DESIGN AND DEVELOPMENT OF A LATHE TOOL DYNAMOMETER

THESIS
submitted in partial fulfilment of the requirments
For the Degree of
MASTER OF ENGINEERING
IN
MACHINE DESIGN (MECHANICAL)

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C E R T I F I C A T E

Certified that the dissertation entitled "THE DESIGN AND DEVELOPMENT OF A LATHE TOOL DYNAMOMETER" which is being submitted by Shri R.S. Raghava in partial fulfilment for the award of the Degree of Master of Engineering in Machine Design (Mechanical) of University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of 1st May '63 to 31st Oct 63. for preparing dissertation for Master of Engineering Degree at the University.

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Dated:
4th November, 1963.

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November 4,1963. R.S. RAGHAVA.

C O N T E N T S

ABSTRACT

Designing a satisfactory machine tool necessitates the determination of tool forces. This project is an attempt to study forces, coming on the lathe tool; due to various parameters such as depth of cut and feed etc.

The forces are measured by means of straingage type torsional dynamometer. The dynamometer is designed and fabricated in the University Workshop. The graphs between the force and various parameters are drawn, then an emperical formula has been established in force, depth of cut and feed rate.

PART - I

THEORETICAL REVIEW

CHAPTER - I.

ANALYTICAL EVALUATION OF FORCES.

CHAPTER - I.

INTRODUCTORY.

The term "Machinability" does not lend itself to an exact definition, acceptable to all authorities. The "Ease" with which a given material may be worked with a cutting tool changes with the "Machine Variables". The various quantities that define the particular machine set-up used in carrying out a given operation on the work material are as follows:

1. Cutting speed
2. Dimensions of the cut (Feed, Depth etc.)
3. Tool Geometry (angles, radii etc.)
4. Tool Material
5. Cutting Fluid
6. Rigidity and tool chatter.

Likewise, for a given set of machine conditions, the "ease" of machining varies with the "work material variables". These variables are:

1. Hardness
2. Tensile properties
3. Chemical composition
4. Micro-structure
5. Degree of cold work
6. Strain hardenability.

Further, the criteria for judging the "ease" of working a metal vary with with preference of experimenter

C H A P T E R - I.

MACHINABILITY

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2. Tensile properties
3. Chemical composition
4. Micro-structure
5. Degree of cold work
6. Strain hardenability.

Further, the criteria for judging the "ease" of working a metal vary with the preference of experimenter or the requirements of the job. Some of the more common of these criteria, used singly or jointly as a measure of the ease of working a metal, are given below:

General criteria

1. Life of the cutting tool between two resharpenings
2. Magnitude of tool forces
3. Quality of the surface finish.

These three criteria are directly related to the machining cost. Three quantities - tool life; tool forces; and finish - have become the most commonly accepted measures of machinability for shop use. Out of these three quantities mentioned, the forces developed by cutter of a machine tool and the power requirements of the motor are of importance for following reasons:

a) The selection of the proper size of motor to be employed on the machine tool.

b) The design of the power transmission from the motor to the cutting tool.

c) The design of the feed mechanism.

d) The determination of stresses and deflection in the frame and various parts of the machine tool.

e) The purpose of design of jigs, fixtures and special devices for holding the work during machining operation.

f) The selection of the proper size of the cutting tools and their applications.

Because of above reasons, the tool forces play an important part in the design of machine elements. To know these forces, it is essential to develope the apparatus. In the present work the lathe tool forces are measured with the help of a dynamometer.

TOOL FORCES

The system of cutting forces is three dimensional in the general metal cutting operations. With the exception of orthogonal cutting, when the resultant force on the tool has only two components. The following assumptions have to be made before the forces can be analysed.

These assumptions are as follows:

1. The chip is in a stable mechanical equilibrium under the action of the forces exerted on it at the tool face and the shear plane.
2. The shear surface is a plane extending upwards from the cutting edge.
3. The intensity of stress and strain is constant throughout the shear plane.
4. Micro-structure of the work material and the chip is the same.
5. Cutting edge is a straight line extending perpendicular to the direction of motion and generates a plane surface as it moves past the work.
6. The chip does not flow to either side.
7. The depth of cut is uniform.
8. The width of the tool is greater than that of work-

piece.

9. The tool moves relative to the work with uniform velocity.

10. A continuous chip is formed without built-up edge.

11. The tool is perfectly sharp and there is no contact along the clearance face.

Although the assumptions are not absolutely correct, the results of the analysis are reasonably accurate.

When the chip is isolated as a free body (Fig.1-1), we need consider only two forces. The force between the tool face and the chip (R) and the force between the work-piece and the chip along the shear plane (R'). For equilibrium, these must be equal:

$$R = R' \qquad \dots \qquad (1)$$

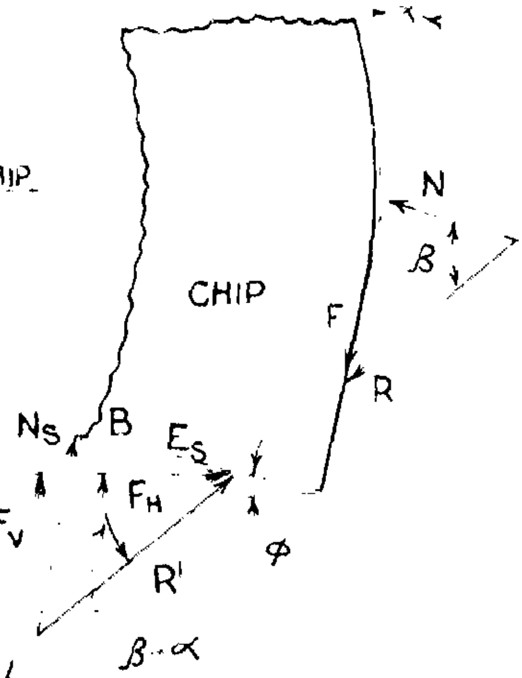
The forces R & R' are conveniently resolved into three sets of components as shown in Fig. 1-2.

1. In the horizontal and vertical directions F_h and F_v
2. Along and perpendicular to the shear plane F_s and N_s
3. Along and perpendicular to the tool face F and N.

For convenience and simplicity, the forces R and R' are plotted at the tool point instead of at their actual point of application. R and R' (which are equal and parallel) are coincident, and are made the diameter of the dotted reference circle shown.

Analytical relationships may be obtained for the shear and friction components of force in terms of the horizontal and vertical components F_h and F_v. F_h and F_v are the components determined experimentally by means of strain gage dynamometer (Chapter III).

FIG. 1.1 FREE BODY DIAGRAM OF CHIP
SHOWING THE FORCE ACTING



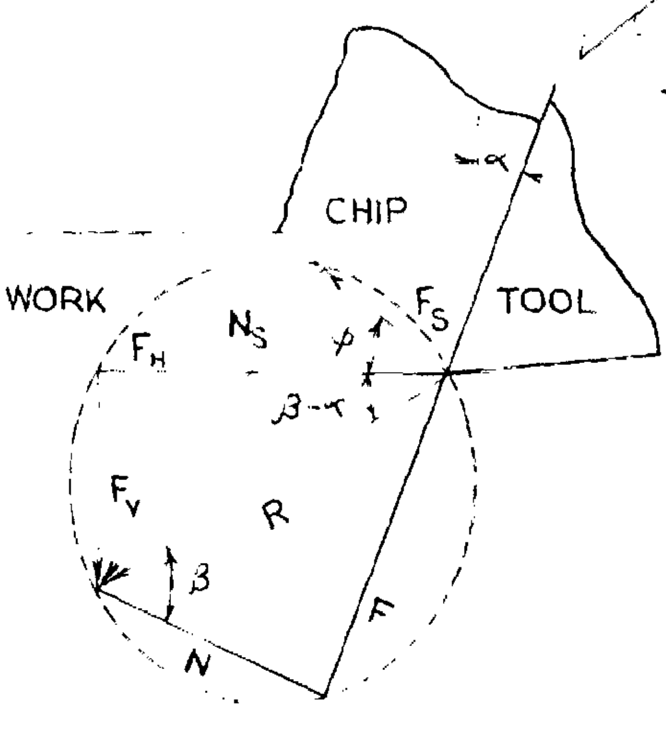
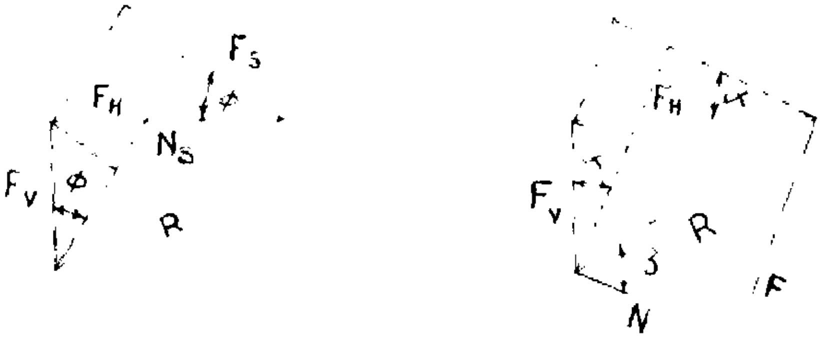


FIG. 1.2 COMPOSITE CUTTING FORCE CIRCLE

FIG. 1.3 RESOLUTION OF RESULTING CUTTING FORCE



A SHEAR PLANE FORCE

B. TOOL PLANE FORCE

From Fig. 1-3a it is evident that

$$F_s = F_h \cos \phi - F_v \sin\phi \quad \ldots. \quad (2)$$

$$N_s = F_v \cos \phi + F_h \sin \phi \quad \ldots. \quad (3)$$

$$= F_s \tan (\phi + \beta - \alpha)$$

Similarly from Fig. 1-3b

$$F = F_h \sin\alpha + F_v \cos\alpha \quad \ldots. \quad (4)$$

$$N = F_h \cos\alpha + F_v \sin\alpha \quad \ldots. \quad (5)$$

Thus knowing horizontal and vertical components of the force F_h and F_v, rake angle of the tool, and the shear angle ϕ, it is possible to calculate shear force components F_s and N_s, Friction force F, Normal reaction N and the coefficient of friction ( )

$$= \tan = \frac{F}{N} = \frac{F_h \sin\alpha + F_v \cos\alpha}{F_h \cos - F_v \sin}$$

$$= \frac{F_v + F_h \tan\alpha}{F_h - F_v \tan\alpha} \quad \ldots. \quad (6)$$

In turning operations, we have three components of the force:

1. Tangential force
2. Longitudinal or Feed force
3. Radial force.

The radial force component of the cutting force is normally small in magnitude (about 10% of the total force) and can be neglected without much loss of accuracy.

TOOL NOMENCLATURE

A single point tool embodies several geometrical elements which are classified and defined specifically. Each tool consists of a shank and a point.

A typical tool designation will consist of the following:

1. Tool material
2. Tool size
3. Tool angles and nose radius.

The size of a tool of square or rectangular section is expressed by giving in the order, viz. the width of shank W, the height of shank H and the tool length L.

The various tool angles are defined below:

Back rake angle:

This is the angle between the face of the tool and the base of the shank or holder, usually measured in a plane through the side-cutting edge and at right angles to the base Fig. 1-4. It is positive if the face slopes downward from the point toward shank, tending to reduce the included angle of the tool point; it is positive if the face slopes upward toward the shank.

Side rake angle:

It is the angle between the face of the tool and the base of the shank or holder; it is usually measured in a plane perpendicular to the base and to the side-cutting edge.

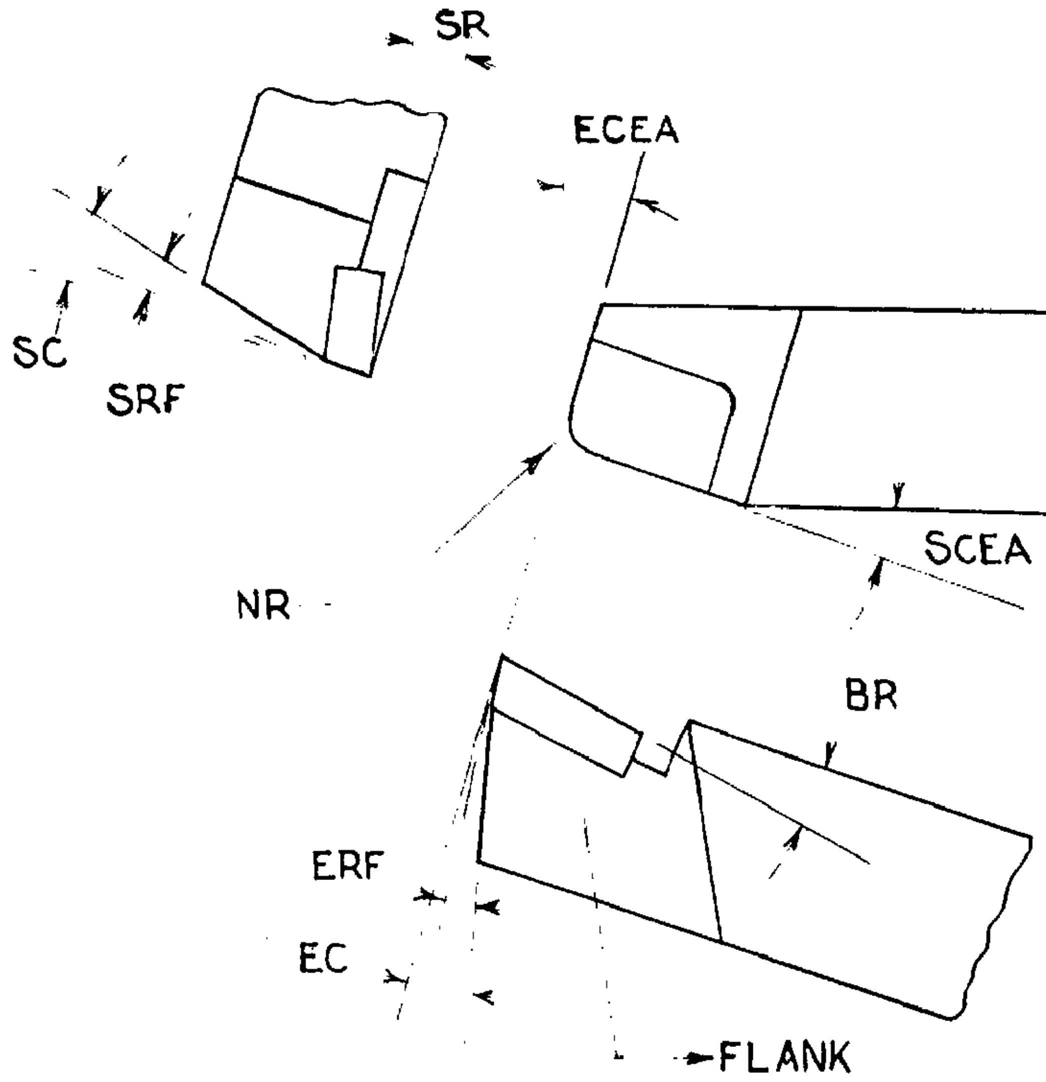
Side relief angle:

An angle between the portion of the side flank immediately below the side-cutting edge and a line drawn through this cutting - edge perpendicular to the base is known as side-relief angle Fig.1-4.

End-relief angle:

This is the angle between the portion of the end

FIG 1.4 VARIOUS ANGLES ON A SINGLE POINT TURNING TOOL



BR = BACK RAKE ANGLE.
SR = SIDE RAKE ANGLE.
ERF = END RELIEF ANGLE.
SRF = SIDE RELIEF ANGLE.
E.C = END CLEARANCE ANGLE.
SC = SIDE CLEARANCE ANGLE.
ECEA = END CUTTING EDGE ANGLE.
SCEA = SIDE CUTTING EDGE ANGLE.
NR = NOSE RADIUS.

flank immediately below end-cutting edge and a line drawn through that cutting edge perpendicular to the base. It is usually measured in a plane at right angles to the end flank.

Clearance angle is the angle between a plane perpendicular to the base of the tool or holder and that portion of the flank immediately below the relieved flank. Side clearance angle is measured in the plane of the back rake angle, similarly, end clearance angle is measured in the plane of side rake angle. The clearance angle is greater than its corresponding relief angle, except when only one plane exists on the flank, in which case the clearance and relief angles would coincide.

Side cutting edge angle:

In Fig. 1-4, this is the angle between the straight side -cutting edge and the side of the tool shank.

End cutting edge angle:

This is the angle between the cutting edge on the end of the tool point and a line at right angles to the side of the tool shank.

As shown in Fig.1-4 the nose radius of tool is the radius at the cutting point of the tool.

Tool character is a convenient and abbreviated designation to specify the angles of a single point tool as below:

Tool character 8° 14° 6° 6° 6° 0° $\frac{3}{64}$"R

Back rake angle	8°
Side rake angle	14°
End relief angle	6°
Side relief angle	6°
End cutting edge angle	6°
Side cutting edge angle	0°
Nose radius	$\frac{3}{64}$"R

TOOL SHAPE VERSUS PERFORMANCE

The performance of a tool is generally measured in terms of tool life, power consumption and the economy of cutting operation. A tool is paid to have a good performance when tool life is long, power consumption in cutting is low and metal removal is done economically.

Each of the rake angles, relief angles, nose radius side-cutting edge angle and edge cutting angle affects the tool performance considerably care should, therefore, be taken in selecting their values.

Rake angles:

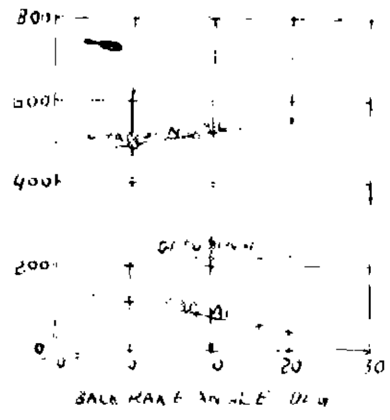
The most advantageous combinations of rake angles vary greatly with tool material, work material and economics of the job. The rake angle forces the chip to slide off in a convenient direction. A tool with positive rake angles has the best thermal efficiency of cutting. Positive rake angles reduce the cutting forces and to certain extent increase the tool life.

Increasing the back rake angle has more effect upon radial force Fig. 1-5a than upon other components since the radial forces are of small values, the effect of varying the back rake is of small significance. This angle is usually changed to control the chip flow direction by forming a shear angle, causing the chip to flow away from, or toward the work. In Fig. 1-5a, changing the back-rake angle from 0° to 16° decreased the radial tool force from 110 lb. to 60 lb.

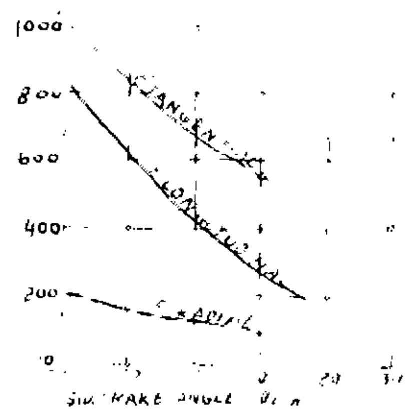
DEPTH OF CUT 1/4 INCH

CUTTING SPEED 80 RPM

FEED 1/64" PER REVOLUTION



(a)



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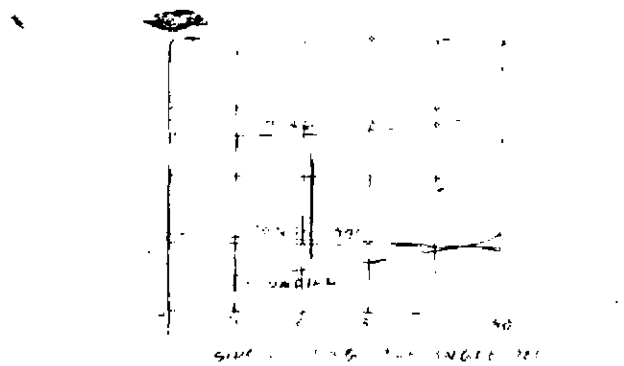


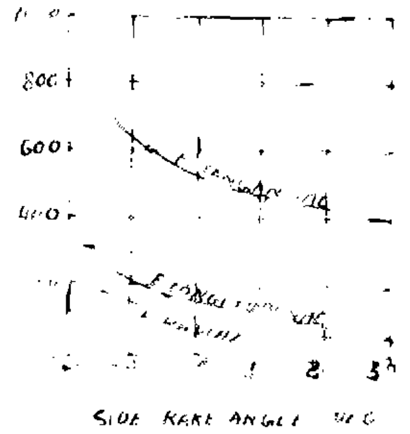
OTHER TEST CONDITIONS SAME AS ABOVE EXCEPT

SPEED - 200 RPM

(c)

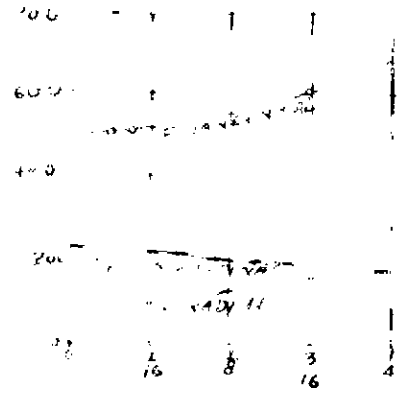
OTHER CONDITIONS SAME EXCEPT

SPEED - 200 RPM



(d)

ALL CONDITIONS SAME



(e)

EFFECT OF TOOL GEOMETRY ON CUTTING FORCES

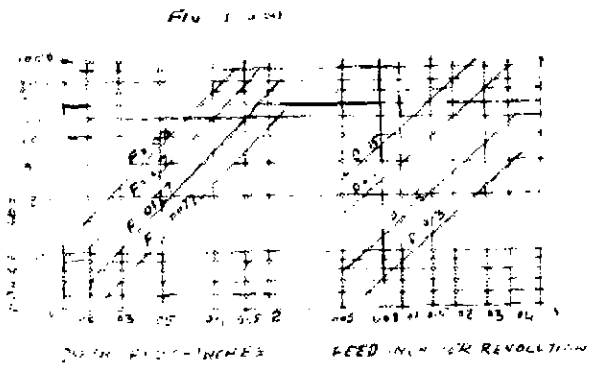
The side rake angle is very effective in reducing the tool forces. As shown in Fig. 1-5b, the tengential tool force was decreased from 1000 lb. to 400 lb. by increasing the side rake from -20° to +30°. Other two forces were also reduced considerably increasing the side rake angle produced a greater effect in reducing tool forces when cutting at low speeds than at high. By comparing Figs. 1-5b and 1.5c it will be seen that increasing the speed from 80 fpm to 200 fpm had a definite influence on decreasing the longitudinal tool force. When using a side rake angle of -10°, the longitudinal force was reduced from 610 lb. to 215 lb. by increasing the cutting speed, This explains why sintered carbide tools using negative rake angles should be operated at higher speeds.

Side cutting edge angle:

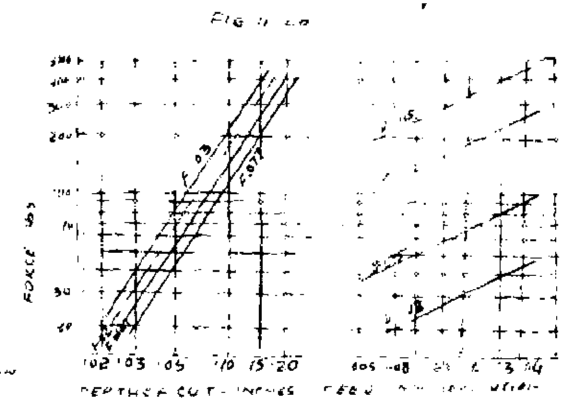
Due to increase in this, the radial tool force is increased, changing the side cutting edge angle from 0° to 45° causes the radial tool force to be doubled as shown in Fig. 1-5e. Since higher side-cutting-edge angles cause a longer and thinner chip, the efficiency of metal cutting is slightly reduced and the tangential tool force slightly increased as shown in Fig. 1-5e.

Relief angles:

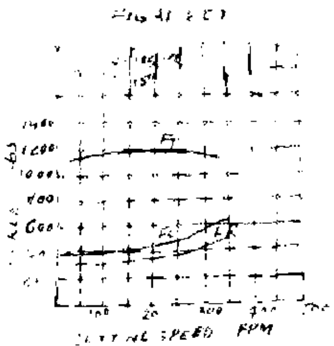
The end relief angle should be sufficient to keep the work from rubbing with the flank. The side relief angle in turning should be greater than the feed helix angle. The end relief angle reduces the cutting forces



Tangential Forces



Longitudinal Forces



Annealed [illegible] Steel Speed · [illegible] FPM

Tool Designation 8 4 [illegible] 6 6 [illegible] 3/64 R

Ver[illegible]cal And [illegible] Force Test Data Plotted On Log-Log Paper To Determine The Exponents Of The Cutting Force Equation

Effect Of Cutting Speed On The Magnitude Of The Forces on the tool to the extent that it makes the tool point more keen. However, this angle should be kept as small as possible to give more material support under the cutting edge to raise the tool endurance.

The relief angles should be small for hard metal and large for soft metals.

Nose radius:

The nose radius has some influence on the cutting force. Large nose radius gives increase in the radial and tangential force. Larger nose radii prolong tool life, better surface finish, but cause greater tool forces, through less efficient cutting and the tendency of the tool to chatter.

It is required to compare the experimental data obtained from the dynamometer setup with the available data, it is essential that tool geometry should be same. For this reason, a special high speed steel tool having same designation was prepared. The various tool angles were measured from bevel protractor (Appendix-3).

MACHINE VARIABLES VERSUS TOOL FORCES

The most common machine variables which affect the cutting forces are:

Depth of cut and feed:

The size of the cut influences the cutting force. From the results of the metal cutting tests to-date, Fig. 1-6a-b shows the effect of these variables on the cutting forces. From this several conclusions can be drawn:

1. A change in feed has less effect on the cutting forces than a change in depth.
2. More important, the cutting forces do not increase in direct proportion, to an increase in feed, but follow the exponential law.

<u>Cutting speed:</u>

At higher speeds, the cutting force is independent of speed. At lower speeds, the results are most erratic and unexplainable.

<u>Effect of metal variables:</u>

The forces are dependent on the metal to be machined. They are directly connected with tensile strength, hardness and the carbon content. For the experiment a mild steel was chosen whose tensile, strength hardness and carbon content, were measured (Appendix I and II).

CHAPTER - II.

D Y N A M O M E T R Y.

CHAPTER - II.

DYNAMOMETRY:

In order to analyse any metal cutting operation on a quantitative basis, certain observations must be made before, during and after a cut.

The number of observations that can be made before or after a cut is unrestricted but the number of observations that can be made during a cut is limited. One of the important measurements of this type is the measurement of cutting force components. Dynamometers are required to measure these force components. A dynamometer is like a spring scale as it measures forces in terms of deflections produced by the forces. The diflections produced by the forces are very small and before ~~it~~ they can be read accurately have to be magnified several times by mechanical, pneumatic or electrical means.

2.1. Dynamometer requirements

Two of the main requirements of a dynamometer are, the sensitivity and the rigidity. They always have conflicting requirements. The sensitivity of a good dynamometer would be ± 1% i.e. a dynamometer designed for mean force of 100 lbs. should give readable increment for 1 lb. variation in the force. No dynamometer is free from deformation completely, but a good dynamometer should be rigid enough not to be influenced by the inherent deformation. Other main criterion of a dynamometer is its natural frequency of vibration. The accuracy will be impaired if resonance created. The natural frequency of vibration should, therefore, be large (at least 4 times the rpm the job).

A dynamometer measuring force component in three directions (x, y and z) should have no cross-sensitivity i.e. a force applied in x-direction should give no reading of deflections in y or z direction. Force components may be computed by the use of simultaneous equations, if a dynamometer has some cross sensitivity. This makes immediate interpretation of the data difficult.

A linear relationship between the recorded quantity and the force is a desirable property of a good dynamometer.

A dynamometer must be stable with respect to time, temperature and humidity thus requiring only occasional checks once it is calibrated. It should be applicable to higher speeds of operations.

2.2. TYPES OF DYNAMOMETERS:

Dial indicator type:

This type is capable of reading diflections to about 10^{-4} inch. inspite of the simplicity of construction, this type is not used extensively because of large friction and inertia. Some leaverage is generally used with this type of dynamometer for accuracy of reading. Figure 21 shows the dial indicator dynamometer diagramatically.

Hydraulic pressure cell type:

Hydraulic pressure cell in conjunction with a

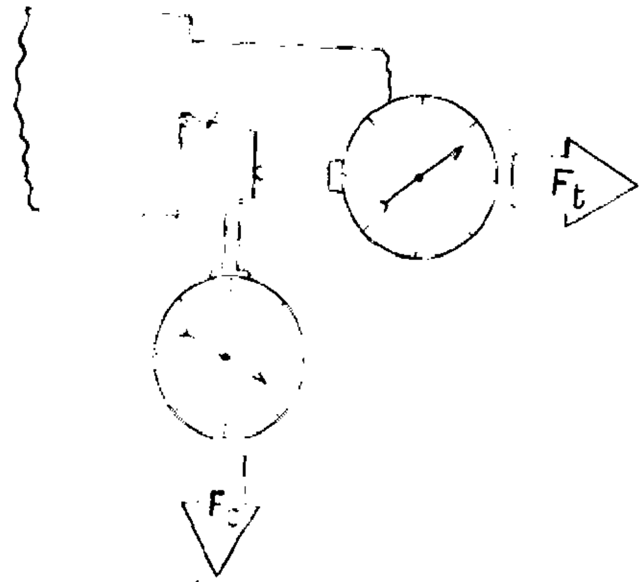


FIG 2 1 DIAL INDICATOR DYNAMOMETER

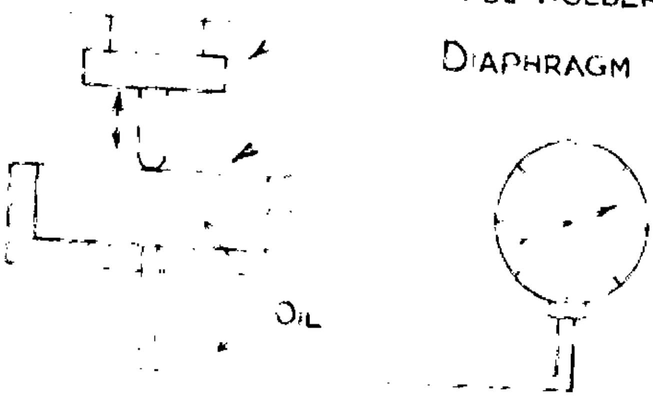


FIG 2 2 BASIC PRINCIPLES OF HYDRAULIC DYNAMOMETER pressure gage facilitate force components measurement at a distance. The schematic diagram of this type of dynamometer is shown in Fig. 2-2.

Pneumatic type:

The principle of working of this type dynamometer is that change in back pressure when a flat surface is brought closer to a sharp-edge orifice is proportional to the diflection of flat surface which in turn is proportional to the force of the tool. The basic principle is explained by Fig. 2-3. Such type of dynamometer is reliable if supplied with pure air at constant pressure. The chips removed from the work during cutting process are a source of trouble in this type of dynamometer. The range over which the dynamometer has linear characteristic is small and the dynamometer tends to be bulky.

Optical type:

Of the many types of optical devices in use, those using interferometric methods are more popular, and reliable as the wavelength of light is used as yardstick. The device shown diagrammatically Fig. 2-4 acts as an optical lever by which small angular diflections α can be measured if L is large.

For small values of δ, $\delta = 2 L\alpha$.

Though such a device is simple in principle, it is not easily adopted for force measurements in metal cutting.

Piezoelectric crystal type:

These crystals because of their well known

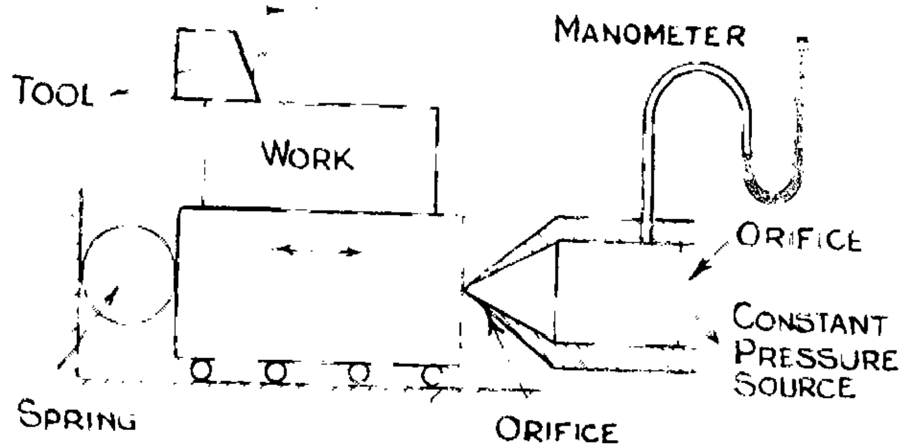


FIG. 2 3 BASIC PRINCIPLES OF PNEUMATIC DYNAMOMETER

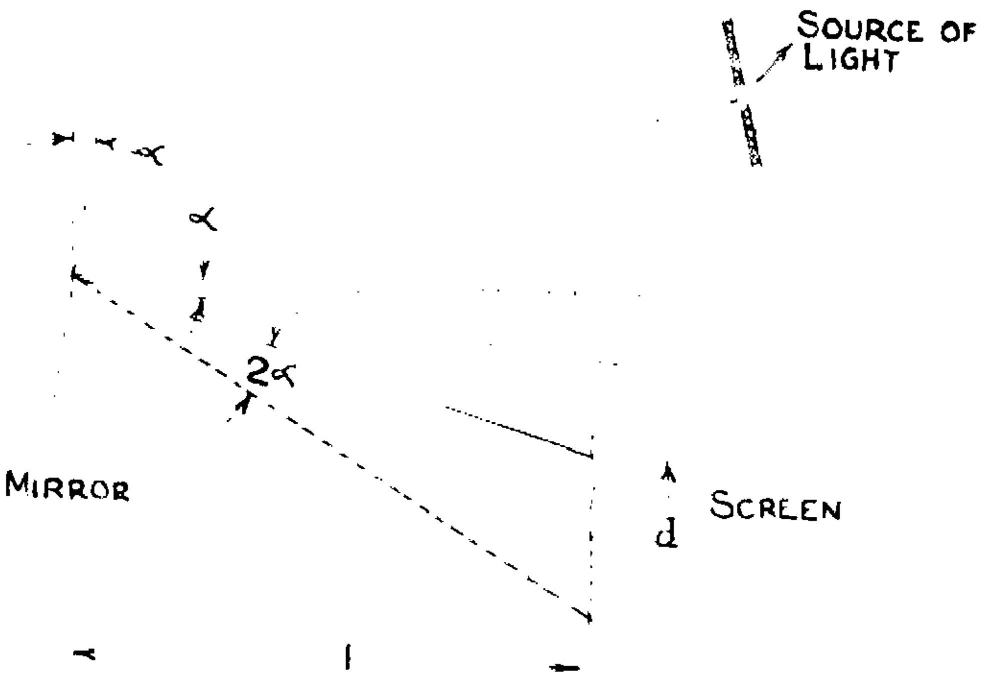


FIG. 2 4 PRINCIPLE OF OPTICAL DYNAMOMETER property of generating e.m.f. in proportion to the pressure exerted on them can be used for force measurements. Electric leakage gives major trouble in practice.

Electric type dynamometer:

In this category, wire resistance strain gage type is more popular. It works on the principle that the resistance of wire increases when it is stretched and it decreases when the wire is compressed. This principle is made use of in wire strain gage. This is discussed in the part 2 of the thesis. It has very good sensitivity and rigidity. It has good response to dynamic forces also. Considering merits and demerits our choice falls on this type.

PART - II

PRESENT WORK

CHAPTER - I.

DESIGN AND FABRICATION OF SET-UP

C H A P T E R - I.

DESIGN OF STRAIN GAGE DYNAMOMETER

1.1. Description:

Before starting the design, it is necessary to give brief description of the setup. The adjoining photograph shows the dynamometer along with calibration rig. The high speed steel tool of standard geometry is held in the tool box (2). This tool holder is monolithic with the shaft. This is held in tool holder by means of bolts. The shaft is rigidly held in the end plates (3). Dowel pins have been driven in, to resist the rotation of the shaft. The strain gage are cemented on the shaft. The end plates are screwed with the bed (1) which can be fixed on the cross-slide of the lathe.

1.2. Design considerations:

The output of the gages is directly proportional to the strain in the material, so it is essential that such material should be chosen which fulfil certain requirements.

We see that, for a hollow circular shaft

$$\text{Torque, } T = \frac{qI_p}{R}$$

$$= G(e_1 - e_2)\,\frac{(R_1^4 - R_2^4)}{2R_1}$$

$$= \frac{E}{2(1+\mu)}\;\frac{(R_1^4 - R_2^4)}{R_1}$$

For e to be higher, young's modulus of the material should be small, section modulus should also be small, but yield strength should be high. Due to these considerations

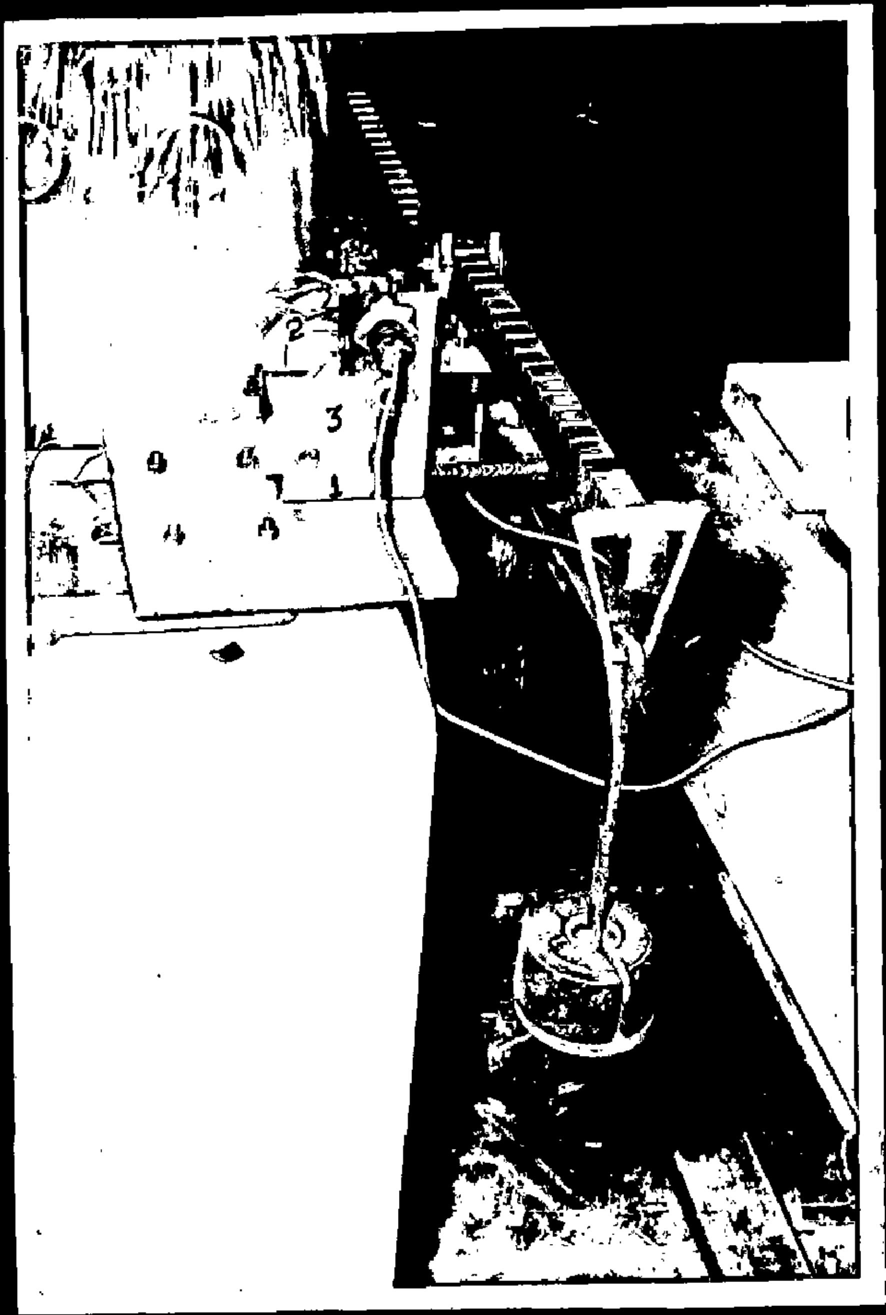


FIG. 1. Dynamometer On Calibrating Rig.

carbon steel and hollow section has been adopted.

1.3. Design procedure

As already described in the part I, lathe tool experiences the forces in two directions i.e. vertical and longitudinal. These forces play an important part in the design of the tool holder. The magnitude of these forces varies as the machine or material variables change. But initial values of these forces have been assumed (Manual of metal cutting ASME). Of course, these values are on conservative side, because the lathe, on which the instrumentation is to be carried is of a smaller horse power.

The values assumed are:

F_t (vertical force) = 1000 lbs.

F_L (longitudinal force) = 500 lbs.

Axial force is neglected.

These forces have various effects on the tool holder. These are:

1. F_t causes torsion and the bending of the shaft.
2. F_L causes bending and direct force in the shaft.

In the design of the shaft the combined effect of these forces is considered and the values of principal stresses determined.

Before proceeding to the calculations certain assumptions have been made:

1. The shaft is rigidly fixed at the ends.
2. It does not rotate with vibration.

Assuming outer and inner diameters of shaft, $\frac{3}{4}$" and $\frac{5}{8}$" respectively.

The polar moment of inertia

$$= \frac{\pi}{32}\left\{(3/4)^4 - (5/8)^4\right\}$$

$$= \frac{\pi}{32} \times \frac{61}{64} \times \frac{11}{64}$$

The shear stress in the shaft according to formula

$$\frac{T}{I_p} = q/r$$

$$q = \frac{T \times r}{I_p}$$

$$= \frac{1630 \times 3 \times 64 \times 64 \times 32}{\pi \times 61 \times 11 \times 8}$$

$$= 38000 \text{ psi.}$$

For annealed high carbon steel this value is safe.

1.4. Fabrication considerations:

Fabrication of shaft (A_3)

The shaft dimensions should be finished in thousands of an inch. The bore of the shaft be reamed to avoid any eccentricity . Round keys have been cut, because if the keys are square, and are not exactly diametrically opposite, they will cause trouble in the assembly. The ends of the shaft have been kept round, because it is difficult to machine the square hole accurately. The squares ends prevent rotation of the shaft.

Finishing of the endplates (A_2)

The holes should be accurately marked otherwise they will cause bending of the shaft.

3) There is no yielding of the supports.

4) There is no initial stresses present in the shaft.

Calculations:

Assuming tool overhang = 1.5"

We have:

1. Torsion in the shaft due to F_t

$$= 1000 \times 1.5 = 1500 \text{ lb.in.}$$

2. Maximum bending moment in the shaft at point A due to F_t (bending moment diagram is shown in Fig. 1-1)

$$= \frac{WL}{8} = \frac{1000 \times 5}{8} = 625 \text{ lb.in.}$$

3. Bending moment due to force F_L at the point A in the shaft Fig. 1-1

$$= \frac{M}{4} \text{ where } M = W \times L$$

$$= \frac{WL}{4} = \frac{500 \times 1.5}{4} = 190 \text{ lb.in.}$$

Bending due to force F_t is in the vertical plane and due to F_L in the horizontal plane. So the resultant bending moment is

$$= \sqrt{625^2 + 190^2}$$

$$= 652 \text{ lb.in.}$$

Assuming failure according to the maximum shear stress theory

$$\text{Equivalent torque} = \sqrt{652^2 + 1500^2}$$

$$= 1630 \text{ lb.in.}$$

Finishing of the bed(A_1)

The surfaces marked A and B are mutually perpendicular to each other. If they are little inclined then the endplates may not seat and the shaft may be bent, thereby causing the initial stresses in the shaft.

DESIGN OF THE MEASURING APPARATUS

Choice of the gages

The gages were to operate at room temperature and medium stresses. Also they are going to be installed on the curved surface. So paper base gages with high gage factor were used. The specifications are:

Paper base K.W.R. - 5

Resistance in ohms - 120 ± 0.5%

Gage factor - 2.9 ± 2%

Check on the sensitivity of the instrument

Before installing the gages on the shaft, it is essential to calculate theoretically whether the equipment will be sensitive to the minimum load or not. The minimum load has been taken 40 lbs.

If the gain factor of the amplifier and indicater (scope) is c volts/cm. then the number of centimeters on the scope for the torsion gages will be

$$L = \frac{dV_m \times 10^6}{c}$$

$$\text{Where } dV_m = \frac{VR_m\,(GF_1e_1 + GF_3e_3 - GF_2e_2 - GF_4e_4)}{R_m\left(\frac{R_2}{R_3} + \frac{R_3}{R_2} + 2\right) + R_1 + R_2 + R_3 + R_4}$$

Symbols carries usual notations and the bridge circuit shown in Fig. 11 .

Here the resistance of the gages:

$$R_1 = R_2 = R_3 = R_4 = 120 \text{ ohms}$$

and also

$$GF_1 = GF_2 = GF_3 = GF_4 = 2.9$$

and $R_m = 1$ megohm.

Stresses in the shaft

$$= \frac{60 \times 3 \times 64 \times 64 \times 32}{\times 11 \times 61 \times}$$

$$= 1400 \text{ psi}$$

and the strain in the shaft

$$e = \frac{1400}{E}$$

$$\text{also } e_1 = e_2 = e_3 = e_4 = \frac{1400}{E}$$

$$\text{Now } dV_m = \frac{VR_m \quad GFe}{4R_m + 4R_1}$$

$$= \frac{V \times 10^6 \times \frac{4x2.9x1400}{E}}{4(10^6 + 120)}$$

$$= \frac{V \times 2.9}{12x104}$$

wherefrom

$$L = \frac{V \times 2.9 \times 10^6}{12 \times 10^4 \times C}$$

$$= 2.41 \frac{V}{C}$$

1.6. <u>Installation of gages</u>

It has been discussed in the first chapter that in the orthogonal cutting only two forces are significant. The tangential force F_t produces torsion and the bending moment in the shaft and the longitudinal force F_L produces bending moment in the shaft. The force F_t will be measured by measuring the torsion in the shaft. The force F_L will be measured by measuring bending moment in the shaft.

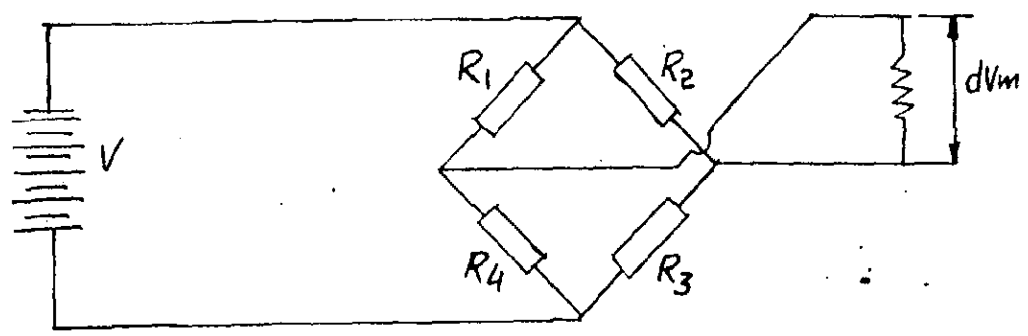
Installation of the bending gage:

The bending gages should be so located that they should measure the bending caused by F_L but should be immune to the bending moment due to F_t. It is clear from the bending moment diagram Fig.(1.2) that bending moment changes its sign. This point of contra-flexure is ¾" from the ends assuming the shaft to be of uniform section and with encastered ends. The gages 1 and 3 are on front side of the shaft and 2 and 3 are on rear.

Suppose the output of each gage due to F_L is X and Y due to F_t. Then the net output of each gage is as follows:

Gage No.	Output.
1	X + Y
2	-X -Y
3	-X + Y
4	X - Y

Now connecting the gages in the bridge as shown:



WHEATSTONE BRIDGE CIRCUIT OF STRAIN GAGES

We see, the output dV_m of the bridge is proportional to:

$$\frac{(X + Y) - (-X-Y) + (X-Y) - (-X + Y)}{4X}$$

which is independent of Y. Hence the gages are insensitive to the force F_t. Moreover, the bending gages are at the neutral axis of the force F_t, hence they will not sense any strain due to this force. The bending gages will also be insensitive to torsion because gages 1 and 2 sense same type of strain and being in the adjacent arms of the bridge, the effect is neglected. Similarly gages 3 and 4 are immune to torsion.

Installation of the torsion gages:

Gages 5, 6, 7 and 8 Fig.(1-2) are torsion once. They are at 45^0 to the shaft axis. All the four gages are parallel to each other. Gages 5 and 7 being on the same helix sense same type of strain . Gages 6 and 8 also sense same type of strain, but opposite to 5 and 7. They are so arranged in the bridge that the net effect is cumulative.

It is essential that the torsion gages should also be insensitive to bending. The bending moment in the shaft is caused by the forces F_t and F_L. For the force F_L, the torsion gages are on the neutral axis, hence they must not be strained. Secondly, as already mentioned, the mid-point of the gage grid is on the top most fibre so the tension and compression caused by F_L as well as F_t should be equal and opposite. So these gages are insensitive to the bending moment due to F_t and F_L.

Temperature Compensation:

The output of the gages should be insensitive to temperature variation. It is assumed that temperature variation is equal in all the gages. Let this change in resistance be ΔR and dR is the change due to strain. Then putting these values in the wheatstone's bridge equation, we have

$$dV_m = \frac{V R_m \left(dR/R_1 + dR/R_3 - dR/R_2 - dR/R_4 \right)}{R_m \left(R_2/R_3 + R_3/R_2 + 2 \right) + R_1 + R_2 + R_3 + R_4}$$

$R_1 = R_2 = R_3 = R_4$ The total change in strain $= \Delta R + dR$

Then

$$dV_m = \frac{V R_m \{ (dR + \Delta R) + (dR + \Delta R) - (-dR + \Delta R) - (-dR + \Delta R) \}}{4 (R_m + R_1)}$$

$$= \frac{V R_m \, dR}{R_m + R_1}$$

Hence the output is independent of temperature variations ΔR

Procedure for installation:

1. The neutral axes for horizontal and vertical bending have been marked with the help of vernier height gage.

2. The surface is cleaned with acetone and then neutralized with a 20% solution of ammonium hydroxide.

3. The gages are trimmed on the outside paper to get them in sizes which can be easily accommodated on the shaft in the windows.

4. The tracing paper template is made and windows are cut for the gages as shown in the Fig. (1.3) .

5. The torsion gages are to be correctly located in the windows both axially and at an angle of 45°. This must receive utmost care otherwise they would not be insensitive to bending moment and axial thrust.

6. Similarly, the bending gages are mounted such that grid axis is at the neutral axis of the shaft.

7. Duco-cement on the gage and the shaft is applied. It is allowed to dry for a minute and then the gage is pressed in position giving slow oscillatory motion to the thumb. Pressure does not exceed 1 lb. otherwise the grid will be damaged.

8. If the surface of the shaft is too smooth the gages will not steck. For this reason the surface should be scratched slightly at the place, where gages are to be cemented.

All the eight gages are fixed in the above manner and the cement is allowed to dry and gages to set.

Connexions of Bridge:

a. The gages are tested for continuity by multi-meter.

b. The bottom of leads is insulated by tape.

c. Now the flexible wires are soldered with the leads. The two leads have also been insulated to each other.

d. These leads are also soldered to the eight pin socket.

e. The scotbh tape is wrapped around the leads on the shaft for mechanical protection.

f. All the gages are numbered.

g. Again the continuity of the gage and the insulation to the ground is checked.

1.7. CALIBRATION

In order to interpret the output voltage in terms of the forces, it is essential that the dynamometer be calibrated in place. The calibration is done by applying known loads and noting the scope deflection for each load, and calibration curve is obtained which is a straight line.

In the present experiment, the maximum force which is anticipated is nearly 1000 lbs. to apply this load a gadget has been designed. Fig. B (Appendix II) shows the assembly drawing. There are two horizontal levers Fig. (B_2 - B_4, Appendix IV) pivoted on ball bearing races and furnished with push rods, which fit between the levers and the calibrating bit, and so placed that when weights are hung on the levers, the push rods transmit to the dynamometer, forces corresponding in direction to the two components (tangential and longitudinal) of the force encountered in cutting operation,and in the intensity to the weight applied multiplied by the distance of the weight to the pivot centre. The vertical and horizontal push rods act at 1" and ¾" respectively from the pivot centre. The levers are provided with V-grooves at 1" spacing over the entire length.

The length of the push rods has been kept minimum to avoid the possiblity of buckling. Ball bearings are provided to minimize the friction.

In cutting operation the load coming on the tool is point load. To conform with the actual cutting conditions, a ball has been put inside the calibrating bit Fig.(2C - Appendix 4).

When the set-up was calibrated for the vertical force, it was observed that some force was also transmitted in the horizontal direction. This may be due to the inclination of the push rod or the friction in the bit and the ball. To avoid this, the ball was placed on the flat surface. The ends of the push rods were also flat. This reduces the friction and also does not check horizontal movement of the ball, thereby, if any force in the horizontal direction is transmitted, can be observed easily.

CHAPTER - II.

EXPERIMENTAL PROCEDURE.

CHAPTER - II.

EXPERIMENTAL PROCEDURE.

Description of Apparatus: (2.1.)

1. Lathe:- The lathe used for the test work is a 0.6 hp. machine. It has only six speeds. Due to small hp. of the machine, the tests could not be carried to the higher range. The lathe is manufactured by Parmar & Co. Rajendra-Nagar.

2. Tepic strain indicator:- This portable wheatstone bridge is intended for determining static and dynamic strains when used with resistance strain gages of any make having a resistance of 100 to 1000 ohms and a guage factor of 2.0 to 4.0. The scale of the instrument reads directly in units of strain.

The instrument has three working ranges:

1. Static
2. Dynamic (1)
3. Dynamic (2)

Dynamic (1) is more sensitive and used for measuring small strains. Knob No.9 Fig.(2.1) has got these ranges.

3. Oscilloscope:- As the nature of the forces is dynamic, the strain indicator alone could not be used. The output of the strain gages from the Tepic indicator was fed to the dual beam oscilloscope. It has make "Tektronix type 502" and sensitivity from 20V/cm. to 200 V/cm.

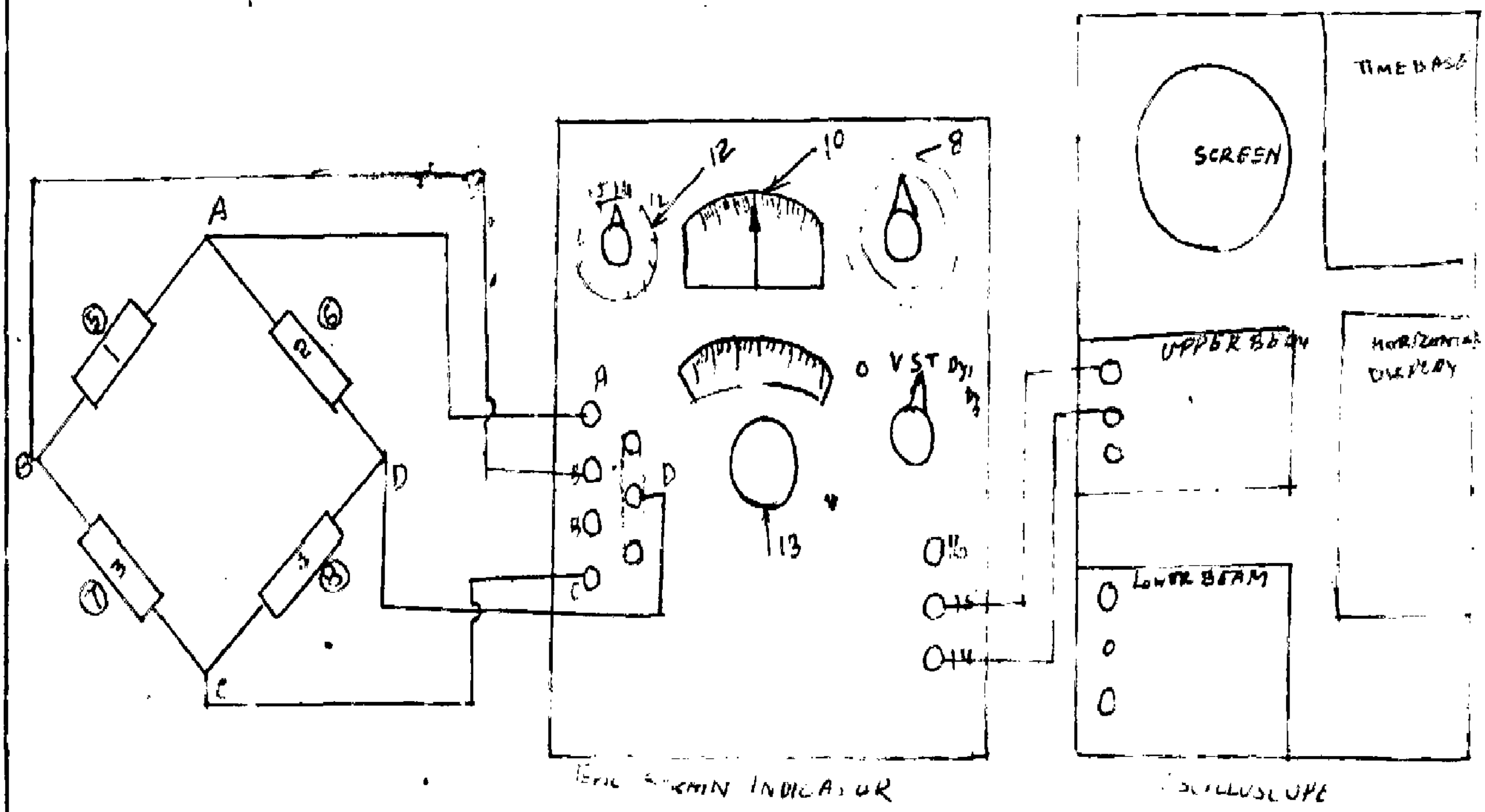


FIG- 5-1 BRIDGE CIRCUIT . FOR MEASUREMENT OF THE FORCES

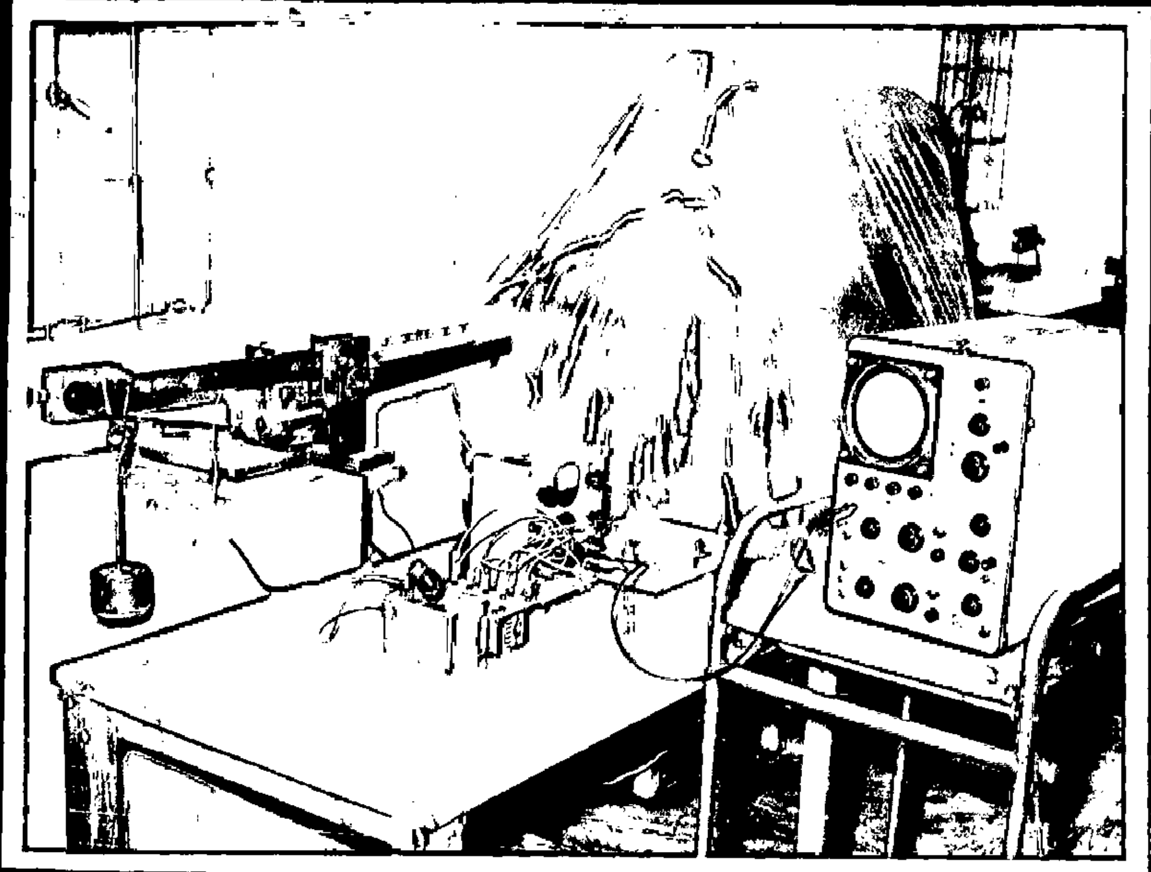


FIG. 2. Dynamometer On Calibrating Rig.

2.2. <u>Calibration</u>

1. The test equipment is put on the calibration rig. The strain gages are connected as shown in Fig.(2.1) . The output leads are connected at A, B, C and D Fig(2.1)

2. The power supply is checked by turning knob No.9 to the position 'V'. The needle must then be within green line of the scale 10.

3. Knob No.8 is turned to gage factor value 2.9.

4. Connector No. 6 is removed.

5. Before loading, the potentiometer reading is turned to 1.0 and the range extension switch No. 12 to position 14. If now the pointer of the galvanometer is on the right, the range switch is turned to left.

6. After this adjustment by means of range No. 12 we proceed for fine adjustment. Precision potentiometer No. 13 has two knobs, one above the other. The lower is for rapid adjustment, the upper for final accurate adjustment.

7. Now the Knob No. 9 is turned to the position Dynamic (1).

8. Now terminals 14 and 15 are connected to the upper beam of the oscilloscope.

9. Now the calibration rig is loaded and the scope beam deflection is noted correspondingly.

Before calibrating the torsion gages, the sensitivity of the gages was checked for the horizontal force. It was done by turning the set-up at right angle and holding it in the benchvice. Then static loads were applied. It was observed that cross-sensitivity was 8%

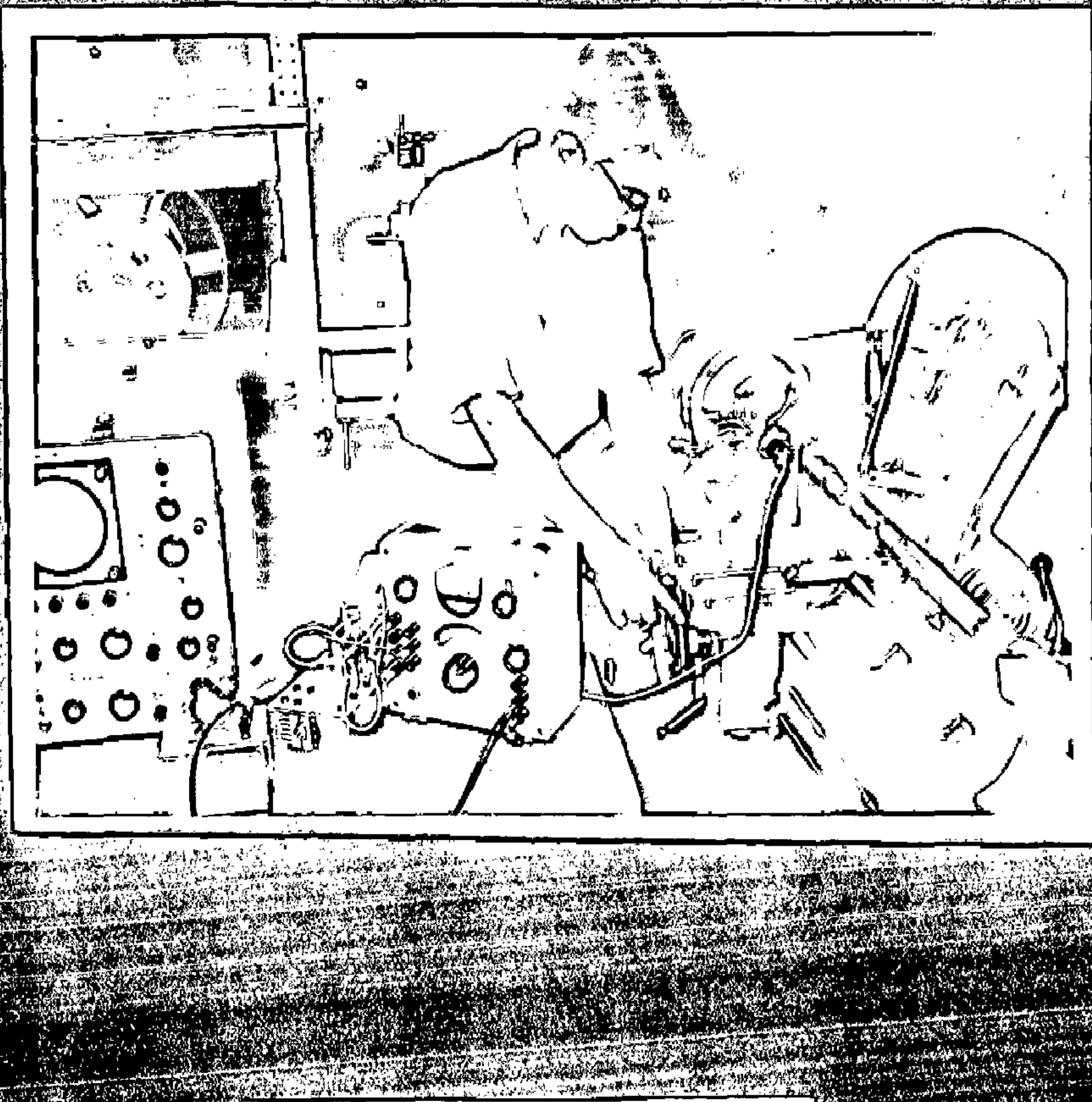


FIG. 3. Dynamometer On Lathe.

which is permissible.

Similarly the bending gages were checked for vertical load. They had nearly 40% cross-sensitivity. The gages were placed at many places but no satisfactory result was achieved. It gave very tough time but with no results. Hence it was advised to measure only one force. The reason for this discripancy may be, the shape of the theoretical and actual bending moment diagram is very much different. From the data recorded for the vertical force, a calibration curve is drawn (Graph 1). Table 3.1 gives the calibration values.

2.3. Testing

The gages were connected to the strain indicater and the output from the indicater was fed to the scope. Then the lathe was started, observations were recorded for various depths of cut, feed and the speed for mild steel rod of 1.25" dia. and 30" long. While recording the observation for variable depth of cut, the speed and feed were kept constant. Similarly the test was repeated for the remaining two variables. The test was carried on castiron for variable depth of cut. The observations were recorded by means of photographs. These observations are tabulated in chapter III. The physical properties of the material were determined (Appendix 2). Then with the help of calibration curve and the tabulated values of the observations the tangential force is calculated. Now the graphs (3.2, 3.3, 3.4 and 3.5) were plotted in tangential force and machine variables (depth of cut feed and speed), on log-log paper.

Speed:- To know the speed of work piece, the rpm of the lathe spindle were measured by means of mechanical tachometer and the speed is calculated.

Feed:- The lathe is provided with the following change gears:

(25, 30, 40, 40, 45, 50, 55, 57, 60, 65, 70, 75, 80, 90, 100, 127)

The lead screw has six threads per inch. For various combinations of change gears different feeds were calculated.

Depth of cut:- It was measured directly on the scale of the cross-slide. It gives the reading in thousands of an inch.

CHAPTER - III.

EXPERIMENTAL RECORD AND DATA ANALYSIS.

CHAPTER - III.

EXPERIMENTAL RECORD AND DATA ANALYSIS

3.1. Observations:-

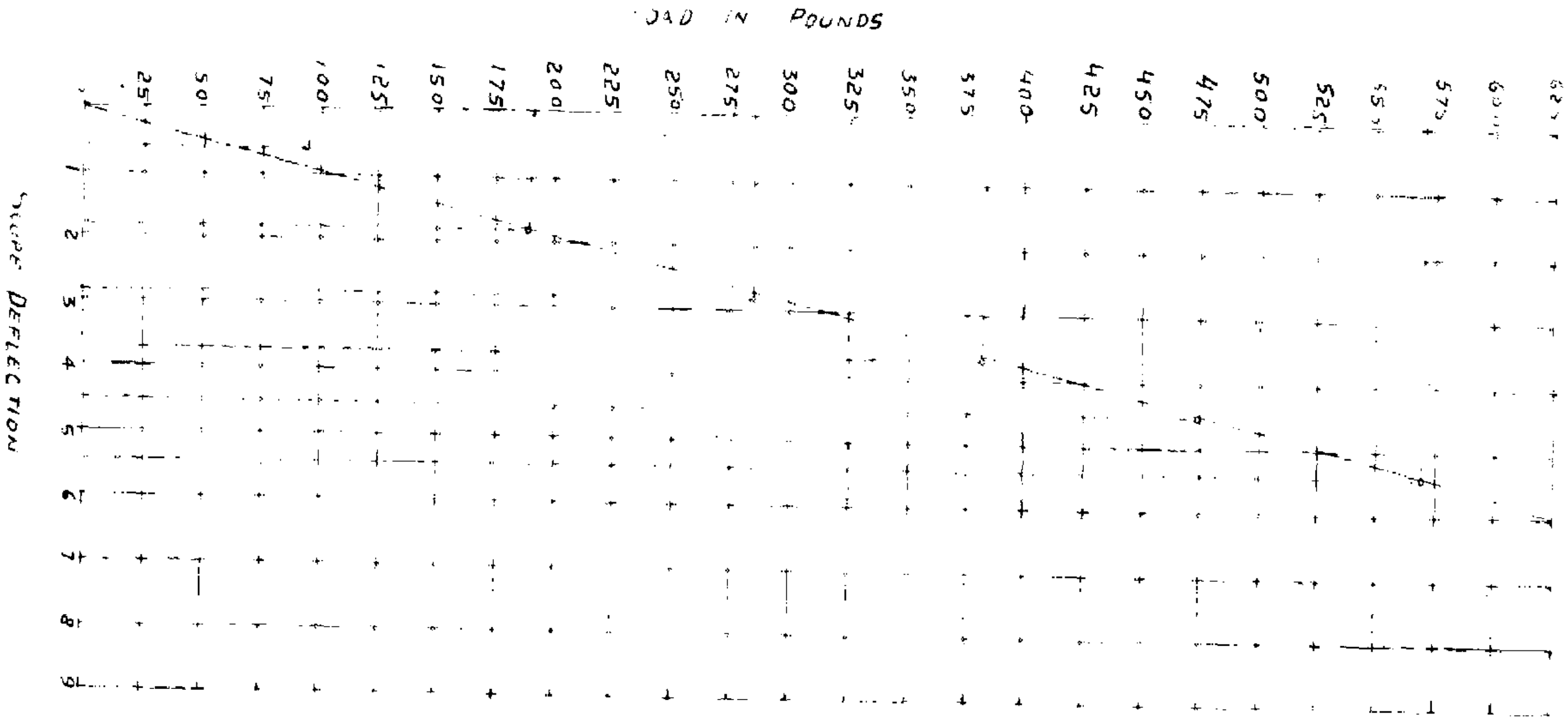
The test results are tabulated as follows:

Table 3-1.

Scope sensitivity - 20 mV/cm.

Indicator range - Dynamic (1)

Load in lbs.	95	190	285	380	475	570	665
Scope beam diflection in cms.	0.6	1.8	22.8	3.7	4.5	5.4	6.3



CALIBRATION GRAPH FOR TANGENTIAL FORCE COMPONENT

SENSITIVITY - 20mv/cm

Table 3-2.

Work material - Mild steel % carbon - 0.232

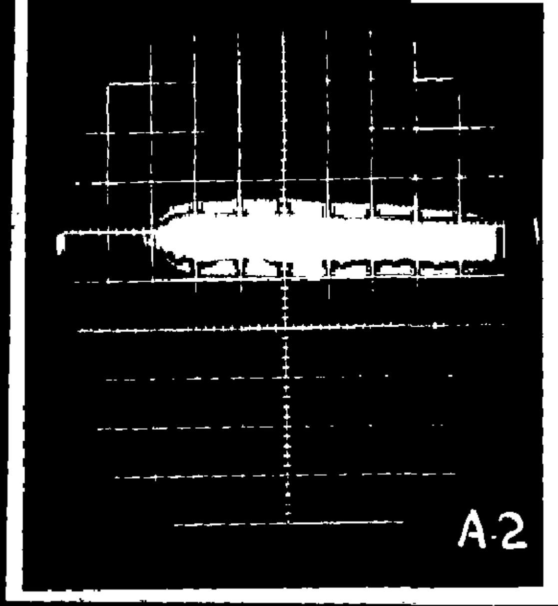
Yield strength - 16.4 tsi speed -

Feed - 0.031IPR Cutting fluid - AIR

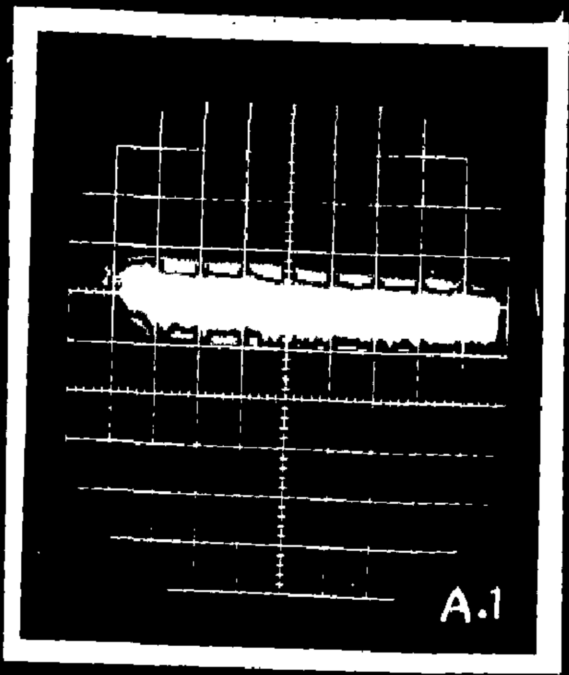
Tool material - High speed steel.

Tool Geometry - $80^\circ - 14^\circ - 6^\circ - 6^\circ - 6^\circ - 0^\circ - 3/64^\circ R$

Photo No.	A1	A2	A3	A4	A5	A6	A7
Scope sensitivity	10mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm
Zero position of beam.	4cm from bottom	4cm from bottom	4 cm from bottom	4cm from bottom	4cm from bottom	4cm from bottom	4cm from bottom
Depth of cut in thous	10	20	40	50	60	80	90
F_t in lbs.	78	132	227	262	282	370	390
Scope beam diflection	1.4	1.3	2.2	2.5	2.7	3.5	3.7



A.2



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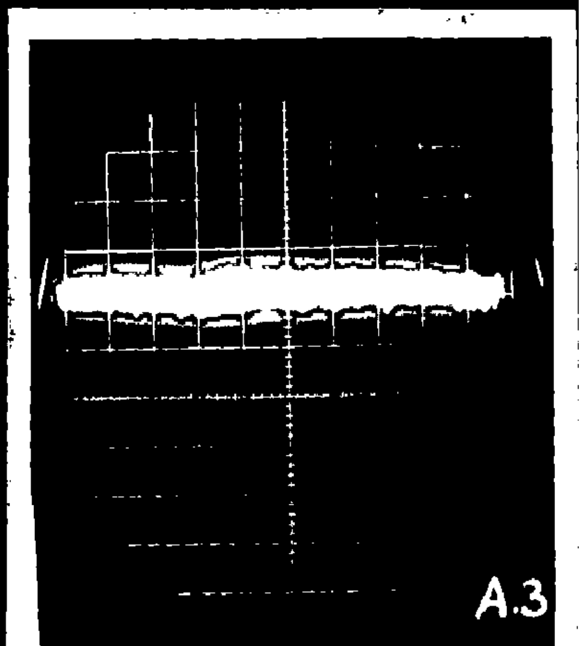
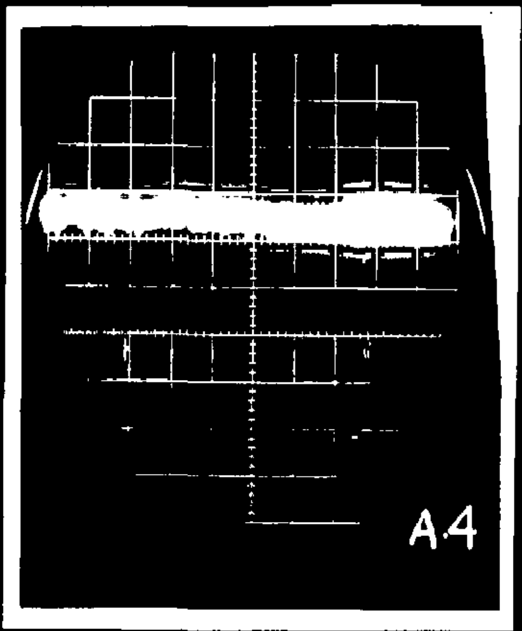
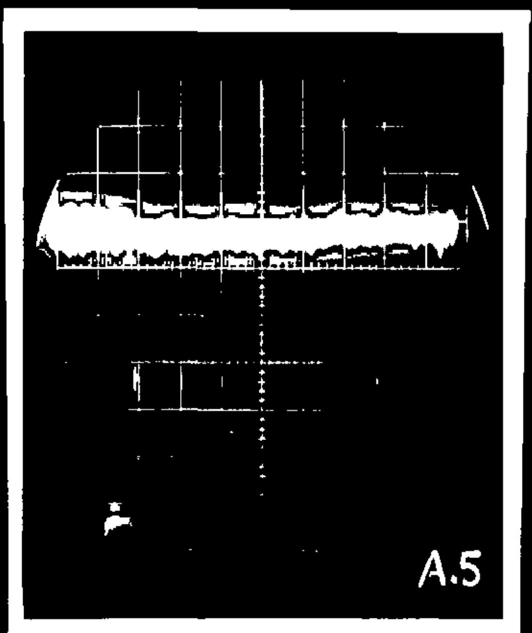


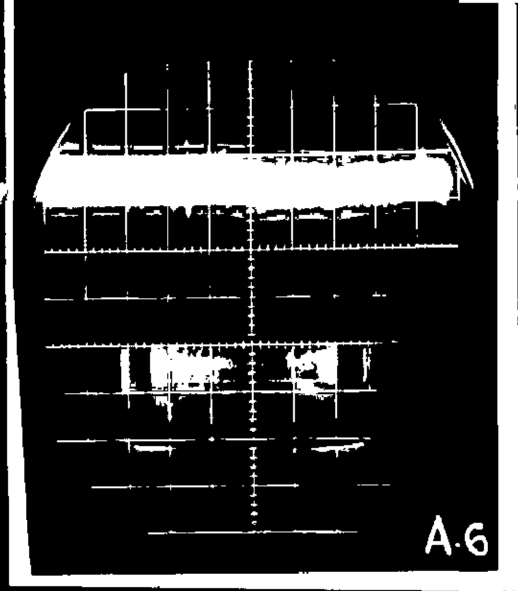
A.3



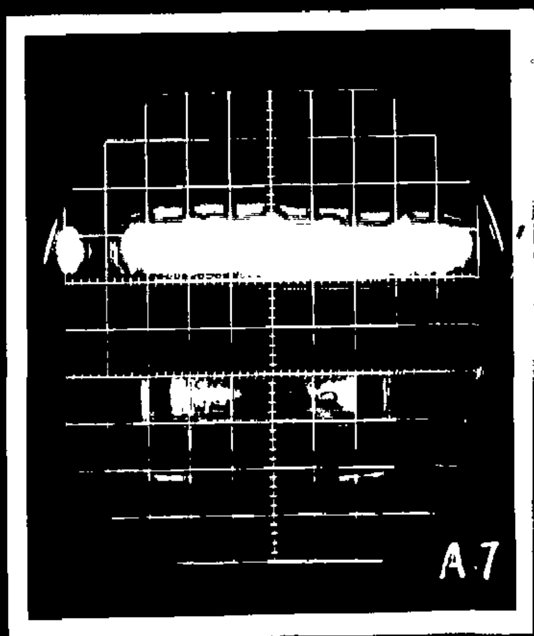
A·4



A.5



A·6



A·7

TABLE - 3-3.

Work material - cast iron. % carbon 3.09.

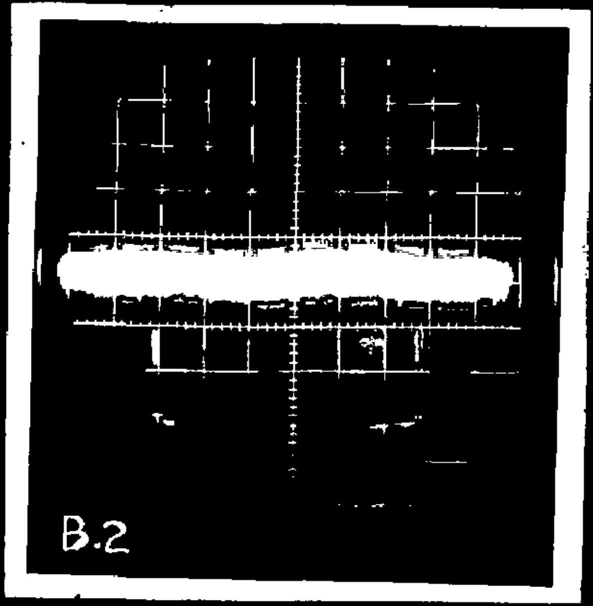
Ultimate strength - 11.2 tsi Cutting fluid - Air.

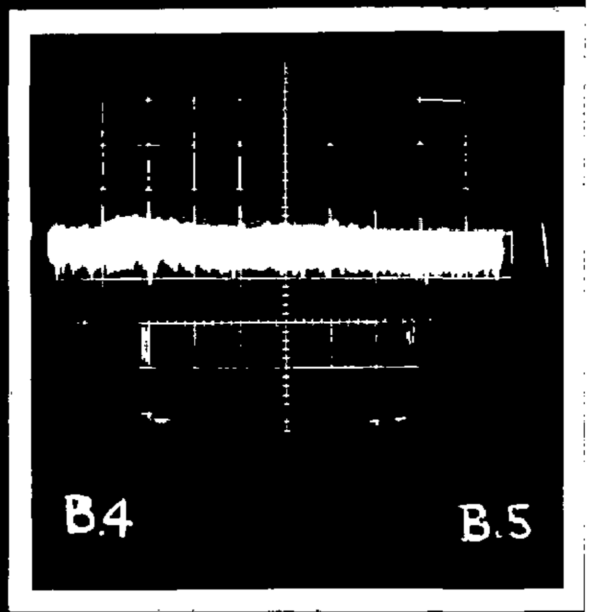
Speed 21.0 fpm. Feed -0.31 IPR.

Tool Material - High speed steel.

Tool Geometry - $8^\circ - 14^\circ - 6^\circ - 6^\circ - 6^\circ - 0^\circ$ - 3/64R

Photo No.	B_2	B_3	B_4	B_5	B_6	B_8
Scope Sensitivity	20mV/cm.	20mV/cm.	20mV/cm.	20mV/cm.	20mV/cm.	20mV/cm.
Zero position of beam.	4cm from top	4cm from bottom	4cm from bottom	4cm from bottom	4cm from bottom	4cm from bottom
Depth of cut in Thous.	20	40	60	80	100	140
Scope beam disp.	1.0	1.5	1.7	2.2	2.5	3.2
F_t in lbs.	100	157.5	175	227.5	262	332


B.2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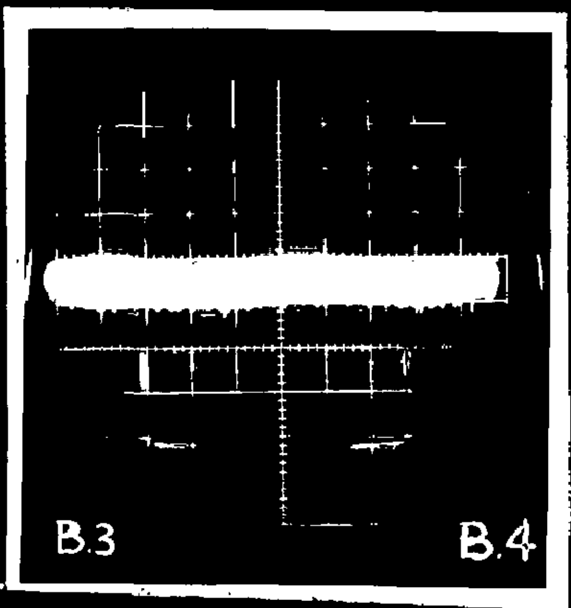
B.5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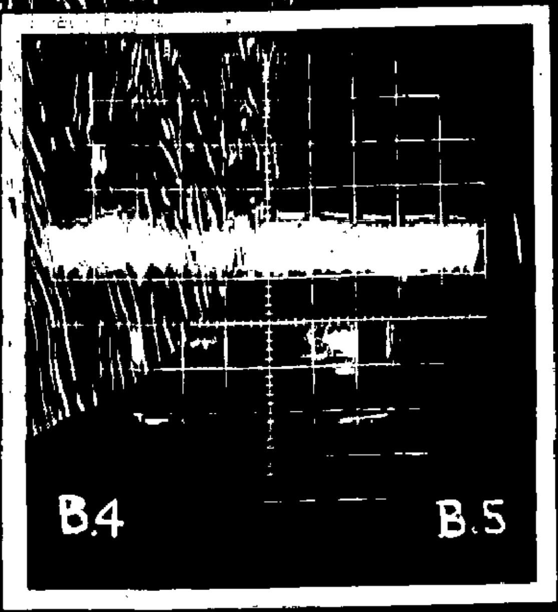
B.4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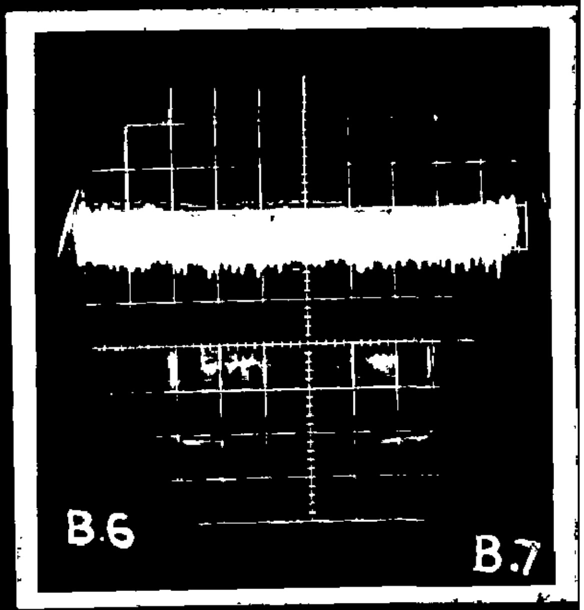
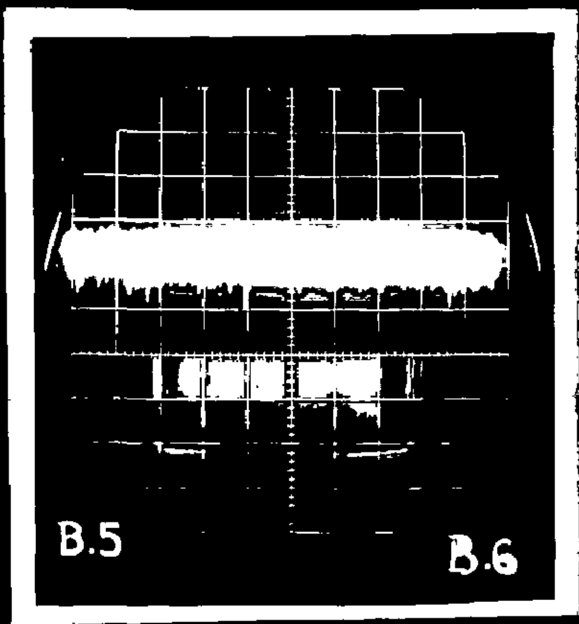
B.5


B.6
B.7


B.5
B.6

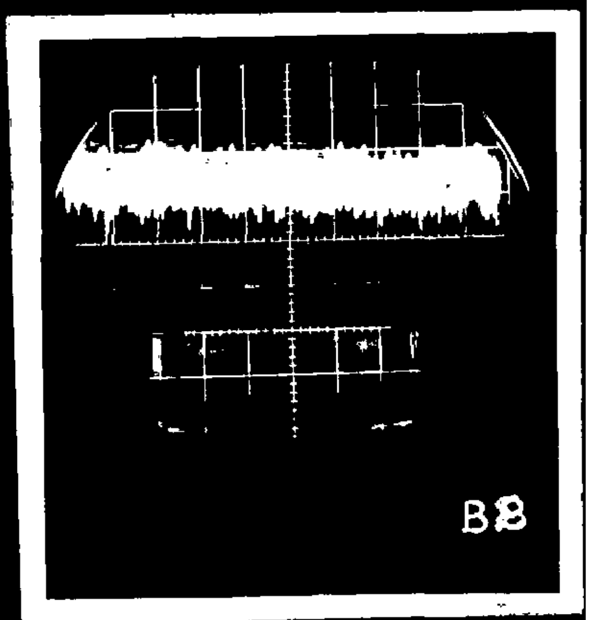

B8

TABLE 3-4.

Work material - Mild steel   % carbon 0.232

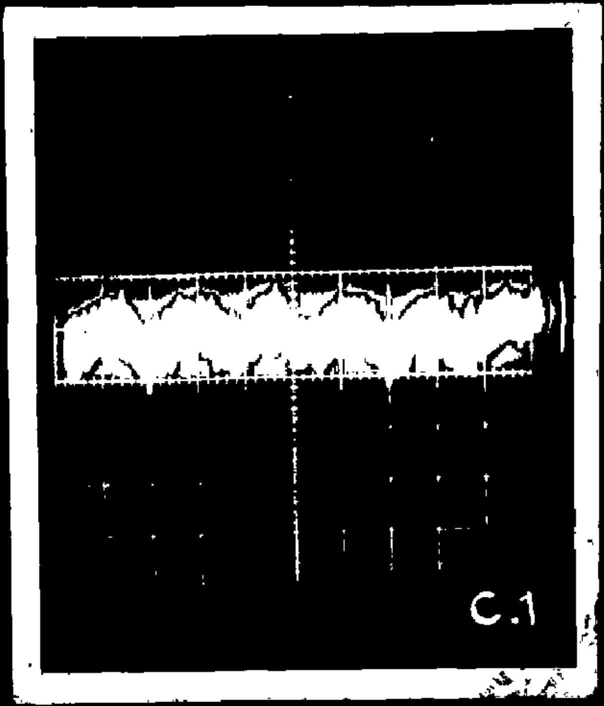
Yield strength 16.4 tsi   Cutting fluid Air.

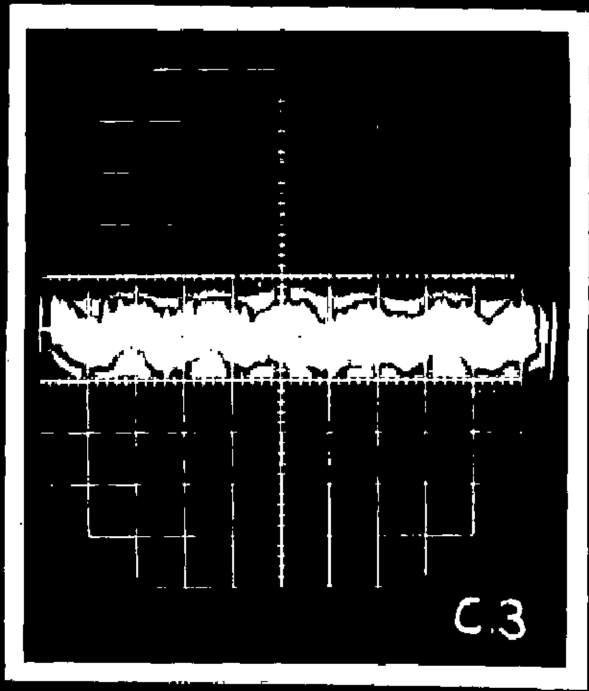
Speed 13 fpm   Depth of cut 0.03"

Tool material High speed steel

Tool Geometry - $8^{\circ} - 14^{\circ} - 6^{\circ} - 6^{\circ} - 6^{\circ} - 0^{\circ}$ - 3/64R

Photo No.	C_5	C_4	C_1	C_6	C_2	C_3	C_7
Scope sensitivity	20mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm
Zero position of beam.	4cm from top	3cm from top	4cm from top	4cm from top	4cm from top	3cm from top	3cm from top
Feed IPR	0.0175	0.0246	0.0375	0.0416	0.05	0.0555	0.0666
Scope beam dipp.	0.6	0.9	1.2	1.6	1.6	2.1	2.8
F_t lbs.	60	90	125	167	167	217	292


C.1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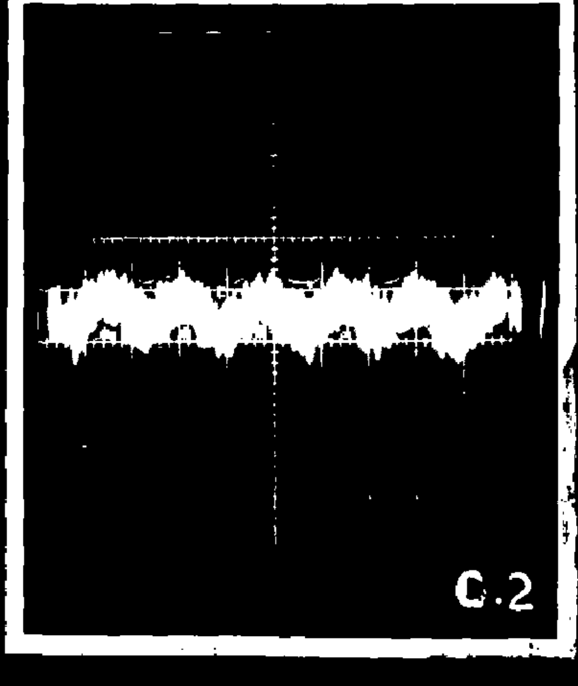
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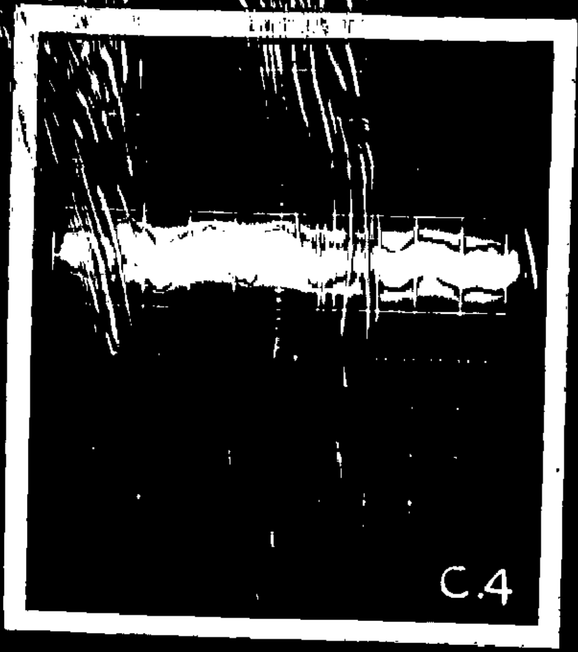
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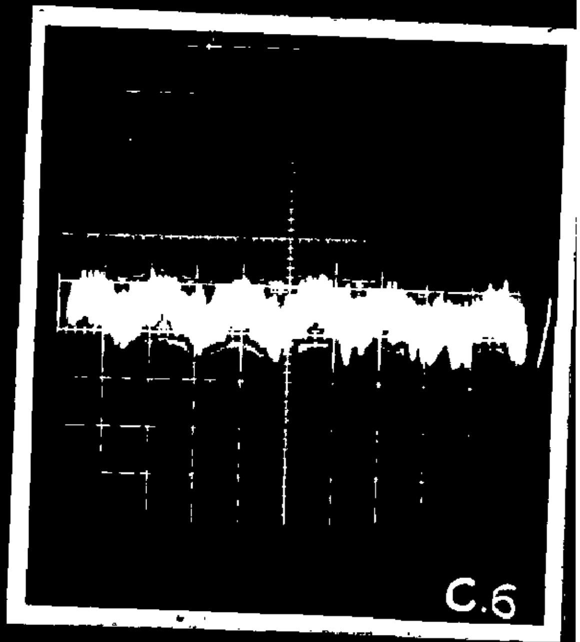
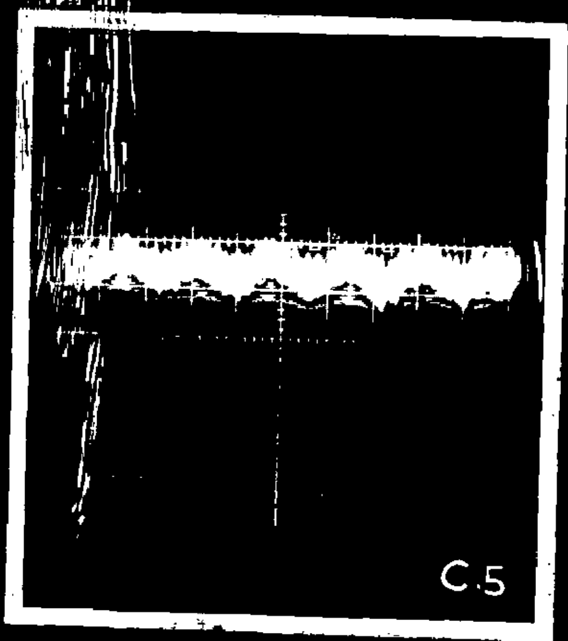

C.6


C.5

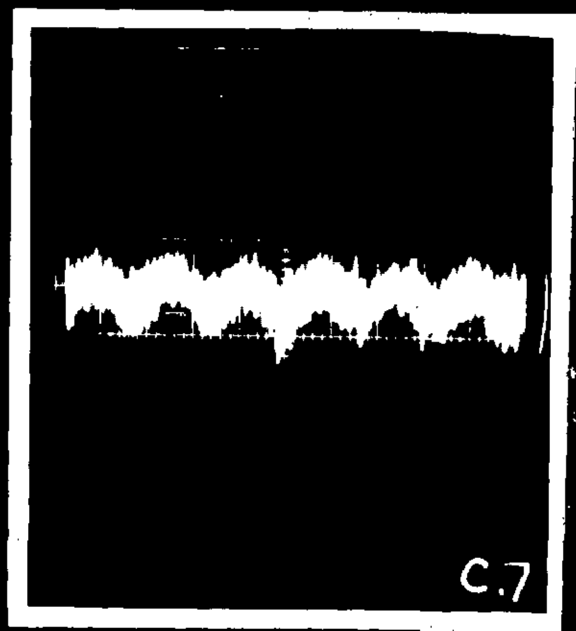

C.7

TABLE 3-5.

Work material - Mild steel   % carbon 0.232

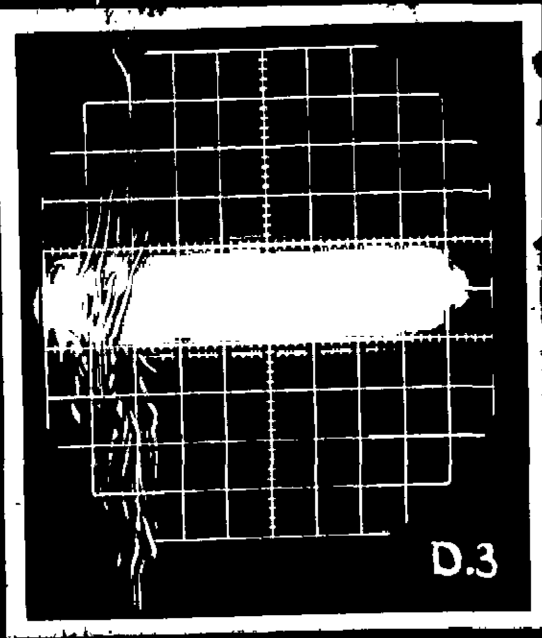
Yield strength 16.4 tsi   Cutting fluid Air

Feed 0.0246 IPR   Depth of cut 0.01"

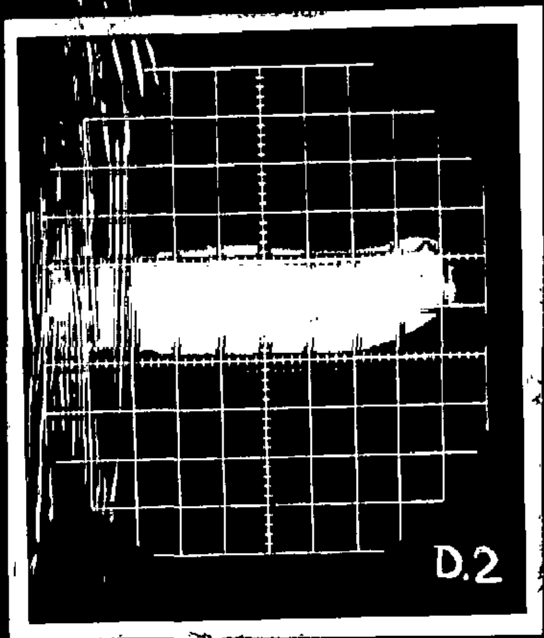
Tool material - High speed steel

Tool Geometry - $8^{o} - 14^{o} - 6^{o} - 6^{o} - 6^{o} - 0^{o}$ - 3/64R

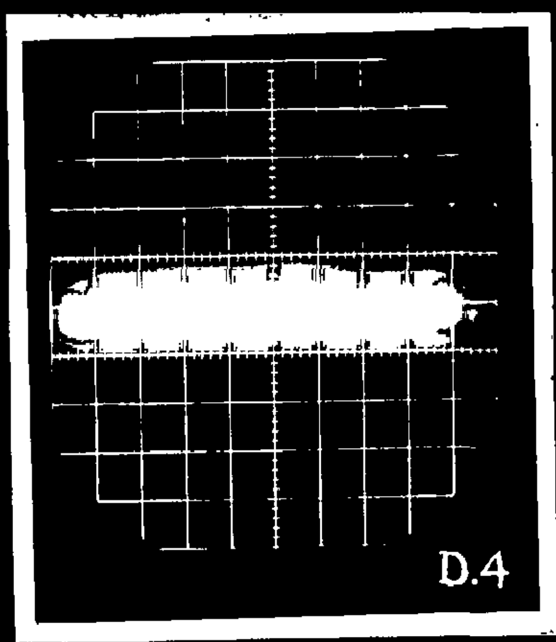
Photo No.	D_8	D_2	D_3	D_4	D_5	D_6
Scope sensitivity	20mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm	20mV/cm
Zero position of beam	4cm from top	4cm from top	4cm from top	4cm from top	4cm from top	4cm from top
Speed fpm	9.1	13.2	21.4	59.0	91.0	147.5
Beam displacement cm.	0.5	0.7	1.0	1.2	1.5	1.7
F_t in lbs.	50	70	100	120	155	175



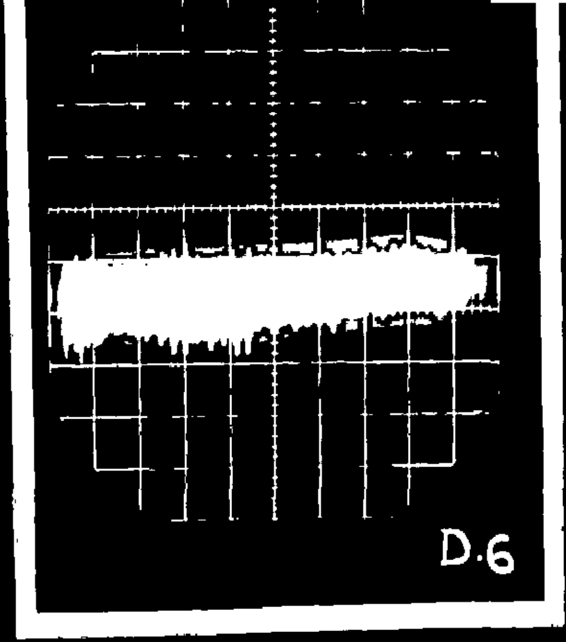
D.3



D.2



D.4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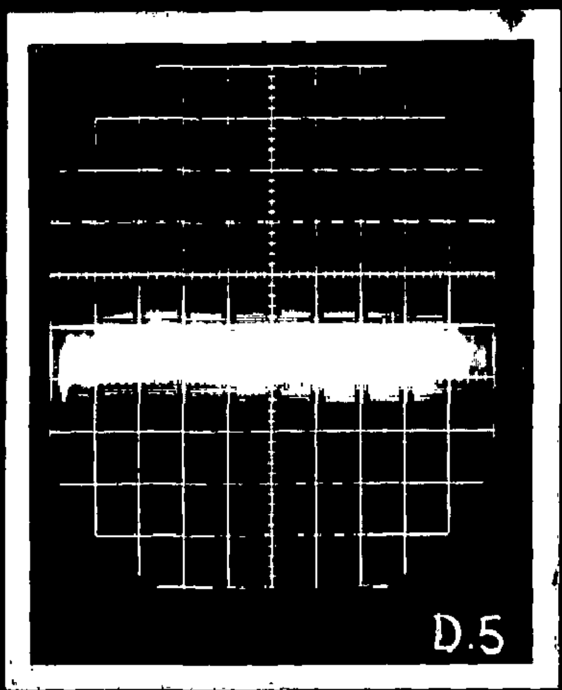
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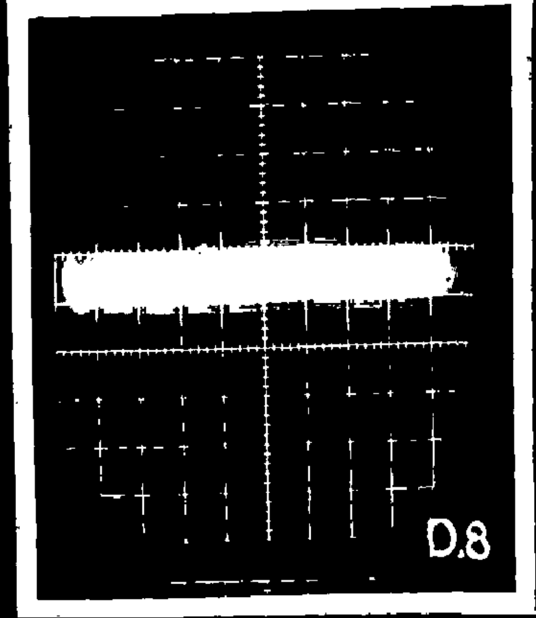

D.8

ANALYSIS

Graphs:- Tangential force versus depth of cut, feed and speed graphs are plotted in the log-log paper (Graph 2, 3, 4 & 5). It is clear that the graph is more closely to straight line. So from here we can draw the conclusion that some relation exists in force, feed and depth of cut. The relation between these quantities can be established analytically.

From the graph it is clear that relation in these variables is of exponential nature. This can be shown as:

$$F = Cf^a d^b \qquad (1)$$

where

F = Tangential force

K = Constant

f = feed I.P.R.

d = depth of cut in inches

a & b = Constants to be determined analytically

For the first case when f is constant F varies with d equation (1) can be written as:

$$F = K_1 d^b \qquad (2)$$

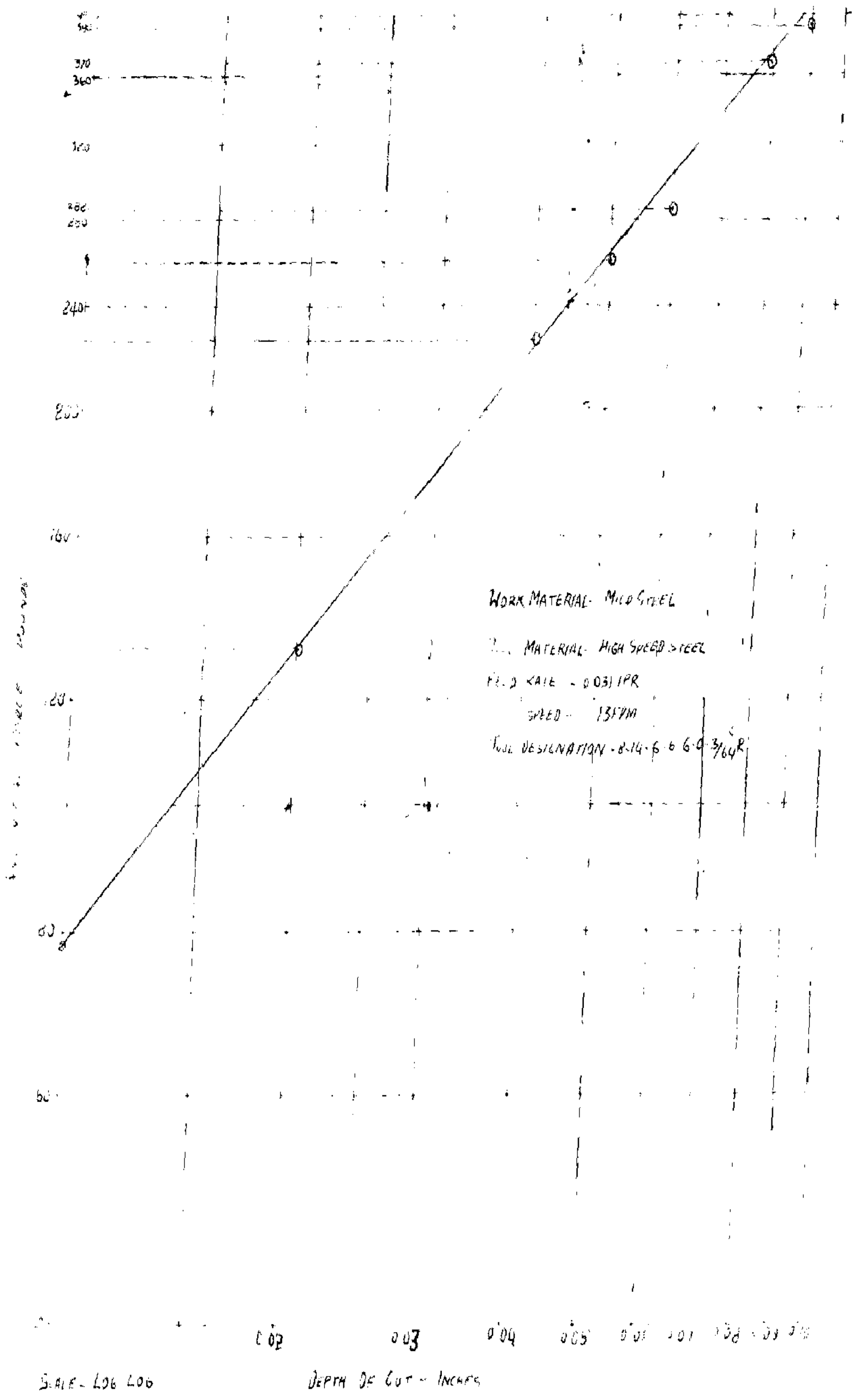
(Where $K_1 = Cf^a$ = Constant)

Equating the logarithms of both side of equation (2), we have

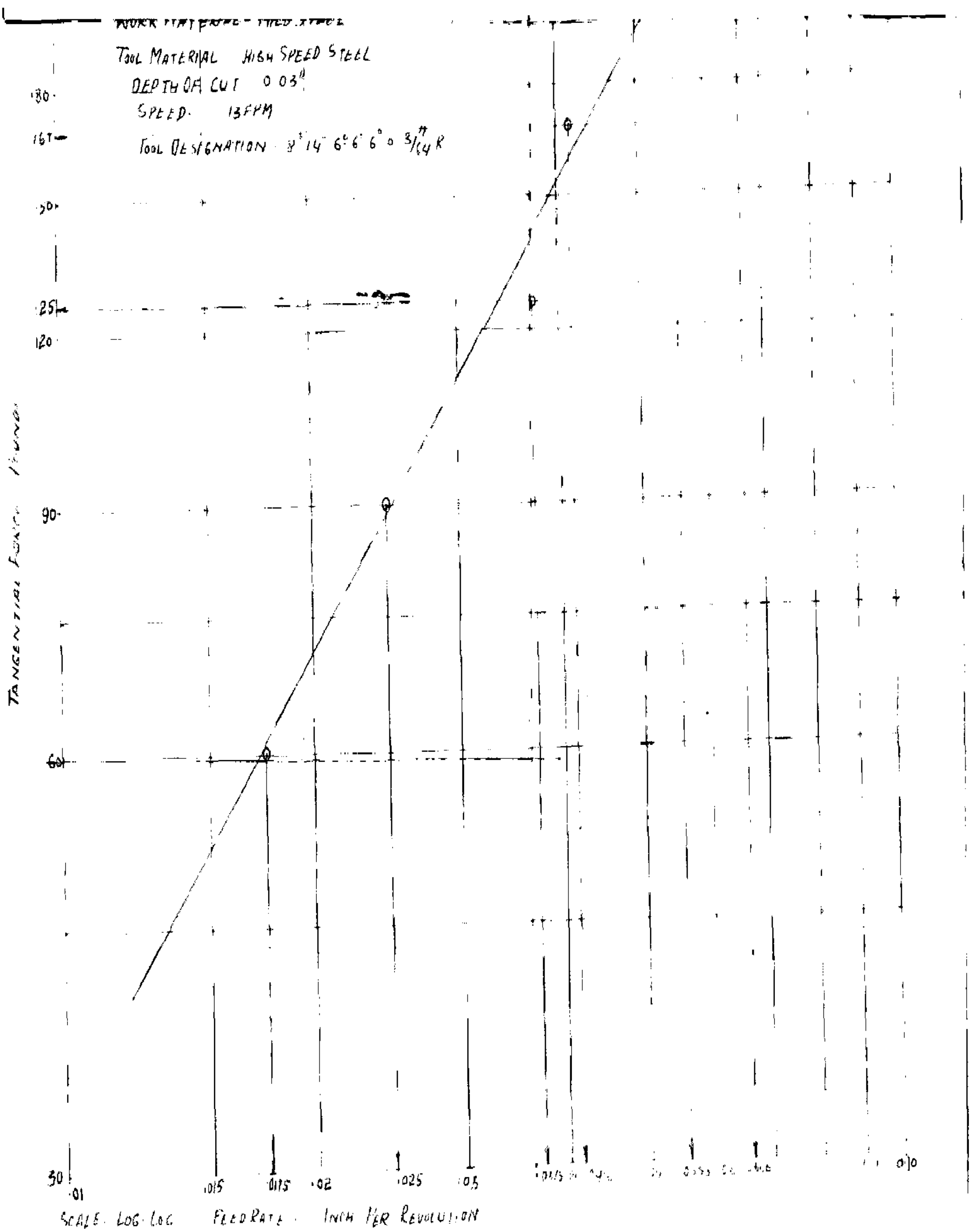
$$\text{Log } F = \text{Log } K_1 + b \text{ Log } d$$

Let this equation be as

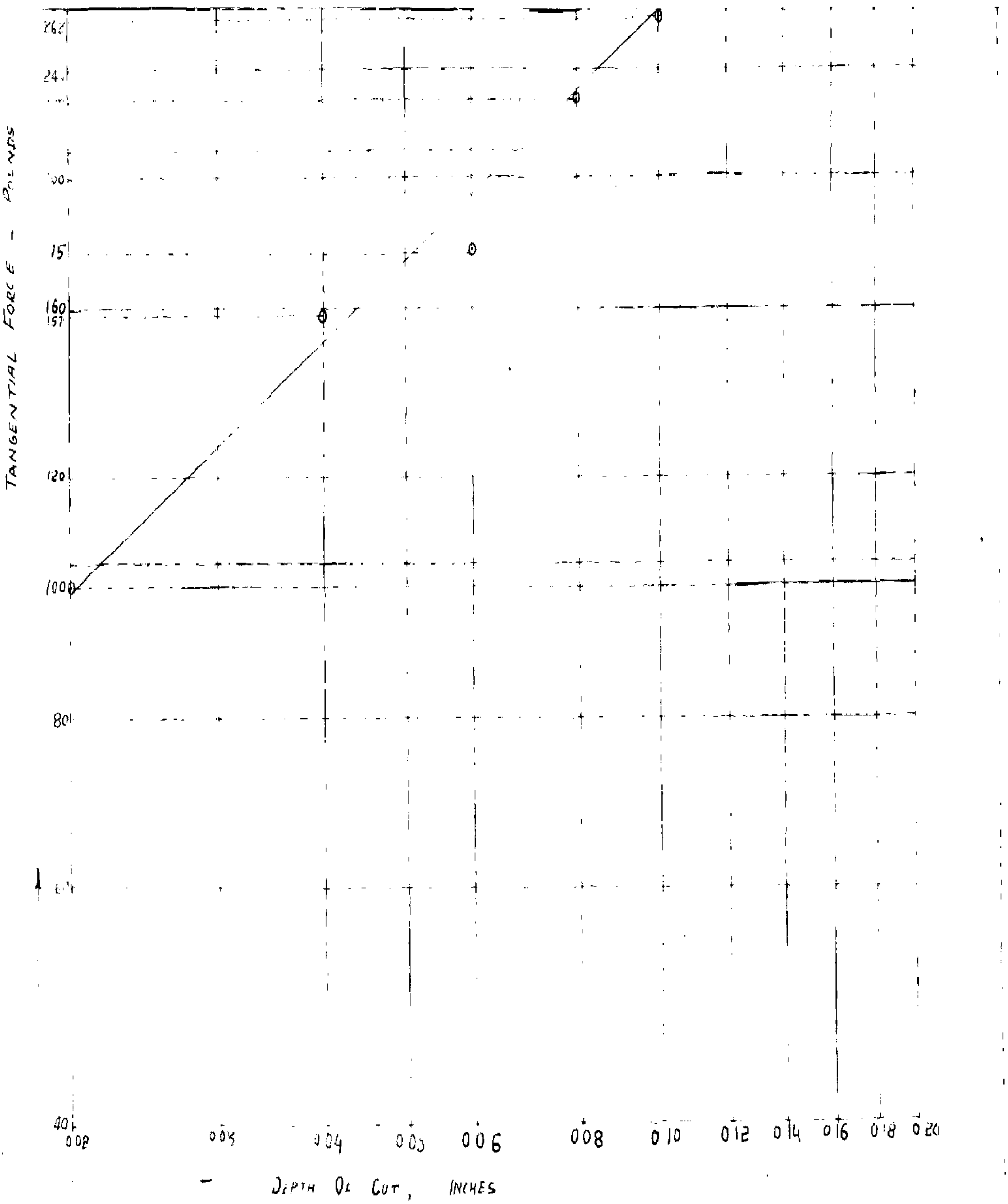
$$Y = A + BX \qquad (3)$$



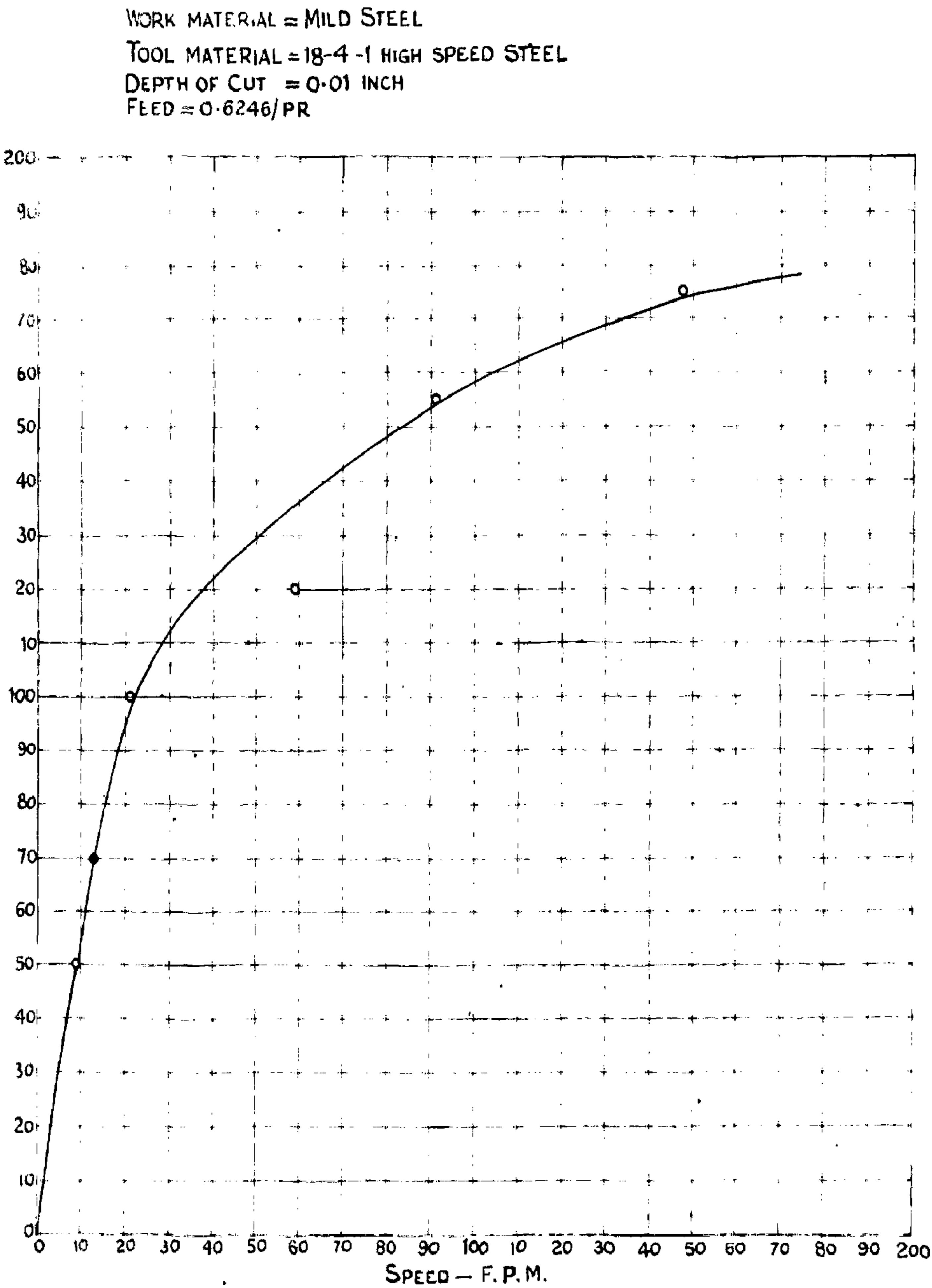
WORK MATERIAL- MILD STEEL
TOOL MATERIAL- HIGH SPEED STEEL
FEED RATE - 0.031 IPR
SPEED - 135FPM
TOOL DESIGNATION - 8-14-6-6-6-0-3/64R
0.02
0.03
0.04
0.05
SCALE - LOG LOG
DEPTH OF CUT - INCHES
240
200
160
120
80
60



GRAPH 3 EFFECT OF FEED RATE ON TANGENTIAL FORCE AT CONSTANT SPEED AND DEPTH OF CUT



LOG LOG GRAPH 4 EFFECT OF DEPTH OF CUT ON TANGENTIAL FORCE AT CONSTANT FEED AND SPEED



GRAPH 5. EFFECT OF SPEED ON TANGENTIAL FORCE KEEPING SPEED AND FEED CONSTANT

Where

$Y = \text{Log } F$

$A = \text{Log } K_1$

$B = b$

$X = \text{Log } d$

In order that this straight line equation be the best estimate of the data, the values of A & B should be such that the sum of the squares of the deviations of the actual values of Y in the distribution from their estimates given by the equation (3) should be minimum. This can be put as follows:

$(Y_1 - A - BX_1)^2$ should be minimum.

In order to satisfy this condition the differential coefficients of this expression with respect to the constants A & B should be respectively zero, as given by equations (4) & (5):

$$Y_1 - A - BX_1 = 0 \qquad (4)$$

$$Y_1X - AX - BX_1^2 = 0 \qquad (5)$$

Now the required values of X, Y, XY, X^2 are calculated for every set of values of F & d and their sum found as shown in Table I.

Substituting the values of X, XY, Y & X^2 from Table 1 in equation (4) & (5) we have

$$7A + 11.23754B = 16.39650$$

$$11.23754A + 18.74840B = 26.84212$$

From solving these two simultaneous equations values of A & B obtained are

$A = 1.16388$, $B = 0.73409$

TABLE I

d Inch	d Thous.	F	Log d[1] X	Log F Y	XY	X^2
0.01	10	78	1.00000	1.89209	1.89209	1.00000
0.02	20	132	1.30103	2.12057	2.75893	1.69268
0.04	40	227	1.60606	2.35603	3.77450	2.56660
0.05	50	262	1.69897	2.41830	4.10862	2.88650
0.06	60	282	1.77815	2.45025	4.35691	3.16182
0.08	80	370	1.90309	2.56828	4.88752	3.62175
0.09	90	390	1.95424	2.59106	5.06355	3.81905
Total ...	...		11.23754	16.39650	26.84212	18.74840

TABLE II

6

f IPR	f' = 1000f	F	Log f' X	Log F Y	XY	X^2
0.0175	17.5	60	1.24304	1.77815	2.21031	1.54515
0.0246	24.6	90	1.39093	1.95424	2.71821	1.93469
0.0375	37.5	125	1.57403	2.09691	3.30060	2.47757
0.0416	41.6	167	1.61909	2.22272	3.59878	2.62145
0.0500	50.0	167	1.69897	2.22272	3.77633	2.88650
0.0555	55.5	217	1.74429	2.33646	4.07546	3.04255
0.0666	66.5	292	1.82347	2.46538	4.49555	3.32504
Total ...	...		11.09382	15.07658	24.17524	17.83295

From which the resulting equation can be written:

$$Y = 1.16388 + 0.73409\ X$$

Or

$$\mathrm{Log}_{10}\ F = 1.16388 + .73409\ \mathrm{Log}_{10}\ d'$$

Now on replacing d' by d we have -

$$\mathrm{Log}_{10}\ F = 1.16388 + 0.73409\ \mathrm{Log}_{10}\ (1000\ d)$$

Which finally comes out to be

$$\mathrm{Log}_{10}\ F = 3.36615 + \mathrm{Log}_{10}\ d^{0.73409}$$

On taking Anti-Log of both sides we get:

$$F = 2323.6\ d^{0.73409} \qquad (6)$$

Similarly writing the equation for F & f we get the equation:

$$F = K_2 f^a$$

Again taking Log of both sides

$$\mathrm{Log}\ F = \mathrm{Log}\ K_2 + a\ \mathrm{Log}$$

Again writing the equation in the form of

$$Y = A + B\ X$$

Now putting the values of X, Y, XY, X^2 from Table II in the equation 4 & 5 we have

$$11.09382\ A + 17.83295\ B = 24.17524$$

$$7.00000\ A + 11.09382\ B = 15.07658$$

On solving these two simultaneous equations, values of A & B are:

$$A = 0.37782$$

$$B = 1.12061$$

On substituting the values of A & B in the parent equation, we have

$$Y = 0.37782 + 1.12061\ X$$

Or

$$\text{Log}_{10} F = 0.37782 + 1.12061 \text{Log}_{10} f'$$

On changing f' to f the above equation changes to:

$$\text{Log}_{10} F = 3.73965 + 1.1206 \text{Log}_{10} f$$

On taking Anti-Log of both sides the final equation becomes:

$$F = 5491.0 \; f^{1.12061} \qquad (7)$$

From the equation (6) & (7) we can write that:

$F \propto d^{0.73409}$

and also

$F \propto f^{1.12061}$

So F is also proportional to product of two i.e.

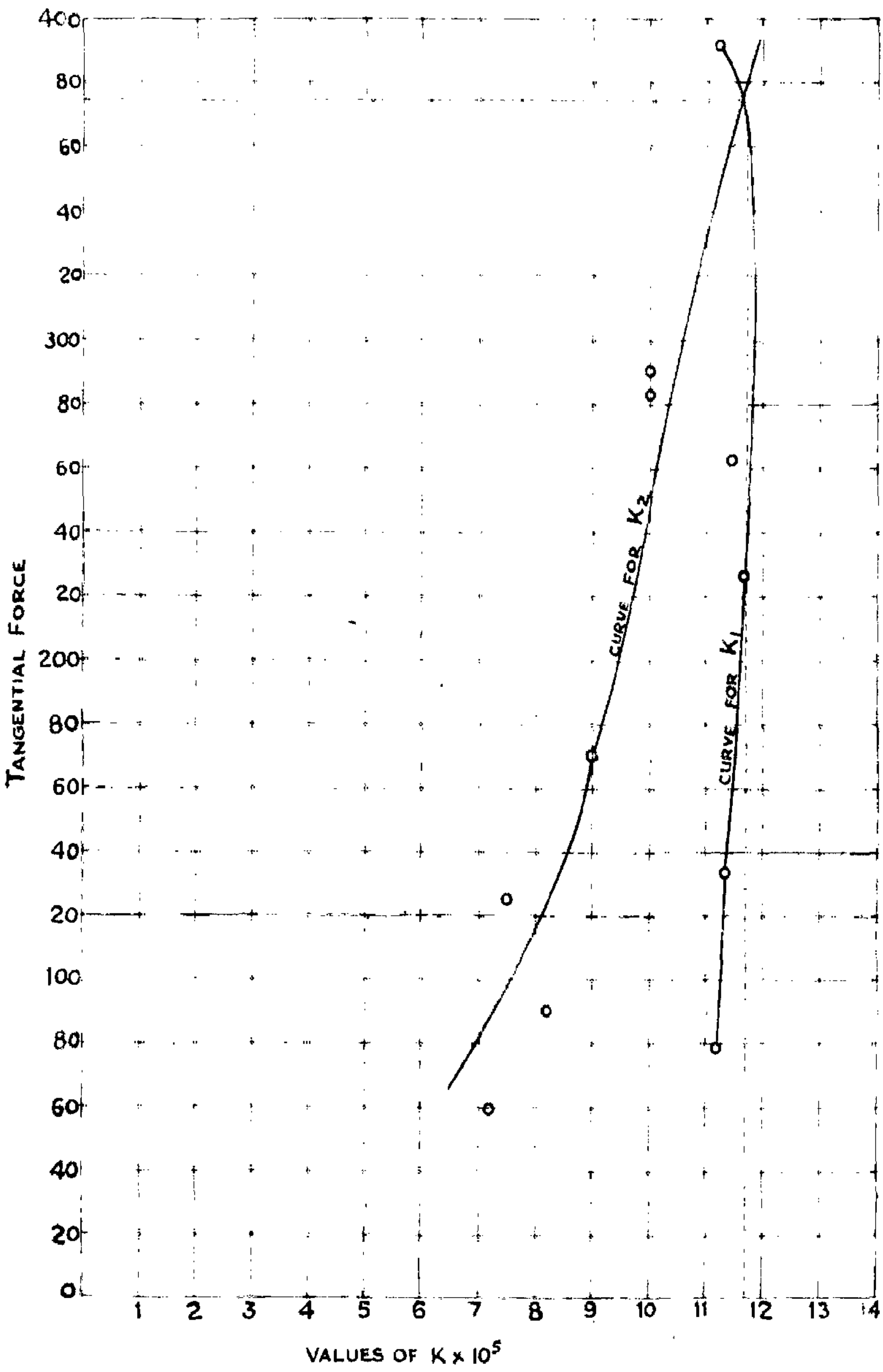
F is proportional to $d^{0.73409} \; f^{1.12061}$

On changing the sign of proportionality to equality the above equation changes to :

$$F = K \, d^{0.73409} \; f^{1.12061} \qquad (8)$$

Now we are interested to determine the value of this K. From tables (3.2) & (3.4) knowing values of F, d and f and putting these in equation (8) value of K may be determined. Vakious values of K_1 are found from table (3.2) and K_2 from table (4). They are given in tables (3.5) & (3.6).

Now we have to find the value of K which is agreable to both tables. This is done by plotting the values of K_1 & K_2 as abscissa and F as the ordinate (Graph 6). These two curves cut at the point and this value of K is accepted. The value of K is 117000. Hence



GRAPH-6 DETERMINATION OF VALUE OF PROPORTIONALITY CONSTANT K the emperical equation comes out to be:

$$F = 117000\, f^{1.12061}\, d^{0.73409}$$

TABLE (3.5)

d in Thous.	10	20	40	50	60	80	90
F in lbs.	78	132	227	262	282	370	390
K_1	112200	114200	118600	116100	100900	116700	112000

TABLE (3.6)

f	.0175	.0246	.0375	.0416	.0555	.0666
F	60	90	125	167	217	292
K_2	71800	81900	74700	89900	88400	98200

CHAPTER - IV.

DISCUSSION OF RESULTS AND CONCLUSIONS.

CHAPTER IV

DISCUSSION OF RESULTS AND CONCLUSIONS

4.1 Comparision - It is required that the data obtained from the experiment should be compared with the available data. The available data has been adopted from the graphs(1.6 a & b part I). It is tried that the test conditions of the existing as well as the experimental data should be same, but due to small horse power of the lathe, they are not strictly observed. The higher speed could not be available. The comparative statement has been prepared in the Table IV-1.

From the table it is observed that the experimental results are much lower than the existing results. The rates between the two is nearly one is to two. This ratio is nearly same for variable feed and variable depth of cut. The reasons of this variation may be speed. Because the speed in one case is very small. As has been discussed earlier, that at lower speeds the tool forces are influenced by this. The other reason may be that tool angles may not be very accurate because in two consecutive grindings the tool geometry may change a little. From the above discussion we infer that the existing and experimental results do not cor-relate to each other.

TABLE IV-1

Available data from Graph 1.6 (a-b)				Experimental data from Graph (3 & 4)			
Work material - Mild Steel % Carbon - 0.21 Yield Strength 19900 psi				Work material - Mild Steel % Carbon 0.232 Yield strength = 36000 psi			
Depth of cut in thous.	Feed IPR	Speed fpm	Tangential force (F_t) lbs.	Depth of cut in thous.	Feed IPR	Speed fpm	Tangential force (F_t) lbs.
20	0.03	80	180	20	0.031	13.0	100
30	0.03	80	230	30	0.031	13.0	130
40	0.03	80	300	40	0.031	13.0	150
50	0.03	80	360	50	0.031	13.0	170
60	0.03	80	400	60	0.031	13.0	190
70	0.03	80	450	70	0.031	13.0	220
30	0.015	80	125	30	0.015	13.0	50
30	0.02	80	160	30	0.02	13.0	70
30	0.025	80	190	30	0.025	13.0	90
30	0.03	80	210	30	0.03	13.0	110
30	0.04	80	290	30	0.04	13.0	150

N.B. - The above table shows comparative values of Tangential force for available and experimental data.

4.2. Investigation Of Fitness Of Derived Formula:-

In the table IV-2 it has been investigated that to what extent the derived emperical formula correlates with the actual experimental values. It is seen that for constant feed and variable depth, the formula is more closely correlated with the experimental values, while for constant depth and variable feed, the difference is pronounced at lower values, but decreases at higher values. So from this discussion it can be inferred that the above formula is best fit to the experimental data.

TABLE IV - 2.

Depth of cut in inch	Feed in I.P.R.	Values of tangential force (lbs.) as determined from experimental record	Values of tangential force (lbs.) as determined from derived formula	Percentage deviation
0.010	0.0310	78.0	81.3	3.8
0.020	0.0310	132.0	135.0	2.2
0.040	0.0310	227.0	224.0	1.3
0.050	0.0310	262.0	263.0	0.37
0.060	0.0310	282.0	302.0	7.1
0.080	0.0310	370.0	372.0	0.6
0.090	0.0310	390.0	400.0	2.4
0.030	0.0175	60.0	90.0	50.0
0.030	0.0246	90.0	120.0	33.0
0.030	0.0375	125.0	190.0	52.0
0.030	0.0416	167.0	210.0	25.8
0.030	0.0555	217.0	282.0	25.0
0.030	0.0666	292.0	338.0	15.0

4.3. Discussion Of Results And Conclusions:-

The forces developed in the cutting operation are proportional to depth of cut and feed. According to derived empirical formula, (Eq. Chapter III).

$$F = 117000\, d^{0.73409}\, f^{1.12061}$$

It can be seen that the force is not directly proportional the parameters (depth of cut, feed) but follows a exponential law. The depth of cut has more pronounced effect on the cutting forces compared to the feed rate.

From the graph (2 and 3) it is clear that larger forces are required to mild steel as compared to cast iron. From graph (6) it is observed that the force versus speed curves is steep at lower feed rates, but becomes flat topped at higher speeds. It shows that the effect of speed on the tool force is pronounced at lower values while negligible at higher speeds.

From the above formula, it can be seen that if family of curves are drawn between force and depth of cut for various values of feeds the lines will be parallel to each other.

Similarly a family of curves between force and feed for various values of depth of cut will be parallel to each other.

APPENDIX - I.

METALLURGICAL ANALYSIS OF THE MATERIAL

The test material used in the present study was analysed for its carbon contents. The procedure and the apparatus employed together with the results obtained are described as below:

Determination of Carbon

The percentage weight of carbon in the material is determined by the volumetric direct combustion method. The apparatus used is shown in the adjacent photograph.

Principle

When a current of pure dry oxygen is passed over pig iron, steel and ferrous alloys in suitable physical condition say drillings or powder, heated to about 1100°C in an electric furnace, the non-metallic elements carbon, sulphur and phosphorus are converted into oxides which are solids. The gaseous products consisting of CO_2, SO_2 P_2O_5 and excess of oxygen are collected in the burette(1) with water as the confining medium. Due to the high solidarity of SO_2 and P_2O_5 in the water, they are dissolved. The reading of the burette when the levels of water in it and the levelling bottle are the same, gives the volume of CO_2 and excess O_2. This mixture is then passed into the absorption bulb (2) filled with an absorbent. The residual gas is transferred back to the burette and its volume measured at the temperature of the water in the jacket (3). The difference between the readings is the volume of CO_2 at the test pressure and temperature. From this volume the weight of carbon is calculated.

Procedure

The Strohlein apparatus used was ready by filling the burette jacket (4) with water, the levelling bottle (5) with acidulated water. The burette was opened to the atmosphere by opening the stop cocks, The levelling bottle was then raised until the water reaches the non-return valve. Then the cock was closed and levelling bottle returned to its initial position which equals to the zero of the burette.

One gram of drillings are placed in a combustion boat and introduced in the furnace (12) maintained at about 1100°C. Some time is given to the sample to be heated. The O_2 supply from the cylinder is slowly regulated and passed through Caustic Potash and Sulphuric Acid. The cocks are opened to furnace, so that gaseous mixture may enter the burette. When the liquid level in the burette reaches the zero level the cock (11) is quickly closed. Now the valve is opened to the absorbent bottle and gas transferred to it. The levelling bottle is again brought down to its initial position. The level is adjusted and reading noted. This gives the volume of CO_2 resulted from 1 gm. of carbon.

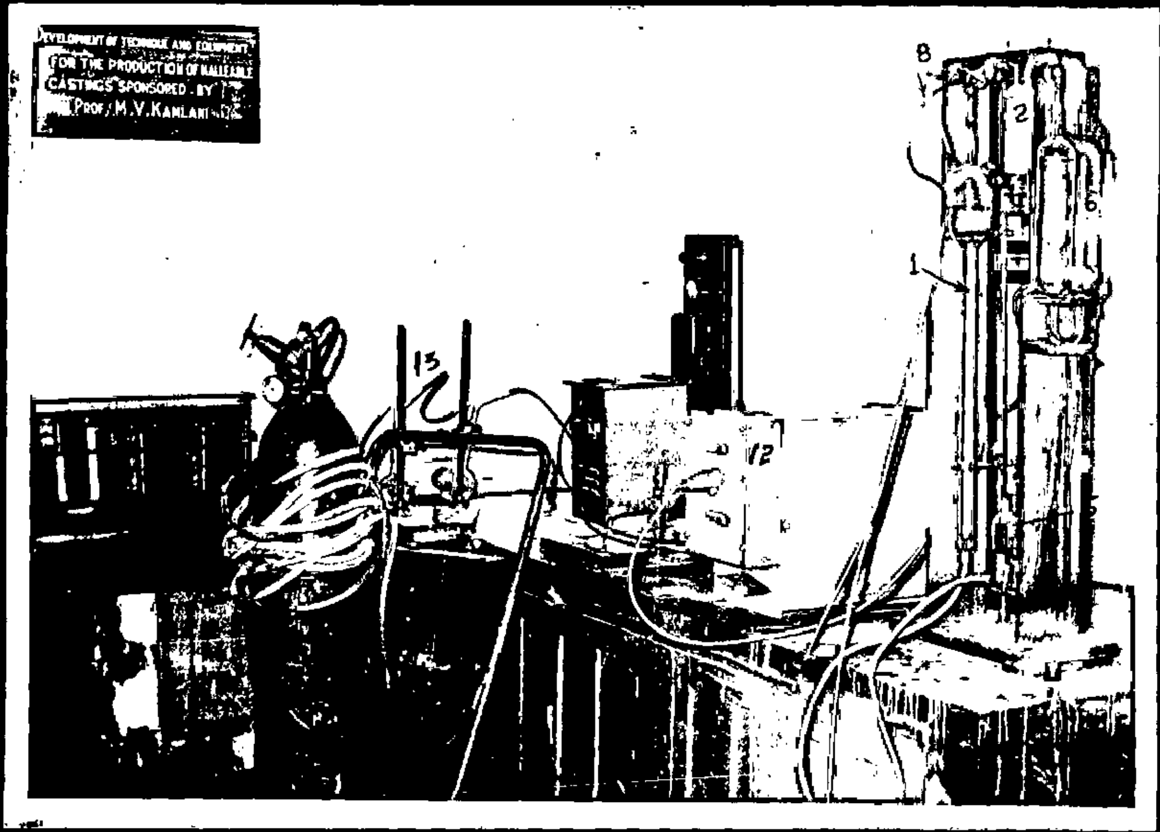


FIG. 4. Strohlein Apparatus For Carbon Determination.

EXPERIMENTAL RECORD

The observations are given in table No.1, for the determination of carbon in mild steel. The drillings were taken from the tensile test specimens.

TABLE - I.

Barometer Pressure - 73 cm.

Tensile test specimen No.	No. of tests	Burette reading diff.	Burette reading average	Temp. of jacket water.
1	1	0.25		31^oC
	2	0.24	0.25	"
	3	0.26		"
2	1	0.26		"
	2	0.27	0.26	"
	3	0.25		"
3	1	0.25		"
	2	0.25	0.255	"
	3	0.26		"

Calculations and Results

The burette in the Strohlein apparatus was graduated to measure directly the percentage weight of carbon content at N.T.P., but it could not be possible to use this scale to advantage since the chart, necessary to correct the values thus obtained for the temperature and pressure under the test conditions was not available. Therefore the existing scale was calibrated to read the volume absorbed. And the weight of the carbon was calculated. The calculations are shown for the first sample:

Calibration factor:-

Burette reading x 20 = CO_2 in C.C.

<u>Model Calculations (Sample -1)</u>

Av. burette reading = 0.25

CO_2 absorbed = 5.0 ml.

Now 22.4 liters of CO_2 at NTP results from the combustion of 12 gms of carbon.

Then volume of 22.4 liters CO_2 at test conditions is

$$= \frac{76 \times 22.4 \times 1000 \times 304}{73 \times 273} \text{ ml.}$$

So

$$\frac{76 \times 22.4 \times 1000 \times 304}{73 \times 273} \text{ results from 12 gm C.}$$

Hence 5 ml. will result from

$$= \frac{73 \times 273 \times 12}{76 \times 22.4 \times 1000 \times 304} \times 5.0$$

This represents the carbon content in 1 gm. of the sample.

$\therefore$ %age weight of carbon in the sample

$$= \frac{73 \times 273 \times 12 \times 100}{76 \times 22.4 \times 1000 \times 304} \times 5$$

$$= 0.0455 \times 5$$

As the test conditions are same here 0.0455 can be taken as constant and the general formula can be written as:

$0.0455 \times CO_2$ = percent weight of carbon.

With the help of above formula, the % weight of carbon is calculated in all the samples and tabulated in table II.

TABLE - II.

Sample No.	% carbon by weight	Average value
I	0.228	
II	0.236	0.232
III	0.232	

Similarly the carbon analysis was made for castxxx iron. Here we know that carbon content is higher in cast iron so CO_2 produced will be more. As the capacity of the buratte is small so 0.1 gm. of cast iron was taken. Tests are carried for three samples of cast iron and the test results tabulated in table No.III. The percentage weight of carbon in cast iron was calculated and tabulated in table No.IV.

TABLE - III.

Sample	No. of tests	Burette reading diff.	Average	Temperature of jacket water
	1	0.33		31° C
1	2	0.35	0.336	"
	3	0.33		"
	1	0.34		31° C
2	2	0.33	0.34	"
	3	0.35		"
	1	0.34		31° C
3	2	0.33	0.34	"
	3	0.35		"

Here the test conditions are same as in the case of mild steel except that weight of drillings is 0.1 gm. so formula becomes

$0.455 \times CO_2 = \%$ wt. of carbon.

TABLE - IV.

Sample	CO_2 ml.	% carbon by wt.	Average value
1	6.72	3.06	
2	6.8	3.10	3.09
3	6.8	3.10	

APPENDIX - II

RESULTS OF THE STATIC TESTS

Tensile & Hardness Test:- The tensile test pieces were pnepared from the bar stock, from which the turning test pieces were prepared to ensure the same material. The physical properties were calculated and listed in the Table I.

TABLE I

Test piece No.	Yield strength tsi	Ultimate strength tsi	Breaking strength tsi	Hardness Rockwell
1	16.45	28	20.7	86, 87, 88
2	16.7	28.7	23.0	90, 91, 92
3	16.1	27.4	20.0	84, 85, 86
Average	16.4	28.03	21.2	86.5

TABLE II

(Physical properties of Cast iron)

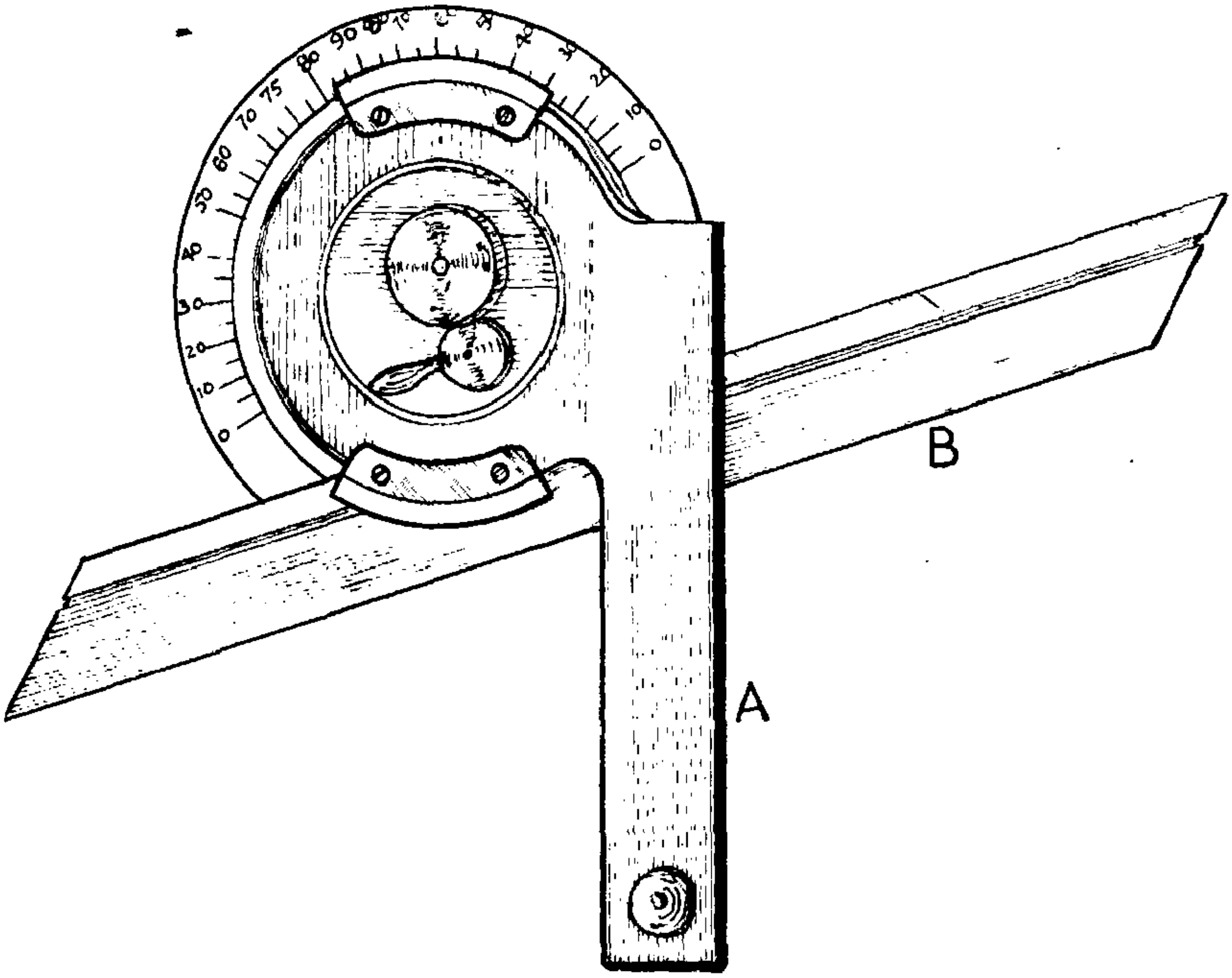
Test Piece No.	Ultimate strength tsi	Hardness Rockwell
A	11.4	60
B	11.0	58
C	11.2	58
Average	11.2	59

A P P E N D I X - III.

MEASUREMENT OF TOOL GEOMETRY

The tool angles are measured by bevel protractor Fig.(1). The following procedure is adopted:

1. Tool shank is made perfect rectangular.
2. The surface A Fig.(1) of the bevel protractor is set on the bottom of the shank and surface B on the front. The reading on the protractor is front relief angle.
3. Again surface A is set on the bottom of shank (breadth wise), and surface B on flank, it gives the side rake.
4. Now surface A is on the side of the tool and surface B on the top then (90 - side rake - protractor reading) is back rake.
5. The end cutting edge angle is measured by putting surface A along length of the shank and surface B along the edge. The edge cutting angle is(180^0 - protractor reading).
6. Side cutting edge angle is zero so it can be judged by any straight edge.
7. The nose radius is measured by the help of outside radius and fillet gage.



PROTRACTOR

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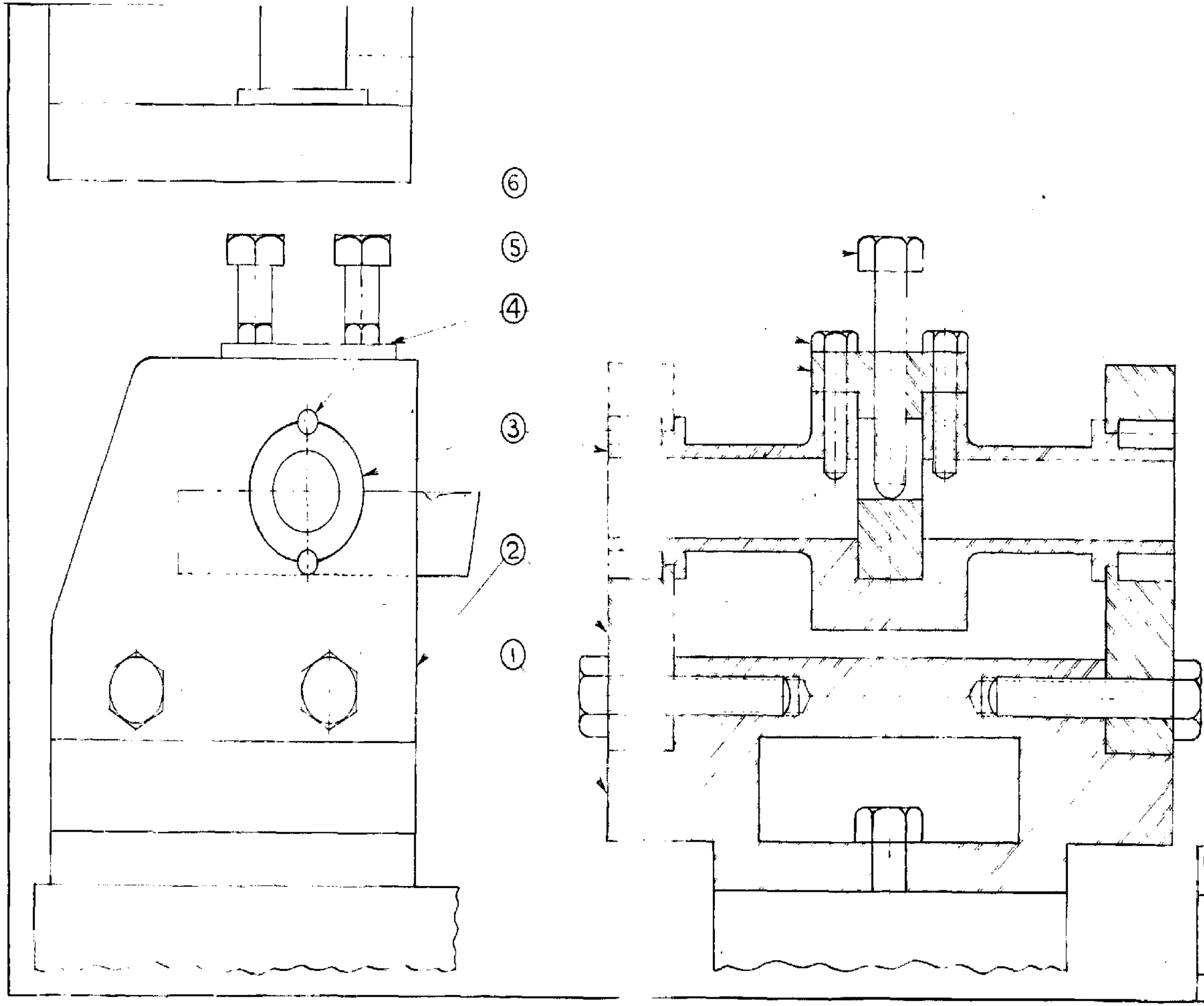
14. "Strain Gage Techniqué" M.I.T. Cambridge.
15. "Instrumentation Laboratory Manual" Suresh Chandra and A.B.L. Agraval.

APPENDIX - IV.



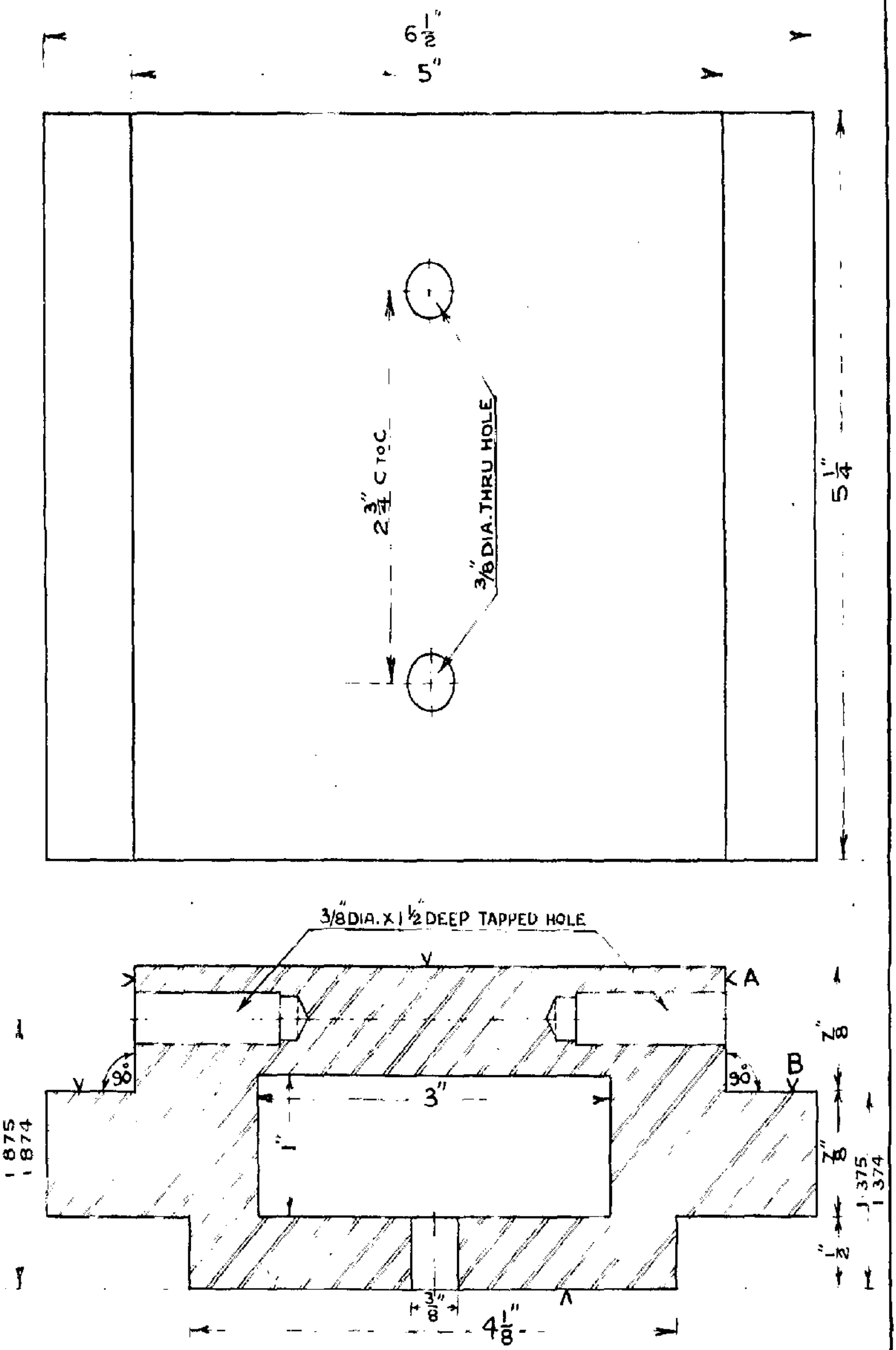
No.	Name
1	Bed
2	End Plates
3	Shaft
4	Cap
5	Bolt
6	Key
7	
8	

MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ROORKEE

LATHE TOOL DYNAMOMETER

R.S.R

A-



MATERTIAL: CAST IRON

INSTRUCTIONS.

1. SURFACES A & B (BOTH SIDES) SHOULD BE PERPENDICULAR
2. DO NOT USE FILE ON THESE SURFACES.

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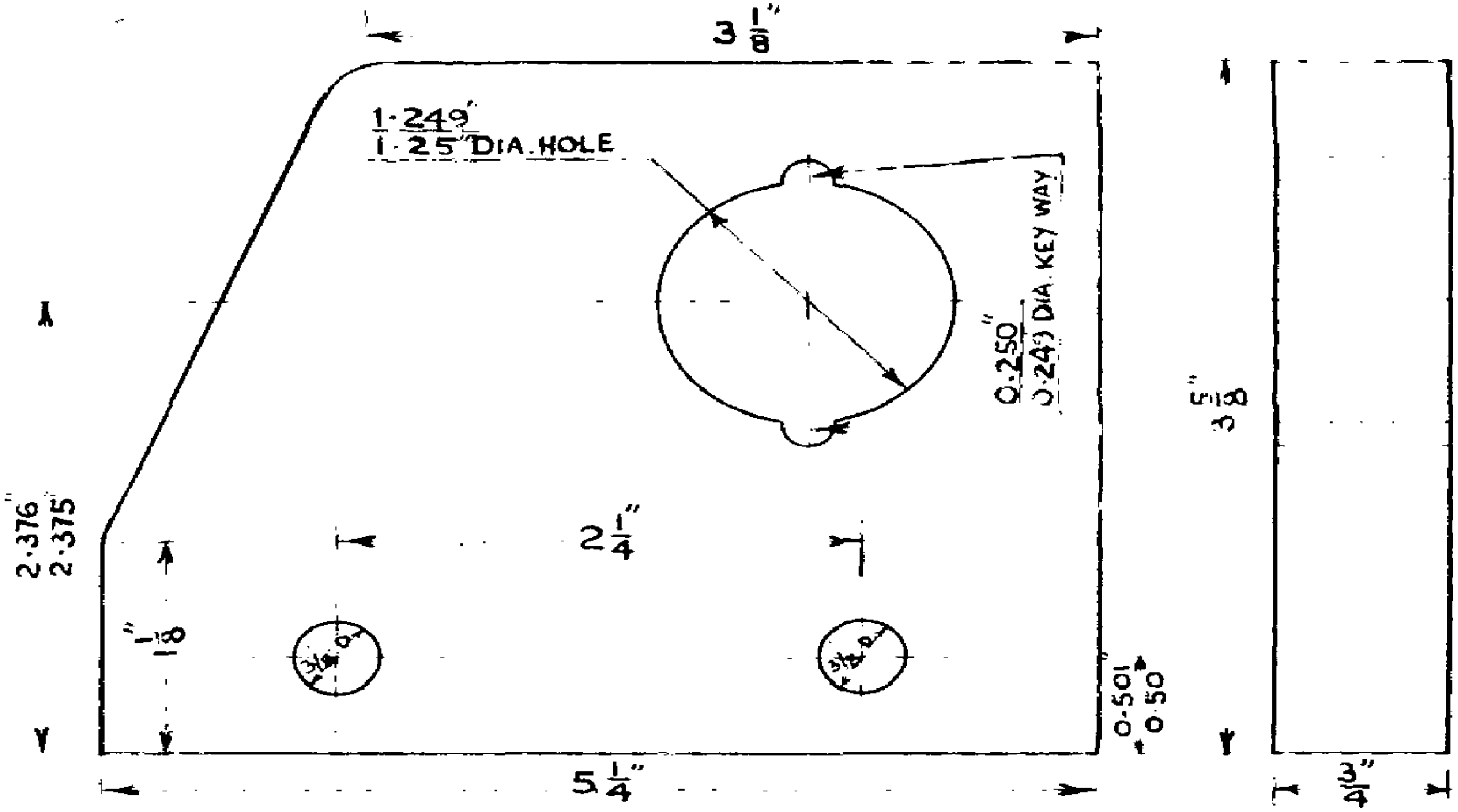
BED (1 REQD)
R.S.R
A-1

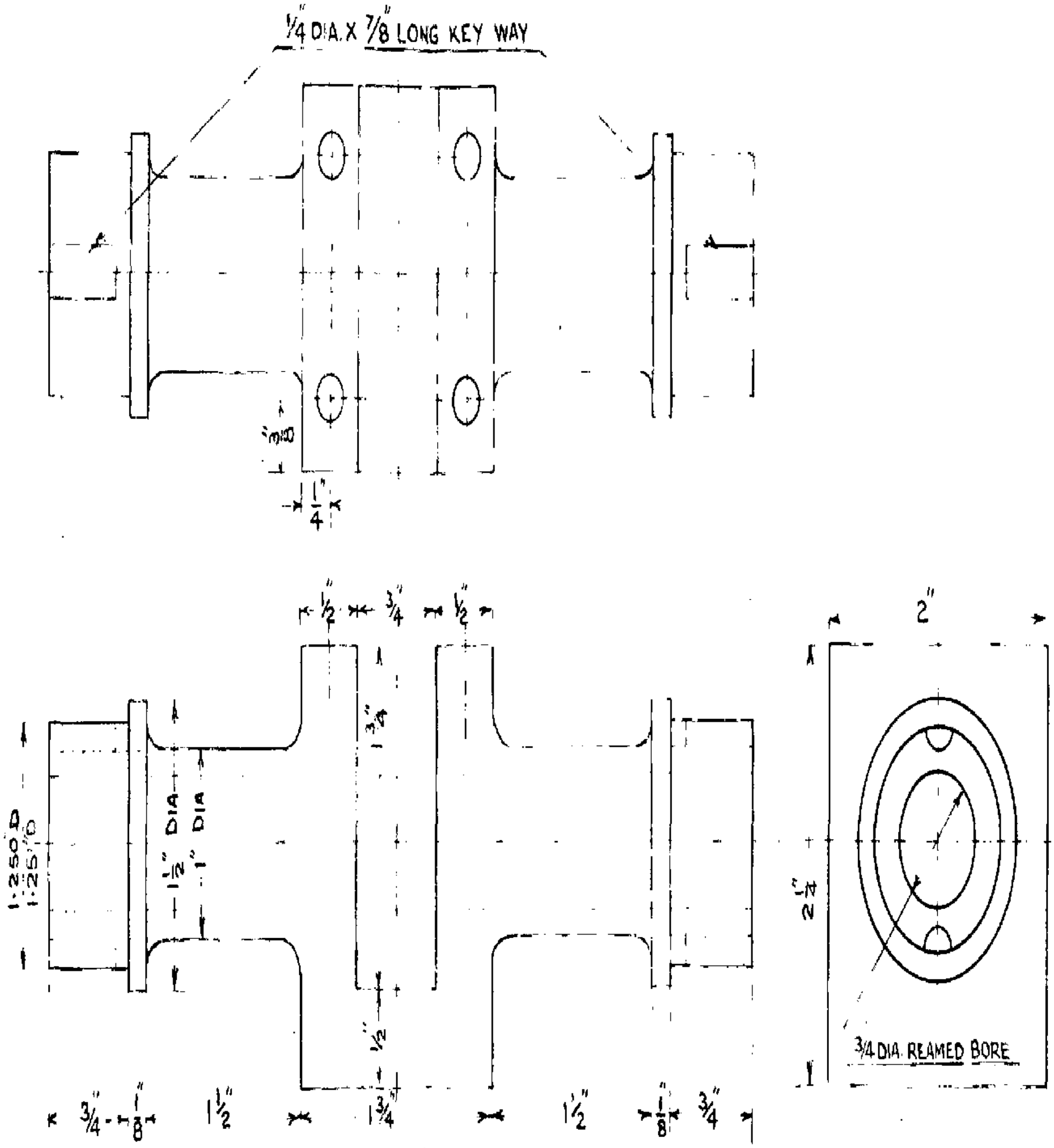


MATERIAL :– MILD STEEL
MACHINED ALL OVER

PROCEDURE:–

1 FINISH ONE SURFACE OF EACH PLATE.
2 HOLD THE TWO PLATES AS ONE.
3 FINISH THE PLATES FROM ALL SIDES.
4. DRILL AND TAP THE BOLT HOLES
5. TIGHTEN THE TWO PLATES BY BOLTS
6 DRILL AND REAM THE 1¼" DIA. HOLE.
7 ASSEMBLE THE PLATES IN A–2
8.

MECHANICAL ENGINEERING DEPARTMENT UNIVERSITY OF ROORKEE	
END PLATE (2-REQD.) R.S.R.	
A-2.	



MATERIAL :- MILD STEEL

FINISH: ALL SURFACES TO BE SMOOTHLY FINISHED

PROCEDURE

1. FIRST TURN ROUND PORTION.
2. FINISH THE CENTRAL CUBICAL PORTION.
3. HOLD ONE END IN THE THE LATHE CHUCK, BORE AND REAM
4. HOLD REAMED BORE ON A MANDREL AND BORE THE HULE IN THE LATER HALF.
5. CUT SLOT.
6. DO NOT USE FILE FOR FINISHING THE SURFACES.

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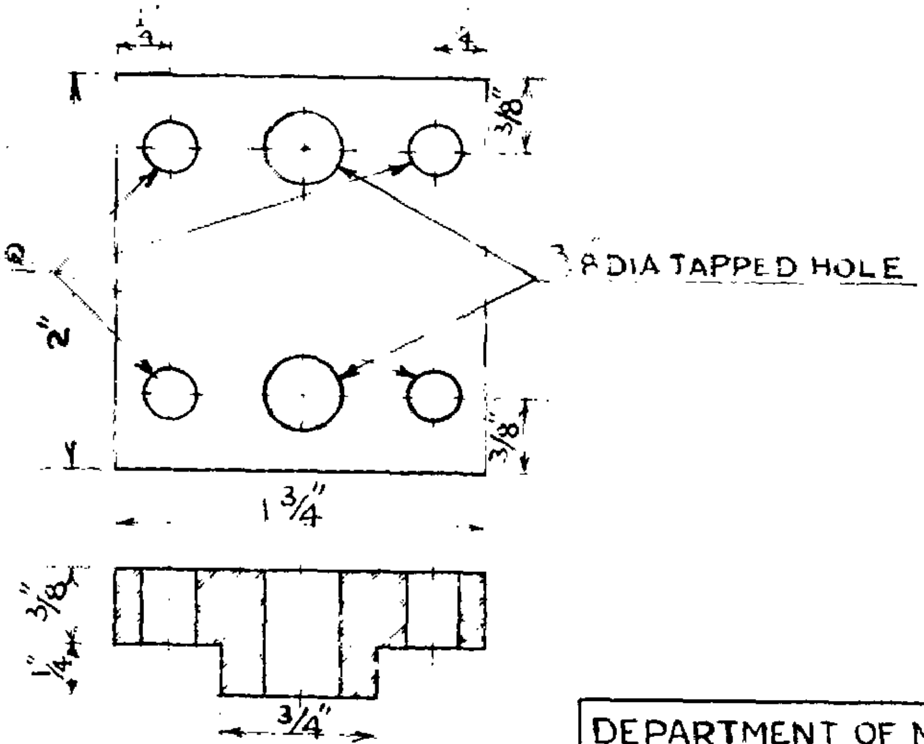
SHAFT (1-REQD.)
LATHE TOOL DYNAMOMETER
R.S.R.

A-3



MATERIAL :- MILD STEEL

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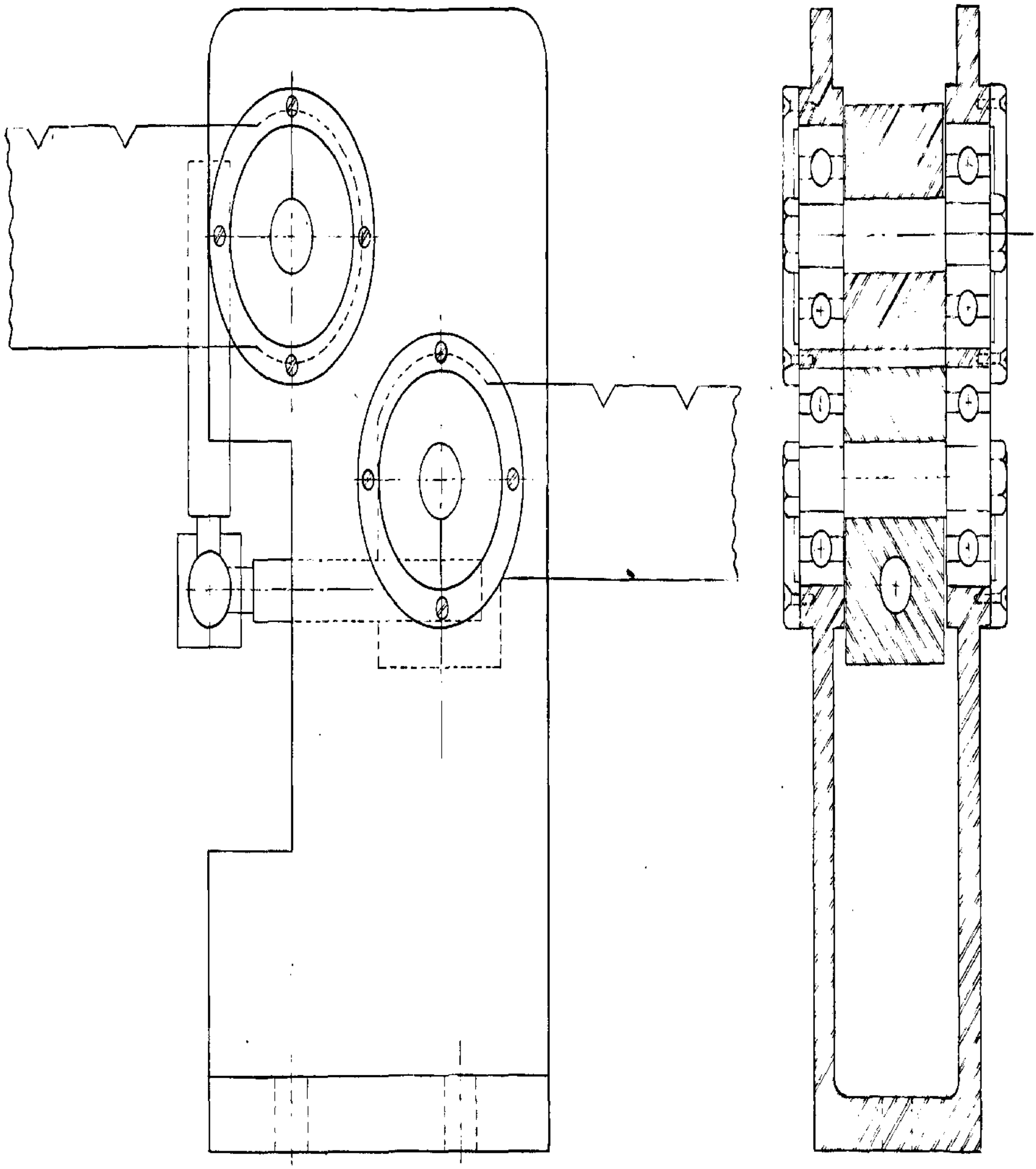
CAP - 1 REQUIRED R.S.R
A-4

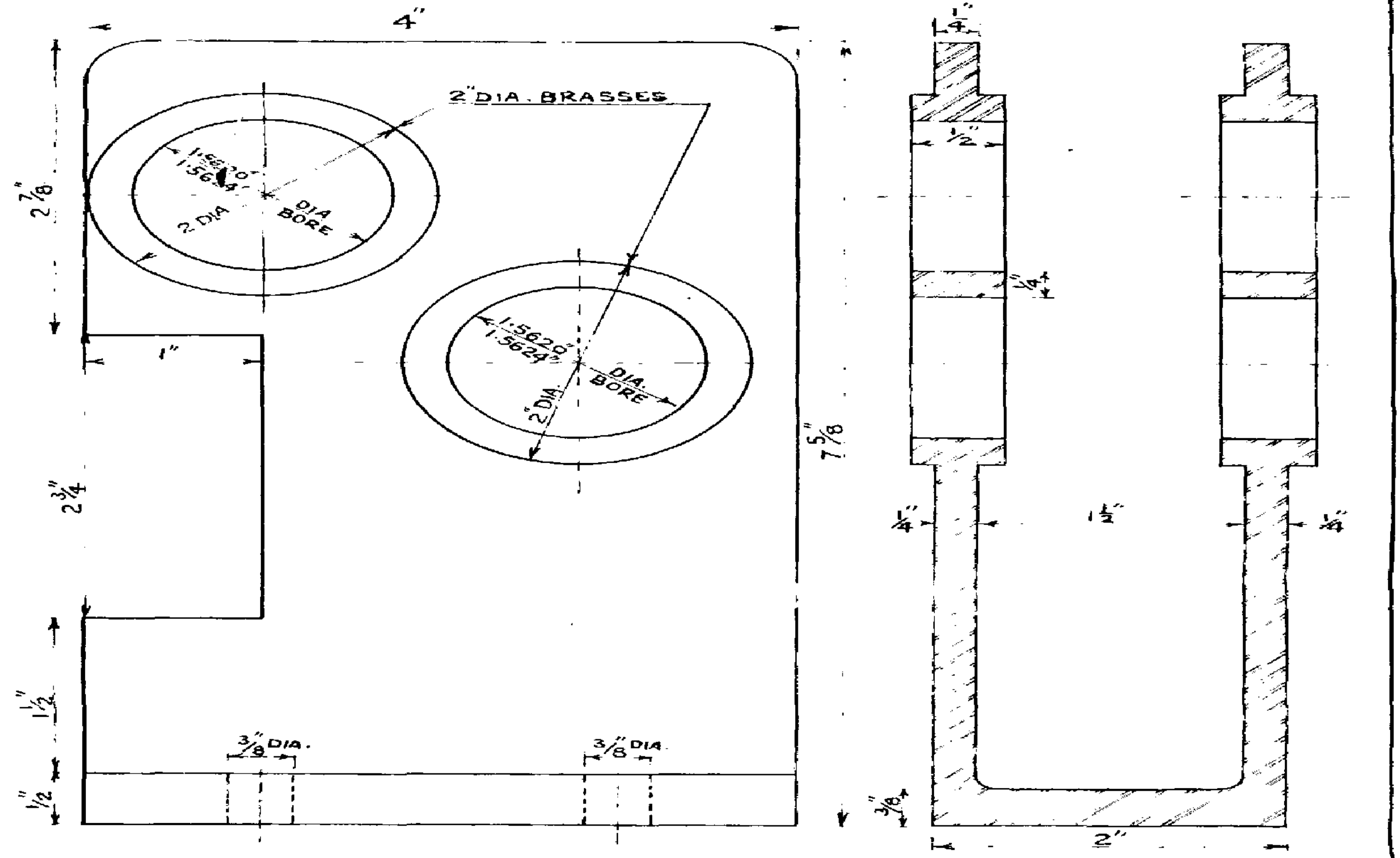


DEPARTMENT OF MECH ENGINEERING
UNIVERSITY OF ROORKEE

ASSEMBLY OF CALIBRATING FIXTURE

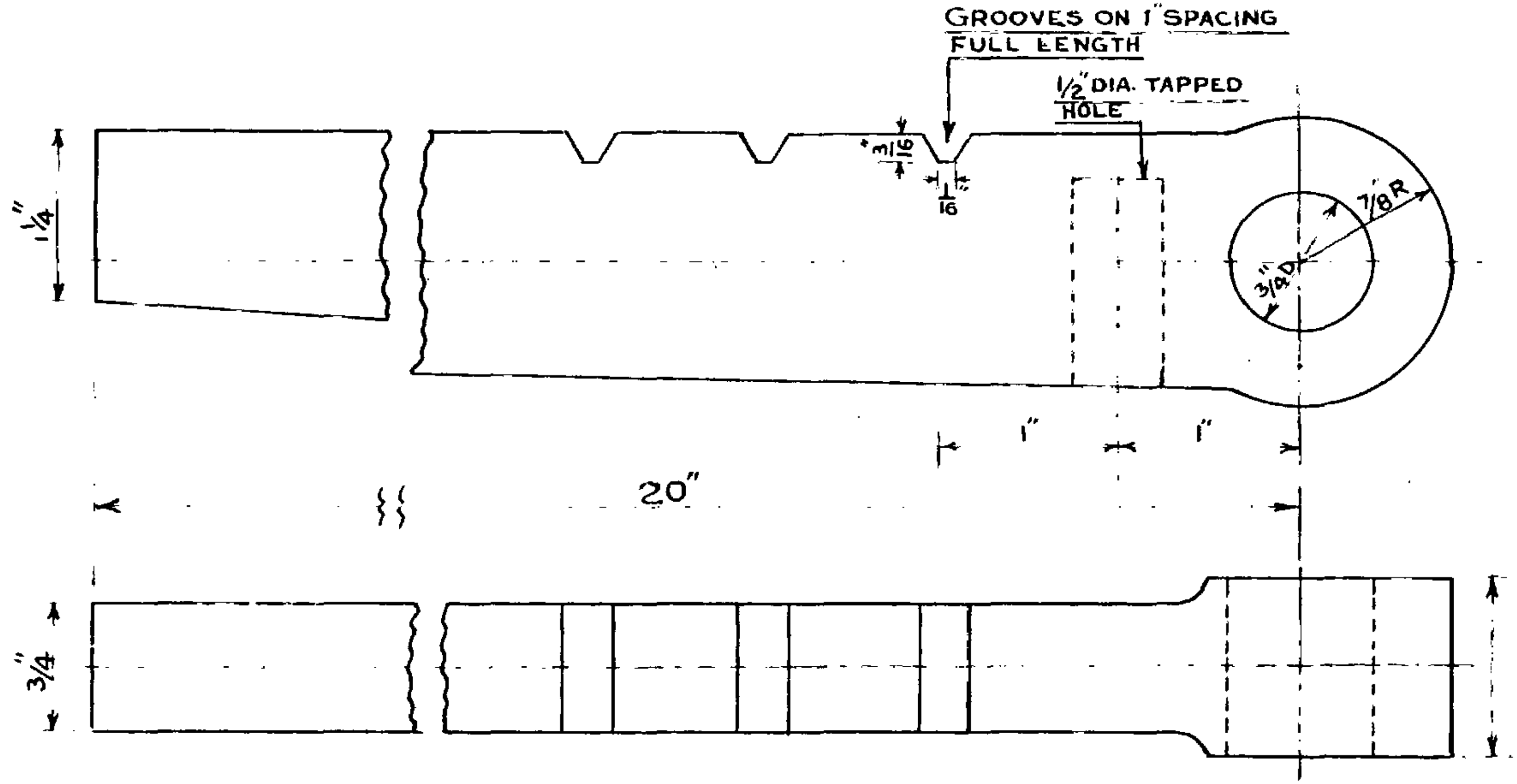
R.S.R.

B-



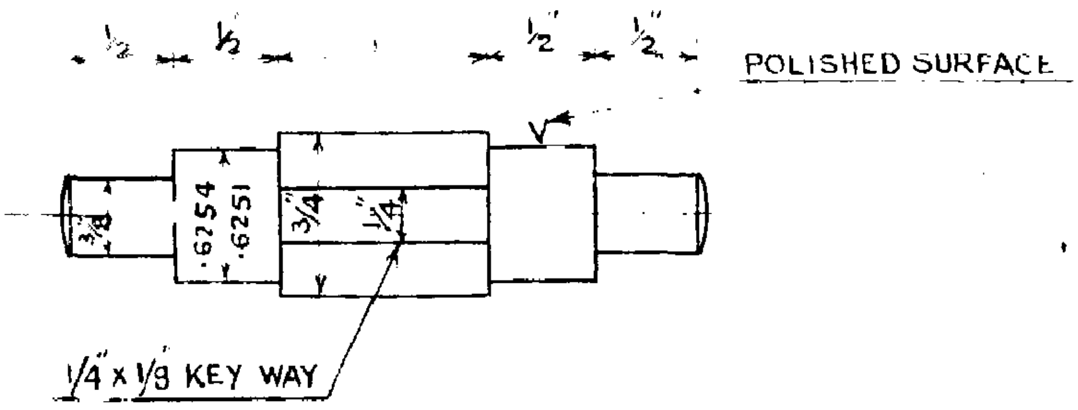
MATERIAL:- CAST IRON

DEPARTMENT OF MECH. ENGINEERING UNIVERSITY OF ROORKEE
HOUSING - 1 REQUIRED R.S.R
B-1



MATERIAL: - MILD STEEL

DEPARTMENT OF MECH. ENGINEERING UNIVERSITY OF ROORKEE	
LINK - 1 REQUIRED R S.R.	
B-2	



MATERIAL: - MILD STEEL

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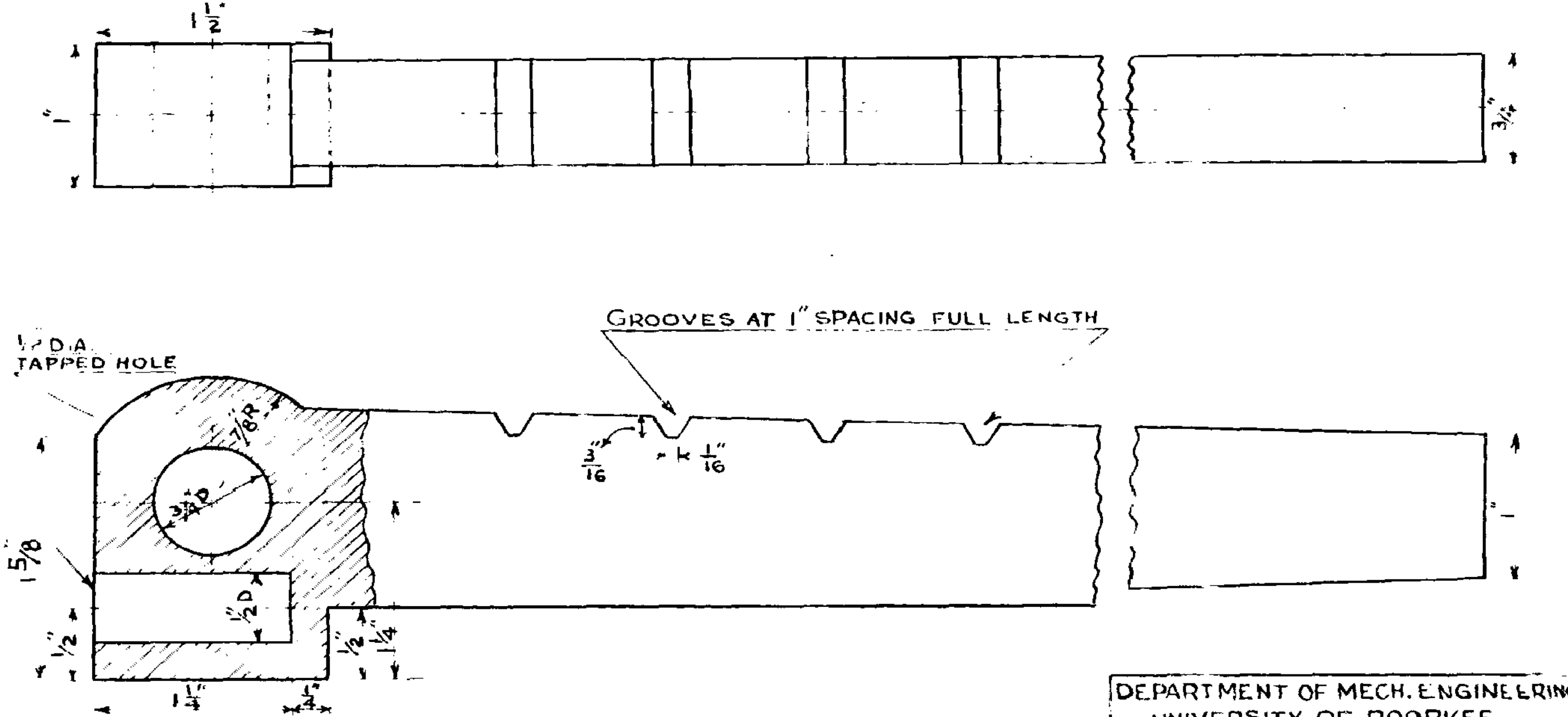
PIN - 2 REQUIRED

R.S.R.

B - 3

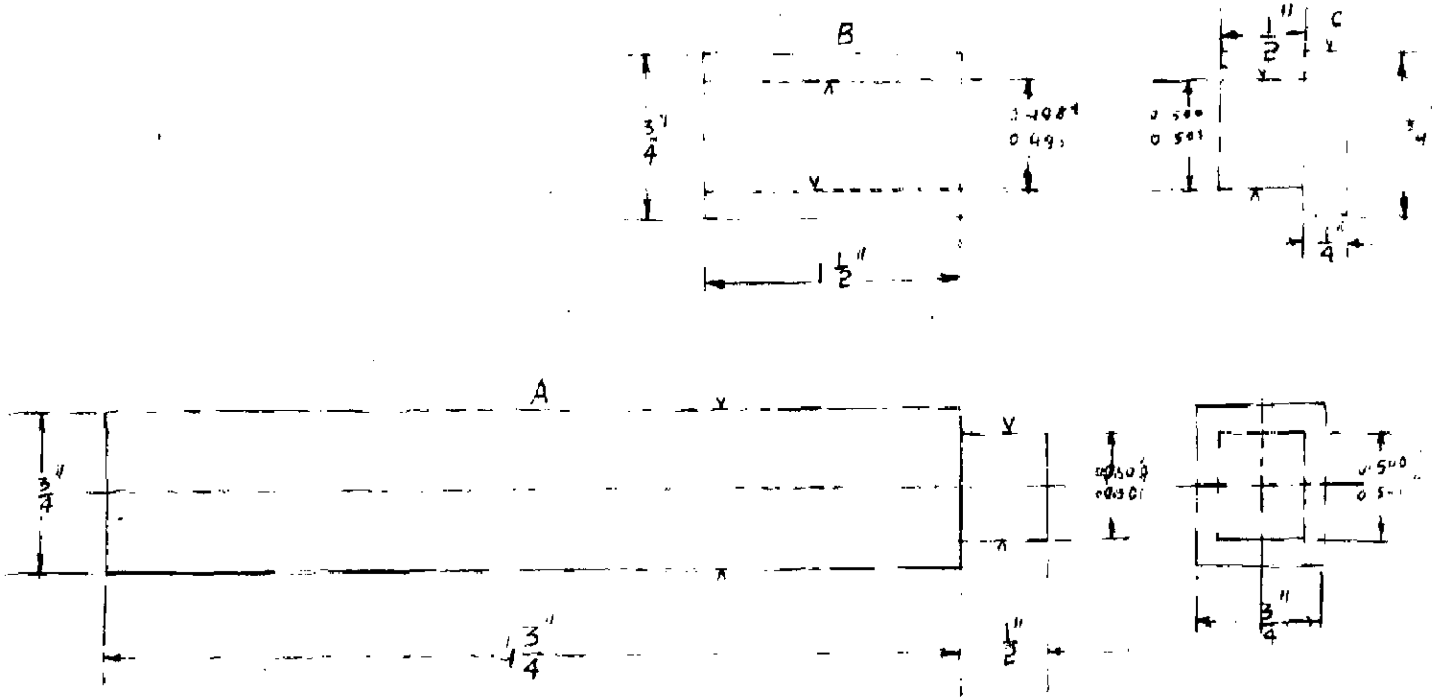


MATERIAL:- MILD STEEL

DEPARTMENT OF MECH. ENGINEERING
UNIVERSITY OF ROORKEE

CALIBRATING FIXTURE LINK
1 REQUIRED
R.S.R

B- 4



A And C Are To Fit In B

Material- Mild Steel

University Of Roorkee

Deptt Of Mech. Engg

Calibrating Bar

Lathe Tool Dynamometer

K S K

M.E. Dissertation

C 1 2