DESIGN OF DISPLACEMENT PICKUPS

A.R. Chandrasekaran* and B.L. Mehrotra**

SYNOPSIS

This paper deals with the design and fabrication of a seismic displacement pickup.

INTRODUCTION

Vibration pickups are required in connection with instrumentation of various research projects currently planned to be executed at the Earthquake Engineering Laboratory at Roorkee. The principles of design of such pickups are well known. These pickups are now commercially available in foreign countries. Taking into account the following factors, namely, availablity of materials locally, ease of fabrication in large numbers, simple auxiliary instrumentation and ease of calibration, a pickup has been designed and fabricated at the Earthquake Engineering Laboratory at Roorkee. This paper describes the details of the pickup.

PRINCIPLES OF DESIGN

In the variety of applications where pickups would be used, more often than not, a fixed reference would not be available for measurement of absolute motion. Therefore a seismic type pickup is chosen in which the relative motion between the mass and the support could be made proportional to the motion of the support (for a particular range of frequencies).

From the equation of motion of a seismic pickup, it can be shown that (Myklestad, 1956)

$$Z = y_o \eta^2 \mu \sin(\omega t + \alpha)$$

where Z = relative displacement between the mass and the support

y_o = maximum amplitude of the support which is assumed to move sinusoidally

η = ratio of forcing frequency to the natural frequency of the system

μ = dynamic magnification factor

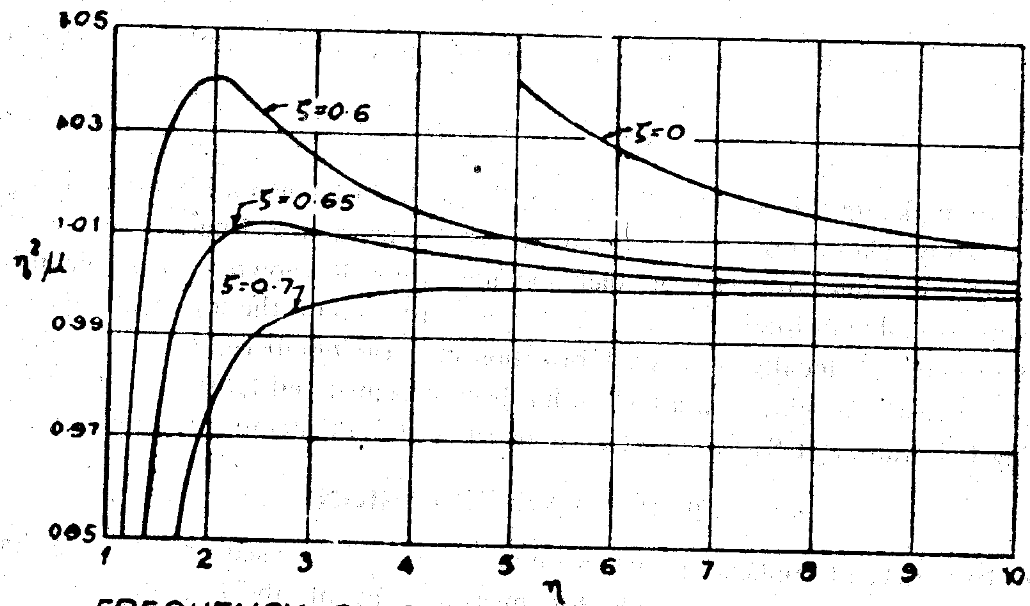
$$= \frac{1}{[(1-\eta^2)^2 + (2\eta\zeta)^2]^{\frac{1}{2}}}$$

* Reader in Civil Engineering, School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee

** Senior Fellow, (Ministry of Education, Govt. of India) University of Roorkee, Roorkee.

ζ = damping in the system expressed as a fraction of critical damping
ω = forced frequency of the support
t = time
a = phase difference between relative motion Z and base motion y

Figures 1 and 2 show respectively the frequency response and phase response curves. It can be observed that /Z/ is almost equal to y_o for η greater than 4.00 and ζ between 0.00 and 0.70.



FREQUENCY RESPONSE OF DISPLACEMENT PICKUP

Figure 1

Displacement pickups cannot have flat frequency response below their natural frequency. The size and weight of the pickup increases with decrease in natural frequency of the pickup. Therefore the natural frequency has to be chosen as a compromise between the size of the pickup and the low frequency response. The natural frequency that is adopted is 4.5 c.p.s.

If the damping is zero, there would be no phase distortion. However, zero damping is not advisable, as the pickups would pass through resonance every time it operates. If η is large, phase distortion is negligible for damping, (ζ), beween 0.00 and 0.70. A damping of 0.15 has been adopted in this case.

MEASUREMENT OF RELATIVE DISPLACEMENT

Of the various methods of measurement, 'Electrical Gauging' in which the mechanical quantity is converted into an equivalent electrical quantity, is best suited for vibration pickups. The various methods of measuring relative displacement have been discussed in detail by Mehrotra (1964), where it is concluded that linear variable differential transformer (L.V.D.T.) type is most suitable for displacement pickups.

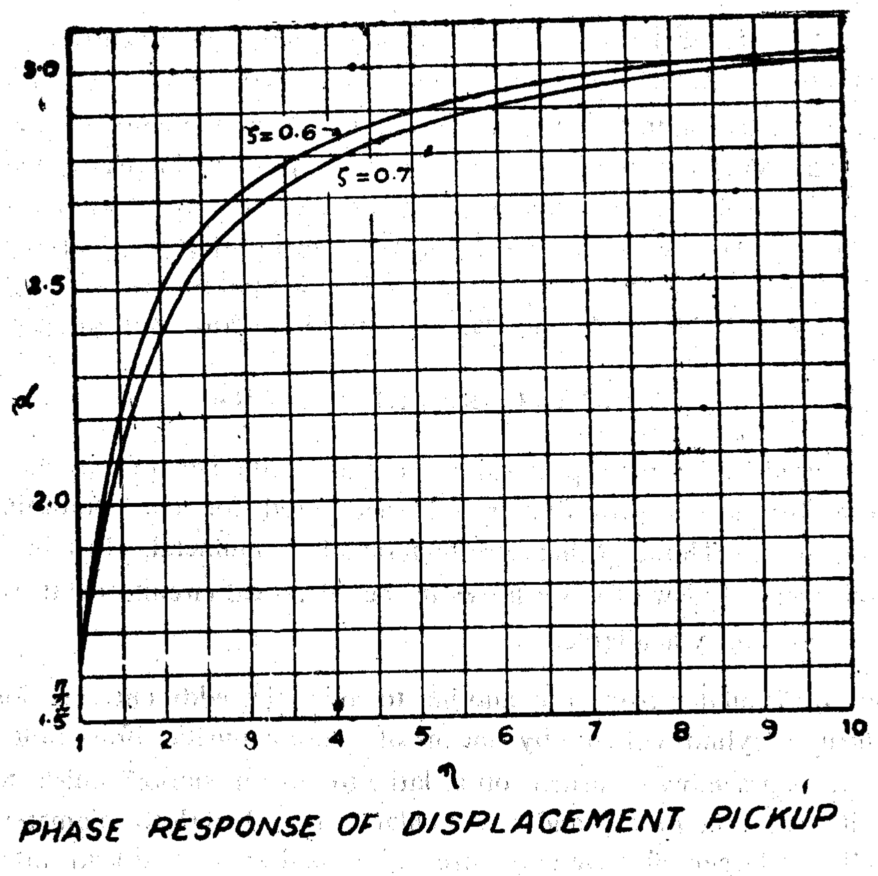


Figure 2

PRINCIPLE OF L.V.D.T.

The output of L.V.D.T. depends upon the mutual inductance between a primary and secondary coil. The basic components are shown in fig. 3. It consists of a core of magnetic

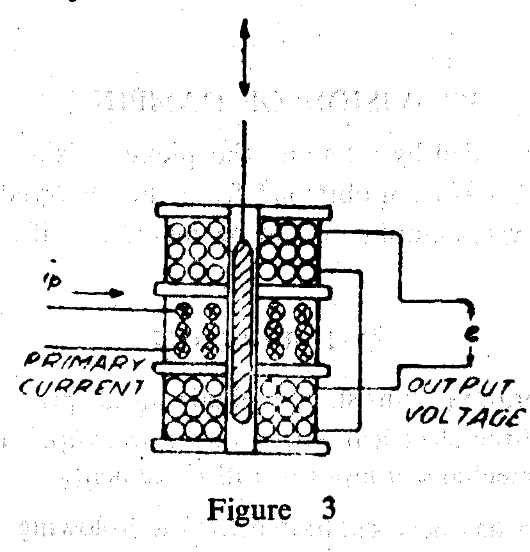


Figure 3

material, a primary coil and two secondary coils. The centre coil is energised with alternating current. This causes a magnetic flux to be produced, linking the centre coil (primary) with each of the others (secondaries). The secondaries are connected such that the voltages induced in them by mutual inductance oppose each other. As the core is moved up or down, the inductance and induced voltage of one secondary coil are increased while those of the other are decreased. The output voltage is the difference between two induced voltages. For some core position, the voltages balance and the combined output of the secondary combination is very very small. This position is called the balance point. In this type of transducer, the output voltage is proportional to the displacement of the core over an appreciable range.

L.V.D.T. CORE PREPARATION

The core used in the pickup consists of a large number of circular discs of 15/32" diameter. These discs are cut out of a metal sheet used for core stampings in the audio frequency transformers. Though other core materials like mumetal, dustcore etc., are more efficient from the point of view of lesser losses in the electrical circuit, metal sheets have been used because they are easily available.

The discs are insulated from one another to minimize eddy current loss and are kept in position to form a cylindrical core by means of a nonmagnetic brass bolt passing tightly through them. This assembly is turned on a lathe to give a smooth finish to the core. As the desired small size of the pickup and a particular ratio of length to diameter of the effective core does not allow a larger effective core size, additional brass and lead attachments had to be provided to bring the core weight to 0.24 lbs. so as to get the desired natural frequency.

DETAILS OF SPRING

A helical spring of rectangular cross section was found to give the least value of spring constant in conjuction with small size. The designed spring is also given a hardening treatment to increase its ductility.

PROVISION OF DAMPING

Damping has been provided by filling up the pickup casing with thin transformer oil. A damping value (ζ) of 0.15 has been obtained from the observed frequency response curve for forced vibration. However, damping could be increased, if necessary, by using a more viscous oil.

CALIBRATION

The process of calibration consists in obtaining a proper relationship between the quantity to be measured and the electrical output of the pickup. In this case, the electrical output is a voltage and the mechanical input is a displacement.

The fabricated pickup has been calibrated for the following conditions :

(i) Static Calibration—"Pickup Open"

(ii) Dynamic Calibration—"Pickup Open"
that is undamped

(iii) Dynamic Calibration—"Pickup Closed"
that is damped.

Figures 4 to 7 give the calibration curves

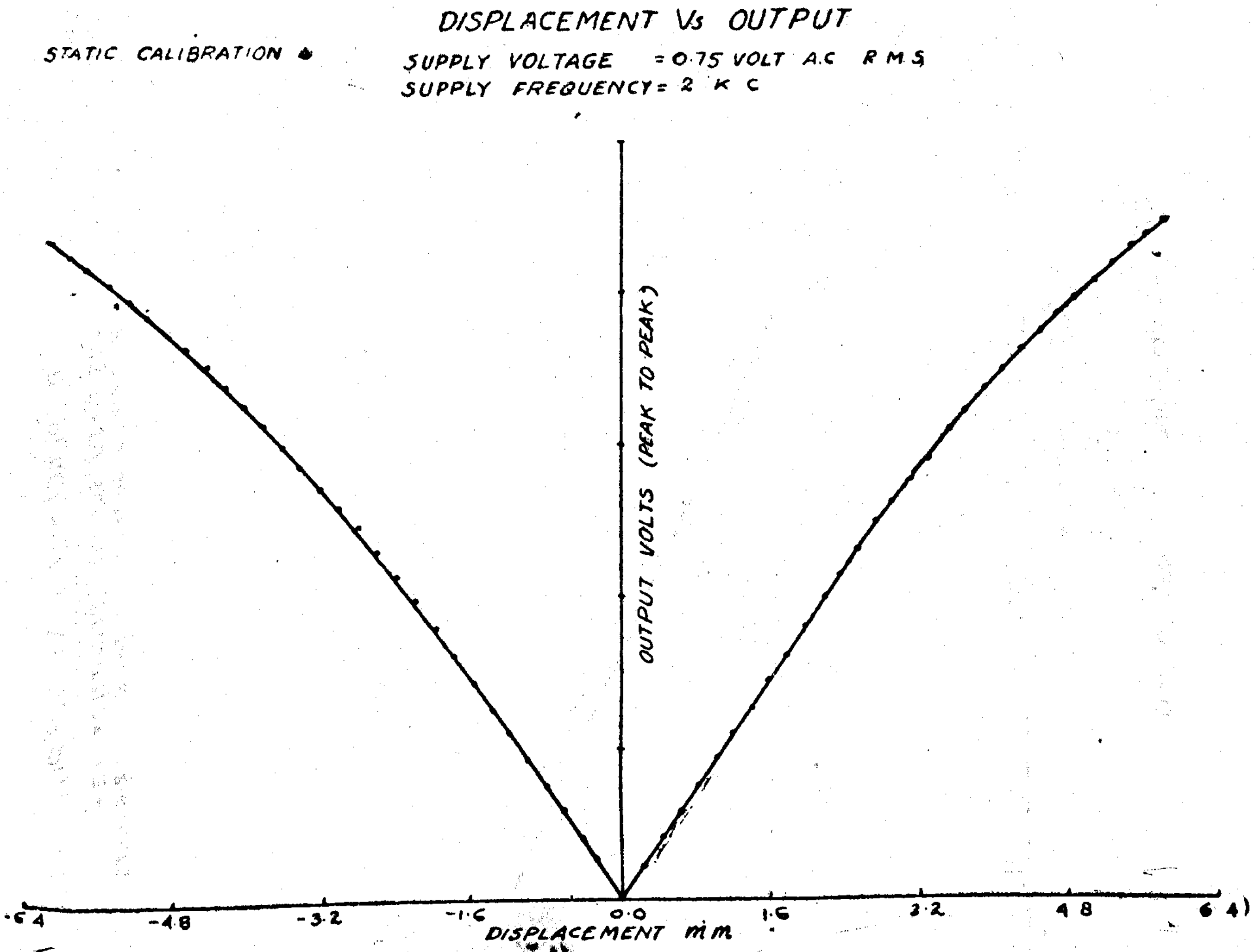


Figure 4

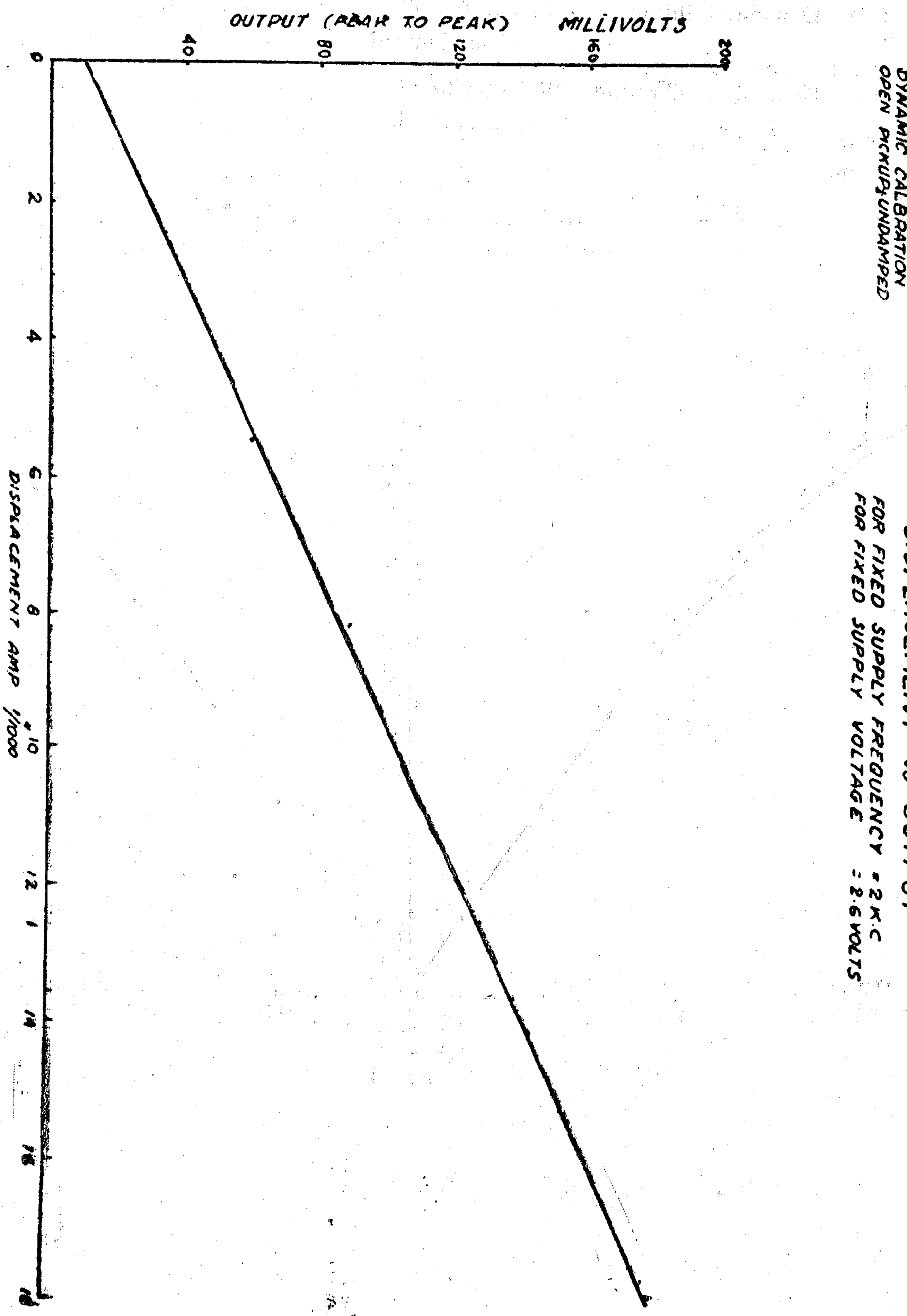


Figure 5

Note:—Voltage measured peak to peak

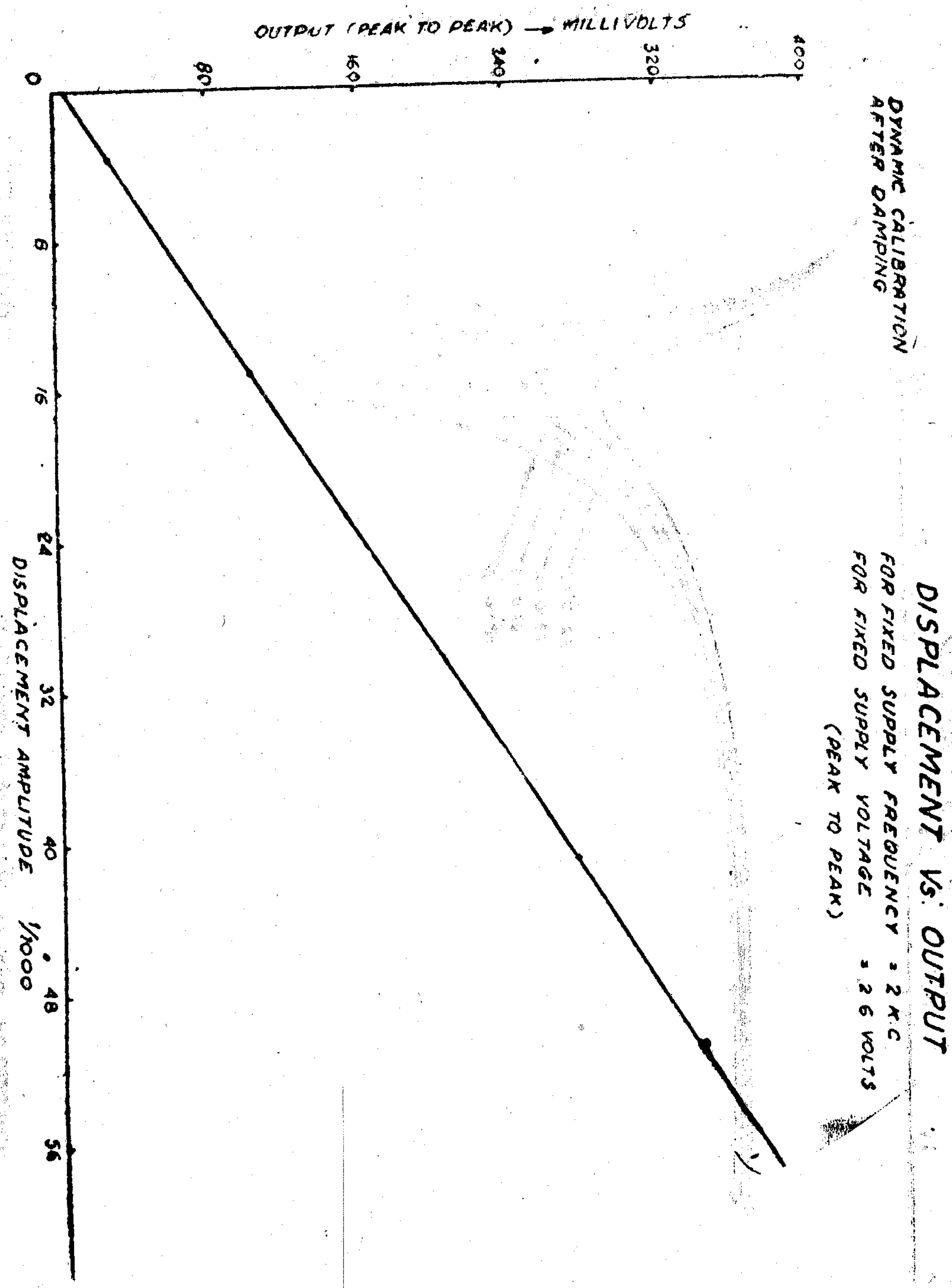

DISPLACEMENT Vs. OUTPUT
FOR FIXED SUPPLY FREQUENCY = 2 K.C
FOR FIXED SUPPLY VOLTAGE = 2 6 VOLTS
(PEAK TO PEAK)
DYNAMIC CALIBRATION
AFTER DAMPING
OUTPUT (PEAK TO PEAK) → MILLIVOLTS
0
80
160
240
320
400
8
16
24
32
40
48
56
DISPLACEMENT AMPLITUDE 1/1000

Figure 6

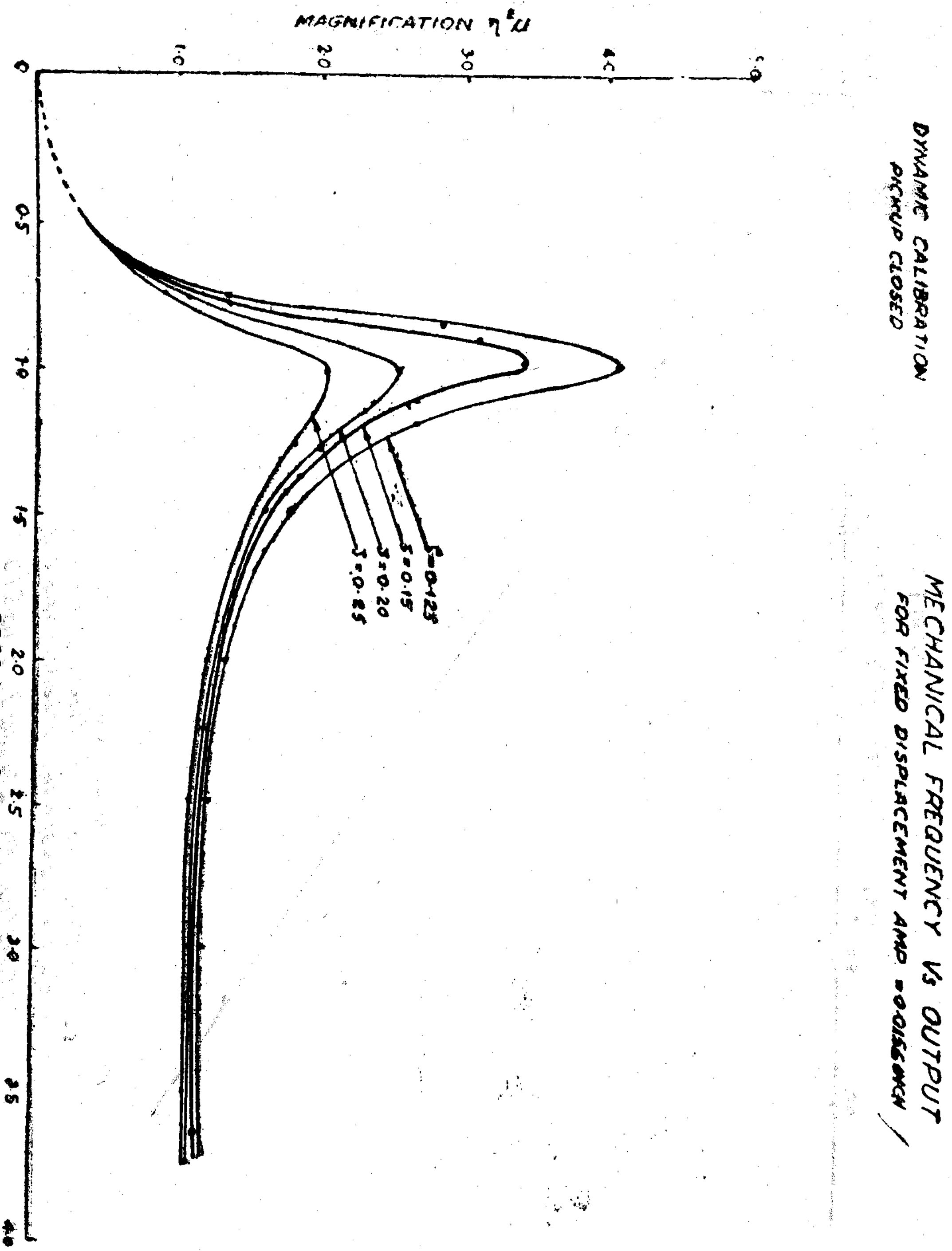

MECHANICAL FREQUENCY VS OUTPUT
DYNAMIC CALIBRATION
PICKUP CLOSED
MAGNIFICATION
FREQUENCY RATIO = η
ξ=0.125
ξ=0.15
ξ=0.20
ξ=0.25

Figure 7

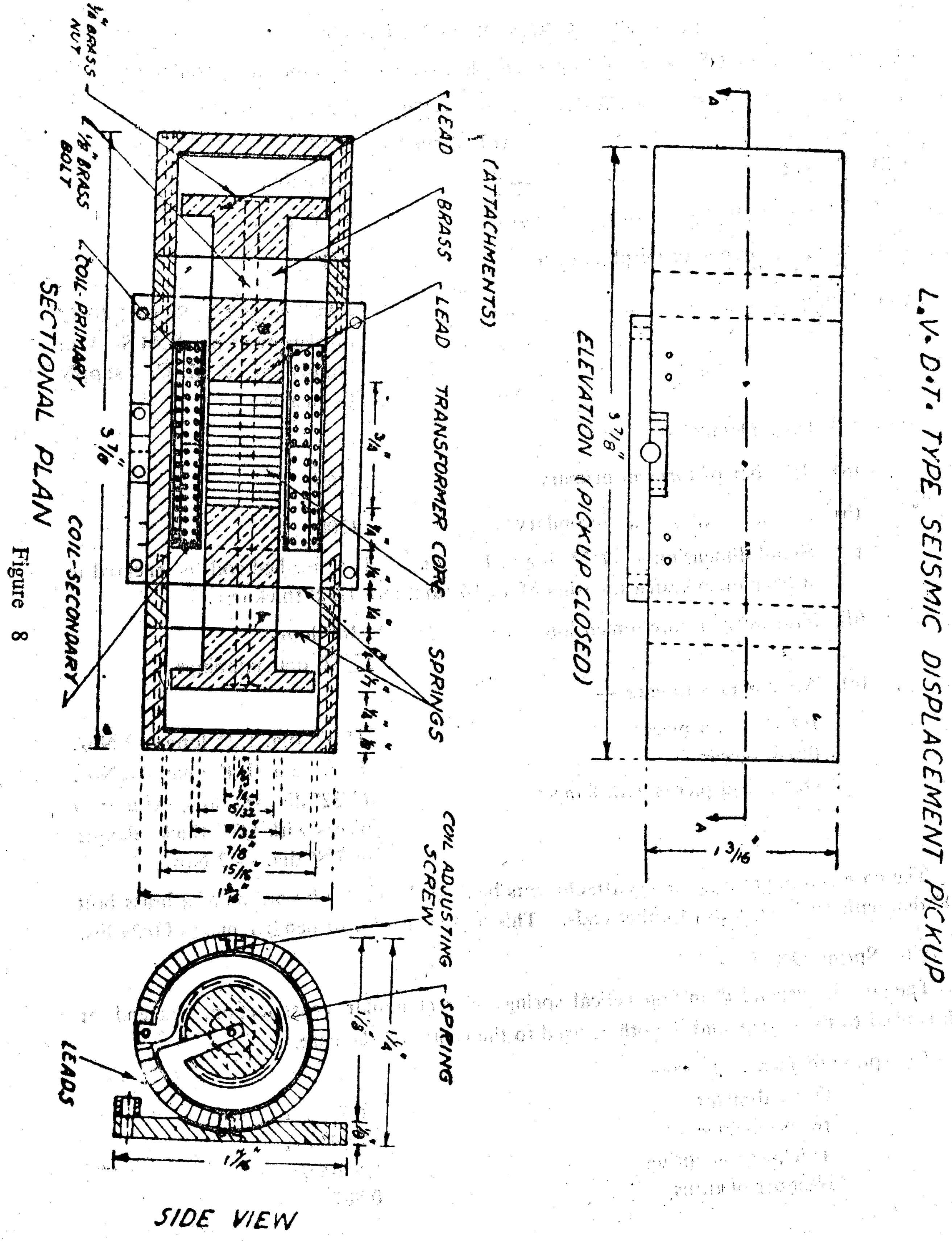

L.V.D.T. TYPE SEISMIC DISPLACEMENT PICKUP
ELEVATION (PICKUP CLOSED)
SECTIONAL PLAN
SIDE VIEW
LEAD
(ATTACHMENTS)
BRASS
LEAD
TRANSFORMER CORE
SPRINGS
COIL-PRIMARY
COIL-SECONDARY
BRASS NUT
BRASS BOLT
COIL ADJUSTING SCREW
SPRING
LEADS
3 7/8"
1 3/16"
3 7/8"
7/8
15/16
1 1/4"
1/8"

Figure 8

SPECIFICATIONS OF THE PICKUP

Figure 8 gives details of the pickup. The detailed specifications are as follows :

(i) The overall size of the Pickup is —(a) length — $3\frac{7}{8}''$

(b) diameter— $1\frac{3}{16}''$

(ii) Weight ... ... 0.505 lbs.

(iii) Natural frequency ... ... 4.5 c. p. s.

(iv) Max. Amplitude of Displacement ... 1/4"

(v) Calibration factor ... ... 4 Millivolts R.M.S. per 1/1000" displacement per R.M.S. Volt supply at 2 K. C. supply frequency.

(vi) L.V.D.T. Details —

(a) Number of turns in primary... 400

(b) ,, ,, ,, Secondary 1200

(c) Spool dimensions—17/32" bore,, $1\frac{1}{4}''$ long. The finished coil is encased in a bakelite cylindrical casing of 15/16" dia. and 1/32" thickness.

(d) Transformer core dimensions 3/4" long, 15/32" dia stampings

(e) Attachments to core —

Interior lead pieces	15/32" dia; 1/2" long —2 Nos.
Brass pieces	15/32" dia. 1/4" long —2 Nos.
Outer lead pieces with flanges	15/32" dia 1/4" long cylindrical pieces with 1/7" thick flanges of 7/8" dia. — 2 Nos.

The core stampings and all the attachments being tied tegether by means of a brass bolt of 1/8" dia. with 1/4" dia. nuts at either ends. This makes a total suspended mass of 0·24 lbs.

(vii) Spring Details—

The core is suspended on four helical springs of rectangular cross section, one end of which is fixed to the casing and the other, fixed to the centre of the core.

The spring diamensions are—

Outer dimeter	7/8" dia
Inner dimeter	47/72" dia
Thickness of spring	5.5/1000"
Number of turns	0·887

(viii) Housing details:—

The entire assembly with the coil is housed in a cylindrical sleeve of 15/16″ inner diameter and 1/8″ thick walls. The sleeve is made into five parts as shown in figure 8 so as to allow for proper placing of springs and to allow for ease in repairs. Adequate keys and screws are provided to make the assembly leak proof. A coil-adjustment screw is provided which when tied fixes the coil at a desired balanced position.

(ix) Damping—

Two holes are provided for filling thin transformer oil which provides viscous damping value of 0.15.

Rubber stops at the end walls are provided to absorb shocks and prevent damage to the springs.

PERFORMANCE OF THE PICKUP

The linear behaviour of the transfer characteristics with respect to more or less all the involved parameters as seen from the characteristic curves indicates that the pickup performs satisfactorily. The auxiliary instrumentation necessary for recording the output is an audio frequency oscillatior, an A.C. Amplifier, a phase sensitive demodulator and an oscilloscope. These equipments are of standard variety and should be available in any instrumentation laboratory. Knowing the natural frequency of the pickup, the calibration could always be checked even in the sealed condition, by giving a known tilt to the pickup.

ACKNOWLEDGEMENT

Dr. Jai Krishna, Professor and Director of Earthquake School, Roorkee gave active encouragement to this research project. Mr. A.P. Sharma and Mr. L. Chand of Earthquake School are responsible for the fabrication of the pickup.

REFERENCES

Mehrotra, B.L., (1964) "Study of Displacement Pickups", M. E. Thesis, University of Roorkee, Roorkee.

Myklestad, N.O., (1956) "Fundamentals of Vibration Analysis", McGraw Hill Book Co., New York, N.Y.