ANALYSIS OF LINEAR INDUCTION MOTORS

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ANALYSIS OF LINEAR INDUCTION MOTORS

Summary

The linear induction motor has been the subject of considerable reasearch works and many applications of this machine have been proposed.

The main objective of this thesis is to obtain a general solution of the magnetic vector potential based on a proposed three dimensional mathematical model , which is applicable to different types of linear motor windings.

The proposed mathematical model takes the currents in the overhang regions of the stator winding , which is termed by " end -currents " , into account.And to do this , it is assumed that the stator width is extended from both sides to be equal to the rotor width.

This implies that air gap reluctance is increased, to compensate this effect , the current sheet in the overhangs is assumed to vary as {1 - sin (θ)} function or as exponential decaying function.

The magneto-motive force distribution of single layer and double layer winding having empty slots at the ends of stator are obtained.Also,general expression for equivalent current sheet have been derived which has a constant deponds on the type of winding used.

Expressions for the air gap magnetic flux density , thrust, output power , power factor ,and efficiency are obtained.

The results are obtained using computer programmes for two linear motors , the first one has single layer winding ,and the second is double layer winding.

The derived solution is used to determine tle value of the rotor thickness which give the maximum thrust , and it is used also in the determination of the performance characteristics of a proposed linear machine used a motor or generator.

LIST OF PRINCIPAL SYMBOLS

a = Semiwidth of stator, m

A_{xi}, A_{zi} = i th region magnetic vector potential components, Wb/m.

A_{ν} = Fourier-coefficient of primary current sheet in z-direction, A/m

b = Semiwidth of rotor sheet, m

B = magnetic flux-density, Wb/m^2,

B_{xi}, B_{yi}, B_{zi} = i th region magnetic flux-density components, Wb/m^2.

2C = thickness-of secondary plate, m.

C_n = j α_n D_n.

D_n = Fourier-coefficient of magnetomotive force expression in x-direction.

E = electric field intensity, V/m.

E_{x2}, E_{z2} = electric field intensity components in air gap region, V/m.

F = thrust, N

2g = effective air gap between stators, m.

h = stator iron core height, m.

H_x, H_z = magnetic field intensity components, A/m.

i_a, i_b, i_c = three-phase currents of primary winding, A.

i_s = electric current passing in coil side/slot, A.

I_{max}, $\hat{I}$ = maximum value of primary current, A.

$j = \sqrt{-1}$.

J_x, J_z = equivalent primary current sheet components, A/m.

K = π/τ

K_n = factor depending on the No. of coil groups of primary winding.

K_{wn} = Winding - distribution factor for harmonic of order n.

2 ℓ = primary winding length, m.

2L = primary core length (primary winding length and longitudinal-end-effect attenuation length), m.

n = harmonics orders in x-axis direction.

N = number of coil groups per phase.

P_g = electromagnetic active power, W.

P_2 = output power, W.

q = No. slots / pole / phase.

s = slip.

S_g = secondary input, VA.

t = time, sec.

v = Motor speed, m/s.

x,y,z = cartesian co-ordinates.

Greek letters.

μ_i = i th region permeability, H/m.

μ_o = air gap permeability, ($4 \pi \times 10^{-7}$) H/m.

σ_i = i th region conductivity 1/Ωm).

τ = primary winding pole pitch, m.

τ_c = primary winding coil span, m.

τ_s = slot pitch, m.

ω = primary angular frequency, s^{-1}.

ν = harmonics order in z-direction.

η = efficiency.

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INTRODUCTION

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INTRODUCTION

After over twenty five years of research and development, linear induction motors are now finding applications in innovative transportation systems.

Linear induction motors are finding their first applications in low speed urban transit vehicles, such as the magnetically suspended Advanced Transit Shuttle link now carrying passengers between Birmingham Airport, Birmingham International railway station and the United Kingdom National Exhibition Center.

Linear electric drives are essential for vehicles with non contact suspension, and provide wheeled vehicles with propulsion that is in independent of wheel rail adhesion, This later characteristic can be exploited in new transportation applications.

Many methods have been proposed for the theoretical analysis of the high speed Linear Induction Motors (L.I.M.) by various investigators/1:8/ regarding the end effects in a short stator; single-and double sided linear induction motor.Both types are important in practice.

The single - sided linear motors can be analyzed in quite the same way (or through a slight modification) as the double sided linear motor.If the linear induction motor were of infinite width, the eddy currents would flow parallel to the slot currents over most of the stator width. However, in practical L.I.Ms, the width may be quite small compared with the pole pitch,then the eddy currents in the rotor sheet will flow in roughly elliptical patterns. This is occur because the armature reaction has a greatest value on the longitudinal center line. Moreover the air gap-flux density will vary across the stator width, and will be greatest at the stator edges. From this point view, the term (transverse edge effect) is used to describe the eddy current and flux density patterns which results.

The influence of edge effect of short primary L.I.Ms has been particularly intensively investigated, the end effect of short primary L.I.M. is caused by two factors: the finiteness of primary winding length in the travelling direction of magnetic field; and the finiteness of primary core length. The former is responsible for the eddy current induction inside the secondary member, i.e rotor sheet, due to the abrupt change of magnetic flux at the entry and exit ends of the motor. The presence of the eddy cu-rrents make the magnetic flux distribution non-uniform, thus worsening the operating characteristics of the motor, the latter produces the drag force at the exit end.

Since it is difficult to analyze the effect of the finiteness of primary core length accurately,only the effect of the finiteness of primary winding length is taken into account.

The one dimensional analysis /1/ is too much of an approxima-tion,since it completely ignores the tangential and transverse co-mponents of the flux density in the air gap.

The advantage of this analysis is to show the physical phen-omena of the longitudinal edge effect in a simple form. The one dimensional mathematical model is given in Fig.(1.1), in which the air gap flux density has no variation in the y and z-direction. Also, the rotor sheet has an infinite width in the z-direction, i.e the rotor induced current will flow parallel to the slots of the stator.

Therefore:

$$Bg(x) \equiv (0,B_y,0), \text{ and}$$

$$J_s(x) \equiv (0,0,J_r).$$

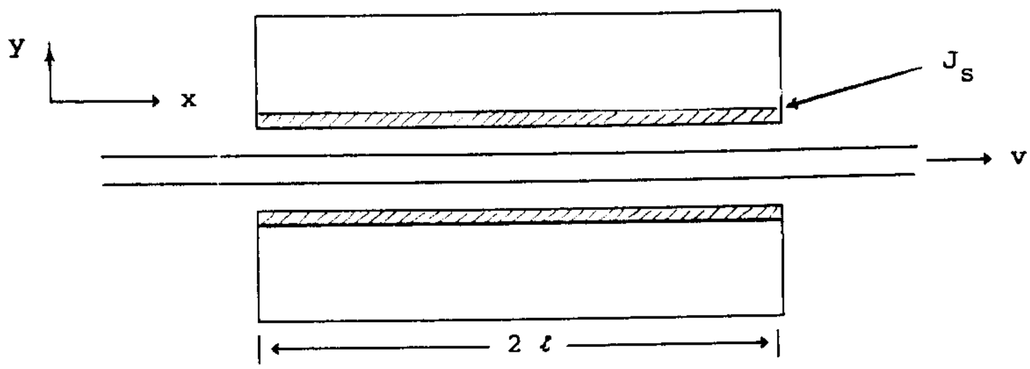

Fig. (1.1) Model of the linear induction motor for one-dimensional analysis.

The two dimensional analysis given in /2/ investigates only the effects of the stator width, i.e transverse edge effect, neglecting the longitudinal edge effects by assuming that the stator length is infinite or the motor has a large number of poles.

This analysis is fruitful to know how the value of the stator iron core width relative to the rotor width affects on the performance characteristics of L.I.M.The corresponding mathematical model is given in Fig. (1.2), in which the air gap flux density has no variation in both y and z direction. But the rotor sheet has a finite width, so the induced currents in the rotor member will flow in elliptical patterns.

Therefore:

$$Bg(x,z) \equiv (0,B_y,0) \quad , \qquad \text{and}$$

$$J_r(x,z) \equiv (J_{rx},0,J_{rz}).$$

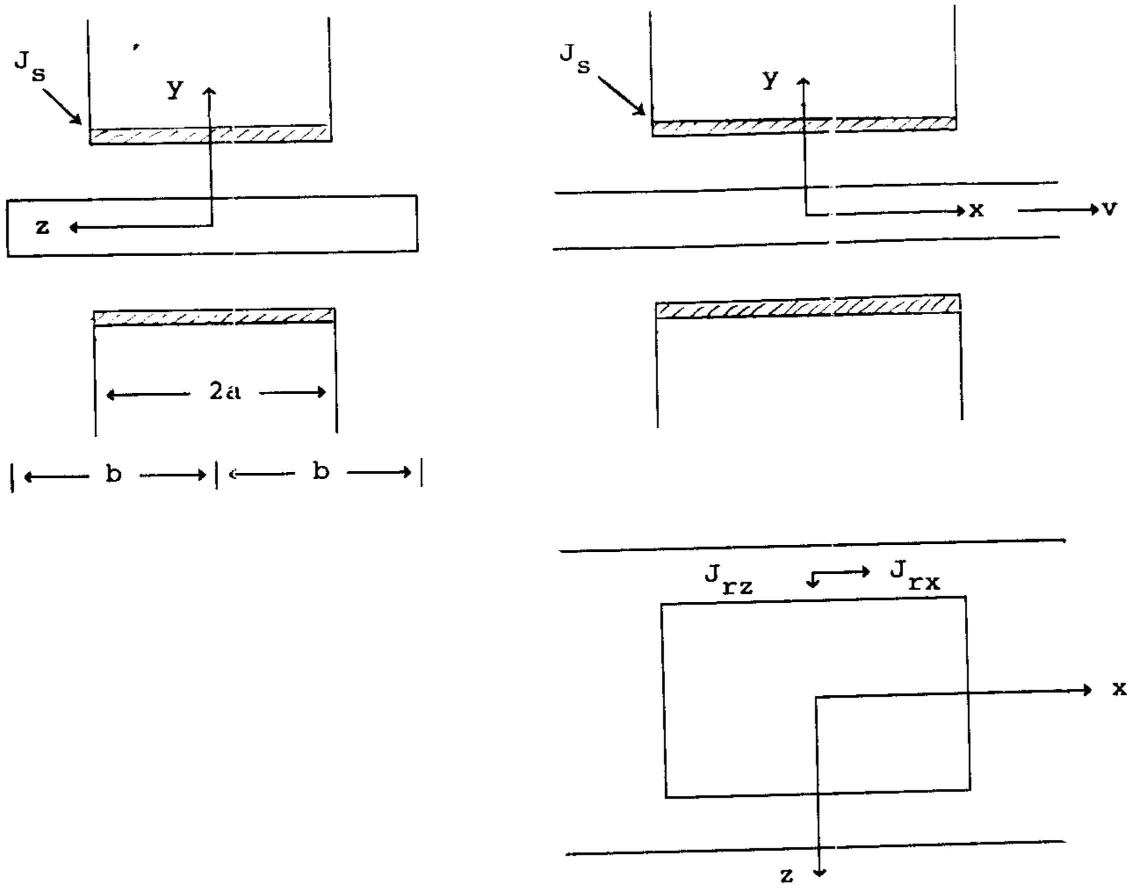

Fig. (1.2) Model of the linear induction motor for two dimensional analysis.

Also, the two dimensional analysis given in /2/ investigates the longitudinal edge effects neglecting the effect of the finite widths of the stator iron core and rotor, but the skin effect in the rotor is considered. Solving the filed equations, it is considered that the air gap flux density is varying along the air gap length and the rotor has infinite width.

Thus :

$$Bg(x,y) = (B_x, B_y, 0) ,$$

$$J_r(x,y) = (0, 0, J_{rz}) .$$