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DEVELOPMENT OF FLAT INDUCTION MOTOR

O.Ishizawa, T.Katoh, S.Hayano and Y.Saito

College of Engineering, Hosei University,
Kajino, Koganei, Tokyo 184, Japan

ABSTRACT

Recently, we have proposed a coreless film shape axial type induction motor for application to small devices. In this paper, we describe a designing strategy of exciting coils based on the inverse problem approarch. Further, by employing a hysteretic material for the rotors, we experimentally show that our flat induction motor exhibits a desirable torque-speed characteristics for the mechanical control use, i.e. high starting torque and constant synchronous speed. Thus, our new induction motor has a possibility to realize the magnetic induction type actuators by employing a large number of magnetic poles and high frequency excitation, even though the electric field types are commonly employed.

1. INTRODUCTION

The electric motor utilizing electric field energy does not require a large amount of currents but its speed and torque control technologies have not been established yet. 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 simplest mechanical structure and the cheapest producing cost, 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, the application of the high frequency excitation to the machines equipped a large number of magnetic poles reduces the operation current into small value but increases the iron loss. Furthermore, it is difficult to reduce their size and weight, because their mechanical structure and coil arrangement are too complex to reduce their size.

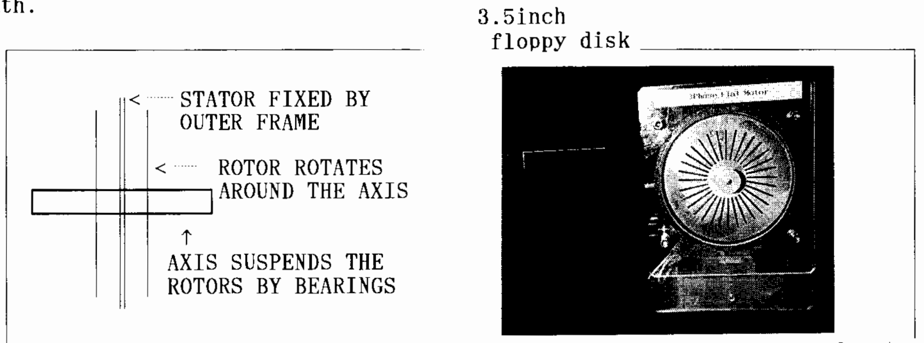
Recently, we have proposed a coreless film shape axial type induction motor for the application to small devices [1,2]. In this paper, we describe a designing strategy of exciting coils based on the inverse problem approarch [3,4]. Further, by employing a hysteretic magnetic material for the rotors ,we experimentally show that our flat induction motor exhibits a desirable torque-speed characteristics for the mechanical control use, i.e. high starting torque and constant synchronous speed.

Thus, we have succeeded to show that our new induction motor has a possibility to realize the magnetic induction type actuators by employing a large number of magnetic poles and high frequency excitation, even though the electric field types are commonly employed.

2. FLAT INDUCTION MOTOR

2.1 *Basic Structure*

Figure 1(a) shows a schematic diagram of the motor. The stator is composed of the polyphase coils, which are designed by the inverse problem approach. Figure 1(b) shows an initial tested motor which is composed of the 3 phase stator coils giving 4 poles magnetic fields and the rotors constructed by soft iron having 32 slits in order to control the rotor current flowing path.



(a) (b)

Figure 1. (a) Schematic diagram of a film shape axial type induction motor.Stator polyphase coils are fixed to the outer frame. The rotors are suspended by the bearings fixed to the axis. (b) An initial tested motor. The stator is composed of the 3 phase coils giving 4 poles magnetic fields.The rotors are composed of the soft iron having 32 slits.

2.2 *Stator Coils Design*

Basic designing strategy of our motor is just same as those of the conventional polyphase squirrel cage induction motors [5]. Namely, the stator coils fed by the balanced polyphase alternating currents yields a sinusoidally distributed revolving magnetic field on the surface of flat stator, and the rotors located both sides of flat stator with small air gap are constructed by the thin circular plates having the slits similar to the squirrel cage rotor.

Conventional designing method of the magnetic devices, for example MRI magnet, magnetic shielding and electric machines, is that the desired magnetic field distribution is iteratively evaluated by solving a governing equation with given electric current condition. On the contrary, in this paper, the electric current distribution is estimated by the sampled pattern matching (SPM in short) method with given the desirable magnetic field distribution condition [3,4,6-10]. This means that a designing strategy is proposed here by means of the inverse analysis approach. Conventional approach to the regular or forward problems yields a unique solution so that iterative approach is essentially required to reach a final goal of the designing. On the other side, our inverse approach based on the SPM method provides a unique solution pattern [3,4,6-10]. As a concrete example, we try to decide the layout of the exciting coils in order to realize a sinusoidally magnetic field distribution along with the radial as well as tangential directions of the stator surface having circular shape.

Let us consider a following system equation

$$\mathbf{U} = \sum_{i=1}^{m} \mathbf{I}_i \mathbf{d}_i , \qquad (1)$$

where the vector **U** is composed of the magnetic fields H_1, H_2, $\cdot$,H_n in the direction of rotating axis in Fig. 1(a) caused by the m-th unknown loop currents I_1, I_2, $\cdot$, I_m. Further the vector $\mathbf{d}_i$ (i=1,2,·,m) is given by considering the Biot-Savart's law and unit current element [3].

Thus, we have to evaluate the m-th unknown loop currents with the condition n ≠ m.

The formal algorithm of our SPM method is as follows. At first, we calculate a pattern matching figure γ_i using the column vectors $\mathbf{d}_i$ and **U** of (1), and then find the maximum pattern matching figure. Namely, if a point h takes the maximum of

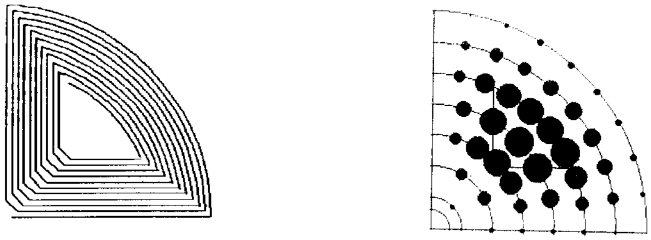
$$\gamma_i = \mathbf{U}^T \cdot \mathbf{d}_i \ [\,|\mathbf{U}|\,|\mathbf{d}_i|\,],\ i=1,2,\cdot,m, \tag{2a}$$

then we call h as a first pilot point and associated vector $\mathbf{d}_h$ is called the first pilot pattern vector. The second step is carried out by combining the first pattern vector $\mathbf{d}_h$ and remaining pattern vectors in (1). Namely, we search for the maximum of

$$\gamma = \mathbf{U}^T \cdot (\mathbf{d}_h + \mathbf{d}_j)/[\,|\mathbf{U}|\,|\mathbf{d}_h + \mathbf{d}_j|\,],\ j=1,2,\cdot,m;\ j \neq h. \tag{2b}$$

If a point g takes the maximum in (2b) then g is the second pilot point and $\mathbf{d}_g$ is the second pilot pattern vector. Similar processes are continued up to the peak pattern matching figure γ.

Figures 2(a) and 2(b) show the stator coil layout obtained by SPM method and magnetic field distribution normal to the stator surface, respectively.



(a) (b)

Figure 2. (a) Designed stator coil layout by SPM method. (b) Measured magnetic field distribution normal to the stator surface.

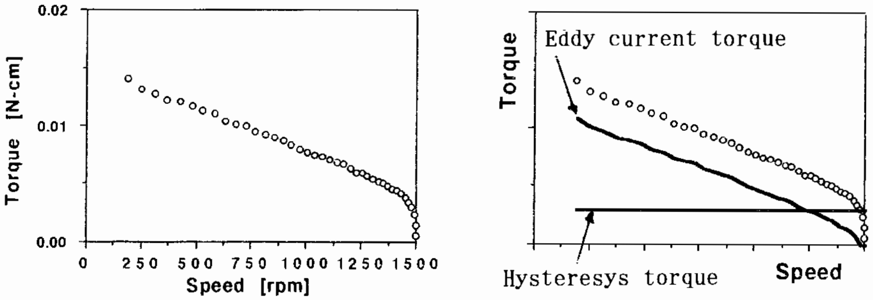
2.3 *Torque-Speed Characteristic*

In order to measure the torque-speed characteristic of the tested motor, we used a following relationship:

$$T = J(d\omega/dt) + F\omega$$
$$\simeq J(d\omega/dt), \tag{3}$$

where T,J,F,ω and t denote the torque, angular moment of inertia, rotational friction coefficient, angular velocity and time, respectively. Analytical calculating of the angular moment of inertia J and measuring the time variation of angular velocity dω/dt provide the torque-speed characteristic of the tested motor.

Figure 3(a) shows the obtained torque-speed characteristic. From Fig. 3(a), it is obvious that this tested motor has the high starting torque and effective torque at the synchronous speed. As shown in Fig. 3(b), this can be considered that the starting torque is composed of the torques due to the eddy current and hysteresis but the torque at synchronous speed is obtained as a hysteresis motor.



(a) (b)

Figure 3. (a) Measured torque-speed characteristic. (b) Decomposition of the torque. Namely, one is an eddy current and the other is a hysteresis.

3. CONCLUSION

As shown above, we have succeeded in utilizing an inverse problem approach to the designing strategy of stator coil layout, and clarified that our proposed the coreless film shape axial type polyphase induction motor has a useful torque-speed characteristic for the micromachine's mechanical power source use.

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