CoA Note 15



# The College of Aeronautics

# Cranfield



# Machinability Investigations into Stainless Steel Rex 448

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# THE COLLEGE OF AERONAUTICS

## CRANFIELD



Machinability investigations into
special materials

Part 1

Stainless steel Rex 448 hardened
and tempered to Brinell minimum
321, maximum 375

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This Report deals with the machinability of Firth-Vickers materials.

Reference REX 448 (Stainless Steel) in the hardened and tempered condition. U.T.S. 70-75 tons; Brinell hardness 321 minimum, 375 maximum.

CONTENTS:

SECTION 1 - The development of a single point cutting tool (Lathe Tool).

SECTION 2 - The application of this tool to the turning process to determine the optimum surface speed and best feed rate.

SECTION 3 - The determination of the life of the cutting tool when used at optimum surface speed and best feed.

SECTION 4 - The modification of the single point tool to meet a special requirement; i.e. to be applied as a single tooth in a face milling cutter which is suitable for use when face milling Rex 448 sheet in the hardened and tempered condition.

The machining process must be designed to result in the minimum distortion in the finished component and give a good surface finish. Further, it is desirable that the finished dimensions shall be achieved at one pass and an area of 32 square feet be covered between re-grinds of the milling cutter.

SECTION 5 - Conclusions.

SECTION 6 - Results of practical application. Report on results of the application of the proposed cutter design, etc.

## SECTION 1. THE DEVELOPMENT OF A SINGLE POINT CUTTING TOOL (LATHE TOOL).

### 1.1. Equipment.

#### The Machine Tool:

German WF Centre Lathe 8" centres.
This machine is powered by 9 h.p. A.C. motor.
Speeds range from 19 to 1500 r.p.m.
Feed range from .05 mm. to 8.0 mm. per revolution.
88 changes.

#### Force Measuring Equipment:

The College of Aeronautics Lathe Tool Dynamometer.
Capacity 1000 vertical load - pounds
500 feed load - pounds
300 back load - pounds
Sensitivity 2 pounds - $1\frac{1}{4}$ pounds and $\frac{1}{2}$ pound respectively.

#### The Tools:

$\frac{1}{2}$-inch square section high speed steel 18:4:1
$\frac{1}{2}$-inch square shank tipped (Tungsten Carbide) Wimet N.S. Grade.

#### The Material:

As supplied -

| | |
|---|---|
| in lengths | 15" x $1\frac{1}{2}$" x 1" bar tempered Brinell minimum 321, maximum 375. |
| 2 lengths | 15" x $1\frac{1}{2}$" x 1" bar soft. |
| 1 length | 15" x 5" x 5" bar tempered Brinell minimum 321, maximum 375. |
| Sheet | 27" x 7" in two thicknesses 0.125 ins. and 0.200 ins. |
| 3 sheets | in both tempered and soft condition. |

## 1.2. Material Preparation.

The $1\frac{1}{2}$" x 1" section bars were turned to 1" diameter; no difficulty was experienced in this operation, using the techniques accepted by current practice and found by experience. The work was carried in the lathe chuck and backed by a live tail stock centre, two passes were used to reduce the section to round.

## 1.3. Method.

(a) All tools were ground and lapped to 5-10 micro-inch finish on cutting faces before each test.

(b) Each test was repeated three times; all three results must be within $2\frac{1}{2}$% of each other before they are averaged and the average plotted. After each series of tests, some points were selected at random and the conditions repeated.

Should any of the three test readings fail to qualify, either in the series or the random sets, the whole series is repeated after stripping the test equipment down and re-setting.

(c) All averaged points are shown in the graphs. Smoothing and drawing of curves was carried out by the Drawing Office, who knew nothing of the required results. This was done to eliminate any bias on the part of the research personnel.

(d) Depth of cut remained constant throughout the whole investigation at 0.050 inches.

(e) All results taken cutting dry.

## 1.4. Tests to determine the optimum maximum rake.

### (a) Preliminary test to determine a reasonable surface speed.

A tool was prepared with the following geometry (BSS.1886 terminology) :-

| | |
|---|---|
| Shank $\frac{1}{2}$" square section high speed steel. | |
| Front top rake | $0^{\circ}$ |
| Plan approach angle | $0^{\circ}$ |
| Plan trail angle | $6^{\circ}$ |
| Clearance angles | $6^{\circ}$ |
| Nose radius | 0.010 inches |
| Cutting edge side rake | $12\frac{1}{2}^{\circ}$ |

This tool was used at surface speeds of 30, 54, 60, 74 and 85 surface feet per minute with a feed rate of 0.020 ins. per revolution. It was observed that this range of speed had no effect on forces, and that good chip flow was achieved at 60 feet per minute, hence the maximum angle tests were commenced at this surface speed.

b.

With a speed constant at 60 feet per minute, depth of cut 0.050 ins., all tool angles were made constant as follows, except the cutting edge side rake which was varied over the following range -

| | | |
|---|---|---|
| Constants - | Shank ½" square high speed steel | 18:4:1 |
| | Plan approach angle | $0^{\circ}$ |
| | Plan trail angle | $6^{\circ}$ |
| | Clearance angles | $6^{\circ}$ |
| | Nose Radius | 0.010 inches |
| | Front top rake | $0^{\circ}$ |

Cutting edge side rake - $10^{\circ}$ $12\frac{1}{2}^{\circ}$ $15^{\circ}$ $17\frac{1}{2}^{\circ}$ $20^{\circ}$ $22\frac{1}{2}^{\circ}$ $25^{\circ}$ $27\frac{1}{2}^{\circ}$ $30^{\circ}$

Each angle was applied and test results taken as specified in 1.3. The tests were repeated for various feeds, i.e. 0.05, 0.10, 0.15, 0.20, 0.25, 0.30 mm. per revolution.

The results are shown graphically in Figs.1 and 2.

The back forces in this case were found to be so small that they can be ignored.

## SECTION 2. THE APPLICATION OF THE TOOL TO THE TURNING PROCESS TO DETERMINE THE OPTIMUM SURFACE SPEED AND BEST FEED RATE.

### 2.1. Tests to determine optimum surface speed.

From the test curves determining best maximum rake, it may be seen that a cutting edge side rake of 15° will take full advantage of the steep fall in forces, and not sacrifice tool section unduly; hence this angle completes the tool constants which are used for this series of tests.

Feed selected constant at 0.15 mm. per rev.

Surface speed is the only variable.

The tests comprise of tests at a wide range of speeds, i.e. 19 to 450 feet per minute; as the higher surface speed would burn out a high speed steel tool, this was replaced by the carbide tipped tool, as mentioned in Section 1 (1.1).

Fig.3 shows the feed and vertical force plotted graphically.

### 2.2. Tests to determine best feed rates.

From the results above, it is found that 60 feet per minute is in the best speed range for high speed steel; hence this speed is used with the tool constant as for speed tests and feed is varied over a range 0.05 to 0.33 mm. per revolution in twelve steps.

Graph 4 shows the results of these tests and precise feed rates used.

## SECTION 3. THE DETERMINATION OF THE LIFE OF THE CUTTING TOOL WHEN USED UNDER OPTIMUM CONDITIONS OF SURFACE SPEED AND FEED RATE.

The cutter as used for preparing the specimen sheets was used under optimum conditions and after covering a surface of 6 square feet showed no appreciable amount of wear.

NOTE:

Due to the limited supply of material, a full series of tests to determine a life surface speed relationship could not be carried out.

The results of life surface speed tests will be added to this Report as an Appendix.

## SECTION 4. THE MODIFICATION OF THE SINGLE POINT TOOL TO MEET A SPECIAL REQUIREMENT.

4.1.

This problem is related to the application of the face milling cutter to a special task which is -

> To taper face mill sheets of Rex 448 hardened and tempered to the following dimensions :-
>
> Sheet 'A' - 5 ft. by 4 ft. in area, tapered from 0.200 ins. to 0.180 ins. over the 5 ft. length.
>
> Sheet 'B' - 7 ft. x 4 ft. in area tapered from 0.125 ins. to 0.08 ins. over the 7 ft. length.

Surface finish to be as good as possible, and the finished component to have the minimum of distortion after machining. It is also desirable to finish at least one side of each sheet between tool regrinds.

4.2.

This problem may be approached in two parts.

4.2.1. The geometry of the cutter tooth to be arranged in such a way that very little force is applied in a compressive sense into the finished surface of the sheet, and further there is no tendency for the cutter to exert any appreciable lifting action to the sheet.

This limitation results in the main forces of the cutting action being restricted in direction to a plan parallel with the surface of the sheet and level with the stock to be removed.

Fig.5 shows a simplified sketch of the major force diagram resulting from the cutting action of the proposed cutter, the geometry of which is as follows :-

| | |
|---|---|
| Helix angle (for HSS tool) | zero and $-3^{\circ}$ in the case of carbide tools. |
| Radial rake | $15^{\circ}$ |
| Bevel angle | $15^{\circ}$ |
| Corner relief | $45^{\circ}$ x 1/32" |
| Face finishing flat | 0.030 |
| Face relief | $1\frac{1}{2}^{\circ}$ |
| Clearance angles | $10^{\circ}$ x 0.020" |
| Secondary angles | $18^{\circ}$ |

This cutter is designed for a feed rate of 0.006" per tooth.

4.2.2. The life of the cutter.

This value can be read from the life speed curve, Section 3.

## SECTION 5. CONCLUSIONS.

Rex 448 hardened and tempered to 65 to 75 tons is not extremely difficult to machine and the life of the cutting tools is found to be acceptable when best surface speeds and optimum feed rates are used.

The material has a fairly high capacity to work harden. Hence it is advisable to use feed rates which permit the cutting tool to advance into the unhardened material at each pass. Further, the highest positive cutting angles also prove best. They cut with less force and hence the work hardening effect from that force is reduced.

Distortion in the finished components is largely due to the results of work hardening and when the correct cutting action is adopted with its reduction in work hardening, distortion is minimised.

## SECTION 6. RESULTS OF PRACTICAL APPLICATION.

### The Application of the Proposed Face Milling Cutter.

The sheets as supplied were 27" x 7" x .200". It was found necessary to reduce this size to 17" x 6" x .200" as the magnetic chuck to be used for holding the sheet while machining is carried out is limited to this smaller size.

The work was placed on the machine shop with no special preparation, i.e. as a normal job.

Instructions were given to the milling machine operator as follows :-

> Using the 4" dia. insert face mill 10 teeth
> H.S.S. supplied.
> Surface speed 65 feet per minute.
> Feed 3.6 ins. per minute (0.006" tooth load)
>
> Reduce the supplied sheet from 0.200 ins. thickness to approximately 0.050 ins. thickness, by removing the stock equally from both sides, i.e. 0.075" a side. Depth of cut to be 0.075 ins., i.e. one pass. The area of the sheet to be covered in two passes on one side and three passes on the other.

Sheet 'A' is this specimen as received from the shop. The surface finish is reasonably good.

A talysurf record of the surface shows that from the peaks to the base of surface roughness measures 0.0005 ins., and that there is no distortion in the sheet due to machining.

### Sheet 'B' - Instructions to Operator.

> Mill as for Sheet 'A' to the following dimensions: at one pass for depth and three passes over area. Reduce the thickness by 0.030 ins. From other side, remove stock to leave sheet 0.155 ins. to 0.130 ins. Taper over the 17 ins. length.

Surface finish records show similar to Sheet 'A'. Height of peak from base of crater 0.0005 ins. and no distortion from the machining.

Cutting fluid used in tests on Sheets 'A' and 'B' was -

Soluble oil and water 15:1 ratio.

Sheet 'C'.

This smaller specimen was machined with an insert blade carbide face milling cutter. (Wimet Multi-Mill Grade of Carbide S.58 - Wickman).

The tooth form is as for H.S.S. with the exception of $-3^{o}$ helix angle.

Surface speed 240 feet per minute.

Tooth load 0.006 ins.

The specimen was cut dry, on one side removing 0.026 ins. in one pass. The result of this was a rough surface finish which was due to the swarf being retained round the cutter and in the worked surface due to the magnetic chuck on which the work was supported.

The specimen as supplied was machined with a small flow (one pint per minute) of EVCO 113 Cutting Oil - Edgar Vaughan & Co. Ltd., Birmingham.

This was used to protect the surface of the sheet and good results were obtained.

Average 25-30 micro-inches and less than 0.0002 ins. from base to peak of machining marks.

There is no distortion due to machining.

## A P P E N D I X.

### DETERMINATION OF THE MAYER EXPONENT.

The Mayer exponent is a measure of the strain hardenability of a metal. It gives an indication of the amount of hardening to be expected in a material due to the strain in cutting. The hardening which the metal undergoes during the machining process due to plastic deformation has an appreciable effect on the life of a cutting tool.

The exponent is derived from the relationship between the load applied by a spherical indenter ball (as in the Brinell hardness test) to the diameter of the impression made by the ball in the material. This relationship is of the form -

$$L = ad^n$$

L = applied load in Kg.

d = diameter of indentation in mm.

a = constant characteristic of the metal and the diameter of the ball.

n = Mayer exponent

If load is plotted against diameter of indentation on log-log paper, a straight line results. The slope of the line gives the Mayer exponent n. The exponent must be greater than or equal to 2. A Mayer exponent of 2 signifies that the material has no capacity for work hardening.

Tests carried out on a Brinell machine gives an exponent of 2.16

For comparison, the equivalent value for Titanium 150A hot forged is . . . . . . . . . . . . . . 2.27
and Nimonic 90 forged bar is . . . . 2.19

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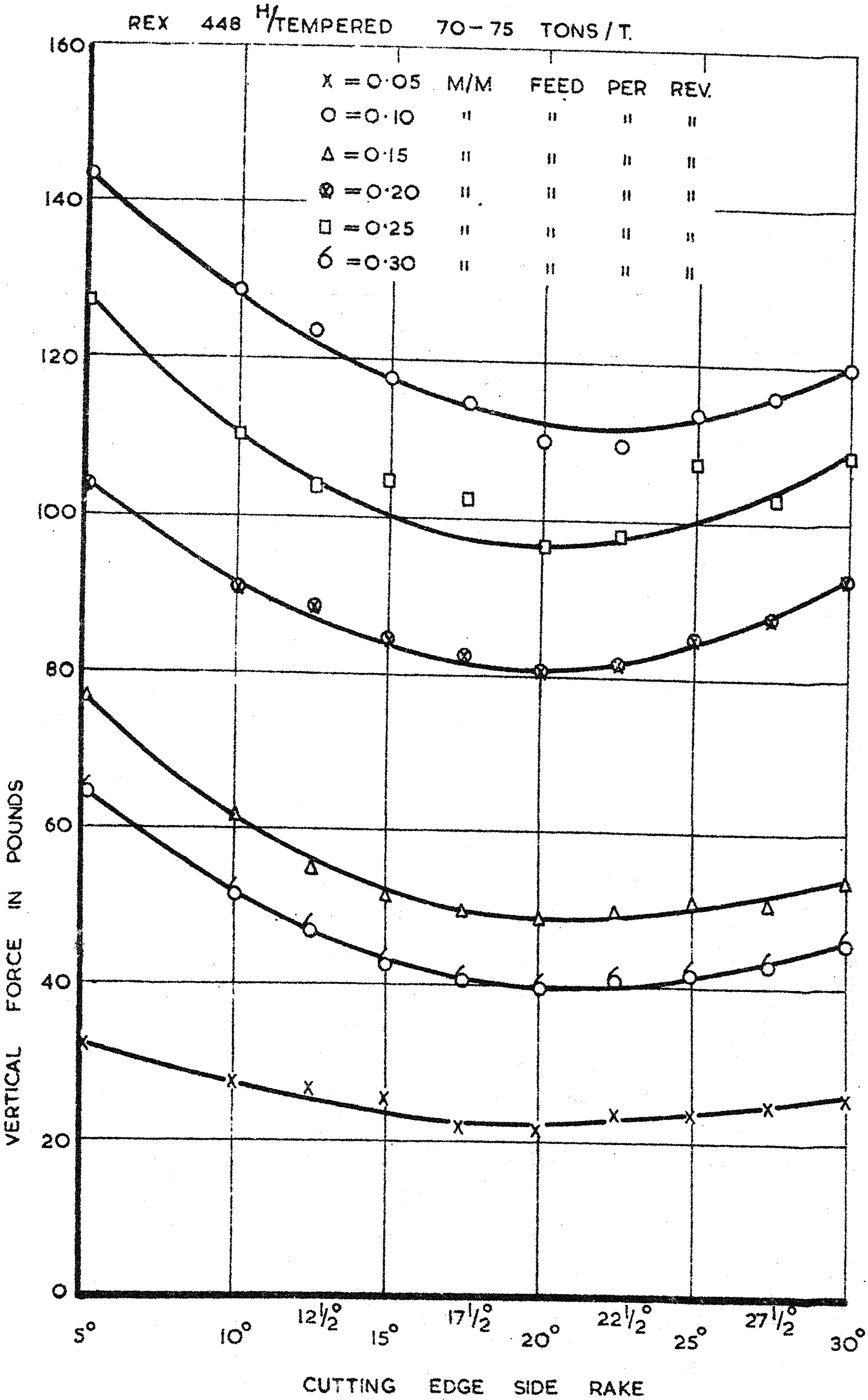
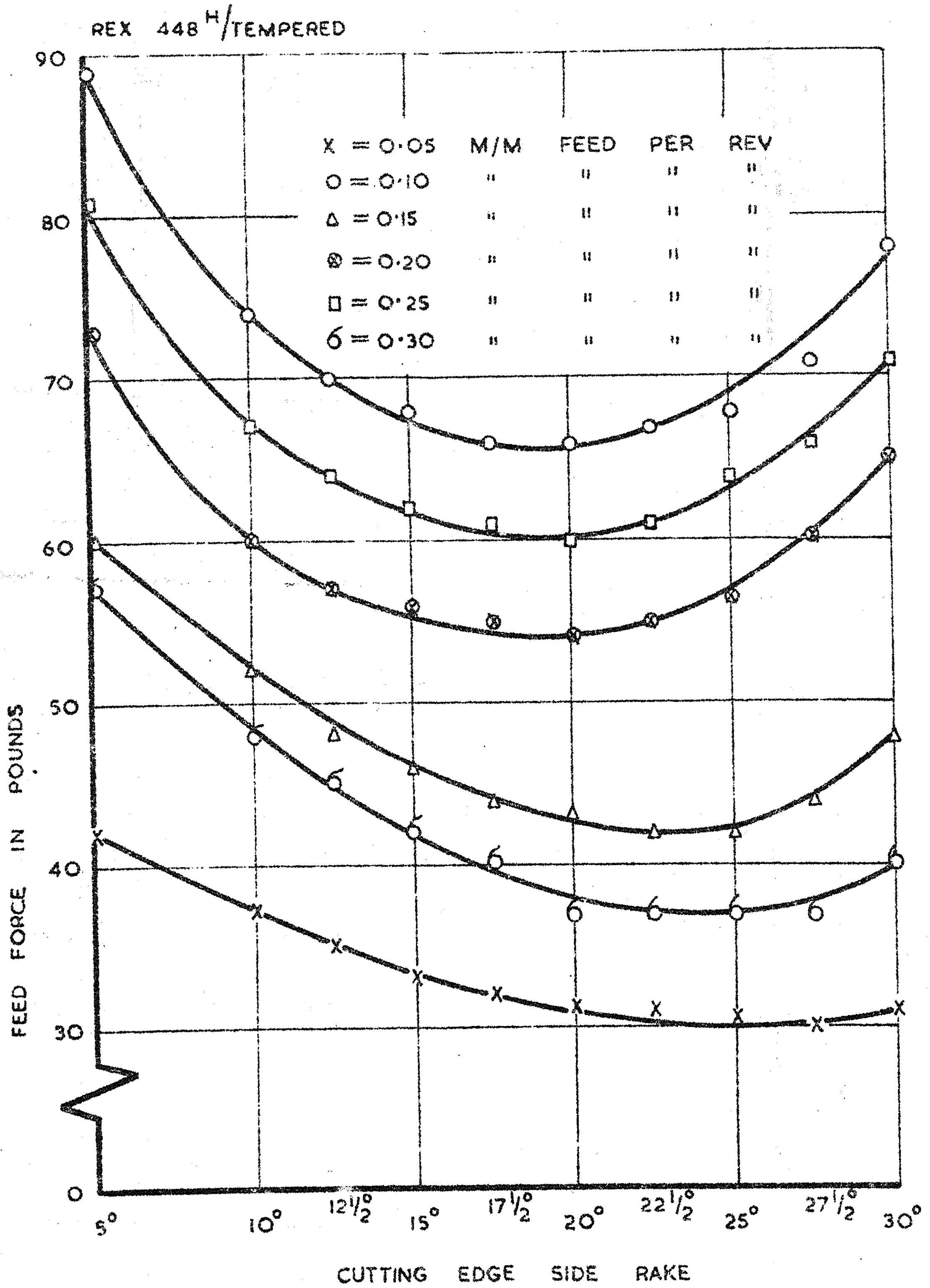


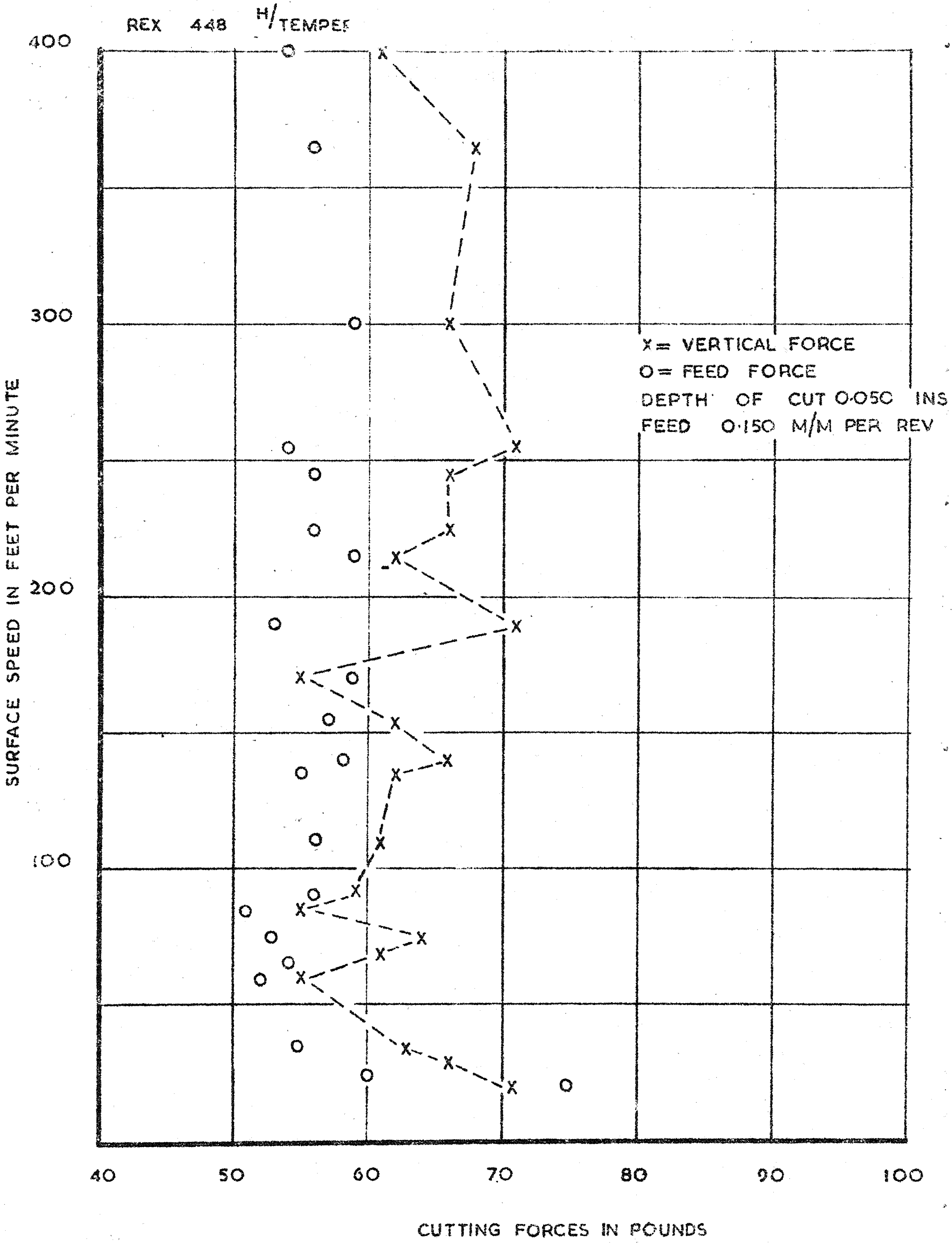

VERTICAL FORCES CUTTING EDGE SIDE RAKE V's CUTTING FORCES.

FIG. I.



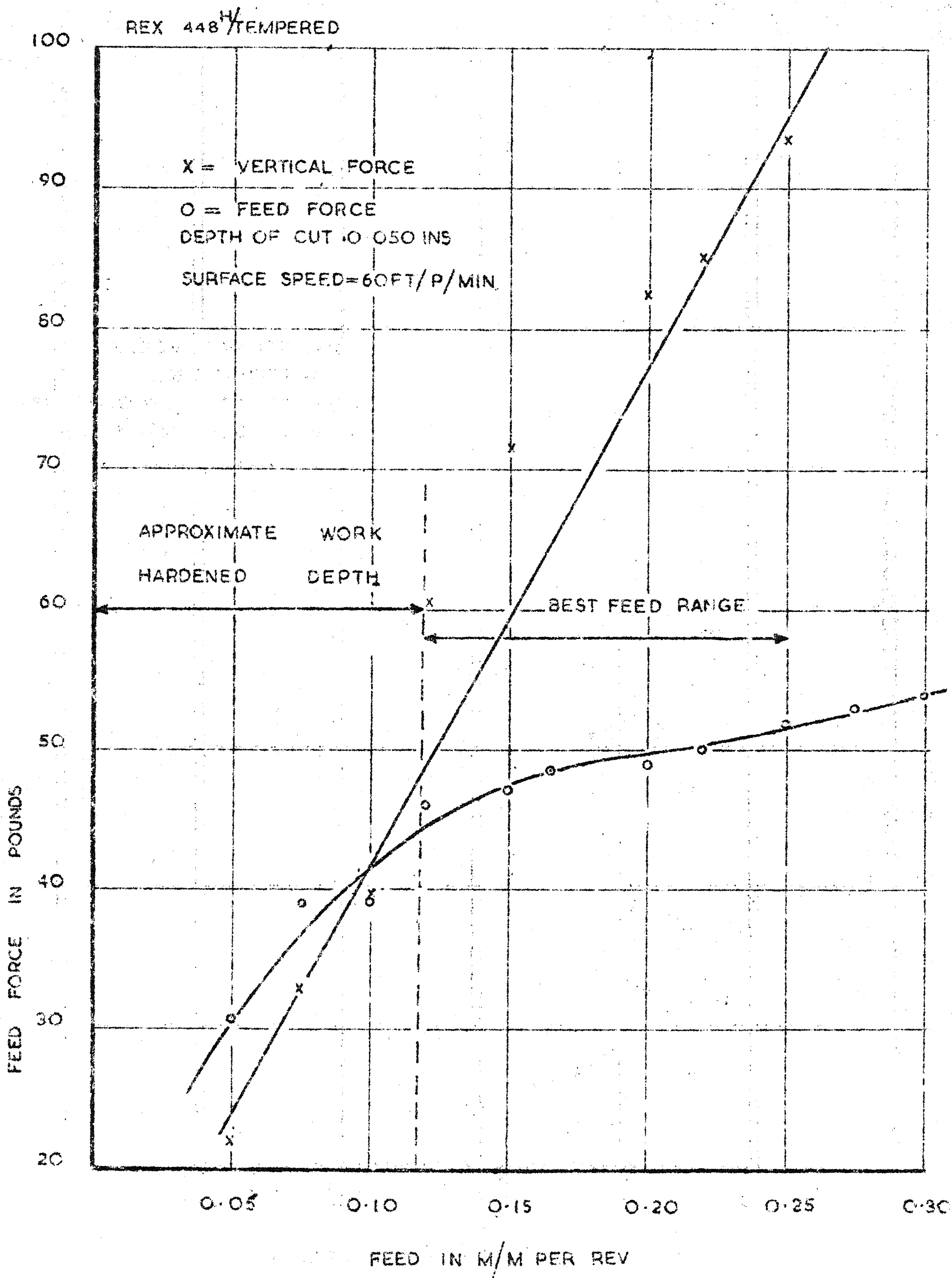

FEED FORCES. CUTTING EDGE SIDE RAKE V^S CUTTING FORCES.

FIG. 2.




SURFACE SPEED Vs CUTTING FORCES

FIG. 3.



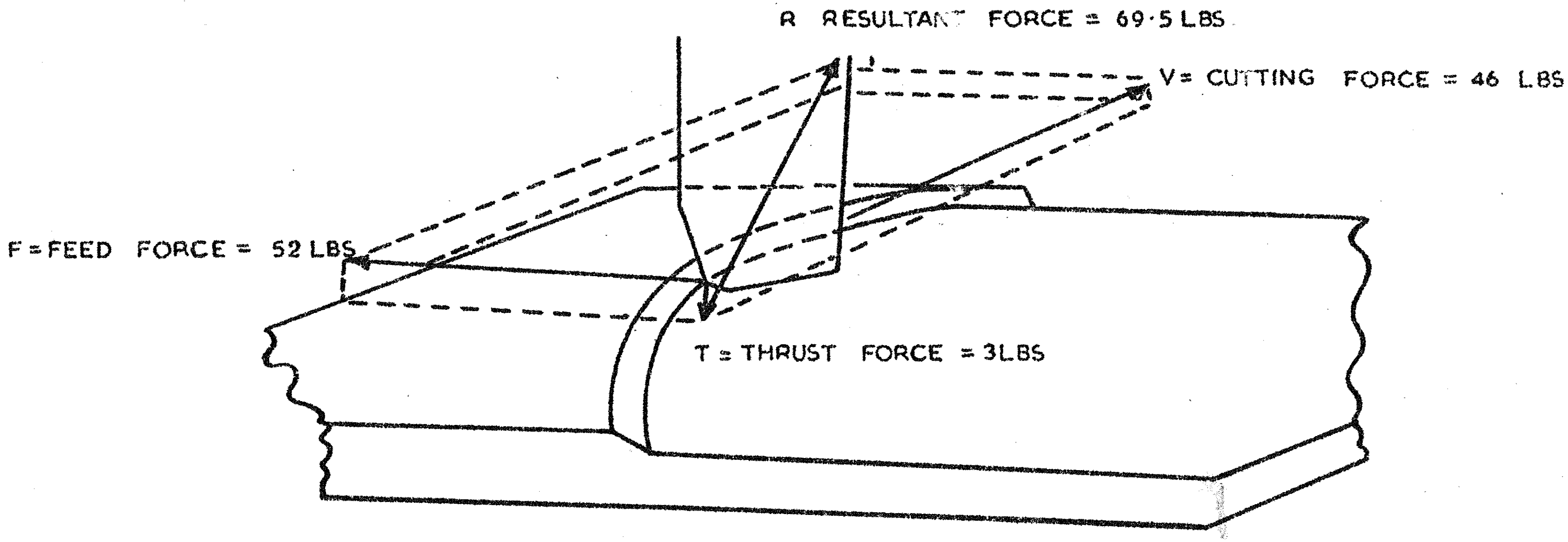

FEED RATE PER REVOLUTION Vs CUTTING FORCES

FIG. 4.

NOTE :- ALL MAJOR FORCES ACT IN THE PLAIN OF THE SHEET.

THIS ARRANGEMENT AVOIDS WORK HARDENING THE FINISHED SURFACE

DEPTH OF CUT 0·05 ins
FEED (TOOTH) 0·006 ins.
SURFACE SPEED 60 ft/min.




**SIMPLIFIED FORCE DIAGRAM.**

OBTAINED WHEN USING PROPOSED CUTTER
ON REX 448 H/TEMPERED

FIG. 5.