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Design and Construction of a Model of a Magnetic Train

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ABSTRACT

The magical magnetic levitation has fascinated philosophers and scientists in the past. The recent advances, especially in magnetic materials and power electronics, have focused this attention on the application of electromagnetic suspension and levitation techniques to advanced ground transportation. There are different technology available for suspension and propulsion, but the entire field is given an encompassing title of 'maglev'. Only high speed ground vehicle has caught the imagination of the media. But there is also a wide range of industrial applications i.e. material handling, product transportation to which magnetic suspension techniques could be profitable. This project deals with the design and construction of a model of a simple maglev system with the existing technology available in this country. The suspension of the maglev system has been done by arrays of permanent magnets. The repulsive force between two permanent magnets has been used for floating the train body in the air. The propulsion has been done by Linear Induction Motor (LIM). The linear induction motor has been made by making electromagnet and placing them in a straight line and connecting them in a three phase sequence. The design of linear induction motor has been done considering the weight and velocity of the train and the design algorithm is completely user-interactive. During the design, end effects and edge effects are neglected. During the test, the train was run successfully with some vibration which can be reduced by using magnetic feedback control.

Keywords: Maglev, Suspension, Propulsion, LIM

1. Introduction

A magnetic train runs on the principle of Maglev. In Maglev system, a vehicle is suspended form guide ways and propelled through a definite course [1]. The mechanical methods commonly used in transportation like the use of wheels, bearings, axles etc. are obsolete in a Maglev system. In this project, the levitation has been achieved by permanent magnets and propulsion has been done by Linear Induction Motor (LIM).

2. Theory:

2.1 Permanent Magnet

When two similar poles of two permanent magnets are kept close to one another, a repulsive force is created which tends the magnets to swift away from one another. The hysteresis loop of the permanent magnetic materials describe their magnetic properties i.e. flux density B and field strength H [2].

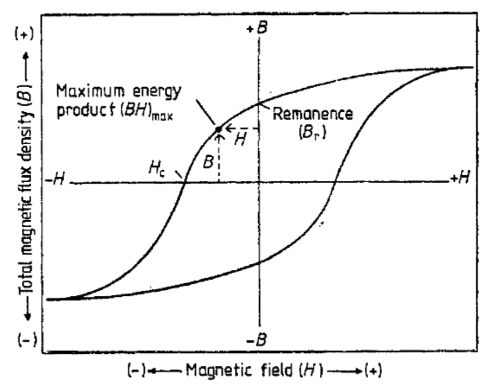

Figure 1: B-H loop of a permanent magnet illustrating the point where the product B-H is maximum.

The force of attraction or repulsion between two magnets is given by the expression $F = B^2/2\mu_0$ per unit area. When the permanent magnets repulse with one another the flux

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density (B) is no longer constant rather is varies at different sections. Due to this reason, according to Earnshaw's corollary, it is impossible for a body to be held in stable equilibrium against displacements in all directions if the system is constituted of permanent magnets only [3].

2.2 Linear Induction Motor:

A Linear Induction Motor (LIM) is an AC asynchronous motor that is designed to produce motion through a straight line. The basic principle of LIM operation is similar to that of a conventional rotating squirrel-cage induction motor.

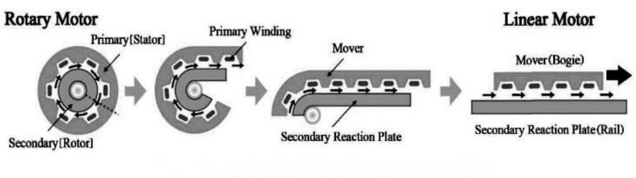

Fig 2: Concept of a linear induction motor from a rotary motor [4]

The Single sided LIM synchronous velocity Vs is the same as that of the rotary induction motor, given by

$$V = \frac{2\omega R}{p} = 2f\tau \qquad (1)$$

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The parameter τ is the distance between two neighboring poles on the circumference of the stator, called pole pitch, defined as [5]

$$\tau = \frac{2\pi R}{p} \qquad (3)$$

The stator circumference of the rotary induction motor, $2\pi R$, is equal to the length of the LIM stator core, L_s. Therefore, the pole pitch of a LIM is

$$\tau = \frac{2\pi R}{p} = \frac{Ls}{p} \qquad (4)$$

The current sheet strength, i.e., the amount of current per unit stator length (Ls) in a current sheet of a Single sided LIM can be calculated as in Nasar and Boldea [6] as follows:

$$J_m = \frac{2\sqrt{2} m k_w N_c I_1}{L_s} \qquad (5)$$

Winding factor,

$$k_w = k_p k_d \qquad (6)$$

k_p is the pitch factor which can be found by

$$k_p = \sin\left(\frac{\theta_p}{2}\right) \qquad (7)$$

K_d is the breadth or distribution factor given by

$$k_d = \frac{\sin\left(\frac{q_1\alpha}{2}\right)}{q_1 \sin\left(\frac{\alpha}{2}\right)} \qquad (8)$$

The power input to the stator windings is given by

$$P_i = mV_1 I_1 \cos\varphi \qquad (9)$$

Synchronous speed, V_s=2*pole pitch*frequency of current

For a slip of s, the speed of the secondary in a linear motor is given by

$$v_r = (1-s)v_s \qquad (10)$$

3. Design

3.1 Design Considerations

A low performance LIM was targeted as the cost was a major concern.

Size of each permanent magnet (24.4×19.25×20) mm.

Length of the train body = 16 cm.

Final width of the train 21.20 cm.

From experiment it has been seen that

Each permanent magnet can lift 112.5 gm.

Total weight of the train = Weight of the train body + Weight of the permanent magnets fitted with the body= 176+14*8 = 288 gm.

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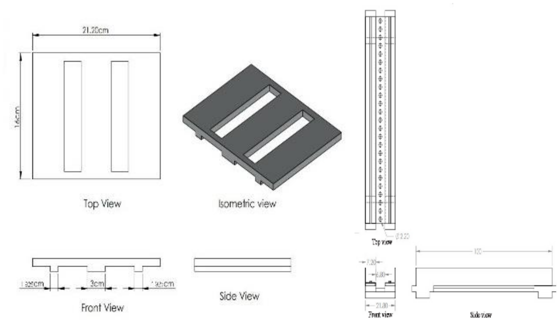
3.2 Design of the Track

Length of the track is 100 cm.

Width of the track is 14.075 cm.

Height of the guide track is 7.2 cm from the base.

U shape guide ways was used.



(a) (b)

Fig 3: Design of the (a) train body and (b) suspension track

3.3 Design of the Linear Induction Motor (LIM)

3.3.1 Targeted power for LIM

Synchronous speed of the linear induction motor

,v_s = 2*pole pitch*supply frequency in Hz.

So that the velocity of the primary designed linear induction motor was

$$v_s = 2*12*50 = 1200 \text{ cm/sec} = 12 \text{ m/sec}$$

Considering 15 % slip the velocity of the secondary in a linear induction motor

$$v_r = (1-.15)*12 \approx 10 \text{ m/sec}$$

Drag force acting on the train body

$$F_D = 0.5*1.204*10^2*1.8*21.20\times10^{-4} = 0.22 \text{ N}$$

Power required to overcome the aerodynamic drag is

$$P_d = 0.229*10 = 2.2 \text{ W}$$

Force required to accelerate the train in 10s from 0 m/s to 10 m/s is

$$F_a=0.288*1 = 0.288 \text{ N}$$

Power required to accelerate the train from 0 m/s to 10 m/s is

$$P_a = 0.288*10 = 2.88 \text{ W}$$

Frictional force in the guide plate

$$F_f = \mu_k N = 1.4*2.83 = 3.962 \text{ N}$$

Frictional power

$$P_f = 3.962*10 = 39.62 \text{ W}$$

So total power required to run the train = (2.2+2.88+39.62) = 44.7 W

3.3.2 General Specifications

Number of phases, m = 3

Line to line voltage,V_{line} = 220 V

Electrical frequency, f = 50 Hz

Number of poles, p = 8

Number of slot per pole per phase, q_1 = 1

Target electromagnetic thrust, F_s = 10 N

3.3.3 Determination of Pole Pitch and Slot Pitch

Optimum space required for each pole is 4 cm (Considering optimum bolt size with washer and winding space).

So, pole pitch, τ = 12 cm = 0.12 m

Slot pitch,

$$\lambda = (\tau/mq_1) = \frac{0.12}{3*1} = 0.04 \text{ m} = 4 \text{ cm}$$

3.3.4 Determination of Current

$$V_1 = V_{line}/\sqrt{3} = 220/\sqrt{3} = 127 \text{ V}$$

$$I_1 = \frac{Fs\,Vr}{mV1\,\eta\cos\varphi} = \frac{10*10}{3*127*.5} = 0.5 \text{ A}$$

3.3.5 Determination of Optimum Wire Size and Optimum no. of Turns

Total area of copper wire,

$$A_{wt} = 2\pi r_w L + 2\pi r_w^2$$

As r<<< l, so $2\pi r^2$ is negligible. So,

$$A_{wt} = 2\pi r_w L = \pi D_w L = \pi D_w * \pi D_c Nc = \pi^2 D_w D_c N_c.$$

Bolt size 1.2 cm

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Assume after winding, each pole size will be 2.2 cm

So,

$$D_c = \frac{1.2+2.2}{2} = 1.7 \text{ cm} = 0.017 \text{ m}$$

Again,

$$A_{wt} = (I_1/J_1) = \pi^2 D_c D_w N_c = 0.1 D_w N_c.$$

Again

$$J = \frac{2\sqrt{2}mKwNcI1}{Ls}$$

$$k_w = k_p k_d = 1*1 = 1 \text{ where}$$

$$k_p = \sin(\theta_p/2) = \sin 90^o = 1$$

$$k_d = \sin(q_1\alpha/2) / (q_1 \sin(\alpha/2) = \sin(1*\alpha/2) / 1*\sin(\alpha/2) = 1$$

$$J_1 = \frac{2\sqrt{2}*1*3*.5*Nc}{100} = 0.043N_c$$

So

$$D_w N_c = I_1 /(0.1*J_1) = 0.5/ (0.0043N_c)$$

$$\text{Or, } D_w N_c^2 = 116.2$$

For wire no. #25D_w = 0.45mm = 0.00045m

So,

$$N_c = \sqrt{(116.2/.00045)} = 508.2 \approx 510.$$

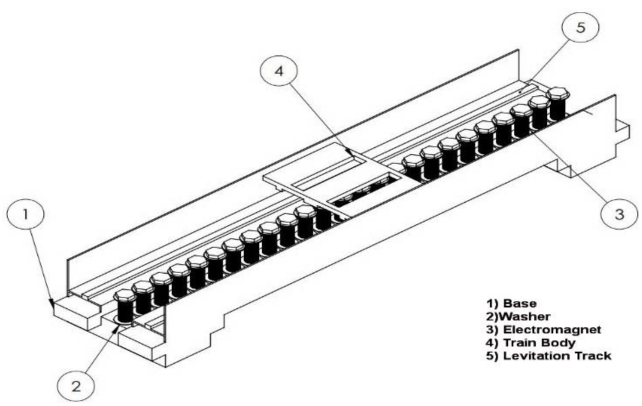
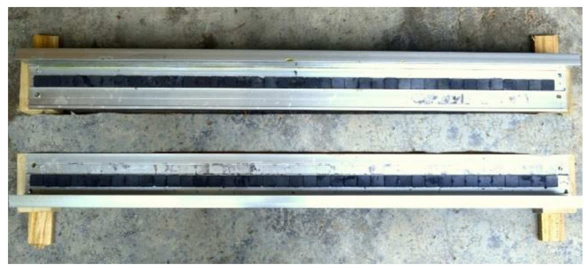


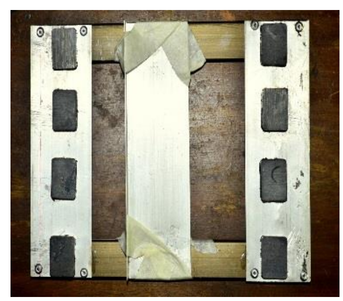
Fig 4: Design of the maglev system

4. Construction

Thai aluminum bar (21.2×1.5) cm was used for the structure as it has low weight and rigid enough comparing to the other available material. Permanent magnets were attached to the track in a single array using super glue. Sequence was maintained for winding i.e. 1-4-7-10 no. 2-5-8-11 no. bolt for making three phase winding. Copper wire was winded tightly so that the wire didn't lose and make good magnetic flux.



(a)



(b) (c)

(d)

Fig 5: Constructed view of (a) Maglev track, (b) LIM (c) Train body (d) Final assembly

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5. Experiments and Performance Test

Maximum weight that can be carried by the train was 513 gm.

Maximum velocity achieved: 0.75m/s

Levitation achieved 1 cm

So physical air gap, g_m = 1 cm

Magnetic air gap, g_o = 1+.1 = 1.1 cm

Carter's coefficient, $k_c = \frac{\lambda}{\lambda - \gamma go} = \frac{4}{4-1.97*1.1} = 2.18$

Here,

$$\gamma = \frac{4}{\pi}\left[\frac{1.2}{2*1.1} arctan\left(\frac{1.2}{2*1.1}\right) - ln\sqrt{(1 + \left(\frac{1.2}{2*1.1}\right)\left(\frac{1.2}{2*1.1}\right)}\right]$$

= 1.97

So effective air gap g_e = 1.97*1.1 = 2.16 cm

6. Discussion and Conclusion

The maglev train ran successfully although having some difficulties. As the train body touched the guide plate, a frictional resistance force was produced. It created obstacle and lowered the speed of the train. Also sometimes the train body just vibrated instead of going forward. The main reason was that the force and velocity produced by the LIM could not match with the high frequency of the current.

NOMENCLATURE

A_s: Area of slot, m^2
A_w: Area of copper wire for one turn per slot, m

A_{wt}: Total area of copper wire, m^2

D_w: Diameter of copper wire, m

f: Electrical frequency, Hz

F_s: Electromagnetic thrust generated by rotor, N

g_e: Equivalent air gap, m

g_{ei}: Equivalent air gap considering edge effects , m

g_m: Mechanical air gap, m

g_0: Magnetic air gap, m
G: Goodness factor
I_1: RMS input phase current, A

V_1: RMS Input Phase, V

V_r: Rotor Velocity, m/s

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V_s: Synchronous Velocity , m/s

φ : Angle between voltage and current ,

η: Efficiency
λ: Slot Pitch, m
μ_0: Permeability of free space, H/m

ρ_w: Volume resistivity of Copper, Ω-m

τ: Pole pitch, m

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