EFFECT OF CUTTER VIBRATIONS ON SURFACE FINISH UNDER DIFFERENT CUTTING CONDITIONS IN HORIZONTAL MILLING MACHINE

A Dissertation
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MECHANICAL ENGG. (Production)

By
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CERTIFICATE

Certified that the dissertation entitled " EFFECT OF CUTTER VIBRATIONS ON SURFACE FINISH UNDER DIFFERENT CUTTING CONDITIONS IN HORIZONTAL MILLING MACHINE" which is being submitted by Sri Avinashi Lal Kapur in partial fulfilment for the award of Degree of Master of Engineering in MECHANICAL ENGINEERING (PRODUCTION ENGG.) 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 about eight months from Jan. 1965 to Sept.1965, for preparing the dissertation for Master of Engineering Degree at this University.

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GLOSSARY OF SYMBOLS.

F	Feed rate, inches per minute.
F_t	Feed rate, inches per tooth.
W	Width of cut, inches.
d	depth of cut, inches.
$H.P_c$	horse-power required at the cutter.
α	horse-power required per cubic inch of metal removed.
cim	metal removal rate in cubic inches per minute.
η	overall efficiency of the milling machine.
mil	one thousandth of an inch = .001".
μ''	micro inch = 10^{-6} in.
D	dia. of milling cutter, inches.
V	cutting speed in feet per min.
S	cutting speed in inches per minute.
N	revolutions of the cutter per min.
R_a	surface roughness in micro-in(μ'') CLA value.
C_u	cutter position on the arbor, measured from spindle nose.
C_L	clamp position on the arbor measured from spindle nose.
B.H.N.	Brinell Hardness Number.

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CHAPTER I

INTRODUCTION

INTRODUCTION

In modern manufacturing, machine tool vibrations have assumed considerable significance and still more emphasis has been placed on them during recent years. It is so because many people have recognised that accuracy, tool life, production costs and above all the surface finish are amply influenced by the vibrations in machine tools.

Machine tools have always vibrated and will continue to do so. We strive to control these vibrations and keep them at or below tolerable level. This was simpler in the past than it is today because the older machine tools had fewer auxiliary mechanisms, lower speed and feed ranges, and were comparatively less complex in construction. Today an arsenal of sophisticated instruments is available for the investigation of machine tool vibrations. However, in the final analysis the finished surface itself will reflect the dynamic behaviour of the machine tool.

Although vibrations in machine tools play an important role, yet survey of the literature reveals that very little experimental or theoretical work has been published on the subject up to the beginning of the last decade. First in Japan and then in other countries some work was done and only lathes and lathe tools were investigated. The pioneers in this field were Shizuo Doi in Japan (1931, 1937, 1940)

R.N.Arnold(1)° in England (1960) and A.J.Chisholm(2) in England (1969). During the past few years the increasing demand for greater output, accuracy and better finish has caused the vibration problems in machine tools to gain gradually in importance. Consequently the behaviour of machine tools under the effect of periodic or fluctuating forces has been the object of close investigation by many investigators, for instance in 1953, Ivor Bendixen(3) performed a series of tests on vibrations in knee type horizontal milling machine. He made systematic investigations on the importance of clamping and unclamping the various elements. In 1958, Dr. Ing. H. Optiz(4) investigated the influence of vibrations on the surface conditions and tool life. He concluded thus:

> "The quality of the surface in milling is affected by vibration movements which may be both self-excited or forced vibrations. But on account of the varying cutting forces, the forced vibrations are of primary importance."

In 1960, F.Koenigsberger and S.M.Said(5) made an experimental study of the dynamic characteristics of a milling machine and correlated the results with the surfaces produced during cutting operations. In their conclusions they stated that the quality of the machined surfaces followed a pattern approximately similar to that of the machine vibrations.

° The figures appearing in the parenthesis refer to bibliography at the end of thesis.

Recently J.Peters(6) has reported the results of his research carried out in this field. His investigation aimed at finding as to whether there is any correlation between dynamic characteristics of a machine tool and the surface produced on the work piece. For this purpose, he made his studies on five different lathes. On the basis of the results of his experiments he has concluded that there is a very good agreement between the vibration and the surface roughness CLA values. Others who merit a mention so far as their contribution to this field is concerned are R.S.Hahn; S.A. Tobias and W.Fishwick; A.O.Schmidt; W.L.Kennicott and J.M.Galimberti. It may be of interest to note that at present more than 50 percent of the industrial research and development effort is being directed towards reducing vibrational disturbances.

Since technically, a machine tool constitutes, from vibrational point of view, an extremely complex structure a theoretical discussion of the arising problems is not readily accessible. An experimental approach to this matter is, therefore, better suited (4). Such an experimental attempt has been made in the present work to study some of the dynamic characteristics of a milling machine and to correlate the results with the surfaces produced during cutting operations and it has been shown that a good correlation between the transverse vibrations of the cutter and the surface roughness of the work piece exists.

The modern milling machine cuts metals in fundamentally the same way as it has been done since man first started to use machinery to fashion more of his needs in metals. In a horizontal milling machine, the milling cutter is mounted, on the arbor which is supported in bearings both at the drive end and the clamp end. The action of a milling cutter, during milling operation, is analogous to the hammering action-each tooth striking individual blows on the work piece. Consequently the arbor and hence the cutter vibrates. To increase the stiffness of the arbor it is clamped to over-hanging arms, the whole assembly being called as 'arbor assembly'. From the vibrational point of view the 'arbor assembly' forms a highly complicated system to be dealt with by analytical methods. The problem is further complicated by the nature of cutting forces which is rather difficult to predict in dynamic operations. Since the position of the cutter and clamp can be varied at will along the length of the arbor, we get a different system at every new setting. This adds more to the intricacy of the problem if studied analytically. These considerations necessitate the experimental approach to the study of the problem.

No machine tool is free from vibrations. More causes for vibrations occur in milling machines than in any other machine tool(7). These vibrations may be forced or self-excited. Both forced and sustained vibrations are known to be prejudicial to accuracy, output and surface finish of the work piece; but in milling the forced vibrations are of primary importance.(4)

The present study has, therefore, been limited to the study of the effect of forced vibrations of the arbor assembly. Self-excited vibrations are not considered in this investigation.

In milling operations, the fluctuation of the cutting forces with interrupted chip formation caused by successive engagements of cutter teeth, which forms chips of varying cross-sections, is the most important source of forced vibrations. These exciting forces are usually considerably higher than the disturbing forces caused by unbalanced masses, incorrect tooth pitch of the gear, electric motors etc.(8) These variable forces occur not only on the peripheral direction of the milling cutters but also in the radial direction, so that vibrations are produced in vertical relationship with the milled surface which may have a damaging effect on the surface quality. Moreover, the angular velocity of the milling spindle is subjected to cyclic deviations due to repeated entrance and exit of cutter teeth with respect to work. This causes torsional vibrations which may also contribute to the roughness of the milled surface. The present analysis, however, confines itself to considering the motion of the tool with respect to the workpiece in a direction normal to the cut surface. This is because only motion in this direction has a direct effect on the surface finish and dimensional accuracy(9).

Apart from vibrational aspects, there is a large number of variables which also influence the surface quality of a milled surface, for instance, speed of the milling cutter feed rate of the workpiece, depth of cut, hardness of the material being milled, type of the milling cutter employed— its material and tooth angles, method of milling adopted, sharpness of the cutting edge, cutting fluid used etc. However, due to the limitations of both time and facilities available an attempt has been made to investigate the effect of only a few important parameters. These include speed, feed, depth of cut, cutter and clamp positions. With the help of dimensional analysis, an empirical relationship correlating different cutting conditions and surface roughness has been suggested.

In the present-day competitive industrial world, there is well-nigh a ' craze ' for greater output. We may augment the production rate by employing heavier feed rates and deeper depths of cut as permitted by the available capacity of the machine, but this is not always feasible especially when we have to satisfy certain surface finish requirements also. The empirical relation suggested, it is hoped, could be of some help in planning the milling operations where approximate range of the surface quality desired is known.

CHAPTER II

SURFACE QUALITY

SURFACE QUALITY

2.1. DEFINITIONS:

In any machining process, some degree of surface irregularity is inevitable. Under sufficient magnification a machined surface is seen to be made of a series of peaks, ridges and valleys. They are visible to the naked eye if the surface is quite rough.

Surfaces in general are very complex and result from several kinds of variations. The principal elements of surfaces have been defined by the American Standard Association in ASA-B-46; 1-1947, as follows:-

SURFACE:

The surface of an object is the boundary which separates that object from another substance.

ROUGHNESS:

Relatively finely spaced surface irregularities on surfaces produced by machining and abrasive operations, the irregularities produced by the cutting action of tool edges and abrasive grains and by the feed of the machine tool are roughness. Roughness may be considered as being superposed on a wavy surface.

WAVINESS:

The surface irregularities which are of greater spacing than the roughness. On machined surfaces, such irregularities may result from machine vibrations, strains, deflections etc.

FLAWS:

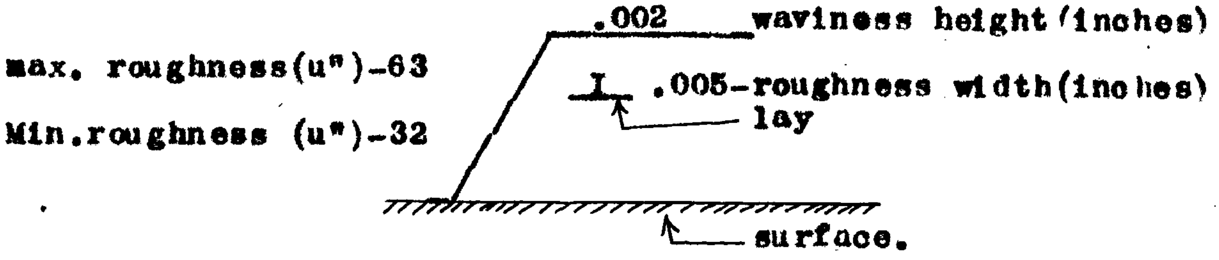
Irregularities which occur at one place or at relatively infrequent intervals in the surface e.g. scratch, ridge or a hole.

LAY:

The lay of a surface refers to the direction of predominant surface pattern or surface marks as observed in the direction at right angles to the line representing the surface.

2.2- DESIGNATION OF SURFACE QUALITY.

Surface specifications, like tolerances, should convey a specific idea from the designer to the tool engineer. Roughness, lay and waviness may be designated on drawings by the use of the following standard symbols.



2.3. FUNCTIONAL IMPORTANCE OF SURFACE QUALITY.

Certain qualities in the surface layer are important for various classes of service, for instance, the conditions imposed on the races of a ball or roller bearing where heavy loads must be carried by very small areas, while under the action of rolling friction, demand that the surfaces must possess a high degree of homogeneity, elasticity and hardness.

The finish and texture of fitting and mating surfaces have an important effect on the bearing friction, rate of wear, initial tolerances, retention of lubrication, stick-slip phenomenon etc.

The reliability of a press or force fit and its approach to theoretical conditions is largely dependent on surface quality and finish. Even for surfaces which do not fit or serve as bearings, smoothness is often important since in highly stressed parts, fatigue cracks originate from the surface blemishes. The influence of surface roughness on the mechanical properties of solids can be particularly shown by the study of fatigue strength. It is known that a fine surface microgeometry improves fatigue strength. This has been proved experimentally by Cazand and Pomey(25) who have made the following conclusions:

(i) Fatigue strength usually decreases when surface roughness increases. A number of little juxtaposed scratches of the same size, however, mutually relieve their stresses

(ii) Corrosion resistance is also improved by improvement in surface quality.

Another characteristic sensitive to a micron is the state of flow along a wall. This phenomenon is equally important in aerodynamics and hydrodynamics, where it follows the same laws. Increasing roughness causes increasing flow instability. The passage from laminar to turbulent flow is accompanied by increase of the energy lost by friction, and of heat convection flow through the boundary layer. This means that better control of surface finish can result in such benefits as decrease of the friction force (aerodynamic drag) or increase of heat transfer (fluid flow exchanges).

2.4. ROUGHNESS EVALUATION SYSTEMS:

For assessment of surface roughness of cross-section profiles and for the numerical evaluation of the graphs, it is essential to establish some international standard for the definition of roughness and its measurement. However, an international agreement on the gauge and the unit of surface roughness has not yet reached. Consequently many differences have arisen in different standards which can be classified into two main groups viz.,

(i) Standards choosing a Mean Line as reference line for the numerical evaluation-the M-System, e.g. American and British Standards.

(ii) Standards choosing an Envelope-the E-system, e.g. German and Swiss Standards.

2.41. THE M-SYSTEM.

The M(Mean line) system consists of the mean line L_m and two L_m - parallel upper and lower reference lines L_o and L_n within sampling length, ℓ (Fig.1). The mean line L_m is a line having the form of the geometrical profile of the specimen within the limits of the sampling length (meter cutoff), and is so positioned that within the sampling length the sum of squares of the deviations (equally spaced ordinates) of the profile from the mean line is minimum. This line is unique in position and direction but its graphical determination is somewhat difficult.

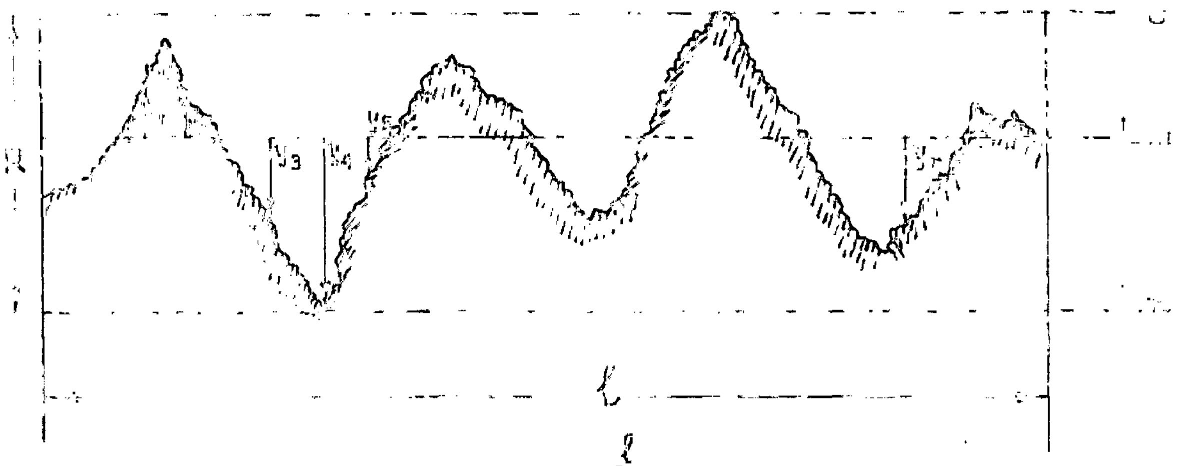
The mean line is found automatically by electrical integrating instruments. The electrical integrating instruments refer to the mean line of the alternating current flowing through them and which represents the profile. This mean line is also called 'centre line' when the areas embraced by the profile above and below the line are equal.

The reference lines L_o and L_n are in most standards touching the highest peak and the lowest valley within the sampling length ℓ.

Various standards are based on different measures as discussed below:-

(i) Depth Measures:

The peak to valley value, R, is the distance between the upper and lower reference lines L_o and L_n. This value is a measure of the total depth of the surface irregularities within the sampling length and therefore the most direct of



$$R_a \text{ or } (CLA) = \frac{1}{\ell}\int_0^{\ell} |y|\, d\ell$$

$$RMS = \sqrt{\frac{1}{\ell}\int_0^{\ell} y^2\, d\ell}$$

FIG.1. PROFILE CURVE OF MACHINED SURFACE

all surface roughness values.

(ii) C.L.A. Measures:

The centre line average value, R_a, is the arithmetical average value of the departure of the whole of the profile, both above and below the mean line (taking all ordinates as positive) throughout the sample length ℓ, in a plane substantially normal to the surface. The basic formula is given in the figure.

Both the British Standard No.1134; 1950 and the American Standard B. 46-1955 are based on this measure, the quantity being called the centre-line-average (CLA) value in the British Standard and the arithmetic average (a.a.) value in the American Standard.

(iii) R.M.S. Measure.

The root-mean-square value, R.M.S., is the geometrical average value of the departure of the whole profile both above and below its mean line. The mathematical expression is

$$RMS = \sqrt{\frac{y_1^2 + y_2^2 + y_3^2 + \ldots\ldots y_n^2}{n}}.$$

The RMS value was formerly used in the U.S.A. standard (ASA B-46) but has in 1955 been replaced by the R_a value.

2.42. THE E-SYSTEM.

During the last few years another system, the E (envelope) system has been developed and is at present used as standard in some countries. This system is based on a "contacting envelope" instead of the mean line and is roughly built up in the following way:

A certain circle with radius R, which is normally 250 mm is rolled across the surface to be tested. The centre of the circle will describe a curve and this curve is displaced in a direction perpendicular to the geometrical profile to a position where it is contacting some of the highest peaks in the effective profile. The locus of centre for the rolling circle is in the position thus determined, called the "curve of form".

In a similar manner another circle with radius r, which is normally 25 mm. is now rolled across the surface. The locus of centre of this circle is also displaced in a direction perpendicular to the geometrical profile by such a degree that the curve is touching some of the highest peaks in the effective profile. In this position the locus of centre for the small circle is called the "contacting envelope". Now in this basic measuring system it is rather easy to distinguish between the different kinds of deviation of the effective profile (effective surface) from the geometrical profile.

The area between the geometrical profile and the "curve of form" represents the errors of form; the area between the "curves of form and the "contacting envelope" represents the waves (secondary texture) and the area between the "contacting envelope" and the effective profile represents the roughness (primary texture).

From graphic recording of the surface, the "contacting envelope" is much easier to determine than is the mean line. It may, however, be pointed out that at present no instrument has been designed to measure according to E-System.

2.5. MEASUREMENT OF SURFACE QUALITY.

There are many methods available for measuring surface conditions. Some of them are:-

A. OPTICAL METHODS:

(i) Profile microscope.
(ii) Comparison microscope.
(iii) Optical flat.
(iv) Photographs.

B. ELECTRICAL METHODS:

(i) Surface analyser.
(ii) surface comparator.

C. CHEMICAL METHODS:

(i) Fax Film surface comparator.

D. MECHANICAL METHODS:

(i) Profilometer or Talysurf.
(ii) RODI (Roughness Operated Displacement) Integrator.
(iii) Philips Roughness Tester.

Since the Philips Roughness Tester Model PR-9150 available in the Department of Mechanical Engineering, University of Roorkee, Roorkee, was out of order, 'Talysurf' was used for testing the roughness of the machined pieces. In passing it may be stated that this was the only surface roughness measuring instrument available near Roorkee. The instrument is with the Indian Institute of Technology, Hauz Khas, New Delhi. The details of this instrument are given in Chapter III.

CHAPTER III

EXPERIMENTAL SETUP & PROCEDURE

EXPERIMENTAL SET-UP AND PROCEDURE

3.1. DESCRIPTION OF SET-UP:

Photograph No.1 shows the details of the set-up for the experimentation. The Universal Milling Machine Model 2AGU (Adcock and Shipley) was selected for the experiment because of its greater horse-power rated capacity and its automatic feed mechanism. A high speed steel milling cutter with straight teeth was used because it was a suitable cutter available. The workpieces were prepared from mild steel B.H.N.148, Fig. 2. shows the details of a specimen test piece.In order to utilize the full grip of the vice, the 6" long test pieces were prepared and the width was kept as half inch so as to allow overhang for the delicate corners of the milling cutter tooth.

The various instrument used in the experiment are detailed below:-

3.11. VIBRATION PICKUP:

With the progress in electronics and development of new electronic equipment, measurement and analysis of vibrations have become very convenient. Most of the pick-ups used today are generally based on electronic principles. However, out of the pick-ups available in the Instrumentation laboratory of the Mechanical Engineering Department, the CEC's vibration transducer was found suitable to pick-up the vibrations. This transducer is of 4—102A type, linear

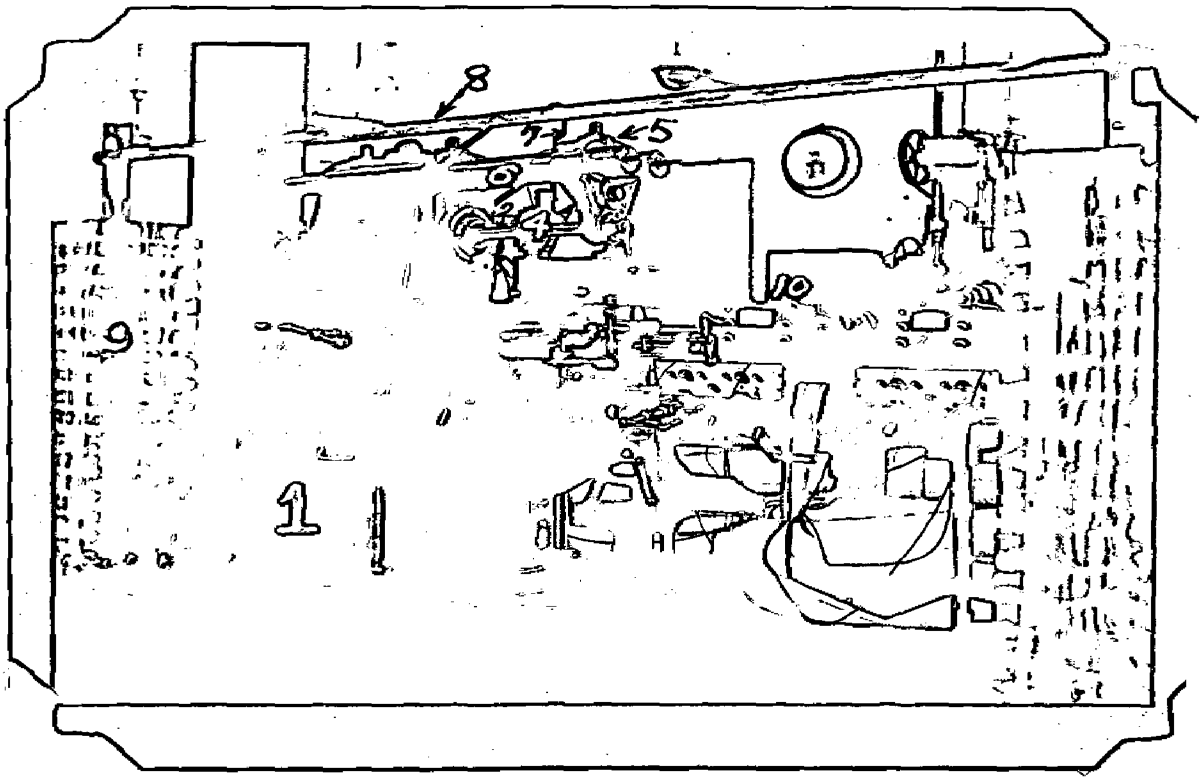


PHOTO NO.1: EXPERIMENTAL SET-UP

1. Milling Machine. 2. Arbor.
3. Milling cutter. 4. Vibration pick-up.
5. Clamp. 6. Overhanging arms.
7. Clamp bar (8) Horizontal bar.
9. Brick columns. 10. Vibration motor.

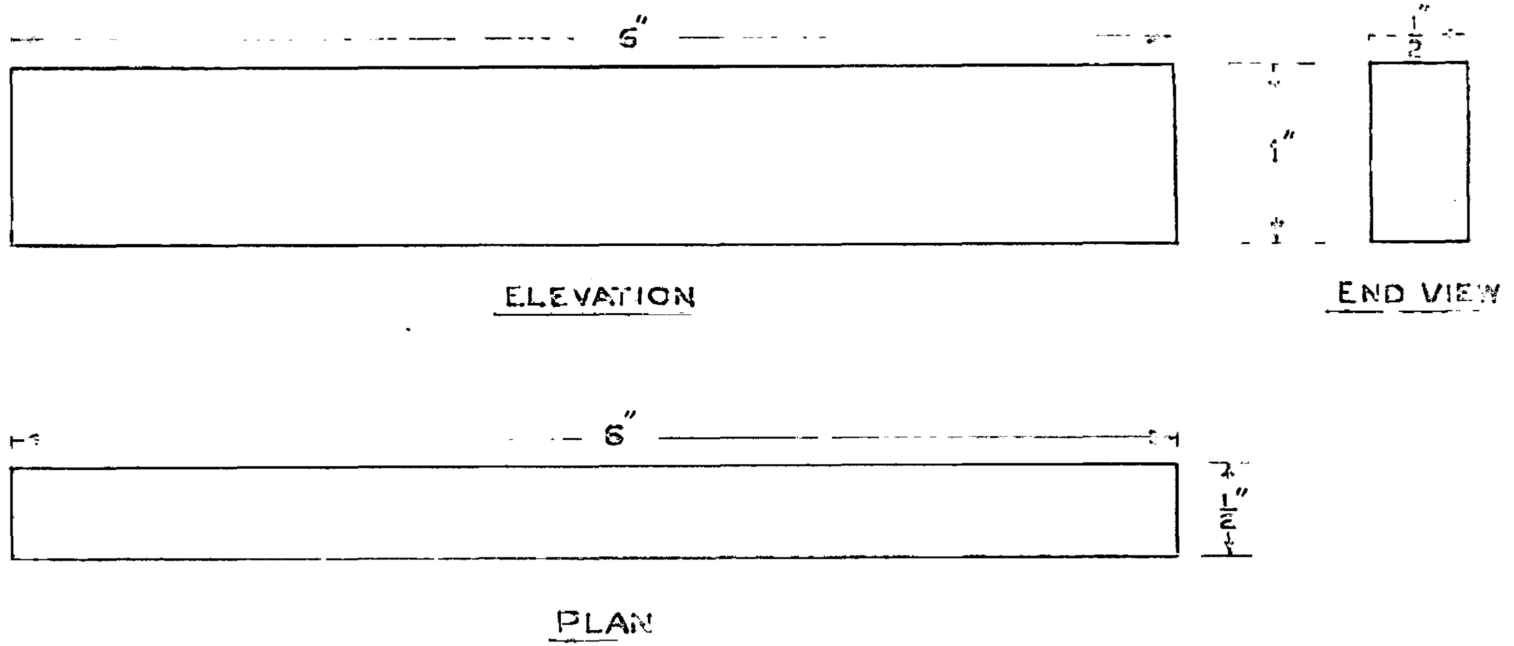


FIG. 2 TEST PIECE (M.S. B.H.N. 148)

velocity, omnidirectional with a 18-inch integral cable terminating in a cannon CK 3 — 12 connector.

3.12. VIBRATION METER:

The Type 1— 117 vibration meter (CEC) used in these tests is a compact and accurate indicating-type instrument which provides a convenient means for measuring the average velocity (inches per second) and the peak-to-peak displacement (mils) of mechanical vibrations when it is employed with self-generating linear or torsional pick-ups. The system (pick-up with vibration meter) may be used for vibration studies of machine tools, presses, elevators and buildings — any place where vibration may occur and should be studied if failure is to be avoided. Fig. 3 shows the suggested circuit for use of CEC Vibration meter.

3.13. SURFACE MEASURING INSTRUMENT:

Model 3 'Talysurf' (Photo.2) was used for measuring the roughness of surfaces of the test pieces milled at different cutting conditions.

The 'Talysurf' instrument makes use of a sharply pointed stylus to trace the profile of the surface irregularities. A flat shoe or rounded skid is generally used to provide a datum. The pick-up unit carrying the stylus and the flat shoe or skid or datum attachment is traversed across

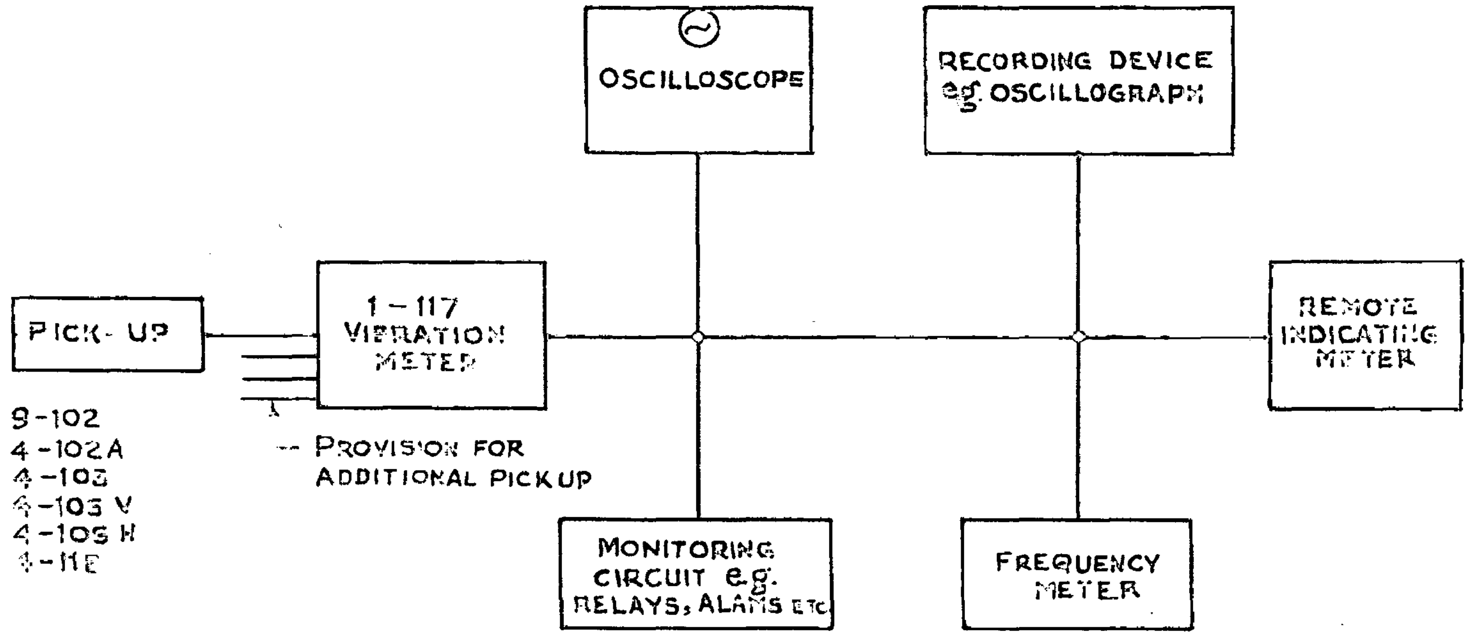


FIG.3 SUGGESTED CIRCUITS FOR USE OF CEC VIBRATION METER

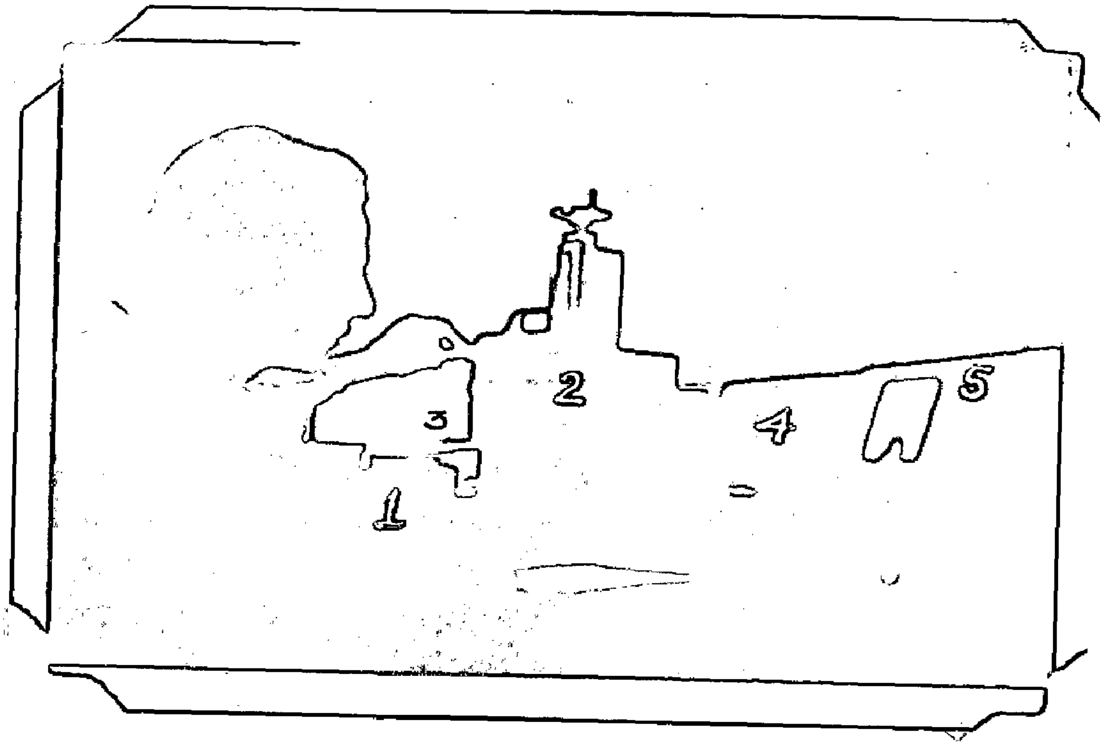


PHOTO-No.2. "TALYSURF" Model 3.

1. Stand. 2. Gear box. 3. Pick-up.
4. Amplifier. 5. Average Motor.

the surface by means of a motorised driving unit (the Gear Box). By means of an electro-magnetic transducer actuated by the stylus, its up and down movements relative to the shoe are converted into corresponding changes in an electric current. These changes are amplified by means of a valve amplifier and are then used to control:

(i) A Graph Recorder
(Not shown in the photograph).

(ii) An Average Meter, which shows the centre line average (C.L.A.) index of all irregularities coming within a prescribed length of surface.

Detailed specifications and description of all the equipment and instruments used in this experimentation are given in Appendix — A.

3.2. TEST PROCEDURE:

Before starting the experiment it was ensured that the milling machine was in good working condition by checking its feed and speed ranges, lubrication and belt drive. The milling cutter and clamp were mounted on the arbor at a specified distance from the spindle nose, the pick-up assembly (Fig.4) being mounted just close to the cutter position. The vibration pick-up was kept in vertical position by two steel rings having exact sliding fit with the body of the pick-up. These rings were screwed to one end of a clamp bar, the other end of which was fastened by screws to

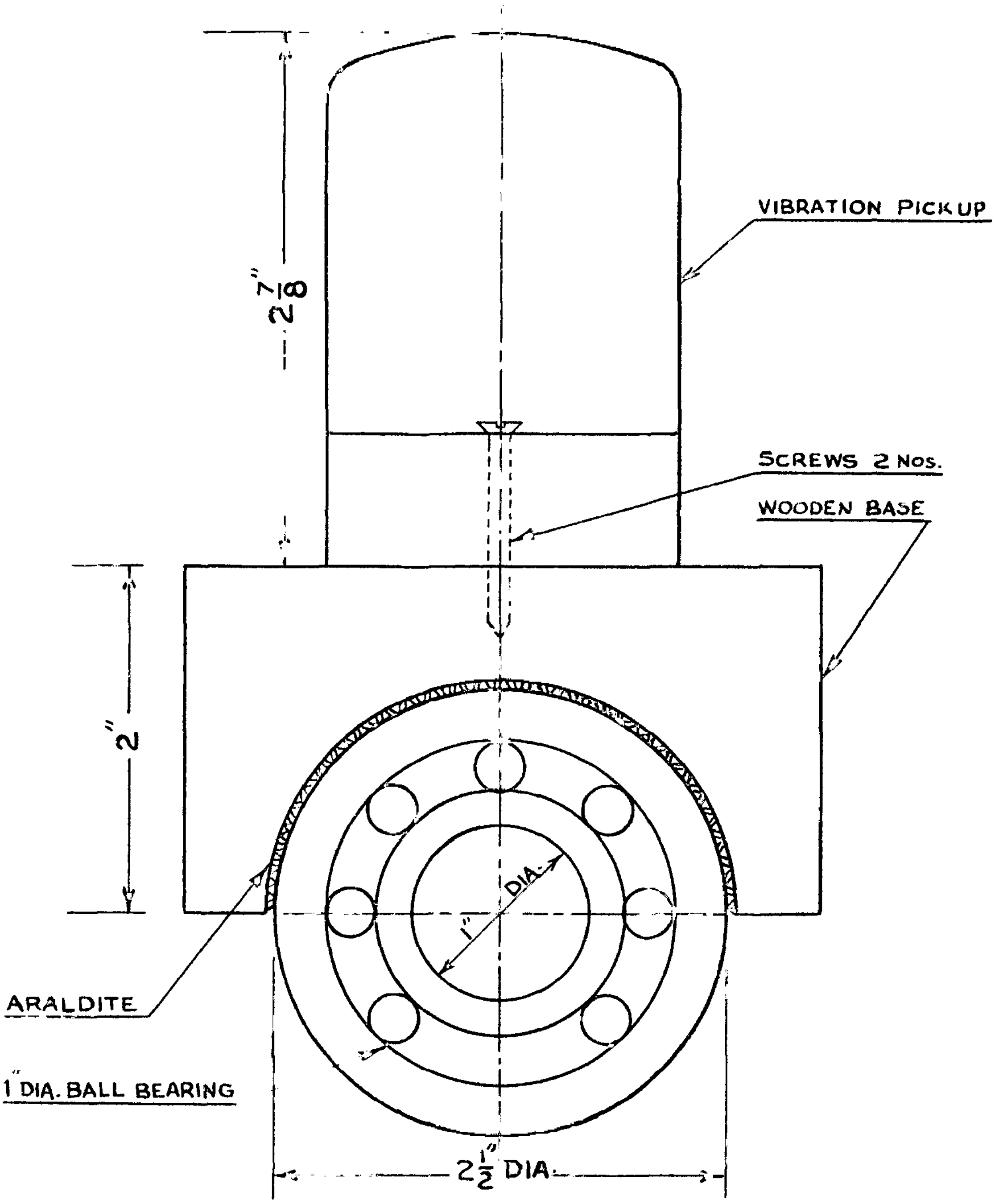


FIG. 4 VIBRATION PICK UP ASSEMBLY

SCALE: FULL SIZE

horizontal bar supported by two brick columns on either side of the machine. The pick-up was connected to the vibration meter with the help of leads provided with the instruments. The workpiece was securely held in the vise and its surface to be milled was made parallel to the table of the machine. The workpiece was brought exactly under the milling cutter. The machine was run at a predetermined speed, feed and depth of cut. Simultaneously the meter was also put on to indicate the amplitude of vibrations during the operations.

The above procedure was repeated for a number of workpieces by changing the cutting conditions for every observation. After milling, the quality of surface finish obtained on the workpiece was tested with the help of Talysurf surface measuring instrument as detailed above in para 3.13. The Talysurf gave centre line average (C.L.A) values of surface roughness in microns. Table 1 (Chapter IV) is a detailed record of all the observations and calculations made in the test.

In order that no disturbance due to the running of other machine tools may come in, the tests were carried out at the time when no other machine nearby was working. Only conventional method of milling i.e. up-milling was employed for all the tests. In order to increase tool life cutting fluid was used.

It may be stated here that after the milling operation every test piece was cleaned, greased and properly wrapped in packing paper. The pieces were carefully packed in a wooden box. The packed pieces were carried to Indian Institute of Technology, New Delhi for testing the roughness of the surface.

CHAPTER IV

OBSERVATIONS AND RESULTS

OBSERVATIONS AND RESULTS

4.1. SELECTION OF PARAMETERS:

To plan in advance the efficient employment of milling facilities it is necessary to have the following information available:

material of the workpiece and its size;
capacity of the machine;
speed and feed ranges;
diameter of the cutter used;
production rate etc.

In our problem the material of the test pieces was mild steel B.H.N.148. The most generally recommended values of speed and feed for milling this material are:

surface speed, V : 60-120 feet per min.
feed per tooth, F_t: upto 0.02 inches.

Also, diameter of the cutter used is = 6 inches.
And rated horse power of the machine is = 3 H.P.

All the calculations were made with the help of chip volume, speed and feed calculator (Kearney and Trecker Milwaukee). However, the series of steps that are involved are given below:

(i) Select Cutting Speed:

The cutting speed of a milling cutter is the peripheral linear speed resulting from rotation. It is a product of cutter circumference and number of revolutions per minute, usually expressed in feet per minute (f.p.m)or surface feet per minute (s.f.p.m).

$$V = \frac{\pi DN}{12}$$

where,

V = cutting speed f.p.m. or s.f.p.m.

π = 3.1416.

D = diameter of cutter, inches.

N = revolutions per minute of cutter (r.p.m.)

whence,

$$N = \frac{V}{D \times \frac{\pi}{12}}$$

$$= \frac{V}{D \times 0.26}$$

$$= \frac{V}{0.26D} \text{ r.p.m.}$$

(ii) <u>Determine the feed rate:</u>

The rate at which the workpiece advances past the cutter is the feed rate, measured in inches per minute(i.p.m).

$$F = F_t . n . N.$$

where,

F_t = feed per tooth, inches.

n = number of cutter teeth.

N = revolutions per minute of cutter.

(iii) <u>Determine the metal removal rate:</u>

The metal removal rate for all types of milling is the volume of metal removed in a unit of time, customarily expressed in cubic inches per minute (cim).

$\therefore$ cim = $W \times d \times F$

where, W = width of cut, inches.

d = depth of cut, inches.

F = feed rate, inches per minute

(iv) Determine the power required:

Milling machines like other machine tools absorb part of the power exerted on them. This is due to the frictional losses, gear-train inefficiencies, mechanical condition etc. Consequently the horsepower required in a milling operation is composed of the power needed for actual cutting or metal removal and the power needed to overcome friction in the spindle and feed mechanisms and other losses. For best performance, these power requirements should not exceed the rated horse power of the driving motor.

The horsepower required at the cutter is given by

$H.P_c$ = cim x

where, α = horsepower at the cutter when the rate of metal removal is one cim.

Therefore, the horsepower required for a cut may be expressed as

$$H.P_c = W \times d \times F \times \alpha.$$

$$= W \times d \times F_t \times n \times N \times \alpha.$$

$$= \text{Rated } H.P. \times \eta.$$

where, $H.P_c$ = horsepower available at the cutter.

η = overall efficiency of the milling machine.

The value of α varies with kind of material and type of milling.

Another method of calculating horsepower required for milling is by use of 'K' factor.

'K' FACTOR

Ratios of metal removal rate per horsepower (cim per h.p. at the cutter) have been established for various materials.

$$K = \frac{cim}{H.P_c}$$

$$= \frac{W x d x F}{H.P_c}$$

or

$$H.P_c = \frac{W \times d \times F}{K}$$

Thus total horsepower required at the cutter equals amount of material removed per minute divided by K.

The K-factor, like α, varies with type and hardness of material; also for the same material it varies with the feed per tooth increasing as the chip thickness increases. Time consuming trials are required to determine the quantities involved because in each case the K-factor represents a particular rate of metal removal and not a general or average rate.

To make available a quick approximation of the total power requirements, a milling machine selector table has been devised Table 27-9.(21) which estimates the metal removed in cubic inches per minute for various rated horsepowers of the machines. Corresponding to the 3 horsepower rated capacity of a milling machine the maximum metal removal rate (cim) for mild steel is 0.78. All calculations made for power requirements are according to this figure.

The computation of all the values corresponding to different cutting conditions employed were made with the help of volume, speed and feed calculator. These values have been tabulated in Table - I given at the end of this chapter.

6.2. SPECIMEN CALCULATIONS :

Let the cutting speed be = 100 fpm.

$$\therefore \text{ R.P.M. of the cutter } = \frac{V}{0.26D}$$

$$= \frac{100}{0.26 \times 6}.$$

$$= 64.$$

$$= 67$$ — the nearest r.p.m. value available on the machine.

Now, corresponding to 67 r.p.m. the cutting speed can be found.

$$\text{New cutting speed} = \frac{\pi DN}{12}$$

$$= 0.26D \times N$$

= 0.26 x 6 x 67

= 106 f.p.m.

Also, number of teeth of cutter = 20

And if feed rate is = 5 inches per minute,

then, feed per tooth = $\frac{F}{n.N}$

= $\frac{5}{20x67}$ inches.

= .0037 inches.

Now, width of cut = 0.5 inches

And, if depth of cut = 0.094 inches

then, metal removal rate, cim = W x d x F

= 0.5 x 0.094 x 5.

= 0.236.

All the values were calculated like this and tabulated in Table — I. It may be observed that the first five speeds available on the machine viz. 30, 41, 54, 67, and 88 r.p.m. approximately cover the recommended ranges of speed and feed.

Table -I contains all the calculated and observed values of the data pertaining to this experiment,

4.3. DESCRIPTION OF GRAPHS:

In order to study the effect of different parameters on the surface roughness of the workpiece, the observed data (Table 1) has been presented in the form of graphs as described below:

Figure 5 is a plot of the amplitude of the cutter and surface roughness keeping feed per tooth constant. The feed per tooth has been kept constant because cutting speed and feed are directly related to it whereas other cutting conditions affect the amplitude of the cutter only.

Figure 6 is a graph showing the influence of cutter amplitude on the surface roughness in general where effect of feed per tooth is not taken into account for close ranges. The scatter of the points is due to the different feeds per tooth included.

Figures 7 to 9 show the effect of speed, feed and depth of cut on the surface roughness at different settings as indicated in the individual graphs.

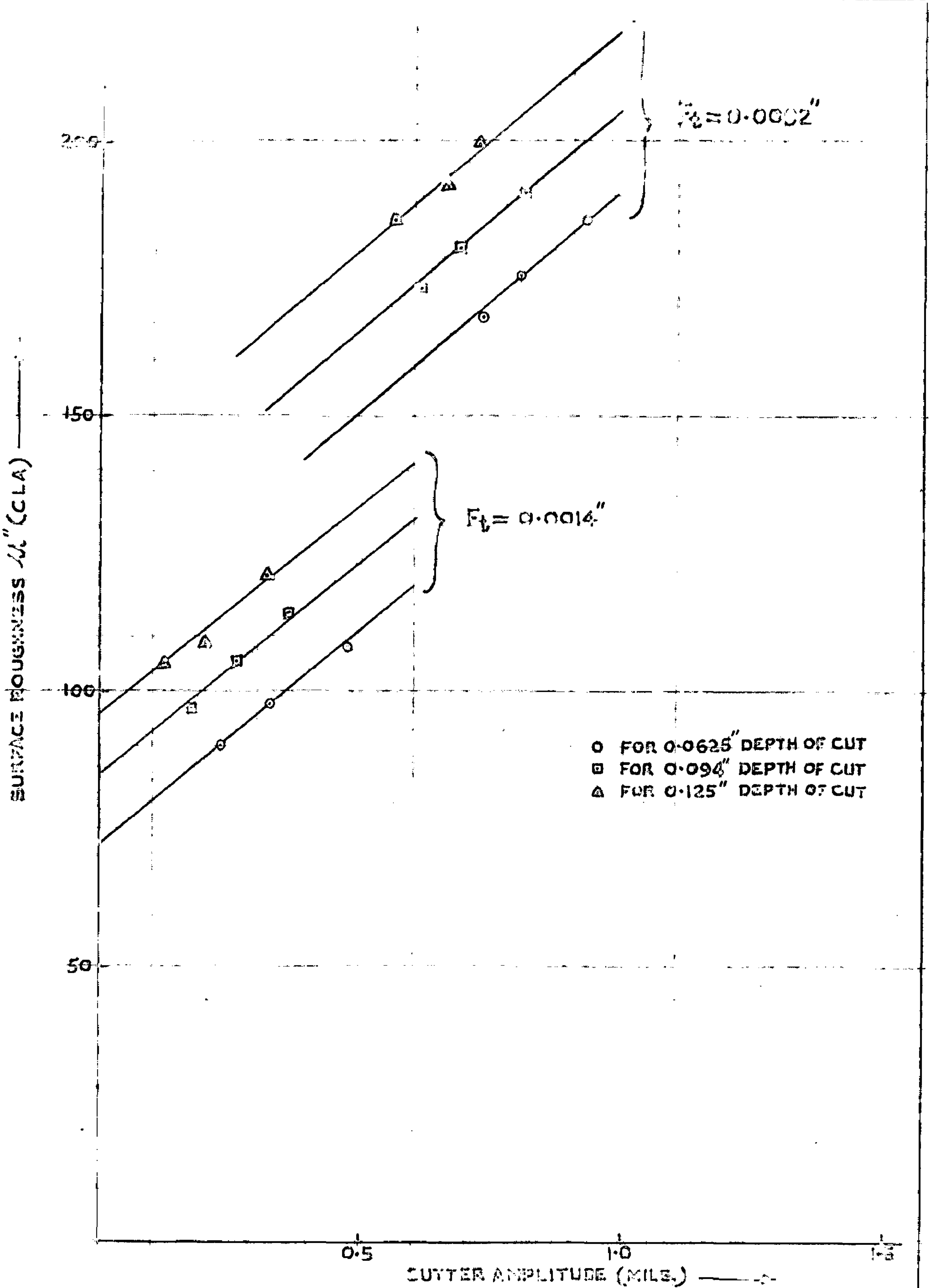


FIG.2 EFFECT OF CUTTER AMPLITUDE ON SURFACE ROUGHNESS AT F_t CONSTANT

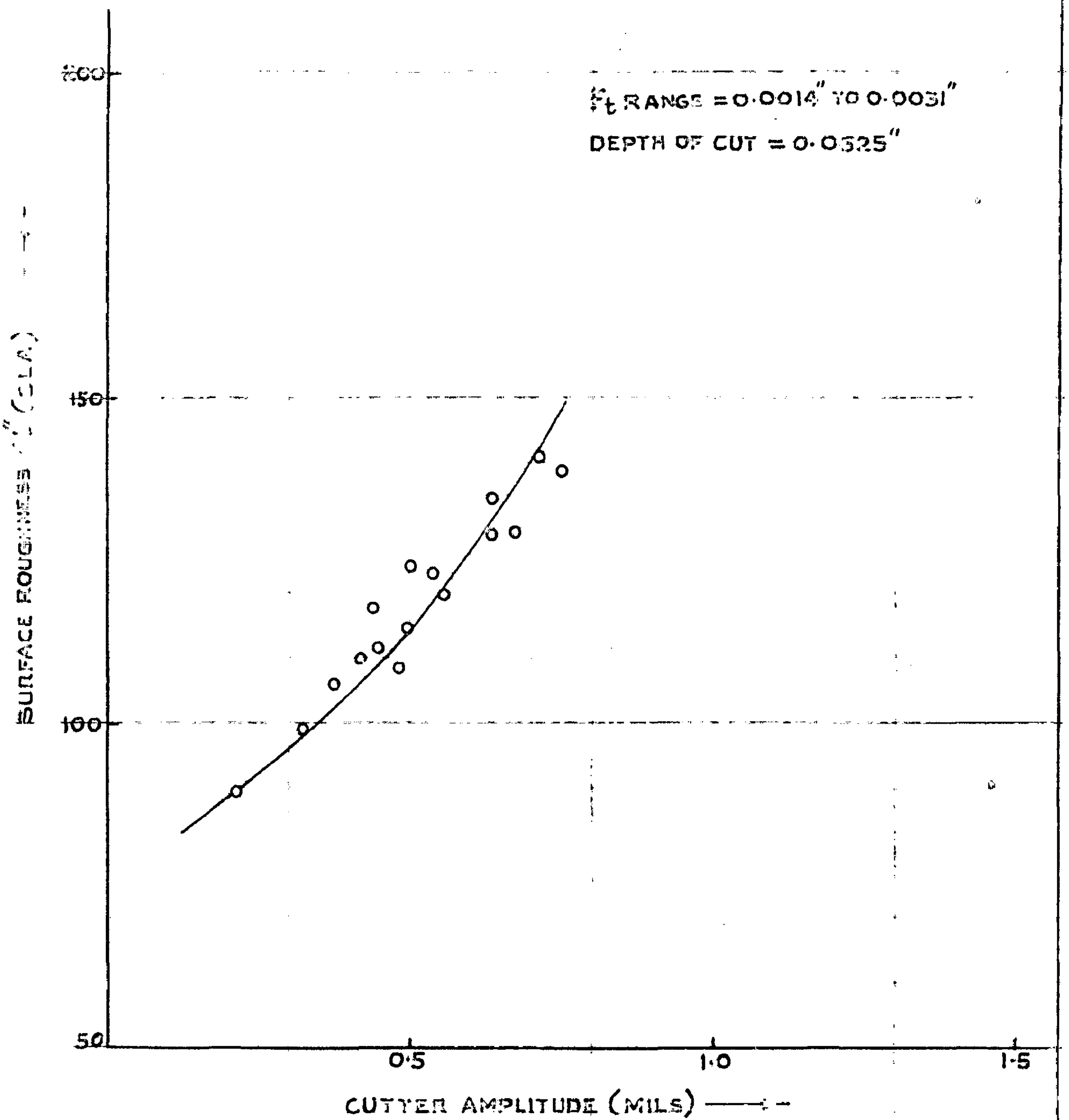


FIG. 6 VARIATION OF SURFACE ROUGHNESS WITH CUTTER AMPLITUDE

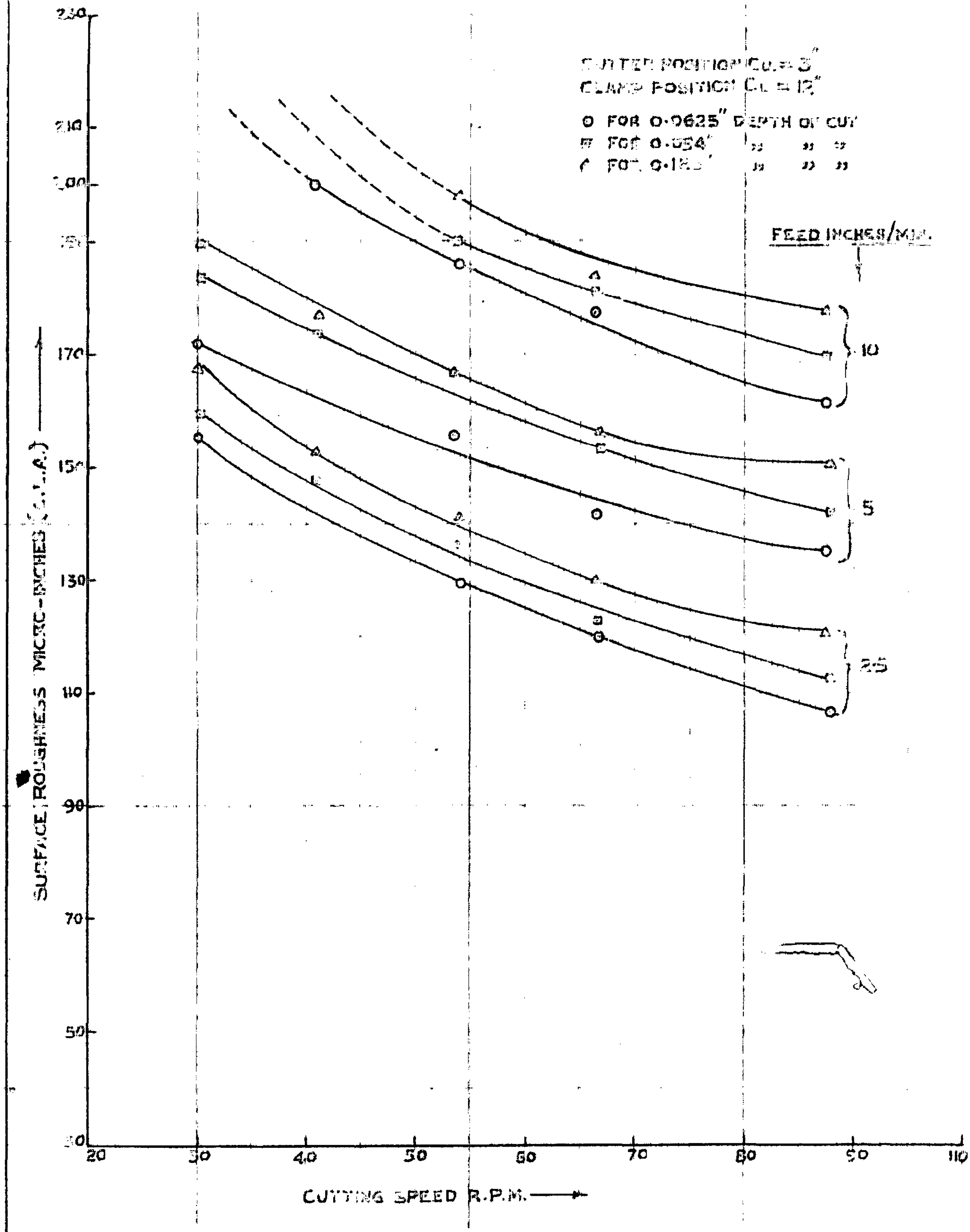


FIG.7 CUTTING SPEED V. SURFACE ROUGHNESS

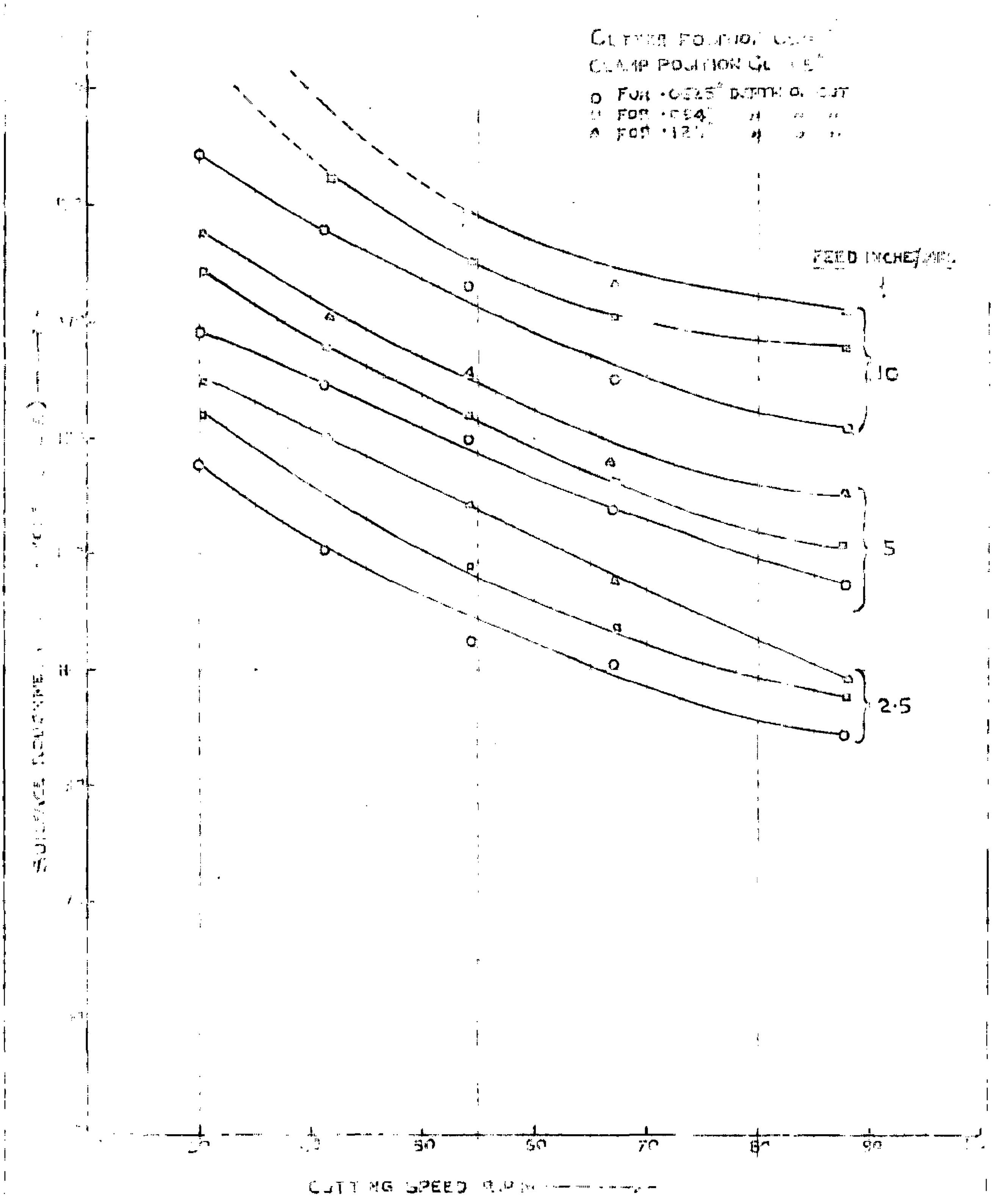


Fig.6 CUTTING SPEED v. SURFACE ROUGHNESS

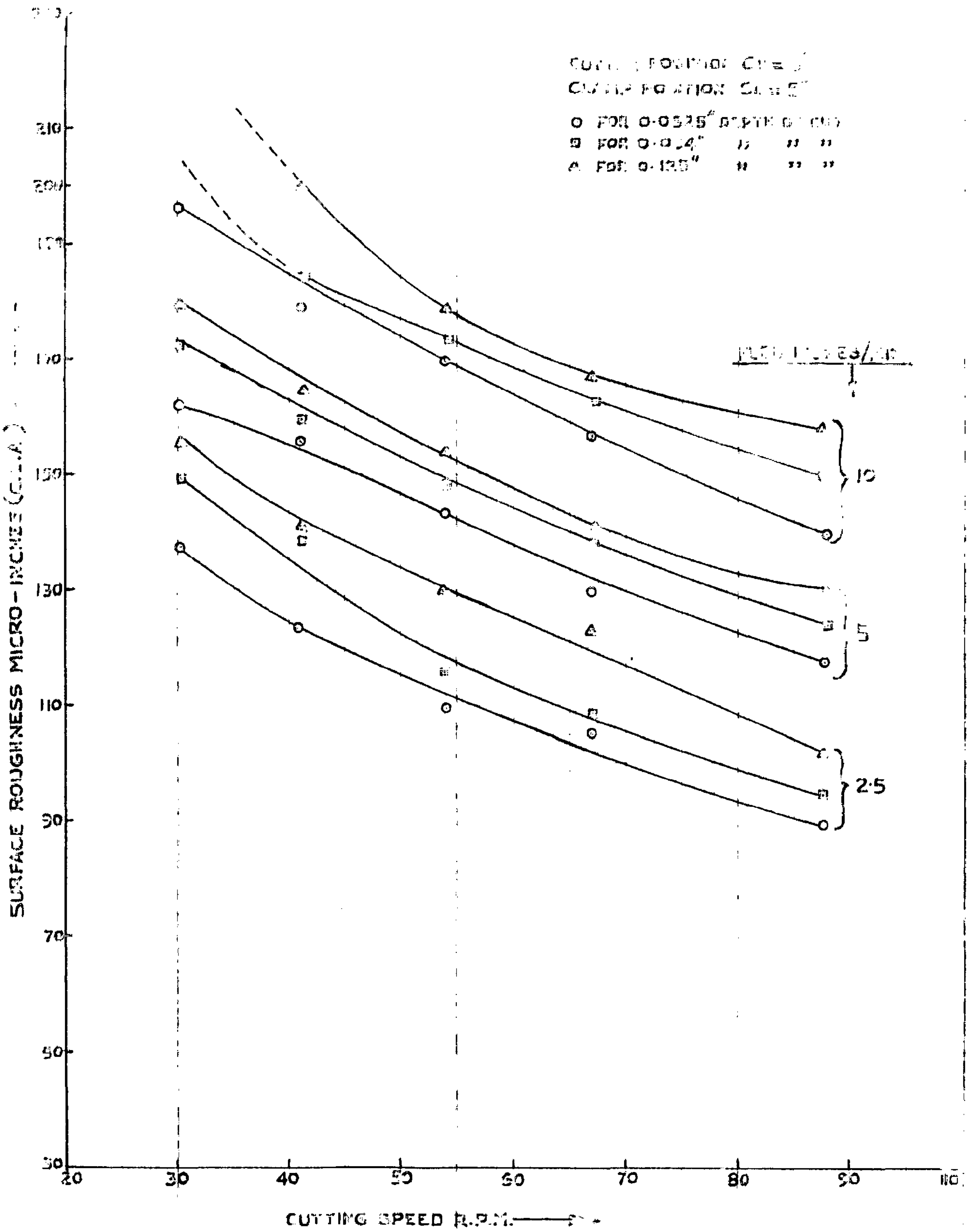


FIG.3 CUTTING SPEED Vs SURFACE ROUGHNESS

Table - 1

Cutter Position = C_a = 3"

Clamp Position = C_L = 12"

S.No	SPEED			FEED		Depth of cut inches	Cutter Vibration amplitude mils.	Surface roughness micro-in
	R.P.M. N.	F.P.M. V.	IN.P.M. S	IN.PER MIN. F	IN. PER TOOTH F_t	d		CLA(R_a)
1	2	3	4	5	6	7	8	9
1.	30	47.0	564	2.5	.0042	.0625	0.90	155
2.	41	64.5	774	2.5	.0031	.0625	0.75	140
3.	54	85.0	1020	2.5	.0023	.0625	0.67	130
4.	67	106.0	1272	2.5	.0019	.0625	0.55	120
5.	88	139.0	1668	2.5	.0014	.0625	0.47	108
6.	30	47.0	564	2.5	.0042	.094	0.78	160
7.	41	64.5	774	2.5	.0031	.094	0.65	148
8.	54	85.0	1020	2.5	.0023	.094	0.60	137
9.	67	106.0	1272	2.5	.0019	.094	0.46	123
10.	88	139.0	1668	2.5	.0014	.094	0.35	114
11.	30	47.0	564	2.5	.0042	.125	0.68	168
12.	41	64.5	774	2.5	.0031	.125	0.51	153
13.	54	85.0	1020	2.5	.0023	.125	0.48	141
14.	67	106.0	1272	2.5	.0019	.125	0.42	130
15.	88	139.0	1668	2.5	.0014	.125	0.31	121
16.	30	47.0	564	5.0	.0084	.0625	1.07	172
17.	41	64.5	774	5.0	.0062	.0625	0.98	165
18.	54	85.0	1020	5.0	.0046	.0625	0.88	156
19.	67	106.0	1272	5.0	.0037	.0625	0.71	142
20.	88	139.0	1668	5.0	.0028	.0625	0.64	136
21.	30	47.0	564	5.0	.0084	.094	0.90	184
22.	41	64.5	774	5.0	.0062	.094	0.84	174
23.	54	85.0	1020	5.0	.0046	.094	0.76	165
24.	67	106.0	1272	5.0	.0037	.094	0.68	154
25.	88	139.0	1668	5.0	.0028	.094	0.58	142

1	2	3	4	5	6	7	8	9
26.	30	47.0	564	5.0	.0084	.125	0.80	190
27.	41	64.5	774	5.0	.0062	.125	0.70	176
28.	54	85.0	1020	5.0	.0046	.125	0.62	166
29.	67	106.0	1272	5.0	.0037	.125	0.59	156
30.	88	139.0	1668	5.0	.0026	.125	0.52	151
31.	30	47.0	564	10.0	.0170	.0625	1.30	*
32.	41	64.5	774	10.0	.0125	.0625	1.13	200
33.	54	85.0	1020	10.0	.0092	.0625	0.92	186
34.	67	106.0	1272	10.0	.0076	.0625	0.84	178
35.	88	139.0	1668	10.0	.0056	.0625	0.70	161
36.	30	47.0	564	10.0	.0170	.094	1.18	*
37.	41	64.5	774	10.0	.0125	.094	1.10	*
38.	54	85.0	1020	10.0	.0092	.094	0.80	190
39.	67	106.0	1272	10.0	.0076	.094	0.73	181
40.	88	139.0	1668	10.0	.0056	.094	0.65	172
41.	30	47.0	564	10.0	.017	.125	1.00	*
42.	41	64.5	774	10.0	.0125	.125	0.80	*
43.	54	85.0	1020	10.0	.0092	.125	0.72	200
44.	67	106.0	1272	10.0	.0076	.125	0.61	183
45.	88	139.0	1668	10.0	.0056	.125	0.57	178

Cutter Position = C_u = 3"

Clamp Position = C_L = 9"

46.	30	47.0	564	2.5	.0042	.0625	0.77	145
47.	41	64.5	774	2.5	.0031	.0625	0.63	130
48.	54	85.0	1020	2.5	.0023	.0625	0.49	115
49.	67	106.0	1272	2.5	.0019	.0625	0.45	111
50.	88	139.0	1668	2.5	.0014	.0625	0.32	98

* R_a value above 200

1	2	3	4	5	6	7	8	9
51.	30	47.0	564	2.5	.0042	.094	0.70	154
52.	41	64.5	774	2.5	.0031	.094	0.50	136
53.	54	85.0	1020	2.5	.0023	.094	0.47	128
54.	67	106.0	1272	2.5	.0019	.094	0.37	117
55.	88	139.0	1668	2.5	.0014	.094	0.25	105
56.	30	47.0	564	2.5	.0042	.125	0.57	160
57.	41	64.5	774	2.5	.0031	.125	0.48	150
58.	54	85.0	1020	2.5	.0023	.125	0.45	138
59.	67	106.0	1272	2.5	.0019	.125	0.35	125
60.	88	139.0	1668	2.5	.0014	.125	0.19	108
61.	30	47.0	564	5.0	.0084	.0625	0.98	168
62.	41	64.5	774	5.0	.0062	.0625	0.91	159
63.	54	85.0	1020	5.0	.0046	.0625	0.80	150
64.	67	106.0	1272	5.0	.0037	.0625	0.65	137
65.	88	139.0	1668	5.0	.0028	.0625	0.50	125
66.	30	47.0	564	5.0	.0084	.094	0.83	178
67.	41	64.5	774	5.0	.0062	.094	0.73	165
68.	54	85.0	1020	5.0	.0046	.094	0.64	154
69.	67	106.0	1272	5.0	.0037	.094	0.54	142
70.	88	139.0	1668	5.0	.0028	.094	0.46	131
71.	30	47.0	564	5.0	.0084	.125	0.75	185
72.	41	64.5	774	5.0	.0062	.125	0.62	170
73.	54	85.0	1020	5.0	.0046	.125	0.55	161
74.	67	106.0	1272	5.0	.0037	.125	0.45	146
75.	88	139.0	1668	5.0	.0028	.125	0.42	142
76.	30	47.0	564	10.0	.0170	.0625	1.20	*
77.	41	64.5	774	10.0	.0125	.0625	0.95	192
78.	54	85.0	1020	10.0	.0092	.0625	0.80	176
79.	67	106.0	1272	10.0	.0076	.0625	0.72	167
80.	88	139.0	1668	10.0	.0056	.0625	0.63	156

1	2	3	4	5	6	7	8	9
81	30	47.0	564	10	.0170	0.094	1.15	*
82	41	64.5	774	10	.0125	0.094	0.80	194
83	54	85.0	1020	10	.0092	0.094	0.68	180
84	67	106.0	1272	10	.0076	.094	0.63	173
85	88	139.0	1668	10	.0056	.094	0.58	168
86	30	47.0	564	10	.0170	.125	0.95	*
87	41	64.5	774	10	.0125	.125	0.72	*
88	54	85.0	1020	10	.0092	.125	0.66	192
89	67	106.0	1272	10	.0076	.125	0.52	176
90	88	139.0	1668	10	.0056	.125	0.48	172
		Cu = 3"		C_L =	6"			
91	30	47.0	564	2.5	.0042	.0625	0.68	138
92	41	64.5	774	2.5	.0031	.0625	0.54	124
93	54	85.0	1020	2.5	.0023	.0625	0.42	110
94	67	106.0	1272	2.5	.0019	.0625	0.38	106
95	88	139.0	1668	2.5	.0014	.0625	0.22	90
96	30	47.0	564	2.5	.0042	.094	0.64	150
97	41	64.5	774	2.5	.0031	.094	0.43	129
98	54	85.0	1020	2.5	.0023	.094	0.33	116
99	67	106.0	1272	2.5	.0019	.094	0.28	108
100	88	139.0	1668	2.5	.0014	.094	0.17	99
101	30	47.0	564	2.5	.0042	.125	0.52	156
102	41	64.5	774	2.5	.0031	.125	0.40	141
103	54	85.0	1020	2.5	.0023	.125	0.36	130
104	67	106.0	1272	2.5	.0019	.125	0.33	123
105	88	139.0	1668	2.5	.0014	.125	0.11	104
106	30	47.0	564.	5.0	.0084	.0625	0.92	162
107	41	64.5	774	5.0	.0062	.0625	0.86	156
108	54	85.0	1020	5.0	.0046	.0625	0.71	144
109	67	106.0	1272	5.0	.0037	.0625	0.56	130
110	88	139.0	1668	5.0	.0028	.0625	0.44	118

1	2	3	4	5	6	7	8	9
111	30	47	564	5	.0084	.094	0.78	173
112	41	64.5	774	5	.0062	.094	0.66	160
113	54	85.0	1020	5	.0046	.094	0.58	149
114	67	106.0	1272	5	.0037	.094	0.48	136
115	88	139.0	1668	5	.0028	.094	0.39	124
116	30	47.0	564	5	.0084	.125	0.69	180
117	41	64.5	774	5	.0062	.125	0.56	165
118	54	85.0	1020	5	.0046	.125	0.48	154
119	67	106.0	1272	5	.0037	.125	0.36	140
120	88	139.0	1668	5	.0028	.125	0.32	131
121	30	47.0	564	10	.0170	.0625	1.0	*
122	41	64.5	774	10	.0125	.0625	0.88	185
123	54	85.0	1020	10	.0092	.0625	0.73	168
124	67	106.0	1272	10	.0076	.0625	0.60	156
125	88	139.0	1668	10	.0056	.0625	0.46	140
126	30	47.0	564	10	.0170	.094	0.90	*
127	41	64.5	774	10	.0125	.094	0.69	184
128	54	85.0	1020	10	.0092	.094	0.60	173
129	67	106.0	1272	10	.0076	.094	0.45	160
130	88	139.0	1668	10	.0056	.094	0.42	150
131	30	47.0	564	10	.0170	.125	0.82	*
132	41	64.5	774	10	.0125	.125	0.75	*
133	54	85.0	1020	10	.0092	.125	0.56	186
134	67	106.0	1272	10	.0076	.125	0.43	168
135	88	139.0	1668	10	.0056	.125	0.40	165

1	2	3	4	5	6	7	8	9
		C_u = 6" ,		C_L = 12"				
136	30	47.0	564	2.5	.0042	.0625	1.29	*
137	41	64.5	774	2.5	.0031	.0625	1.18	*
138	54	85.0	1020	2.5	.0023	.0625	1.08	*
139	67	106.0	1272	2.5	.0019	.0625	0.95	189
140	88	139.0	1668	2.5	.0014	.0625	0.86	168
		C_u = 6"		C_L = 9"				
141	30	47.0	564	2.5	.0042	.094	1.25	*
142	41	64.5	774	2.5	.0031	.094	1.14	*
143	54	85.0	1020	2.5	.0023	.094	1.00	*
144	67	106.0	1272	2.5	.0019	.094	0.90	197
145	88	139.0	1668	2.5	.0014	.094	0.79	182

CHAPTER V

DISCUSSION & CONCLUSIONS

5.1- ANALYSIS AND CORRELATION OF DATA:

From the curves drawn in Figs. 7 to 9 it is obvious that the surface roughness is related to all the parameters taken into consideration during the tests. Mathematically, we say $R_a = F\ (S, F, d, C_u, C_L)$. Let us assume that the relation between variables considered is of the form

$$K_o = R_a^{\alpha} . S^{\beta} . F^{\gamma} . d^{\theta} . C_u^{\phi} . C_L^{\xi} .$$

where,

K_o = a constant.

R_a = surface roughness in micro-inches. (CLA value)

S = cutting speed in inches per minute.

F = feed rate in inches per minute.

d = depth of cut in inches.

C_u = cutter position measured from spindle nose, inches.

C_L = clamp position measured from spindle nose, inches.

$\alpha, \beta, \gamma, \theta \ldots$ = unknown constants.

Dimensionally, this is equal to:

$$K_o = (L)^{\alpha} . \left(\frac{L}{T}\right)^{\beta} . \left(\frac{L}{T}\right)^{\gamma} . (L)^{\theta} . (L)^{\phi} . L^{\xi} .$$

Equating the coefficients of L & T on both sides, we get

$$0 = \alpha + \beta + \gamma + \theta + \phi + \xi$$

$0 = -\beta - \gamma.$

or $\gamma = -\beta$ .... (1)

and $0 = \alpha + \theta + \phi + \xi$ .... (2)

Let π_1, π_2, π_3 & π_4 be the dimensionless parameters, then:

	α	β	γ	θ	ϕ	ξ
π_1	1	0	0	-1	0	0
π_2	0	-1	+1	0	0	0
π_3	0	0	0	1	-1	0
π_4	0	0	0	0	1	-1

whence

$\pi_1 = \frac{R_a}{d}$, a non-dimensional factor.

$\pi_2 = \frac{F}{S}$, a non-dimensional factor.

$\pi_3 = \frac{d}{C_u}$, a non-dimensional factor.

$\pi_4 = \frac{C_u}{C_L}$, a non-dimensional factor.

Let $F(\pi_1, \pi_2, \pi_3, \pi_4) = K$.

or $\pi_1 = K (\pi_2)^m (\pi_3)^n (\pi_4)^p$. .... (3)

where K, m, n, p are unknown constants, and π_1, π_2, π_3, π_4, are non-dimensional groups.

Now, varying the two variables — one π_1 and any one of the other three, keeping the rest constants, we get three equations:

$$\pi_1 = K_1 \, (\pi_2)^m \qquad \ldots (4)$$

$$\pi_1 = K_2 \, (\pi_3)^n \qquad \ldots (5)$$

$$\pi_1 = K_3 \, (\pi_4)^p \qquad \ldots (6)$$

where $K_1 = K \left(\frac{d}{C_u} \right)^n \left(\frac{C_u}{C_L} \right)^p$ = a constant.

$K_2 = K \left(\frac{F}{S} \right)^m \left(\frac{C_u}{C_L} \right)^p$ = a constant.

$K_3 = K \left(\frac{F}{S} \right)^m \left(\frac{d}{C_u} \right)^n$ = a constant.

Now Figs. 10 to 12 are respectively the plots of equations (4), (5), & (6) whence the values of m, n & p and K_1, K_2 & K_3 can be determined. For sake of illustration let us consider equation (4):

$$\pi_1 = K_1 (\pi_2)^m$$

Taking logs. of both sides, we get :

$$\log \pi_1 = \log K_1 + m \log \pi_2 .$$

or $\log \frac{R_a}{d} = \log K_1 + m \log \left(\frac{F}{S} \right)$

This is obviously an equation of a straight line(cf.y=mx+c). To plot this, we choose $\log \left(\frac{R_a}{d} \right)$ as ordinate and $\log \left(\frac{F}{S} \right)$ as abscissa, including only those values of $\left(\frac{R_a}{a} \right)$ and $\left(\frac{F}{s} \right)$ for which $\frac{d}{C_u}$ and $\frac{C_u}{C_L}$ are constants e.g. we can consider first five observations from Table-1.

	$Y = \log \frac{R_a}{d}$	$X = \log \frac{F}{S}$.
1.	$\log \frac{.000155}{.0625} = \bar{4}.190-\bar{2}.796$ $= -2.60$	$\log \frac{2.5}{564} = 0.398 - 2.751$ $= -2.35$
2.	$\log \frac{.000140}{.0625} = \bar{4}.158-\bar{2}.796$ $= -2.64$	$\log \frac{2.5}{774} = 0.398-2.889$ $= -2.49$
3.	$\log \frac{.000130}{.0625} = \bar{4}.114-\bar{2}.796$ $= -2.68$	$\log \frac{2.5}{1020} = 0.398-3.009$ $= -2.61.$
4.	$\log.\frac{.000120}{.0625} = \bar{4}.079-\bar{2}.796$ $= -2.72$	$\log \frac{2.5}{1272} = 0.398-3.105$ $= -2.70$
5.	$\log \frac{.000108}{.0625} = \bar{4}.033-\bar{2}.796$ $= -2.76$	$\log \frac{2.5}{1668} = 0.398-3.22$ $= -2.82.$

These points constitute the line drawn in Fig.10.

Now we have to find the values of m — the slope of this line, and of $\log k_1$ - the intercept made by the line on y - axis.

To this end, take any two points on the line say, P_1 $(-2.57, -2.67)$ & P_2 $(-2.70, -2.71)$,

then:

$$m = \frac{y_1 - y_2}{x_1 - x_2}$$

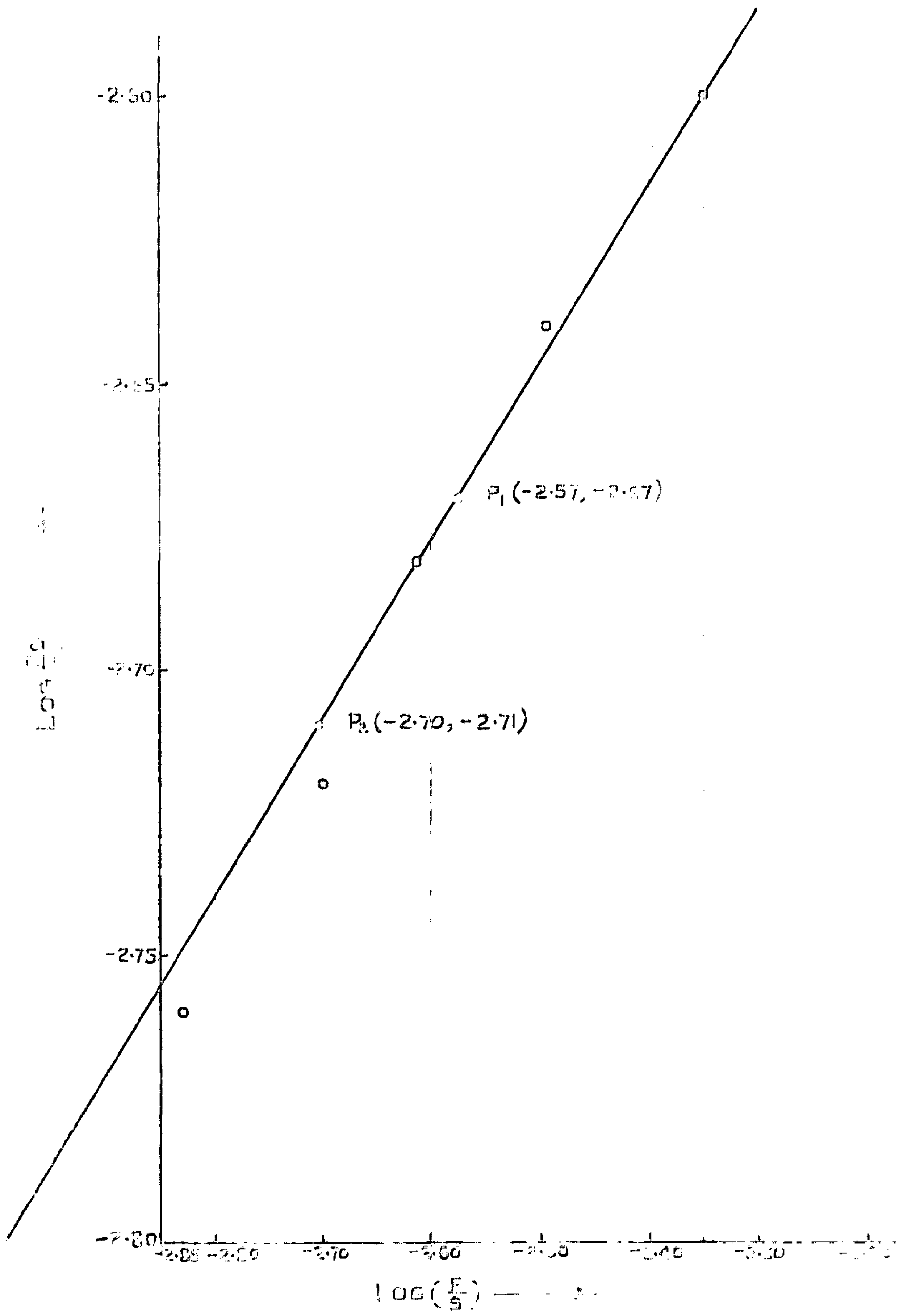


FIG. 10 : PLOT OF LOG [illegible] VALUE [illegible] ([illegible] AND [illegible] CONSTANT)

$$= \frac{-2.67 - (-2.71)}{-2.57 - (-2.70)}$$

$$= \frac{0.04}{0.13}.$$

$$= \underline{+ 0.3.}$$

Also, $y = mx + c$

$$\therefore -2.71 = 0.3\ (-2.70)+c$$

$$\text{or} \quad c = -1.90.$$

$$\therefore \log k_1 = -1.90$$

$$= \bar{2}.10.$$

whence $k_1 = .0126.$

so that we have:

$$m = 0.3$$

$$k_1 = 0.0126.$$

$$\frac{d}{C_u} = \frac{.0625}{3} = 0.0208.$$

$$\frac{C_u}{C_L} = \frac{3}{12} = 0.25$$

Proceeding in the same way the lines (5) and (6) are plotted in Fig. 11. and Fig. 12. respectively. From these we get:

$$n = -0.90$$

$$k_2 = 0.0000773$$

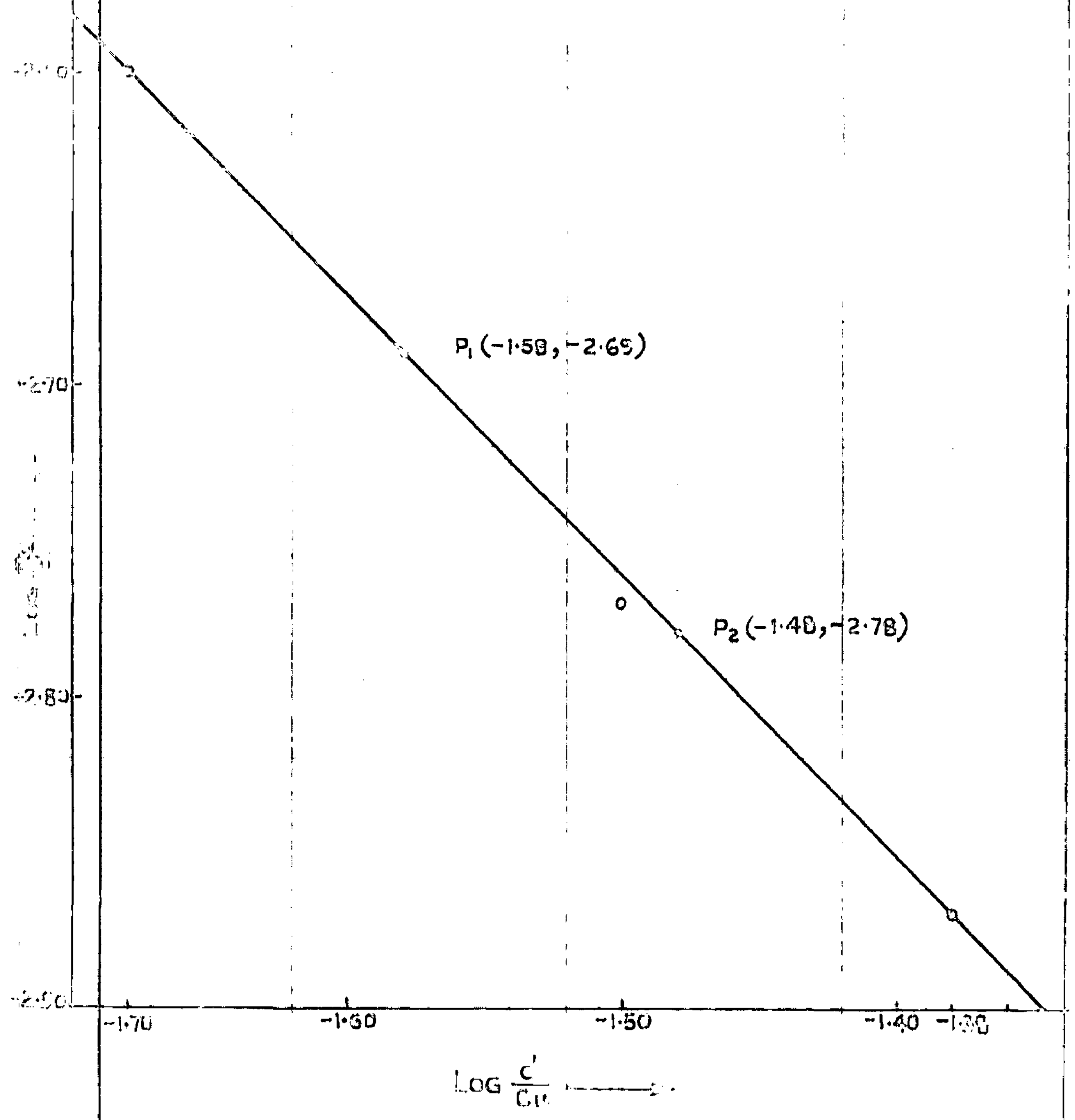


FIG.[illegible] PLOT OF LOG $\frac{H_c}{i}$ VS LOG $\frac{c'}{C_H}$ (AT $\frac{E}{D}$ AND $\frac{C_H}{C_L}$ CONSTANT)

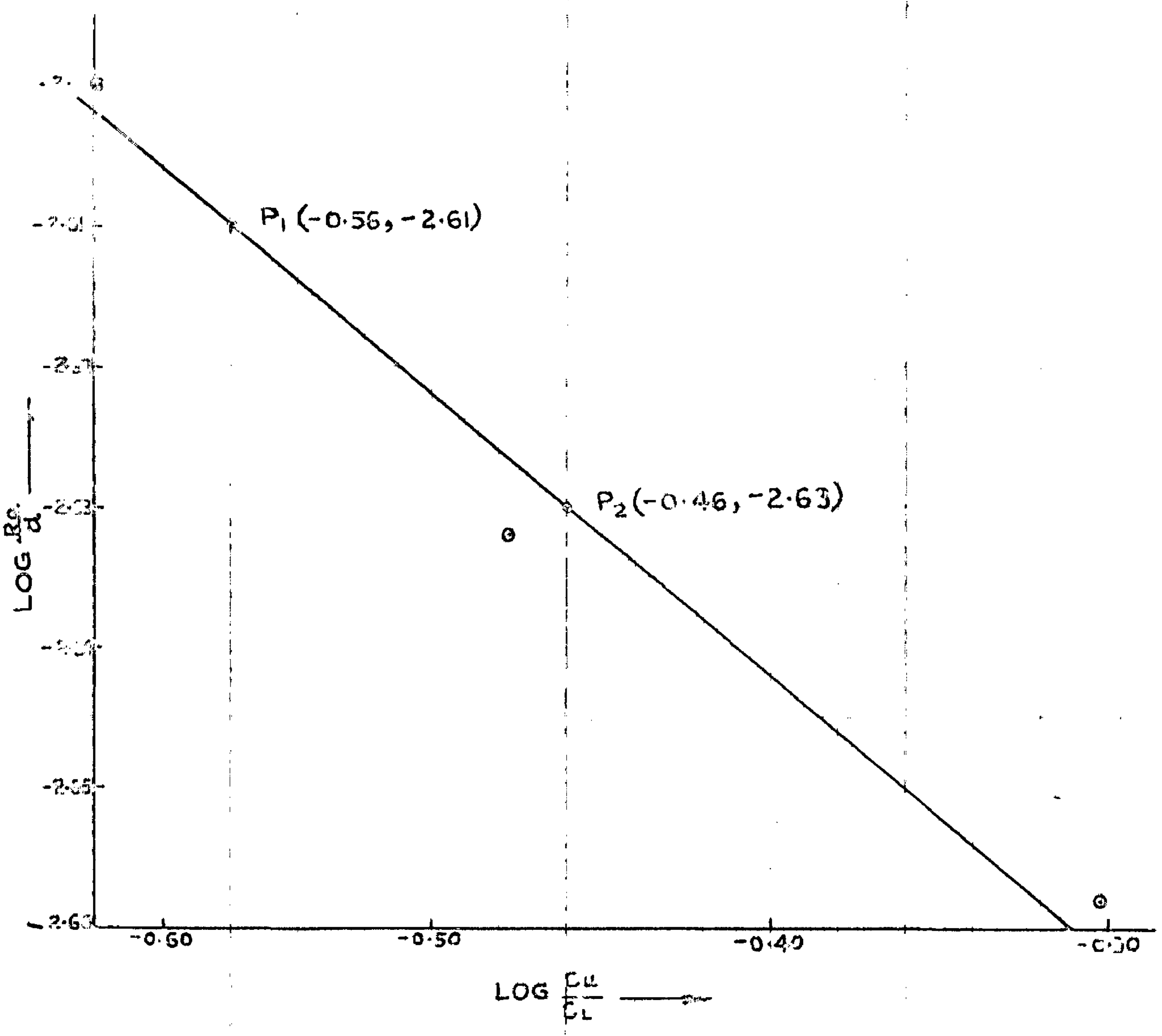


FIG.12 PLOT OF LOG $\frac{Ra}{d}$ Vs LOG $\frac{Cu}{CL}$ (AT $\frac{F}{S}$ AND $\frac{d}{Cu}$ CONSTANT)

$$\frac{F}{S} = 0.00444$$

$$\frac{C_u}{C_L} = 0.25.$$

and

$$p = -0.20$$

$$k_3 = 0.0019$$

$$\frac{F}{S} = 0.00444.$$

$$\frac{d}{C_u} = 0.0208$$

Having known the values of all the constants, we can find the value of K from equations (4), (5) and (6) separately: Thus,

$$K = \frac{0.0126}{(0.0208)^{-0.90} x (0.25)^{-0.20}}$$

$$= 288 \times 10^{-6} \qquad \text{....} \quad (7)$$

$$K = \frac{0.0000773}{(.00444)^{0.3} \times (0.25)^{-0.2}}$$

$$= 298 \times 10^{-6} \qquad \text{.....} \quad (8)$$

&

$$K = \frac{0.0019}{(.00444)^{0.3} \times (.0208)^{-0.9}}$$

$$= 292 \times 10^{-6} \qquad \text{.....} \quad (9)$$

$$\text{Mean value of } K = \frac{288 + 298 + 292}{3} \times 10^{-6},$$

$$= \frac{878}{3} \times 10^{-6}.$$

$$= 292.6 \times 10^{-6}.$$

$$= 293 \times 10^{-6} \qquad \ldots (10)$$

Putting these values of m, n, p & K in eqn.(3) we get:

$$\left(\frac{R_a}{d}\right) = 293 \times 10^{-6} \times \left(\frac{F}{S}\right)^{0.3} \times \left(\frac{d}{C_u}\right)^{-0.9} \times \left(\frac{C_u}{C_L}\right)^{-0.2}$$

$$R_a = 293 x 10^{-6} \times \left(\frac{F}{S}\right)^{0.3} \times \left(\frac{C_u}{d}\right)^{+0.9} \times \left(\frac{C_L}{C_u}\right)^{+0.2} \times d^{1}$$

$$\text{or } R_a = 293 \times 10^{-6} \times \left(\frac{F}{S}\right)^{0.3} \times C_u^{0.7} \times C_L^{0.2} \times d^{0.1} \qquad \ldots (11)$$

Equation (11) is an equation expressing an approximate relationship of surface roughness with different parameters.

CHECK:

The empirical relation suggested above (eqn. 11) must hold good for any observation. Selecting at random observations No: 16, 85, & 131, for instance, we get:

For No.16:

$$\left(\frac{F}{S}\right)^{0.3} = \left(\frac{5}{564}\right)^{0.3}$$

$$= 0.242$$

$(C_u)^{0.7} = (3)^{0.7}$

$= 2.16$

$(C_L)^{0.2} = (12)^{0.2}$

$= 1.645.$

$d^{0.1} = (.0625)^{0.1}$

$= 0.758$

Substituting in eqn. (11),

$R_a = 293 \times 10^{-6} \times 0.242 \times 2.16 \times 1.645 \times 0.758.$

$= 122 \times 10^{-6}$

But observed value of roughness is

$= 172 \times 10^{-6}.$

$\therefore$ Error $= (192-172) \times 10^{-6}$

$= 20 \times 10^{-6}.$

% error $= \frac{20}{172} \times 100$

$= 11.6$

$\simeq 12\%.$

<u>For No.85:</u>

$(\frac{F}{S})^{0.3} = (\frac{10}{1668})^{0.3}$

$= .216$

$(C_u)^{0.7} = (3)^{0.7}$

$= 2.16$

$(C_L)^{0.2} = (9)^{0.2}$

$= 1.55$

$(d)^{0.1} = (.094)^{0.1}$

$= 0.78$

Substituting in eqn. (11) ;

$R_a = 393 \times 10^{-6} \times 0.216 \times 2.16 \times 1.55 \times 0.78$

$= 164 \times 10^{-6}$.

Observed $R_a = 168 \times 10^{-6}$.

% Error $= \frac{4}{168} \times 100$

$= 2.4\%$

(iii) <u>For No.131:</u>

$(\frac{F}{S})^{0.3} = (\frac{10}{564})^{0.3}$

$= 0.3$

$(C_u)^{0.7} = (3)^{0.7}$

$= 2.16.$

$(C_L)^{0.2} = (6)^{0.2}$

$= 1.43.$

$(d)^{0.1} = (0.125)^{0.1}$

$= 0.812$

$\therefore R_a = 293 \times 10^{-6} \times 0.3 \times 2.16 \times 1.43 \times 0.812.$

$= 222.$

Observed R_a = * (above 200 μ*)

The %error cannot be found.

5.2- DISCUSSION OF RESULTS:

The results of the present study have been presented in the form of graphs and an empirical relation.

Figures 5 & 6 represent graphically the effect of cutter amplitude on the surface roughness. It would be observed that the surface becomes rougher with the increase in amplitude of the cutter.

Figures 7 to 9 graphically represent the pattern of change of surface roughness at different cutting conditions. It would be observed that in the range of cutting conditions employed, surface roughness.

(i) increases with the increase in feed and depth of cut.

(ii) decreases with the increase in cutting speed.

It would further be observed that almost the same pattern of change is maintained for all the conditions employed.

The equation (11) is an empirical relationship embodying all the parameters considered. Although the equation is far from precise in the strict sense of a mathematical expression, yet the assumptions made in the experiment in addition to personal errors of observation etc., may warrant the lack of exactness in it.

Again, surface finish becomes poorer as the distance of the cutter and clamp from the spindle nose increases.

5.3- CONCLUSIONS:

The conclusions reached by this experimental study are based on the results of the experiment. These conclusions and the suggested relationship may or may not apply to other materials or other cutting conditions. The results that the present study has yielded may be summarised below:

(i) Under normal operating conditions, the roughness of a milled surface is reduced as the cutting speed is increased; and for a given cutting speed, the surface becomes rougher as the feed rate is increased.

(ii) For a given cutting speed and feed rate, surface finish becomes poorer as the depth of cut is increased.

(iii) For a better finish the cutter and clamp should be as near the spindle nose as possible.

(iv) Good surface finish and high production rate go ill-together, depending as both do on the feed rate & depth of cut.

(v) For good surface finish the vibrations of the arbor assembly should be minimum. This demands more rigidity, smoother cutting operation, and small cutting forces.

5.4- SCOPE FOR FURTHER RESEARCH:

The present study was performed on mild steel which was the only readily available material. The study can be made on other materials and effect of other parameters can also be studied. To analyse the effect of vibrations on surface finish, it is desirable that both the vibrations and the surface profiles be recorded with the help of recording devices.

APPENDIX _ A

SPECIFICATION TABLES

TABLE-I

ADCOCK AND SHIPLEY (ENGLAND)
UNIVERSAL MILLING MACHINE MODEL 2AGU

SPECIFICATIONS

(1) **TABLE**	
Working surface, overall.	40"x10"
Longitudinal traverse, hand.	23".
Longitudinal traverse, automatic.	23"
Transverse traverse, hand.	8"
Vertical traverse, hand.	14"
(2) **TWIN OVERARMS.**	
Diameter of each.	3".
(3) **SPINDLE SPEEDS.**	
Number of changes.	12
'A' range R.P.M.	30 to 600
'B' range R.P.M.	60 to 1200.
(4) **ARBOR**	
Diameter	1".
Nose to arbor support.	17"
Nose to arm brace.	$21\frac{1}{2}$ "
(5) **FEEDS** (Longitudinal only)	
Number of changes.	9
Range, inches per minute.	$\frac{1}{2}$" to 10"
(6) Horse power required.	3.
(7) Speed of motor.	1430 R.P.M.

TABLE-II

MILLING CUTTER DATA.

Diameter of cutter	6"
Number of teeth.	20.
Width of cutter.	$\frac{3}{4}$"
Diameter of arbor.	1"
Material of cutter.	HSS (Batu).
Included or lip angle.	80^{o}-15'
Radial rake angle.	5^{o}-30'
Relief angle.	4^{o}-15'.

TABLE_III

THE TYPE 1-117 VIBRATION METER (CEC)

SPECIFICATIONS

1. POWER:

30 watts, 105 to 125 volts (115 V nominal) 50/60/400 cycles. Maximum voltage change within specifications will cause less than 2% in amplifier gain.

2. AMPLIFIER:

(a) Input Impedance.	...	10,000 ohms, Changeable to 50,000 ohms.
(b) Linearity Deviation.	....	Less than ±3% of full scale at all specified frequencies.

(c) Temperature:

Meter operable from	- 10°c to + 40°c.
Withstands temperature from -	40°c to +50°c.
Indication changes less than °c in operable range.	- 0.2%, per

3. SENSITIVITY AND FREQUENCY RESPONSE:

(a) Velocity Measurements:

Normal sensitivity Range (Vx1.0).

Frequency response within ± 3% from 5 to 5000 cps.

High sensitivity Range (Vx0.1)

Frequency response within ±3% from 5 to 5000 cps.

(b) Displacement Measurements:

Normal Sensitivity Range (Dx1.0)

High Sensitivity Range (Dx0.1)

Frequency response within ± 4% from 5 to 5000 cps in both the ranges.

4. GENERAL DESCRIPTION:

Four individual input channels. Channel selector dial provided.

Meter direct reading in average velocity or peak to peak displacement.

Outputs for recording oscillograph, cathode ray oscilloscope and external meter.

Compatible self-generating transducers are the only accessories required.

Individual sensitivity adjustment for each channel.

Adjustable internal calibration voltage.

5. PHYSICAL CHARACTERISTICS:

Height $8\frac{1}{4}$ inches, width $10\frac{1}{2}$ inches. depth $9\frac{1}{2}$ inches; weight 23.5 pounds- with three accessory fitters.

6. COMPATIBLE TRANSDUCERS.

CEC transducers 4-102A, 4-103, 4-106V, 4-106H, 4-118 and 4-102 are compatible for use with the 1-117. Displacements from 0.005 to 15.0 degrees peak to peak may be made direct reading when CEC transducers are used. With these transducers, velocities from 0.5 to 1500 inches per second or from 5.0 to 15,000 degrees per second may be made direct-reading on the meter.

The 1-117 vibration meter may be adjusted to read directly in the prescribed units (mils, inches per second etc). When used with any self-generating transducer whose sensitivity is 50 to 150 MV/inch/second.

TABLE -IV

SURFACE MEASURING INSTRUMENT MODEL 3
'TALYSURF' (TAYLOR-TAYLOR HOBSON, ENGLAND)

DESCRIPTION

Model 3 Talysurf comprises following parts:

(i) Stand (consisting of base, column and Vee block)

(ii) Gearbox (the driving unit).

(iii) Standard Pick-up.

(iv) Roughness standard.

(v) Amplifier.

(vi) Rectilinear graph recorder.

(vii) Triple cut-off average meter.

(viii) Complete set of inter-connecting leads, double and wrench, plastic cover.

1. **STAND:** The stand has a work table in the form of a T-slotted surface on which a vee block, or such other mounting device as the user may provide, can be clamped.

2. **GEAR BOX:** The Gear Box provides three motorised speeds of traverse for the pick-up giving respectively 20x and 100x horizontal magnification and a speed suitable for the average reading. The Gear Box traverses the pick-up across the work. It contains internally a carriage onto which the pick-up is plugged, the carriage being suspended on ligament-hinged links for approximately straight line motion. During the traverse the carriage operates switch contacts which control the Average Meter.

To reduce wear, shoes or skids are made of tungsten carbide.

3. **PICK-UP:** The standard pick-up is provided with interchangeable nosepieces carrying either a rounded skid or flat shoe or the datum attachment for generating the datum, the choice depending on the nature of specimen. The diamond stylus has a tip dimensions of .0001 in (.0025 m) and bears on the specimen with a force of about 0.1 gram (100 milligrams).

The stem of the whole pick-up body plugs into the socket in the Gear Box Carriage. At its forward end, the body carries a nose piece having a slider which rests on the surface to be measured and slides over the crests.

The rear end of the stylus arm actuates a variable inductance by means of which the movements of stylus are converted into corresponding changes in an electric current. After amplification these changes are either recorded to provide the profile graph, or averaged to give the CLA Index Number.

4. **AMPLIFIER:** The amplifier is designed to feed an average meter or recorder or both, these units connecting independently into separate sockets at the back of the amplifier. The fine adjustment knob enables the slight adjustments pen or pointer without changing the height of the gear bo

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4. <u>AMPLIFIER:</u> The amplifier is designed to feed an average meter or recorder or both, these units connecting independently into separate sockets at the back of the amplifier. The fine adjustment knob enables the slight adjustments pen or pointer without changing the height of the gear box.

Six different magnifications can be selected by the magnification switch. The setting of the magnification switch also determines the scale on which the C.L.A. values are read on the average meter.

5. TRIPLE CUT-OFF AVERAGE METER:

The Triple Cut-off Average Meter provides for a wide range of surface and gives a choice of three cut-off values with three associated lengths of travel. The cut-off values (0.01 in., 0.03 in and 0.10 in) are standard in the British B.S. 1134-1950 and the American B-46-1955 specifications. The longest cut-off will serve for measuring the texture of rougher grades and surfaces afflicted with chatter marks. The shortest cut-off is needed for measuring finishes on very short parts such as piston rings.

The Average meter is connected to amplifier through a 18-way lead. The dial on the meter shows the C.L.A. values of the roughness in microns. In Talysurf instruments, the pointer fluctuations (so common in ordinary current measuring instruments) are avoided by using an integrating meter which is connected to the output from the amplifier for a predetermined time of operation controlled by contacts in the Gear Box. The meter sums the fluctuations of current which the instrument receives as the stylus traverses the work and shows the average value directly on the scale.

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