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Certificate

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This is to certify that the project report entitled

DESIGN AND DEVELOPMENT OF PERMANENT MAGNET LINEAR OSCILLATORY MOTOR

has been submitted by

Mr.______________________________ Roll No._______________

in partial fulfilment of the award of
Bachelor of Engineering
in the Electrical and Electronics Engineering
Branch of the Bharathiar University, Coimbatore
during the academic year 1994-'95.

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Guide

Head of the Department

Certified that the candidate with University Register No. ______________

was examined in Project Work Viva - Voce on ____________

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Internal Examiner

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External Examiner

ACKNOWLEDGEMENT

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Our thanks are due to all those who directly or indirectly helped us in completing this Project.

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SYNOPSIS

Applications like space power systems computer numerical controlled machine tools, short stroke linear motions vibrators, shuttles in textile machineries and artificial heart pump in bio medical engineering require motors with accurate oscillating/reciprocating linear motion. Permanent magnet LOM is one such type on which extensive research is being carried out.

This project deals with the design and development of a permanent magnet LOM. A 32 Votts, 7 H_z 1.6 Amp motor is designed to produce a force of 35 newtons and the design procedure is reported in detail. The motor is fabricated and its various test results are also presented in this report.

Due to nonavailability of PMs readily, the capacity of the motor fabricated is limited to a low value. The capacity can be increased by getting higher power magnets.

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LIST OF SYMBOLS

a_c	Conductor area	mm^2
a_s	Slot area	mm^2
A	Area of the Stator Iron core	mm^2
A_T	Total area of Stator	mm^2
A_{s1}	Area of the slot 1	mm^2
A_{s2}	area of the slot 2	mm^2
A_b	Area of the Linear bearing	mm^2
B	Flux Density	
B_a	Axial airgap flux density at attraction	
B_p	Axial airgap flux density at repulsion case	T
B_o	Airgap flux density when primary current is off	T
B_r	Residual fluxk density of Permanent Magnet	T
B_{PM}	PM flux density	T
D	Diameter of Stator	mm
D_m	Diameter of the Mover	mm
d_b	Linear bearing outer diameter	mm
dil	Slot 1 Inner diameter	mm
di2	Slot 2 Inner diameter	mm
do1	Slot 1 outer diameter	mm
do2	Slot 2 outer diamter	mm
F_A	Attraction force	N
F_R	Repulsion force	N
F	Motor force	N

f	Frequency	Hz
g	Airgap	m
H_c	Coercivity	A/m
H_m	Magnetic field intensity at operating point of PM	A/m
H_r	Magnetic field intensity along radial direction	A/m
I	Current	A
J	Current density	A/mm^2
k_s	Space factor	
l_s	Stroke length	mm
L	Inductance	[illegible]
L_{pm}	Leength of the PM1	mm
l_m	Length of the PM2	mm
L_s	Length of the stator	mm
L_M	Length of the mover	mm
L_s	Depth of the slot	mm
L_R	Average radial magnetic circuit length	mm
L_b	Length of the Linear bearing	mm
N	Number of turns of the primary coil	
R	Coil Resistance	ohm
$Ø$	Magnet flux	Wb
u_{max}	Maximum speed	m/sec
μ_0	Permeability of the free space	H/m
W_m	Stored energy in the magnetic field	W.sec
W_i	Weight of the iron in Mover	kg
W_{pm}	Weight of the PMs	kg
W_t	Total weight of Mover	kg
W_{s1}	Width of the slot 1	mm
W_{s2}	Width of the slot 2	mm
Z	Impedance	ohm

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6 TESTING

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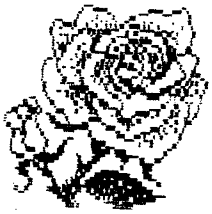

LINEAR OSCILLATORY MOTOR

CHAPTER 1

LINEAR OSCILLATORY MOTOR

1.1 Introduction

Many linear motion devices in industry require a limited movement in which the moving member oscillates. Such motion is often governed by a prescribed distance-time relationship. Such applications range from short-stroke linear motion vibrators, such as dynamic cone-type loud speakers to stirling-engine driven linear-motion reciprocating alternators, compressors, and textile machineries. The frequency of oscillations could be as high as 15 KHz. The length of strokes may go upto 2 m. The maximum speed is in the range of 5 to 10 m/sec.

Applications requiring strokes longer than a few centimeters within this low speed range should be approached as problems pertaining to drives having a forward acceleration-costing-braking profile. However applications with strokes of less than 5 cm will permit only accelerating and speed reversal periods during the oscillatory motion. A fast speed reversal with minimum energy loss in such devices is imperative. Such linear motion reciprocating electric motors require special considerations in terms of motor topology, dynamics, and control.

1.2 Merits and Demerits

1.2.1 Merits:

a. High flux densities in the airgap by using Ferrite or rare earth magnets.

b. Efficient use of the primary coils by making a tubular structure.

c. Simple and rugged construction.

1.2.2 Demerits:

a. High cost of Ferrite/Rare earth magnets.

b. Difficulties in making a laminated primary.

1.3 Types of LOMs:

The two types of LOMs are

i. Permanent Magnet Linear Oscillatory Motor

ii. Solenoid Linear Oscillatory Motor

1.3.1 Permanent Magnet Linear Oscillatory Motor

PM LOM with one stator slot and permanent magnet placed on the plunger is shown in the fig 1.1. More slots and PM poles of alternate polarities may be added to obtain a higher thrust, with the coils connected in series. When the plunger moves back and forth, the primary coils experience a flux reversal and hence an AC voltage is induced in the coils.

1.3.2 Solenoid Linear Oscillatory Motor

The Solenoid Linear Oscillatory Motor is as shown in the fig 1.2. The solenoid LOM is a magnetic device that operates as a motor by virtue of the attraction force between two soft iron surfaces and two magnetized cores. A periodic switching of the two cores will result in an oscillation (or vibration) of the moving armature. Such a device may be used to drive a compressor.

1.4 SCOPE OF THE PROJECT

Thesre LOMs find wide range of applications in every linear oscillation problems. Among these types, permanent magnet linear oscillatory motor is preferred because it can be operated with both attraction and repulsion forces. The present project work deals with the design and development of one such PMLOM. Also the control unit requirement for this PMLOM is dealt with in this report.

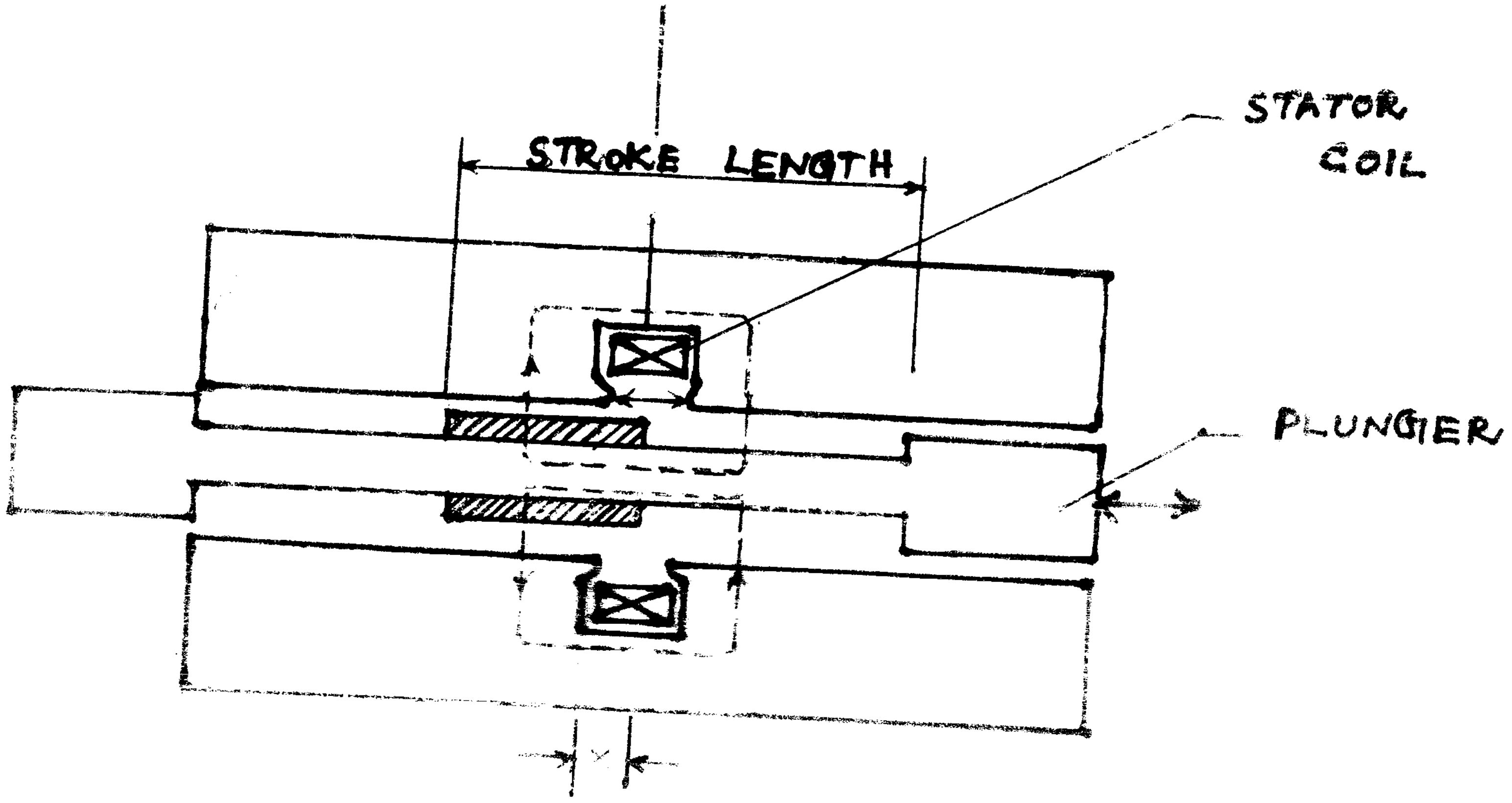

FIG 1.1 PERMANENT MAGNET LINEAR OSCILLATORY MOTOR

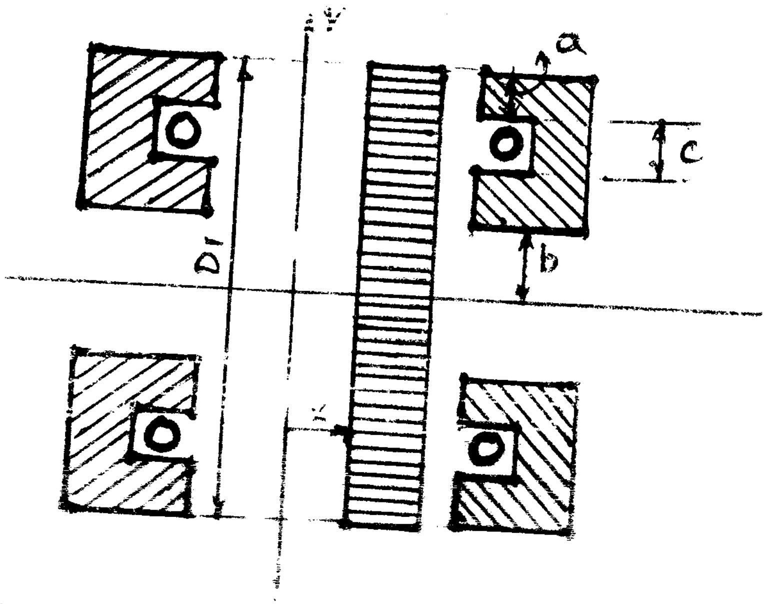

Fig 1.2. SOLENOID LINEAR OSCILLATORY MOTOR

PERMANENT MAGNET LINEAR OSCILLATORY MOTOR

CHAPTER - 2

PERMANENT MAGNET LINEAR OSCILLATORY MOTOR

2.1. Introduction:

PMLOM is a device which directly uses the forces of attraction and repulsion between a magnet and an electromagnet. It can easily be powered and controlled. It has a high force density, higher efficiency and smaller size and weight compared to most of the existing small motors. It can satisfy the performance requirements with a variable stroke volume. There are little vibration and noise.

2.2. Construction of PMLOM:

Several topological variations of the electromagnetic structures are feasible. To illustrate the operation of the motor in the oscillating mode we have chosen a cylindrical structure with two stators, each having two slot-embeded coils, and a mover with permanent magnets. PMLOM essentially consists of two major components Mover and Stator as shown in the fig. 2.1. Stator and Mover are made up of magnetic materials 045 steel.

Here on the stator face two grooves are made and coil 1 and coil 2 combination called coil I is placed on the stator 1 and coil 3 & coil 4 combination called coil II is placed on the stator 2. On the mover's both faces grooves are made and permanent magnets are placed in it. The positioning of the coils and the permanent magnets are such that the pole faces of electromagnet and permanent magnets are align on each other axially.

2.3. Principle of Operation:

The principal of operation of a PMLOM is as shown in the fig. 2.2. The proposed PMLOM is controlled magnet system and has a variable axial airgap. For the relative polarities of the currents in the various coils verified that there will be an attraction force between coil I & PMs and repulsion force between coil II & PMs. Thus the mover will tend to move to the left. At the end of the stroke, the polarities of the currents in coil I and coil II are simultaneously reversed. This reversal changes the direction of the forces. A repulsion force now exists between coil I and PMs and an attraction force between coil II and PMs. Consequently, the mover tends to move to the right. At the end of the stroke the polarities of the currents in the coils I & II are reversed again and so on. Hence sustained oscillations are obtained.

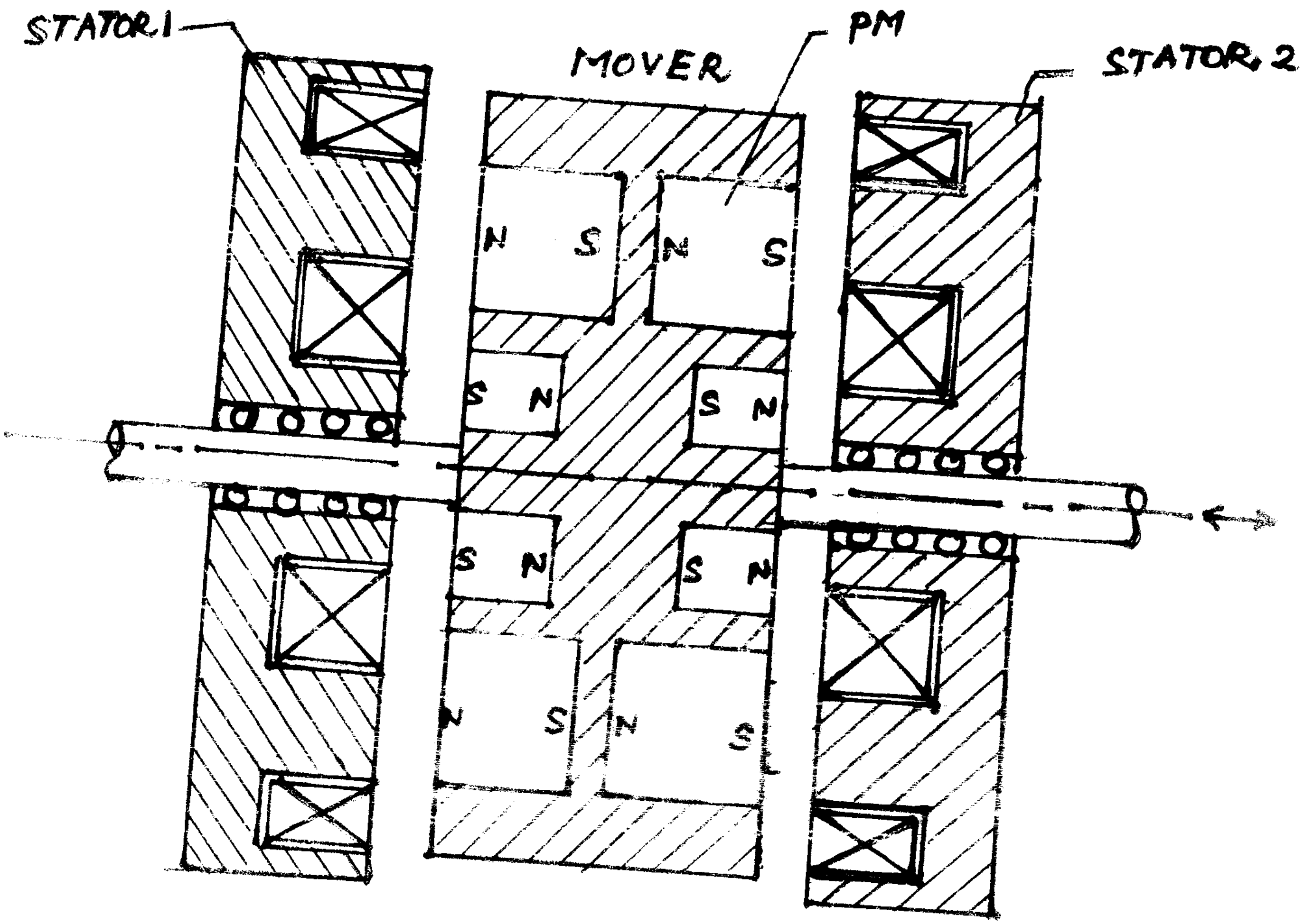

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Fig. 2.1. CONSTRUCTION DIAGRAM OF PMLOM

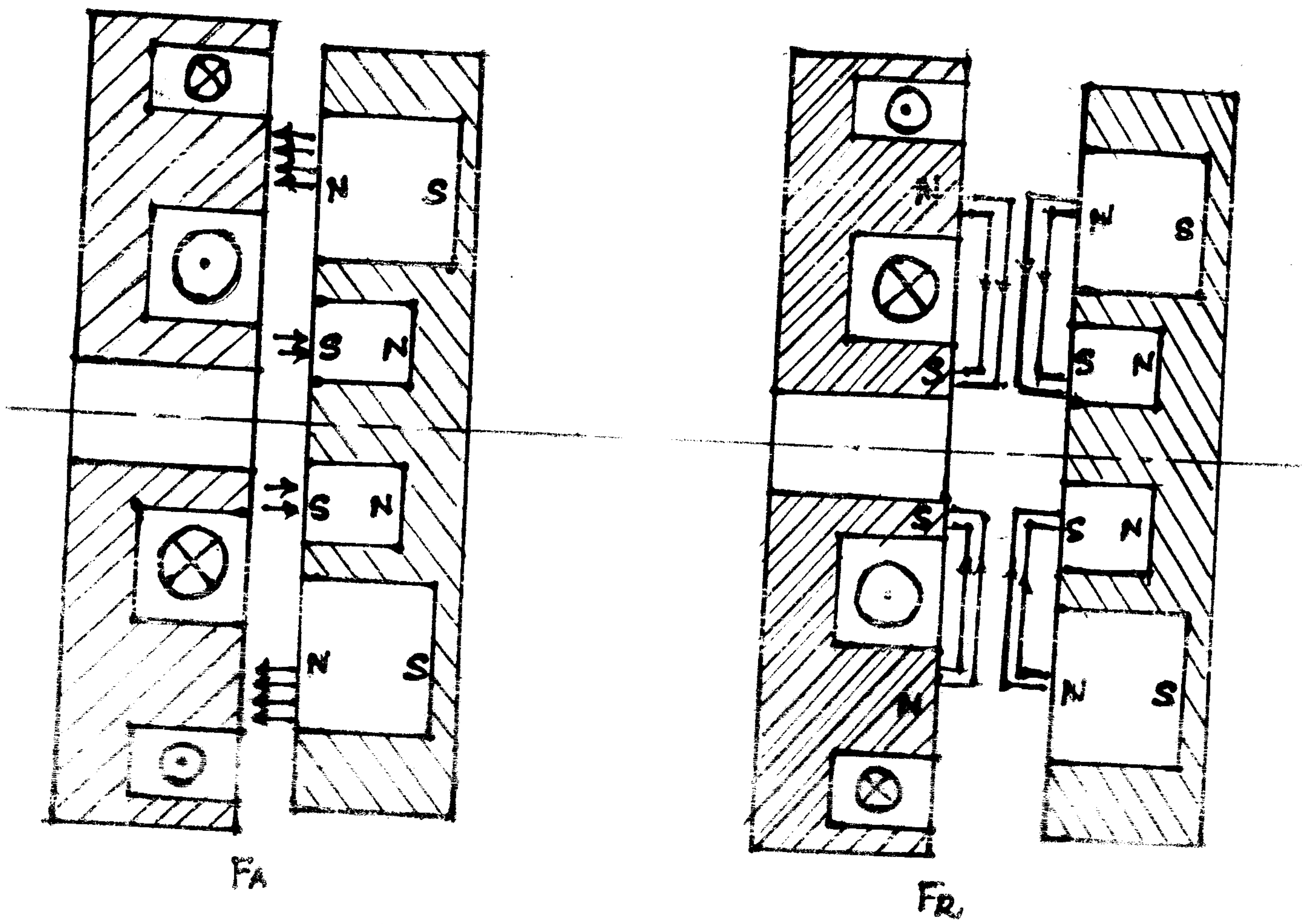

Fig. 2.2 PRINCIPLE OF OPERATION OF [illegible]

CHAPTER - 3

MAGNETIC CIRCUIT

3.1. Permanent Magnet system requirement:

A Permanent Magnet is a Ferromagnetic or Ferrimagnetic material that can sustain a high inherent magnetization at normal ambient temperatures and act as a passive source of MMF and flux. The basic properties of PM material are Remanence (B_r), Higher Coercivity (H_c), Recoil permeability, aging characteristics, curie point, mechanical working, cost and availability. The operating point should approach (BH) max. The curie temperature is that at which inherent magnetization fails. The mechanical properties are hardness, stress limits, elastic modulus and magnetic stability as a function of time and stressing. Electricity, high resistivity reduces eddy current losses under changing load conditions and a high retentivity stabilizes the permanent magnet over its working life. Higher Coercivity gives greater reserve against large reluctance. Ferrifes and Rare-earth magnets provide high coercivity and make possible magnets of large area and very short length contrasting with metallic permanent magnets.

3.2. Demagnetization characteristics of Permanent magnet:

The BH curve (or) hysteresis loop of the magnet is the result of domain changes within the magnetic materials. The magnet is operated in the second quadrant of the BH curve. This curve is known as demagnetization characteristic of the magnet shown in fig. 3.1. The demagnetization curve cf a magnet is essential to determine the operating flux density in the airgap. Usually the demagnetization curve is supplied by the magnet manufacturer. The important points on the demagnetization curve are remanence, coercivity and (BH)max point.

3.2.1. Effect of varying airgap on thee PM system:

The PM must develop the mmf to overcome the mmf required for the reluctance drop of the airgap and the mmf required for the other portions of the circuit. The operating point for a finite airgap be at some point 'A' on the demagnetization curve. If the airgap is increased, then the mmf required for the airgap also increases which makes the magnet in develop a larger mmf. This implies that the flux density of the magnet falls from point 'A' to point 'B' along the major loop. If again the airgap is restored to its original value, the operating point will not return to the original value A, but to a new point 'C' along the line BC, which is known as Recoil line. Recoil line is almost parallel to the tangential line at the point B_r on the demagnetization curve.

3.2.2. Effect of external demagnetization force on PM system:

A part of the winding ampere turns is used to demagnetize the main mmf. This demagnetizing mmf causes the operating flux density to fall along the recoil line from point 'C'. The operating point without any demagnetizing force, the operating point falls down from point 'C' to a lower value 'D'. In the normal operation, the operating point will vary between 'C' and 'D'.

3.3. FERRITE MATERIALS & THEIR PROPERTIES

3.3.1. Ferrites:

The basic ingredients used in the mannufacture of PML Sitrox magnets are Ferric oxide ($Fe_2 O_3$), Barium Carbonate ($BaCo_3$) or Strontium Carbonate ($SrCo_3$). The purest grades of raw material are used and tests are conducted on every in-coming lot to ensure their quality. The raw materials are throughly blended in intensive mixer and are formed into pellets in a pelletiser. The pellets are then calcined at high temperature in a gas-fired rotary furnace. Subsequently, the pellets are pulverized and wet milled to the required particle size.

3.3.2. Wet Process:

After wet milling the slurry is fed into a die and pressed to the shape at a very high pressure. Anisotropic grades are pressed under the influence of a powerful magnetic field.

3.3.3 Dry Process:

In this process the slurry is dried and mixed with a lubricant and pressed to shape in the dry condition.

The pressed magnets from both the processes are sintered in a continous type furnace. Sintered magnets are then ground to the required size and cleaned in an ultrasonic cleaning machine. Finally, the magnets are inspected for size and magnetic properties.

3.3.4. Characteristics:

Ferrite magnets are very hard but more brittle and more prone to cracks and chipping on edges and corners. They are characterized by a very high normal and intrinsic coercive force, but a rather low residual induction and are virtually free from the effects of a self-demagnetization which permits use of shorter lengths. They possess a very high electrical resistivity which makes them ideally suited for high frequency applications, the eddy current effects being almost negligible.

3.4. Calculation of Magnetic circuit parameters:

The demagnetization curve of the PMs used in this project is as shown in the fig. 3.2. The dimensions of the PMs used in this motor are also given in fig. 3.3 & fig. 3.4.

From Ampere's law, neglecting the reluctance frop in the iron and the leakage fluxes in the slot and airgap, the main flux density in the airgap is determined by the magnetic circuit analysis of the permanent magnet and the electromagnet. When the polarities of magnetic poles are opposite the MMFs of primary coil and secondary PM assist each other. But when the polarity is same, the MMF's of primary coil and secondary PM oppose each other. Thus, according to Amphere's law

$$\frac{B}{0}\, 2g = 2H L \pm NI \qquad (3.1$$

When the primary current is turned off, the permanet magnet operates at the point 'O' of the demagnetization curve shown in fig

3.2. Point 'O' is determined by the load line, g/L_m. When the primary current is turned on and the polarities are opposite, the Pm operates at the point 'A' of the demagnetization curve, and a large attraction force is produced. When the polarity is the same, the PM operates at point 'P' and a small residual force is produced.

The airgap flux density varies with x, i.e. airgap value g, such that the airgap flux density is given by

$$B_a = B_o + B \qquad (3.2)$$

and

$$B_p = B_o - B \qquad (3.3)$$

In (3.2) and (3.3) B_o and B are functions of the airgap 'g' and can be determined by the demagnetization curve, airgap load line and NI. Hence,

$$B = \frac{B_r}{1 + (B_r g/H_c \; {}_o L_m)} \qquad (3.4)$$

$$B = \frac{NI}{2L\,[(H_c/B_r) + (g/ \; {}_o L_m)]} \qquad (3.5)$$

These parameters are calculated and used in the design of PMLOM.

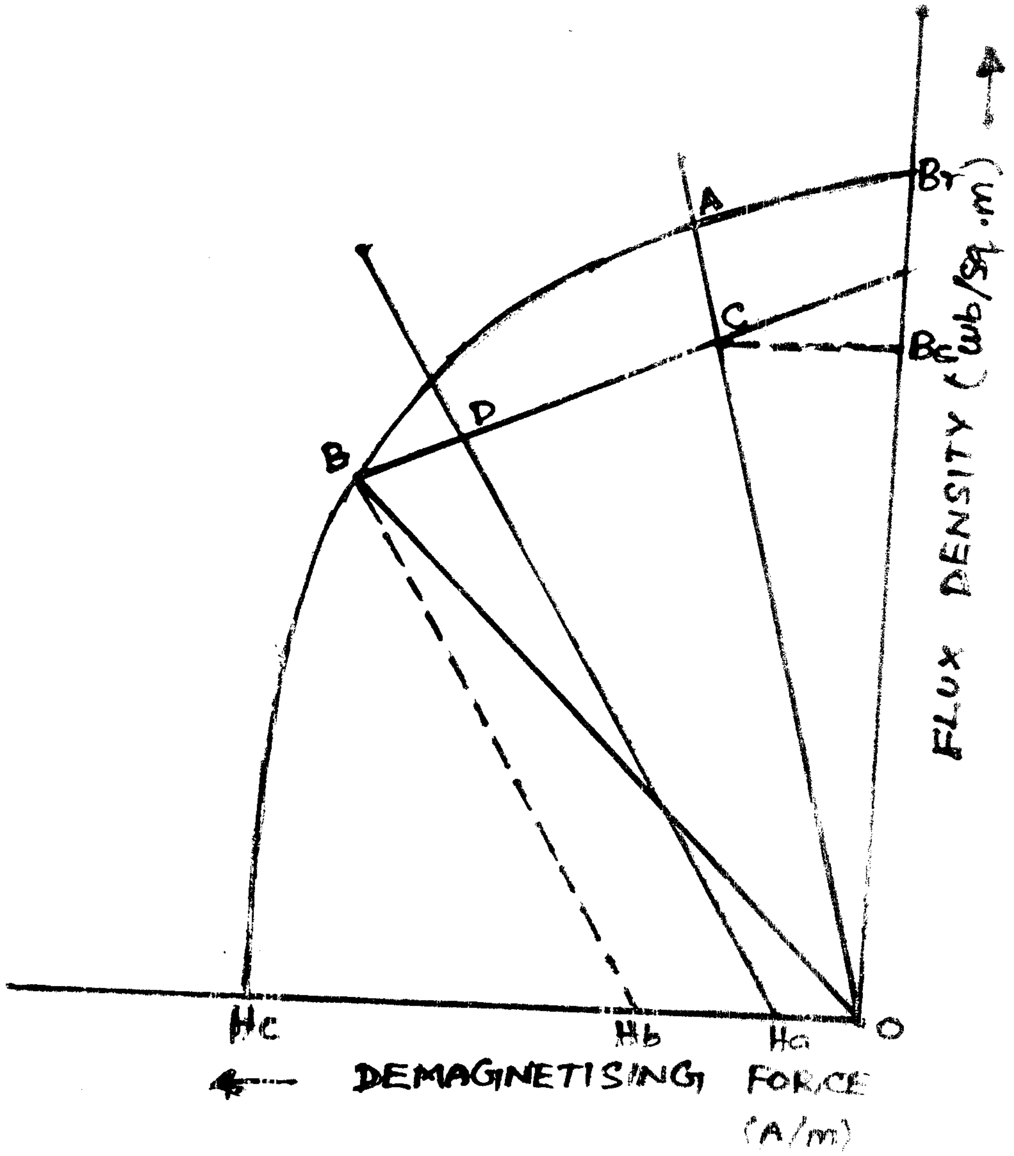

Fig 3·1 DEMAGNETIZATION CHARACTERSTIC

$B_r = 0.4 T$

$H_c = 159155 A/m$

$1 Tesla = 10^4 gauss$

$1 oersted = 0.0796 KA/m$

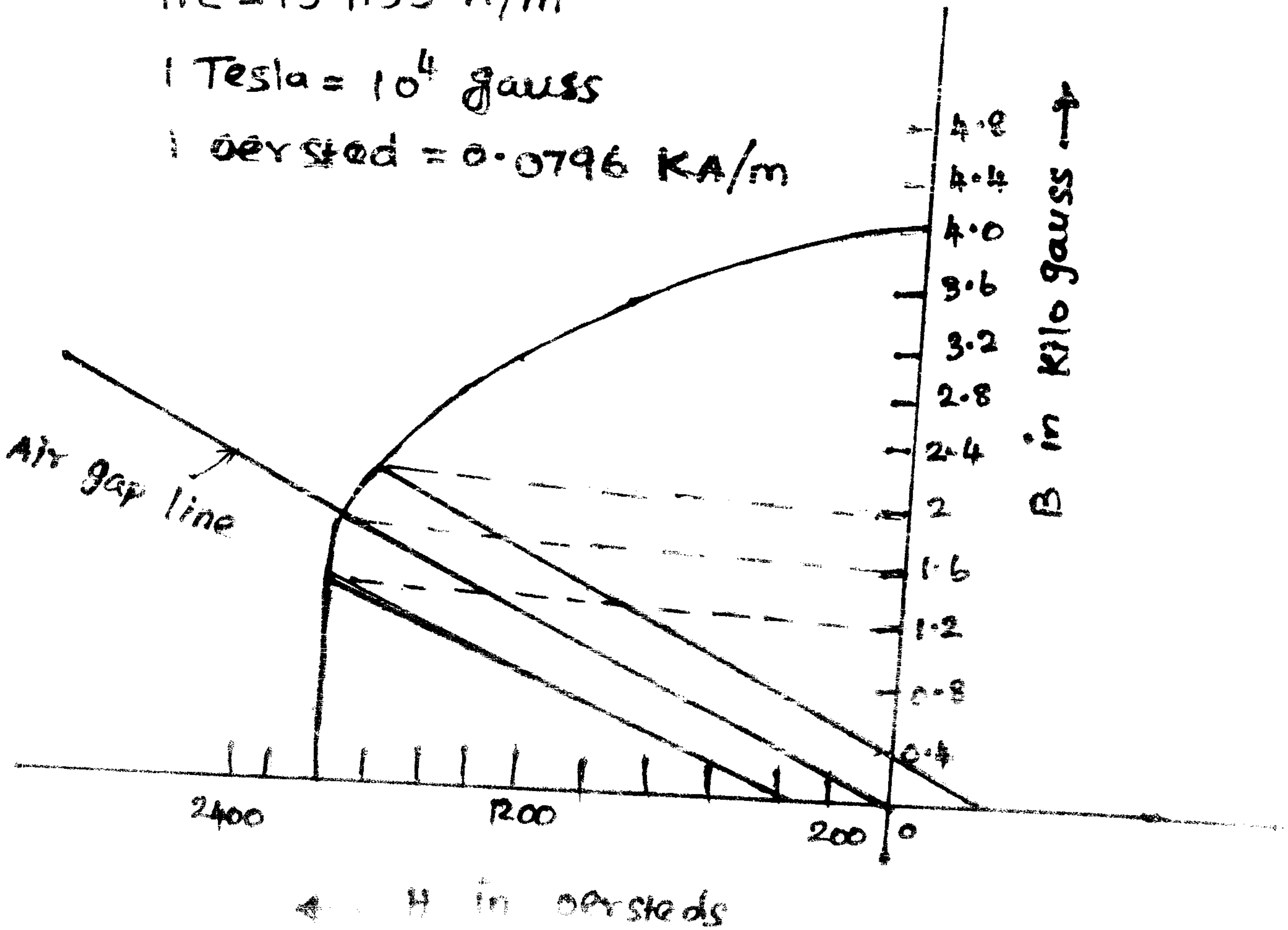

Fig. 3.2 DEMAGNETIZATION CURVE AND OPERATING POINTS

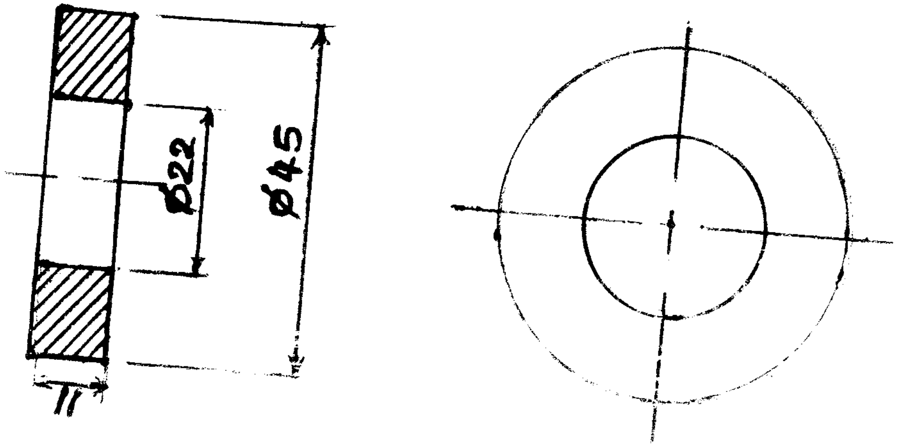

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Fig. 3.9 PERMANENT MAGNET

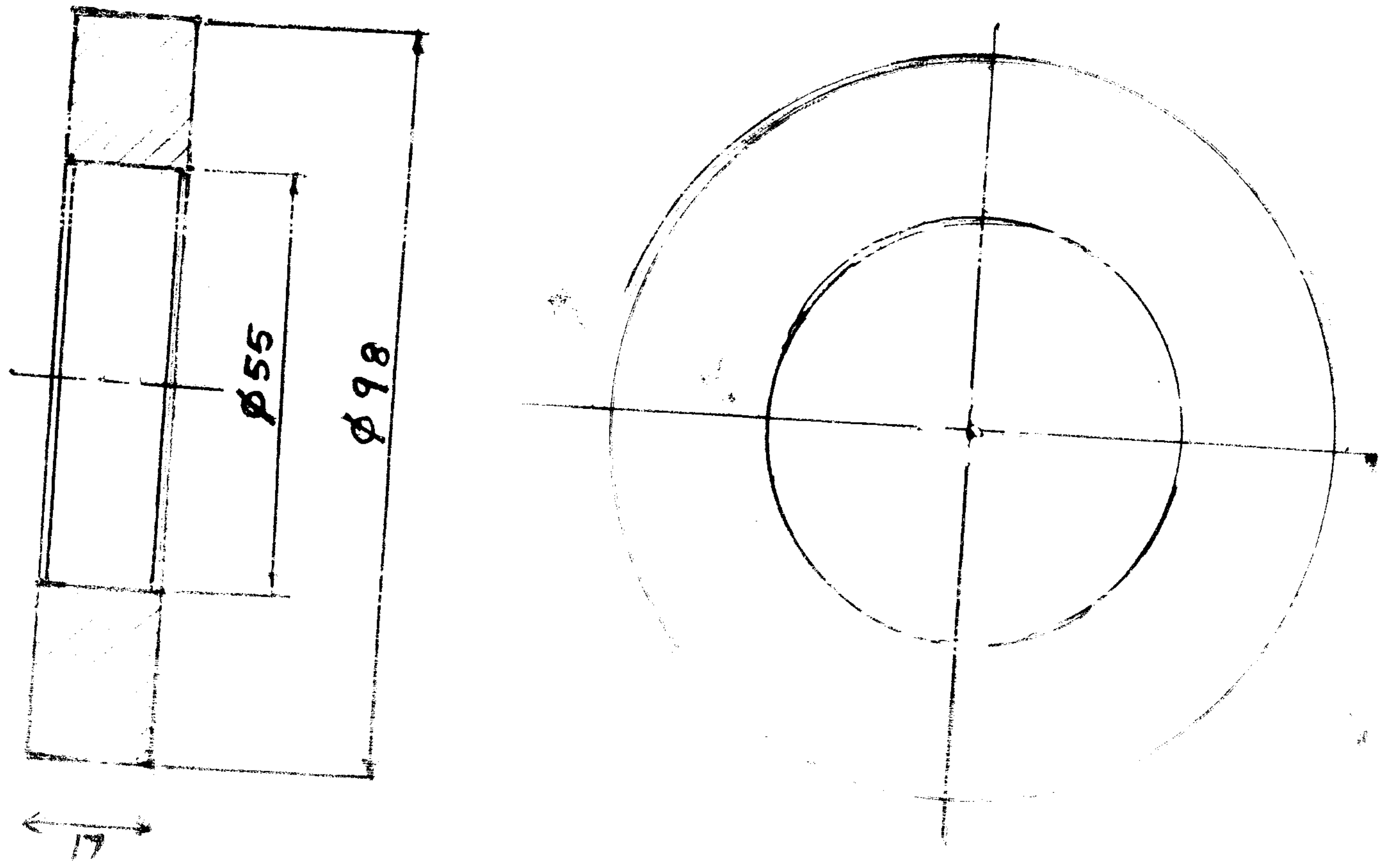

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Fig. 3.4 PERMANENT MAGNET

CHAPTER - 4

DESIGN OF PMLOM

4.1. Salient points in the design of PMLOM:

The specification of PMLOM are load, weight, stroke length and maximum speed.

The first step in design is to determine the Attraction force and repulsion force required by the motor for the given specifications. Next is to calculate Ampere turns of the stator winding to provide the required force. Then the various dimensions of stator and mover are decided.

The design and development of PMLOM involves material constraints particularly permanent magnets and Linear Bearings. Taking these constraints into account, the design of the PMLOM can be done as outlined in the following sections.

4.2. Specifications for the Design:

For a stroke length of 9 mm, the motor should be capable of oscillating at a maximum speed of 63 mm/sec. The load weight is taken as 35 Newtons and load friction as Zero.

4.3. DESIGN

4.3.1. Determination of Attraction Force:

From the law of the conservation of energy, the force in terms of the coil current I and the variation of the inductance L with position x is given by:

$$F = \frac{1}{2} I^{2} \frac{dL}{dx} = \frac{Wm}{x} \qquad (4.1)$$

Since the inductance is given by:

$$L(x) = NO/I = NAB/I \qquad (4.2)$$

the flux density is $B = B_{o} \pm B$

therefore

$$dL(x)/dx = (NA/I)dB/dg \qquad (4.3)$$

From (3.2) through (3.5) we obtain:

$$dB/dg = \pm \frac{2H_{c}L_{m} - NI}{2 \quad {}_{o}g^{2}[(H_{c}L_{m}/B_{r}g)+(1/ \quad {}_{c})]^{2}} \qquad (4.4)$$

If (4.3) and (4.4) are substituted into (4.1), the force is given by:

$$F = \frac{NIA}{2 \quad {}_{o}g^{2}} \pm \frac{2H_{c}L_{m} - NI}{2[(H_{c}L_{m}/B_{r}g) + (1/ \quad {}_{c})]^{2}} \qquad (4.5)$$

From (4.5), the attraction force is given by,

$$F = \frac{NIA}{2 \quad {}_{o}g^{2}} \frac{(2H_{c}L_{m} + NI)}{2[(H_{c}L_{m}/B_{r}g) + (1/ \quad {}_{c})]^{2}} \qquad (4.6)$$

In this equation (4.6), H_{c}, B_{r} and L_{m} values are taken from given PM specifications.

4.3.2. Determination of Airgap:

The mover will travel for a stroke length of 9 mm. To avoid hitting of mover against stator while travelling, a rubber washer of thickness 3 mm is provided. Hence total airgap length becomes 12 mm.

4.3.3. Stator Iron area calculation:

Since the length of the stator is restricted to 24 mm to seat, a linear bearing of same length, the available area for providing the stator winding is limited. So the total winding is grouped into two parts. The value of slot width is selected to match the pole produced by the electromagnet with the poles of Permanent Magnet. The various dimensions are shown in fig. 5.1. The depth of the slot is assumed as 15 mm initially.

Area of the Stator Iron core

= Total area of the Iron core - (Area of the slot 1 + Area of the slot 2 + Area of the Linear Bearing)

$$A = A_T - (A_{s1} + A_{s2} + A_b) \qquad (4.7)$$

$$= DL_s - [(do1-di1)L_S] + [(do2-di2)L_S] + [d_b L_b]$$

Since we know the values of A & g, we can calculate the value of NI from equation (4.6)

4.4. Determination of Repulsion Force:

Now, considering the repulsion force, we have the polarities of the currents reversed. The fluxes in the airgap are predominately radial. We now have a force of repulsion between the coil and the PMs. For a small airgap and for a uniform flux density in the airgap simple magnetic circuit approach yields the magnetic stored energy. From Ampere's law, neglecting the reluctance drop in the iron, the flux density of coil is related to the potential (MMF) by

$$H_E = NI/L_R \tag{4.8}$$

and

$$B_{PM} = {}_oH_E = {}_oNI/LR \tag{4.9}$$

The PM operating point is determined by (3.4) using $g = L_R$, the PM flux density becomes:

$$B_{PM} = B_r/[1+(B_r L_R/H_c \quad {}_oL_m)] \tag{4.10}$$

The total stored magnetic energy in the airgap by the radial airgap fluxes is then given by:

$$W_R = D^2/4 \quad [(\quad {}_oH_E^2/2) + (B_{PM}^2/2 \quad {}_o)] \tag{4.11}$$

Hence the repulsion force becomes:

$$F = W / x = \frac{D^2}{4} \quad \frac{B_{PM}^2}{2 \quad {}_o} + \frac{o}{2} \quad \frac{NI}{L_R}^2 \tag{4.12}$$

The maximum speed can be calculated using the following equation.

$$0_{max} = i_s \tag{4.13}$$

4.5. Design of Stator:

The total ampere turns NI is obtained from equation (4.5). Taking the current as 1.6A, we can find the number of turns per coil. The area of cross section of the conductor is found out by assuming a proper current density. Taking the current density as 6.5 A/Sq.mm for short time duty,

$$a_c = I/J \qquad (4.14)$$

From the calculation SWG24 copper wire is selected.

Using the value of the area of the wire, the slot area is recalculated.

$$a_s = a_c N/K_s \qquad (4.15)$$

For this slot area, area of the stator Iron core is checked. And the length of the slot is increased to 17 mm.

4.6. Design of Mover:

The PMs are placed on the both faces of the Mover. The outer diameter of the Mover is decided by the diameter of the available PM. A allowance of 20 mm is given in the outer diameter for the machining process.

The length of the mover here is more than twice the length of the permanent magnets. For mechanical support a gap of 10 mm is given between the PMs. The length of the mover is taken as follows:

4.7. Design Calculation:

Specifications:-

Load Weight : 35 N

Stroke Length : 9 mm

Max. Speed : 63 mm/sec.

From PM manufacturers:-

B_r = 0.4 T (Residual flux density)

H_c = 159155 A/m (Coercivity)

I. To find the Ampere turns required by the Motor:

$$F = \frac{(NI)_A^{2}}{2\,{}_{o}g^{2}} \quad \frac{2H_cL_m + NI}{2\left(\frac{H_cL_m}{B_r g} + \frac{1}{{}_{o}}\right)}^{2}$$

F_A = 35 N

H_c = 159155 A/m

${}_o$ = 4 x 10^{-7} H/m

g = 9 x 10^{-3}

L_m = Length of the Magnet = 17 x 10^{-3} m

A = Area of the Stator iron core

= Total area of Iron core – (Area of slot 1 + Area of slot 2 + Area of the Linear bearing)

Area of the Linear Bearing: (A_b)

Available Linear bearing size:

Length = 24 mm, diameter : 15 mm

A = $d_b L_b$

$= \quad \times 15 \times 10^{-3} \times 24 \times 10^{-3}$

$A = 1.131 \times 10^{-3}$ m2

Area of the Slots:

Assumptions:-

Inner diameter of slot 1 = 38 mm

Outer diameter of slot 1 = 69 mm

Inner diamter of slot 2 = 98 mm

Outer diameter of slot 2 = 118 mm

Depth of the slot L_s = 17 mm

$A_{s1} = (do1 - di1) \times L_s$

$= (69.38) \times 17 \times 10^{-3} \times 10^{-3}$

$= 1.655 \times 10^{-3} m^2$

$A_{s2} = (do2 - di2) \times L_s$

$= (118 - 98) \times 10^{-3} \times 17 \times 10^{-3}$

$= 1.068 \times 10^{-3} m^2$

Diamter of the Stator:

= Diameter of Linear Bearing + Diameter of slots + thickness of steel

= 15 mm + 103mm + 10 mm

= 128 mm

Total area of Iron core: A_T

$$= \quad DL_s$$

$$= \quad 128 \times 10^{-3} \times 24 \times 10^{-3}$$

Length of Stator depends on available Linear Bearing Length

$$A_T \quad = \quad 9.651 \times 10^{-3}\, m^2$$

$$A \quad = \quad A_T - (A_{s1} + A_{s2} + A_b)$$

$$= \quad [9.651 - (1.6556 + 1.068 + 1.131)] \times 10^{-3}$$

$$= \quad 5.7964 \times 10^{-3}$$

To find the Ampere turns:

$$F_A \quad = \quad \frac{(NA)_A}{} \left[\frac{(2H_c L_m + NI)}{\frac{H_c L_m}{Brg} + \frac{1}{o}} \right]^2$$

$$35 \quad = \quad \frac{(NI) x 5.7964 x 10^{-3}}{2 x 4 x \quad x 10^{-7} \; (9 x 10^{-3})^2} \left[\frac{(2 x 159155 x 17 x 10^{-3} + NI)}{2 \quad \frac{159155 x 17 x 10}{0.4 x 9 x 10^{-3}} + \frac{1}{4 \quad x 10^{-3}}} \right]$$

NI 1219

Assume current I = 1.6 A

$$N \quad = \quad \frac{1219}{1.6}$$

$$= \quad 761.875$$

N 800 turns

The total winding is grouped into two parts:

In slot 1 : 425

In slot 2 : 375

To find the area of the Conductor:

Assume current density J = 6.5 A/mm^2 (for short time duty)

$$a_c = \frac{I}{J} = \frac{1.6}{6.5\times10^{-3}}$$

$$a_c = 0.2463 \text{ mm}^2$$

Area of the slot:

$$A_s = \frac{a_c \times N}{K_s}$$

where K_s is space factor

Assume $K_s = 0.4545$

$$A_s = \frac{0.2463\times800}{0.4545}$$

$$A_s = 433.53 \text{ mm}^2$$

Designn of Mover:

Diameter of the Mover is decided by the outer diameter of the PM available.

A allowance of 20 mm is given for the machining process.

Therefore Diameter of the Mover $D_m = 98 + 20$

$= 118$ mm

Length of the Mover = (Length of PM) x 2 + 10 mm (Mechanical support b/w PM's)

= 2 x 17 + 10 mm

= 44 mm

Max. Speed: $U_{max} = l_s \times f$

$$f = \frac{U_{max}}{l_s}$$

$$= \frac{63 \text{ mm/sec}}{9 \text{ mm}}$$

$$f = 7 \ H_z$$

Air gap flux density when the primary current is off,

$$B_o = \frac{B_r}{1 + \frac{B_r g}{H_c \mu_o L_m}}$$

$$= \frac{0.4}{\frac{0.4 \times 12 \times 10^{-3}}{159155 \times 4 \quad \times 10^{-7} \times 17 \times 10^{-3}}}$$

$$= 0.1659 \ T$$

$$B = \frac{NI}{2L_m \frac{H_c}{B_r} + \frac{g}{L_m \mu_o}}$$

$$= \frac{1219}{2x17x10^{-3} \left(\frac{159155}{0.4} + \frac{12x10^{-3}}{17x10^{-3} x4 \quad x10^{-7}} \right)}$$

$= \quad 0.03736 \text{ T}$

Air gap flux density

In Attraction case, $B_a = B_o + B$

$= 0.1659 + 0.03736$

$= 0.2032 \text{ T}$

Air gap flux density in the Repulsion case,

$B_p = B_o - B$

$= 0.1659 - 0.03736$

$= 0.12854 \text{ T}$

Permanent Magnet flux density

$$B_{pm} = \frac{B_r}{1 + \dfrac{B_r L_R}{H_c \quad {}_o L_m}}$$

L_R - Length of the Magnetic circuit

$L_R = 12 \ x10^{-3}$ mm

$$B_{pm} = \frac{0.4}{1 + \dfrac{0.4 \ x \ 12 \ x \ 10^{-3}}{159155x4 \quad x10^{-7} x17x10^{-3}}}$$

$= \quad 0.16585 \text{ T}$

4.3. Design Sheet:

The design of PMLOM is carried out following the procedure explained in the previous sections. the design particulars arrived at are given in Table 4.1

Table 4.1. Design Particulars of PMLOM

Attraction Force		F_A	35	N
Stroke length		l_s	9	mm
Frequency		f	7	Hz
Maximum speed		u_{max}	63	mm/sec
Airgap flux density when the primary current is off		B_0	0.6159	T
Axial airgap flux density for attraction case		B_a	0.2032	T
Axial airgap flux density for repulsion case		B_p	0.1285	T
PM flux density		B_{PM}	0.1659	T
Current		I	1.6	A
Size of the copper wire		S	24	SWG
Conductor area		a_c	0.2463	mm^2
Current density		J	6.5	A/mm^2
Number of turns in coils	Coil 1 & 3	N_{13}	475	
	Coil 2 & 4	N_{24}	325	
Slot area		a_s	433.5	mm^2
Space factor		K_s	0.4545	
Coercivity		H	159155	A/m
Remanence		B_r	0.4	T
Airgap Length		g	12	mm

Average radial magnetic circuit Length	L_R	12	mm
Diameter of the Mover	D_m	118	mm
Diameter of the stator	D	128	mm
Lengthof the stator	L_s	24	mm
Slot 1 inner diameter	di1	38	mm
Slot 1 outer diameter	do1	69	mm
Slot 2 inner diameter	do2	98	mm
Slot 2 outer diameter	do2	118	mm
Width of the slot 1	Ws1	15.5	mm
Width of the Slot 2	Ws2	10	mm
Depth of the slot	L_S	17	mm
Linear bearing outer diameter	d_b	15	mm
Length of the magnet	L_m	17	mm
Length of Mover	L_M	44	mm
Length of the Linear bearing	L_b	24	mm
Total area of the stator	A_T	9650.9	mm^2
Area of the slot 1	A_{s1}	1655.6	mm^2
Area of the Slot 2	A_{s2}	1068	mm^2
Area of the Linear bearing	A_H	1131	mm^2
Area of the stator iron core	A	0.005796	m^2
Number of ampereturns	NI	1219	A
weight of iron in mover	Wi	2.1	Kg
Weight of PMs	W_{pm}	0.7	Kg
Total weight of Mover	W_M	2.8	Kg

CHAPTER 5

DEVELOPMENT OF PMLOM

5.1 Salient points in the development of PMLOM

The over all performance of the machine is mainly affected by the development process. A good process shall have better performance of the machine. Also, the development process of this unconventional machine takes few trials in each stage of the process.

5.2 Development of the Stator

Stator is made up of mild steel. It is machined to proper dimensions by turning process. The Stator is as shown in the fig 5.1. Formers made up of mild steel are machined to the coil internal diameter size. Copper wires are wound on the former for the coils of required number of turns.

Coils I & II of 800 turns each divided into 2 parts are wound and insulated with cotton tape. Varnish is applied on the coils after placing inside the slots to get better insulation.

A inner diameter of 15 mm with 15h6 tolerance is machined and Leaner bearing is seated in it. The Linear bearing diagram is shown in fig 5.2.

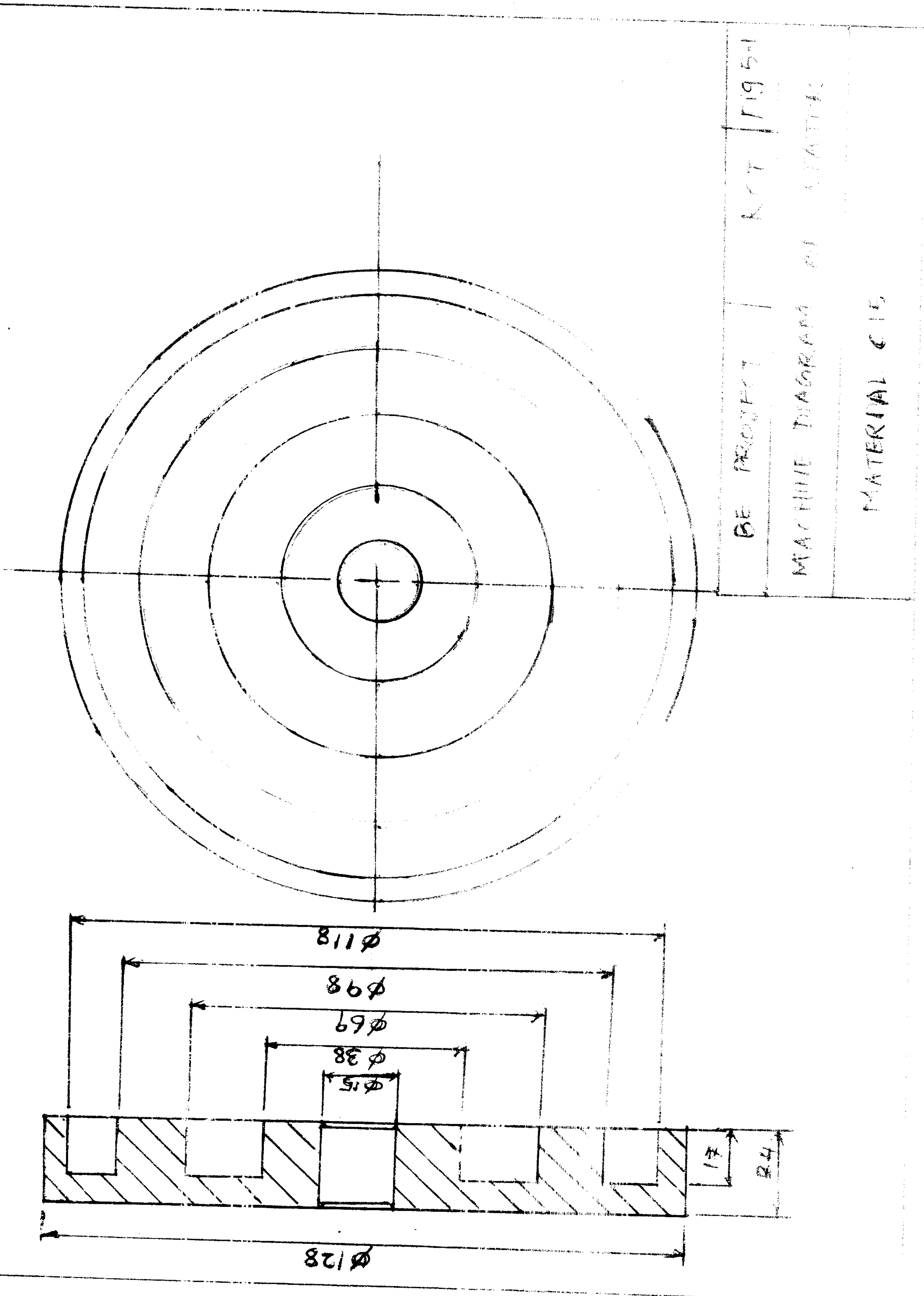
5.3 Development of the Mover

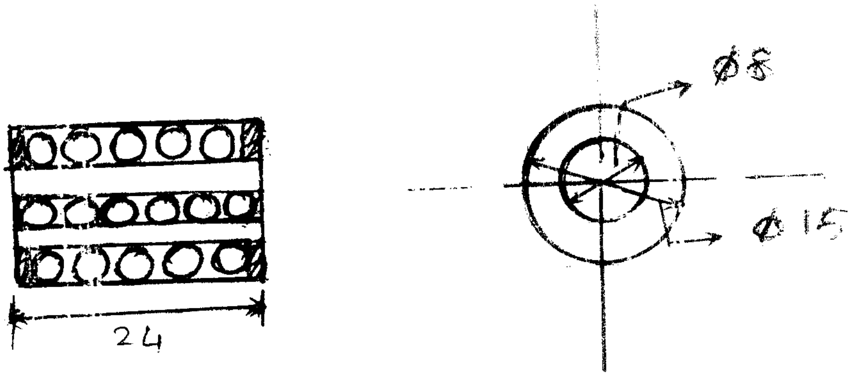
Mover is made up of iron core. On both sides of the mover two grooves are made by turning to the dimensions as shown in the fig 5.3. Adhesive material araldite is applied in the grooves and Ring type Permanent Magnets are placed.

An inner diameter of 8mm is drilled in the mover and shaft machined with knurling operation in its center is fitted in it. The machine diagram of shaft is shown in fig 5.4.

5.4 Overall Asssmbly

The transperant material is machined and is used as enclosure. The two stators are placce in the both sides of it. The end leads drawn from the stators are connected to the terminal box for external supply .

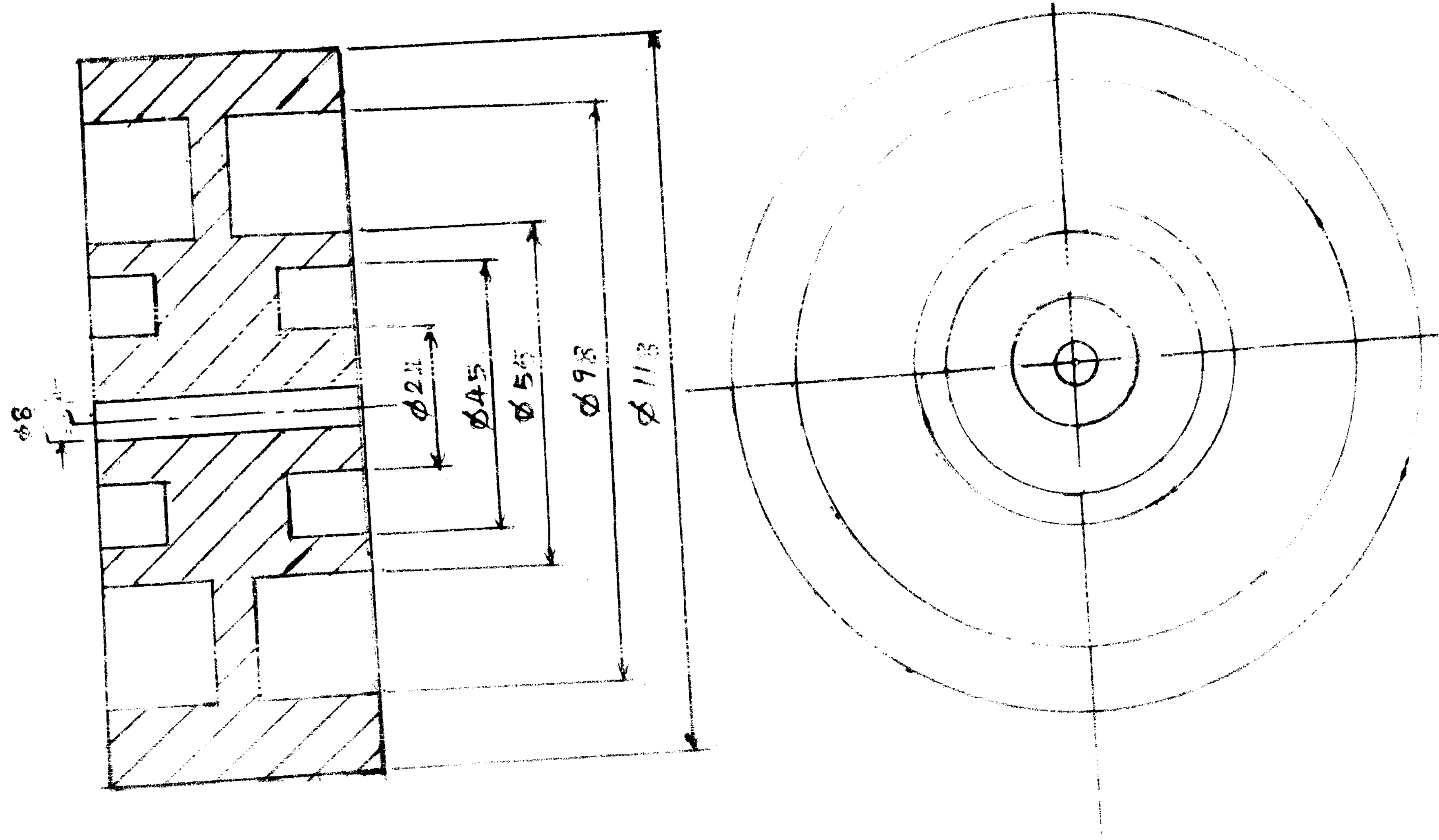
BE PROJECT
KCT
Fig 5.1
MACHINE DIAGRAM OF STATOR
MATERIAL C15
ø118
ø98
ø69
ø38
ø15
17
24
ø128



BE PROJECT

KCT

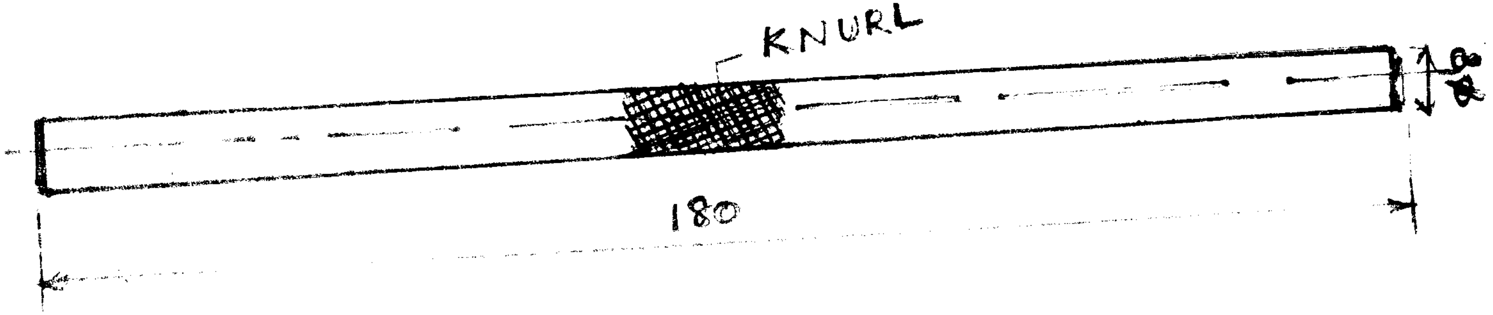
FIG 5.2. LINEAR BEARING



BE PROJECT

FIG 5.3 MOVER

Mat. C15



BE PROJECT	KCT	FIG.5.4
MACHINE DIAGRAM OF SHAFT		
MATERIAL C15		

CHAPTER 6

TESTING

6.1 Resistance and Imedance Measurement

6.1.1 Resistance Measurement

The test set-up for resistance measurement is as shown in fig 6.1. The DC current flowing through the coil-I is varied by using a lamp load. For different values of DC current, the voltage drop across the coil-I is measured. The readings of Ammeter and Voltmeter are tabulated and average resistance is calculated. This is repeated for the coil-II also as in Table 6.1.

6.1.2 Impedance Measurement

Each coil impedance is measured using a test set up as shown in fig 6.2 The AC current flowing through the coil-I is varied by using by using a lamp load. For different values of AC currents, the voltage drop across the coil-I is measured. The readings of Ammeter and Voltmeter are tabulated and average impedance is calculated. This is repeated for the other coil-II also. The readings are given in Table 6.2.

6.2 Measurement of Oscillations Vs Frequency

The ideal supply requirement for the developed model is single phase square wave supply, as a first trial, it is tested with a sinusoidal supply. The complete test set up is shown in Fig 6.3.

The required variable voltage, variable frequency supply is obtained from a DC motor - slip ring induction machine set. The stator of the slip ring induction machine is fed with a 50 Hz AC supply through a 3 phase auto transformer. The output voltage is The output voltage is taken from the rotor of the slip-ring induction motor. By varying the speed of the set, variable voltage, variable frequency single phase supply is obtained and given to the PMLOM.

The single phase supply is connected across the coil terminals as shown in the fig 6.3. The frequency is varied low value and the current in the coil is raised upto 3A. Now mover oscillates. However No.of oscillations of the mover can be changed by varying the frequency of operation.

6.4 Load Test on PMLOM

The developed model is tested with spring load. The current taken for various load condition is observed and tabulated.

Table 7.1 Resistance Measurement

Name of coil	Trial No.	I amps	V Volts	R ohms	mean R ohms
COIL-I	1	1.4	30.0	21.34	21.34
	2	2.0	42.5	21.25	
COIL-II	1	1.8	35.5	19.72	19.99
	2	2.0	40.5	20.25	

Table 7.2 Impedance Measurement

Name of Coil	Trial No.	I amps	V volts	Z ohms	mean Z ohms
COIL-I	1	1.0	40.0	40.00	40.00
	2	1.4	56.0	40.00	
COIL-II	1	1.8	72.0	40.00	40.00
	2	2.0	80.0	40.00	

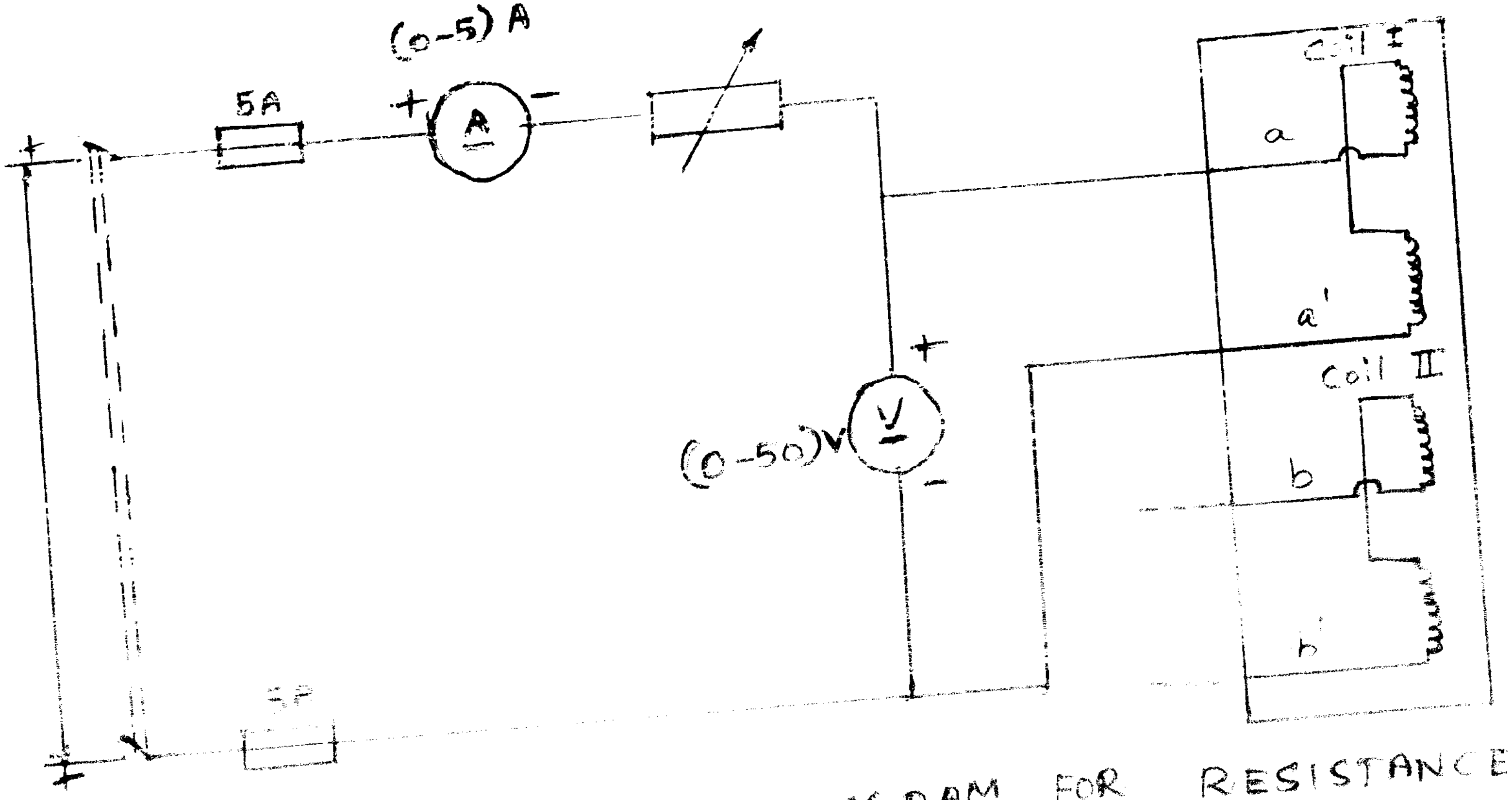


FIG 6.1 CIRCUIT DIAGRAM FOR RESISTANCE MEASUREMENT

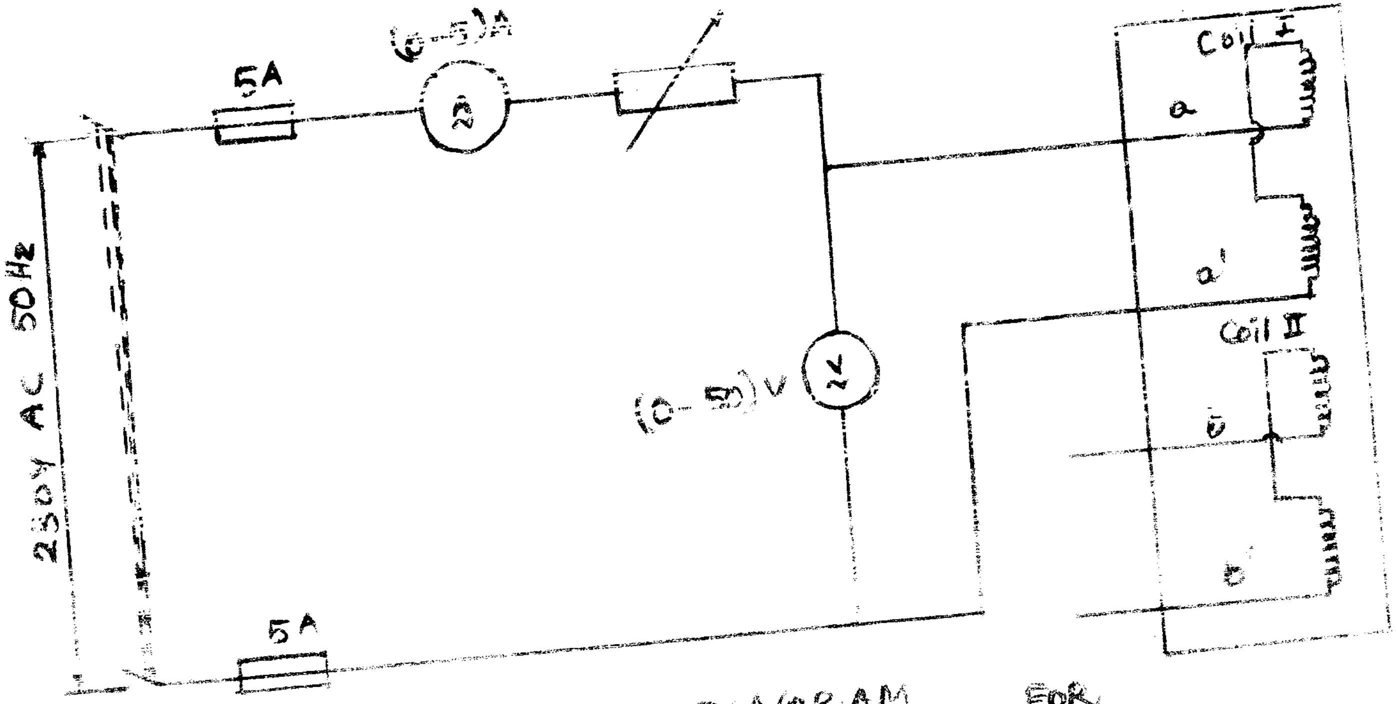


Fig 6.2 CIRCUIT DIAGRAM FOR IMPEDANCE MEASUREMENT

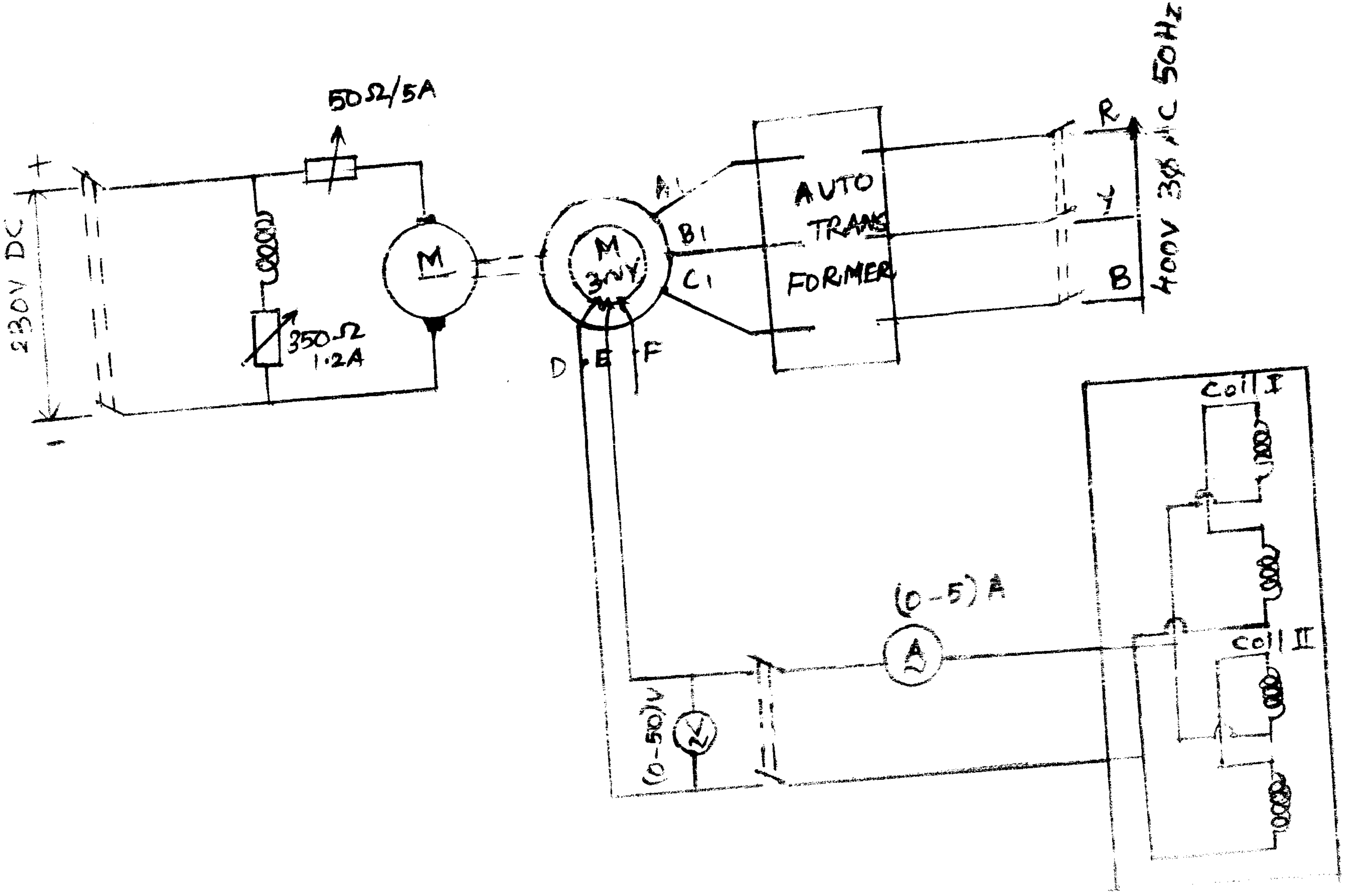


FIG. 6.3 TEST SETUP FOR PMLCM

Oscillations Vs frequency Characterstic

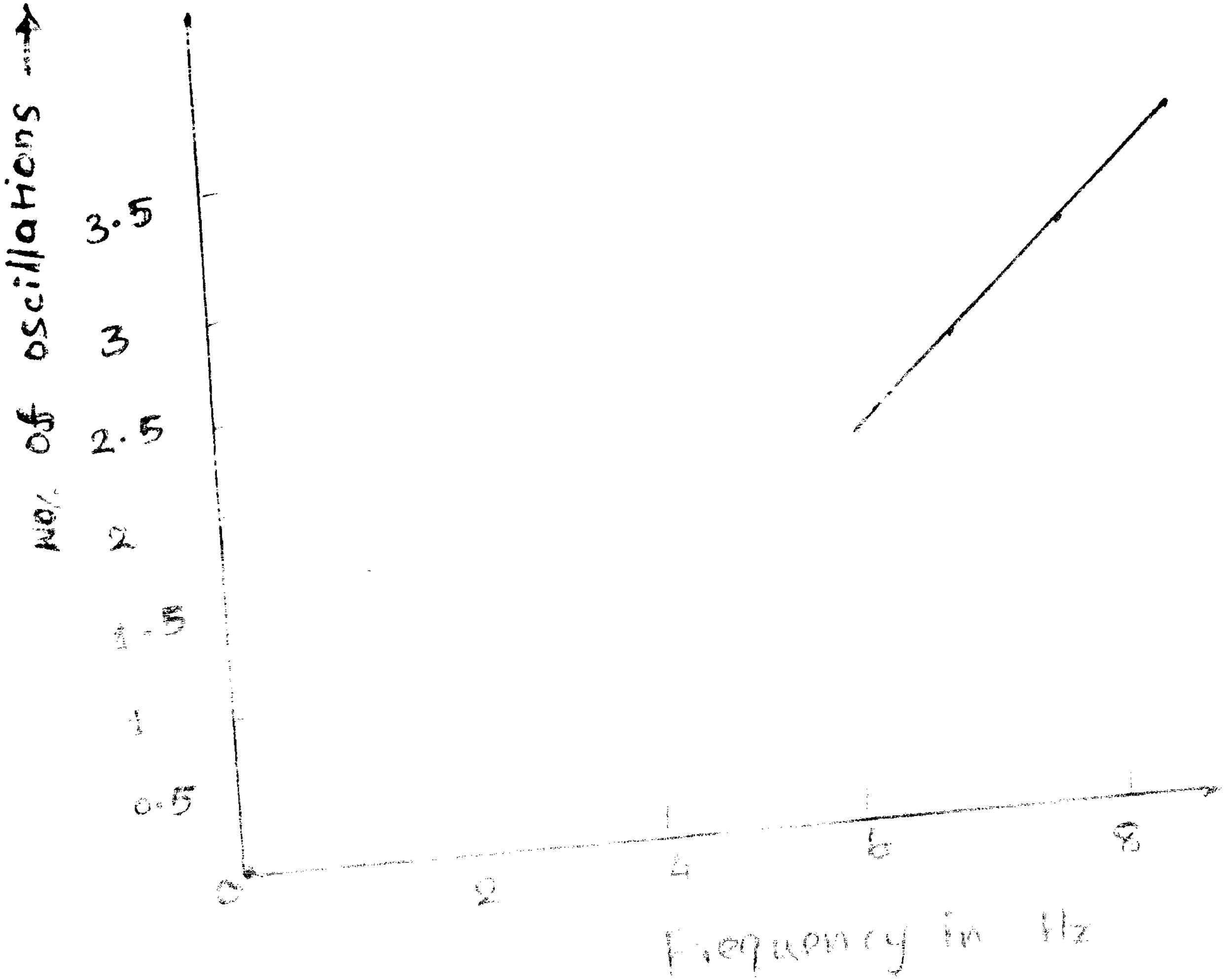


Fig 6.4

Load Test on PMLOM

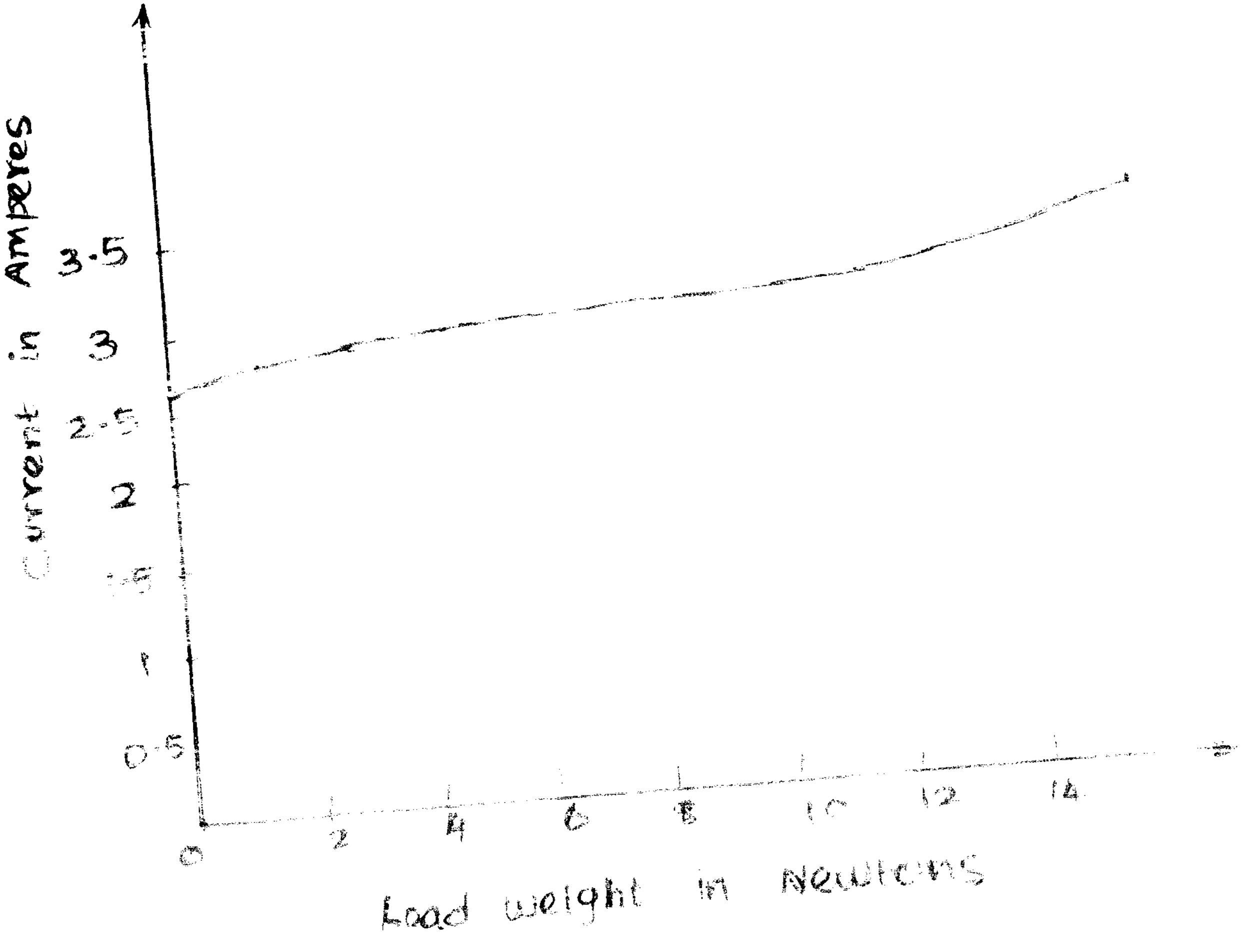


Fig 6.5

CHAPTER 7

CONCLUSION

A 32V, 7 Hz., 1.6A PMLOM has been designed, fabricated and tested successfully.

We can reduce the size of the machine by using rate earth magnets.

Another model can be developed using silicon steel (E-type core) magnetic material.

For getting the required oscillations, PMLOM stator coils to be energised periodically. This requires single phase low frequency supply. So, the precise control of the oscillations can be done by microprocessor based system. The microprocessor based control system also used to maintain the air gap and decelarate the mover.

--oOo--

COST ESTIMATION:

The actual expenditure incurred in developing the prototype PMLOM is given in Table 7.1.

Table 7.1 - Cost Particulars

S.No.	Materials	Quantity	Cost (Rs)
1.	Mild Steel	10 Kg.	250
2.	Permannent Magnet	4 Nos.	200
3.	Linear bearing	2 Nos.	800
4.	Copper Wire	300 gms	100
5.	Polycarbonate Sheet (enclosure)	1 No.	700
6.	Fabrication Cost		300
7.	Miscellaneous		200
		Total	2550

The total cost works out to be Rs. 2550/-

APPLICATIONS:

The FMLOMs are mostly employed in key applications which require oscillating/reciprocating movement.

Some of the major applications are listed below:

1. Computer numerical control machine tools
2. Total artificial heart
3. Space power systems
4. Short stroke linear vibrators
5. Compressors
6. Textile machines
7. Robotics
8. Control switch

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