CoA Note No. 34

THE COLLEGE OF AERONAUTICS

CRANFIELD

POST NUBES LUX

MACHINABILITY DYNAMOMETERS USED AT THE COLLEGE OF AERONAUTICS

by

J. CHERRY

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Contents

INTRODUCTION

Much more interest in machinability investigations has been shown in recent years, both by colleges and by Industrial Research departments, due partly to the difficulty encountered in machining some of the new gas turbine materials and partly to the availability of simple and economical dynamometers as are described in this Note.

These dynamometers were designed to provide simple robust instruments capable of being easily applied to a wide range of machines without modification. Direct mechanical movement is the basis of their construction and this has been justified by the trouble free service given over a period of five years. Almost onehundred of each of these instruments are being used, and so many requests have been received for a more comprehensive account of their range of uses that the preparation of this Note seemed justified.

It is encouraging to see the vigour displayed by industry and the Colleges in this field since so much remains to be done to establish practical machinability, data for British materials. By collaboration between investigators it should be possible to arrange a programme of research to cover a wide range of materials with the minimum duplication.

The illustrations of the instruments are shown by the courtesy of Coventry Grinders Ltd., Coventry.

2. LATHE DYNAMOMETER

2. 1. Construction

The instrument resolves the resultant load on the tool into three components in the principal planes as shown in Fig. 1. This is achieved by designing the Toolholder Body, shown in Fig. 2, to permit rocking in the vertical and horizontal directions and to allow sliding in the backwards direction. In the diagrammatic section, Fig. 3, the Toolholder Body is shown in position. A vertical load 'V' causes the toolholder to rock on the cylindrical surfaces 'AA', the movement being resisted by diaphragm (6) whose deflection is measured by the dial indicator shown. Similarly a horizontal load 'H' causes the toolholder to rock on surfaces 'BB', resistance being applied by diaphragm (7). Surfaces 'AA' and 'BB' are ground and lapped to be a close sliding fit in housing (8), hence a back load 'Z' causes the toolholder to slide backward against diagram (10). Thus the values of all three components can be determined. Housing (8) is made intwo parts to permit adjustment to the closest degree. The lower part which carries the load is made integral with the shank for maximum support.

2. 2 Calibration and Toolsetting

Calibration tests are conducted on the apparatus shown in Fig. 4 in which actual cutting tests are simulated as closely as possible.

In calibrating, an adaptor replaces the tool and the vertical and horizontal loads are applied at a position one inch from the end of the clamping shank. This face is used as a datum for setting the tool which should also be one inch to the centre of the cut, hence the toolpoint should be one inch plus half the depth of cut from the datum face as shown in Fig. 5. A typical calibration chart is shown in Fig. 6.

2. 3 General Information

A photograph of the dynamometer is shown in Fig. 7.

Overall Dimensions

Length = $6\frac{1}{4}$", width = 4", depth = $3\frac{3}{4}$" (including dial indicators)

Loading Range

The standard range of diaphragms will permit the following loads to be applied:-

Vertical	1000 lbs.	(1 div. = 10 lbs. approx.)	using $\frac{1}{10,000}$ indicators
Horizontal	500 lbs.	(1 div. = 5 lbs. approx.)	
Back	300 lbs.	(1 div. = 3 lbs. approx.)	

Should it be required to increase or decrease the sensitivity it is a simple procedure to change the diaphragms, however re-calibration would be necessary.

Fitting to Lathe

The standard shank is 1" x 1" x $4\frac{9}{16}$", hence the dynamometer will fit any machine suitable for a tool of 1" square section.

Tools

The toolholder body is ground for $\frac{3}{4}$" round tools but square tools up to $\frac{1}{2}$" may be used by employing an adaptor as shown in Fig. 5.

Dial Indicators

Three $\frac{1}{10,000}$ dial indicators are used.

2. 4 Uses of Lathe Dynamometer

Some of the purposes for which the dynamometer may be used are outlined below:-

2. 4. 1. Determination of power available for cutting, also machine efficiency
2. 4. 2. Determination of optimum tool geometry
2. 4. 3. Determination of machinability data for materials
2. 4. 4. Comparison of lubricants and coolants
2. 4. 5. Analysis of cutting force relationships
2. 4. 6. Workshop machinability comparator
2. 4. 7. Special Applications

2. 4. 1. Determination of power available for cutting, also machine efficiency

When estimating machining times it is necessary to know the maximum power available at the cutting tool, otherwise a task may be set beyond the capacity of the machine. The dynamometer may be used to measure power available directly.

Under normal cutting conditions it is only necessary to measure the vertical load, at maximum motor load, as the other loads are not significant.

The calculation is :-

$$\text{HP at Tool} = \frac{\text{Vert. load} \times \text{speed feet/min (at the mean depth of cut)}}{33,000}$$

$$\text{Machine efficiency} = \frac{\text{HP at Tool}}{\text{Electrical HP consumed } \left(\frac{\text{Watts}}{746}\right)}$$

This data may be usefully recorded for estimating purposes.

2. 4. 2. Determination of optimum tool geometry

By judicious use of the dynamometer an approximation to the optimum tool shape for maximum metal removal can speedily be obtained. The sequence in the determination of angles is as follows:-

2. 2. 1. Best True Rake Angle
2. 2. 2. 2. Best Clearance Angle
2. 2. 2. 3. Best Plan Approach Angle.

A description of the test for best true rake will serve as a guide for the other angles.

2. 4. 2. 1. Best True Rake Angle

For this test a series of knife tools with different side rakes is used, as shown in Fig. 8. With this type of tool the true rake and side rake are coincidental* hence it is a simple matter to vary the true rake. Tests are conducted under standard conditions in which the vertical and horizontal loads are measured for varying true rakes. These tests are repeated for different rates of feed. Typical results are shown in Figs. 9a. and 9b.

Inspection of the results for . 020 feed/revolution reveal a minimum load at 20° true rake with an increase beyond this angle. Such a result indicates that edge breakdown has occurred on the 25° tool during the period of the test therefore it would be prudent to select an angle less than 20°. Since tool life is affected by the friction caused by the cutting load and the volume of tool material dissipating heat a compromise has to be made between maximum true rake and maximum volume of tool material. The choice will be governed to a degree by the tool material and the process for which the data is required. Milling with tungsten carbide tools would prejudice the choice to a less acute angle than when turning with high speed tools. The curves shown in Fig. 9 were for turning with high speed tools and under these conditions a choice of 15° true rake would appear satisfactory. Examination of the effect of this choice on the other feed rates supports the likelihood of its suitability.

In order to check this assumption life tests were conducted in which the tools were run to destruction. The results of these tests which were conducted over the extreme rates of feed are shown in Fig. 10. It is therefore apparent that with practice and a knowledge of the operating conditions close approximation to optimum angles can quickly be obtained by using the dynamometer technique.

2. 4. 2. 2. Best clearance angle

Using the true rake as previously determined, the clearance angles are varied and cutting loads measured as previously.

2. 4. 2. 3. Best plan approach angle

Adopting the angles previously determined a similar procedure is conducted for the plan approach angle.

* For further information on the definition of true rake angle see 'Fundamentals of cutting tool geometry' by G. V. Stabler.

Other angles may be determined in a similar manner.

When time and material supply permits, full scale life tests should be subsequently performed, for conclusive results.

2. 4. 3. Determination of machinability data for materials

Once the optimum tool shape has been derived for a given material further experiment can proceed to determine various machinability data such as:-

2. 4. 3. 1. Machinability index for power
2. 4. 3. 2. Specific cutting capacity
2. 4. 3. 3. Effect on power of variation in depth of cut and rate of feed.

2. 4. 3. 1. Machinability index for power

This machinability index gives a measure of the ease with which a material cuts and is defined as the vertical pressure on the tool required to shear a standard chip section of 0. 1" depth x 0. 010" thickness, thus

M. I. (P) = vertical pressure for . 1" x . 010" chip section.

This is easily obtained by setting the dynamometer to cut a standard chip section 0. 1" x 0. 010" and measuring the vertical load.

2. 4. 3. 2. Specific cutting capacity

An alternative method of expressing the ease by which a material machines is by stating the volume removable per horse power consumed, this is termed the Specific Cutting Capacity, thus

$$\text{S. C. C.} = \text{Volume removable per HP/minute} = \frac{396}{\text{Machinability index}}$$

This information is also of value for estimating purposes.

2. 4. 3. 3. Effect on power of variation in depth of cut and rate of feed

In most practical situations it is not convenient to use the standard chip section, therefore it is necessary to know the effect on power consumption when a departure is made from standard conditions.

The relationship between vertical pressure on the tool, depth of cut and rate of feed can be expressed in the form -

$$V.P. = M.I. \times 1000 \times d.^{x} f^{y}$$

V. P. = vertical pressure
Where d = depth of cut (ins.)
and f = rate of feed (ins.)

The value of 'y' is found by keeping 'd' constant and varying 'f'. The value of 'x' is found by keeping 'f' constant and varying 'd'.

S. C. C. can then be adjusted to suit the operating conditions.

2. 4. 4. Comparison of lubricants and coolants

When conducting experiments of the above nature it is generally necessary to replace the standard diaphragms by the more sensitive type.

The effect of different lubricants and coolants on the machinability index can be measured directly by the dynamometer. Unless the fluids under comparison have appreciable differences in their chemical combination with the tool material, a comparison of the cutting loads gives guidance to their relative proficiency.

2. 4. 5. Analysis of cutting force relationship

Much of the credit for the advances made into the theory of metal cutting must go to M. E. Merchant, Cincinnati Milling Machine Co., Ohio. His paper on 'Mechanics of the Metal Cutting Process' presents an elegant method of analysing the cutting force system. Merchant considers the chip as being in equilibrium under equal and opposite resultant forces R and R^1 as shown in Fig. 11a. Fig. 11b represents these forces in a condensed form.

Measurement of forces F_c and F_t are made by the dynamometer from which the resultant force R, the friction force F and the coefficient of friction τ can be derived.

Readers interested in this analysis are recommended to study Merchant's paper.

2. 4. 6. Workshop Machinability Comparator

It is often found in practice that material which meets the normal specification with regard to Brinell hardness and tensile strength behaves very differently when being machined. Loss of production often results from the lower rates of cutting necessary when material has poor machining characteristics. In conjunction with other factors the determination of the machinability index by the dynamometer provides an indication of the machining characteristics of the material.

Much argument between operators and rate-fixers could be avoided if a standard of machinability was set and material tested for machinability before being issued to the workshop.

2. 4. 7. Special Applications

In addition to the normal turning operations the lathe dynamometer has been used for planing tests. Work of this type has been conducted by Sheffield University for planing rock (see Fig. 16) with satisfactory results.

3. DRILL DYNAMOMETER

3. 1. Construction

The drill dynamometer measures thrust and torque during the drilling operation. This is achieved by direct mechanical means as illustrated diagrammatically in Fig. 12.

Test specimens are clamped to table (2), the thrust load being translated through spindle (1) which rests on a ball bearing and whose movement is resisted by diaphragm (4). Deflection of this diaphragm is measured by dial indicator (6) through bell crank (5).

Torque is also translated by means of spindle (1). In this case ball bearing (10) which is fitted to the spindle is resisted from turning by cantilever (9) whose deflection is measured by a dial indicator as shown.

3. 2. Calibration and toolsetting

The instrument is calibrated in the manner illustrated in Fig. 13.

Before clamping the test specimen to the table it is important to ensure alignment of machine spindle and dynamometer spindle. A centre hole is provided in the dynamometer spindle for this purpose.

3. 3. General information

Range:- The standard instrument has the following range -

Thrust = 500 lbs.
Torque = 100 inch lbs.

Overall dimensions:-

Dia. = $5\frac{3}{4}''$
Height = $5''$

Dial indicators:-

$\frac{1}{10,000}$ dial indicators are used

Extension piece:-

An extension piece is necessary for fitment to the thrust indicator. (This is supplied with the instrument).

3. 4. Uses of the drill dynamometer

Although the variables in the drilling process are not so easily manipulated or controlled as in the turning process none the less with adequate care most of the functions of the lathe dynamometer can be achieved with the drilling instrument, as the following list illustrates:-

3. 4. 1. Determination of power available for cutting also machine efficiency
3. 4. 2. Determination of optimum tool geometry
3. 4. 3. Determination of machinability data for materials
3. 4. 4. Comparison of lubricants and coolants
3. 4. 5. Analysis of cutting force relationships
3. 4. 6. Workshop machinability comparator
3. 4. 7. Special applications

3. 4. 1. Determination of power available for cutting also machine efficiency

Horsepower available for drilling is found in a similar manner as for turning. In this case the torque (inch lbs.) at maximum electrical load is noted also the drill speed and converted to HP. as follows:-

$$\text{HP. available at drill} = \frac{\text{Torque (ins. lbs.) } \overline{\text{II}} \text{ x RPM}}{198,000}$$

Machine efficiency is determined from the relationship

$$\text{\% machine efficiency} = \frac{\text{mech. HP. available at max. load}}{\text{electrical HP. consumed}} \text{ x } 100$$

3. 4. 2. Determination of optimum tool geometry

The principal angles of a drill are - helix angle, clearance angle and point angle as shown in Fig. 14.

3. 4. 2. 1. Helix angle

The helix angle corresponds to the side rake in turning, however it is only possible to alter the helix angle when conducting tests by changing the drill hence care has to be taken to ensure that other features such as web thickness, point angle and clearance angle are identical. It is advisable that a set of drills is selected and retained for this test.

The selection of this angle is determined similarly as for the true rake angle in turning.

3. 4. 2. 2. Clearance angle

In determining this angle it is preferable to retain the same drill throughout and re-grind the different clearance angles. By this procedure there is greater opportunity of maintaining consistency of the other features.

3. 4. 2. 3. Drill point angle

Similarly with this investigation one drill only should be used and reground with different point angles.

It is stressed once more that when time and material permit full scale life tests should be made.

3. 4. 3. Determination of machinability data for materials

The drill dynamometer can be used to determine similar data as the lathe instrument such as:-

3. 4. 3. 1. Machinability index for power
3. 4. 3. 2. Specific cutting capacity
3. 4. 3. 3. Effect on power of variation of drill diameter and rate of feed.

3. 4. 3. 1. Machinability index (power)

To conform to the standard chip section as for turning, i. e. 0.10" depth of cut x 0.010 width, a simple procedure is used to obtain the desired depth of cut. In this, a No. 33 drill (.1130 dia.) is reduced to .1125 dia. and is used to drill a pilot hole in the specimen.

Subsequently a 5/16" (.3125") dia. hole is drilled thus making 0.10" depth of cut.

Using the above procedure in conjunction with a feed rate of 0.010" per rev. the torque is measured in inch pounds.

The machinability index (power) is then calculated as follows:-

$$\text{M. I. (power)} = \frac{\text{Torque (in lbs.)}}{.212} = \text{pressure on cutting edge}$$

3. 4. 3. 2. Specific cutting capacity

As for turning

$$\text{S. C. C.} = \frac{396}{\text{machinability index}}$$

3. 4. 3. 3. Effect on power of variation of drill diameter and rate of feed

When the standard chip section is varied the effect on power may be determined by applying the exponential indices for diameter and feed per rev. as found in the following relationship.

$$\text{Pressure on cutting edge} = \text{M. I.} \times d^{a} \times f^{b} \times 1000$$

'a' is determined by keeping 'f' constant and varying 'd'; similarly 'b' is determined by keeping 'd' constant and varying 'f'.

3. 4. 4. Comparison of lubricants and coolants

It is more difficult to control this experiment in the drilling operation since the swarf may prevent effective functioning of the test fluids. One method which assists the application of the lubricants and coolants is to employ test specimens of a smaller diameter than the drill being used: the workpiece is then completely drilled away thus eliminating clogging of the swarf.

3. 4. 5. Comparison of cutting force relationships

An approximation to orthogonal cutting can be achieved if the drill is ground with a flat (180°) cutting point. To avoid the effect of web thickness it is necessary to drill a pilot hole as in section 3. 4. 3. 1. Also, to prevent the flat drill from wandering it should be guided in a drill bush as shown in Fig. 15.

The translation of torque and thrust readings into Merchant's nomenclature of cutting force Fc and thrust force Ft is as follows:-

$$Fc = \frac{\text{dynamometer thrust load}}{2}$$

$$Ft = \frac{\text{torque (inch lbs.)}}{\text{mean dia. of cut}}$$

Example

Assuming a pilot hole of .1125 diameter has been drilled, followed by a drill of .3125 diameter then the

$$\text{mean dia. of cut} = .3125 - \frac{(.3125 - .1125)}{2}$$

$$= .2125$$

The values for friction F and the coefficient of friction τ are derived as formerly.

3. 4. 6. Workshop machinability comparator

In combination with other factors and as hardness, strength etc. the machinability index as described in Section 3. 4. 3. 1. gives guidance to the machining characteristics of a material and an inspection of this feature prior to the commencement of machining often prevents bad material being issued to the works.

3. 4. 7. Special applications

Tapping

The drill dynamometer may be used for the measurement of torque during tapping operations. Since torque is an important factor on tap breakage this measurement assists in the evaluation of tap design and lubrication.

APPENDIX I

Users of Lathe Dynamometers

Acton Technical College	Acton	London
Cumberland Technical College	Workington	Cumberland
Grantham Technical College	Grantham	Lincoln
Chance Technical College	Smethwick	Birmingham
Hatfield Technical College	Hatfield	Herts.
Nottingham & District Technical College		Nottingham
The University of Leeds		Leeds
Ipswich School of Technology		Ipswich
Leeds College of Technology		Leeds
Rotheram College of Technology		Rotheram
Murex Limited	Rainham	Essex
Jarrow Technical Institute	Jarrow	Durham
Durham University, Kings College		Newcastle-upon-Tyne
Rhondda Technical Institute	Tonypandy	Rhondda, Glam.
Medway Technical College	Gillingham	Kent
Merthyr Tydfil Technical College	Merthyr Tydfil	Glam.
Aylesbury Technical School		Aylesbury
Wolverton Technical College	Wolverton	Bucks.
Glasgow Stow College		Glasgow
Denbighshire Technical College		Wrexham
Twickenham Technical College	Twickenham	Middlesex
Croydon Polytechnic		Croydon
Leicester College of Technology and Commerce		Leicester
Mechanical Engineering Research Laboratory		Glasgow
Stroud Technical College	Stroud	Gloucester.
College of Aeronautics	Cranfield	Bucks.
British Thomson-Houston Co. Ltd.		Rugby
Armstrong Siddeley Motors Ltd.		Coventry
Reading Technical College		Reading
Maidstone Technical Institute	Maidstone	Kent
Burnley Municipal College	Burnley	Lancs.
Isle of Wight Technical College		Isle of Wight
Swansea Technical College		Swansea
Basingstoke Technical Institute	Basingstoke	Hants.
Wimbledon Technical College	Wimbledon	London
Bristol College of Technology		Bristol
Accrington College of Further Education,		Accrington, Lancs.
Keighley Technical College	Keighley	Yorks
Fletcher Miller Ltd.	Hyde	Manchester
Melbourne University	Victoria	Australia
Coventry Grinders Ltd.	Coventry	Warwick.
Gorvic Products Ltd.	Coventry	Warwick.
Derby Technical College		Derby.

APPENDIX I (Contd.)

Impregnated Diamond Products Ltd.		Gloucester
North Staffordshire Technical College		Stoke-on-Trent
Royal Aircraft Establishment	Farnborough	Hants.
Dartford Technical College	Dartford	Kent
Woolwich Polytechnic		Woolwich
Portsmouth Municipal College	Portsmouth	Hants.
Dewsbury and Batley Technical College,		Batley, Yorks.
Chesterfield Technical College		Chesterfield
North East Essex Technical College, Colchester		Essex
Kingston Technical College	Kingston-on-Thames,	Surrey
Stafford County Technical College,		Stafford
Wigan & District Mining & Technical College,		Wigan, Lancs.
Birmingham College of Technology		Birmingham
Rolls Royce Ltd.	East Kilbride	Lanarkshire
Openshaw Technical College	Openshaw	Manchester
Northampton College of Technology		Northampton
Carbon Dioxide Co. Ltd.	Epsom	Surrey
Sheffield University		Sheffield
South East Essex Technical College and Art School		Dagenham, Essex
Cambridge University		Cambridge
Warrington Technical College		Warrington
Barrow Central College of Further Education		Barrow-in-Furness, Lancs.
Bromsgrove College of Further Education, Bromsgrove,		Worcs.
Royal Technical College	Salford	Lancs.
Wolverhampton & Staffordshire Technical College		Wolverhampton
Newton Heath Technical College		Manchester 10.
Slough College of Further Education,	Slough	Bucks.
Newport Technical College	Newport	Mons.
North Herts Technical College	Letchworth	Herts.
High Wycombe College of Further Education,		High Wycombe, Bucks.
Southall Technical College	Southall	Middlesex
Royal Ordnance Factory	Maltby, Nr. Rotheram,	Yorks.
Rolls Royce Ltd.		Derby
Erith Technical College	Belvedere	Kent
North Oxfordshire Technical College		Banbury
Constantine Technical College		Middlesborough
Hendon Technical College	Hendon	London
Brighton Technical College		Brighton
North West Wilts College of Further Education, Chippenham, Wilts.		
St. Helens Technical College	St. Helens	Lancs.
Darlington Technical College		Darlington
Leigh Technical College	Leigh	Lancs.
D. Napier & Son Ltd.	Acton	London
Manchester Oil Refinery Ltd.		Manchester

APPENDIX I (Contd.)

Kidderminster College of Further Education		Kidderminster
Short Brothers & Harland Ltd.		Belfast
Southampton Technical College		Southampton
Sheffield College of Technology		Sheffield 1.
Glamorgan Technical College	Treforest	Glam.

APPENDIX II

Users of Drill Dynamometers

Acton Technical College	Acton	London
Grantham Technical College	Grantham	Lincoln
Chance Technical College	Smethwick	Birmingham
Hatfield Technical College	Hatfield	Herts
Nottingham & District Technical College		Nottingham
The University of Leeds		Leeds
Liverpool College of Technology		Liverpool
Ipswich School of Technology		Ipswich
Leeds College of Technology		Leeds
Rotheram College of Technology	Rotheram	Yorks.
Jarrow Technical Institute	Jarrow	Durham
Durham University, Kings College		Newcastle-upon-Tyne
Rhondda Technical Institute	Tonypandy	Rhondda, Glam.
Medway Technical College	Gillingham	Kent
Merthyr Tydfil Technical College	Merthyr Tydfil	Glam.
Aylesbury Technical School	Aylesbury	Bucks.
Wolverton Technical School	Wolverton	Bucks.
Stroud Technical College	Stroud	Gloucester.
Glasgow Stow College		Glasgow
Denbighshire Technical College	Wrexham	North Wales
Twickenham Technical College	Twickenham	Middlesex
Croydon Polytechnic	Croydon	Surrey
Leicester College of Technology & Commerce		Leicester
Mechanical Engineering Research Laboratory,	East Kilbride,	Glasgow
South East London Technical College		London, S. E. 4.
College of Aeronautics	Cranfield	Bucks.
British Thomson-Houston Co. Ltd.		Rugby
Armstrong Siddeley Motors Ltd.	Coventry	Warwick.
Reading Technical College		Reading
Maidstone Technical Institute	Maidstone	Kent
Burnley Municipal Technical College,	Burnley	Lancs.
Isle of Wight Technical College	Newport	Isle of Wight
Swansea Technical College	Swansea	Glam.
Basingstoke Technical Institute	Basingstoke	Hants.
Chester College of Further Education,	Chester	Ches.
Wimbledon Technical College	Wimbledon	London
Bristol College of Technology		Bristol
Accrington College of Further Education,	Accrington	Lancs.
Keighley Technical College	Keighley	Yorks.
Fletcher Miller Ltd.	Hyde	Manchester
Carlisle Technical College	Carlisle	Cumberland
Melbourne University	Victoria	Australia
Coventry Grinders Ltd.	Coventry	Warwick.
Gorvic Products Ltd.	Coventry	Warwick.

APPENDIX II (Contd.)

Derby Technical College		Derby
Impregnated Diamond Products Ltd.		Gloucester
North Staffordshire Technical College,	Stoke-on-Trent,	Staffs.
Royal Aircraft Establishment	Farnborough	Hants.
Dartford Technical College	Dartford	Kent
Woolwich Polytechnic		Woolwich
Portsmouth Municipal College	Portsmouth	Hants.
Dewsbury & Batley Technical & Art School,	Batley	Yorks.
Erith Technical College	Belvedere	Kent
Chesterfield Technical College	Chesterfield	Derbyshire
North East Essex Technical College,	Colchester	Essex
North Herts Technical College,	Letchworth	Herts
Guildford County Technical College,	Guildford	Surrey
Birkenhead Technical College,	Birkenhead	Cheshire
Kingston Technical College	Kingston-upon-Thames,	Surrey
Stafford County Technical College,		Stafford
Wigan & District Mining & Technical College,	Wigan,	Lancs.
Birmingham College of Technology		Birmingham, 1.
Glamorgan Technical College		Glamorgan.
Openshaw Technical College	Openshaw	Manchester
Cambridge University		Cambridge
Warrington Technical College	Warrington	Lancs.
Barrow Central College of Further Education,	Barrow-in-Furness,	Lancs.
Wolverhampton & Staffordshire Technical College,		Wolverhampton
Newton Heath Technical College	Newton Heath	Manchester, 10.
Slough College of Further Education,	Slough	Bucks.
Newport Technical College	Newport	Mons.
High Wycombe College of Further Education,	High Wycombe,	Bucks.
Southall Technical College	Southall	Middlesex
Rolls Royce Ltd.		Derby
North Oxfordshire Technical College,	Banbury	Oxon.
Constantine Technical College		Middlesborough
Brighton Technical College		Brighton
North West Wilts College of Further Education,	Chippenham,	Wilts.
Kidderminster College of Further Education		Kidderminster
St. Helens Technical College	St. Helens	Lancs.
Darlington Technical College		Darlington
Enfield Technical College	Enfield	Middlesex
Manchester Oil Refinery Ltd.		Manchester, 17.
Luton College of Further Education		Luton
Sheffield College of Technology		Sheffield, 1.

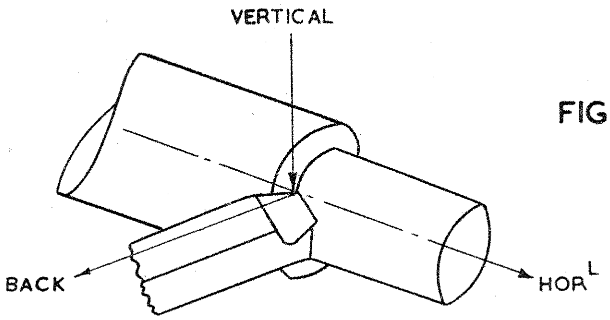


FIG. 1.
DIAGRAM OF LOADS
ACTING ON TOOL

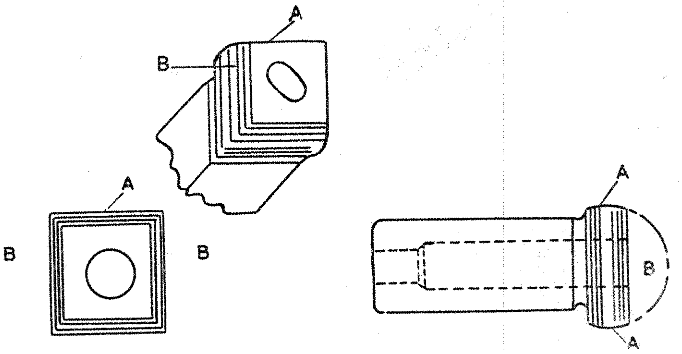


FIG. 2.

TOOL HOLDER BODY

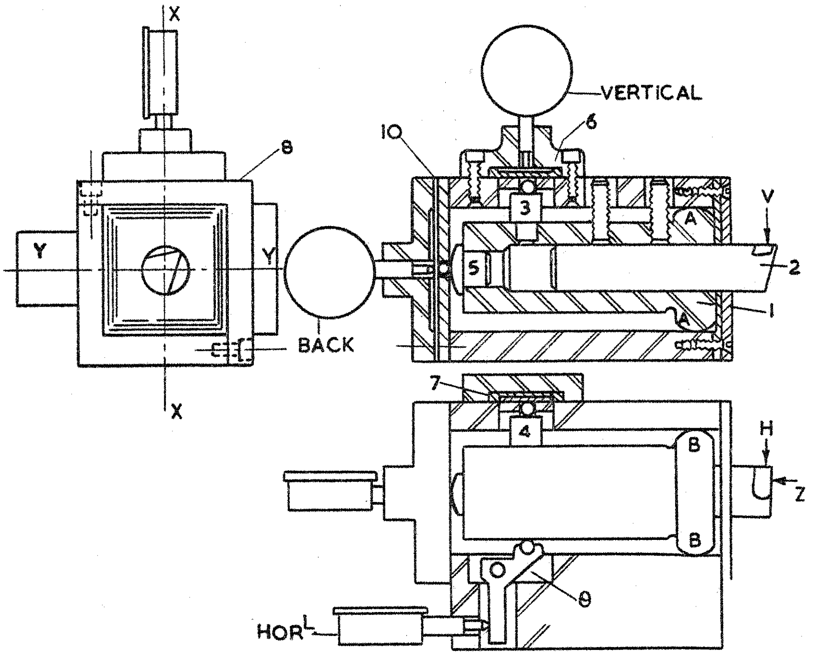


FIG. 3.

CONSTRUCTION OF DYNAMOMETER

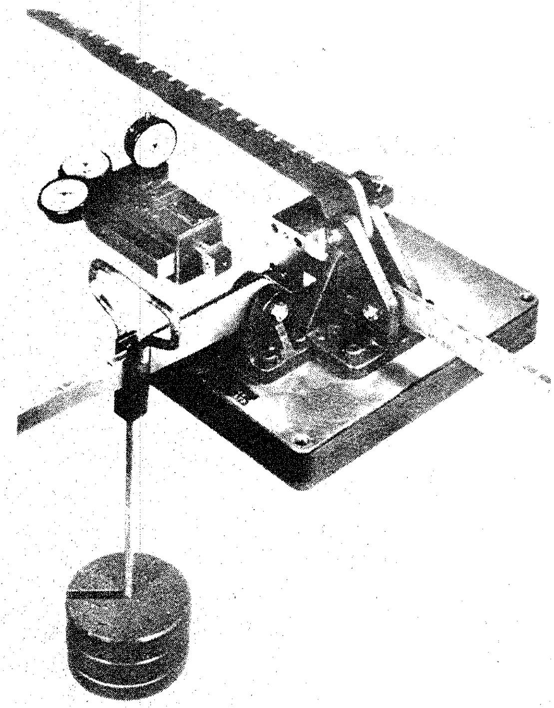


FIG. 4.

CALIBRATION UNIT

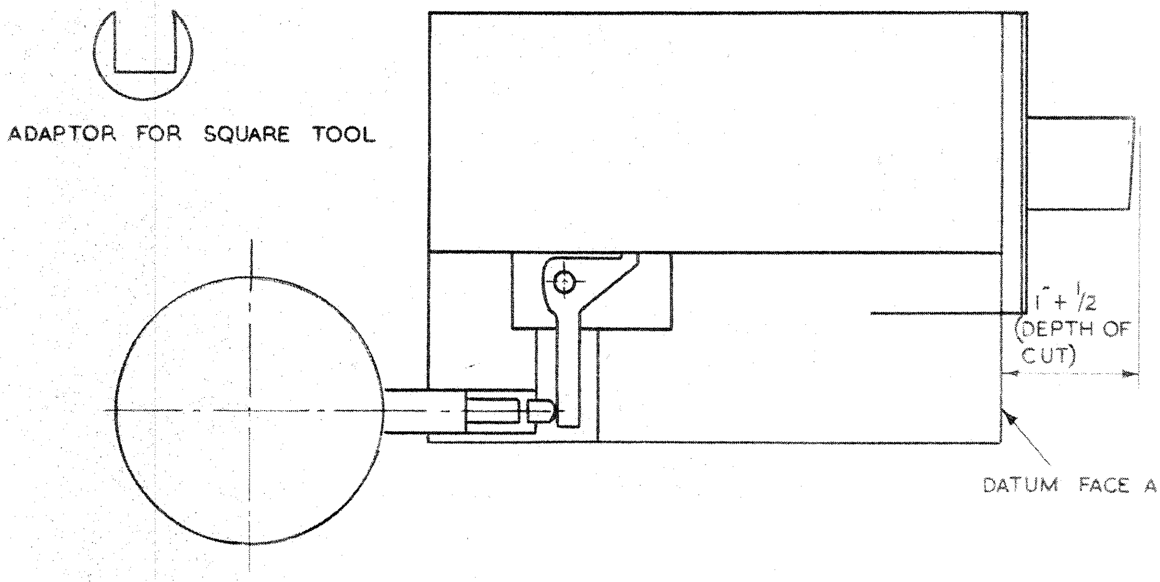


DIAGRAM OF LATHE TOOL DYNAMOMETER.

FIG. 5.

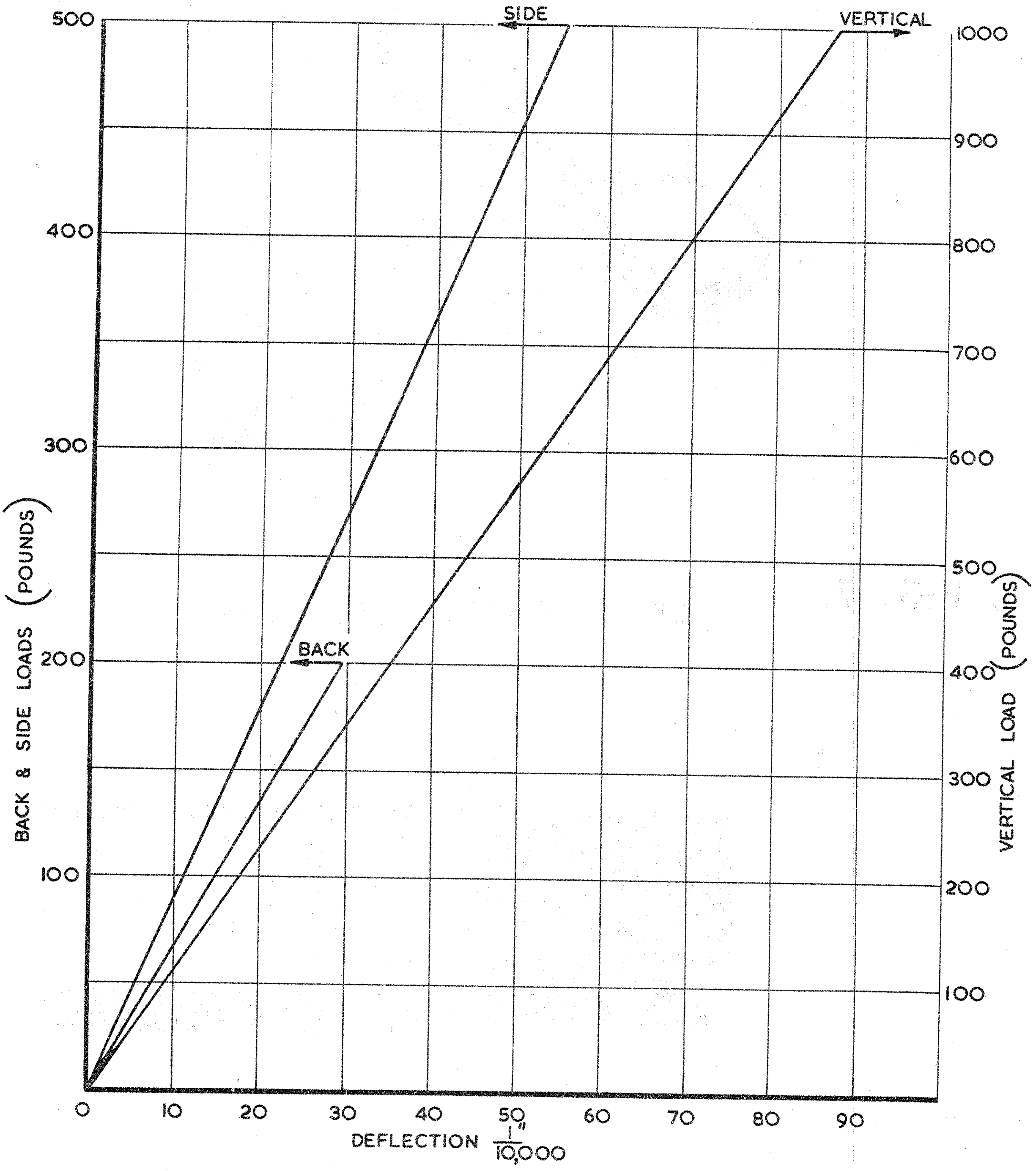


FIG. 6. LATHE DYNAMOMETER

CALIBRATION CHART

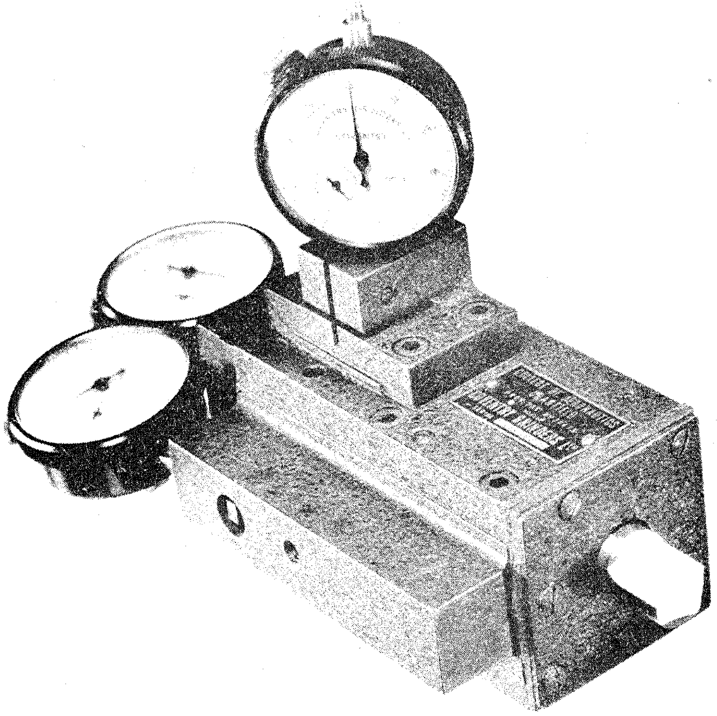


FIG. 7. LATHE DYNAMOMETER

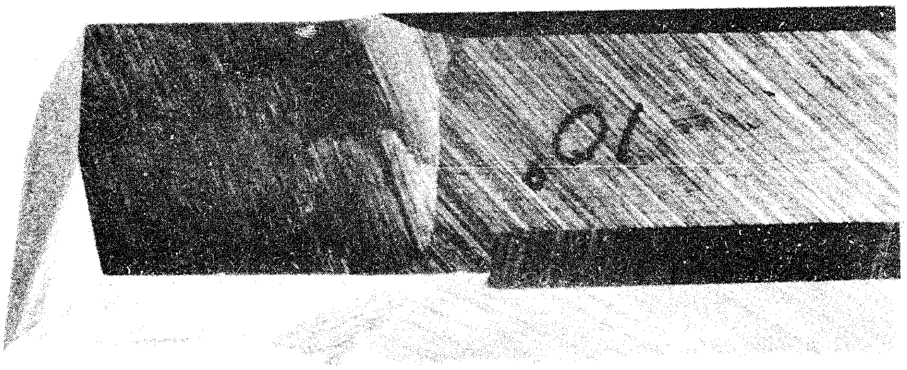


FIG. 8. 10° SIDE RAKE TOOL

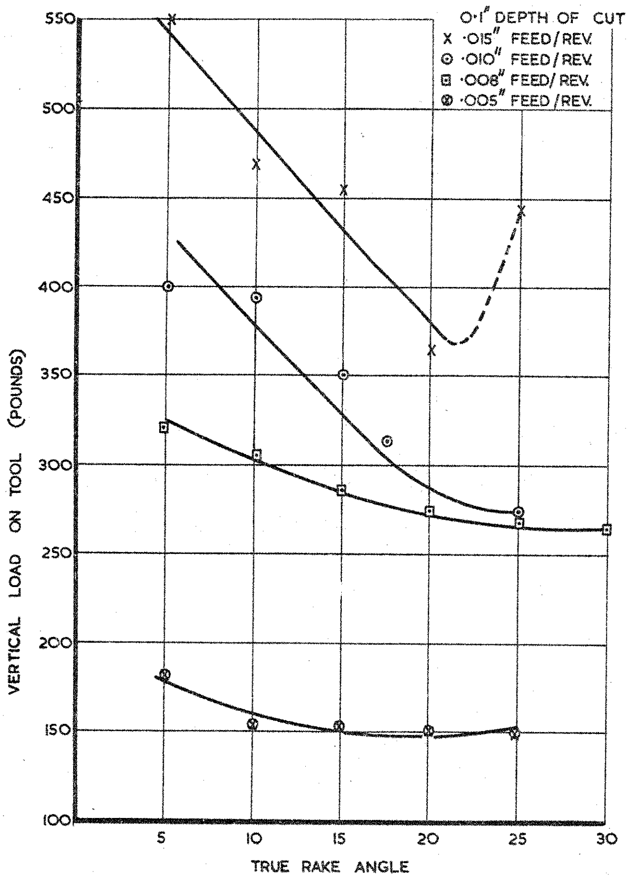


FIG. 9a. VERTICAL TOOL LOADS FOR VARIOUS TRUE RAKE ANGLES

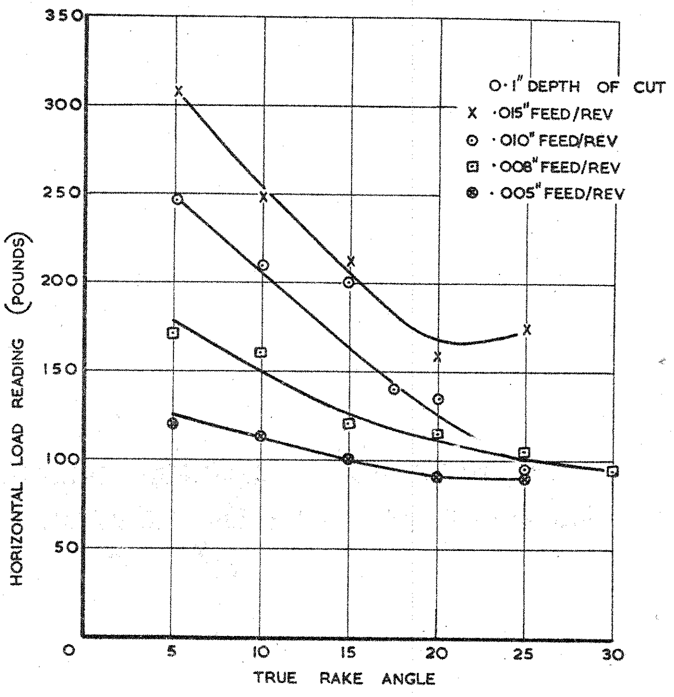


FIG. 9b. HORIZONTAL TOOL LOADS FOR VARIOUS TRUE RAKE ANGLES

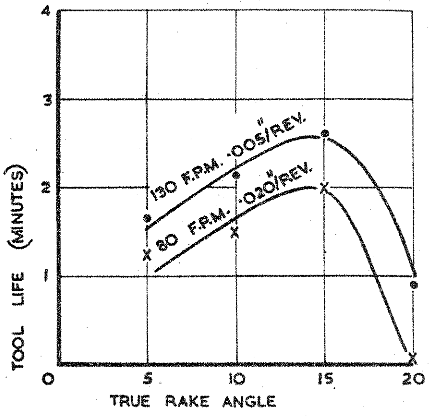


FIG. 10. TOOL LIFE FOR VARIOUS TRUE RAKE ANGLES

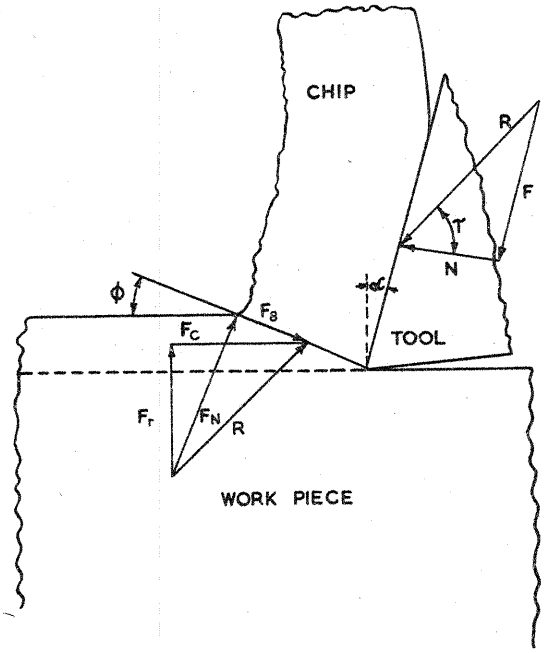
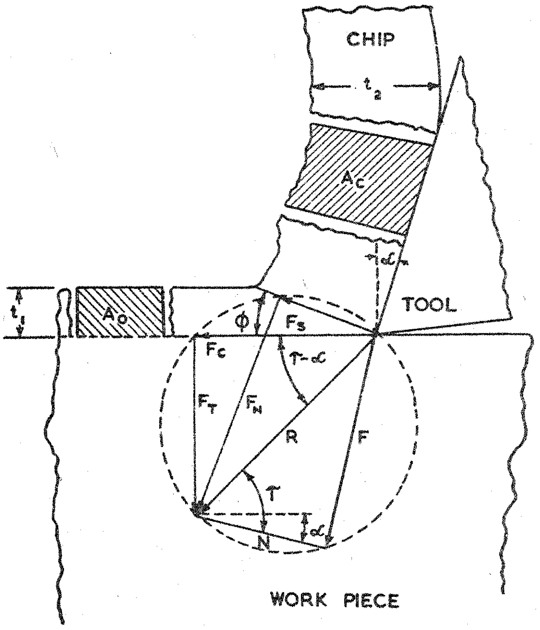


FIG. 11a.

FORCE SYSTEM HOLDS CHIP IN STABLE MECHANICAL EQUILIBRIUM.

FIG. 11b

CONDENSED FORCE DIAGRAM SHOWING RELATIONSHIPS BETWEEN COMPONENTS



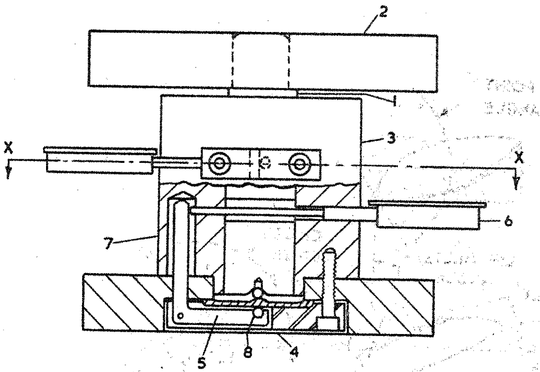
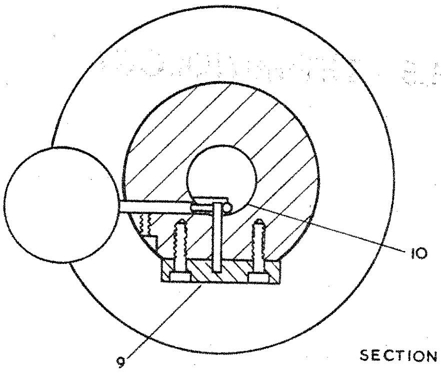
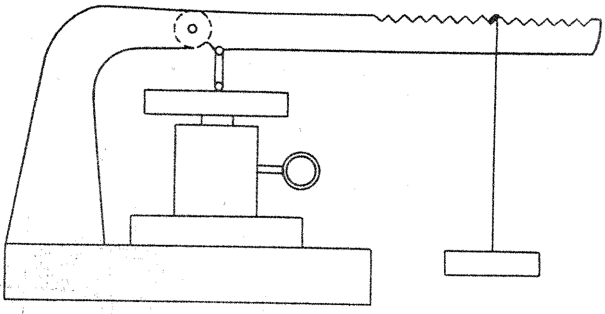


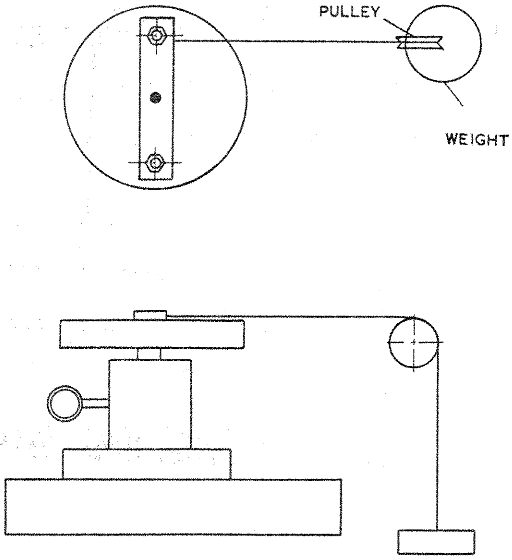
FIG. 12.
DIAGRAM OF DRILL DYNAMOMETER



SECTION XX

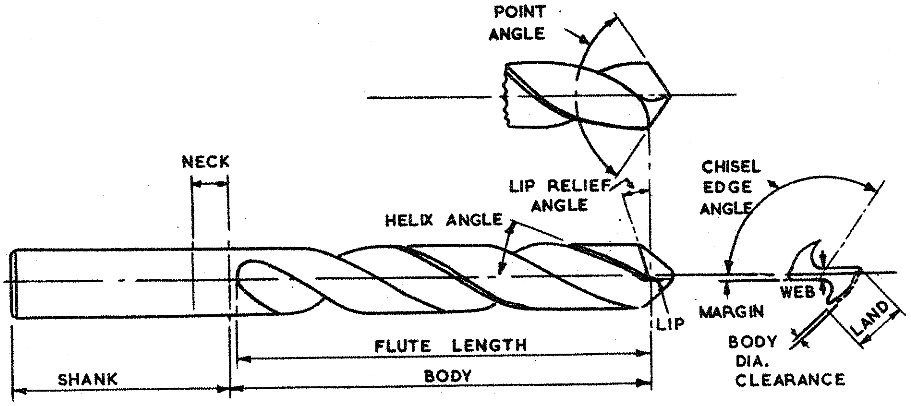


CALIBRATION FOR THRUST



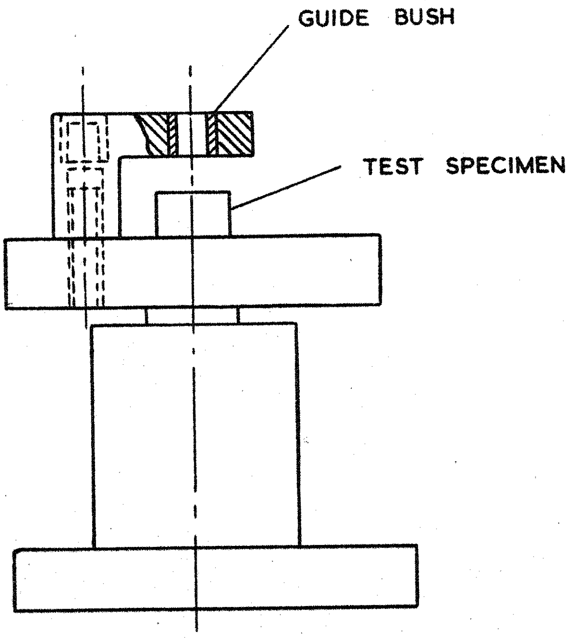
CALIBRATION FOR TORQUE.

FIG. 13.
CALIBRATION UNIT



CUTTING ANGLES FOR DRILLS TERMINOLOGY

FIG. 14.



DRILLING WITH GUIDE BUSH.

FIG. 15.

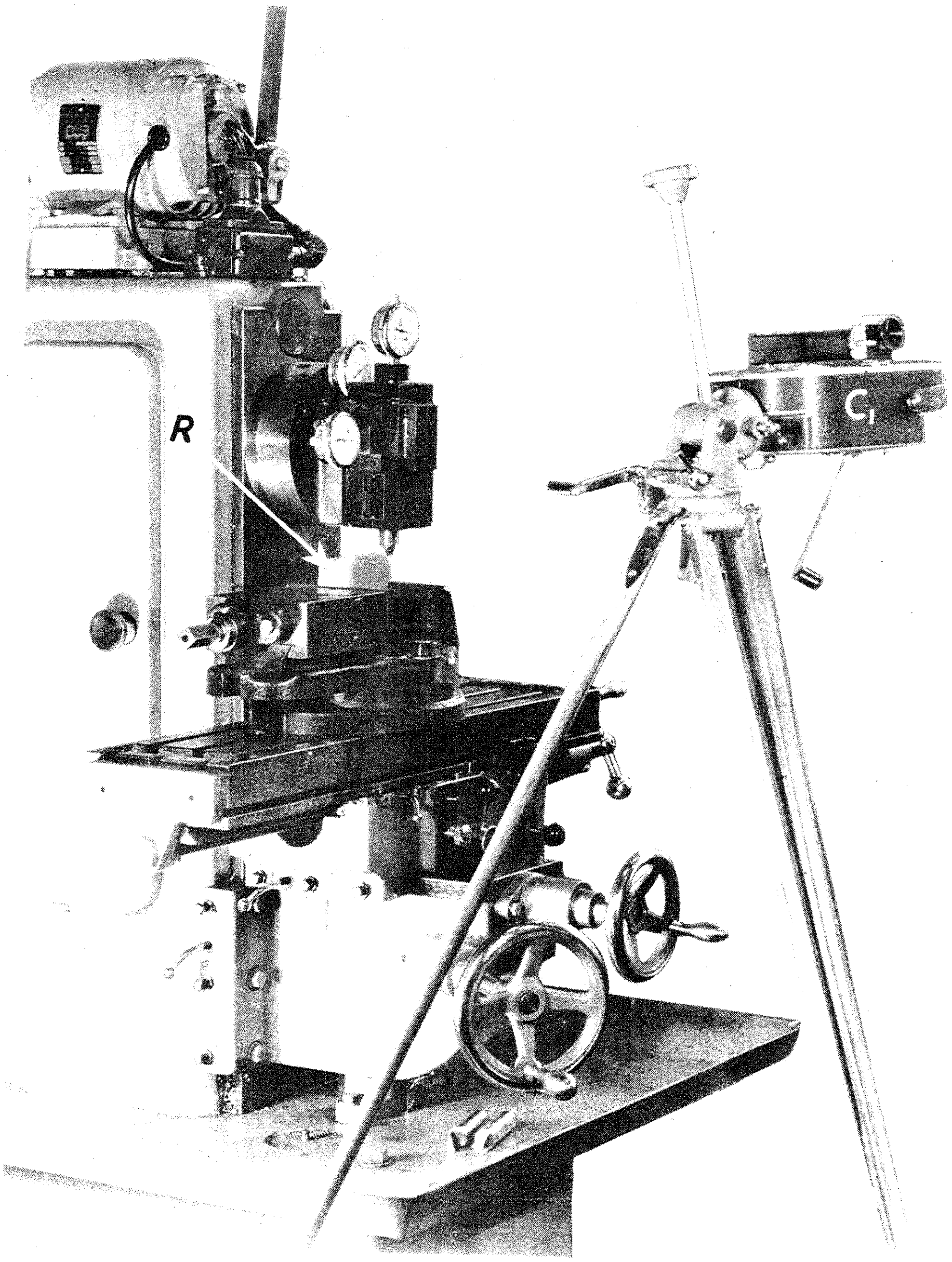


FIG. 16.

LATHE DYNAMOMETER USED FOR TESTS ON PLANING ROCK