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Double-sided linear induction motor with a rotary solid steel-secondary disc

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SUMMARY

The performance of a double-sided linear induction motor (DLIM) with a rotary steel-secondary disc is investigated. The thrust force found experimentally is compared with the theoretical thrust force found by the first author earlier using a two dimensional field analysis [8]. In this analysis, periodic variation with time and periodic distribution with distance is assumed. The normal j-operator method of representing steady-state a. c. quantities is adopted. The travelling wave is assumed to move tangentially along the stator length. Using Maxwell's equations, expressions for the thrust, force and the disc current density were obtained.

Key words*: linear induction machine, double-sided stator, disc rotor, magnetic field strength, thrust force, disc current density.*

1. INTRODUCTION

Short-primary sheet-secondary type linear induction motors have been proposed for a number of applications [1] including high-speed ground transportation [2-3]. Flat double-sided linear induction motor (DLIM) can be used for direct propulsion of belts in various belt conveyors [4-6].

An electromagnetic approach to the single-sided linear motor is given by Shobair [7]. An analysis of the DLIM is given by Shobair [8].

The motor under investigation is a double-sided linear induction motor with a rotary solid steel-secondary disc. This motor is one form of various forms of DLIM. The rotor disc is made to rotate under the effect of a tangential (thrust) force produced by the motor.

In the present paper, the analysis given by Shobair [8] is applied to the motor under investigation. Predicted thrust force given of the motor of reference [8] is compared with that obtained from experimental measurements.

2. DESCRIPTION OF THE MOTOR AND TEST SETUP

The designed LIM is double-sided and the stators on both sides have the same features. The rotor has been produced from St.35 steel whose thickness is 15 mm so as to make rotary motion of 1200 mm diameter.

It is possible to adjust the air gap by bringing near or removing the rotor from the stator with the help of a mechanism that has been put together on a tripod which carries the rotor upright to the floor.

The two stators on both sides have completely the same characteristics. The thickness of the siliceous iron sheet used in the stators is 0.3 mm. On the first side of each of these siliceous iron sheet there are 36 slots. On the other side, there are three sparrow-tails to replace the stator iron sheet into the stator.

The depth of the stator slots is 18 mm, and their width is 8 mm. 434 of the cultivated sheets of siliceous iron are brought together and pressed. As a result two stator iron sheets have been obtained and the thickness of each one is 130 mm. These iron sheets have been put together with the help of three sparrow-tails. The stator core has been obtained from aluminum moulding with a thickness of 20 mm and length of 660 mm. The stator windings have been wrapped up by a double-layered copper conductor of 3×0.65 mm diameter so that they have four poles. In each stator slot there are 44 couples of turns.

In order to obtain the experimental results load conditions, a fucoult break system was used as load.

3. MATHEMATICAL MODEL

3.1 Configuration

Figure 1 shows the double-sided stator linear induction motor configuration in which the rotor conductor is “sandwiched” between two sets of stator windings. The two iron stator sides provide a complete magnetic circuit. Coordinate axes are chosen as indicated in the figure.

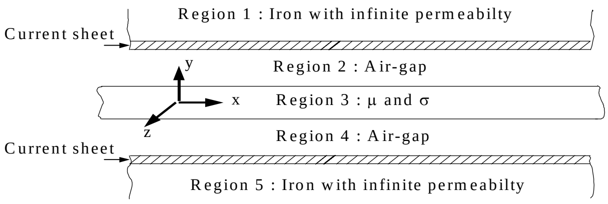

Fig. 1 Model of double-sided linear induction motor

The stator surface is assumed to carry a travelling-wave current sheet of linear density J_m (A/m). The configuration of Figure 1 is divided into five homogenous regions:

a) Top and bottom stators (regions 1 and 5), with infinite permeability;

b) The air gap between the stators and the slab surfaces (regions 2 and 4);

c) The slab (region 3) of relative permeability μ and conductivity σ.

3.2 Assumptions

To simplify the problem, the following assumptions are introduced in deriving the equations:

a) End effects are ignored.

b) The current sheet flows in the z-direction; hence *B* and *H* have a x-component and a y-component but have no z-component. Thus the model provides the two-dimensional problem in the x-y plane with respect to *B* and *H*.

c) Stator iron has a very high permeability so that the magnetic field strength in regions in 1 and 5 is assumed to be zero.

d) The permeability of the rail is constant.

The last two assumptions are accepted because the motor runs with low magnetic induction.

3.3 Governing Equations

Since the complete mathematical model has been published [8], it was not found worthwhile report in a detail. Only the governing equations related to the present work are described hereunder for the sake of completeness.

i) Disc field intensity:

The normal component of field intensity in the disc is given by [8]:

$$H_{y(3)} = -j(k/\mu)\cdot J_m \cdot \cosh\alpha\, y \cdot e^{j(\omega_s t - kx)} / \Delta_1 \tag{1}$$

where:

$$\Delta_1 = \left[K \cdot \cosh\alpha b \cdot \sinh K(a-b) + (\alpha/\mu)\sinh\alpha b \cdot \cosh K(a-b)\right] \tag{2}$$

$$\alpha^2 = k^2(1 + jGs) \tag{3}$$

and G is a goodness factor defined as:

$$G = \omega\mu\mu_0\sigma / K^2 \tag{4}$$

ii) Disc Current Density

The disc current density is in the z-direction and it is given by:

$$J_r = \frac{dH_{y(2)}}{dx} - \frac{dH_{x(2)}}{dy} \tag{5}$$

which yields:

$$J_r = j\omega_s\mu_0\sigma J_s \cosh\alpha y \cdot e^{j(\omega t - kx)} / \Delta_1 \tag{6}$$

iii) Thurst Force

The thrust force per wavelength and per meter width is given by:

$$\begin{aligned} F_{t\lambda} &= \int_a^b \int_x^{x+\lambda} R_e\left\{\left(\frac{J_r}{\sqrt{2}}\right)\cdot\left(\frac{B^*{}_{y(3)}}{\sqrt{2}}\right)\right\} dx\cdot dy = \\ &= \mu\mu_0 \int_a^b \int_x^{x+\lambda} R_e\left\{\left(\frac{J_r}{\sqrt{2}}\right)\cdot\left(\frac{H^*{}_{y(3)}}{\sqrt{2}}\right)\right\} dx\cdot dy \end{aligned} \tag{7}$$

The $\sqrt{2}$ in the above equation are the peak/rms ratio of a sinusoidal wave. With the aid of equations (1) and (6), after performing the integration, the expression for the thrust force per meter length and per meter width is found to be:

$$F_t = 0.25(\mu_0 \cdot J_m)^2 (K\sigma\omega_s)\cdot\left(\frac{\sinh 2\gamma a}{\gamma} + \frac{\sin 2\beta a}{\beta}\right)\cdot\left(\frac{1}{E^2 + F^2}\right) \tag{8}$$

where γ and β are the real and imaginary parts of α. The real and imaginary parts of Δ_1 are E and F.

4. RESULTS AND DISCUSSION

Thrust-slip characteristic of the motor under investigation is shown in Figure 2. The advantages of the investigated motor are: (1) The justification of Shobair’s analysis [8] is established by comparing the prediction based on it with the 50 Hz excitation; (2) Predicted and experimental data are in reasonable agreement; (3) Discrepancy between the two sets of results is mainly due to the neglecting of both end effects and the nonlinear variation of rotor reluctivity with flux density. The inclusion of these effects is under investigation.

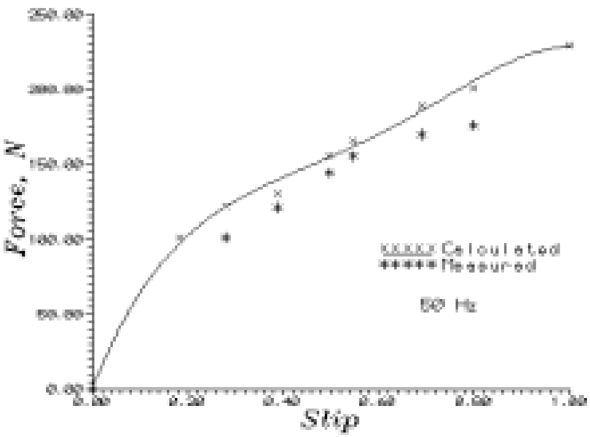

Fig. 2 Thrust speed characteristic

5. CONCLUSION

The paper presents theoretical and experimental results of the variation of the thrust force with speed for a double-sided linear induction motor (DLIM) with a rotary solid iron disc. The main discrepancy is between experimental and predicted values due to the neglecting end effects and the nonlinear variation of rotor reluctivity with flux density. It is believed that such discrepancy will vanish if these effects are included.

NOMENCLATURE

- B — Magnetic flux density (T)
- H — Magnetic field strength (A/m)
- J_m — Linear current density at both interface of regions 1 and 2 and interface of regions 4 and 5, (A/m) of the x-ordinate; current is in the z-direction
- J_r — Surface current density inside the slab (A/m^2)
- K — $2\pi/\lambda$
- $Re\{\}$ — Real part of what is between the brackets {}
- ω — Angular velocity of the supply voltage (rad/sec)
- ω_s — Slip angular velocity = $2\pi x$ slip frequency
- x — Distance measured along the stator surface (m)
- $x(i)$ — Subscript denotes the x-component in region i
- y — Distance measured from and normal to the center line of the air-gap (m)
- $y(i)$ — Subscript denotes the y-component in region i
- λ — Wave length of the travelling wave = Length of the pole pitches (m)
- μ — Relative permeability of the disc material
- μ_o — Permeability of free space
- σ — Conductivity of the disc material
- $*$ — Superscript denotes the conjugate of the preceding variable

REFERENCES

[1] G.W. Mclean, Review of recent progress in linear motors, *IEE Proceeding*, Vol. 135, Pt. B, No. 6, pp. 380-416, 1988.

[2] S. Yamamura, *Theory of Linear Induction Motors*, Wiley, 1978.

[3] S.A. Nasar and Del Cid, Jun., Propulsion and levitation forces in a single-sided linear induction motor for high speed ground transportation, *Proceedings IEE*, Vol. 61, pp. 638-644, 1973.

[4] M. Poloujadoff, *The Theory of Linear Induction Machinery*, Clarendon Press, Oxford, 1980.

[5] E.R. Laithwate, *Induction Machines for Special Purposes*, Newnes Ltd, London, 1966.

[6] S.A. Nasar and I. Boldea, *Linear Motion Electric Machines*, J. Wiley and Sons, New York-London-Sydney-Toronto, 1976.

[7] A.I. Shobair, An electromagnetic approach to single-sided linear machines, Proceedings of Al-Azhar Engineering 3rd International Conference, Cairo, Egypt, Vol. 5, pp. 295-214, 1993.

[8] A.I. Shobair, An electromagnetic approach to double-sided linear induction machines, Proceedings of Minia 1st Conference in Engineering and Technology, Minia, Eygpt, 1995.

DVOSTRANI LINEARNI INDUKCIJSKI MOTOR S ROTIRAJU]IM SEKUNDARNIM DISKOM OD KRUTOG ^ELIKA

SA@ETAK

U ovom ~lanku ispituje se rad dvostranog linearnog indukcijskog motora s rotiraju}im krutim sekundarnim diskom od ~elika. Eksperimentalno prona|ena sila pritiska uspore|uje se s teorijski prona|enom silom pritiska, koju je ranije pronašao prvi autor, koriste}i se analizom dvodimenzionalnog polja [8]. Ova analiza pretpostavlja periodi~ku varijaciju u vremenu i periodi~ku distribuciju u odnosu na udaljenost. Primijenjena je uobi~ajena metoda j-operatora u predstavljanju stabilnog stanja a. c. veli~ina. Pretpostavlja se da se putuju}i val giba tangencijalno po duljini statora. Pomo}u Maxwell-ovih jednad`bi dobili su se izrazi za pritisak, silu i gusto}u struje diska.

Klju~ne rije~i*: linearni indukcijski motor, dvostrani stator, rotor, jakost magnetskog polja, sila pritiska, gusto}a struje diska.*