CHAPTER 8

SUGGESTIONS FOR FURTHER WORK

(1) In this experimental work a study was made of the friction of brass on steel. To study the variation of coefficient of friction of metals, various materials should be used.

(2) Tests should be conducted on different sample geometries.

(3) Since load, speed and frequency of vibration are variables, further research should be performed using further values of these.

APPENDIX

A strain gauge force transducer was designed to measure force at contact surfaces. The force was calibrated from standard dead weight to electrical voltage. The electrical voltage from the transducer was not affected by the frequencies of vibration. The following analysis of the transducer gave the relation between the electrical voltage and the inertia force.

Transducer Analysis (Fig. A1.)

Differential equation of motion

$$m_o \ddot{x} + k x - k y = 0 \text{ ....(1)}$$

$$m_2 \ddot{y} + k y - k x = F_o \sin wt \text{ ....(2)}$$

Assume simple harmonic motion so that

$$x = X \sin wt \qquad\qquad y = Y \sin wt$$

Then $\dot{x} = w X \cos wt \qquad\qquad \dot{y} = w Y \cos wt$

$$\ddot{x} = - w^2 X \sin wt \qquad\qquad \ddot{y} = - w^2 Y \sin wt$$

Substitute in eq. (1)

$$m_o(- w^2 X \sin wt) + k(X \sin wt) - k(Y \sin wt) = 0$$

$$X (k - w^2 m_o) - Y (k) = 0$$

$$Y = (k - w^2 m_o) \frac{X}{k}$$

$$Y = (1 - \frac{w^2}{k} m_o) X \text{ .... (3)}$$

From equation (2)

$$m_2(-w^2 Y \sin wt) + k(Y \sin wt) - k(X \sin wt) = F_o \sin wt$$

$$Y(k - w^2 m_2) - X k = F_o$$

$$X(-k) + Y(k - w^2 m_2) = F_o$$

From equation (3)

$$X(-k) + (k - w^2 m_2)\left(1 - \frac{w^2}{k} m_o\right)X = F_o$$

$$X\left(-k + k\left(1 - \frac{w^2}{k} m_2\right)\left(1 - \frac{w^2}{k} m_o\right)\right) = F_o$$

$$X = \frac{F_o/k}{\left(-1 + \left(1 - \frac{w^2}{k} m_o\right)\left(1 - \frac{w^2}{k} m_o\right)\right)}$$

$$= \frac{F_o/k}{\left(-1 + 1 - \frac{w^2}{k} m_2 - \frac{w^2}{k} m_o + \frac{w^2}{k} m_o m_2\right)}$$

$$= \frac{F_o/w^2}{\left(\frac{w^2}{k} m_o m_2 - (m_o + m_2)\right)}$$

Deflection of the transducer $Z = (X-Y)$

$$Z = X - \left(1 - \frac{w^2}{k} m_o\right)X = \frac{w^2}{k} m_o X \qquad \text{(Y from eq. (3))}$$

Newton's principle

$$F = m\,a$$

$$= m\,w^2\,X = \frac{m\,F_o}{\left(\frac{w^2}{k} m_o m_2 - (m_o + m_2)\right)} \quad \text{.....................} \quad (4)$$

And $V = \propto Z$

$$= \propto \frac{w^2}{k} m_o X$$

$$= \propto \frac{w^2}{k} m_o \frac{m\,F_o}{\left(\frac{w^2}{k} m_o m_2 - (m_o + m_2)\right)}$$

$$= \propto \frac{F_o m_o/k}{\left(\frac{w^2}{k} m_o m_2 - (m_o + m_2)\right)} \quad \text{.......................} \quad (5)$$

From this we find the calibration of V and F is (5)/(4)

$$\frac{V}{F} = \propto \frac{m_o}{km}$$

$$\text{or } V \text{ (voltage output)} = \propto \frac{F\, m_o}{k\, m}$$

$$= \propto (m_1 + m_2) \frac{F}{k\, m}$$

$$= \propto \left(\frac{1}{k} + \frac{m_1}{k\, m} \right) F$$

This depends on m_1 and m, but is independent of w. Thus, no effects are expected from resonance of the transducer assembly.

Transducer Stiffness

Friction was also affected by the amplitude of vibration. The amplitude of vibration depends on the stiffness of the transducer, frequencies of vibration, and vibrated mass. The stiffness of the transducer was found by measuring the contraction of the transducer and the corresponding weight as in Fig. A2.

Transducer Resonance Curve (Fig. A4.)

Since the power amplifier did not have enough power to drive the transducer, then amplitude of vibration of the transducer was assumed to act as a simple harmonic motion. A resonance curve was then found from the formula

$$\frac{X}{F_o} = \frac{1/k}{1 - \left(\frac{w}{w_n}\right)^2}$$

From curve (Fig. A4.), it is seen that the resonance frequency is about 400 c/s. The sensitivity of the transducer is almost linear above the frequency of 800 c/s.

Coefficient of Friction from Data

The recorded data were normal force in lb. and strain in percent. The line in Fig. A8. was drawn from the first series of test in table 9-1. The slope of the line is

$$\mu = \frac{2.4 \times 0.18}{1.2} = 0.36$$

Force on the normal force axis is 1.2 lb. The ratio of the motor torque arm to the radius of the rotating ring is 2.4 . Strain on the strain axis is 0.045 %. From Fig. A5., 0.045 % strain can be converted to 0.18 lb. The coefficient of friction is defined as the the ratio of frictional force to normal force. Frictional force can be calculated from the ratio of the motor torque to the ring radius.

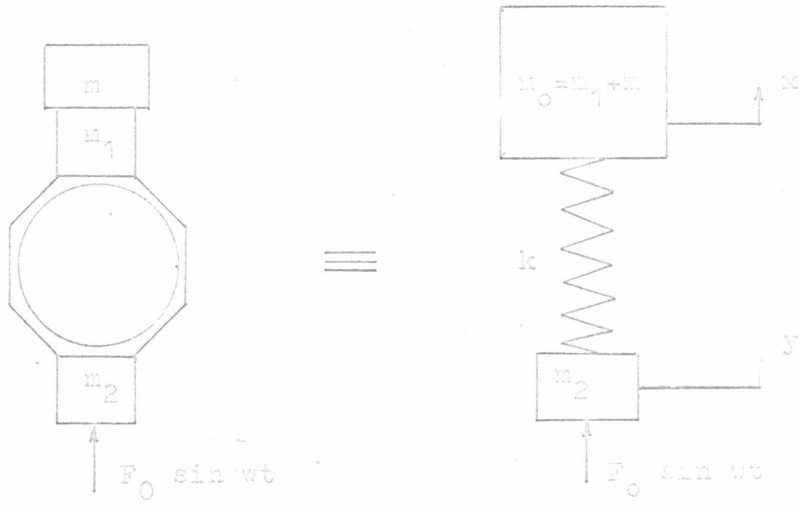


Fig. A1. TRANSDUCER AND EQUIVALENT VIBRATING SYSTEM.

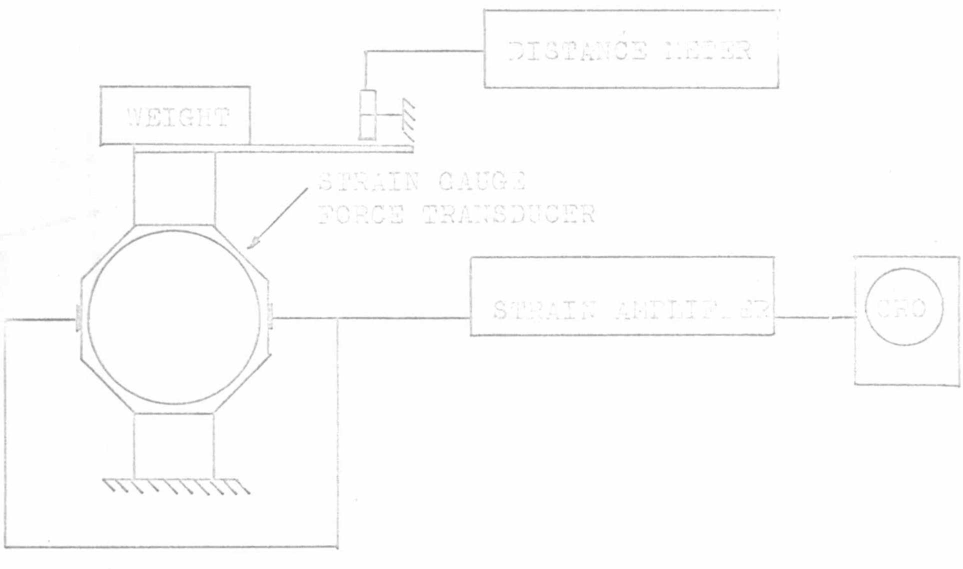


Fig. A2. SCHEMATIC ARRANGEMENT OF THE APPARATUS TO FIND THE STIFFNESS OF THE TRANSDUCER AND RELATIONSHIP BETWEEN FORCE AND STRAIN.

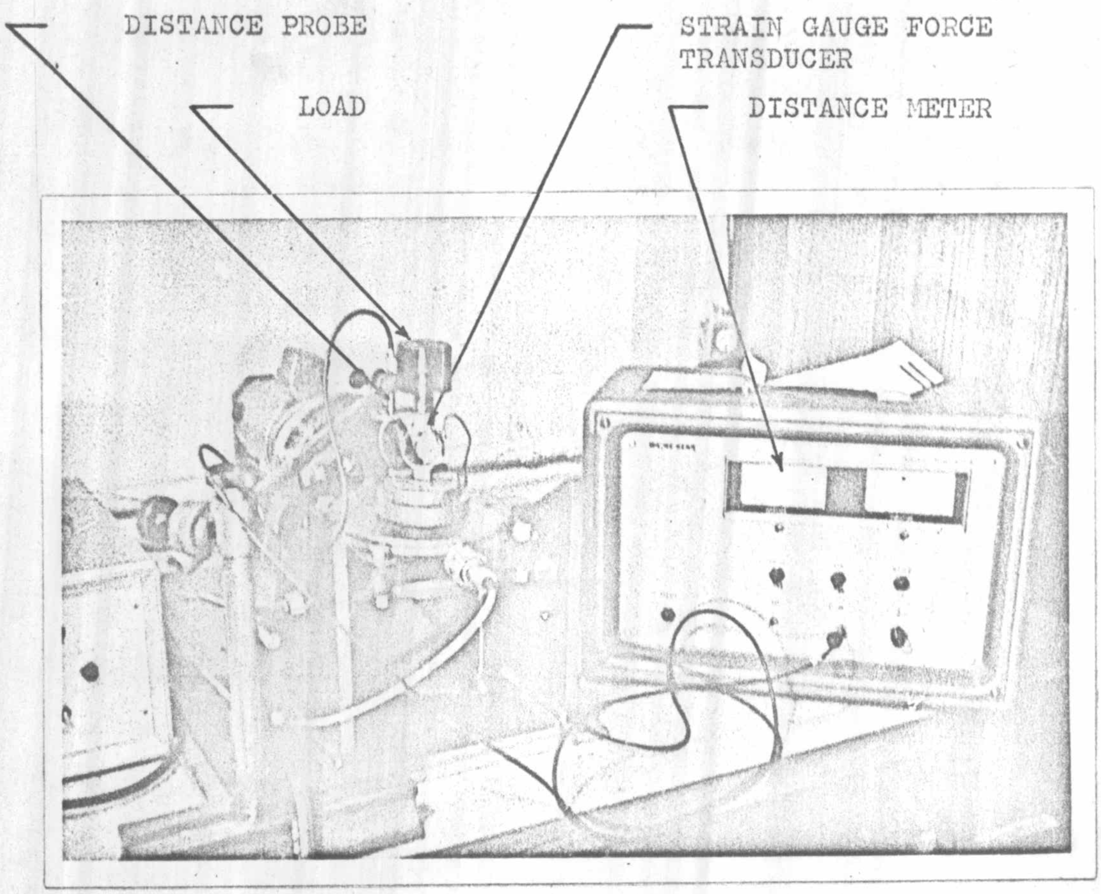


Fig. A3. PHOTOGRAPH OF THE ARRANGEMENT OF THE APPARATUS TO FIND THE STIFFNESS OF THE STRAIN GAUGE FORCE TRANSDUCER.

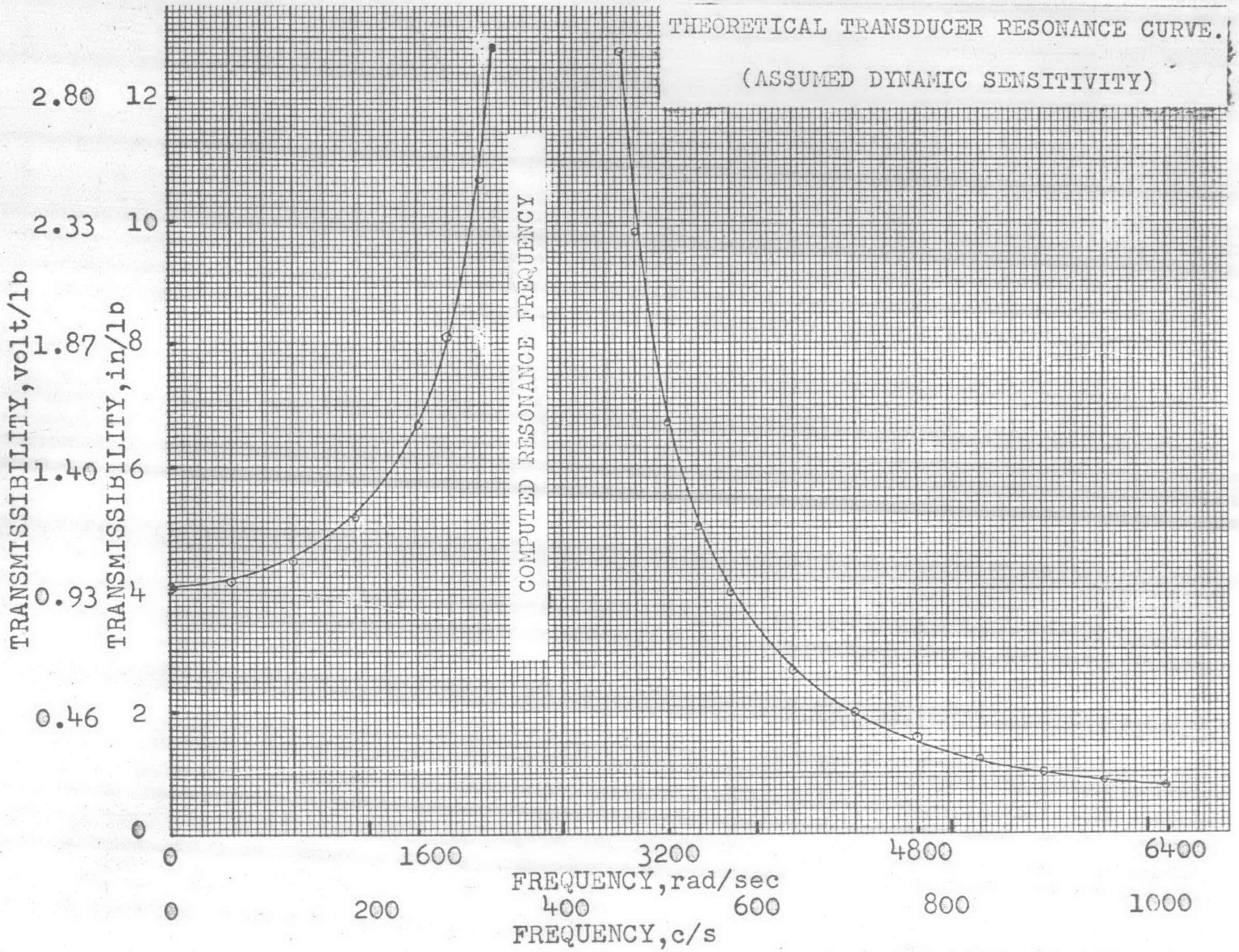


Fig. A4. THEORETICAL TRANSDUCER RESONANCE CURVE.

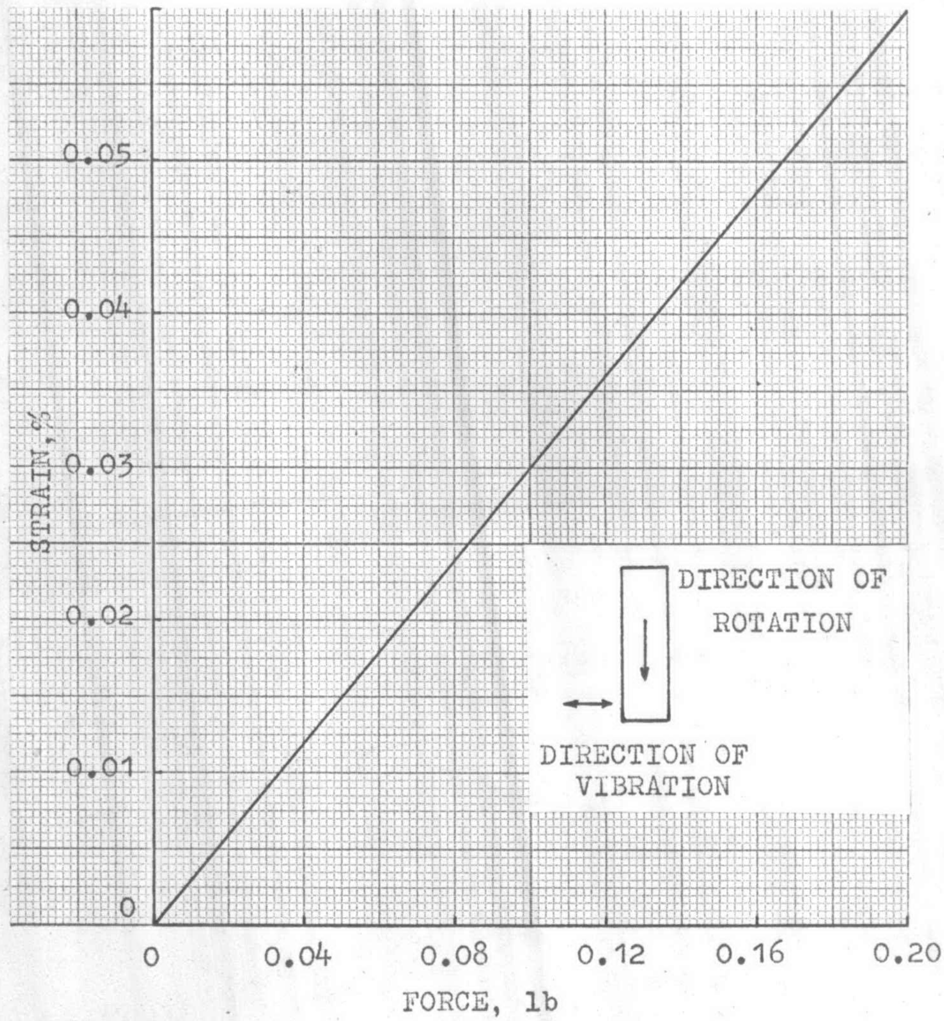


Fig. A5. CALIBRATION CURVE OF MOTOR TORQUE TRANSDUCER.

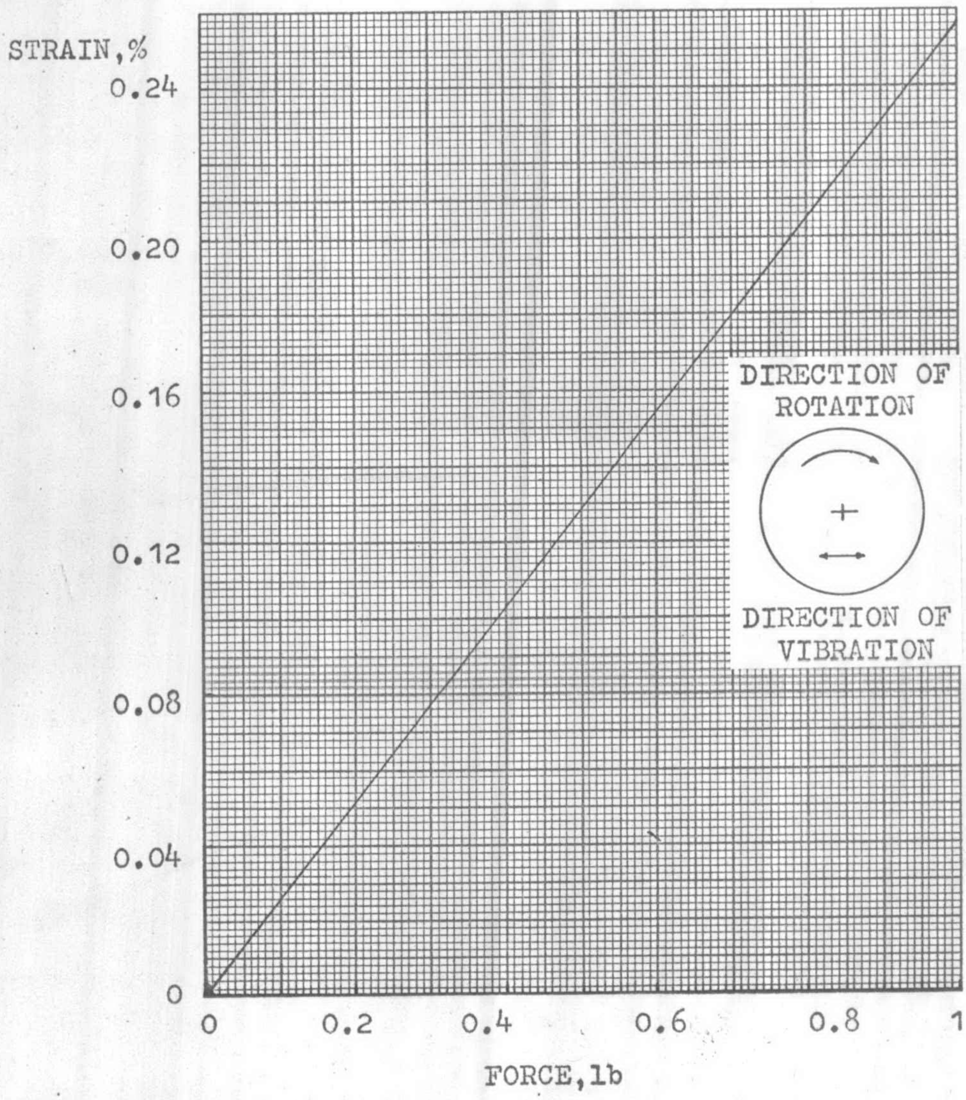


Fig. A6. CALIBRATION CURVE OF MOTOR TORQUE TRANSDUCER.

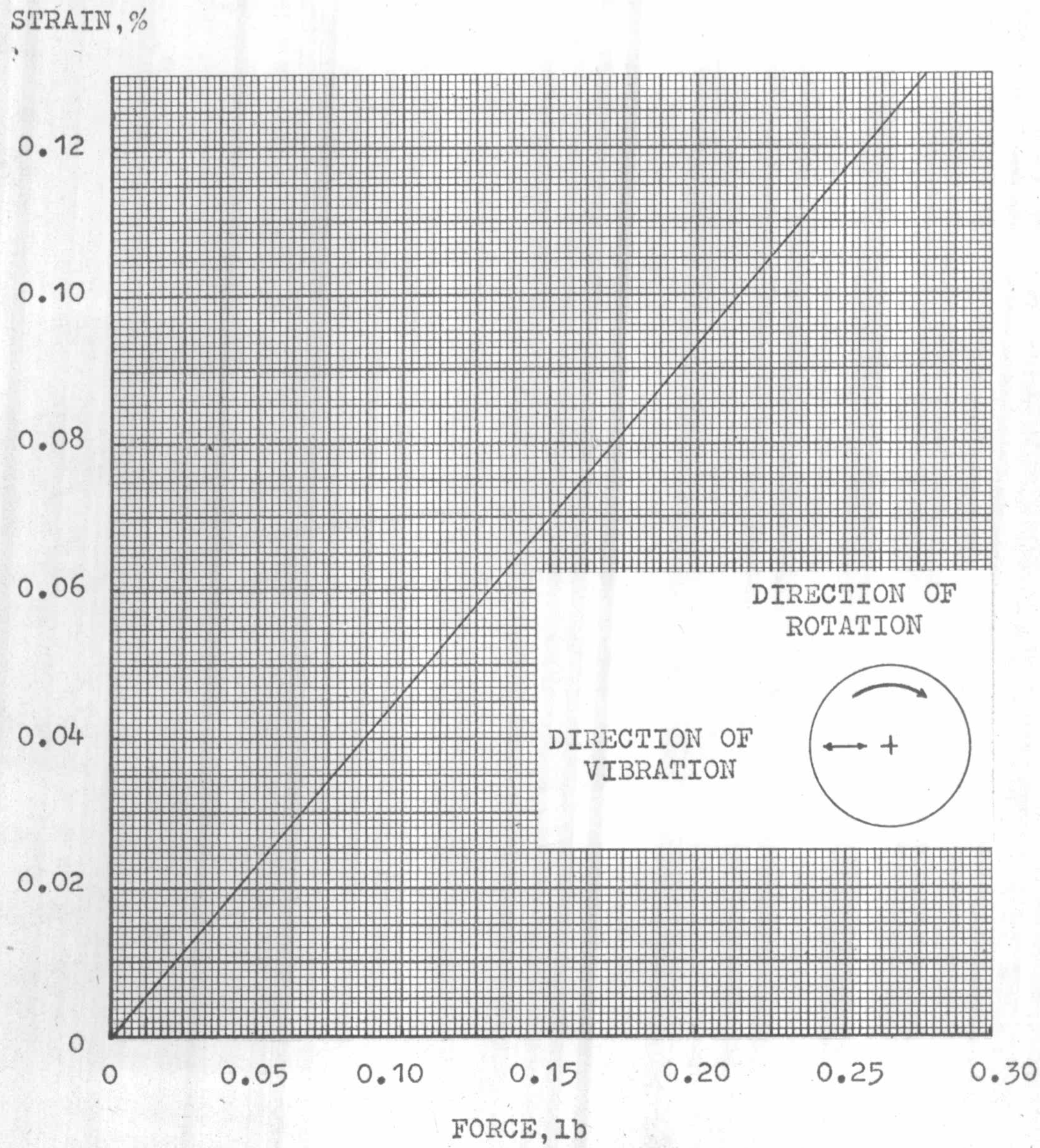


Fig. A7. CALIBRATION CURVE OF MOTOR TORQUE TRANSDUCER.

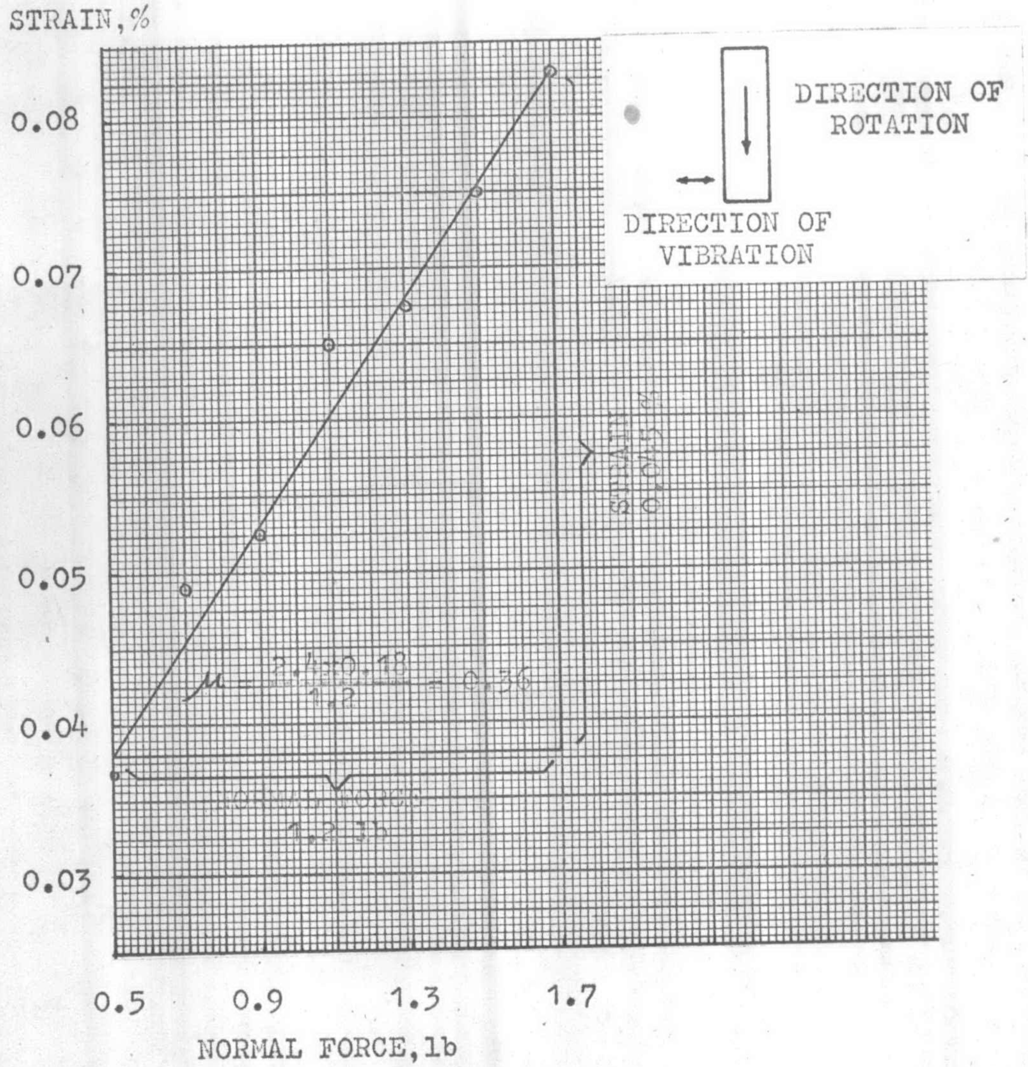
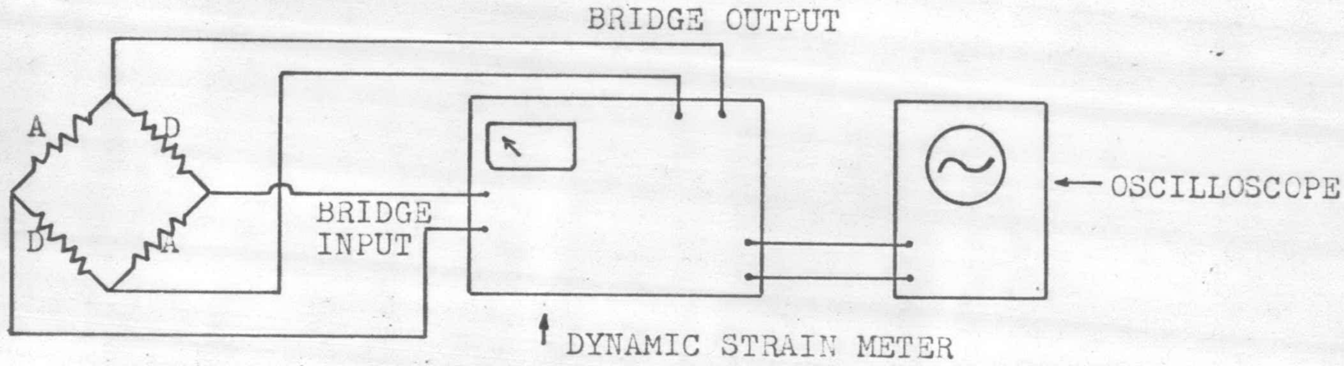
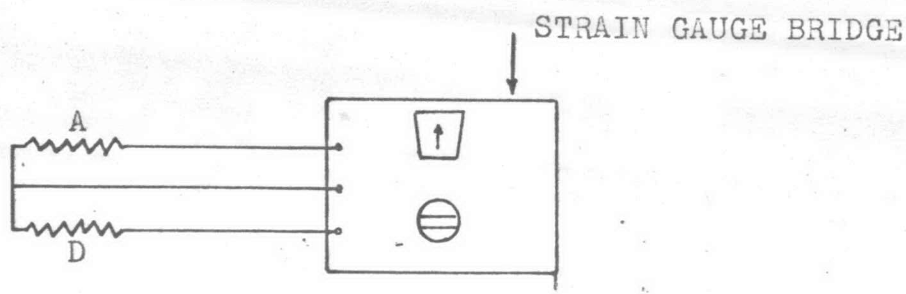


Fig. A8. GRAPH BETWEEN NORMAL FORCE AND STRAIN.



A - ACTIVE GAUGE ON THE FORCE TRANSDUCER.
D - DUMMY GAUGE.

FIG. A9. BRIDGE CIRCUIT OF THE FORCE TRANSDUCER.



A - ACTIVE GAUGE ON THE TORQUE ARM TRANSDUCER.
D - DUMMY GAUGE.

FIG. A10. BRIDGE CIRCUIT OF THE TORQUE ARM TRANSDUCER.

Static - Kinetic Friction

In Fig. A11., strain from the torque arm transducer was recorded by the pen recorder on the graph paper. The graph showed the static friction to be greater than the kinetic friction before slipping start. As soon as slipping occurs the kinetic friction decreased to a steady value with a constant speed.

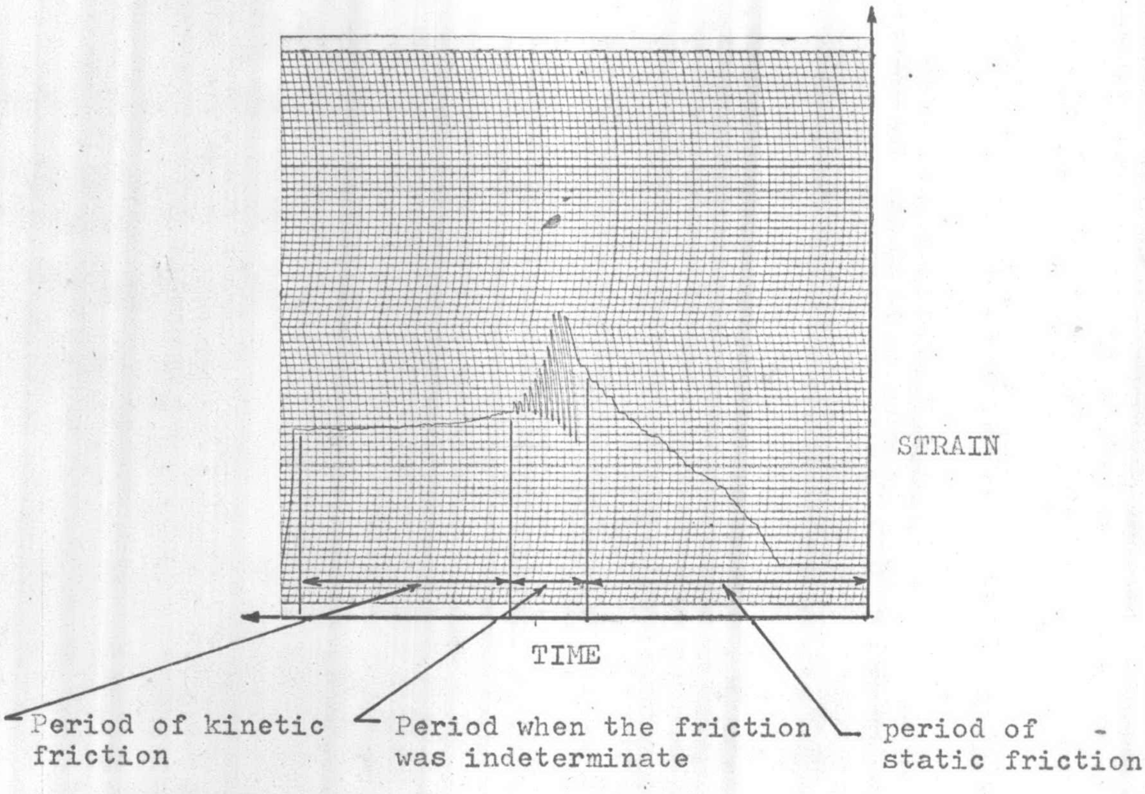


Fig. A11. Static - kinetic Friction.