AEIC' 93

AL-AZHAR ENGINEERING THIRD INTERNATIONAL CONFERENCE

December 18-21 1993

FACULTY OF ENGINEERING
AL - AZHAR UNIVERSITY
NASR CITY, CAIRO, EGYPT

VOLUME (5)

ELECTRICAL ENGINEERING

Eiectrical Power and Machines

Page

PROFILES OF FLUX LINES TRAJECTORIES IN THE VICINITY OF HYBRID AC/DC TRANSMISSION LINES
Mohamed M. AboElsaad and Mousa A Abd-Allah 387

THRUST DERATING DUE TO STABILITY REQUIREMENTS OF THE ZIGZAG LINEAR SYNCHRONOUS MOTOR-PAIR INTEGRATING LIFT AND THRUST FOR MAGLEY VEHICLES
S. M. Al-Kasimi and M. J M Alawi 396

COMPUTATION OF EDDY-CURRENT LOSS IN TRANSFORMER WINDINGS
A.A Dahab 407

A NEW BEARINGLESS TRAPIZOIDAL-PASSIVE-ROTOR SYNCHRONOUS MACHINE
S. M. Al-Kasimi 419

THRUST DERATING DUE TO STABILITY REQUIREMENTS OF THE TRAPIZOIDAL LINEAR SYNCHRONOUS MOTOR-PAIR INTEGRATING LIFT AND THRUST FOR MAGLEY VEHICLES
S. M. Al-Kasimi 427

THE ACCELERATION CHARACTERISTICS OF A PAIR OF TRAPIZOIDAL LINEAR SYNCHRONOUS MOTORS AS COMPARED TO A ZIGZAG PAIR VERSION FOR MAGLEY APPLICATION
S M Al-Kasimi 435

A COMPARISON BETWEEN OPTIMUM AND NATURAL SAMPLED PWM SWITCHING TECHNIQUES
G Hashem, J Richardson, S A Kandil, and A A Sayyar . . 446

POTENTIAL AND ELECTRIC FIELD DISTRIBUTION ALONG THE INTERFACE OF GIS SPACER
M S. M Rizk, S M El-Safty, A Nosseir, M Awad 455

EFFECT OF SPHERICAL VOIDS WITHIN INSULATION STRUCTURES ON THE ELECTRIC FIELD DISTRIBUTION
H. M Ismail 467

ELECTRODE SURFACE ROUGHNESS INITIATED BREAKDOWN IN COMPRESSED SF6 GIS
Sayed A Ward . . . .

EXPERIMENTAL STUDY OF
BREAKDOWN IN NON-UNIFC
M. A. Abd-Allah, M. S. M. Rizk

A CHARGE SIMULATION MO
WITHIN SOLID DIELECTRIC1
H. M. Ismail . . . .

.PREDICTION OF STEADY TI
RATING FOR A WATER CO(
Sanaa A. M. Shehata . . . . .

STUDIES ON THE NEW INS
El-Sayed M. El-Refais . . . . .

'ANALYTICAL AND EXPERIM
EFFECT OF THE SOIL MOI
CHARACTERISTICS OF UN
Fatma A Mohamed . . . . .

THEPERFORMANGE OF TI
ASSOCIATED WITH AUTOI
G. M. A. El-Salam, A. A. Atia

MICROPROCESSOR-EASE
MULTIPLE RELAYS
S. M. W. Ahmed . . . .

EVALUATION&REDUCTIO
PARTIAL&COMPLETE FAI
CORRECTION CAPACITO
DISTRIBUTION SYSTEM V
Mohamed A. A. Wahab A
Khalil . . . .

DETECTION METHOD BA
QUANTITIES IN HV RADI/
M. M. M Mahmoud . . . . .

PREFOMANCE EVALUAT
ALGORITHMS
M. M Mansour K M. El-N

ɔils

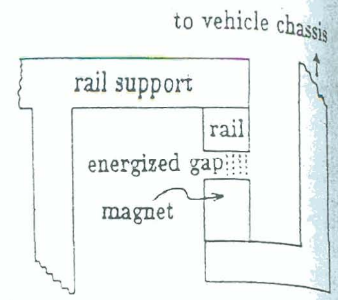


Fig.2 Boggie support

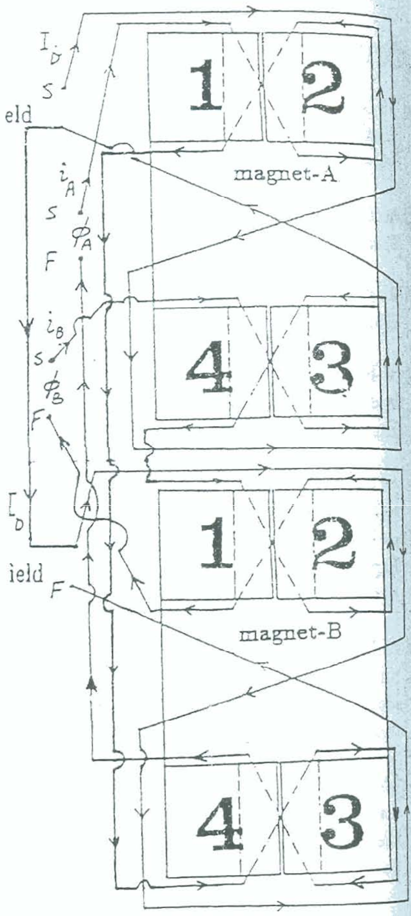


Fig.4 Coil connections for TLSMP

4

AEIC'93

L-AZHAR ENGINEERING THIRD
NTERNATIONAL CONFERENCE
ECEMBER 18-21, 1993

المؤتمر العلمى الدولى الثالث
كلية الهندسة - جامعة الازهر
من ٥ الى ٨ رجب ١٤١٤ هـ
من ١٨ الى ٢١ ديسمبر ١٩٩٣م

THE ACCELERATION CHARACTERISTICS OF A PAIR OF TRAPIZOIDAL LINEAR SYNCHRONOUS MOTORS AS COMPARED TO A ZIGZAG PAIR VERSION FOR MAGLEV APPLICATIONS

S. M. Al-Kasimi*

* Assistant prof., Electrical and Computer Eng. Dept., Umm-Ul-Qura University, P.O.Box 6112, Makka, Saudi Arabia.

ABSTRACT

The Zigzag Linear Synchronous Motor, ZLSM, is a machine that provides a combined lift and thrust for maglev vehicles. A maglev vehicle is a vehicle that is supported by magnetic attraction between controlled electromagnets fixed to its chassis and a pair of iron tracks. The magnet of ZLSM is U-shaped and acts as a two-pole machine in which each pole is split into two sub-poles. Each sub-pole is surrounded by a coil fed by an inverter such that the field could be distorted among the four sub-poles. The rail of the ZLSM is zigzag shaped and will move relative to the sub-poles to minimize reluctance, hence propulsion is obtained.

The ZLSM machine is unable to start itself at some standstill positions. This problem is solved by putting another ZLSM quarter of a cycle apart whereby each pair will start the other.

The ZLSM version was modified by changing the shape of the rail to a trapezoidal one, and hence obtaining a Trapizoidal Linear Synchronous Motor, TLSM. Although this motor is self-starting, it was found that putting a pair of them quarter of a cycle apart would improve some of its acceleration properties.

This paper describes in theory the acceleration characteristics of a two-pair TLSM machine that could be used for maglev transport utilizing integrated lift and thrust. It also compares the merits of a twin-pair to a single TLSM machine and to a twin-pair of ZLSM machines.

KEYWORDS

Zigzag; Trapizoidal; Linear; Synchronous; Machine; Maglev; Suspension; Propulsion; Transportation.

INTRODUCTION

The Zigzag Linear Synchronous Motor, ZLSM, is composed of the magnet shown in Fig. 1, within the maglev vehicle boggie shown in Fig. 2. This magnet is reacting against a zigzag shaped rail. The main poles of ZLSM are excited by field current through dc coils, which is controlled to sustain a constant gap, Z. Each of the main poles is split into two sub-poles. These are surrounded by inverter-fed ac coils distorting the field among the sub-poles, whereby propulsion is obtained.

McLean [1, 2] and West [1, 3] have found that a twin ZLSM pair will be necessary to enable self start. This Zigzag Linear Synchronous Motor Pair, ZLSMP, was found to have no second harmonic component in the field circuits when the two ZLSM machines were placed quarter of a cycle apart as shown in Fig. 3, with the coils connected as shown in Fig. 4.

For the same magnet, Al-Kasimi [4] have found that if a trapizoidally shaped rail was used instead of the zigzag one, then this Trapizoidal Linear Synchronous Motor, TLSM, is self-starting. Another feature, he found, is that the switching frequency of the inverters is half that required for ZLSM for same speed.

This paper proves that a twin TLSM pair placed quarter of a cycle apart as shown in Fig. 5 with the coils connected as shown in Fig. 6, will be advantageous for having pulsation-free acceleration characteristics. The resulting Trapizoidal Linear Synchronous Motor Pair, TLSMP, characteristics are compared to those of a single TLSM and to those of ZLSMP.

NOTATIONS

The symbols used in this paper are listed below:

$\alpha_{hs}, \alpha'_{hs}$ horziontal steady acceleration relative to gravity in TLSM, ZLSM respectively

$\alpha_{hsx}, \alpha'_{hsx}$ maximum horziontal steady acceleration relative to gravity in TLSM, ZLSM

A sub-pole surface area

A_i, A'_i energized area of sub-pole i in TLSM, ZLSM

B_i, B'_i flux density over sub-pole i in TLSM, ZLSM

E_X, E'_X open circuit induced voltage at phase X coil terminals in TLSM, ZLSM

ϕ_k, ϕ'_k flux due to all sub-polar m

F_h, F'_h horizontal thrust force in

F_v, F'_v vertical lift force in TLSM

I_D, I'_D current flowing in the field

i_X, i'_X current flowing in phase X

μ_0 permeability of air

M_D, M'_D net dc mmf excitation of

$\overline{M}_D, \overline{M}'_D$ optimum M_D, M'_D values

m_X, m'_X ac mmf of phase X armat

m, m' peak values of ac mmf ex ZLSM

$\overline{m}, \overline{m}'$ optimum m, m' values for

m_j, m'_j resultant mmf excitations

N number of turns of ac coil

N_D number of turns of dc coil

p pole pitch

θ, θ' phase angles of ac excitat

$\overline{\theta}, \overline{\theta}'$ optimum phase angles at

T, T' time period to complete

t time starting zero when r

u speed of rail relative to m

ω, ω' angular frequency of ac s

W weight of supported bogg

Z energized air gap

ASSUMPTIONS

For simplicity, the following assum

1. All sub-poles have the san

Machine; Maglev; Suspension; Propul.

SM, is composed of the magnet shown
gie shown in Fig. 2. This magnet is
nain poles of ZLSM are excited by field
ed to sustain a constant gap, Z. Each
. These are surrounded by inverter-fed
poles, whereby propulsion is obtained.

hat a twin ZLSM pair will be necessary
Synchronous Motor Pair, ZLSMP, was
nent in the field circuits when the two
ycle apart as shown in Fig. 3, with the

e found that if a trapizoidally shaped
en this Trapizoidal Linear Synchronous
eature, he found, is that the switching
uired for ZLSM for same speed.

placed quarter of a cycle apart as shown
wn in Fig. 6, will be advantageous for
ristics. The resulting Trapizoidal Linear
eristics are compared to those of a single

below:

lative to gravity in TLSM, ZLSM respec-

celeration relative to gravity in TLSM,

TLSM, ZLSM

TLSM, ZLSM

phase X coil terminals in TLSM, ZLSM

ϕ_k, ϕ'_k flux due to all sub-polar mmfs that leaves sub-pole k in TLSM, ZLSM

F_h, F'_h horizontal thrust force in TLSM, ZLSM

F_v, F'_v vertical lift force in TLSM, ZLSM

I_D, I'_D current flowing in the field of TLSM, ZLSM

i_X, i'_X current flowing in phase X ac coils of TLSM, ZLSM

μ_0 permeability of air

M_D, M'_D net dc mmf excitation of field winding per pole in TLSM, ZLSM

$\overline{M}_D, \overline{M}'_D$ optimum M_D, M'_D values for maximum thrust in TLSM, ZLSM

m_X, m'_X ac mmf of phase X armature winding per sub-pole in TLSM, ZLSM

m, m' peak values of ac mmf excitation of any phase per sub-pole in TLSM, ZLSM

$\overline{m}, \overline{m}'$ optimum m, m' values for maximum thrust in TLSM, ZLSM

m_j, m'_j resultant mmf excitations around sub-pole j in TLSM, ZLSM

N number of turns of ac coil around any sub-pole

N_D number of turns of dc coil around any pole

p pole pitch

θ, θ' phase angles of ac excitations in TLSM, ZLSM

$\overline{\theta}, \overline{\theta}'$ optimum phase angles at maximum thrust conditions in TLSM, ZLSM

T, T' time period to complete one cycle in TLSM, ZLSM

t time starting zero when rail completely links sub-poles 1 and 3

u speed of rail relative to magnet

ω, ω' angular frequency of ac supply in TLSM, ZLSM

W weight of supported boggie

Z energized air gap

ASSUMPTIONS

For simplicity, the following assumptions were made in the analysis to come.

1. All sub-poles have the same surface area, A, with identical ac coils around

them fed with sinusoidal ac current phase-locked to rail.

2. Width of slot in the main poles is negligible, and field mmf excitations of dc coils around them are constants.

3. Fringing, leakages, steel and copper losses, windage, friction and other drag forces are ignored.

4. Air gap, Z, is homogeneous ater the sub-poles, and faces equal areas both at rail-surface above it and at magnet-pole-surface below it throughout motion.

5. The energized area per pole is composed of two portions. Each portion belongs to one of the two adjacent sub-poles within the main pole and is assumed to vary sinusoidally between zero and A.

6. The motor does no rotation and it has constant speed, u, relative to the track; which is assumed rigid.

7. The motor force is composed of two components only, namely, along gravity line and along direction of motion. Although some force component in the third direction is exerted, it will be ignored.

8. Flux linkage for any ac coil varies sinusoidally between a minimum of zero when its sub-pole is fully uncoupled to rail and a maximum when its sub-pole is fully coupled to rail.

THEORITICAL ANALYSIS OF TLSMP PERFORMANCE

When the rail of TLSMP moves in the direction indicated in Fig. 5, Al-Kasimi [4, 5] found that the flux linkages of ac coils per magnet vary in-phase for adjacent sub-poles and so can be series-connected forming one phase. This phase is in quadrature to the other phase of the opposing sub-poles. The period and angular frequency of these variations are given respectively by: $T = 4p/u$ and $\omega = \pi u/2p$.

This illustrates the connections shown in Fig. 6, per motor. Note that in each motor, phase-A leads phase-B by a quarter of a cycle; and that the dc coils are connected so as to build constructive flux components. Hence, th:

$$M_D = N_D\, I_D\,,$$

$$m_A(t) = N\, i_A(t) = m\, cos(\omega t + \theta)\ \& \qquad m_B(t) = N\, i_B(t) = m\, sin(\omega t + \theta)\,;$$

and assuming positive sense when forcing flux to leave the sub-poles of motor-A, then:

$$m_1(t) = -M_D - m_A(t)\,, \qquad m_2(t) = -M_D + m_A(t)\,,$$
$$m_3(t) = +M_D + m_B(t)\ \& \qquad m_4(t) = +M_D - m_B(t)\,.$$

The energized areas of motor-A are approximated to:

$$A_1(t) = (A/2)\,[1 + cos(\omega t + \pi/4)\,, \qquad A_2(t) = (A/2)\,[1 - cos(\omega t + \pi/4)]\,,$$
$$A_3(t) = (A/2)\,[1 + cos(\omega t - \pi/4)]\ \& \qquad A_4(t) = (A/2)\,[1 - cos(\omega t - \pi/4)]\,.$$

The fluxes of motor-A are given [5], using

$$\phi_1(t) = -\mu_0\, A_1\, [2\, M_D + 2\, m_A +$$
$$\phi_2(t) = -\mu_0\, A_2\, [2\, M_D$$
$$\phi_3(t) = +\mu_0\, A_3\, [2\, M_D + 2\, m_B -$$
$$\phi_4(t) = +\mu_0\, A_4\, [2\, M_D - 2\, m_B -$$

From the above equations, the sub-polar

$$B_1(t) = \phi_1(t)/A_1(t) = -\mu_0\, [2\, M_D + 2$$
$$B_2(t) = \phi_2(t)/A_2(t) = -\mu_0\, [2\, M_D - 2$$
$$B_3(t) = \phi_3(t)/A_3(t) = +\mu_0\, [2\, M_D + 2$$
$$B_4(t) = \phi_4(t)/A_4(t) = +\mu_0\, [2\, M_D - 2$$

The TLSM A lift force, F_{v_A}, is given [5] b

$$F_{v_A}(t) = \mu_0\, A\, [8\, M_D^2 + 3\, m^2 + 8\, M_D\, m\, cos$$

Hence, the lift force, F_{v_A}, of TLSM-A is c which is partially supporting the boggie w pulsating at four times the synchronous motor-A can be neutralized by that of m of motor-B.

The time-shift is obtained by displacing be as shown in Fig. 5. This is seen to g will not contribute to neutralizing the p four times the synchronous frequency.

On the other hand, the θ-shift is obtained motor-B to the two-phase inverter suppl nent, this θ-shift must be quarter of a cyc shown in Fig. 6.

Hence, the TLSM-B lift force, F_{v_B}, is ob

$$F_{v_B}(t) = \mu_0\, A\, [8\, M_D^2 + 3\, m^2 + 8\, M_D\, m$$

Hence, the TLSMP lift force, F_v, of the lifts the boggie weight, W, actively by fi

$$F_v(t) = F_{v_A}(t) + F_{v_B}(t) = W = \mu_0\, A\, (1$$

The open cicuit induced voltages at ac found to be:

$$E_A(t) = -\mu_0\, \omega\, A\, M_D$$
$$E_B(t) = -\mu_0\, \omega\, A\, M_D$$

The TLSM-A thrust force, F_{h_A}, can be

$$F_{h_A} = (E_A\, i_A + E_B\, i_B)/u = \mu$$

urrent phase-locked to rail.

les is negligible, and field mmf excitations
onstants.

copper losses, windage, friction and other

er the sub-poles, and faces equal areas both
magnet-pole-surface below it throughout

composed of two portions. Each portion
ent sub-poles within the main pole and is
etween zero and A.

d it has constant speed, u, relative to the

two components only, namely, along grav-
motion. Although some force component
., it will be ignored.

ries sinusoidally between a minimum of
uncoupled to rail and a maximum when
rail.

PERFORMANCE

direction indicated in Fig. 5, Al-Kasimi
ils per magnet vary in-phase for adjacent
d forming one phase. This phase is in
osing sub-poles. The period and angular
pectively by: $T = 4p/u$ and $\omega = \pi u/2p$.

Fig. 6, per motor. Note that in each
ter of a cycle; and that the dc coils are
components. Hence, with:

$_D I_D$,

$m_B(t) = N i_B(t) = m \sin(\omega t + \theta)$;

flux to leave the sub-poles of motor-A,

$m_2(t) = -M_D + m_A(t)$,

$m_4(t) = +M_D - m_B(t)$.

imated to:

$A_2(t) = (A/2)[1 - \cos(\omega t + \pi/4)]$,

$A_4(t) = (A/2)[1 - \cos(\omega t - \pi/4)]$.

The fluxes of motor-A are given [5], using superposition, as:

$$\phi_1(t) = -\mu_0 A_1 [2 M_D + 2 m_A + m \sin(2\omega t + \theta - \pi/4)]/2Z,$$
$$\phi_2(t) = -\mu_0 A_2 [2 M_D - 2 m_A + m \sin(2\omega t + \theta - \pi/4)]/2Z,$$
$$\phi_3(t) = +\mu_0 A_3 [2 M_D + 2 m_B - m \sin(2\omega t + \theta - \pi/4)]/2Z \ \&$$
$$\phi_4(t) = +\mu_0 A_4 [2 M_D - 2 m_B - m \sin(2\omega t + \theta - \pi/4)]/2Z.$$

From the above equations, the sub-polar flux densities are found for motor-A as:

$$B_1(t) = \phi_1(t)/A_1(t) = -\mu_0 [2 M_D + 2 m_A + m \sin(2\omega t + \theta - \pi/4)]/2Z,$$
$$B_2(t) = \phi_2(t)/A_2(t) = -\mu_0 [2 M_D - 2 m_A + m \sin(2\omega t + \theta - \pi/4)]/2Z,$$
$$B_3(t) = \phi_3(t)/A_3(t) = +\mu_0 [2 M_D + 2 m_B - m \sin(2\omega t + \theta - \pi/4)]/2Z \ \&$$
$$B_4(t) = \phi_4(t)/A_4(t) = +\mu_0 [2 M_D - 2 m_B - m \sin(2\omega t + \theta - \pi/4)]/2Z.$$

The TLSM-A lift force, F_{v_A}, is given [6] by:

$$F_{v_A}(t) = \mu_0 A [8 M_D^2 + 3 m^2 + 8 M_D m \cos(\theta - \pi/4) + m^2 \sin(4\omega t + 2\theta)]/8Z^2. \quad (1)$$

Hence, the lift force, F_{v_A}, of TLSM-A is composed of two components: one steady which is partially supporting the boggie weight, W, via field control; and the other pulsating at four times the synchronous frequency. This pulsating component of motor-A can be neutralized by that of motor-B by properly shifting both t and θ of motor-B.

The time-shift is obtained by displacing both motors apart which was chosen to be as shown in Fig. 5. This is seen to give half-cycle time-shift for motor-B and will not contribute to neutralizing the pulsating component since it operates at four times the synchronous frequency.

On the other hand, the θ-shift is obtained by carefully connecting the two phases of motor-B to the two-phase inverter supply. For neutralizing the pulsating component, the θ-shift must be quarter of the cycle. This was obtained by the connections shown in Fig. 6.

Hence, the TLSM-B lift force, F_{v_B}, is obtained as:

$$F_{v_B}(t) = \mu_0 A [8 M_D^2 + 3 m^2 + 8 M_D m \cos(\theta + \pi/4) - m^2 \sin(4\omega t + 2\theta)]/8Z^2.$$

Hence, the TLSMP lift force, F_v, of the twin pair has only steady component that lifts the boggie weight, W, actively by field control. This force is given by:

$$F_v(t) = F_{v_A}(t) + F_{v_B}(t) = W = \mu_0 A (16 M_D^2 + 6 m^2 + 8\sqrt{2} M_D m \cos\theta)/8Z^2. \quad (2)$$

The open cicuit induced voltages at ac terminals of motor-A in Fig. 6 can be found to be:

$$E_A(t) = -\mu_0 \omega A M_D N \sin(\omega t + \pi/4)/Z \ \&$$
$$E_B(t) = -\mu_0 \omega A M_D N \sin(\omega t - \pi/4)/Z.$$

The TLSM-A thrust force, F_{h_A}, can be obtained using the energy principle as:

$$F_{h_A} = (E_A i_A + E_B i_B)/u = \mu_0 \pi A M_D m \sin(\theta - \pi/4)/(2p Z). \quad (3)$$

Likewise, the TLSM-B thrust force, F_{h_B}, can be found using the above shifts as:

$$F_{h_B} = \mu_0 \pi A M_D m \, sin(\theta + \pi/4)/(2p\, Z).$$

Hence, the TLSMP thrust force, F_h, of the twin pair is:

$$F_h = F_{h_A} + F_{h_B} = \mu_0 \pi A M_D m \, sin\theta/(\sqrt{2} p\, Z).$$

The steady thrusting acceleration, α_{hs}, relative to gravity could, hence, be obtained as:

$$\alpha_{hs}(\theta, m) = \mu_0 \pi A M_D(\theta, m) m \, sin\theta/(\sqrt{2} p W Z); \qquad (4)$$

where $M_D(\theta, m)$ is an implicit function of θ and m given in eq. (2).

The maximum of $\alpha_{hs}(\theta, m)$ for a given θ occures at $\overline{M}_D(\theta)$ and $\overline{m}(\theta)$. This could be found using eqs. (2) and (4) to give:

$$\overline{M}_D(\theta) = M_D(\theta, \overline{m}(\theta)) = \sqrt{0.375}\, \overline{m}(\theta), \qquad (5)$$

$$\overline{m}(\theta) = Z \sqrt{\frac{2W}{\mu_0 A (3 + \sqrt{3} cos\theta)}} \;\&$$

$$\alpha_{hs}(\theta) = (\pi Z/p) \cdot \frac{sin\theta}{2(\sqrt{3} + cos\theta)}.$$

On the other hand; the maximum value, α_{hsx}, of $\alpha_{hs}(\theta)$ occures at $\overline{\theta}$, found as:

$$\overline{\theta} = \pm[\pi - cos^{-1}\sqrt{(1/3)}].$$

This would *give:*

$$\overline{m} = Z \sqrt{W/(\mu_0 A)},$$

$$\overline{M}_D = Z \sqrt{0.375\, W/(\mu_0 A)} \;\&$$

$$\alpha_{hsx} = |\, \alpha_{hs}(\overline{\theta}) \,| = (\pi Z/p) \sqrt{0.125}.$$

REVIEW ANALYSIS OF TLSM PERFORMANCE

Two schemes of TLSM performances are possible for comparison: scheme-A where one TLSM-A lifts the whole weight; and scheme-3 where two TLSM-A lift the whole weight or equiveleantly one TLSM-A lifts half the weight.

The expressions for F_v and F_h in both schemes are identical to those given in eqs. (1) and (3) for F_{v_A} and F_{h_A} respectively. Hence, in a similar treatment to that of TLSMP, both schemes have identical expressions for maximum steady thrusting acceleration at any given θ. This occures at the same ratio given in eq. (5) between $\overline{M}_D(\theta)$ and $\overline{m}(\theta)$. The value of 6 that gives steady thrusting acceleration was found to be:

$$\overline{\theta} = \pi/4 \pm [\pi - cos^{-1}\sqrt{(2/3)}]$$

giving a maximum of:

$$\alpha_{hsx} = (\pi Z/p) \sqrt{0.5}.$$

This corresponds to the following values respectively:

$$\overline{m} = 2 Z \sqrt{W/(\mu_0 A)},$$

$$\overline{M}_D = Z \sqrt{1.5\, W/(\mu_0 A)} \;\&$$

REVIEW ANALYSIS OF ZLSMP PER

When the rail of ZLSMP moves in the di
that the flux linkages of ac coils for i
and hence can be series-connected forr
frequency of these variaions are given r
This illustrates the connections shown i

With treatment similar to that of TLSM
are obtained for ZLSMP:

$$m'_1(t) = -m'_3(t) = -M'_D - m'_A(t),$$

$$M'_D = N_D I'_D,$$

$$A'_1(t) = (A/2)[1 + cos(\omega' t)],$$

$$A'_3(t) = A'_1(t),$$

$$\phi'_1(t) = -\mu_0 A'_1 (M'_D + m'_A)/Z,$$

$$\phi'_3(t) = -\phi'_1(t),$$

$$B'_1(t) = -\mu_0 (M'_D + m'_A)/Z,$$

$$B'_3(t) = -B'_1(t) \;\&$$

Hence, the ZLSM-A lift force is given !

$$F'_{v_A}(t) = \mu_0 A [2 M'^2_D + m'^2 + 2 M'_D m' \ldots$$

$$+ m'^2 cos(\ldots$$

This is composed of two components:
the boggie weight, W, via field cont
synchronous frequency. This pulsating
by that of motor-B by properly shiftin

The time-shift is obtained by displacin
be as shown in Fig. 3. This is seen to g
and will neutralize the pulsating com
frequency; provided the θ'-shift is ma
another phase in quadrature-lag to t
supply is required, where:

$$m'_B(t) = N i'_B(\ldots$$

This explains the ZLSMP connections

ound using the above shifts as:

$r/4)/(2p\,Z)$.

pair is:

$.\,sin\theta/(\sqrt{2}\,p\,Z)$.

gravity could, hence, be obtained

$sin\theta/(\sqrt{2}\,p\,W\,Z)$; (4)

. m given in eq. (2).

s at $\overline{M}_D(\theta)$ and $\overline{m}(\theta)$. This could

$\sqrt{0.375}\,\overline{m}(\theta)$, (5)

$\overline{3\,cos\theta)}$ &

$n\theta$

$+\,cos\theta)$.

of $\alpha_{hs}(\theta)$ occures at $\overline{\theta}$, found as:

$(1/3)]$.

$\mu_0\,A)$ &

$/p)\,\sqrt{0.125}$.

IANCE

ible for comparison: scheme-A where heme-B where two TLSM-A lift the fts half the weight.

ies are identical to those given in eqs. nce, in a similar treatment to that of ssions for maximum steady thrusting at the same ratio given in eq. (5) that gives maximum steady thrusting

$s^{-1}\sqrt{(2/3)}]$,

$p)\,\sqrt{0.5}$.

0

This corresponds to the following values of $\overline{m}$ and $\overline{M}_D$ for scheme-A and scheme-B respectively:

$$\overline{m} = 2\,Z\,\sqrt{W/(\mu_0\,A)}, \qquad \overline{m} = Z\,\sqrt{2\,W/(\mu_0\,A)},$$
$$\overline{M}_D = Z\,\sqrt{1.5\,W/(\mu_0\,A)}\ \& \qquad \overline{M}_D = Z\,\sqrt{0.75\,W/(\mu_0\,A)}.$$

REVIEW ANALYSIS OF ZLSMP PERFORMANCE

When the rail of ZLSMP moves in the direction indicated in Fig. 3, West [3] found that the flux linkages of ac coils for magnet-A vary in-phase for all sub-poles and hence can be series-connected forming one phase. The period and angular frequency of these variaions are given respectively by: $T' = 2p/u$ and $\omega' = \pi\,u/p$. This illustrates the connections shown in Fig. 4 for motor-A.

With treatment similar to that of TLSMP, the following corresponding expressions are obtained for ZLSMP:

$$m_1'(t) = -m_3'(t) = -M_D' - m_A'(t), \qquad m_2'(t) = -m_4'(t) = -M_D' + m_A'(t),$$
$$M_D' = N_D\,I_D', \qquad m_A'(t) = N\,i_A'(t) = m'\,cos(\omega'\,t + \theta'),$$
$$A_1'(t) = (A/2)\,[1 + cos(\omega'\,t)], \qquad A_2'(t) = (A/2)\,[1 - cos(\omega'\,t)],$$
$$A_3'(t) = A_1'(t), \qquad A_4'(t) = A_2'(t),$$
$$\phi_1'(t) = -\mu_0\,A_1'\,(M_D' + m_A')/Z, \qquad \phi_2'(t) = -\mu_0\,A_2'\,(M_D' - m_A')/Z,$$
$$\phi_3'(t) = -\phi_1'(t), \qquad \phi_4'(t) = -\phi_2'(t),$$
$$B_1'(t) = -\mu_0\,(M_D' + m_A')/Z, \qquad B_2'(t) = -\mu_0\,(M_D' - m_A')/Z,$$
$$B_3'(t) = -B_1'(t)\ \& \qquad B_4'(t) = -B_2'(t).$$

Hence, the ZLSM-A lift force is given [3] as:

$$F_{v_A}'(t) = \mu_0\,A\,[2\,{M_D'}^2 + {m'}^2 + 2\,M_D'\,m'\,cos\theta' + {m'}^2\,cos(2\omega'\,t + 2\,\theta') + 2\,M_D'\,m'\,cos(2\,\omega'\,t + \theta')]/2Z^2.$$

This is composed of two components: one steady which is partially supporting the boggie weight, W, via field control; and the other pulsating at twice the synchronous frequency. This pulsating component of motor-A can be neutralized by that of motor-B by properly shifting both t and θ' of motor-B.

The time-shift is obtained by displacing both motors apart which was chosen [3] to be as shown in Fig. 3. This is seen to give quarter-cycle time-shift lag for motor-B and will neutralize the pulsating component operating at twice the synchronous frequency; provided the θ'-shift is maintained at zero. This would involve using another phase in quadrature-lag to the first one. Hence, a two-phase inverter supply is required, where:

$$m_B'(t) = N\,i_B'(t) = m'\,sin(\omega'\,t + \theta').$$

This explains the ZLSMP connections shown in Fig. 4.

Hence, the ZLSMP lift force, F'_v, of the twin pair has only steady component that the boggie weight, W, actively by field control. This force is given by:

$$F'_v(t) = F'_{v_A} + F'_{v_B} = W = \mu_0 \, A \, (2 \, {M'_D}^2 + m'^2 + 2 \, M'_D \, m' \, cos\theta')/Z^2 \, . \qquad (6)$$

The open circuit induced voltage at ac terminals of motor-A in Fig. 4 can be found [3] to be:

$$E'_A(t) = -2\mu_0 \, \omega' \, A \, M'_D \, N \, sin(\omega' t)/Z$$

This leads to:

$$F'_{h_A}(t) = \mu_0 \, \pi \, A \, M'_D \, m' \, [sin\theta' - sin(2\omega' t + \theta')]/(p \, Z).$$

Likewise, the ZLSM-B thrust force, F'_{h_B}, can be found using the above shifts as:

$$F'_{h_B}(t) = \mu_0 \, \pi \, A \, M'_D \, m' \, [sin\theta' + sin(2\omega' t + \theta')]/(p \, Z).$$

Hence, the ZLSMP thrust force, F'_h, of the twin pair is:

$$F'_h = F'_{h_A} + F'_{h_B} = 2 \, \mu_0 \, \pi \, A \, M'_D \, m' \, sin\theta'/(p \, Z).$$

The steady thrusting acceleration, α'_{hs}, relative to gravity could, hence, be obtained as:

$$\alpha'_{hs}(\theta', m') = 2 \, \mu_0 \, \pi \, A \, M'_D(\theta', m') \, m' \, sin\theta'/(p \, W \, Z) \, , \qquad (7)$$

where $\overline{M'_D}(\theta', m')$ is an implicit function of θ' and m' given in eq. (6).

The maximum of $\alpha'_{hs}(\theta', m')$ for a given θ' occures at: $\overline{m'}(\theta')$. This could be found using eqs. (6) and (7) to give:

$$= \overline{m'}(\theta') \sqrt{0.5} \, ,$$

$$\overline{m'}(\theta') = Z \sqrt{\frac{\sqrt{2} \, W}{\mu_0 \, A \, (\sqrt{2} + cos\theta')}} \quad \&$$

$$\alpha'_{hs}(\theta') = (\pi \, Z/p) \cdot \quad sin\theta'$$

On the other hand, the maximum of $\alpha'_{hs}(\theta')$ occures at $\overline{\theta'}$, found as:

$$\overline{\theta'} = \pm 3\pi/4 \, ,$$

would give maximum value, α'_{hsx}, for α'_{hs} as:

$$\alpha'_{hsx} = | \, \alpha'_{hs}(\overline{\theta'}) \, | = \pi \, Z/p$$

at:

$$\overline{m'} = Z \, \sqrt{2 \, W/(\mu_0 \, A)} \; \&$$

$$\overline{M'_D} = Z \, \sqrt{W/(\mu_0 \, A)} \, .$$

CHARACTERISTICAL MERITS A

The TLSMP, TLSM and ZLSMP
starters. For the same speed, the fi
the third. Their maximum thrustin
$(\pi \, Z/p)$ are: $\sqrt{0.125}$, $\sqrt{0.5}$ and 1 r
in terms of $Z \sqrt{W/(\mu_0 \, A)}$ of: $\sqrt{0.}$
scheme-A, TLSM scheme-B and ZI
ture excitations in terms of $Z \sqrt{W/}$
machines have pulsation-free propul
pulsation-free lift, whereas both TL
monic. The magnitude of these pul

CONCLUSION

For same speed, TLSMP and TLSI
operate at half the switching freque
accelerations.

On the other hand, TLSMP is ad
pulsation; with the price of less rati
less excitation of both field and arm
in TLSMP exercises a braking effe

REFERENCES

[1] McLean, G. W. and West, A
Vehicles Using the Z
Maglev Transport Now and fc

[2] McLean, G. W. (1988). Rev
Proc., Vol. 35, Part B, No. 6:

[3] West, A. N. (1982). The Cc
chine. PhD Thesis, Elect. Eng

[4] Al-Kasimi, S. M. (1992). A I
Integrated Lift and Thrust U
East Power System Conf., M

[5] Al-Kasimi, S. M. and BaQu
teristics of The Trapizoidally
as Compared to The Zigzag
Second Internati
Egypt, Vol. 5: 392-409.

ne twin pair has only steady component that
y field control. This force is given by:

$$\text{l}\,(2\,M_D'^{\,2} + m'^2 + 2\,M_D'\,m'\cos\theta')/Z^2\,. \quad (6)$$

ac terminals of motor-A in Fig. 4 can be

$$A\,M_D'\,N\,sin(\omega' t)/Z\,.$$

$$in\theta' - sin(2\,\omega' t + \theta')]/(p\,Z).$$

can be found using the above ts as:

$$n\theta' + sin(2\,\omega' t + \theta')]/(p\,Z).$$

;he twin pair is:

$$\pi\,A\,M_D'\,m'\,sin\theta'/(p\,Z).$$

lative to gravity could, hence, be obtained

$$(\theta', m')\,m'\,sin\theta'/(p\,W\,Z)\,, \quad (7)$$

of θ' and m' given in eq. (6).

occures at: $\overline{m}'(\theta')$. This could be found

$$\overline{0.5}\,,$$

$$\frac{\sqrt{2}\,W}{(\sqrt{2} + cos\theta')} \;\&$$

$$\frac{sin\theta'}{(\sqrt{2} + cos\theta')}\,.$$

) occures at $\overline{\theta}'$, found as:

$$/4\,,$$

$'_{hs}$ as:

$$= \pi\,Z/p\,,$$

$$\overline{(\mu_0\,A)}\;\&$$

$$_0\,A)\,.$$

CHARACTERISTICAL MERITS AMONG TLSMP, TLSM AND ZLSMP

The TLSMP, TLSM and ZLSMP are two-phase linear machines that need no starters. For the same speed, the first two run at half the swithing frequency of the third. Their maximum thrusting accelerations relative to gravity in terms of $(\pi\,Z/p)$ are: $\sqrt{0.125}$, $\sqrt{0.5}$ and 1 respectively. These occure at field excitations in terms of $Z\,\sqrt{W/(\mu_0\,A)}$ of: $\sqrt{0.375}$, $\sqrt{1.5}$, $\sqrt{0.75}$ and 1 for TLSMP, TLSM scheme-A, TLSM scheme-B and ZLSMP respectively. The corresponding armature excitations in terms of $Z\,\sqrt{W/(\mu_0\,A)}$ are: 1, 2, $\sqrt{2}$ and $\sqrt{2}$ respectively. All machines have pulsation-free propulsion. Furthermore, TLSMP and ZLSMP have pulsation-free lift, whereas both TLSM schemes have lift pulsations at fourth harmonic. The magnitude of these pulsations relative to gravity is one half.

CONCLUSION

For same speed, TLSMP and TLSM are advantageous over ZLSMP in that they operate at half the switching frequency; with the price of less rating for propulsive accelerations.

On the other hand, TLSMP is advantageous over TLSM in that it has no lift pulsation; with the price of less rating for propulsive acceleration and consequently less excitation of both field and armature. This is because each of the twin motors in TLSMP exercises a braking effect on the other.

REFERENCES

[1] McLean, G. W. and West, A. N. (1984). Combined Lift and Thrust for Maglev Vehicles Using the Zigzag Synchronous Motor. Proc. Int. Conf. on Maglev Transport Now and for the Future, IMechE: 87-97.

[2] McLean, G. W. (1988). Review of Recent Progress in Linear Motors. IEE Proc., Vol. 35, Part B, No. 6: 380-416.

[3] West, A. N. (1982). The Control of a Linear Homopolar Synchronous Machine. PhD Thesis, Elect. Eng. Dept., Manchester University.

[4] Al-Kasimi, S. M. (1992). A New Synchronous Motor for Maglev Train With Integrated Lift and Thrust Using A Trapizoidal Rail. Proc. Second Middle East Power System Conf., MEPCON'92, Assiut University, Egypt: 67-69.

[5] Al-Kasimi, S. M. and BaQubas, A. O. (1991). The Acceleration Characteristics of The Trapizoidally Railed Linear Homopolar Synchronous Motor as Compared to The Zigzag Version for Maglev Applications. Proc. Azhar Engineering Second International Conference, AEC'91, Al-Azhar University, Egypt, Vol. 5: 392-409.

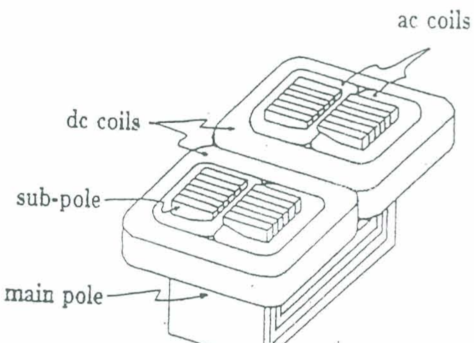


Fig.1 Magnet

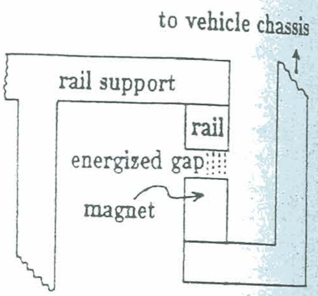


Fig.2 Boggie support

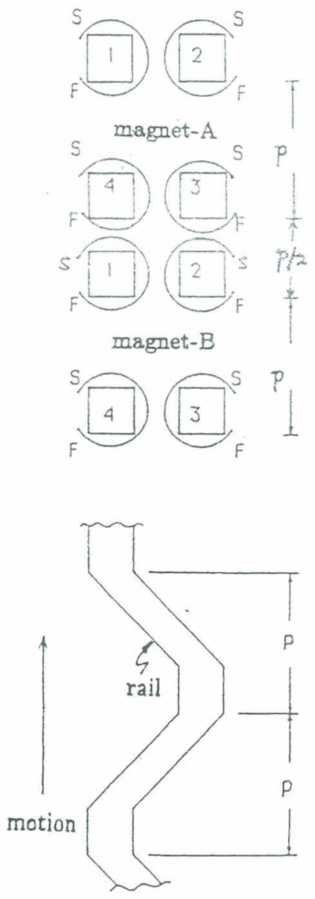


Fig.3 Rail of ZLSMP

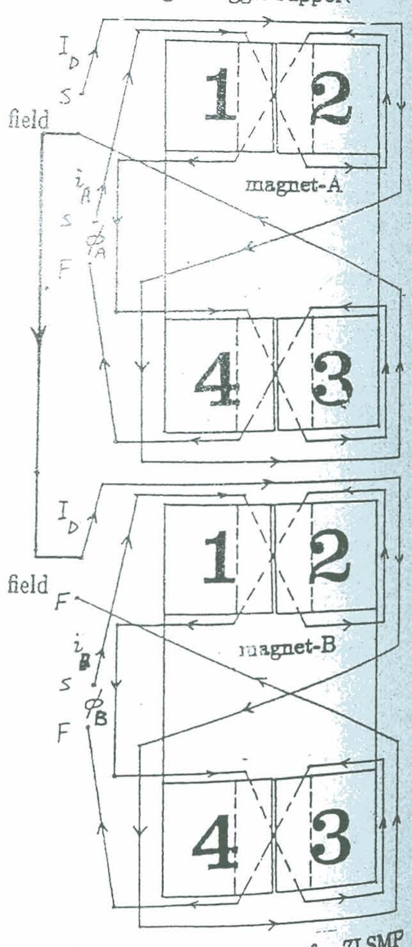


Fig.4 Coil connections for ZLSMP

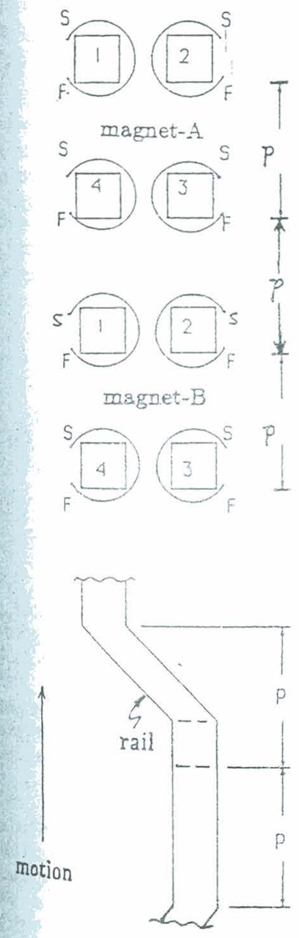


Fig.5 Rail of TLSMP

c coils

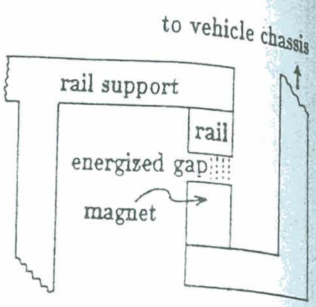


Fig.2 Boggie support

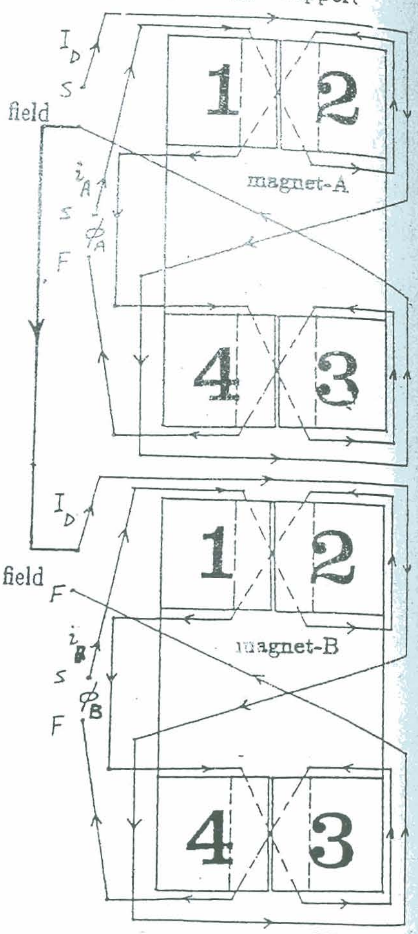
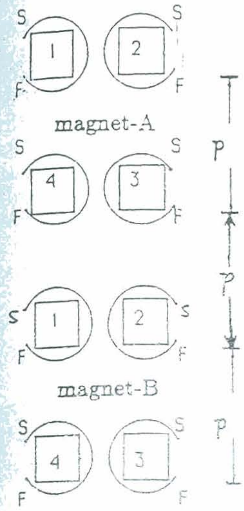


Fig.4 Coil connections for ZLSMP



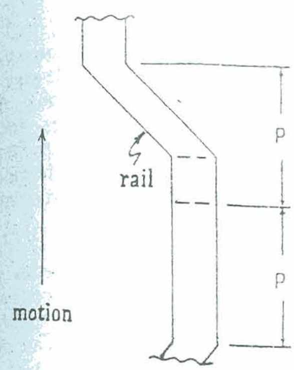


Fig.5 Rail of TLSMP

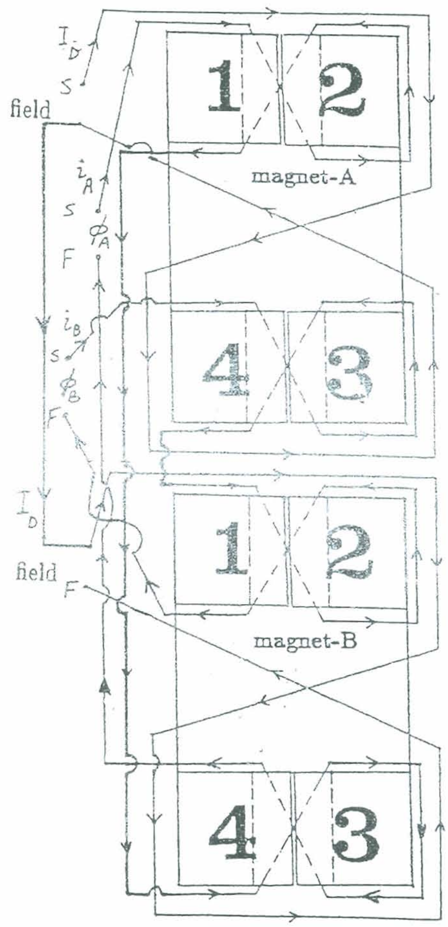


Fig.6 Coil connections for TLSMP