad [W], \qquad (7a)$$

$$T_m = 3[p/(s\omega)]I_{2s}'^2 \quad [N\text{-}m], \qquad (7b)$$

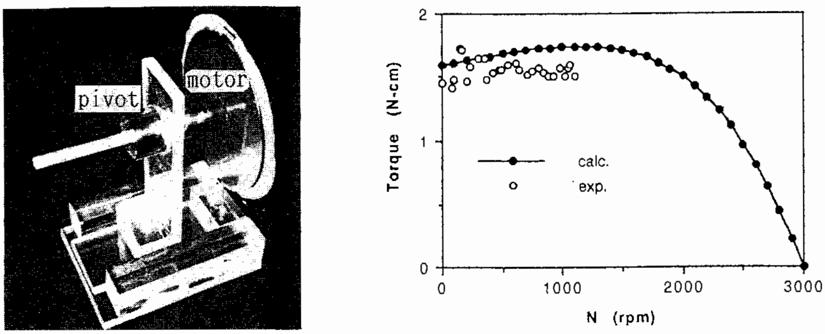
where p and I_{2s}' are the number of pole pairs and rotor current at an arbitrary slip s.

2.3 Experimental

Figure 2(a) and 2(b) show a picture of the tested motor and the torque vs. speed curve. The experimental torque T_m was obtained by measuring the stator current I_1 and total input power P_{in} at an arbitrary slip s, viz.,

$$T_m = p[P_{in} - 3 \cdot R_1 I_1^2]/\omega. \qquad (8)$$

As shown in Fig.2(b), the maximum output power of this tested motor was about 2-5[W], further, fairly good agreement between the experimented and calculated results were obtained.



(a) (b)

Figure 2. (a) Tested trial motor. (b) Torque vs. speed characteristic.

3. CONCLUSION

As shown above, we have proposed the coreless film shape axial type polyphase induction motor for the small machines use. The tests of an initial trial motor have suggested that the motor utilizing magnetic field energy may be possible to exploit for the micromachine's mechanical power source use.

4. REFERENCES

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