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회전-리니어 병용 유도전동기의 특성해석

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Optimal Construction of Rotary-Linear Induction Motor

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Abstract - In this paper, we propose a new type of tubular linear induction motor(TLIM) with two-dimensional motion. The proposed motor consists of four short primary LIMs arranged on a same circumference and a common secondary. By adopting independently energized ring-windings to the primary, we can expect the reduction of coil-end region and the freedom of alternating current supply. The secondary conductor is capable of producing any one of rotary, linear, and helical motions by controlling the phase of supply currents in each primary winding. From the 3-D finite element analysis and the experiment, we derive the feeding conditions to increase the subsidiary rotary-force and an optimal arrangement of primary currents to reduce the number of slot.

KEYWORDS
Tubular linear induction motor, two-dimensional motion, ring-winding, four-quadrant operation.

1. INTRODUCTION

While the commercial motor produces only one-dimensional (linear or rotary) motion, we are concerned with a two-dimensional motion by means of linear induction motor (LIM), for applying a drill-motor. The proposed motor consists of plural short primary LIMs arranged on a circumference, as a tubular LIM [4],[5]. On the other hand, we combine the secondary conductors and the back-irons into one member. We also adopt independently energized ring-windings of double-layer to the primaries. By using ring-windings, the space between neighboring primaries is reduced, which enables to develop the sufficient rotary-force without the primary yoke. Giving the phase differences among the supply currents for each primary winding, the whole primary provides the subsidiary rotary-force besides the principal linear-one.

The purpose of this paper is to derive the appropriate condition for obtaining the higher rotary-force, which is subsidiarily developed by the interaction of the primaries and secondary magnetic fields, in our proposed motor. Each primary is energized by multiphase supply with independent phase shifters. We investigate the driving characteristics of the proposed motor by 3-D finite element analysis, in order to obtain the feeding conditions to increase the rotary-force. In addition, we derive an optimal arrangement of the slot currents in the short primary LIM by using ring-windings of double-layer. The adequacy of analysis results is confirmed by experiment.

2. STRUCTURE OF PROPOSED MOTOR

Figure 1 shows the structure of the proposed rotary-linear induction motor (RLIM), and Fig.2 the four-quadrant operation of the secondary conductor. In Fig.1, each primary winding is energized by multiphase supply with independent phase shifter, and the secondary conductor is separated from its back iron. This conductor is made of aluminum and movable, supporting by a rotary-linear bearing system.

Controlling the phase angles of supply currents in each primary winding, the operation of the secondary conductor is possible in any of four quadrants of the linear/rotary plane, as shown in Fig.2. The number of the primary core is assumed 3, 4, and 6 in the analysis model. Furthermore, by adopting ring-winding instead of usual drum-winding, the pole pitch of the primary winding can be altered by controlling its slot currents even after the machine has been manufactured.

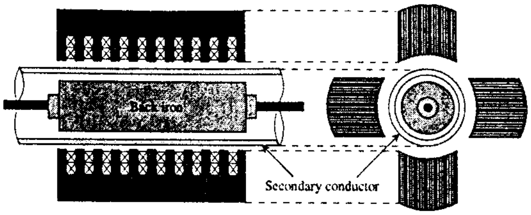


Fig.1. Construction of the proposed RLIM.

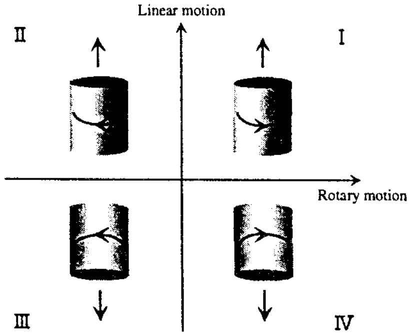


Fig.2. Four-quadrant operation of the secondary.

3. FINITE ELEMENT ANALYSIS

We investigate the driving characteristics of the proposed motor per unit primary by finite element analysis. In the analysis, periodicity is assumed on the linear direction of the motor. We first derive the optimal feeding conditions for increasing rotary-force, and then design the experimental machine based on the analytical results.

3.1 Formulation

We analyze the electromagnetic field of the proposed motor by using three-dimensional finite element analysis based on the A-ϕ method. In case of nodal elements, we apply the Galerkin method to obtain,

$$-\int_{\Omega} \mathrm{grad}\, N \times \frac{1}{\mu} \mathrm{rot} A \, \mathrm{d}\Omega - \int_{\Omega} N J_0 \, \mathrm{d}\Omega + \int_{\Omega} N \sigma \left(\frac{\partial A}{\partial t} + \mathrm{grad}\, \phi \right) \mathrm{d}\Omega = 0 \tag{1}$$

$$-\int_{\Omega} \mathrm{grad}\, N \cdot \sigma \left(\frac{\partial A}{\partial t} + \mathrm{grad}\, \phi \right) \mathrm{d}\Omega = 0 \tag{2}$$

where N is the scalar shape function for a nodal element.

3.2 Analysis Results

When the each primary current is given an appropriate phase, the spatial distribution of air-gap flux density is not symmetrical on the circumference and the eddy currents flow diagonally, which contribute to the rotary-force, as shown in Figs.3 and 4. In Fig.5, at the cost of a little linear-force, the rotary-force becomes maximum in 90 degree. Figure 6 shows the relationship between the coil-end region and the rotary-force per pole pitch. By adopting the ring-winding instead of the conventional drum-one, the space between neighboring primaries is reduced, which influences the rotary-force.

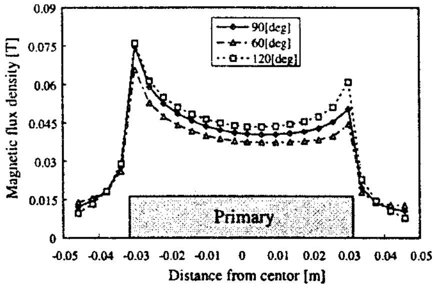


Fig.3. Distribution of magnetic flux density (slip=1).

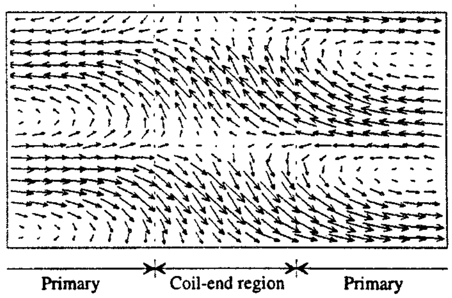


Fig.4. Configuration of eddy currents (slip=1).

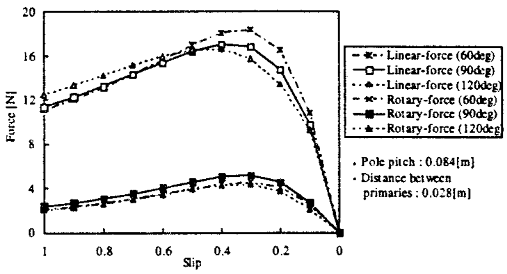


Fig.5. Force versus slip in phase differences.

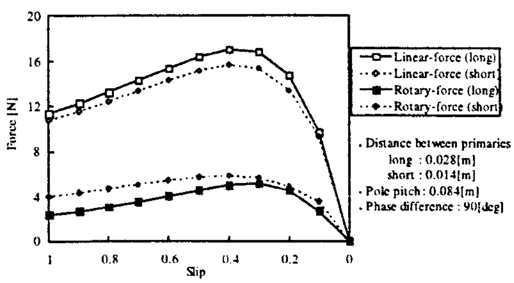
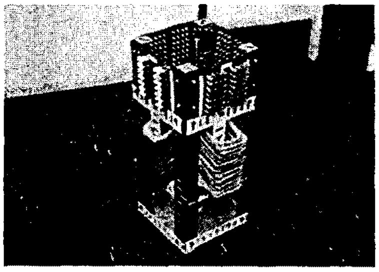


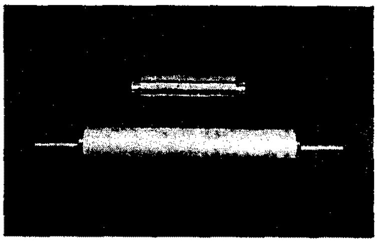
Fig.6. Force versus slip for coil-end region.

4. EXPERIMENTAL MACHINE

Figure 7 shows the RLIM used for our experiment and table 1 the specifications. The experimental machine consists of four short primaries for single-sided LIM arranged on same circumference and a common secondary. For controlling the value and the phase of primary current in each slot, we adopt an independently energized ring-winding as the primary one. The secondary conductor is supported by a linear-rotary bearing system (No.NB-RK20GUU), produced by Japan Bearing Co., Ltd.. Since the back-iron is fixed on the axis, only the secondary conductor is movable in the linear and rotary directions.



(a) Overview of RLIM



(b) Structure of the secondary

Fig.7. Experimental machine.

TABLE 1. EXPERIMENTAL SPECIFICATIONS

Item	Symbol	Value [Unit]
A unit primary length	L	0.196 [m]
A unit primary width	W	0.056 [m]
Number of primary	N_p	4, (3, 6)
Number of slot	N_s	14
Number of pole	p	Variable
Number of turn	N	80 [turns]
Length of secondary conductor	L_a	0.6 [m]
Width of secondary conductor	M_g	1491.7 [g]
Thickness of secondary conductor	T_a	0.003 [m]
Material of secondary conductor		Aluminum
Input current	I	2.0 [A]
Frequency	f	50 [Hz]
Length of air-gap	g	0.007 [m]

Since enlargement of the pole pitch corresponds to reduction of the coil-end region, the larger pole pitch provides the larger rotary-force. Fig.8 shows the characteristics of secondary force measured by experiment.

1) Two-phase winding with full-pitch.
ABabABabABab
abABabABabAB (14slots)

2) Three-phase winding with one slot short-pitch.
AcBaCbAcBaCb
aCbAcBaCbAcB (14slots)

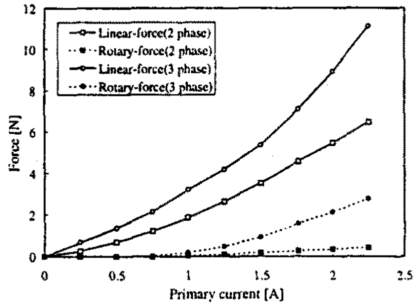


Fig.8. Comparession of force.

5. CONCLUSION

The purpose of this paper is to derive the feeding condition to increase the subsidiary rotary-force and an optimal arrangement of slot currents in our two-dimensional motor. From the analysis and experimental results, we could conclude the following:

1)Adopting ring-windings energized by multiphase supply to the primary, the space between neighboring primaries is reduced, which enables to obtain the sufficient rotary-force without the primary yoke.

2)The large pole pitch and the phase difference of 90 degree produce the maximum rotating flux.

3)Feeding twelve-phase supply to the primary ring-windings, we derived an optimal arrangement of the slot currents in the short primary LIM.

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