Estimating and Planning
for
Engineering Production

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Estimating and Planning
for
Engineering Production

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To

My Mother and Father

PREFACE

Estimating as applied to engineering production is a portion of the preliminary work necessary before the actual production commences. If carried out with skill it permits the work to proceed smoothly and at the minimum of expense. In practice, it covers a complete layout of the various manufacturing processes: the decision as to producing the various components within the establishment or purchasing from specialist concerns; making allocation for all patterns, tools, gauges and sundry equipment; checking the plant capacity and putting forward recommendations for new machines; determining the times for each process, also the labour and material charges, so that effective control can be maintained.

The work as a whole is based upon the author's own experience in a number of industries. As always happens the information has in part been paid for by experience also obtained from other sources. Where the origin of the information is known it is given in the Bibliography at the end of the book. In a number of instances it is now impossible to give the real source of information, as it may have been gained through contact with trade representatives, a clash of opinion, or carried subconsciously after reading an article in a journal.

Reference is made to the work done by the Manchester Society of Engineers and given in the L.T.R.C.'s, 1922, Report. From the viewpoint of a production engineer the work published by the A.S.M.E. is perhaps the most valuable after the masterpiece by F. W. Taylor on the Art of Metal Cutting. The author tenders thanks to the Council of the A.S.M.E. for permission to give in this work the tables of cutting speeds and feeds.

An attempt has been made to broaden the scope of the published data on single-point tools to cover other machining operations connected with ferrous and non-ferrous metals as listed in the current British Standard and the S.A.E. specifications. Thus such operations as milling and gear cutting are brought within the scope of the tables. Moreover, the given data permit the cutting speed and chip dimensions to be related to a given machine's capacity. Hence this has the tendency to remove any doubt a production engineer may have, when laying out a series of metal-cutting operations, as to the ability of the machine to take a chip of a given size. Arising out of the control permitted by the correct use of the data, the work should prove useful to all engaged in production: works superintendents or managers, estimators or planning engineers, ratefixers and foremen, also mechanics interested in getting the best out of the machines.

It is also hoped that the work will prove of value to those teaching and receiving tuition in Managerial and Production Engineering subjects.

P. S. HOUGHTON.

BIRMINGHAM.

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CHAPTER I

The Slide Rule

The slide rule (fig. 1.1) is an instrument designed to simplify multiplication, division, involution, and evolution without resorting to the normal arithmetical processes. Its use enables involved calculations to be rapidly performed. To read a slide rule calls for no greater skill than that necessary to read the vernier. The principle upon which the slide rule is built is logarithmic; hence, when multiplication is necessary, the settings on the rule are added, and the answer taken direct from the rule. When division is called for, the divisor is subtracted from the dividend and the remainder gives the answer to the problem. Slide rules are also marked to permit logarithms, sines, tangents, powers of numbers, the square, and other roots to be easily obtained without resorting to mathematical tables. In addition, there are a number of special rules, each designed for a specific purpose.

As is to be expected, the construction of the slide rule varies according to the maker. However, in all designs, the main features remain constant, in that each has three parts, (*a*) the body, (*b*) the slide, (*c*) the cursor. The body has two or more scales engraved on its face, and is machined so that the slide is retained in it, yet is free to move along the entire length. The slide, having two or more scales on its face, runs in slots cut in the body, and thus permits the setting for multiplication, &c. The cursor runs up and down the body and is used to facilitate setting the slide and reading off the results. Across the glass a hair line is cut, and this enables the settings to be made with considerable accuracy.

The size of a slide rule varies; the three chief sizes are approximately 5, 10, and 20 inches in effective length. This naturally affects the accuracy, as the longer the rule the more space there is for the various scales. With a small rule, direct reading to the first figure is usual, with the second estimated; longer rules give direct readings

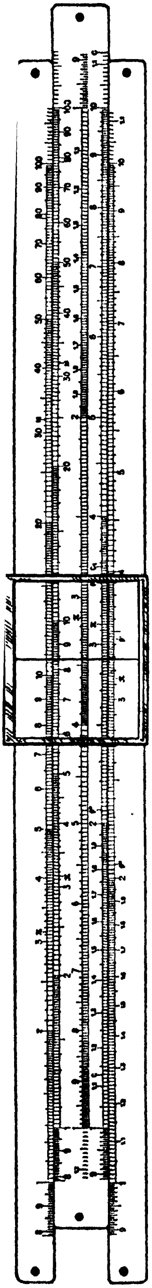


Fig. 1.1.—The slide rule

for the second and third figures, with the third and fourth estimated. The accuracy of the results obtained is sufficient for a large mass of calculations which form the day-to-day work of an engineering establishment having drawing, planning, estimating and rate-fixing departments, as often accuracy to the second or third figure is all that is called for; where greater accuracy is essential, then the normal arithmetical processes are adopted, or use is made of six- or seven-figure logarithmic tables; alternatively a calculating machine may be used.

1. **Markings.**

Before attempting to use a slide rule the markings on the various scales should be understood. Taking the normal 10-in. rule and lettering the four main scales A, B, C, D, it will be found that the top scales A and B are marked alike, and the main divisions are numbered 1 to 100, or a double marking of 1 to 10. The scales C, D running along the bottom edges of the slide and body also have identical marking, with the main divisions numbered from 1 to 10; in some instances the end division is numbered 1.

The scales on a slide rule are logarithmic, hence the decreasing distance between each consecutive unit as the numbers increase from 1 to 10. However, all divisions are indicated by natural numbers, thus giving direct readings without the need for mathematical tables.

Examining the scales A, B, it will be noticed that from 1 to 10 each consecutive unit is clearly marked, but on the other half of the scale the increment is often 10, that is, the markings read 10, 20, 30, &c. The next thing is to note the manner in which each of the main divisions is subdivided. This is given in tabular form opposite.

Examining the scales C, D, it is seen that the numbers run consecutively from 1 to 10; on some

TABLE 1.—THE DIVISION OF THE A AND B SCALES ON A 10 IN. SLIDE RULE

Division on scale A, B	Number of divisions	Subdivided into	Value of division	Value of subdivision
1 to 2	10	5	·1	·02
2 to 3	10	2	·1	·05
3 to 4	10	2	·1	·05
4 to 5	10	2	·1	·05
5 to 6	10		·1	
6 to 7	10		·1	
7 to 8	10		·1	
8 to 9	10		·1	
9 to 10	10		·1	
10 to 20	10	5	1	·2
20 to 30	10	2	1	·5
30 to 40	10	2	1	·5
40 to 50	10	2	1	·5
50 to 60	10		1	
60 to 70	10		1	
70 to 80	10		1	
80 to 90	10		1	
90 to 100	10		1	

rules the 10 is given as 1. The division of each of these units varies, as is shown in tabular form below.

TABLE 2.—THE DIVISION OF THE C AND D SCALES ON A 10 IN. SLIDE RULE

Division on scale C, D	Number of divisions	Subdivided into	Value of division	Subdivision
1 to 2	10	10	·1	·01
2 to 3	10	5	·1	·02
3 to 4	10	5	·1	·02
4 to 5	10	2	·1	·05
5 to 6	10	2	·1	·05
6 to 7	10	2	·1	·05
7 to 8	10	2	·1	·05
8 to 9	10	2	·1	·05
9 to 10	10	2	·1	·05

It is important that the value of each of the above markings is memorized. When using a slide rule the ease and rapidity with which the calculation can be made, and the accuracy achieved, depend upon the value assigned to each subdivision.

2. The Decimal Point.

With all slide-rule calculations the position of the decimal point is left to the last; then it is determined by inspection of the expression. In many instances its position is self-evident. With others it is necessary to make an approximation so that from the rough working the position of the decimal point may be ascertained.

3. Multiplication.

Where a series of numbers given in the normal notation is converted into common logarithms, the sum of the logs gives the log of the answer. This may be expressed algebraically as

$$\log A + \log B = \log (A \times B).$$

As the slide rule is logarithmic in principle, multiplication is performed by adjusting the slide in relation to the body until the end of the slide is over the requisite number, thus marking off the multiplicand. Then, using the cursor, the position of the multiplier is found on the slide, and the value of the combined lengths is read off the scale on the body. This gives the results of the multiplication.

Example 1.—Multiply 2 by 3.

For the general run of multiplication the scales C, D are normally used and, working with these, the stages in the problem are as follows (see fig. 1.2):

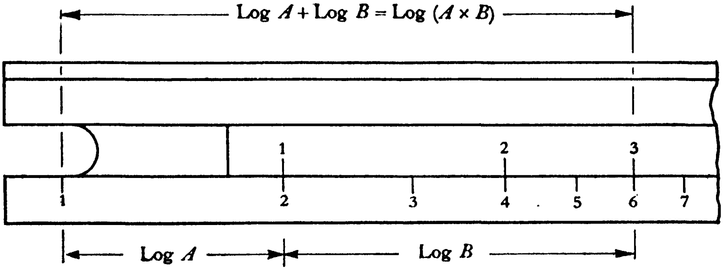


Fig. 1.2.—Multiplying on a slide rule

1. Move the slide until the commencement of the C scale is over 2 on the D scale.

2. Move the cursor along until it is over 3 on the C scale.

3. Take the reading on the D scale given by the hair line on the cursor. This will be found to be 6.

The setting is illustrated graphically in fig. 1.2 and is typical of the ease with which multiplication can be performed with a slide rule.

In some instances the value of the multiplicand makes it impossible to obtain a result when the left-hand end of the slide is brought into position over the number on the D scale. This creates no difficulty as, when this happens, the right-hand end of the slide is placed opposite the multiplicand on the D scale, and the reading is taken in the usual way.

Example 2.—Multiply 6 by 2.

Using the scales C and D, the stages in this example are (see fig. 1.3):

1. Move the slide across to the left until the end of the C scale is over 6.
2. Move the cursor along until it comes over 2 on the C scale.

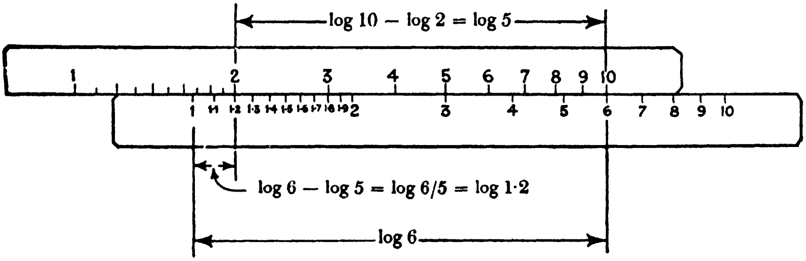


Fig. 1.3.—Multiplying by slide rule

3. Take the reading on the D scale as given by the hair line on the cursor. It will be found that the two on the C scale comes over the second division between 1 and 2 on the D scale. The reading is thus 1·2, and as there are no decimal figures in the question the answer is 12.

From these two illustrations the rule for multiplying can be given:

To multiply, place over the requisite marking on scale D the appropriate end of the slide. On scale D, opposite the given position on scale C, read off the answer. Fix the decimal point by inspection.

4. Division.

It has been shown above that, with the slide rule, multiplication consisted of adding the values as represented on scales C and D. Therefore the process of dividing must be the reverse and entail the subtraction of one number from another. This follows the practice when using logs and expressed algebraically is thus

$$\log A - \log B = \log (A \div B).$$

Division is normally performed—see fig. 1.4—with the scales C and D; the stages necessary in the process are thus:

1. On scale D set the cursor over the value of the dividend.
2. Adjust the slide so that the value of the divisor on scale C is under the hair line on the cursor.
3. Adjust the cursor so that it is over the end of scale C in contact with scale D.
4. Read off the value given by the cursor on scale D.
5. Determine, by inspection, the position of the decimal point.

Example 3.—Divide 7 by 2.

The stages in this are as follows (see fig. 1.4):

1. Using scale D, set the cursor over 7.
2. Move the slide until 2 on scale C is under the cursor line.

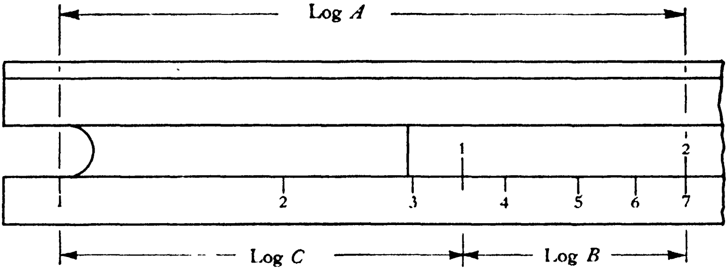


Fig. 1.4.—Dividing on the slide rule

3. Move the cursor until it is over the end of scale C and giving a reading on scale D.
4. Read the value under the cursor line on scale D. This is 3·5.
5. Determine the decimal point; in this instance it is evident that the answer is 3·5.

Example 4.—Divide 81 by ·9.

With questions of this type it often becomes worth while to rearrange the decimal point so that the divisor is made a whole number.

Thus, the above question, arranged so that the decimal point in the divisor is removed, becomes

810 divided by 9.

The stages in this example are:

1. On scale D set cursor over 81.
2. Adjust slide so that 9 on scale C is under the cursor line.
3. Move cursor to the end of the slide still in contact with the scale D.
4. Read off the value on scale D. This is 9.
5. Determine, by inspection, the position of the decimal point. From the rearranged figures 90 is found to be the answer.

More examples of multiplying and dividing involving the decimal point and three or four figures are given below.

Example 5.—Multiply 3·125 by 56·55.

The stages in this example are as follows:

1. Bring the right-hand end of the scale C over 3125 on scale D. Note that the 5 must be determined " by eye ".
2. Move the cursor until the hair line is over 5655 on the C scale. Here, too, the last 5 must be determined by eye.
3. Read the result on the D scale. This is 1767.
4. Determine the decimal point. By inspection the approximate answer is 170. Hence the required answer is 176·7.

Example 6.—Multiply 7875 by 12·55.

The stages in this example are as follows:

1. Move the slide so that the L.H. end of the slide, scale C, is over 7875 on scale D. Note that the actual setting is by eye. The markings on the rule are not fine enough to give the direct setting for this.
2. Move the cursor so that the reading on scale C is 1255. This is also set by eye.
3. Read the result on scale D. This is 988.
4. Determine the position of the decimal point. By inspection there should be five digits in front of the decimal point, hence the answer is 98,800.

Example 7.—Divide 57·75 by 3·775.

1. On scale D set cursor over 5775 (by eye).
2. Adjust slide so that 3775 on scale C is under the cursor line.
3. Move cursor to end of slide in contact with scale D.
4. Read off the value on D scale under the cursor line. This is 153.
5. Determine the decimal point. Inspection gives the approximate answer as 15. Therefore the answer is 15·3.

5. Proportion.

Problems involving both multiplication and division can also be dealt with on a slide rule. When estimating, questions of simple proportion constantly crop up and are readily solved in the following manner.

Example 8.—Find the weight of 18½ in. of 2 in. dia. bar given that 1 ft. weighs 8·9 lb.

Expressing this in the usual manner, and bringing the lengths to the same units, we have

$$12 : 8{\cdot}9 = 18\tfrac{1}{2} : x,$$

or

$$x = \frac{18{\cdot}5}{12} \times 8{\cdot}9.$$

This expression may be solved using (*a*) scales A and B, or (*b*) C and D.

(*a*) Using scales A and B:

1. Set the cursor line over 185 on L.H. end of scale A.
2. Set scale B (L.H. end) to read 12 under the cursor line.
3. Move cursor along to read 89 on scale B (L.H. end).
4. Read off the value under the cursor line on Scale A. This is 137.
5. Determine the decimal point. Rough working suggests 14 lb. Hence the answer is 13·7 lb.

(*b*) Using scales C and D:

1. Set cursor to 185 on scale D.
2. Set scale C to give a reading of 12 under the cursor line.
3. Bring cursor to end of scale C in contact with scale D.
4. Adjust the slide bringing the R.H. end under the cursor line.
5. Adjust cursor to give a reading of 89 on the C scale.
6. Read the value on D scale under the cursor line; this is 137.
7. Determine the decimal point. Answer 13·7.

It will be noticed that if scales A and B are used there is one stage less than when scales C and D are chosen. In practice the method adopted depends upon use; where scales C and D are normally chosen the necessary working for a problem of this type would be done with them.

6. Squares and Square Roots.

Squares and square roots can be obtained direct from readings taken from the fixed scales A and D. Referring back to the description given of the markings on the various scales, it will be noticed that scale A runs from 1 to 100 or it has a double scale running from 1 to 10. The markings on scale D run from 1 to 10. But 100 is the square of 10, and 10 the square root of 100; hence, as the scales A and D are logarithmic, the square or square root of any number can be easily obtained by reading across from one scale to the other.

Squares of Numbers.—To obtain the square of any number, set the cursor to that value on scale D, then read off the number given under the cursor line on scale A. Fix the decimal point by inspection.

Example 9.—Evaluate 16^2.

The stages are as follows:

1. Set the cursor over 16 on scale D.
2. Read off the value on scale A as given by the cursor line. This is 256.
3. Determine the decimal point. By inspection there are 3 figures in front of the decimal point, therefore the answer is 256.

Similarly, $2{\cdot}375^2$ will be found to equal 5·64.
$3{\cdot}16^2$,, ,, ,, 10·0.
$4{\cdot}5^2$,, ,, ,, 20·25.
$72{\cdot}5^2$,, ,, ,, 5260.

Other powers can readily be obtained by repeated multiplication and the work can be simplified by multiplying the powers of the number. In some instances a special scale enables the cube of a number to be obtained in a similar manner to that given for the square of a number.

Square Roots of Numbers.—When using the slide rule to determine the square root of a number, the preliminary stage is to group the figures off in pairs and thus determine the commencing figure of the root. This follows the practice adopted when finding the square root by arithmetical means. It is necessary because of the relationship between the scales A and D, A being, in linear measure, half of D. Therefore the value obtained varies according to which portion of scale A is used.

The procedure for determining the square root of any number is as follows:

1. Group off the figures of the number in pairs as for the arithmetical process of calculating the square root; the whole number to the left of the decimal point, the decimal fractions to the right of the decimal point.
2. Determine, by inspection, the first figure of the root.
3. Set the cursor over the number using scale A. Note the position of the cursor on scale A must give the first figure of the root as determined by inspection on scale D.
4. Read off the value given by the cursor line on scale D.
5. Determine the position of the decimal point by the grouping as done at 1.

Example 10.—Evaluate $\sqrt{992{\cdot}25}$.

The stages in finding the square root of the above number are as follows:

1. Group off the number in pairs: 9 92·25; this gives an approximate answer of 31.
2. Set cursor over 99225 so as to give a 3 as the first figure in the square root. This is the L.H. portion of scale A.
3. Read off the value given by the cursor line on scale D; this is 315.
4. Determine the decimal point; from the grouping at 1, above, the answer will have 2 figures to the left of the decimal point, therefore the answer is 31·5.

Example 11.—Evaluate $\sqrt{99{\cdot}225}$.

This question has the same figures as Example 10 but the decimal point is in a different position. The stages in the working are identical with those outlined above.

1. Group off the number in pairs: 99·22 5. This gives 10 as the approximate answer.
2. Set cursor over 99225 so as to obtain an answer of approximately 10. This means the cursor is set over 99225 on the R.H. portion of scale A.
3. Read off the value given by the cursor line on scale D; this is 996.
4. Determine the decimal point; from the grouping of the figures 10 is given as the approximate answer, hence there is only one figure to the left of the decimal point. The answer is 9·96.

Example 12.—Evaluate $\sqrt{0{\cdot}1806}$.

The necessary stages are given below:

1. Group off the number in pairs: 0·18 06; this gives 0·4 as the approximate answer.
2. Set cursor over 1806 on scale A so the other portion of the line gives on scale D a reading of 4 plus. This means that the cursor is set over 1806 in the R.H. portion of scale A.
3. Read off the value given by the cursor line on scale D; this is 425.
4. Determine the decimal point. From 1 above the approximate answer is known to be 0·4, hence the required answer is 0·425.

OTHER SCALES ON THE SLIDE RULE

7. Logarithms.

A scale enabling logs to base 10 to be read off the rule is sometimes given on the back of the slide and indicated by the letter L. To read off logs the D scale is used in conjunction with the slide and an index line given in the recesses at each end of the rule is used for setting.

The stages necessary to obtain the log of a number are as follows:

1. Set end of slide over the number on D scale.

2. Reverse the rule and read off the value on scale marked L, using the index line in the recess.

3. Determine the characteristic.

Example 13.—Determine log 30·00.

1. Set end of slide over 3 on scale D.

2. Reverse the rule and read off the value on the L scale, using the index line in the recess. This is 477.

3. Determine the characteristic; this is 1.

4. Write down the log; this is 1·477.

8. Sines.

A scale for reading the value of sines is usually found on the back of the slide and is marked S. The markings on the scale commence at approximately 34 minutes of angle; the value of the sine is read off scale B and the values assigned to the readings must be on the following basis:

The commencing 1 of the A scale equals ·01.
The centre 1 or 10 of the A scale equals ·10.
The finish of the scale A, whether marked 1 or 100, equals 1·00.

The stages necessary to obtain the sine of an angle are as follows:

1. Set the required angle under the index line in the recess at the end of the rule.

2. Reverse the rule and read off the value on scale B under the end of scale A.

Example 14.—Determine the value of sin 45°.

1. Set slide so that 45° on scale S is under the index line.

2. Reverse rule and read off the value on B scale. This is ·707.

Similarly, sin 30° gives a reading of ·500,
sin 60° „ „ „ ·866,
sin 5° „ „ „ ·087,
sin 15° „ „ „ ·259.

9. Tangents.

The slide rule is given a scale on the back of the slide which permits tangents to be read off in a similar manner to that adopted when finding sines. The scale used is marked T and the readings are taken off scale C, using the end of scale D as index point. The tangent readings start at approximately 6°; for values less than 6°, that given by the sine of the angle is used. The maximum angle whose tangent can be read direct from the rule is 45°. If the tangent of an angle greater than 45° is required, then it is necessary to resort to the use of equations. The value assigned to the markings on the rule when finding the tangent of an angle is as follows:

The beginning of scale C is read as ·1.
The end of scale C is read as 1·0.

The procedure to find the value of the tangent of an angle using the slide rule is as follows:

1. Set the angle on scale T under the index line in the recess at the end of the rule.

2. Reverse the rule and read the value on scale C, using the end of D scale as the index line.

Example 15.—Give the value of tan 30°.

The stages are as follows:

1. Move the slide along so that 30° on the T scale is opposite the index mark in the recess at the end of the rule.

2. Reverse the rule and read the value on C scale having the end of D scale as the index. This is found to be ·577. Therefore the answer is ·577.

Similarly the tangent of 10° is ·176,
15° „ ·268,
20° „ ·364.

In general practice it is rare that logarithms or trigonometric ratios are obtained by means of the slide rule. The two reasons for not using the rule extensively for these are (*a*) it is just as easy to take the figures from a set of mathematical tables; (*b*) normally the results of calculations involving their use are required to a greater degree of accuracy than the slide rule can give.

10. Cubes and Cube Roots.

On some rules direct reading of cubes and cube roots is possible by means of a scale running along the centre of the slide; the scale gives the cube of the number on scale C, hence using the cube scale the cube root can be read from scale C. In some instances the cube and cube root of a number can be obtained by using the three scales A, B, and D in conjunction with each other.

Cubes using Scales A, B, and D.—The procedure for this is as follows:

1. Set on D scale the cursor over the number.
2. Adjust the slide so that the end is under the cursor line.
3. Adjust the cursor to give the number on the L.H. portion of scale B.
4. Read off on scale A the value under the cursor line.
5. Determine the decimal point.

Example 16.—Evaluate 3^3.

1. Set cursor over 3 on D scale.
2. Set L.H. end of slide under the cursor line.
3. Move cursor to read 3 on the L.H. end of slide, scale B.
4. Read off the value under the cursor line using scale A. This is 27.
5. Determine the decimal point. None in this instance; hence answer is 27.

The Cube Root of a Number using Scales A, B, and D.—The cube root of a number can be found by reversing the process given for finding the cube. The stages are as follows:

1. Group off the figures comprising the number into threes. This is done (*a*) to determine the position of the decimal point; (*b*) the position of the cursor on scale A for the first setting.
2. Set the cursor over the number on scale A as determined by (1).
3. Move the slide along until the same number is given by the end of the slide on D as appears under the cursor on scale B.
4. Fix the decimal point as determined by (1).

Example 17.—$\sqrt[3]{6859} = 6859^{\frac{1}{3}}$.

1. Mark off in groups of three: 6 859. This gives in the answer two digits to the left of the decimal point, and with 6 in the first group the number is less than 20.
2. Set cursor over 6859 on L.H. portion of scale A.
3. Move slide along until the same number is registered on scales B and D respectively. From (1) above this is around 2; commencing at this figure and working towards the left, it will be found that, at 19, the readings on the scales B and D are identical. Hence this is the required number.
4. Fix the decimal point as determined at (1); hence the answer is 19.

11. Log-log Scales.

One of the outstanding features on some slide rules is the ease with which indices possessing fractional parts can be solved. These rules have what are known as " log-log " scales, i.e. scales having the distances between the various markings based on the log of the common log. The actual arrangement of the scales differs according to the maker. Most rules have the scales placed outside scales A and D; the log-log scales are used in conjunction with the scale C. The highest reading is 1000, and any power up to, or root of a number not exceeding this can be obtained with no greater difficulty than if multiplying.

The procedure to find the power of a number is as follows:

1. Place the cursor line over the number on the log-log scale.
2. Using scale C, adjust the slide to bring the end under the cursor line.
3. Adjust the cursor so that on scale C the cursor line is placed over the given power.
4. Read off the answer on the log-log scale. This is under the cursor line.

Example 18.—Evaluate $3^{1\cdot5}$.

1. Place the cursor over 3 on the log-log scale.
2. Adjust slide so that the L.H. end is under the cursor line.
3. Adjust the cursor to give a reading of 15 on scale C.
4. Read off on log-log scale the value given by the cursor line; in this instance 5·20.

The procedure to find the root of a number is as follows:

1. Adjust the cursor to give on the log-log scale the number.
2. Adjust the slide so the exponent on scale C is brought under the cursor line.
3. Move the cursor to cover the end of the slide.
4. Read off the value under the cursor line on the log-log scale.

Example 19.—Evaluate $\sqrt[1\cdot25]{20} = 20^{1/1\cdot25}$.

1. Place the cursor over 20 on the log-log scale.
2. Adjust slide bringing 1·25 on scale C under the cursor line.
3. Move cursor so that the line is over the end of scale C
4. Read the value on the log-log scale given by the cursor line. This is 11.

12. Other Markings on the Slide Rule.

On the majority of rules there are a number of special markings or constants for use when calculating. Several of these are used when dealing with circumferences or areas of circles. Thus on scales A and B (L.H. end) the constant π is given. On some rules the scales C and D are likewise marked. Another constant is $\pi/4$ or ·7854 and this is marked on the R.H. portion of scales A and B. Lack of space prevents this from being numbered. On scale C a mark C is found, and this is used to determine the diameter of a circle when the area is known or vice versa.

Use of the Constant π *or* 3·1416.

Circumferences of Circles.—By using the constant π on scale A in conjunction with scale B the circumference of any circle can be read off on scale A opposite its diameter on scale B. The same results can be obtained when scales C and D are marked in a similar manner.

Areas of Circles.—The constant π on scale B can in conjunction with scale D be used to give the areas of circles. The end of the slide is placed opposite the radius of the circle on scale D and the area read off on scale A opposite the constant π on scale B.

The Use of the Constant C on Scale C.—The mark C is used to determine the diameter of a circle when its area alone is known. It may also be used to obtain the area from the diameter. The constant is obtained in the following manner:

$$\text{Area of circle} = \cdot 7854D^2.$$

$$\therefore\ D^2 = \text{area} \times \frac{1}{\cdot 7854} = \text{area} \times 1\cdot 273.$$

$$\therefore\ D = 1\cdot 128 \times \sqrt{(\text{area})}.$$

Diameter of Circle from a known Area.

The mark C = 1·128 (see above), and is used to obtain the diameter when the area is known in the following manner. Place the marking C over the left-hand end of D scale. Set the cursor to the known area on A scale. Read on scale C the diameter.

Example 20.—A circle is known to have an area of 6·25 sq. in. and the diameter is required.

Set point C on the C scale over the 1 on the D scale; adjust the cursor over point 625 on the left-hand portion of the A scale. Read off the answer on scale C which is 2·82.

Area from a known Diameter.

Set the constant C on scale C over the end of scale D. Use the cursor to mark off the diameter on C scale. The reading under the cursor line on A scale gives the area.

When the given data call for setting the constant C over the R.H. end of the rule, the slide protrudes a considerable distance. To prevent this, a mark C^1 is normally given on the C scale near the reading 356. This constant enables the readings for areas and diameters to be obtained as with the constant C, the only difference being that the slide protrudes to the right instead of the left.

Example 21.—Using the markings C and C^1, determine the areas of circles having 4 and 9 inches diameter respectively.

(*a*) Set point C over 1 on the L.H. end of the D scale; move the cursor over 4 on the C scale. Read off the area on the answer on the A scale which is 12·57. (The decimal point is, of course, fixed by inspection.)

(*b*) Set point C^1 over the point 1 on scale D; adjust the cursor over point 9 on the C scale; read off the answer on the A scale which is 63·6.

CHAPTER II

Graphical Representation

Graphs, alignment and intersection charts form an important means of expressing the results of experiments in a concise form, permitting the analysis of the possible combination for a machine, and illustrating the results of time studies, production planning, price movements of various commodities, purchases and sales, income and expenditure. Often by careful study of a graph one can forecast the probable trend of events. This is of the greatest value to the management of any concern. Moreover, the plotting of a graph may permit a " law " to be determined from what at first sight appeared to be a mass of unrelated figures. One great value of a well-prepared graph is that it gives an easy visual record of the change that has, is, or can be expected to take place.

1. Movable Scales.

Addition, subtraction, multiplication and division can be readily carried out by movable scales suitably divided.

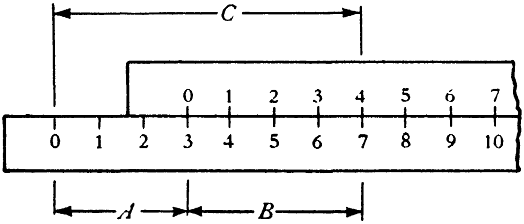


Fig. 2.1.—Adding with movable linear scales

Addition and Subtraction.—The simplest example is that given in fig. 2.1 where there are two movable scales, each being divided into the same linear scale. When adding, the zero on the top scale is placed on the required number on the bottom scale. The position of the second number on the top scale is now taken and also its relationship on the bottom scale. The latter gives the sum of the two numbers, e.g.

$$A + B = C$$

or

$$3 + 4 = 7.$$

For subtraction, the number to be subtracted from is found on the bottom scale, and the number to be subtracted on the top scale is placed over it. Then the reading on the bottom scale as given by the zero marking on the top scale gives the remainder; or

$$C - B = A,$$
$$7 - 4 = 3.$$

Multiplication and Division.—For multiplication and division the markings on the scales are on the logarithmic base, and this class of movable scale is the basis of all slide rules as given in Chap. I, thus:

Multiplication $\log A + \log B = \log C.$

Division $\log C - \log B = \log A.$

2. Reference Axes.

When constructing graphs the axes of reference are two lines drawn at right angles to each other, with the intersection at O (fig. 2.2). The horizontal line is known as the X axis; the vertical line as the Y axis. As the X and Y axes cut at O, the origin, four quadrants are created. These are, in an anti-clockwise direction, XOY, YOX_1, X_1OY_1, Y_1OX, and are known as the first, second, third, and fourth quadrants. This arrangement permits the plotting of both positive and negative values. Positive x values lie to the right of the Y line, whilst those

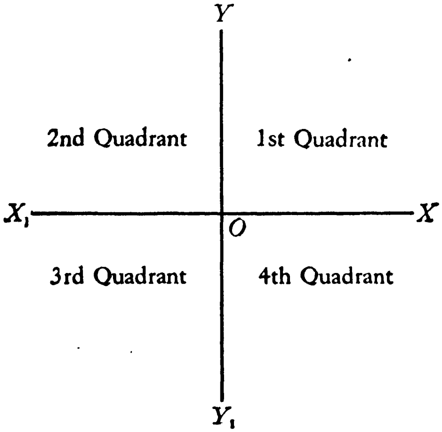
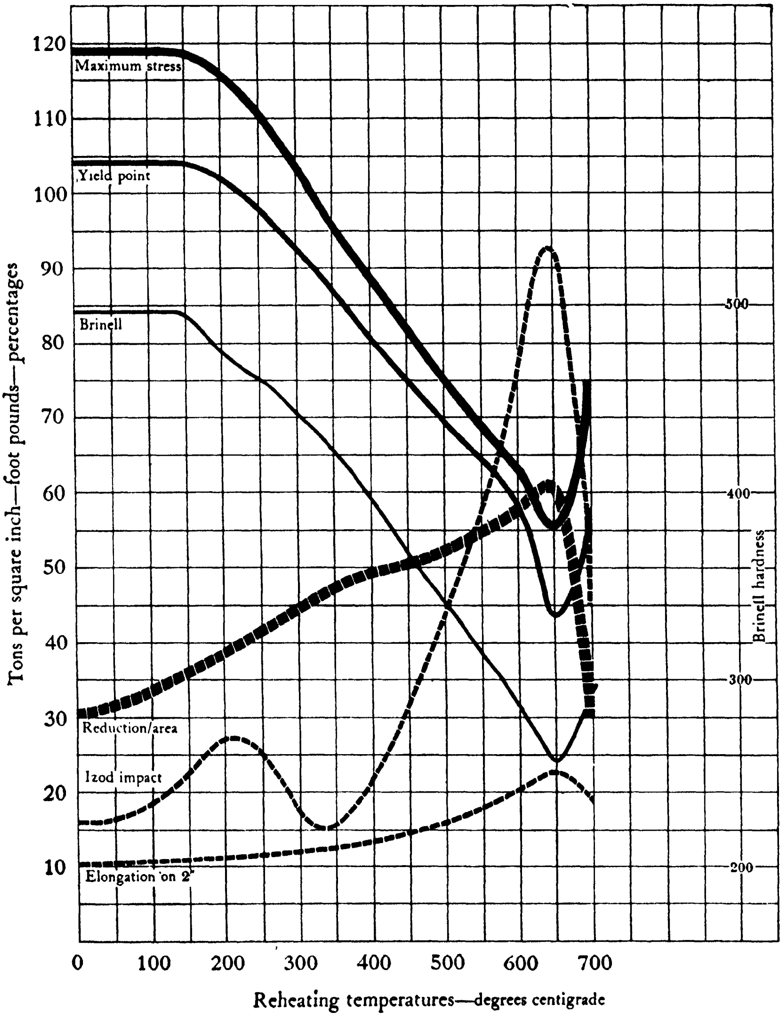


Fig. 2.2.—Reference axes and quadrant numbers

to the left are negative. For *y* values those lying above the X axis are positive, those beneath being negative. In tabular form:

Axis	Positive values	Negative values
X	Quadrants 1 and 4	Quadrants 2 and 3
Y	Quadrants 1 and 2	Quadrants 3 and 4



(By courtesy of *Kayser Ellison*)

Fig. 2.3.—Showing use of normal square graph paper

KE 323 nickel-chromium-molybdenum steel, oil-hardened at 820° C. and reheated at intervals of 50° C. at the indicated temperatures.

As many of the data plotted consist of positive values the first quadrant is chiefly used.

The distances measured along the two axes are known as the rectangular co-ordinates of the given point. Those measured along the X axis are known as the *abscissæ* or the X co-ordinates, whilst those parallel to or along the Y axis are termed *ordinates* or Y co-ordinates. Any point on a graph is found by interpolating the values of the abscissa and the ordinate.

3. Normal Graph Paper.

A large number of graphs are drawn on squared paper, using a linear scale. In the English-speaking countries the inch is normally

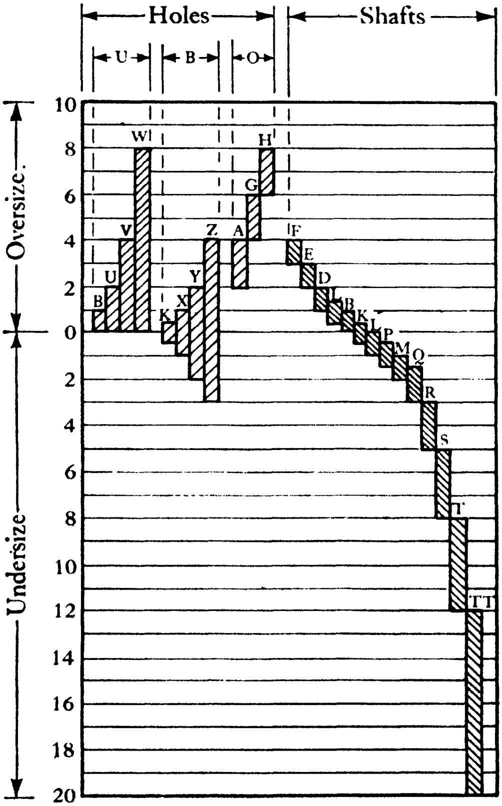


Fig. 2.4.—Bar graph showing the relation of various shaft fits to the different holes as given by B.S. 164. (4″ normal shaft diameter)

the unit and is subdivided into either eighths or tenths. When arranging a graph [1] it is important to see that the chosen scales are suitable and permit easy reading. In many instances the graph does not commence at the zero position but is drawn to cover the required values. The choice of scales should be such that a good-sized graph is constructed and the available paper used to the best advantage. In many instances this calls for a different unit on the Y axis to that chosen for the X axis, and on each graph the chosen values should be clearly indicated. A typical graph illustrating the properties of an alloy steel is given in fig. 2.3 (p. 19). Graphical representation of the limit system as listed in B.S. 164 is shown in fig. 2.4 for a 4-in. dia. shaft and hole, whilst a bar chart giving the melting-points of both soft and hard solders features at fig. 2.5. There are, of course, a number of other arrangements, such as the trilinear diagram as used for alloys, or the polar diagram as chosen for electric bulbs.

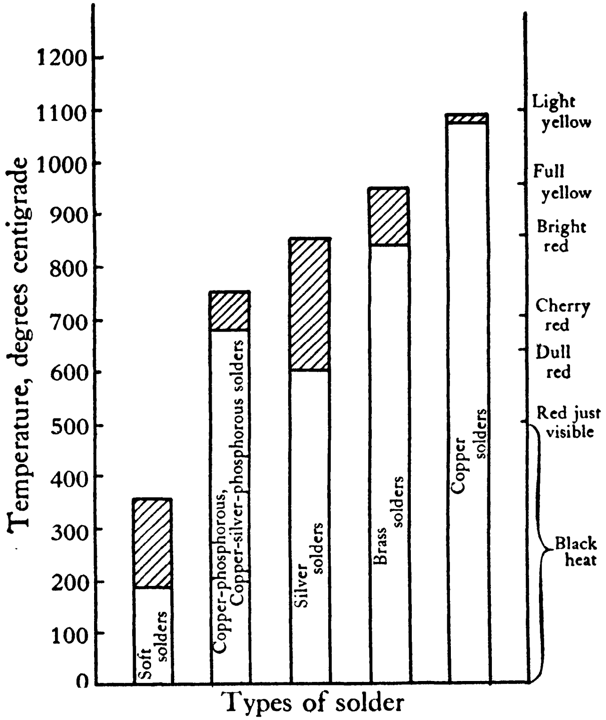


Fig. 2.5.—Bar graph representing the melting range for various types of solder (Cross-hatched area gives temperature range)

4. Graphs on Logarithmic Bases.[1]

When dealing with some problems the use of graph paper drawn to a linear scale proves unsuitable, and recourse has to be had to paper ruled on either semi-logarithmic or bilogarithmic bases so that the rate of change may be clearly shown.

Semi-logarithmic Paper.—Semi-logarithmic graph paper is chosen when a rate of change is taking place, e.g. in the number of cars being used each year, the number of wireless licences issued per year, the tool-life for variations in the cutting speed, and similar things. An example is given in fig. 2.6.

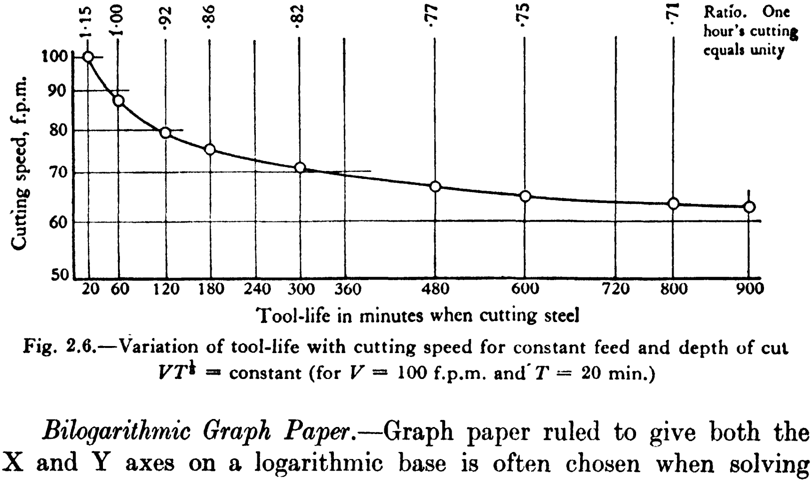


Fig. 2.6.—Variation of tool-life with cutting speed for constant feed and depth of cut $VT^{\frac{1}{8}}$ = constant (for $V = 100$ f.p.m. and $T = 20$ min.)

Bilogarithmic Graph Paper.—Graph paper ruled to give both the X and Y axes on a logarithmic base is often chosen when solving algebraic problems involving multiplication, division, roots, and powers of numbers. It proves useful when it is desired to find if any two variables are connected by a " law " of the form

$$XY^n = C.$$

Now, if logs of both sides of this equation are taken,

$$\log X + n \log Y = \log C.$$

This is an equation of the first degree in ($\log X$) and ($\log Y$); hence, if the values of these are plotted on the respective axes, the result is a straight line.

Example 1.—Fig. 2.7 is such a chart for determining the speed in r.p.m. when the cutting speed in f.p.m. is known.

$$\text{Now linear speed (f.p.m.) or } V_c = \frac{\pi dR}{12}$$

$$= 0{\cdot}262dR.$$

Note.—d is the dia. in in., and R is the r.p.m. of the workpiece. Taking logs of both sides,

$$\log V_c = (\log d + \log 0{\cdot}262) + \log R.$$

Hence the equation is in the same general form as the one above.

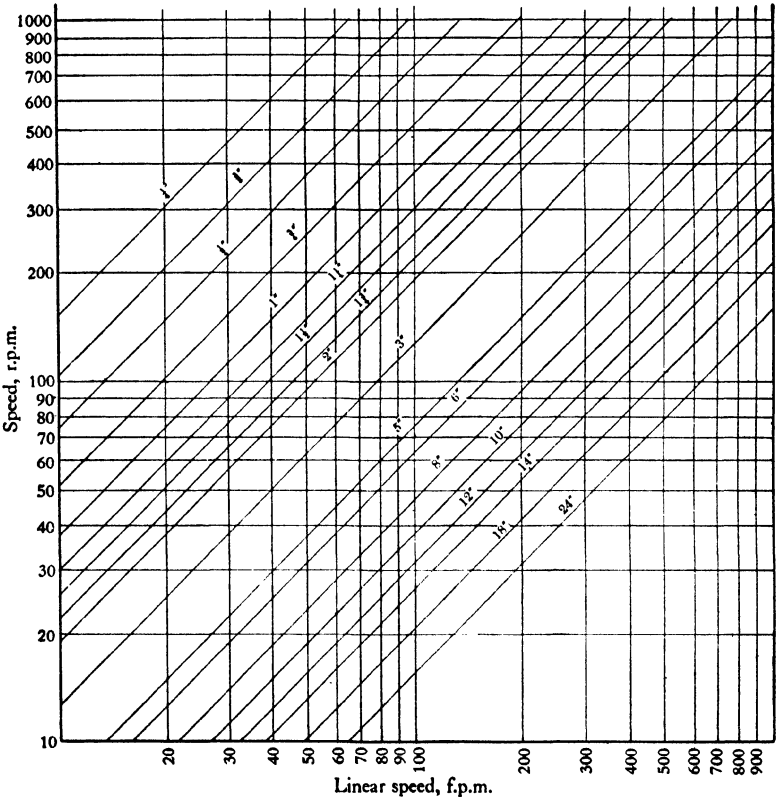


Fig. 2.7.—Bilogarithmic graph—r.p.m./linear speed for different bar sizes

5. Compound Charts.

It may happen that a given problem is too involved for presentation on a single chart. Under such conditions a graphical solution may be obtained by means of a compound chart. This involves breaking down the main problem into two simpler ones, each of which is capable of graphical solution. Then, by the choice of the correct units, the results of one feature can be traced across to the second chart and a solution to the given problem obtained. Fig. 2.8, taken from the

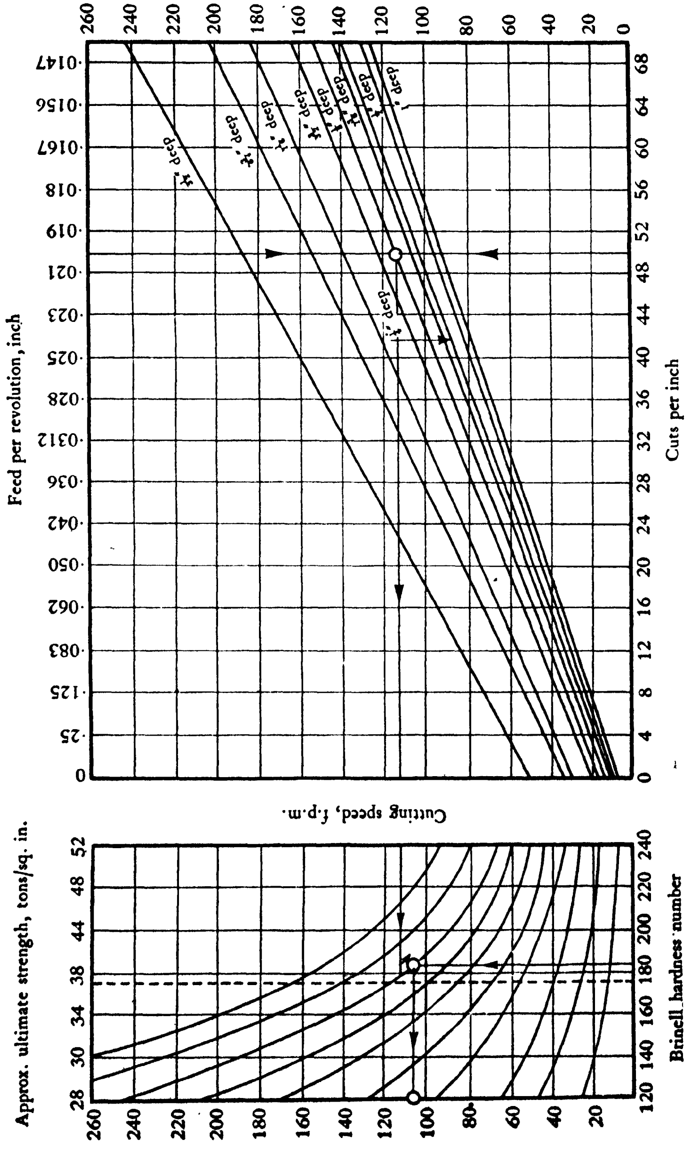


Fig. 2.8.—Compound diagram (based on L.T.R.C. Report) showing the relation between chip size, cutting speed and Brinell hardness number when cutting plain carbon steel. (Tool-life: 2 hours' cutting dry; 30° approach angle; 20° rake; ⅛ in. nose-radius.)
]

L.T.R.C.[2] Report, 1922, exemplifies a chart of this character, and is designed to give the cutting speed for carbon steels of varying composition when the details of the cut are known.

The diagram on the right is for steel of 0·39 C and having a Brinell hardness of 176; given the dimensions of the cut, depth and feed, the appropriate cutting speed can be read direct from the chart. Thus, for a cut ·031 in. deep and a feed of ·015 in., the cutting speed would be, say, 227 f.p.m. When the hardness of the steel differs from that stated it becomes necessary to use both charts. The method is quite simple and is based upon the well-known fact that soft material is machined at higher speeds than hard metal. On the left diagram the vertical dotted line from point 176 of the hardness scale forms the datum; steels having a lower B.H. No. than 176 featuring at the left, those with a higher B.H. No. at the right.

Example 2.—Assuming that a cut $\frac{1}{8}$ in. deep with a feed of ·02 in. is to be taken on steel of (*a*) 183 B.H. No., and (*b*) 126 B.H. No. Take off the appropriate machining speeds.

On the right-hand diagram project upwards from the feed of ·020 in. until the line intersects the line indicating a cut $\frac{1}{8}$ in. deep. Project horizontally across to cut the vertical dotted datum. Follow down the nearest curve until immediately over the known B.H. No. (183) as shown by the thin line. From the point where the thin line from the hardness scale cuts the curve project horizontally across and read off the cutting speed, say 107 f.p.m. Similarly for the steel having 126 B.H. No., but, as the steel is softer, the movement is to the left of the datum line, hence up the curve, until immediately over the point 126 on the hardness scale. The reading, say 225 f.p.m., is then taken on the speed scale.

6. Alignment Charts.[3, 4]

The simplest alignment chart has three parallel scales to represent the values of the different factors involved in a given problem. The arrangement of the scales is such that, when a straight line passes through two known values, the intersection on the remaining scale gives the unknown. Such charts give an easy and rapid solution to numerous technical problems. When more than three scales are involved the construction of the chart becomes more complicated. According to how the scales are chosen alignment charts may be used for addition, subtraction, multiplication and division. For the two former, the scales are drawn upon a linear basis; for the two latter the scales are on a logarithmic base.

Addition.—The illustration (fig. 2.9) gives a chart designed for addition. The three scales start from the same horizontal base-line with the two outer scales spaced equally on either side of the central one. The two outer scales have the same unit but the inner is half that of the outers. The thin line indicates the addition of 4 and 5, the line cutting the central scale at 9. By using the left-hand and central scales, one may use the chart for subtraction.

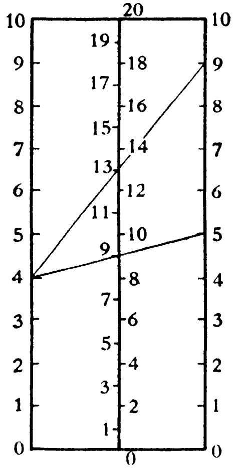


Fig. 2.9.—Alignment chart for addition

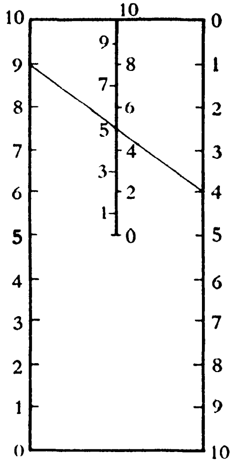


Fig. 2.10.—Alignment chart for subtraction

Subtraction.—An alignment chart design for subtraction is shown in fig. 2.10, the chief difference being in the arrangement of the base-line, which is placed at the top, and the alteration of the run of the scales on the right so that subtraction takes place.

Example 3.—Using fig. 2.9, $9 + 4 = 13$.

Place the set square on 4 on the L.H. scale and on 9 on the R.H. scale. Reading on the centre scale gives the answer 13.

Subtraction using fig. 2.10, $9 - 4 = 5$.

Place the set square over the points 9 and 4 on the L.H. and R.H. scales respectively and read off the answer on the centre scale, in this instance 5.

7. Alignment Charts on Logarithmic Scales.

Multiplying.—The chart designed for multiplying is given in fig. 2.11 and the two outer scales are graduated identically. The inner scale is half that of the two outers and is placed midway between them. Each of the three scales start from the same base-line. The layout gives two examples:

$$1{\cdot}5 \times 3 = 4{\cdot}5 \quad \text{and} \quad 5 \times 10 = 50.$$

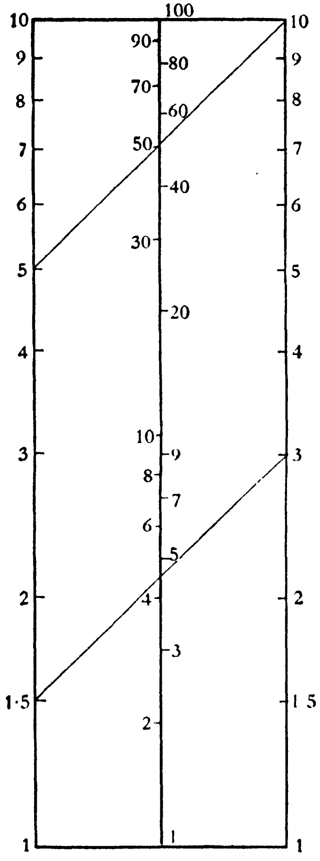


Fig. 2.11.—Alignment chart on a logarithmic base for multiplying

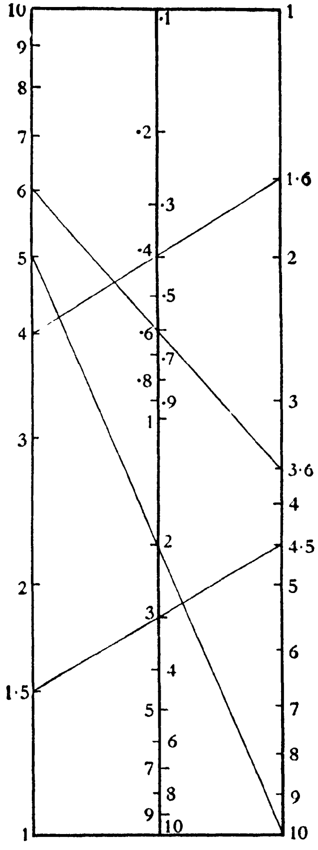


Fig. 2.12.—Alignment chart on a logarithmic base for dividing

The manner of using these scales is identical with those given above for subtraction and addition. The set square is placed over the numbers on the two outer scales and the answer is taken off the central scale.

Division.—The layout for division is shown in fig. 2.12, and it will be noticed that the two outer scales do not start at the same base-line. The method of using the scale has already been given and four examples are:

$$16 \div 4 = 4. \qquad 4{\cdot}5 \div 1{\cdot}5 = 3.$$
$$10 \div 5 = 2. \qquad 36 \div 6 = 6.$$

As with the slide rule, inspection is necessary to determine the position of the decimal point and which portion of the scale to use.

8. Alignment Chart for a Wards No. 7 Turret Lathe.

Alignment charts can be and are designed for a wide range of machine tools. As an example one for a Wards No. 7 turret lathe may be constructed. The details of the machine are:

Max. dia. of work, 14 in.
Max. length of turned work, 30 in.
R.P.M. of machine spindle, 37, 55, 90, 133, 210, 312, 506, 750.
Feed in in., ·077, ·0555, ·0385, ·0263, ·0193, ·01495, ·01075, ·0077, ·0052, ·0037.

Chart Layout.

What is required with a chart of this type is the time necessary to perform a given piece of machining. This in its turn calls for scales to give cutting speed in f.p.m., diameter of the work in in., the spindle speed in r.p.m., the feed in in., and the time to machine a known length. In the layout (fig. 2.13) the two scales to be drawn first were the diameter of the work and the speed in f.p.m.; the arrangement gives 1 in. on the diameter scale opposite 100 f.p.m., and the scales are on the same logarithmic base (here $2\frac{1}{2}$ in. covers 1 to 10); the diameter scale runs upwards from ·1 to 14 inches; the cutting-speed scale downwards from 10 to 1000 f.p.m. Thus both the full range of work and possible cutting speeds are covered.

Spindle Speed (R.P.M.) Scale.—The next scale to be drawn is that giving the spindle speeds. Its position is given as midway between the f.p.m. and diameter of work scales. The scale itself must bear a definite relationship to the other two. Now

$$V_c = {\cdot}262dR \text{ (see p. 23).}$$

Hence taking known values of V_c and R the value of d may be computed and used to give the spindle speeds on the r.p.m. scale. This

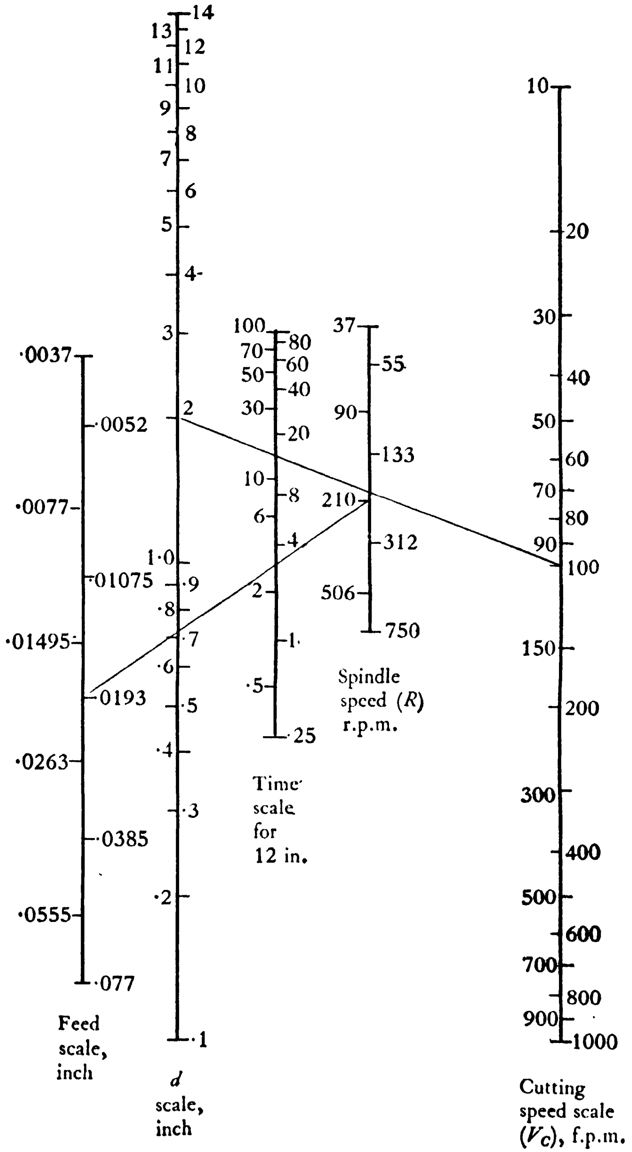


Fig. 2.13.—Alignment chart for Ward No. 7 Turret Lathe

is done in the table below, taking each of the spindle speeds and keeping the cutting speed V_c at 100 f.p.m. Thus

R	37	55	90	133	210	312	506	750
d	10·3	6·95	4·24	2·88	1·82	1·22	0·76	0·51

The various positions on the d scale are marked off and then, using the set square, the positions on the r.p.m. scale are determined by drawing a line through each of the points on the d scale through the 100 mark on the f.p.m. scale.

Feed Scale.—The feed scale is now arranged. According to the machine specification the feeds vary from ·0037 to ·077 in. Thus we may choose the same scale as those used for the "f.p.m." and "d" scales and arrange to have the feed of ·010 in. lying on the same horizontal as 1 in. dia. and 100 f.p.m. The feed scale itself lies to the left of the "d" scale and at a distance equal to half that between the "d" and "r.p.m." scales. The markings on the scale agree with those on the machine.

Time Scale.—The last scale to be drawn on the chart is that dealing with the time required to machine a given length of work. For simplicity the unit used in the example is 12 in. When turning, the two governing factors controlling the machining time are the feed and r.p.m.

The time taken to machine a 12-in. length may be written

$$T = \frac{12}{fR},$$

where f = feed per rev., R = r.p.m.

For the Wards No. 7 turret lathe the two limiting times are:

(1) using a speed of 37 r.p.m. and a feed of ·0037 in.,
(2) „ „ 750 r.p.m. „ „ ·077 in.

$$T \text{ for } (1) = \frac{12}{37 \times \cdot 0037} = \text{say, 88 minutes.}$$

$$T \text{ for } (2) = \frac{12}{750 \times \cdot 077} = \text{say, 0·2 minute.}$$

Hence for practical purposes the T scale need only cover 90 down to 0·25 minute.

Using the above equation, and giving known values to T and R, the feed may be determined. This is shown for a number of points:

T	R	f
90	37	·0036
80	37	·00405
70	37	·00463
2	210	·0286
1	210	·0572

Knowing the positions on the "f" and "r.p.m." scales, those on the time scale can be marked off using the set square to join the respective points.

Example 4.—A bar 2 in. dia. is to be turned for a distance of 12 in. at a speed as near as possible to 100 f.p.m. with a feed of 0·020 in. or the nearest. The stages in determining the time for machining are:

(1) *Speed in r.p.m.*—Use the square to connect 2-in. diameter on the "d" scale with 100 on the "f.p.m." scale. The nearest is shown to be 210.

(2) *Determine the cutting time.*—The nearest feed is ·0193 in. and the speed in r.p.m. is 210. Using the set square to join the two points on the respective scales, a cutting time of, say, 3 minutes is obtained.

9. Intersection Charts.

Intersection charts are designed to bring out the various combinations of a machine, say, a capstan or turret lathe, milling, gear hobbing, grinding, or drilling machine. The construction of such charts involve addition and subtraction, multiplication and division, by graphical methods, hence the layout of graphs for this purpose is given below.

Addition.—The standard graph for addition is given in fig. 2.14 where the X and Y axes have the same linear scale, so that the sloping line 10, 10 makes 45° with the base as do the other sloping reference lines. On the X axis

$$OB + BC = OC.$$
$$5 + 4 = 9.$$

But this may also be read on the Y or X axes by tracing where the intersection of the horizontal and vertical lines takes place, and then running parallel to or tracing along the sloping line till it cuts either the Y or X axes.

The chart may be also used for subtraction by tracing, say, up

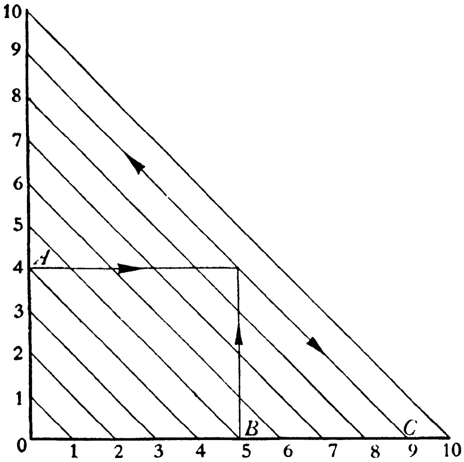


Fig. 2.14.—Intersection chart for addition

the known sloping line until met by the vertical reference line, and from this point moving horizontally to cut the Y axis.

Thus $OC - BC = OB.$

$9 - 4 = 5.$

Subtraction.—A chart designed specifically for subtraction is shown

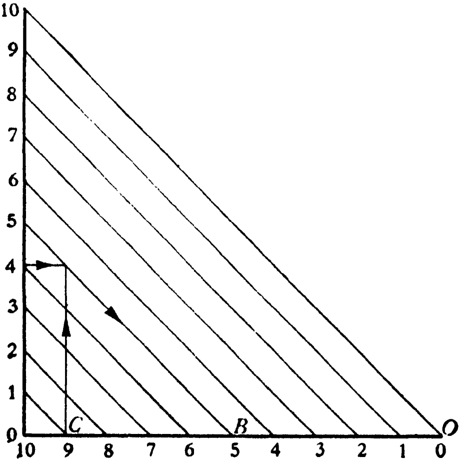


Fig. 2.15.—Intersection chart for subtraction

in fig. 2.15. The difference between the two charts lies in the arrangement of the scales, as for the subtraction the zero point on the X scale is not at the intersection of the reference axes.

$$OC - CB = OB.$$
$$9 - 4 = 5.$$

Using the graph the vertical reference line from 9 on the X axis is traced until it intersects the horizontal line from the position 4 on the Y axis, then tracing down the sloping line to the X axis the answer 5 is obtained.

Multiplication.—The general arrangement of the fig. 2.16 is very similar as that designed for addition, but logarithmic scales are used and commence from the intersection of the X and Y axes. Division of two numbers can also be obtained. The divisor is traced from either the X or Y axis to cut the dividend or sloping reference line; from the intersection point a line is drawn perpendicular to the other axis.

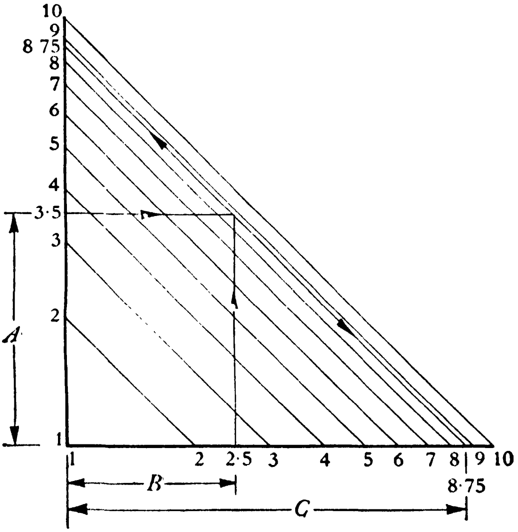


Fig. 2.16.—Intersection chart for multiplication (using bilogarithmic scales)

Example 5.

$$A \times B = C,$$
$$3{\cdot}5 \times 2{\cdot}5 = 8{\cdot}75;$$

or

$$C \div B = A,$$
$$8{\cdot}75 \div 2{\cdot}5 = 3{\cdot}5.$$

Division.—The graph for division (fig. 2.17) is identical with that shown for subtraction excepting that the scales are on a logarithmic base. It differs from fig. 2.16 in that the numbers on the X axis do not commence at the intersection of the X and Y axes. If necessary the layout can be used for multiplication.

Now $A \div B = C$,

$$8{\cdot}75 \div 3{\cdot}5 = 2{\cdot}5;$$

or $B \times C = A$.

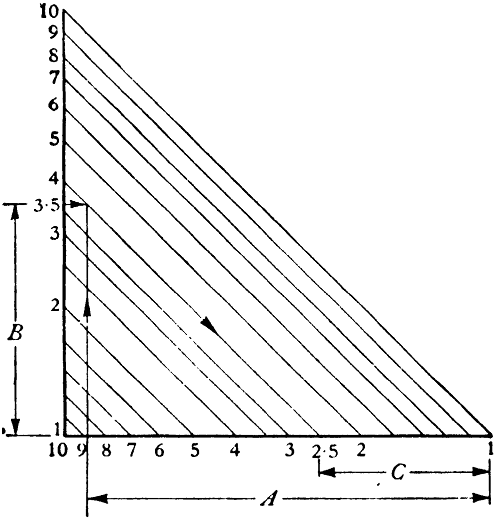


Fig. 2.17.—Intersection chart for division (using bilogarithmic scales)

Subtraction with a Double Pair of Axes.

The arrangement given in fig. 2.15 may be modified so that two pairs of axes are used. This is shown in fig. 2.18, using linear scales.

$$A - B = C,$$

or $A_1 - B_1 = C$.

Getting rid of C, $A - B = A_1 - B_1$.

And so long as the intersection of the horizontal and vertical lines takes place on the same sloping line, this holds good for all values. Giving numerical values,

$$6 - 2 = 4,$$

or $8 - 4 = 4$.

Other values can be traced using the chart.

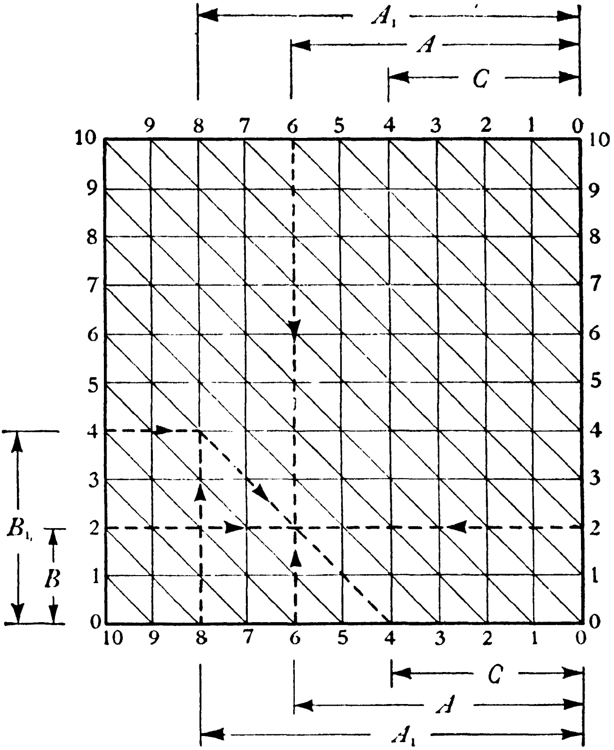


Fig. 2.18.—Subtraction using two pairs of axes and linear scales

Division using Two Pairs of Axes.

Division using a chart having two pairs of axes on a logarithmic base is shown in fig. 2.19, and is derived from fig. 2.17. As the scales are on a logarithmic base,

$$A \div B = C;$$

$$A_1 \div B_1 = C.$$

Getting rid of C, $$A \div B = A_1 \div B_1.$$

Then $$\log A - \log B = \log A_1 - \log B_1.$$

This is the basic equation for a number of intersection charts, and holds good for all values which intersect on the same sloping line. Giving numerical values,

$$9 \div 3 = 3,$$

or $$6 \div 2 = 3.$$

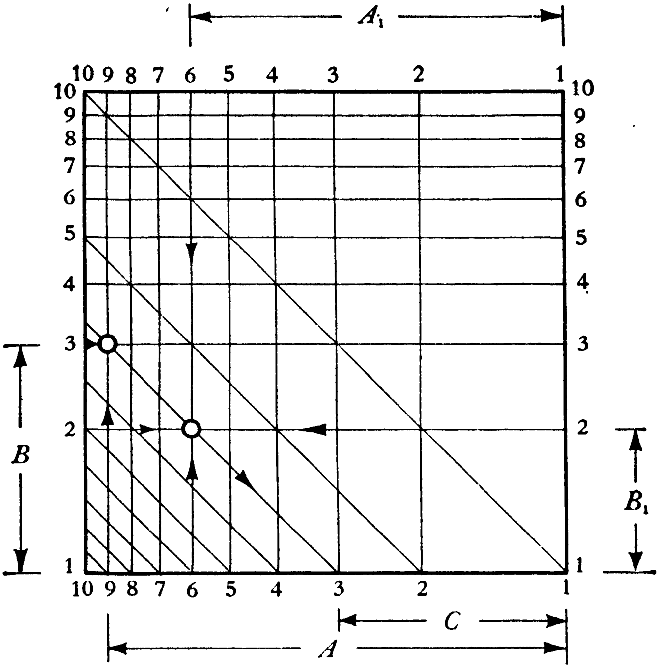


Fig. 2.19.—Division using two pairs of axes and logarithmic scales

10. Planning a Machine Chart.

Taking the above charts a step further, we can represent graphically the variables as encountered on a variety of machine tools. Such charts prove useful when determining the spindle speed to suit a known cutting speed, or when finding the time for given details of the cut.

When turning, the following expressions are known and often used:

Speed in r.p.m., $$R = \frac{12 \times V_c}{\pi \times d} = \frac{3{\cdot}82V_c}{d}.$$

Speed in f.p.m., $$V_c = \frac{dR\pi}{12} = {\cdot}262dR.$$

Cutting time, $$T = \frac{dL\pi}{12V_cf} = \frac{{\cdot}262dL}{V_cf}.$$

T (for 12 in.) $$= \frac{12d\pi}{12V_cf} = \frac{\pi d}{V_cf}.$$

Notation: V_c = cutting speed, f.p.m. d = dia. in inches. R = r.p.m. f = feed per rev. L = length of work in inches. T = cutting time, minutes.

Transposing these to logs,

$$\log R = \log 3{\cdot}82 + \log V_c - \log d.$$
$$\log V_c = \log {\cdot}262 + \log d + \log R.$$

Rewriting the time equation for a 12-in. length,

$$\frac{V_c}{d} = \frac{\pi}{Tf},$$
$$\therefore \log V_c - \log d = \log (\pi/f) - \log T.$$

This is now in the same form as the fundamental equation given above when discussing division using a double pair of axes.

Example 6.—A 12-in. centre lathe has the following particulars: centres, 6¼ in.; largest diameter, 12 in.; length between centres, 24 in.; feed varies between ·001 and ·06 in. The spindle speeds (r.p.m.) are 30, 41, 62, 92, 124, 188, 245, 332, 500, 735, 996, 1500.

Chart Arrangement.—To be of value the chart must show the diameter of the work, the cutting speed in f.p.m., the feed per rev., the spindle speeds (r.p.m.), and the cutting time for a given length. The basic layout of the chart gives the cutting speed on the X axis (p. 39), the diameter of the work is placed on the Y axis and on its right is given the time scale. For simplicity these three scales are, in practice, often drawn on a logarithmic base of 5 in. to cover from 1 to 10, and are laid out to cover the needs of the machine. Since the two side scales are the same, 1 in. dia. is opposite 1 min. of cutting time. But

$$T = \frac{\pi d}{V_c f}.$$

Substituting $$1 = \frac{\pi \times 1}{V_c \times f}.$$

Then $$V_c = \frac{\pi}{f} \text{ or } f = \frac{\pi}{V_c}.$$

With $f = {\cdot}01$, $$V_c = \frac{3{\cdot}1416}{01} = 314.$$

If $V_c = 10$ f.p.m., $$f = \frac{3{\cdot}14}{10} = 0{\cdot}314.$$

Hence for the various values of the cutting speed on the bottom scale those for the feed on the top scale have the following values:

V_c	10	50	60	80	90	100	150	200	300	500	600	800	1000
f	·314	·063	·052	·040	·035	·031	·020	·0157	·010	·006	·005	·004	·003

Spindle Speeds.—The spindle speeds have to be related to the cutting speed (f.p.m.) and the diameter of the work in inches. As the horizontal and vertical scales are identical the spindle speeds (r.p.m.) are given by lines sloping at 45° to the X axis. Using the expression

$$V_c = \cdot 262dR,$$

the cutting speed for 1 in. dia. is:

Spindle speed, R (r.p.m.).	30	41	62	92	124	188	245	332	500	735	996	1500
Cutting speed, V_c (f.p.m.).	7·8	10·7	16·2	24·1	32·5	49·4	64·2	87	131	193	261	393

With the above data known the chart (fig. 2.20) can readily be constructed.

Use of the Chart.

This is best shown by two examples:

(i) An 8-in. dia. mild-steel forging is to be finish-turned with a speed as near as possible to 300 f.p.m. and with a feed of ·010 in. per rev. Check for (*a*) the spindle speed (r.p.m.), and (*b*) the machining time.

(1) Move along the horizontal line from 8 in. dia. until it intersects the vertical line from 300 f.p.m. This is shown at point A, and the nearest spindle speed is 124 r.p.m., giving, say, 260 f.p.m.

(2) Drop from the feed of ·010 in. to intersect the sloping line of 124 r.p.m. This is shown at point B.

(3) Trace horizontally along from B to cut the time scale at C. The time to turn 12 in. along is given as, say, 9·4 minutes.

(ii) A 2-in. diameter bar of steel is to be rough-turned to 1¾ in. diameter, 6 in. long. The cutting speed is to be as near to 100 f.p.m. as is possible and the feed chosen is ·020 in. Determine the spindle speed, r.p.m., and the cutting time.

(1) Tracing along the 2-in. horizontal line until it intersects the 100 f.p.m. vertical line the nearest spindle speed is found to be 188 r.p.m. as shown at D.

(2) Drop vertically from the feed of ·020 in. to the line giving 188 r.p.m.; this gives point E.

(3) Move along horizontally to cut the time scale at F. Reading the scale, the time for a 12-in. length is, say, 3·2 minutes. Hence for 6 in. the time would be, say, 1·6 minutes.

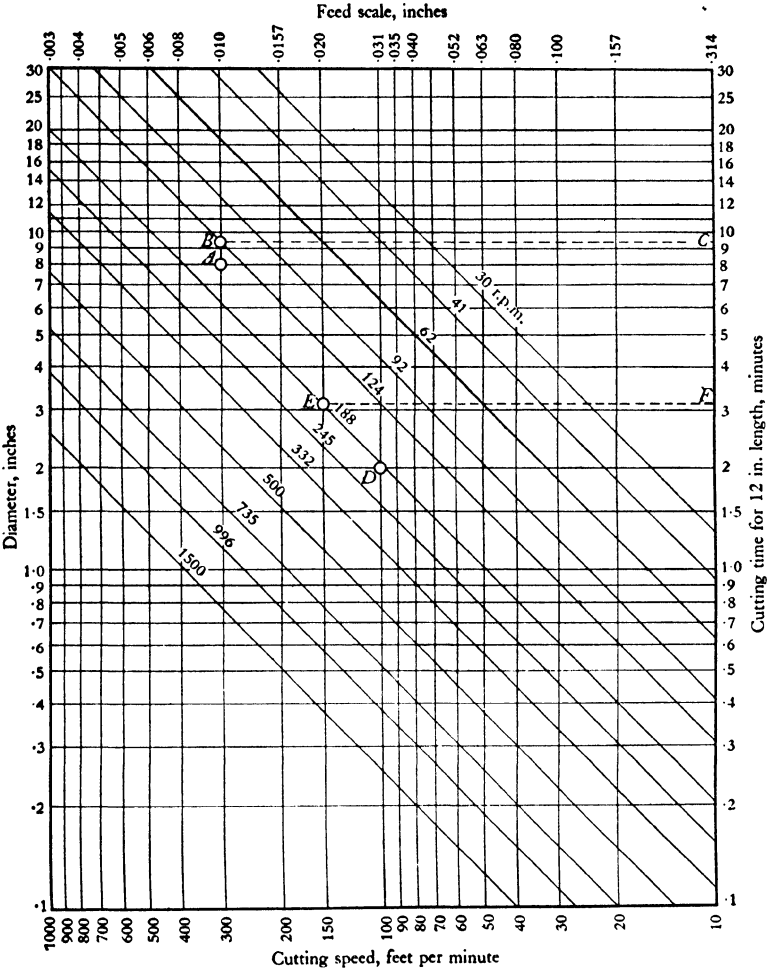


Fig. 2.20.—Relation between spindle speed, cutting speed and time to turn a 12-in. length for a centre lathe

11. Value of the Charts.

The value of a properly drawn chart for each machine cannot be easily estimated. It saves much time, and moreover it brings out what may be the weak spots in the design. For instance, it was not possible to machine the 8-in. diameter job at 300 f.p.m., but it has to be done at 260 instead, simply because the spindle speed of, say, 144 r.p.m. was not available. Hence a reduction in speed of some 13 per cent was taken. Shop conditions will determine if this would prove to be a serious economic drawback.

CHAPTER III

Estimating for Engineering Production

Estimating as it concerns the production engineer may be roughly divided into the following sections: (*a*) calculating the material weights for each component, (*b*) planning the production schedule, (*c*) checking the existing plant to ensure that sufficient capacity is available to give the desired output, (*d*) designing and manufacturing the necessary tools and gauging equipment to ensure that the daily quota is achieved and up to the prescribed standard, (*e*) having sufficient data available to permit the various indirect charges to be allocated with a fair degree of accuracy.

1. Materials to Standard Specifications.

An estimator is called upon to deal with the wide range of materials now available to industry, and it is important to state on each estimate the form, condition, and finish required, so that no difficulty is encountered when buying and during the manufacturing processes. Wherever possible, full use should be made of the relevant national standards for composition, size, strength, tests, and finish. Departures from the above should, where possible, be avoided, as they usually lead to production troubles and higher costs.

2. Form in which Metal is Supplied.

Materials in the metal group as used in engineering are obtained in one of the following forms:

Castings, either sand, gravity, or pressure die-cast. To produce castings entails heating the metal to a molten condition and then pouring it into a specially prepared cavity.

Forgings, drop-stampings, or hot-pressings which call for the metal to be heated to a plastic state, so that it may be hammered into shape or pressed between two dies to give the desired form.

Bar or Billets, which may be (*a*) hot-rolled to size and shape, (*b*) bright-rolled, (*c*) bright-drawn, (*d*) ground to size, (*e*) extruded as in the case of many non-ferrous alloys.

Wire of various cross-sections.

Tube in a variety of sections.

Foil, Strip, Sheet and Plate, and the definitions for these are listed:

> *Foil* is metal rolled to a thickness of ·006 in. or less; it is supplied in coils with widths up to, say, 6 in.
>
> *Strip* is metal rolled over ·006 in. thick and up to ·375 in. It is supplied in coils or flat lengths, and in widths up to 15 in.
>
> *Sheet* is rolled metal over ·006 in. thick and up to ·375 in.; width greater than 15 in. and supplied flat. For many purposes sheet is purchased cut to a given size.
>
> *Plate* is metal over ·375 in. thick with the width and length governed by the specific requirements. Often steel plate is " flame-cut " to size.

3. Condition for Service and Production.

In every instance the service and production requirements must have careful consideration before giving the type and grade of material required for a particular purpose.

Castings.—All castings, unless otherwise stated, are normally supplied in the condition they come from the foundry with only the sand and flash removed. When annealing, machining, and finishing operations are required, the specific requirements should be stated on the inquiry or order form.

Bars and Billets.—The majority of bar materials or billets are supplied in the condition they come from the rolls, draw-bench, or press. Care should be taken to see if free-cutting material is required, or whether a case-hardening grade of steel is necessary. When the assembly operations include welding, it is essential to see that the chosen material will give an effective weld. With medium- and high-carbon steels the condition the material is required in should be given very careful consideration, as it is often desirable to purchase the bars in a fully heat-treated state. This also applies to some alloy steels. To avoid any misunderstanding the suppliers should be given specific instructions as to the condition in which the material is to be delivered.

Wire.—When metal is drawn to a small cross-sectional area it is known as wire and is supplied in coils. The " temper " is adjusted to meet the subsequent manufacturing operation; hence, for coil springs which are not to have any heat treatment, the wire is " hard-drawn ", i.e. it is supplied in a fully work-hardened state. On the other hand, when the material is required for, say, a cold heading-operation, as is necessary when making rivets and small screws, the wire is taken in the soft annealed condition so that the necessary cold-work can readily be performed.

Forgings, &c.—Just how forgings, drop-stampings, and hot-pressings should be sent from the forge depends upon the material, the machining required, and the use to which the article is to be put. Light alloys should be delivered fully heat-treated, ready for service, as they offer no machining difficulties when in this state. Hot brass-pressings normally are sent out as they come from the presses. With steel forgings and stampings, how the forge should supply the goods depends upon a knowledge of the service and machine-shop requirements. In some cases the forgings are best sent out annealed; in others, normalized; in a few, fully heat-treated to give the maximum strength. To avoid trouble, delay, and misunderstandings, specific instructions should always be given to the suppliers. See Tables 60–5, pp. 118–49.

Foil, Strip, and Sheet.—Material in any of these forms is supplied in the following tempers:

Hard,
¾ Hard,
½ Hard,
¼ Hard,
Soft.

Hence, by a suitable choice of " temper ", one can have the material hardness adjusted to suit the specific manufacturing processes. It is the best practice to state the " temper " requirements as a Vickers Diamond Point or Rockwell hardness number.

Rolled Edge.—With strip of a narrow width it is often desirable to purchase the material with what is known as a " rolled edge ", in preference to the sharp, sheared edges which have a tendency to cut the fingers. When producing articles which have to be handled frequently, a rolled edge is preferable as it avoids the necessity for a frazing or burring operation.

Weight or Length.

When ordering material, particular attention should be given to the weight and length of the individual pieces or coils, so that ease of handling is given in transport, in the stores, and in the workshops. Unless conditions are such that long lengths are desirable, the maximum should be, say, 6 ft. and less if the weight does not permit easy lifting. Coils should be restricted to, say, 35 lb. when women workers are called upon to move the metal.

Coils or Flat Lengths.

With strip or foil the best method of ordering must be considered, and here the component to be produced is the governing factor. This is particularly so when flat articles are being made, as under such conditions it is very difficult to remove the camber caused by the coiling. To do so requires skilful flat-hammering, and this is not cheap. Then again, when the material is taken in flat lengths, quicker production times are often obtained, as the strip and scrap are more easily handled. Given an automatic feed on a press, then coil material is desirable.

Thus, before any specific recommendations can be made, a full knowledge of the work to be done, and the machine and tools to use, must be available.

Finishes.

Steel-bar finishes are (*a*) black, and direct from the hot-rolling mills; (*b*) bright-rolled; (*c*) bright-drawn; (*d*) turned or ground. The black bar is used for forgings and machined goods when great accuracy on the outside diameter of the bar is unnecessary. The bright-drawn material is used extensively for the production of machined goods made on capstan and automatic lathes, as, under such manufacturing conditions, it is essential that the size is held to close limits. Ground bars are chosen for a wide range of tools, dowels, and kindred parts.

Non-ferrous bars are normally purchased in the state they come from the extrusion press or mill.

Mild-steel Sheet or Strip.

This class of material is obtained in a number of finishes, the choice of which will depend upon the manufacturing processes.

Abbreviation	Quality	Uses
Blk. Sh.	Hot-rolled sheet.	Flat goods only. No use for bending or cupping as the scale breaks away.
S.O.	Sheared and open-annealed.	Buckets, shovels, trunks, drums, sanitary goods.
P.C.A.	Pickled and close-annealed.	The best quality for all deep-drawn goods. Used particularly for vitreous enamelled goods.
C.R.C.A.	Cold-rolled, close-annealed.	Lock plates, stove plates, trunks, trays, oil stoves, door and box hinges.
P.C.R.C.A.	Pickled, cold-rolled, close-annealed.	Used for pressings that need japanning, &c. Disc wheels, motor-car bodies, mudguards, filing cabinets, black trunks, frying-pans, toys, cycle parts, advertising signs and for printing on. It is the most highly finished of the "black" plates.
	Silver finish or "white to the edge".	These plates are free from blue edges and, having smooth surfaces, are used for lithographing. They are made into canisters, toys and goods as given for the P.C.R.C.A.
B.R.M.S.	Bright-rolled mild steel.	Depends upon the hardness and quality. If required for deep-drawing this should be stated.

Coated Steel Strip and Sheet.

Strip and sheet may be had with various protective coats or finishes and the chief of these are:

Hot-tinned Steel Sheet or Strip.—The former is known as tinned plate, and is used extensively for packing foodstuffs.

Terne Plate is sheet steel coated with a mixture of lead and tin. It is used for making drums to pack grease, &c., but not foodstuffs.

Galvanized Sheet is sheet steel dipped into molten zinc.

Steel Sheet may also be had in polished and plated finishes such as brass, copper, and silver, either bright or oxidized. It may also be had with a printed and lacquered surface.

Brass and Copper Strip and Sheet.—Brass and copper strip and sheet is normally purchased in the "natural" condition. It may, however, be purchased with a protective coating of tin, or polished.

Aluminium Strip and Sheet.—Aluminium strip and sheet is normally supplied in the bright, "as rolled" state. When necessary it may be obtained with a dull, matt, satin or frosted, lacquered or printed surface.

Zinc.—Zinc is obtainable in sheet form and with a variety of finishes, such as brass; copper; silver, bright or oxidized; nickel or chrome-plated. For a range of fancy and ornamental goods, it is often an economy to purchase the material in the finished condition.

Stainless Steel.—With stainless steel the finish varies from descaled, cold-rolled, to a bright, highly polished surface. As the price varies according to the finish it is very important that, when the operation cycle has been determined, the exact requirements are given to the suppliers. It is of little value to order bright, well-polished strip or sheet if the work has to be annealed several times.

CHAPTER IV

Estimating Material Requirements

1. Manufacturing Scrap.

All manufacturing concerns employ a number of people, hence, as it is only human to err, the provision for scrap of one kind or another must be made in every estimate. Just how this will be done will vary according to the circumstances. The two extreme cases are (*a*) on a " one off " order for, say, a large casting; (*b*) production on an automatic lathe or press where many thousands are required, the technique well-known, machines and tools in first-class condition and manned by skilled setters and operators. In the first instance, it may be necessary to make two or more castings before the correct technique is discovered for moulding, feeding, &c.; hence it may be that the percentage scrap figures very largely in the total output. In the second instance, the percentage of scrap will be very small.

Scrap Allowance.—In the case of a standard product it will be found that, for manufacturing purposes, by taking a gross of articles as 150 instead of the normal 144, a scrap margin of 4 per cent is given which has proved adequate when estimating for a wide range of goods. This is equivalent to multiplying the actual weight of metal per gross (144) by 1·04, see paragraph (6), p. 53.

2. Reasons for Scrap.

The reasons for scrap may be roughly given under one or more of the following headings:

(*a*) Carelessness on the part of the operator.
(*b*) Operator inadequately trained.
(*c*) Equipment in poor condition.
(*d*) Equipment poorly designed or made.
(*e*) Defective material.
(*f*) Material not to specification.
(*g*) Careless handling which results in bruising or breakage.
(*h*) Lack of attention on the part of the setter, inspector, or supervisor.
(*i*) Gauging equipment not up to standard or not available.

(*j*) Faulty or ambiguous instructions.

(*k*) Instructions given verbally and in consequence misunderstood.

(*l*) Written instructions misread.

(*m*) Poor works organization.

(*n*) The operating technique unknown and experiments have to be carried out to determine the correct methods.

3. Process Scrap.

On all estimates it is necessary to make due provision for the necessary process scrap involved in the production of a given article. On bar work, it is the swarf and stub ends that have to be discarded; on machined castings and forgings, the swarf; on metal pressings, the scrap webbing, piercings, clippings, and trimmings; on casting, the gating system, feeder heads and risers, along with the inevitable melting losses; on drop-stampings and hot-pressings, stub ends, swarf, scale, and clippings.

Unless due provision is made for the process scrap, the costs of production cannot be effectively estimated, as the difference between the buying of, say, sheet metal and that received for the scrap is not taken into account.

4. Estimating Weights.

When estimating the weights of castings from a drawing it is necessary to determine the volume of metal in the article and multiply the result by the weight per cubic inch. Then

Weight of article = volume × weight per c. in. of the metal.

Example 1.—A cast-iron die as taken from the sand has the following dimensions: O.S. dia., 12 in.; height, 5 in.; recess in top face, 6 in.; dia., 1 in. deep. Weight of 1 c. in. cast iron = 0·26 lb.

$$\begin{aligned}
\text{Gross volume of block} &= \cdot 7854D^2 \times H \\
&= \cdot 7854 \times 12^2 \times 5 = 566 \text{ c. in.} \\
\text{Volume of recess} &= \cdot 7854 \times 6^2 \times 1 = 28 \cdot 3 \text{ c. in.} \\
\therefore \text{ Net volume of casting} &= 537 \cdot 7 \text{ c. in.} \\
\therefore \text{ Net weight of casting} &= 537 \cdot 7 \times \cdot 26 = \text{say, } 140 \text{ lb.}
\end{aligned}$$

From the buyer's viewpoint this is all that matters; the seller, however, has to take into account the process scrap which must include the melting losses, the weight of the gating system, feeder heads, risers, &c., which are returned to the cupola as scrap iron, and hence have a lower value than the pig iron.

When a large number of castings are required, and previous experience is available, it becomes fairly easy to estimate the amount of process scrap per box. For a new job a little experimenting is often required before the correct technique is found. Taking the above example, and assuming the feeder head and gating system required, say, another 140 lb. of metal, then the minimum amount to be melted becomes:

Net weight of casting = 140 lb.
Weight of gates and feeder head = 140 lb.
Metal losses on melting, say, 10 per cent = 30 lb.
∴ The minimum weight required for melting = 310 lb.

An analysis of this kind clearly demonstrates the need for care when estimating the weights of castings and material allocations in a foundry and other manufacturing departments.

Weights from the Pattern.

The weight of a casting may be obtained by first weighing the pattern and then using a conversion factor as given in Table 172 on p. 350. It is necessary, however, to point out that the above method makes no allowance for cores and core prints, the "rapping" of the pattern, or the rubbing of cores.

Machining Allowances.

Often the weight of a casting or forging has to be taken from a drawing which gives the finished machined dimensions. Then one must make due allowance for machining and the amount left on should be adequate for the tools to get well under the scale.

Drop-forgings and Hot-pressings.

When estimating the weights for hot-pressings and drop-forgings, the same procedure as outlined for castings is followed with due allowance being made for the necessary process scrap.

Plastic Mouldings.

The weight of a plastic moulding is estimated in the manner outlined for a casting. Under normal circumstances, a flash allowance of, say, 5% is sufficient; if injection moulding is used, the process scrap allowance must be estimated for each job and mould layout, as for a series of castings. See also pp. 337, 338.

Bar Work.

When estimating weights for bar work on the capstan and automatic lathe it is necessary to take into account (*a*) the parting-off allowance; (*b*) the stub end of each bar that is discarded; (*c*) the amount of metal removed to give the desired article; (*d*) the manufacturing scrap allowance as mentioned at the commencement of this chapter; see also paragraph (6), p. 52.

Example 2.—A pin is to be turned from a 0·5-in. diameter brass bar; overall length 1 in.; dia. of shank, ·25 in.; length of shank, ·75 in.

Assume that the length of the bar is 4 ft. 6 in.; the parting tool ·093 in. wide; the stub end approximately 1 in. long; the brass rod being ·728 lb. per foot run (Table 170, p. 348).

Then length of component plus parting tool = 1 + ·093 = 1·093 in.
Effective length of bar = 54 − 1 = say, 53 in.
No. of articles per bar = 53 ÷ 1·093 = say, 48.
Length of bar per manufacturing gross (150) = $1{\cdot}04 \times 4{\cdot}5 \times \frac{144}{48}$
= say, 14 ft.
Weight of bar = $14 \times {\cdot}728$ = say, $10\frac{1}{4}$ lb.
Net weight of 144 articles = say, 4·00 lb.
Process scrap = say, 6·25 lb.

By allowing on the estimated length a little for the stub end and the parting tool, the following simple expression can be used to determine the weight of bar required per manufacturing gross (150):

$$\text{Weight of bar} = 12{\cdot}5LW.$$

L = the total bar length per article in in.; W = weight per foot run.

Assuming in the above example that the total bar length per article is 1·125 in., then

$$\text{Weight per manufacturing gross} = 12{\cdot}5 \times 1{\cdot}125 \times {\cdot}728$$
$$= 10\tfrac{1}{4} \text{ lb., say.}$$

Tables 170, 171 giving the weights of both round and square bar, also standard hexagons for nuts and bolts, may be found on pp. 348–9.

5. Press Work.

When engaged in sheet metalwork, by hand, spinning, or under the press,[5] it is necessary first to determine the blank size before the metal allocation can be obtained. Just how this may be done depends upon the type of component to be manufactured and the processes involved.

Blank Sizes.

The methods in general use for determining the blank sizes are given below:

Mean Radius for Bending.—On bending jobs it is necessary first to determine the mean radius before the bending allowance can be computed. Given very thin material, the mean radius is obtained by the expression:

$$\text{Mean radius} = \text{inside rad.} + \cdot 5\ (\text{thickness of metal}).$$

With metal of moderate to heavy thickness the above figures are usually on the large side. This is due to the thinning of the metal around the area subjected to bending. To compensate for this and take into account the difference in " pull " of the metal of varying tempers the mean radius is modified to read:

Aluminium up to half-hard; soft brass and copper	M.R. = inside rad. + $\cdot 35T$.
Hard aluminium; half-hard brass and copper; soft steel	M.R. = inside rad. + $\cdot 4T$.
Hard-rolled brass, copper, and steel	M.R. = inside rad. + $\cdot 45T$.

Normally the results of such figuring are accurate enough when the components have limits of, say, $\pm \cdot 020$ in. For very accurate work the figures are " trial " only.

Bending Allowance.—With the mean radius known the allowance for bending is computed using the expression:

$$\text{Bending allowance} = \frac{\text{Angle of bend}}{360} \times 3\cdot 1416 \times 2 \times \text{M.R.}$$
$$= \cdot 0174 \times \text{angle of bend} \times \text{M.R.}$$

It should be understood that the angle of bend is the actual number of degrees the metal is displaced. The above expression may be further simplified:

$$\text{Bending allowance for } 90^\circ = 1\cdot 571\ \text{M.R.}$$
$$\text{,, \quad ,, \quad ,,}\quad 180^\circ = 3\cdot 1416\ \text{M.R.}$$

Surface Area Method.—To determine the blank size for a raising, a cup, or deep-drawn shell, on the assumption that the material is not thinned during the press operations, the surface area method is used. The given assumptions are not strictly true, and in some cases the estimated blank size may be from 5 to 20 per cent greater than is found necessary when the trials are made. The excess amount depends upon the pressure required to control the blank and the " pull " of the metal.

For a shell having a flat bottom, a reasonably square corner, with no thinning or thickening of the metal, the standard expression for the blank size is:

$$\text{Blank dia.} = D = \sqrt{d^2 + 4dH}.$$

$$d = \text{dia. of shell.} \quad H = \text{height of shell.}$$

For irregular shapes, the above formula is useless, but the blank diameter can readily be obtained by the simple expedient of dividing the surface into " elements ", each of which conforms or approximates to a geometric figure. The surface area for each element is computed, and in this way the total area obtained. Knowing the latter, the blank diameter is calculated from

$$D = \sqrt{A \times 1{\cdot}272}.$$

Example 3.—A shell is 2 in. dia. and 4 in. high. Give the blank dia.

$$\begin{aligned} D &= \sqrt{d^2 + 4dH} \\ &= \sqrt{2^2 + 4 \times 2 \times 4} \\ &= 6 \text{ in.} \end{aligned}$$

Mean-height Method.—The mean-height method of determining the blank size is chosen when the walls of a shell are deliberately thinned during the press operation. Knowing the final height of the shell, including the trimming allowance, this figure is then adjusted to that for a shell having a thickness equal to the initial metal.

$$H = \frac{ht}{T} \text{ or } h = \frac{HT}{t}.$$

H = shell height with no thinning. T = initial thickness of metal. t = final thickness of wall. h = final height of shell.

Volume.

When working on thick metal it is usual to compute the volume in a given component plus any trimming allowance that may be necessary. To simplify the calculations the component is divided into "elements" and the volume of each determined. With the total volume and initial thickness of the metal known, the blank area and diameter can be obtained from the expressions:

$$\text{Area of blank} = \frac{\text{volume}}{\text{thickness}},$$

$$\text{Dia. of blank} = \sqrt{\text{area} \times 1{\cdot}272}.$$

6. Blank Layout.

Before any metal allocation can be determined, it is essential to choose the blank layout which gives, all things considered, the most economical use of the material. In a number of instances only one layout is possible; in others, a saving varying from, say, 5–20 per cent can be made. The shape of the article, the operations to be performed, the quantities to be made and how the material is purchased, will determine the layout. Often a considerable saving can be made by using piercings or metal discarded as scrap when blanking or clipping other components.

Allowance for Bridge and Side Strips.—When blanking metal from coil and sheet it is necessary to have the material wider than the blank in order (*a*) to get a clean blank, (*b*) to permit the safe and effective handling of the material. The amount to allow depends upon (i) the class of material; (ii) its thickness; (iii) whether it is sheared to an exact width or not; and (iv) how it is handled, by hand or automatic feed. The table below gives the amount to add to the blank diameter or width if using an automatic feed in order to obtain the strip size for metal up to, say, ·062 in. thick.

Blank dia., inches	Material	
	Aluminium up to ·020 in.	Aluminium over ·020 in., brass, copper and steel
Up to $1\frac{1}{2}$	$\frac{1}{8}$–$\frac{3}{16}$	$\frac{1}{8}$
$1\frac{1}{2}$–3	$\frac{1}{4}$	$\frac{3}{16}$
3–5	$\frac{3}{8}$	$\frac{1}{4}$
5 and over	$\frac{1}{2}$	$\frac{3}{8}$

Slight modifications are made to the above if it permits the use of standard widths and thus avoids shearing to awkward sizes.

Bridge between Blanks.—The bridge allowed between the blanks is usually less than the amount given on the sides, and satisfactory results are obtained when the following table is in use.

Thickness, in.	·010	0·02	·030	·040	·050	·060	·070	·080	·090	·100
Bridge width, in.	·020	·025	·030	·035	·040	·045	·050	·055	·060	·065

On a stagger-feed press a bridge allowance of ·010 in. is usually ample.

Estimating the Metal Weights.

Knowing the blank diameter, metal width, and pitch of the blanks, it is easy to determine the material allocations—using Tables 168, 169, p. 347—for a given job. For this purpose one may adapt the following simple expression for both total and net weights:

Weight per manufacturing gross (150)

$$= \text{surface area} \times \text{wt./sq. ft.} \times \frac{150}{144}$$

$$= 1{\cdot}04AW,$$

where A = surface area, sq. in., W = wt. per sq. ft. of strip or sheet.

Example 4.—A bottle cap is estimated to require a blank 2·750 in. dia.; the metal thickness (aluminium) is to be ·010 in. Give the strip width, pitch of blanks, and the total and net weights. Weight per sq. ft. of aluminium ·010 in. thick (see Table 168, p. 347) is 0·147 lb.

Metal width $= 2\frac{3}{4} + \frac{1}{4} = 3$ in.
Pitch of blanks $= 2\frac{3}{4} + \frac{1}{8} = 2\frac{7}{8}$ in.

Metal weights per manufacturing gross:
Metal $= 1{\cdot}04 \times 3 \times 2\frac{7}{8} \times {\cdot}147 = 1{\cdot}32$ lb.
Component $= 1{\cdot}04 \times {\cdot}7854 \times (2\frac{3}{4})^2 \times {\cdot}147 = {\cdot}91$ lb.
Process scrap $= {\cdot}41$ lb.

Plate and Structural Steelwork.

When estimating for plate and structural steelwork, due allowance must be made for the necessary process scrap arising from cutting the sections to length and shape. Owing to the great variety of jobs that the estimator may be called upon to handle, and the possibility of using short lengths on other jobs, it is impossible to give any hard-and-fast ruling; it is wiser for him to study the conditions operating within the establishment, and to base his allowance upon them, taking care that the figures are reasonable, permitting neither undue waste nor underestimating.

CHAPTER V

Other Charges

1. Bought-out Goods.

With the high stage of specialization now found in every manufacturing community, no firm can hope to produce all the items it requires at an economical price. Hence, many standard lines such as bolts, screws, nuts, washers, cotter pins, springs, and ball bearings are purchased from concerns who confine their activities to the production of a narrow range of articles. As another facet of this specialization, some firms concentrate their efforts on pattern or tool-making, electric installations, sheet metalwork, press work, metal-spinning, sand-casting in both ferrous and non-ferrous metals, die-castings, forgings, drop-stampings, hot-pressings, polishing and plating, also vitreous enamelling, to name but a few. For this reason each estimator should build up a series of records giving the various firms who produce specialities, who will undertake the manufacture of specific articles, or who confine their activities to such processes as polishing, plating, lacquering and vitreous enamelling.

2. Process Material.

In addition to the material required to produce the article, it is also necessary to estimate for what is termed "process material". This term covers all types of lacquer, japan, vitreous enamel, solder and welding rod, tin when used for the hot-tinning process, zinc for galvanizing, nickel, silver, and copper when electroplating, and other similar processes. In each instance the estimate should cover the amount assumed to be deposited upon the article plus an allowance for losses caused by oxidation, spraying, &c.

Lacquer and Japan.—The amount of lacquer or japan[6] required to cover a given area is dependent upon the class of work and the method of application. No one figure can cover all possibilities such as the shape of the article and its size, viscosity of the liquid, unavoidable losses, room temperature and the personal skill of the operator. For these reasons the following conservative figures can only be regarded as suggestions to be modified as circumstances demand.

TABLE 3.—COVERAGE PER GALLON OF LACQUER AND JAPAN

Spraying cellulose or synthetic lacquer.	1 gallon to cover	300 sq. ft.
Spraying japan.	1 „ „	
Dipping in lacquer.	1 „ „	500 sq. ft.
Dipping in japan.	1 „ „	
Brushing lacquer.	1 „ „	300–400 sq. ft.

Vitreous Enamelling.—The weight per square foot of surface area covered may be readily estimated on the assumption that the aim is to get a thin, even coating of "metal" fused upon the article. Owing to the troubles arising from contraction and expansion stresses it is unwise to have too thick a coating. Thus, for a three-coated job, the final thickness should not exceed ·030 in. Normally the weight is estimated on the following basis:

TABLE 4.—COVERAGE PER SQ. FT. FOR VITREOUS ENAMEL COATS

Ground coat.	1·375 oz. per sq. ft.
First coloured coat.	1·25 oz. per sq. ft.
Second coloured coat.	1 oz. per sq. ft.

In a number of instances only two coats are given to the article, and this gives a thinner shell.

The process waste is omitted from the above figures. When the articles are dipped or slushed the material losses are very small; if spraying is adopted, then the losses become heavier and must be allowed for in the estimate. The percentage loss will depend upon the size of the articles and the skill of the operators.

Whether to include the cost of milling the frit in with the price of the enamel depends upon the scheme of costing. If possible, it is better to do so, and then the cost of the material includes:

(*a*) The materials put into the mill.

(*b*) Labour charges in the mill-room.

(*c*) Mill-room expenses such as power, lighting, rent, water, supervision, and any other relevant to the case.

Hot Tinning.—With hot tinning the thickness of the deposit may be taken on the basis of ·00025 in. per face covered. On straightforward jobs the above figure gives a reasonable estimate of the material consumed. When, however, the article has a number of small recesses or open laps into which the tin may find its way, and cannot be readily drained, it may be necessary to increase greatly the above figures.

In some instances this excess tin may be equal to or greater than the amount on the surface proper.

With tin weighing ·263 lb. per c. in., assuming a good deposit, ·00025 in. thick and allowing, say, 15 per cent for melting and other losses, then one pound of new tin may be expected to cover the following surface:

$$\text{Area covered} = \frac{1 - \cdot15}{\cdot263} \times \frac{4000}{144} = \text{say, 90 sq. ft.}$$

When there is a risk that much tin will be entrapped in lapped edges, hollow handles, &c., the above figure must be reduced.

Plated Work.

When estimating for plated work[7] it is sometimes necessary to determine the weight of metal deposited on a component. This is particularly so when handling precious metals. Table 5 gives the deposition of various metals with a current of one ampere and also lists the normal range of current.

TABLE 5.—ELECTRODEPOSITION OF METAL PER HOUR PER AMPERE

Metal	Weight deposited per hour per ampere		Thickness deposited, in. per hour per ampere per sq. in.	Average working current density, amperes per sq. ft.
	Grammes	Grains		
Cadmium.	2·097	32·33	·01482	10 to 15.
Brass.				2½ to 4.
Chromium.	0·3234	4·984	·0058	60 to 80 bright solution. 250 to 300 heavy solution.
Cobalt.	1·1	16·973	·00753	Say 10.
Copper (cy.).	2·372	36·6	·01628	2½ to 4.
Copper (sulp.).	1·186	18·3	·00814	12 with still solution. 20 to 40 with an agitated solution.
Gold.	7·356	113·5	·02316	
	2·452	37·83	·00772	
Iron.	1·44	16·08	·00831	
Lead.	3·865	59·64	·02087	4 to 40 according to solution.
Nickel.	1·095	16·89	·0077	1 to 8 cold solutions. 15 to 30 warm solutions.
Palladium.	0·99516	15·35	·0054	
Platinum.	1·821	28·10	·0052	
Rhodium.	1·2797	19·74	·00603	
Silver.	4·025	62·106	·02325	2 to 4.
Tin.	2·214	34·162	·01846	10 to 15.
Zinc.	1·219	18·81	·01041	40 with chloride solution.

Working from Table 5, estimates can be made of (*a*) the time required to deposit a given weight of metal, providing the current density is known; or (*b*) the weight that may be deposited in a given time; this assumes that the working of the solution is 100% efficient.

Example.—Using a sulphate solution, it is required to deposit copper ·0312 in. thick in 24 hours. Give the current density and weight of the deposit per sq. ft. if the density of copper is 0·32 lb. per c. in.

From Table 5, 1 ampere per sq. in. or 144 amperes per sq. ft. give a deposit ·0081 in. thick.

$$\text{Then time for ·031 in. deposit} = \frac{·03125}{·0081} = 3·86 \text{ hours.}$$

$$\text{And for a 24-hour run, current density per sq. ft.} = \frac{144 \times 3·86}{24}$$

$$= \text{say, 23 amperes.}$$

This falls within the range given in the above table.

$$\text{Weight of metal deposited per sq. ft.} = A \times T \times W$$
$$= 144 \times ·031 \times ·32$$
$$= \text{say, 1·44 lb.}$$

3. Charging Pattern or Tool Costs.

When producing one's own specialities the question of how the necessary pattern or tool charges shall be allocated does not arise, for it is understood that they will be absorbed into the various indirect expenses. But when a foundry or concern specializing in the production of castings, machine-made goods, or metal pressings is quoting against an inquiry, the above simplicity does not exist, and careful attention has to be given to the manner adopted to recover any expenditure on patterns or tools. This is necessary if the supplying concern is not to be faced with a heavy charge for equipment which may prove to be a loss; then there is the viewpoint of the customer, who should not be placed in the position where he is justified in regarding the proposed pattern, mould or tool expenditure as excessive.

Briefly the methods adopted are:

(*a*) Charge the customer with the whole of the estimated or actual expenditure for equipment special to the proposed job.

(*b*) Make a "part cost", and absorb the remainder over the initial order.

(*c*) Make a "part cost", and then absorb the remainder into the various indirect expenses.

(*d*) Make no direct pattern or tool charge but absorb the expenditure into the various indirect expenses.

(*e*) Make no direct pattern or tool charge but spread the expenditure over, say, the first year's anticipated production.

Which of the above methods to adopt must depend upon circumstances, the standing of the customer, and the general policy of the concern. In case any pattern, gauge or tool charge is made there should be a clear understanding as to who owns the equipment.

4. Required Accuracy.[8]

The accuracy required on any machined component has a marked influence upon the production times and the scrap percentage. For these two reasons it is vital that due attention is given to the limiting dimensions stated on any drawing. It is obvious that there cannot be any hard-and-fast ruling to cover every case as the functional needs of each component have to be carefully examined. The suggestion is that for cylindrical fits either the Newall table or the recommendations of B.S. 164 are chosen; for threaded components the limits on the effective and other diameters should conform to B.S. 84.

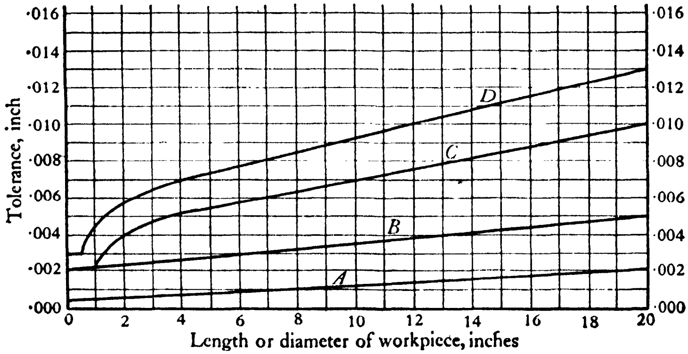


Fig. 5.1.—General manufacturing tolerances

A. Cylindrical grinding. Fine or precision boring and turning. *B*. Finish turning and boring of greater accuracy. Reaming. Broaching. Milling—slab, side and face. *C*. Capstan, turret and automatic lathes. *D*. Normal finish-turning and boring (centre lathes). Shaping. Planing. Slotting.

The above suggestions do not cover such operations as drilling, reaming, turning, or boring; hence the graphs in figs. 5.1 and 5.2, which are based upon the generally accepted practice, can be adopted. In each instance the disposition of the tolerance depends upon the function of that portion of the component. Thus the tolerance may be on the unilateral basis and placed either above or below the nominal size; alternatively it may be used bilaterally, around the nominal dimension. If conditions permit a larger tolerance, then it should be chosen; finer limits often call for longer machining times, specialized equipment, and may result in a high scrap percentage.

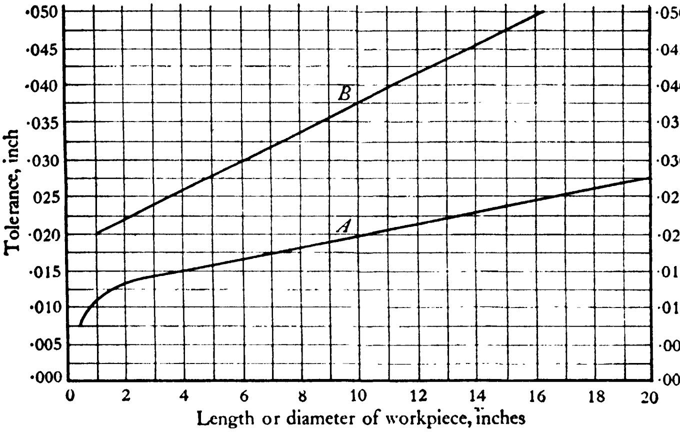


Fig. 5.2.—General manufacturing tolerances
A. Drilling. Rough turning. Rough boring. Disc-grinding flat surfaces.
B. Green sand-castings

5. Quantities.

A very important feature associated with estimating is the number to be produced, or at what point an order can be regarded as finished. The two main things to consider, and if necessary ask for, are given below.

1. *Setting Charges.*—The question of setting charges arises when the methods of production involve tool-setting, and the quantity required is small. As an example, an inquiry may be dealt with on the assumption that batches of not less than 2000 will be required. On this basis the supplying concern has based its price so that it absorbs the high setting-charges and a reasonable profit is obtained. Now assume, for some reason best known to the buyer, a batch of 100 is ordered. The supplier has the same setting-charges, but the smallness of the order precludes the possibility of a profit. Hence he, the supplier, is faced with two alternatives, (*a*) make a loss on the transaction, or (*b*) charge the customer an additional sum to cover the incidental expenses associated with setting the machines. When the latter procedure is followed the additional amount is usually termed a " setting charge ".

2. *Completion of Order.*—"At what stage shall an order for specialities be regarded as completed?" is the next point which requires attention so that unnecessary loss may be avoided. For this reason it is often given in the "Conditions of Sale" that an order shall be regarded as complete when delivery is within, say, ±5–10 per cent of the total ordered. This provision is made so as to avoid setting up for a very small quantity. The actual shortage may be due to insufficient material being sent in by the suppliers, manufacturing scrap, or an error on someone's part.

On many manufacturing processes it is impossible to forecast just how many articles will be scrapped as the work proceeds through the various departments. If no margin has been allowed or insufficient material issued, then a shortage can be expected when the goods reach the warehouse or dispatch bay. Assuming that the usual allowance has been provided for the manufacturing scrap, then, with great care, or a slice of luck, more than the required number will be available for delivery. Thus in both circumstances the manufacturing concern has to suffer a loss if the exact number must be delivered. On the one side is the loss entailed by putting a small additional batch through the shops; on the other is the loss incurred through having to discard the surplus. When estimating, steps should be taken to cover, if possible, such contingencies, bearing in mind that the selling price must be reasonable.

Table 6, by the National Association of Drop Forgers and Stampers,[9] gives the plus and minus tolerances on orders varying from a few to many thousands.

TABLE 6

TOLERANCE ON QUANTITIES ORDERED

Quantity ordered	Tolerance	
	Plus	Minus
Up to 50	4	2
Up to 100	6	3
Up to 300	18	9
Up to 600	24	12
Up to 1000	40	20
Up to 5000	100	50
Up to 10,000	200	100
Up to 15,000	300	150
Up to 20,000	400	200
Over 25,000	500	250

6. Stating Labour Costs.

The manner in which the estimated labour costs are given, should be such as to create no misunderstanding when the establishment has an incentive method of payment in operation. If convenient, it is better to give both the estimated time and the labour charge. (See also Chapter XVI.) The former should be on the basis of the actual time estimated for each operation; the latter should include the incentive payment. Thus, if an article is estimated to take one hour, and the day rate for that type of labour is two shillings per hour, the piece-work price would be given as, say, two shillings and eight pence each, which permits the man to earn the recognized time and a third, as permitted under the Bedaux and other schemes. No allowance should feature on an estimate for the extra payment due to overtime within the works.

7. Packing.

A very careful examination should be made of the question of making the packing charge a direct one. In some instances this is impossible; in others it is feasible, particularly when the articles are sold in containers or cartons which are not returnable. The same condition arises when the distance is such that packing-cases, battens, and similar items cannot be returned.

8. Outside Erection.

When an estimate covers outside erection, it is necessary to ensure that full provision has been made for transport to the site; the question of lodging allowance dealt with; travelling expenses covered; the preparation of foundations; repairs to buildings and roadways; overtime and nightwork; supervision along with any other relevant item included.

9. Transport.

With the question of transport there are two main ideas operating. The first regards all transport as an indirect expense, and therefore it features in the distribution charge, and is recovered by means of the distribution oncosts. The second regards it as a direct charge, and then it features as a separate item in the estimate. Which method is to be used depends upon the articles offered for sale and the custom of the trade.

10. Export Requirements.

When dealing with export orders there are a number of points which must have careful attention in addition to the manufacturing costs. These are transport to the docks, insurance, dock dues, freight and import duties. The influence of these items on the final selling values is great when prices have to include carriage, insurance and freight (C.I.F.). In some instances the price quoted is free on board (F.O.B.), the buyer attending to the other expenses.

For purposes of calculating, a container having an outside volume of 40 cubic feet is assumed to weigh one ton. If the weight of the article exceeds this, then the higher value is taken when deciding the freight charges.

In order to deal with export orders an up-to-date knowledge of the various regulations is essential. For a small concern it is often better to have all export orders handled by a well-established firm of export merchants who have the necessary connexions in the particular country.

CHAPTER VI

Process Planning

1. Operation Schedule.

When the weight of material per unit has been completed and the condition required along with the process material have been decided, the next stage is to prepare a schedule of operations. This work should be planned out in a logical manner (see forms on folders opposite pp. 341–3), and should indicate concisely all stages in the manufacturing cycle. Alongside each operation, details as to the machines allocated, pattern, tool or gauge charges, time required and the labour cost, should be listed. Work of this nature calls for attention to detail, and an excellent all-round knowledge of the many workshop processes. Good results are possible only when the work is properly subdivided; accuracy is unobtainable when a series of operations is grouped under a general heading.

2. Interstage Operations.

Before dealing with the main stages in the operation schedule, attention must be drawn to the overriding need to watch for and list the interstage operations, some of which are given below.

Annealing.—When dealing with many forged, cast, and pressed articles, the necessity arises to allow for an annealing or heat-treatment process so that the effects of work-hardening may be removed, the material placed in a suitable condition for further operations, or treated so that the strength and hardness may be satisfactory for service conditions. For good estimating, any such operation must feature on the operation schedule so that due provision is made for the labour and other charges; just how this will be done depends somewhat upon the scheme of costing. Often the best method is to determine the costs of running the muffle per hour, and base the charges upon the actual or estimated in-and-out time. In this direction a good series of graphs, prepared within the concern from actual time-studies, prove to be of great assistance.

Cleaning.—The interstage operations of cleaning cover degreasing, the paraffin swill, pickling, and drying in hot sawdust. With many metal articles produced on lathes or under the press, the cleaning operations form a very important feature in the cost of production. Hence, in order that each article shall carry its fair share of the total cleaning charges, it is necessary that each cleaning operation be listed on the operation sheet. Here, too, a series of well-prepared graphs prove to be of the greatest assistance.

Frazing.—With a number of operations, a burr or fraze is thrown up and the sharp edge proves unacceptable to either the customer or inspection department. When this is likely to happen, due provision should be made in the estimate to cover the cost of removing the burr. Alternatively, it may be possible to remodel the operation schedule so that the sharp edge is taken away during the machining.

3. Incidental Work. Fatigue, &c.

It is insufficient to take into account only the actual performance of the operation when deciding the times to allow. Allowance must also be made for the following factors:

Incidental Work.—Associated with the many manufacturing processes is work that the operator only performs once or twice a day. Instances may be found in every foundry and workshop. In the former, it is often necessary to allow for damping, throwing up, and milling the sand; in the machine shop, for grinding tools, changing over, and cleaning down the machine; when spraying, for filling and cleaning the gun, and keeping the booth in good condition; many similar instances may be quoted. Every estimate must allow for such factors.

Fatigue and Weariness.—All work brings in its trail fatigue and weariness; much will depend upon the person's interest in the job, the class of work being performed, the general working conditions, the mental activity called for, the need for intense concentration and the length of the working day, to name only a few of the many interacting factors. In this direction due account must also be taken of the hourly fluctuation. Thus a careful time-study over a day's run may show that the minimum hourly output is only 67 per cent of the maximum, whilst the average hourly output is around 75–80 per cent of the maximum. The question of fatigue therefore plays a very important part and should have due consideration.

Personal Conveniences.—Allowance should also be made for personal conveniences, and this is, say, 3 per cent for men and 4 per cent for women.

Usually the estimator will take care of the above by using an overall percentage figure after a complete study of the work has been made. Each job must be considered individually as some operations carry with them longish periods of waiting, others entail hard physical work without any " internal " rest periods; hence the impossibility of having one figure to cover all cases.

4. Press Work.[5]

When estimating for goods made under the press, such of the following items as are applicable to the work in hand must be taken into account when determining the operation times.

Arranging the Metal.—Due allowance must be given for the time the operator must spend when placing the coils or sheets in position for ease of handling.

Wiping and Lubricating the Surfaces.—For successful working under the press it is necessary to ensure that the surfaces of the metal or the partly formed article are free from all foreign matter. The method adopted to remove the dust, dirt and particles of metal will depend upon the size of the strip, blank or component. When small articles are made from coil, and an automatic feeding device is used, the strip may be cleaned by being drawn through a pair of felt pads soaked in a suitable lubricant. As the operation is done during the work cycle no extra cost is involved. The same conditions exist when a pump is used to lubricate the tools and work.

The above conditions are inapplicable to large blanks and articles, hence the operation cycle is: clean, lubricate, feed, operate the press, remove the work. When the operator is called upon to clean the blanks and operate the press, the latter works at but a fraction of its potential efficiency. The remedy here is to arrange for a greater subdivision of labour, and have the cleaning and lubricating done by one group of persons, the operating by another. Where the estimate is prepared on the latter assumption, it should be clearly stated on the appropriate form.

Cleaning Tools.—Due allowance should be made for cleaning the tools so that the work may go through free from scratches.

Feeding.—The feeding of work on the press may be divided into the following groups:

(*a*) Using strip metal in coil form with an automatic feed.
(*b*) Using sheet metal on a stagger-feed press.
(*c*) Using an automatic feeding device such as a chute or dial.
(*d*) Hand feeding

In every instance the actual method of feeding will depend upon the article to be made, the plant available, the quantity required, and the allocation for tool expenditure.

Removing Scrap.—Careful attention should be given to the removing of scrap from the tools. Where possible, automatic methods should be adopted, as the production times can be held within reasonable bounds by fitting suitable ejectors and stripping devices.

Placing Work in Containers.—Another point which has a very important effect upon the estimated times is that associated with the handling of the work after the operation. When the article is such that the surface is easily bruised, or the edges bent, the estimate should provide for handling the work, and placing it in containers, so as to avoid damage during transit from one machine to another. In some establishments there is a staff to do this; in others it falls upon the operator. If the latter is called upon to arrange the work in containers it is best to list the operation on the estimate form.

Operational Times.—The total operational time must cover the handling times, incidental work, fatigue, &c., and the machine times. The latter are often only a fraction of the total time, hence great care is necessary to keep preparatory work down to a minimum.

When producing work from coil on a press having an automatic feeding device, the time is made up by (*a*) placing the coil on the stand; (*b*) adjusting the stops; (*c*) starting the strip; (*d*) removing the scrap webbing; (*e*) clearing the work away from the press. Thus, knowing the strokes per minute and making due allowance for the other factors, one can determine the hourly output.

When using a stagger-feed press the times for operating must cover (*a*) attaching the sheet to the saddle; (*b*) cutting the sheet (knowing the strokes per minute plus the number cut from each sheet, the cutting time can readily be obtained); (*c*) placing the work in containers; (*d*) removing the scrap webbing. Normally greasing of the sheet may be done whilst the press is running, hence should not feature in the list of times allowed.

Given a dial-, plate- or chute-feed press, the operational times are readily obtained, providing the machine runs at a speed which enables the operator to keep it working continuously.

When hand feeding, account must be taken of the time for loading; allowing the machine to come to a standstill, and removing the work. Each job must be judged on its merits. No hard-and-fast ruling can be given (see p. 339).

5. Castings.

When estimating the production times for green sand-castings, it is necessary to take into account some or all of the following items:

(*a*) The size of the article and the number that can be placed in a box.

(*b*) The size of the moulding box, which governs the amount of sand to be handled and the ease of lifting, &c.

(*c*) Hand or machine moulding.

(*d*) The time required to make the mould, including the cutting of gates, risers, &c.

(*e*) Core making and drying.

(*f*) Spraying or painting the cores.

(*g*) Coring up and closing the moulds.

(*h*) Pouring.

(*i*) Breaking the mould and removing the work.

(*j*) Breaking off the gating system.

(*k*) Shot blasting or barrelling.

(*l*) Fettling.

(*m*) All incidental work such as damping down the sand, fatigue, &c.

When dry sand-castings are to be produced, then the above cycle must be adjusted to suit the new conditions. See also p. 327.

6. Drop-forgings and Hot-pressings.

When estimating the times for drop-forgings and hot-pressings, account must be taken of the time required to cut the billet, heat, draw out the form, work under the dies, remove the flash, and planish. It may be that some heat treatment will follow the clipping operation.

7. Die-castings.

The points to cover with die-castings are very similar to those for a sand-casting and include some or all of the following items:

(*a*) Painting the mould.

(*b*) Fixing any inserts.

(*c*) Closing the mould and arranging the core-pins.

(*d*) Pouring.

(*e*) Time for solidification. (This, given several moulds, may fall into the general work-cycle and may therefore be excluded.)

(*f*) Opening the mould, removing core-pins and the article.

(*g*) Fettling.

(*h*) Incidental work associated with melting, heat treatment, &c.

8. Vitreous Enamelling.

When vitreous enamelling with the normal wet process, the stages from receipt of the blanks to the first coat are somewhat as follows:

(*a*) Grease burn or scale.
(*b*) Pickle and dry.
(*c*) Inspect; remove bruises, return bad pickling or drying.
(*d*) Apply ground coat.
(*e*) Dry.
(*f*) Inspect.
(*g*) Fuse.
(*h*) Inspect.

Operations (*d*) to (*h*) are repeated for each additional coat. If the article is to be tipped or marked, then this must be added.

Grease burning is the placing of the greasy work as it comes from the press shop into a muffle or furnace at, say, 650° C. with a small quantity of acid. Burning the grease in an acid-laden atmosphere eases the subsequent pickling operation.

9. Plastic Moulded Goods.

The production estimate for plastic moulded goods (see p. 337) must include some or all of the following items:

(*a*) Making the pellets or weighing the powder.
(*b*) Placing the inserts in position.
(*c*) Placing the pellets or powder into the mould.
(*d*) Placing core-pins in position.
(*e*) Closing the mould.
(*f*) Breathing time.
(*g*) Curing time.
(*h*) Opening the mould.
(*i*) Removing, if necessary, the mould from the press.
(*j*) Removing the core-pins.
(*k*) Removing the work from the mould.
(*l*) Unscrewing the holding pins for the inserts from the work.
(*m*) Placing the mould back in the press, if necessary.
(*n*) Cleaning the mould.
(*o*) Frazing the articles.
(*p*) Doing the required machining stages.
(*q*) Polishing, if necessary.

10. Polished and Plated Work.

When estimating for polished and plated work there are a few factors which must have careful attention before allocating any labour costs. These are:

Surface Condition.—The condition in which the work is to be delivered to the polishing shop must be watched. The surface may be rough, as when castings are sent direct from the foundry, or when a component is sheared from thick metal. Again, a brass article may have a coarse, "orange-peel" surface due to faulty annealing. In each instance the preliminary work to bring the surface up for grease mopping will be expensive, as sanding or emery bobbing will be necessary.

Cleaning Operations.—The cleaning operations usually form the first stage in the production cycle associated with polishing and plating, as oil, grease, suds, or scale must be removed. The actual process will depend upon the material, shape of the article, and its strength; fragile components require very careful handling.

Burnishing.—The shape of the article may be such that polishing is impossible or undesirable and burnishing is necessary. Hand-burnishing of some fancy goods is a rather expensive job as the time required is comparatively long.

Finish.—The standard of finish is very important, as the cost of the preliminary operations will be governed by it. Much will depend upon the condition in which the work is sent to the polishing shop and the handling it receives in transit; bruises are very difficult and expensive to remove. Care should be taken to see that the finish is sufficient for the customer; super finishes are best avoided unless the class of work demands them; they are often uneconomical to produce.

Automatic Polishing.—When a large quantity of a given article has to be handled, the question of automatic polishing should be given very careful attention.

Plating.

If the article is to be plated, the use to which it is to be put governs the class of finish. Some coats are given for protective purposes only; often polishing can be omitted and a deposit of copper, chromium, cadmium, nickel, tin, or zinc given. Where a bright finish is desirable, it may be necessary to polish and plate. When brass or steel goods are required with a bright chromium finish, the various stages in the work cycle are:

Brass (vat plating)	Steel (vat plating)
Clean.	Clean.
Sand or emery bob, if needed.	Sand or emery bob, if needed.
Grease mop.	Grease mop.
Colour off.	Colour off.
Wire.	Wire.
Nickel plate.	Copper plate.
Unwire.	Nickel plate.
Polish.	Unwire.
Wire.	Polish.
Chrome plate.	Wire.
Unwire.	Chrome plate.
Polish, if needed.	Unwire.
	Polish, if needed.

In the above cycle for steel ware, it will be noticed that the article is given a deposit of copper on which is built the nickel and chrome deposits. For the normal run of work, experience has proved that there is less risk of stripping when a copper base coat has been deposited on the steel. It must not be assumed, however, that chromium cannot be deposited without this ground coat. It can, and is, on many types of tools and gauges.

Thickness of Plated Deposit.—The safe thickness for a deposit of nickel is about ·0015 in., otherwise the porosity of the coating is such that the base metal is ineffectively protected. When the deposit is porous, corrosion takes place, and the coating is lifted off the article. In order to give a good life to a zinc-plated article used outdoors, a deposit of, say, ·002–·003 in. thick is desired. If the price permits, the thicker the coating the better, up to, say, ·004 in. Zinc is anodic to iron and steel. (See B.S. 1224, S.A.E., or A.S.T.M. specification for thickness of electrodeposited coatings on steel or non-ferrous metal.)

Lead coating should be ·003–·004 in. thick so as to be free from pores when protection against corrosion is desired. As cadmium is anodic to iron and steel the coating may be thin and porous, yet give protection to the base metal; for this reason the deposit of cadmium is around ·0005–·00075 in. thick. On machined articles a thin protective coating of this type enables threads to be cut with the knowledge that after plating the work will pass the gauges. Bright chromium plating does not give any protection against corrosion as the deposit is too thin and porous; the protection is given by the undercoat, the chromium giving the hard, bright, untarnished finish.

Barrel Plating.

With small articles which do not readily bruise or deform, such as screws, metal pressings, and castings, a barrel-plated finish is given.

11. Lacquered Work.

Many articles are given a coat of lacquer to improve their sales value and prevent corrosion or tarnishing. A few of the points to watch when estimating for this type of work are:

Surface.—With all types of lacquered or japanned work, care must be taken to see that the surface is free from grease and dirt.

Method of Application.—The methods in general use for applying lacquer or japan are (*a*) spraying, (*b*) dipping, (*c*) brushing. Which to use will depend upon the plant available; the class of lacquer required; air drying or stoving; also the size and shape of the article.

Operation Schedule.—The operation schedule will include some or all of the following:

(*a*) Clean surface using spirits and a clean rag.
(*b*) Place mask on article.
(*c*) Place work on turntable.
(*d*) Pick up spray-gun.
(*e*) Spray component.
(*f*) Put down gun.
(*g*) Take work from turntable and remove mask.
(*h*) Place on drying-rack.
(*i*) Stove.
(*j*) Remove from stove.
(*k*) All incidental work such as cleaning and filling the gun, cleaning out the booth, &c.

Thickness of Film.—The thickness of the film of lacquer or japan varies from ·001 to, say, ·003 in., and depends upon the skill of the operator, the room temperature, and the class of lacquer used.

12. Welding.

Welding, that is, the jointing of two metal surfaces by fusion, features largely in engineering, and from this arises the need to estimate the production times for various jobs. Given thin material, as is used to produce domestic hollow-ware, the process can be carried out without the need for any filler metal; thick sections need the use of filler metal.

The process may be roughly divided into two groups, (*a*) gas welding, and (*b*) electric welding; the division being based upon the method adopted to bring the material to the desired temperature. Subdivisions within each grouping are omitted.

The data listed below are for the actual welding only, and do not cover the time required to prepare edges or assemble the parts in a fixture. Such items as these must be studied for each job with a full knowledge of the existing conditions. Moreover, the figures given are average, and may require adjustment to cover the varying operating skill of the personnel.

Times for Gas Welding.

Welding thin, mild-steel components, as found in domestic hollow-ware, with oxy-acetylene flame from high-pressure cylinders. Material around ·03 in. thick. Welding rate per hour, say, 30 feet.

TABLE 7.—OXY-WELDING MILD-STEEL PLATE. VERTICAL WELDING; SINGLE OPERATOR;[10] PLAIN BUTT JOINTS; EDGES NOT BEVELLED

Thickness of plate, in.	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{23}$	$\frac{3}{16}$
Length welded, ft./hour	15	12	10	8	7
Dia. of welding rod, in.	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{5}{64}$	$\frac{3}{32}$
Length of rod used (per ft. of weld), feet.	2·5	2·75	3·25		3·75

TABLE 8.—OXY-WELDING MILD-STEEL PLATE. TWO-OPERATOR VERTICAL WELDING;[10] PLAIN BUTT JOINTS; EDGES NOT BEVELLED

Plate thickness, in.	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$
Length welded, ft./hour.	12	10½	8½	7½	6	5½
Welding rod dia., in.	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{3}{16}$
Length of rod used (per ft. of weld), feet.	7½	6¼	5½	5	7¼	6¼

TABLE 9.—OXY-WELDING. ONE-OPERATOR RIGHTWARD WELDING; BUTT JOINTS; EDGES ON PLATES OVER $\frac{5}{16}$ IN., THICK BEVELLED AT A PREVIOUS STAGE

Plate thickness, in.	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1
Gas consumed/hr., c. ft.	22	30	35	40	55	68	82	100
Length welded, ft./hr.	13½	11	7½	6½	4¾	4	3	2
Welding rod dia., in.	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
Length of rod used (per ft. of weld), feet.	3½	3½	3½	5¼	4¾	6¾	9¾	16½

TABLE 10.—OXY-WELDING CAST IRON USING A FERRO-SILICON WELDING ROD

Thickness, in.		¼	½	¾	1	1¼	1½
Time per ft. run, min.		8	22	30	48	60	80
Gas consumed	Oxygen	3½	10	26	42	75	137
per ft. run, c. ft.	Acetylene	3½	11	28	45	85	145

Flame-cutting Mild-steel Plate.[10]

The oxy-acetylene flame is used for cutting steel plate during manufacture, erection, and dismantling a wide range of work. Given a straight run, the time required to flame-cut a given thickness of metal, excluding the preparatory work, may (failing the use of data prepared under actual operating conditions) be estimated on the following basis:

TABLE 11.—FLAME-CUTTING MILD-STEEL PLATE (SMOOTH SURFACE)

Thickness, in.	⅛	¼	⅜	½	¾	1	1½	2	2½	3	4
Cutting speed, ft./hr.	72	65	60	55	49	44	36	30	26	23	20
Gas used, c. ft./ft. run.											
Acetylene	14	16	18	20	22½	24	27	29	31	35	36
Oxygen	25	45	68	85	115	140	170	190	200	210	320

Spot-welding.[11]

Spot-welding is one of the cheapest methods of fastening two or more parts together. Table 12 gives the time and pressure required.

TABLE 12.—SPOT-WELDING PRESSURE, TIMES AND UNITS

Thickness of metal, in. (each part)	kW capacity	Pressure, lb.	Time for weld, sec.	Tip dia., in.	Units for 1000 welds
·018	4	60	·5	3/16	·6
·036	8	100	·8	3/16	1·0
·064	10	200	·9	3/16	1·5
·128	15	250	1·5	¼	4·5
·187	20	400	3·0	¼	12
·250	30	500	4·0	¼	20
·312	40	750	5·5	⅜	50
·375	50	1000	7·0	½	80

Projection-welding.

This process is simply a development of spot-welding, hence the time for an actual weld is the same. Due consideration must be given to the question of assembling the parts in the fixture, &c.

Butt-welding.

General details as required by an estimator for the electric butt-welding operations are:

TABLE 13.—ELECTRIC BUTT-WELDING OF MILD STEEL. TIME PER WELD

Diameter of bar, in., or equivalent cross-sectional area, sq. in.	Maximum power, kW	Time per weld, sec.	Units per 100 welds
·036	·75	·5	
·064	1·0	·75	
·125	1·5	1·0	·03
·25	5·0	3	·1
·5	8	7	1
1	12	20	12
1·5	35	35	60
2	60	45	125
2·5	90	60	140

Flash Butt-welding Mild Steel.

The figures below are on the basis of, say, round or square section; if there is a great difference between the length and width, then the data in Table 14 do not hold.

TABLE 14.—FLASH BUTT-WELDING MILD STEEL

Cross-sectional area, sq. in.	kVA required	Pressure, lb.	Units per 1000 welds approx.
½	25	800	7
¾	30	1750	20
1	60	3150	34
1½	125	7000	80
2	250	12,500	140
2½	300	25,000	200
3	350	35,000	350
4	500	60,000	550

Seam-welding.

Seam-welding is another development of the standard spot-welding process, and is used to make gas- and water-tight joints with a number of pressed sheet-metal articles. Assuming that the sheets are clean, then the welding speed varies from, say, 6 to 8 ft. per minute according to the shape and thickness.

13. Inspection.

In order to maintain an effective control upon the quality of the product it is essential that, as the articles proceed from one process to another, they are subjected to an independent check. Just how the labour charges associated with inspection may be dealt with when preparing an estimate, depends largely upon the class of goods produced and the works organization, the latter to include the scheme of costing. When the organization is such that a patrol inspector moves constantly from one machine to another, inspection costs must of necessity feature as an indirect charge. If, on the other hand, the article must be inspected at definite stages in the work cycle, these should be listed on the estimate, and so planned that the inspection reveals the defects before much work has been involved. Under these conditions it is quite possible that the inspection expenses may be regarded as a direct labour charge.

CHAPTER VII

Factors Governing Machining Speeds

1. Machining Allowances.

In practice it is the aim of the designer to arrange the size of castings and forgings so that the machine shops have to remove the minimum amount of metal consistent with the production of a component correct to size and having a satisfactory surface finish. The actual machining allowance must depend upon the chosen method of production, also the size and shape of the article. In all instances account must be taken of the necessary draft on a pattern, the surplus left by a feeder head, radii necessary to avoid localization of stress and to give an easy flow into the die cavity.

Forgings and Bar.—Ignoring the requirements special to any manufacturing process, it is necessary on hot-rolled steel bar and forgings to provide the following minimum allowances, so that the machining may remove the decarburized skin:

TABLE 15.—MACHINING ALLOWANCE ON STEEL BARS AND FORGINGS (minimum)

Dia., in.	Allowance, in.
Up to, say, 1.	$\frac{1}{32}$
Over 1 and up to 2.	$\frac{1}{16}$
Over 2 and up to 3.	$\frac{1}{8}$
Over 3 and up to $4\frac{1}{2}$.	$\frac{1}{4}$
Over $4\frac{1}{2}$.	$\frac{3}{8}$

The above figures are on the assumption that the bar or component runs true in the machine, and that the surface is even. Where irregularities exist, then it is necessary to increase the allowance.

Castings.—With sand-castings it is necessary to provide sufficient metal so that the tool will at all times, during the machining process, be under the surface. This prevents the cutting edge from being rubbed away by the hard skin and fused sand. The minimum amount on a small article is, say, ·05 in., but this must be increased to meet the known requirements of size and shape, along with the possibility of distortion. From a machining viewpoint it is a mistake to cut the allowance too fine. From a foundry viewpoint rapid changes in cross-section and large masses of metal are undesirable.

2. The Tool.[12]

The tool affects the cutting speed according to:

(*a*) The class of medium from which it is made.
(*b*) The shape of the cutting edge.
(*c*) The size of the cross-section.
(*d*) The time required between each resharpening.
(*e*) The finish given to the cutting edge and surfaces.
(*f*) The set-up—rigid with the minimum overhang, or poor with a considerable overhang.

3. Machine and Fixture.

The machine available has a great effect upon the cutting speed and chip area that may be used for any job. The main points are:

(*a*) Rigidity of the machine and fixture.
(*b*) The power input.
(*c*) The range of speeds and feeds available.
(*d*) The general condition of the machine.

4. Material to be Cut.

The cutting times are governed by the class of material to be machined and here the two main factors are:

(*a*) The class of material: soft or hard; aluminium or manganese steel.

(*b*) The condition of the material: annealed, hardened, or in a cold-worked state; clean or covered with scale; of uniform hardness or having a number of hard spots; cuts freely or clogs.

Hardness of Steel and Machining.—A careful study by many people over a number of years has shown that the tensile strength and the Brinell Hardness Number have a fairly definite relationship. Knowing the hardness number and class of steel, it is usually possible to form a good idea of the prospective machining speeds. In a general way this is recorded in the table:

TABLE 16.—GENERAL MACHINING CHARACTERISTICS OF STEEL UP TO 100 TONS/SQ. IN.

Tensile strength, tons/sq. in.	B.H. No., 10 mm. ball. 3000 kg.	Class of cutting media	
		High-speed steels	Carbide-tipped tools
30	130	Cuts easily at good speeds.	Cuts easily at high speeds.
40	185	,, ,, moderate speeds.	,, ,, ,,
50	230	,, at moderately low speeds.	,, around 200–300 f.p.m.
60	275	,, only at low speeds.	,, ,, 120–220 f.p.m.
70	322	,, ,, with great difficulty.	,, ,, 100–150 f.p.m.
80	367	Unmachinable.	,, ,, 75–100 f.p.m.
90	410	,,	,, ,, 60-80 f.p.m.
100	457	,,	,, ,, 40-60 f.p.m.

When attempting to relate the B.H.N. of any steel to its machining speed, close attention must be given to the composition of the material. It may contain specific elements which are deliberately introduced into the alloy to ensure certain characteristics. Thus high-speed machining bar has a high percentage of sulphur and manganese or an addition of lead. In the non-ferrous group, lead is added to brass bar to ensure free machining at high speeds.

With iron castings the B.H.N. must be related to both the composition and wall thickness. Thin castings require a high silicon content or a graphitizing medium to avoid the formation of " white iron ".

Then again due allowance must be given to the condition of the material as it is sent forward to the machine shop. The bar may be cold-worked by drawing or rolling; it may have been subjected to a heat treatment (*a*) to assist machining, as when annealed or normalized, (*b*) to give additional strength and hardness, as when hardened and tempered. In the latter condition the higher B.H.N. will require a lower machining speed.

5. Effects of Heat Treatment and Cold-work.

How the various classes of heat treatment affect the hardness of steel is shown in the following tables; they are listed here to emphasize the need to take into consideration the previous treatment of the metal when planning machining operations. The figures are representative only, and much depends upon the size of the component, as "mass" has a very important influence.

Table 17 shows the results when four classes of steel are permitted to cool down from hot-rolling, the effects of cold-drawing after the hot-rolling operations, hot-rolling followed by normalizing, and hot-rolling followed by annealing.

TABLE 17.—EFFECTS OF VARIOUS TREATMENTS OF STEEL ON B.H. NO.

Condition	·15 C free-cutting	·2 C free-cutting	·35 C	Nickel-chromium steel, Ni 1·75, Cr ·6
Hot-rolled and allowed to cool.	149	143	175	151
Cold-drawn.	160	165	200	201
Hot-rolled and normalized.	146	143	176	149
Hot-rolled and annealed.	139	135	163	137

The effects of cold-drawing steel to En 1 A can be seen from the following figures given in B.S. 971.[16]

TABLE 18.—EFFECTS OF COLD-DRAWING EN 1 A

Condition	Tensile strength, tons/sq. in.	Elongation, %
Hot-rolled bar.	28·1	31·5
Cold-drawn bar 11·0 per cent reduction.	33·5	16·0
,, ,, 19·9 ,, ,,	37·1	13·5
,, ,, 27·4 ,, ,,	40·0	11·5
,, ,, 34·8 ,, ,,	41·8	12·0

Large sizes are produced with a very small percentage reduction on diameter during the cold-drawing operation. Owing to the limitations on the hot-rolling process, the smaller diameter bars are, of necessity, subjected to a large percentage reduction during the cold-drawing stage. The result is a higher tensile strength and a greater hardness. The latter has the effect of reducing the cutting speed, see fig. 8.2, p. 105.

The low-carbon steels, if not cold-drawn, often machine better when heated above the critical point and then quenched. The steel in this condition does not clog on the tool nor tear so easily, hence a smoother surface is obtained. Similarly, cold-drawn material usually machines more freely than in the soft, annealed state; moreover, the stiffness created by the cold-working permits the metal to withstand the torsional stresses better. It should be noted, however, that material work-hardened by cold-drawing usually calls for a lower cutting speed.

The effects of hardening and tempering are shown in Table 19 for a 1-in. dia. bar. The progressive softening as the tempering heat is raised are clearly indicated.

TABLE 19.—EFFECTS OF TEMPERING HARDENED STEEL

·2 C steel			3½ Nickel-chromium steel		
Water quench at	860° C.	225 B.H.N.	Oil quench at	880° C.	512 B.H.N.
Temper at	150° C.	225	Temper at	200° C.	488
	200° C.	220		260° C.	465
	260° C.	217		315° C.	438
	315° C.	207		371° C.	405
Oil quench at	880° C.	160		426° C.	370
Temper at	150° C.	160		482° C.	335
	200° C.	159		537° C.	302
	260° C.	158		594° C.	269
	315° C.	155		650° C.	245

The effect of " mass ", that is, the cross-section, upon the effectiveness of any quench is given in Table 20, which covers a ·35–·4 C steel and a 3½ nickel-chromium steel. The more uniform effects of the alloy steel should be noted.

TABLE 20.—EFFECT OF MASS ON B.H.N. WHEN HEAT-TREATING STEEL

Temper at	Position	·35–·4 C steel bar, dia., in.					3½ Nickel-steel bar, dia. in.				
		½	1	2	4	6	½	1	2	4	6
426° C.	O/S.	331	331	321	302	293	375	375	363	341	321
	½ rad.	331	331	285	269	241	375	375	341	302	285
	Centre.	331	311	269	262	241	375	375	321	293	285
650° C.	O/S.	229	229	229	217	212	248	248	248	241	235
	½ rad.	229	229	223	201	197	248	248	241	223	223
	Centre.	229	223	217	201	197	248	248	229	223	223

When the material is annealed or normalized the hardness is more uniform throughout the mass, the effects of any cold-drawing or previous heat treatment being destroyed.

It must be realized that annealing or normalizing does not always place the material in the best condition for a given machining operation. In some instances it is better to heat well below the temperature for quenching so that a spheroidized structure is produced; in other cases heating just under the quenching temperature and slowly cooling enables a clean smooth cut to be taken. Generally, the plain-carbon and the low-alloy tool steels machine better after normalizing. The higher-alloy steels, some of which may be air-hardening, call for a much slower rate of cooling than is possible with the normalizing process; the rate should be adjusted to suit the machining operation, i.e. turning, shaping, milling, broaching, &c. The graphs (figs. 7.1,

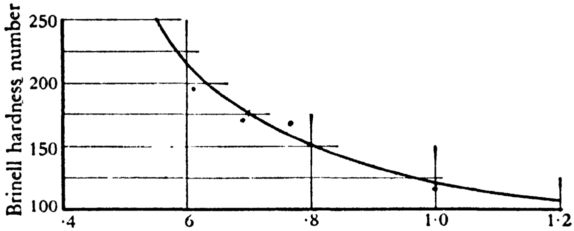


Fig. 7.1.—Machining factor *M* for carbon steel. Hot-rolled or normalized (not free-cutting)

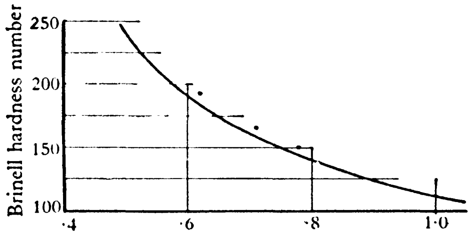


Fig. 7.2.—Machining factor *M* for cold-drawn carbon steel (not free-cutting)

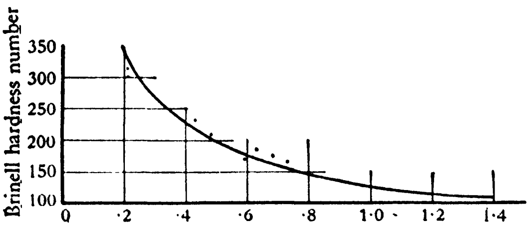


Fig. 7.3.—Machining factor *M* for H.T. carbon steel

7.2, 7.3) show the general tendency of changes in plain-carbon steels due to (*a*) composition, (*b*) cold-working, and (*c*) heat treatment, to influence the hardness and hence the speed at which the material can be machined for a given tool-life.

When machining some of the alloy steels the question of work-hardening during the actual machining process must be carefully watched. Fortunately, with the free-cutting and other carbon steels, the tendency to work-harden is very slight.

6. The Microstructure.

When metal is hard and difficult to machine it is the usual practice to recommend an annealing operation so as to improve the machining characteristics of the material. Such a bald statement needs qualifying in that the machinability of any steel will depend upon its microstructure, and this in turn is affected by cold-work, heat and the rate of cooling. Ignoring the former which is touched upon elsewhere, it may be said that the structure of steel, after an annealing process, depends upon four factors:

(*a*) the temperature to which the work is raised;
(*b*) the period it is held within the prescribed temperature range;
(*c*) the subsequent rate of cooling; and
(*d*) the composition of the material.

With the plain-carbon grades of steel the treatments are roughly on the following basis:

The low-carbon steels (carbon not exceeding ·3 per cent) usually machine best when normalized.

For the medium-carbon steels (carbon lying between ·3 and ·6 per cent) a critical anneal, followed by a soaking period sufficient to ensure uniformity, and furnace cooling will suffice. Note that a "critical anneal" implies heating just beyond the critical or transformation zone.

With the steels coming within the grouping of high-carbon (i.e. carbon over, say, ·6 per cent), then a spheroidizing anneal is necessary to ensure satisfactory machining. In a number of cases the best condition of the material for machining is when the steel has been hardened and tempered to give a sorbitic structure. A general idea of the desired microstructure for a number of machining processes is as follows:

Material	Treatment	Structure	Machining process and condition			
			Turn	Form	Drill	Broach
Low-carbon steel, carbon up to ·3.	Normalize.	Blocky ferrite.	Good.	Good.	Good.	Good.
Medium-carbon steel, carbon ·3 to ·6.	Low-temperature anneal.	Spheroidized.	Good.	Poor.	Fair.	Poor.
Ditto.	Critical anneal.	Lamellar.	Fair.	Good.	Good.	Good.
Ditto.	Harden and temper.	Sorbitic.	Fair.	Fair.	Fair.	Fair.
High-carbon steel, carbon ·6 and over.	Low-temperature anneal.	Spheroidized.	Good.	Good.	Good.	Fair.
Ditto.	Critical anneal.	Lamellar.	Fair.	Poor.	Poor.	Poor.
Ditto.	Harden and temper.	Sorbitic.	Good.	Fair.	Good.	Good.

When large-scale machining operations are to be carried out the economic importance of the correct heat treatment for each machining operation cannot be overestimated, for it results in reduced machining times, a better surface finish, a lower scrap percentage, a higher machine-hour efficiency, and longer tool-life.

7. The Component.

The shape and size of the component will have a marked influence upon the cutting times because of:

(*a*) The manner in which the component can be held.
(*b*) The need to release internal stresses.
(*c*) Its rigidity or fragility.
(*d*) The amount of machining required.
(*e*) The dimensional accuracy and surface finish required.

8. Tool-life.

The relationship between tool-life and cutting speed was first given by F. W. Taylor[13] in his paper to the A.S.M.E. in 1907, " On the Art of Metal Cutting". The expression he gave for steel is

$$VT^n = C.$$

V = cutting speed, f.p.m. T = tool-life in minutes. C = tool-life for 1 minute. $n = \frac{1}{8}$.

Other experimenters, including the L.T.R.C., have confirmed the general expression, although some give a different value to n which varies, according to the material and type of cut, from one experimenter to another from $\frac{1}{5}$ to $\frac{1}{10}$. The L.T.R.C.[2] give the same value as Taylor. For cast iron, C. Barth, one of Taylor's colleagues, gives n as $\frac{1}{12}$.

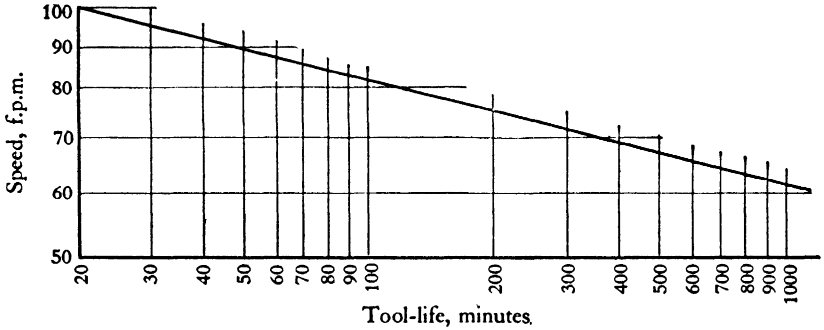


Fig. 7.4.—Relationship between cutting speed and tool-life for a given cut ($VT^{\frac{1}{8}}$ = constant)

(Logarithmic scales)

The question of tool-life is one that must be adjusted to suit the machining conditions. For a simple set-up on a centre lathe or boring machine the most economical time (Taylor)[13] is from 1 to 1½ hours; if the h.s.s. tool needs regrinding in less than an hour, the cost of forging and maintenance is excessive; if it exceeds 1½ hours, it is not removing the metal with sufficient rapidity. When the set-ups are more complicated, as with automatics, multi-tool, and capstan lathes, then the actual cutting-time between each resharpening varies from, say, 4 to 10 hours. To give this, the cutting speed for a given chip size must be reduced; the graph (fig. 7.4) and Table 21 indicate how this should be done to give various times between each resharpening, providing that the tool retains its initial hardness.

TABLE 21.—SPEED FACTORS FOR VARIOUS TOOL-LIVES (T_l), A.S.M.E.,[15] FOR A GIVEN CUT, FEED AND DEPTH OF CUT REMAINING CONSTANT

Tool-life, min.	Carbon steel tools			H.S. steel tools						Stellite " J "			Cemented carbides		
	All cuts on cast iron	Cutting steel		All cuts on cast iron	Cutting steel		Cutting bronzes		Rough cuts on brass	All cuts on cast iron	Cutting steel		All cuts on cast iron	Cutting steel	
		Rough cuts	Form, finish turn, part off		Rough cuts	Form, finish turn, part off	Rough cuts	Form, finish turn, part off			Rough cuts	Form, finish turn, part off		Rough cuts	Form, finish turn, part off
15	1·11	1·32	1·11	1·15	1·19	1·15	1·34	1·26	1·26	1·22	1·29	1·22	1·20	1·25	1·20
30	1·05	1·15	1·05	1·07	1·09	1·07	1·16	1·12	1·12	1·11	1·13	1·11	1·09	1·12	1·09
45	1·02	1·06	1·02	1·03	1·04	1·03	1·06	1·05	1·05	1·04	1·05	1·04	1·04	1·05	1·04
60	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
90	·98	·92	·98	·96	·95	·96	·94	·92	·92	·94	·93	·94	·95	·94	·95
120	·95	·87	·95	·93	·92	·93	·88	·89	·89	·91	·88	·91	·91	·90	·91
180	·92	·80	·92	·89	·87	·89	·79	·83	·83	·86	·82	·86	·87	·84	·87
240	·90	·76	·90	·87	·84	·87	·75	·79	·79	·82	·78	·82	·84	·80	·84
300	·89	·72	·89	·85	·82	·85	·71	·77	·77	·79	·75	·79	·81	·77	·81
360	·87	·70	·87	·84	·80	·84	·69	·74	·74	·77	·72	·77	·79	·75	·79
480	·86	·66	·86	·81	·77	·81	·65	·71	·71	·74	·69	·74	·76	·72	·76
600	·85	·63	·85	·79	·76	·79	·62	·67	·67	·70	·67	·70	·74	·69	·74
720	·83	·61	·83	·77	·74	·77	·60	·65	·65	·67	·64	·67	·72	·67	·72
840	·82	·59	·82	·76	·72	·76	·57	·62	·62	·65	·62	·65	·70	·65	·70
960	·81	·57	·81	·75	·70	·75	·55	·60	·60	·63	·60	·63	·68	·63	·68

9. Depth of Cut and Feed.

The durability of a single-point cutting-tool is improved as the ratio of the depth of cut to the feed is increased, with the cross-sectional area of the chip remaining constant. This is due to a variety of factors, such as:

(*a*) The spreading of the chip along the cutting edge reduces the intensity of pressure.

(*b*) There is more metal immediately beneath the chip to absorb the heat generated; hence the risk of tool failure by local softening is greatly removed.

(*c*) With a thinner chip the temperature at the pressure zone is lower; hence the possibility of the tool failing to hold its "red-hardness" is less.

(*d*) A thinner chip gives rise to less frictional heat as it flows across the face.

(*e*) A thinner chip with its greater surface area permits a more rapid dissipation of the heat by the coolant and the atmosphere.

Experiments by the L.T.R.C. prove that the cutting speed is lowest when the ratio of the depth of cut to the feed is unity; as the ratio becomes greater the speed increases. This also holds when the feed is greater than the depth of cut, but as such machining conditions, except for finishing, lie outside normal machining practice, they are ignored. For rough machining on a centre-lathe, the ratio of the depth of cut to the feed is around, say, 4 : 1 up to 20 : 1, with a mean of, say, 8 : 1. On automatic and capstan lathes, the ratio of the depth of cut to the feed may go as high as 200 : 1; then the question of " chatter " must be watched.

Note that the depth of cut is the maximum distance measuring at right angles to the machined surface; the feed is the distance the tool travels whilst the work makes one revolution: chip thickness is measured normal to the cutting edge.

10. Chip Dimensions and Reaction on Speed.

As mentioned above, each alteration in the depth and feed ratio of a cut calls for a modification to the cutting speed if the tool-life is to remain

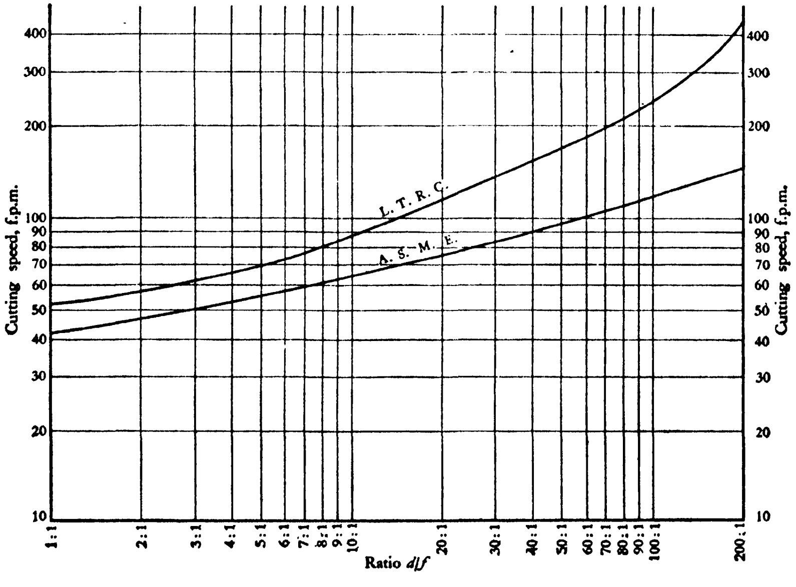


Fig. 7.5.—Relationship between cutting speed and d/f
(Chip area = 0·01 sq. in. Material 0·3 C steel)

constant. The higher the ratio the greater the cutting speed, or, for the same cutting speed, a longer tool-life is obtained. This is exemplified by the normal practice followed on automatics. To cover such variations the L.T.R.C.[2] give the expression:

$$V = 11{\cdot}5 + \frac{2{\cdot}07}{f} + \frac{1{\cdot}6}{d} + \frac{{\cdot}042}{fd},$$

when cutting ·39 carbon steel of 176 Brinell with a tool-life of 20 minutes.

Taking as an example a chip having an area of ·01 sq. in., the computed speed for various ratios of depth of cut to feed from 1 : 1 up to 200 : 1 are given in fig. 7.5. For practical use the speeds seem a little too high even when the tool-life of 20 minutes is taken into account.

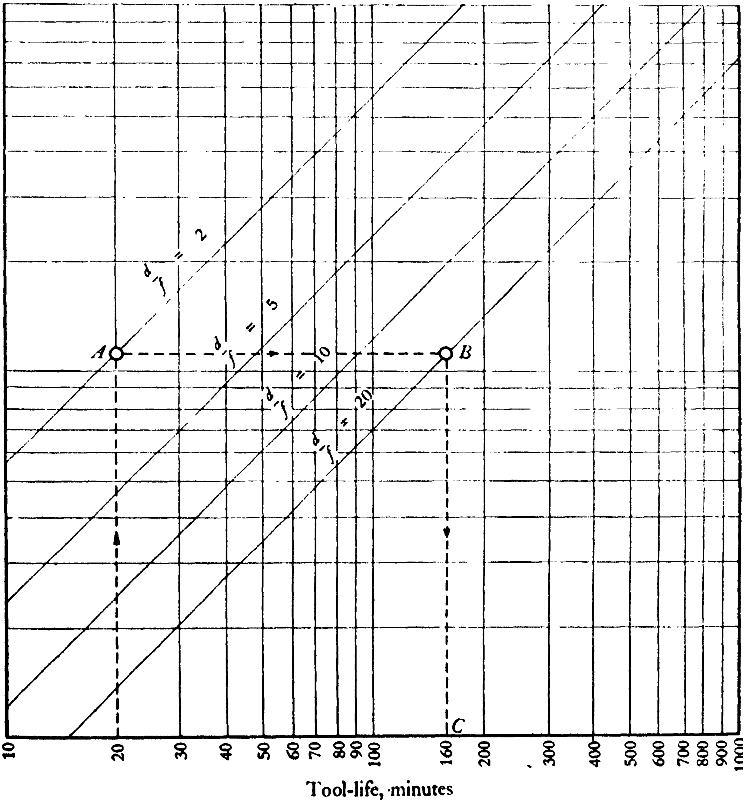


Fig. 7.6.—Variation of tool-life with *d*/*f* ratio for constant chip area

This is particularly so when the speeds given by A.S.M.E.[15] are examined. Fig. 7.5 also gives for comparison the approximate A.S.M.E. suggestions.

Efforts have been made by various people to relate the chip dimensions to the tool-life. The difficulty here is that a cut may give the same ratio but yet have vastly different dimensions. For the normal run of ratios up to, say, 20 : 1 Kronenberg[14] gives the chart shown in fig. 7.6.

Example.—If a cut is made with a *d/f* ratio of 2 : 1, give the tool-life on a change being made to a 20 : 1 ratio, the chip area remaining constant, and the tool-life in the first instance being 20 minutes. Trace up the vertical reference line for 20 minutes until it cuts the sloping line for the required ratio A on the graph; move along horizontally until the line for the new ratio is reached, point B on the graph; drop vertically to reach the X axis at C. Read off the value in minutes, in this instance 160 minutes.

11. Measurement of Cutting Speed.

The cutting speed on cylindrical work is assumed to be measured on the component before a reduction in diameter is made, i.e. the maximum linear speed of the work making contact with the cutting edge is taken.

12. Machining Relationship of Various Metals.

Owing to changes brought about in the structure of a metal by cold-working, heat treatment, varying the proportions of the constituents, or the small addition of a fresh one, it becomes of increasing importance to be able to relate the cutting speed of one metal to that of another. The first difficulty arises in choosing the datum. In this direction the most difficult machining steel—manganese steel—has been chosen by the A.S.M.E.[15] as unity, and the relative values of the other metals have been based upon this. The *M* factor in the various tables give some indication of the relationship for machining a number of the different materials used in engineering construction on the basis ·2 C En 2 C = 1; free-cutting brass = 3·18, aluminium bar = 4. It should, however, be understood that there may be a fair margin of error due to variations in the composition of the metal, treatment, size of the component, &c.

13. Effect of Rake.

The L.T.R.C.[2] Report, 1922, shows that the effects of the rake angle upon the cutting speed is small when using an h.s.s. tool having a rake within the normal range of 15–20°. Roughing with a cut $\frac{3}{8}$ in. deep and $\frac{1}{32}$ in. feed has the maximum speed with a rake of 20°. The speed for the same tool-life quickly falls away as the rake is pushed up to 40°; on the other hand, if the rake angle is decreased, thus giving a stronger tool-section, a small fall in speed is encountered. Light, finishing cuts have the maximum speed with a smaller rake of 15–10°. With a larger rake-angle a considerable decrease in speed is necessary for the same tool-life; given a smaller rake, hence a stronger tool, the decrease in speed is less, being but a few per cent. This is shown in Table 22, taken from the curves given in the L.T.R.C.[2] Report, 1922.

TABLE 22.—EFFECT OF RAKE ON TOOL-LIFE (C_r)

Rake angle, degrees	Dimensions of cut, in.		Conditions
	Depth, in. ·0117 Feed, in. ·100	Depth ·375 Feed ·031	
	Value of rake index C_r		
0	1·00	·89	Material, steel ·5% C and B.H.N. 214.
5	1·00	·90	
10	1·00	·93	
15	·96	1·00	
20	·93	·95	Tool, 30° approach angle, and $\frac{1}{4}$ in. nose-radius.
25	·84	·82	
30	·77	·75	
35	·70	·66	
40	·63	·59	

The experiments tend to show that, with material of increased hardness, a slight decrease in the rake angle permits a higher cutting-speed.

The general run of clearance and rake angles on single-point tools is given in Table 23; it excludes negative-rake turning with the cemented-carbide tools.

TABLE 23.—ANGLES ON LATHE TOOLS [12]

Material cutting	High-speed steel and stellite			Carbide-tipped tools	
	Clearance	Top rake	Side rake (if required)	Clearance	True rake
	deg.	deg.	deg.	deg.	deg.
Mild steel, 22/28 tons.	10	15	15	5	8
Carbon steel, 28/35 tons.	10	12	12	5	8
Carbon steel, 35/45 tons.	8	10	10	5	3
Carbon steel, 45/55 tons.	8	8	8	5	0
Steels over 55 tons.	5	5	5	4	0
12% manganese steel.	5	3	5	4	0
Cast iron and alloys.	8	8	14	5	3
Malleable iron.					
Wrought iron.					
Chilled iron.	3	0	0	2	0
10% nickel iron.	3	3	0	3	0 to 3 negative
Pearlitic iron.					
High silicon iron.					
Aluminium.	10	40*	10	6	20
Aluminium alloys.	10	30*	10	6	13
Brass, soft.	8	10	10	6	3
Brass, hard.	6	5	0	5	0
Bronze, soft.	6	10	10	6	3
Bronze, hard.	6	5	0	5	0
Copper.	8	20	10	6	13
Zinc base alloys.					
Gun metal.	6	5	0	5	0
Monel metal.	6	10	10	6	8

* Approximate maximum for Stellite is 20°

14. Effect of the Cutting-edge Contour.

The results of all experiments indicate that the highest cutting-speed is achieved, for a given chip cross-sectional area, when the length of the cutting edge making contact with the component is at its maximum. In other words, the thinner the chip, the higher the cutting speed. However, a thin chip and a high speed does not always ensure the highest output per hour and, for this reason, it is necessary to fix the chip dimensions and the cutting speed so that each combination removes the surplus material in the shortest time.

Given a long, thin chip, " chatter " at the cutting edge must be considered. It is not experienced to any marked extent when the ratio of the depth of cut to the feed is less than, say, 15 : 1; on a machine in good condition this figure may go up to 20 : 1 or 25 : 1. Over the latter ratio " chatter " is to be expected, except on exceedingly good machines, or when running at very low speeds; the amount of chatter will, of course, depend upon the design and condition of the equipment and set-up.

The L.T.R.C. Report, 1922,[2] indicates that the cutting speed can be increased for changes in the approach angle, providing that the cut is of sufficient depth in relation to the nose-radius. The increase suggested by the Report and that for intermediate values is listed in Table 24.

TABLE 24.—SPEED INCREASES FOR VARIOUS APPROACH ANGLES

Approach angle, degrees	L.T.R.C. suggestions	Suggestions for intermediate angles	T_3
0	1·00		·83
10		1·07	·88
20		1·15	·95
30	1·21		1·0
40		1·33	1·1
45	1·48		1·22
50		1·60	1·32
60	1·87		1·54

Experiments were taken with a tool having a ⅛-in. nose-radius; the increase in speed is due to the formation of a thinner chip measuring normal to the cutting edge.

Whilst changes in the contour of the cutting edge gives speed increases up to, say, 90 per cent, it should be realized that alterations in the chip dimensions, thickness and length, for a known cross-sectional area have even greater influence. This is best seen by means of Table 24A, bearing in mind that the chip thickness is measured normal to the cutting edge.

TABLE 24A.—SHOWING THE INCREASE IN SPEED FOR VARYING VALUES OF d/f FOR CONSTANT AREA (see Table 38, p. 109)

Area	Ratio d/f	Chip size, in.		Cutting speed f.p.m.	% Increase
		T	L		
·002 sq. in.	500 to 1	·002	1·000	424	385
	125 to 1	·004	·500	275	250
	31 to 1	·008	·250	185	168
	8 to 1	·0156	·125	135	123
	2 to 1	·032	·062	110	100

The above figures show that by simply altering the chip dimensions a speed increase of nearly 400% can be achieved for the same tool-life. Hence, when conditions do not permit the use of a tool having the shape given in Tables 30–59, &c., there are two alternatives: (*a*) When the nose-radius is, say, twice the depth of the cut, take the speed increase on the basis of a tool having a 60° approach angle. (*b*) Compute the speed using the A.S.M.E. expression ^{15} as given on p. 101.

In practice the approach angle of a roughing tool is around 20°, as at this point the danger of " chatter " is small. As the approach angle increases, thus presenting a longer cutting-edge to the work, the tendency for " chatter " grows. Hence, in all conditions, the need to adjust the tool profile to suit the job in hand arises.

When roughing with h.s.s. tools the nose-radius should, where possible, be around 4–6 times the feed. If the tool has no nose-radius, it must run at a slower speed for a given depth of cut, feed and tool-life than when a nose-radius is provided. And, as indicated above, the larger the nose-radius in relation to the depth of cut, the higher the speed providing " chatter " does not arise. If, on large work, a tool having no nose-radius is used, the difference in f.p.m. between the extremities of the cutting edge making contact with the article is comparatively small, hence the sharp nose quickly fails. On small-diameter work, the difference in the cutting speed between the extremities of the tool is much greater, hence the tool-life is more satisfactory.

For example, take two components, the outside diameters of which are 9 in. and 1 in. respectively. A cut with a knee tool having no nose-radius is taken to a depth of ¼ in. at a speed of 100 f.p.m. Using the chart in fig. 2.7, p. 23, then:

9-in. dia. cutting at 100 f.p.m. makes, say, 40 r.p.m.
8½-in. dia. cutting at, say, 40 r.p.m. makes, say, 90 f.p.m.
1-in. dia. cutting at 100 f.p.m. makes, say, 380 r.p.m.
½-in. dia. cutting at 360 r.p.m. makes, say, 48 f.p.m.

Now the reduction in cutting speed on the large component is, say, 10 per cent, which cannot affect either the tool-life or cutting speed to any marked extent, but that on the small article is 52 per cent, a tremendous difference. It is, perhaps, worth pointing out that this great difference in cutting speed, when using a tangential or knife tool on small-diameter bar work on the capstan, turret, or automatic lathe, ensures an excellent tool-life. On large-diameter work such tools cannot in the nature of things give such satisfactory results.

When long slender jobs have to be machined the question of nose-radius and approach angle are important. Both should be as small as convenient, so as to restrict the force tending to push the work off the tool and to avoid any tendency to chatter.

If using the cemented, tipped tools, the nose-radius should be as small as convenient, in order to remove any tendency to chatter; this causes the edge to flake and thus ruins the tool.[12]

The results of carefully taken experiments [2] indicate that for a nose-radius above $\frac{1}{8}$ in. the appropriate cutting-speed has a minimum value when the radius is equal to the depth of cut. A radius greater than the depth of cut permits a greater cutting-speed for a given feed and tool-life. This is due to the longer but thinner chip. For economical roughing [12] it seems desirable to choose the better of the two following conditions: (*a*) Have a nose-radius greater than twice the depth of cut. (*b*) Choose a nose-radius equal to, say, 4 to 6 times the feed, and have the remainder of the cutting-edge straight. Such a profile avoids chip distortion and crowding, hence gives the tool greater durability. By combining a suitable approach-angle with a nose-radius of sufficient size, a tool having a economical life can be designed.

15. Value of a Lubricant.

When machining, the use of a lubricant keeps the cutting edge and work cool and enables a higher speed to be used for a stated tool-life. F. W. Taylor [13] proved many years ago that when roughing with an h.s.s. tool an increase of around 50 per cent was possible. When finish-turning, the increase [15] is not so great, being around 16 per cent, the lower figure being due to the fact that abrasion is the dominant factor in the failure of the edge which must maintain size. On the other hand, the combined effect of red-hardness and resistance to abrasion, giving rise to cratering, governs the failure of a tool used for roughing. Where the cutting speed is not increased, the use of a lubricant gives a longer tool-life. Numerical values of the longer tool-life can be taken from a graph based upon $VT^n = C$, when the values of n, V and T for a given job are known or computed as in the examples below. For various combinations of the depth of cut and feed encountered in everyday use, the following data give the general increase in speed when machining steel, assuming that the supply is adequate.

TABLE 25.—VALUE OF THE CONSTANT L_u FOR CUTTING WITH A SUITABLE LUBRICANT

Type of tool	Depth of cut, in.	Value of L_u				
		Feed (in.)				
		Up to ·008	·008-·0156	·0156-·031	·031-·062	·062-·125
Knife tool, no nose-radius, no approach angle.	$\frac{1}{32}$	All 1·16 when tool fails by abrasion as on light finishing or forming cuts.	1·23	1·35	1·34	1·34
	$\frac{1}{16}$			1·37	1·50	1·50
	$\frac{1}{8}$				1·51	1·67
	$\frac{1}{4}$				1·51	1·68
	$\frac{3}{8}$				1·51	1·68
	$\frac{1}{2}$				1·51	1·68
	$\frac{3}{4}$				1·51	1·68
	1				1·51	1·68
Knife tool $\frac{1}{16}$ in., nose-radius, no approach angle.	$\frac{1}{32}$		1·16	1·18	1·25	1·29
	$\frac{1}{16}$		1·18	1·24	1·34	1·41
	$\frac{1}{8}$		1·18	1·29	1·41	1·51
	$\frac{1}{4}$		1·20	1·32	1·45	1·58
	$\frac{3}{8}$		1·21	1·34	1·47	1·61
	$\frac{1}{2}$		1·21	1·34	1·48	1·62
	$\frac{3}{4}$		1·22	1·35	1·50	1·64
	1		1·22	1·36	1·50	1·65
Tool with $\frac{1}{8}$-in. nose-radius, 30° approach angle.	$\frac{1}{32}$		1·16	1·18	1·21	1·26
	$\frac{1}{16}$		1·16	1·20	1·31	1·38
	$\frac{1}{8}$		1·18	1·26	1·38	1·48
	$\frac{1}{4}$		1·18	1·29	1·42	1·55
	$\frac{3}{8}$		1·18	1·30	1·44	1·58
	$\frac{1}{2}$		1·18	1·31	1·45	1·59
	$\frac{3}{4}$		1·19	1·32	1·46	1·61
	1		1·19	1·32	1·47	1·62
Tool with $\frac{1}{4}$-in. nose-radius, 30° approach angle.	$\frac{1}{32}$		1·16	1·16	1·19	1·26
	$\frac{1}{16}$		1·16	1·18	1·24	1·33
	$\frac{1}{8}$		1·16	1·21	1·33	1·45
	$\frac{1}{4}$		1·16	1·26	1·40	1·53
	$\frac{3}{8}$		1·18	1·28	1·42	1·56
	$\frac{1}{2}$		1·18	1·30	1·43	1·58
	$\frac{3}{4}$		1·18	1·31	1·45	1·60
	1		1·19	1·32	1·46	1·61

If intermediate values are necessary, these may be obtained by constructing a graph or they may be computed using the expression

$$L_u = 2{\cdot}2T^{0{\cdot}15}$$

for cuts greater than ·015 in.

The general recommendation as to the volume of cutting lubricant to be used is 5 gallons per minute for the light finishing cuts, and 8 to 10 gallons per minute for heavy roughing cuts. When several tools are working simultaneously on a component, the above figures may need adjustment to ensure each tool is flooded.

Example.—A roughing cut is taken on a steel component using an h.s.s. knife-tool, nose-radius $\frac{1}{16}$ in., with a speed of 75 f.p.m., cut $\frac{1}{4}$ in. deep, and feed ·016 in. The tool-life is known to be 60 min. Operating conditions are changed so that an adequate flow of lubricant can now be used. Give (*a*) the new speed for a run of one hour, and (*b*) the new tool-life if the speed remains unaltered.

Increase in speed for a feed of ·016 in. (Table 25) is 20 per cent.

$\therefore$ New speed for a one-hour run = 75 × 1·2 = 90 f.p.m.

Now with the new speed of 90 f.p.m. a reduction to 75 f.p.m. gives a factor of 75/90, say ·83. Using Table 21, p. 85, the new tool-life becomes, say, 240 min.

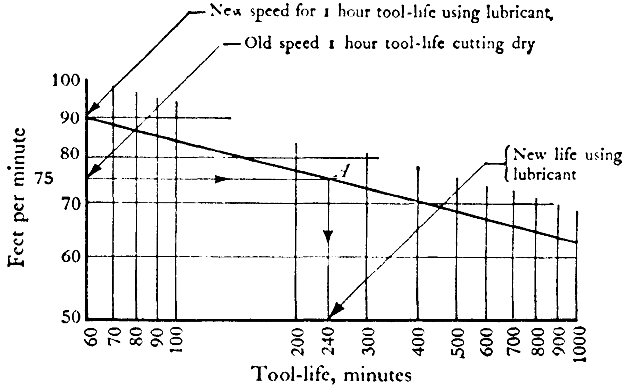


Fig. 7.7.—Tool-life for different speeds using a coolant

Alternatively, use may be made of the graph in fig. 7.7, which gives the tool-life starting at 90 f.p.m. for an hour's duration. The graph is based upon

$$VT^{\frac{1}{8}} = C_t.$$

Here V = 90, whilst T is taken at 60 and 200 respectively.

Now $60^{\frac{1}{8}}$ = say, 1·67.

$200^{\frac{1}{8}}$ = say, 1·942.

Then 90 × 1·67 = say, 150,

and $V \times 200^{\frac{1}{8}} = 150$.

Hence V = say, 77·2, the position on the graph for 200 min. Knowing that the graph, using bilogarithmic scales, is a straight line, it is drawn through the two points: 90 for a 60-min. tool-life and 77·2 for the 200-min. life.

With the graph constructed, a line parallel to the base is drawn from the old tool-life of 75 min. to cut the curve at the point A. Dropping from here a perpendicular to cut the base, a tool-life of 240 min. is given, and agrees with that obtained using Table 21.

This example emphasizes the importance of using a lubricant, but before any decision can be made whether to push up the speed, or work on the longer tool-life, the economics of the particular case must be analysed.

16. Effect of Cutting Media.

Another important factor influencing the cutting speed is the class of material used to make the cutting tool. With the developments in metallurgical science, there are a number of alloy cutting steels available for machining purposes. Taking the 18 . 4 . 1 h.s.s. as unity, the following table[15] gives the approximate relative values:

Table 26.—Approximate Relative Values of various Cutting Material, T_m

Carbon and Low-alloy Steel.	
Roughing	·2–·3
Finishing	·3
High-speed Steels.	
18 . 4 . 1	1·0
14 . 4 . 2	1·0
18 . 4 . 2	1·03
18 . 4 . 3	1·06
18 . 4 . 1 + 4% Co	1·07
18 . 4 . 2 + 4% Co	1·07
18 . 4 . 1 + 8% Co	1·11
18 . 4 . 1 + 12% Co	1·12
Mo W Co type	1·07
20 . 4 . 2 + 12% Co	1·2
Stellite.	
Stellite No. 3	1·6
Stellite J	2·0–3·0
Cemented carbides.	
Tungsten carbide on steel	2·5–3·0
Tungsten carbide cutting cast iron	3·0–4·0
Tantalum or titanium carbide cutting steel	3–6·0

It is necessary to realize that the above figures are suggestions only, particularly when a change is to be made from, say, h.s.s. to a carbide-tipped tool, as the speeds available and the rigidity of the machine will have a marked effect on the success or otherwise of any change. Unless ample power, high speeds, a wide range of feeds, and freedom from vibration are present, it is useless to expect the best output from tools of cemented carbide.

17. Hardening and Tempering Effects.

The class of steel and the effectiveness with which it is hardened and tempered have a great influence upon the cutting speed and the tool-life.

Plain-carbon steel of a comparatively small cross-section—say, $1\frac{1}{4}$ in. sq.—will, upon hardening and tempering, show signs of a definite, hard case with a softer, but tougher core. Whilst the latter enhances the impact value of the material, the efficiency of the tool as a cutting medium is reduced where constant regrinding removes the hard case.

The low-alloy steels have very similar properties to the plain-carbon type and, whilst the cutting speeds lie within the same range, there is a tendency for the alloy steels to take a keener edge, and maintain it on finishing cuts for a longer period.

The addition of tungsten, chromium, molybdenum, cobalt and vanadium in varying amounts, form what are known as the high-speed steels (h.s.s.); the alloying elements give the material a very fine structure which hardens throughout the mass. From a cutting viewpoint this is all to the good, but it must be realized that, with the material in this condition, the impact value is somewhat lower. Such tools require careful setting and, when clamped, must not be subject to any bending strains, as happens if the base is not perfectly clean. When, as is usual with large, solid tools, the cutting edge alone is hardened, the material has a better resistance to such strains, and possesses some degree of elasticity, so that the cutting edge, under normal operations, does not chip. However, with the large tools it is more difficult to obtain the same degree of hardness as is readily achieved on a smaller cross-section. This is owing to the " mass effect ". The heat locked up within the tool has a tempering action, and because of size the cutting edge cannot be cooled with sufficient rapidity.

When grinding h.s.s. tools, care should be taken to ensure that the soft decarburized case is removed. Moreover, attention must be given to the temperature at which each tool is quenched and tempered. Unless both operations are carried out at the correct temperatures, the cutting efficiency will be considerably reduced.

18. Various Operations.

The cutting speed also depends upon the class of operation to be performed. The reduction in speed is made, after due allowance has been provided for the thinness of the chip, so as to avoid shock to the cutting edge; make provision against wear; ensure a satisfactory life to the tool; and give accuracy to the component. These remarks cover such operations as finish-turning, parting off, forming, drilling, reaming, screwing, form-milling. Table 27 gives an approximate ratio for a number of the machining operations encountered in practice.[15]

TABLE 27.—APPROXIMATE RATIO OF CUTTING SPEEDS FOR DIFFERENT OPERATIONS

Turning, rough	1·00
Turning, finish	·90
Parting off	·67
Forming, little or no rake and a high-class finish	·50–·20
Forming with, say, 15° rake and a fair finish	·90–·50
Drilling	·80
Milling, cylindrical	1·00–·5
Milling, face	1·00–·5
Milling, form, as when gear cutting or hobbing	·20
Reaming	·25
Tapping, using hand taps	·25–·1
Tapping, using nut taps	·40–·25
Screw cutting	·20–·1
Screwing with a die head	·20–·1

It will be appreciated that on such operations as finish-turning, reaming, form-turning, form-milling, tapping, and screwing, the resistance offered against abrasion is of greater importance than the red-hardness value of the different cutting media. Thus Tables 30–59, 78–105, 107–120, 123–132 include data for such operations as forming and parting off.

19. Various Combinations.

When machining, the object is to remove the metal quickly and yet produce a surface finish suitable for the particular function. In practice the two extreme combinations are:

(*a*) A slow speed, a deep cut, and the heaviest possible feed.

(*b*) A high speed, shallow depth of cut, and fine feed.

The former is chosen when roughing steel and cast iron with h.s.s. tools; the latter using tipped, cemented, carbide tools. The super h.s.s. tools show up well when machining hard material using the combination in (*a*) above, but do not give such good results on softer metal. In every instance the depth of cut/feed ratio will depend upon the rigidity of the machine and set-up, the amount of metal to remove, the number of cuts to be taken, the surface finish required, the rigidity and condition of the article as received in the machine shop. Thus, when roughing castings and forgings which have a heavy scale, the aim is to choose a heavy feed so that the scale is broken up well in advance of the cutting edge, as this tends to give a longer tool-life.

Between the two extremes there are numerous combinations from which one can choose, to suit the work in hand. To some extent the choice will be limited by the machines upon which the machining has to be done, the method of holding, and the strength of the component.

20. Procedure for Long Runs.

When an article is scheduled for a long run it is wise to experiment with the tool contour, computed speed, feed, and depth of cut, so that, when due allowance has been made for grinding and setting tolos, the most economic combination is used. The results of such experiments should be embodied in the operation schedule and standard drawings then tabulated for future reference.

21. Hardness and Tensile Strength of Steel.[17, 39, 40.]

The composite diagram fig. 7.8 illustrates generally the results of the various treatments upon the hardness and tensile strength of steel. At the top left-hand portion of the chart is shown the maximum hardness obtainable when quenching steel containing carbon up to ·9 per cent. It also shows the minimum hardness after quenching that will ensure satisfactory physical properties after tempering. The bottom left-hand curves give the tensile strength for plain carbon steel when in the annealed, normalized and as-rolled conditions. The central portion gives the relationship between the Brinell hardness number and the tensile strength for fully hardened material, whilst on the right is shown the results of tempering hardened steel. By reference across the B.H.No. for the tempered material may be obtained. The wide range of physical properties that are available indicate the great need for care when planning machining operations.

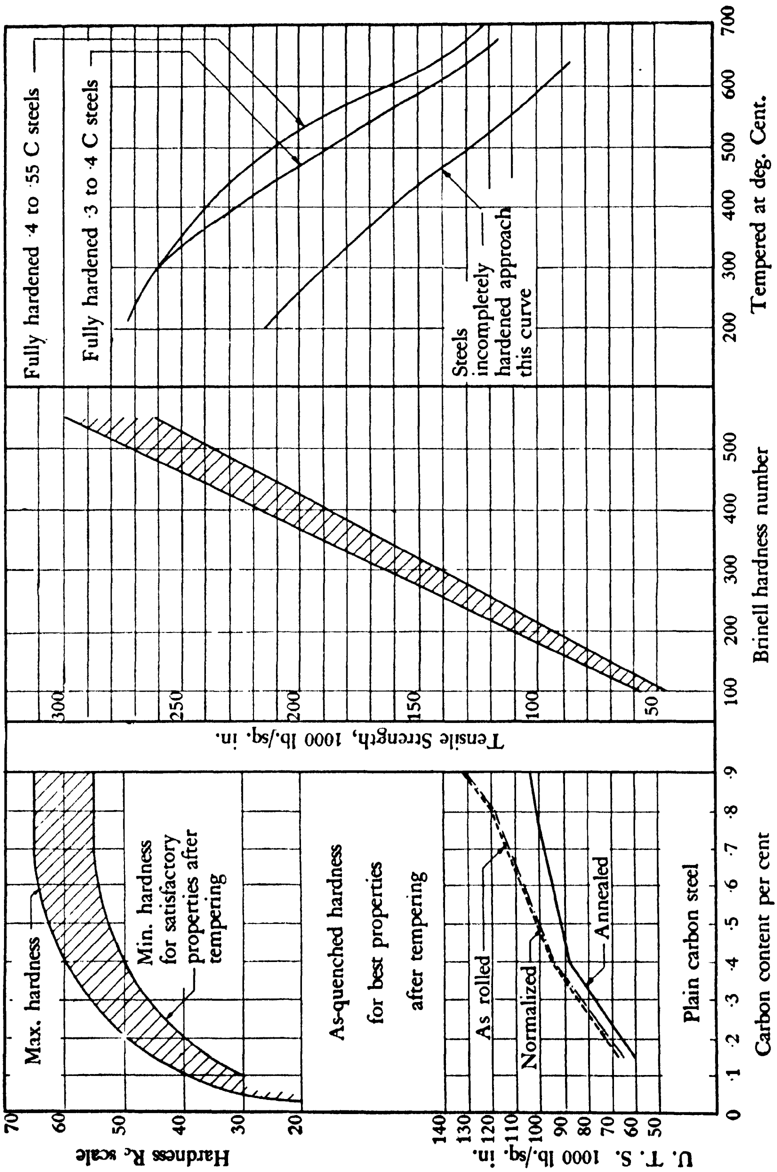


Fig. 7.8.—Chart showing the hardness and tensile strength of heat-treated steel

CHAPTER VIII

Cutting Speed Data for Steel

1. Expressions for Cutting Speeds.

With so many variables the question of choosing the most suitable cutting speed, feed, and depth of cut to suit a given machining operation may at first sight appear incapable of any solution except by the old process of trial and error. The position is rendered more difficult when an attempt is made to compare published data, as often there appears no relationship between the figures derived from various sources. This may be due to insufficient information or differences in tool-shape, cutting media, and the material to be machined. Yet, if the experiences of F. W. Taylor[13] are any guide, it is possible, by making use of such data, carefully tabulating the results of works experiments, and subjecting the whole of the information to a close examination, to list the machining speeds and dimensions of the cut for a given material on the operation chart. Many efforts have been made to reduce the mass of data to an expression capable of easy solution. The ideal is not yet to hand. Kronenberg[14] gives

$$V = C_v \, (1000A)^{-E_v},$$

and Table 28 gives various values associated with the expression.

2. A.S.M.E. Expression.

The expression given by the A.S.M.E.[15] can be simplified by assuming that the machining is done without a lubricant, the efficiency of an 18 . 4 . 1 h.s.s. tool is unity, and the top rake is 15°. Then

$$V_c = \frac{\text{constant depending upon the material determined experimentally}}{(\text{average chip thickness})^a \times (\text{length of contact})^{bT} \times (\text{tool life})^n}$$

or, for 1 hour's cutting,

$$V_c = \frac{C_v}{T^a \times L^{bT} \times 60^n}.$$

TABLE 28.—NUMERICAL VALUES FOR C_v AND E_v FOR THE CUTTING SPEED FORMULA $V = C_v(1000A)^{-E_v}$

Material to be cut	For 18 . 4 . 2 h.s.s. tool and tool-life as below			E_v	Index table for convenient plotting of cutting-speed lines			
	C_v				Tool-life			10^{-E_v}
	60 M no coolant or 480 M with coolant	60 M with coolant	480 M no coolant		60 M no coolant or 480 M with coolant	60 M with coolant	480 M no coolant	
Light alloy.	2160 (Dry)			—·73	404			$\frac{1}{5\cdot4}$
Brass (Brinell 80/120).	575			—·62	138			$\frac{1}{4\cdot16}$
Cast brass.	365			—·44	133			$\frac{1}{2\cdot74}$
Steel castings.	131	182	91	—·36	57	79	39·5	$\frac{1}{2\cdot31}$
Carbon steels. S.A.E. B.S. 970.								
1015 EN 2.	258	360	180	—·41	100	140	70	$\frac{1}{2\cdot57}$
1025 EN 2 E.	206	288	144	—·41	80	112	56	$\frac{1}{2\cdot57}$
1035 EN 8 B.	164	230	115	—·41	64	89·5	45	$\frac{1}{2\cdot57}$
1045 EN 43 A	131	182	91	—·41	51	71	36	$\frac{1}{2\cdot57}$
1060 EN 43 E.	84	118	59	—·41	32·7	46	23	$\frac{1}{2\cdot57}$
Ni Cr steel.	141	198	99	—·57	38·5	54	27	$\frac{1}{3\cdot66}$
Cast iron.								
Brinell, 100.	187	260	130	—·28	98	136	68	$\frac{1}{1\cdot91}$
„ 150.	119	168	84	—·28	62·5	88	44	$\frac{1}{1\cdot91}$
„ 200.	67	94	47	—·28	35	49	24·5	$\frac{1}{1\cdot91}$

Figures are cutting speeds (f.p.m.) for a chip cross-sectional area $A = \cdot001$ in.^{2} M = minutes.

Figures are cutting speeds (f.p.m.) for a chip cross-sectional area $A = \cdot01$ in.^{2}

Note: the computed speed is usually reduced 10% to give a margin of safety. See example below.

The values of the various exponents are given in Table 29, whilst those for the material feature in Tables 60–76, &c.

TABLE 29.—VALUES OF EXPONENTS FOR A.S.M.E.[15] CUTTING-SPEED FORMULA

Tool material	Material to be cut	Exponent				Value of $(60)^n$	
		a	b	n			
				Chips up to ·015 in. thick	Chips over ·015 in. thick	Chips up to ·015 in. thick	Chips over ·015 in. thick
Carbon. Steel.	Steel.	·67	7·2	·075	·200	1·36	2·27
	Cast iron.	·43	7·2	·075	·075	1·36	1·36
H.S.S.	Steel.	·67	2·3	·100	·125	1·51	1·67
	Cast iron.	·43	2·3	·100	·100	1·51	1·51
Stellite.	Steel.	·54	3·7	·142	·178	1·79	2·07
	Cast iron.	·43	3·7	·142	·142	1·79	1·79
Cemented Carbides.	Steel.	·67	1·0	·129	·161	1·70	1·94
	Cast iron.	·43	1·0	·129	·129	1·70	1·70

The above expression takes into account the effect of a nose-radius as L is the full length of the cutting edge making contact with the component and includes the cutting and trailing portions. Hence an enlarged scale drawing of the chip is necessary before one can normally determine L. The calculations are based on the average chip thickness, i.e. the chip area divided by L.

Other factors governing the cutting speed, such as the use of a lubricant, changes in the cutting media, or alterations to the top rake, can be introduced to meet the known operating conditions (see Chap. X, p. 218).

In order to provide a margin of safety, the cutting speeds are usually based on 90 per cent of the computed figures. Under some conditions the data associated with the fine feeds are best checked under shop conditions.

Example.—Compute the speed for cutting En 7 CD (B.H. No. 208) with a knee tool having no approach angle or nose-radius. The depth of cut is to be ¼ in. and the feed ·0156 in. No lubricant is to be used. The rake is 15° and a life of one hour is expected.

Now $$V_c = \frac{C_v}{T^a L^{bT} 60^n}.$$

From Table 60, C_v is estimated to be 8·1.

Hence, grouping the data together $C_v = 8{\cdot}1$, $L = {\cdot}25$, $T = {\cdot}0156$, $n = {\cdot}125$ (Table 29), $60^{\cdot 125} = 1{\cdot}668$, $a = {\cdot}67$, $b = 2{\cdot}3$ (Table 29).

Then $$V_c = \frac{8{\cdot}1}{{\cdot}0156^{\cdot 67} \times {\cdot}250^{2\cdot 3 \times \cdot 0156} \times 1{\cdot}668} = \frac{8{\cdot}1}{{\cdot}0616 \times {\cdot}950 \times 1{\cdot}668}$$

= say, 83 f.p.m.

Giving 10 per cent deduction for a margin of safety, actual cutting speed

= say, 75 f.p.m.

3. Tabulated Data for Steel.

In order to avoid the necessity of calculating the cutting speed for each chip-size and tool-shape, Tables 30–59, &c., may be used; they are based upon A.S.M.E.[15] data for the dry cutting of hot-rolled 2% carbon steel corresponding to B.S. 970[16] En 2 C, or S.A.E. 1020. Fig. 8.1 illustrates the fall in speed as the chip thickness increases.

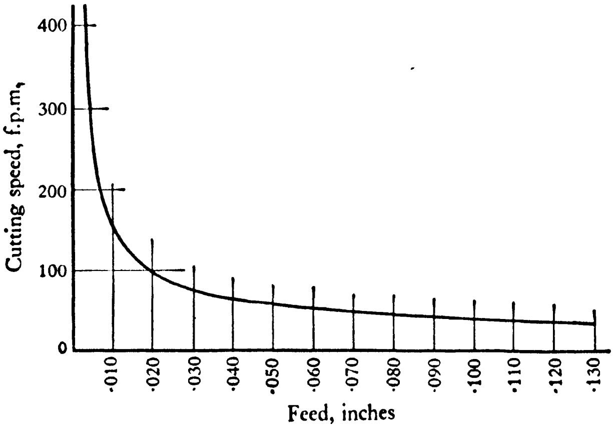


Fig. 8.1.—Variation of cutting speed with thickness of chip: depth of cut constant at ¼ in.

The given data cover tools made from carbon steel, h.s.s. to the normal 18 . 4 . 1 composition, Stellite and the cemented carbides. In order to meet the needs of the work handled in the usual machine shop, the speeds cover the following seven classes of single-point tools:

(*a*) The knife or knee tool having no approach angle or nose-radius.

(*b*) The knife or knee tool having no approach angle, but with a $\frac{1}{16}$-in. nose-radius.

(*c*) The roughing tool having a 30° approach angle and a $\frac{1}{8}$-in. nose-radius.

(*d*) The roughing tool having a 30° approach angle and a $\frac{1}{4}$-in. nose-radius.

(*e*) Tools for finish-turning with and without a nose-radius.

(*f*) Parting tools having small corner radii.

(*g*) Form tools with little or no rake and designed to give an accurate contour on the component.

For steels other than B.S. 970[16] En 2 C, or S.A.E. 1020, the *M* factor, as listed in Tables 60 to 76, is used in the cutting-speed formula, examples of which are to be found below for a wide range of machine-shop activities.

When using these tables and the associated data it is impossible to overstress the need for careful consideration of the composition of the material, the state in which it is forwarded to the machine shop, the shape and means of holding the component, along with the machines available for the work. Any series of tables of the type given must be subject to modification to suit the operating conditions. Taking one instance only, that of the free-cutting steels to En 1 A or S.A.E. 1113, the relative machining speeds between the hot-rolled and cold-drawn

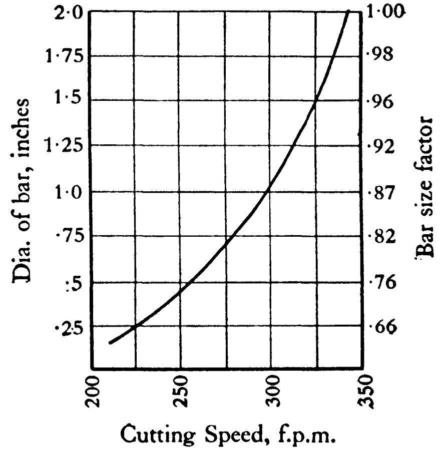


Fig. 8.2.—Variation of cutting speed with bar diameter using a knife tool (free-cutting lead-bearing steel)

material of, say, 130 and 183 Brinell, respectively, are 2·89 to 1·86 or 1·53 to 1 (Table 60, p. 155). Now the Brinell number of a cold-drawn bar depends largely upon its diameter, as the effects of cold-drawing show up more on small sizes than on the larger. For this reason a bar of, say, 2 in. dia. should be run at a higher linear speed than a bar of, say, ·5 in. dia. This is shown in fig. 8.2, p. 105, for lead-bearing steels; the same reasoning applies to the non-lead-bearing materials.

TABLE 30.—ROUGH-TURNING B.S. 970 EN 2 C STEEL, H.R. CARBON-STEEL TOOLS. NO APPROACH ANGLE. NO NOSE-RADIUS. SIDE RAKE 14°. TOP RAKE 8°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	59	39	33	27	23	20	19	17	16·5	16	16	16	16	15·5	15
$\frac{1}{16}$	59	38	32	26	22	19	18	15	15	14	14	13	13	12	11
$\frac{1}{8}$	58	38	32	25	21	18	17	14	13	13	12	12	11	11	10
$\frac{1}{4}$	58	37	26	24	21	17	16	12	11	10	10	10	10	9	9
$\frac{3}{8}$	57	36	25	24	20	16	14	11	11	10	9	9	9	8	7
$\frac{1}{2}$	57	36	25	23	20	15	14	10	9	8	7	6·5	6	5	5
$\frac{3}{4}$	57	36	25	23	20	15	14	10	9	8	6	6	6	5	4
1	57	36	25	22	20	15	13	9	8	7	6	6	5	4	3

TABLE 31.—ROUGH-TURNING B.S. 970 EN 2 C STEEL, H.R. CARBON-STEEL TOOLS. NO APPROACH ANGLE. $\frac{1}{16}$-in. NOSE-RADIUS. SIDE RAKE 14°. TOP RAKE 8°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	95	62	54	41	36	29	26	22	21	20	18	17	17	17	16
$\frac{1}{16}$	79	51	40	34	30	24	22	18	16	16	15	15	14	14	13
$\frac{1}{8}$	70	44	33	29	25	20	18	15	13	12	12	12	12	11	11
$\frac{1}{4}$	63	41	32	27	24	18	16	12	12	11	10	10	10	9	8
$\frac{3}{8}$	61	39	30	25	22	16	15	12	11	10	9	9	9	8	7
$\frac{1}{2}$	60	38	29	24	21	16	14	11	10	9	8	8	7	7	6
$\frac{3}{4}$	59	37	28	23	20	15	13	10	9	8	7	6	5	5	4
1	58	36	27	23	20	15	12	9	8	7	6	6	5	4	3

Table 32.—Rough-turning B.S. 970 En 2 C Steel, H.R. Carbon-steel Tools. 30° Approach Angle. $\frac{1}{8}$-in. Nose-radius. Side Rake 14°. Top Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	132	84	64	54	48	35	31	25	22	20	19	18	17	16	16
$\frac{1}{16}$	91	61	46	41	34	27	23	19	17	16	15	15	14	14	13
$\frac{1}{8}$	80	51	40	34	30	22	20	16	15	13	12	11	11	10	10
$\frac{1}{4}$	71	45	34	29	25	20	18	14	12	11	10	10	9	8	8
$\frac{3}{8}$	69	43	33	28	24	19	17	12	11	10	9	9	8	8	7
$\frac{1}{2}$	67	42	31	27	23	18	16	12	10	9	8	8	7	7	6
$\frac{3}{4}$	65	41	31	26	23	17	15	11	10	8	7	7	6	6	4
1	65	40	30	25	22	16	14	10	9	7	6	6	5	4	4

Table 33.—Rough-turning B.S. 970 En 2 C Steel, H.R. Carbon-steel Tools. 30° Approach Angle. $\frac{1}{4}$-in. Nose-radius. Side Rake 14°. Top Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	147	94	67	60	54	40	36	27	26	23	20	19	19	18	16
$\frac{1}{16}$	128	82	65	53	46	35	31	24	22	19	17	16	16	14	13
$\frac{1}{8}$	92	60	45	38	35	26	23	17	15	14	13	12	12	11	10
$\frac{1}{4}$	79	50	40	32	29	21	18	14	13	11	10	10	10	9	8
$\frac{3}{8}$	73	46	36	30	26	20	18	13	11	10	9	8	7	7	6
$\frac{1}{2}$	71	45	35	29	25	19	17	12	10	9	8	8	7	7	6
$\frac{3}{4}$	68	43	34	27	24	18	16	11	9	8	7	6	5	5	4
1	66	42	33	27	23	17	15	10	8	7	6	6	5	5	4

Table 34.—Forming B.S. 970 En 2 C Steel, H.R. Carbon-steel Tools. No Rake. Tool-life 1 hour Cutting Dry. (Feed = Depth of Cut.)

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed, f.p.m.	51	32	25	20	18	16	14	13	12	12	11	10

Table 35.—Parting Off B.S. 970 En 2 C Steel, H.R. Carbon-steel Tools. 8° Rake. Corner Radii $\frac{1}{64}$ in.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed f.p.m.	50	39	30	25	22	20	18	17	16	15	14	14

Table 36.—Finish-turning B.S. 970 En 2 C Steel, H.R. Carbon-steel Tools. Nose-radius $\frac{1}{8}$ in. $\frac{1}{8}$-in. Flat before Trailing Angle. 20° Top Rake.

Depth of cut, in.	Speed, f.p.m.											
	Feed, in.											
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·125
·005	435	254	225	199	175	147	135	118	110	105	99	91
·010	340	225	180	151	135	110	100	85	76	72	71	62
·015	300	194	170	131	120	94	80	71	65	62	59	51
·020	270	170	140	115	100	80	70	60	55	52	50	42

Table 37.—Rough-turning B.S. 970 En 2 C Steel, H.R. H.S.S. Tool 18 . 4 . 1. No Approach Angle. No Nose-radius. Side Rake 14°. Top Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	420	267	201	174	151	117	102	82	82	82	83	83	84	85	86
$\frac{1}{16}$	418	264	200	173	150	116	100	78	69	63	57	57	56	55	54
$\frac{1}{8}$	418	263	199	171	149	112	95	75	64	57	52	50	47	44	40
$\frac{1}{4}$	416	263	199	167	148	110	93	72	61	55	49	46	44	38	34
$\frac{3}{8}$	416	261	198	167	148	109	93	71	60	54	47	45	43	37	31
$\frac{1}{2}$	412	261	198	167	148	107	92	69	59	52	45	43	40	35	30
$\frac{3}{4}$	412	260	197	165	146	106	91	66	56	50	44	40	37	33	27
1	412	260	197	164	146	105	90	65	55	47	41	37	35	31	25

TABLE 38.—ROUGH-TURNING B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. NO APPROACH ANGLE. $\frac{1}{16}$-IN. NOSE-RADIUS. SIDE RAKE 14°. TOP RAKE 8°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	690	440	320	285	245	190	175	140	125	115	110	108	105	100	93
$\frac{1}{16}$	560	360	280	232	210	157	140	110	98	89	82	80	78	73	66
$\frac{1}{8}$	495	315	240	202	186	135	120	93	80	70	66	64	62	58	51
$\frac{1}{4}$	455	290	225	185	165	122	108	82	70	60	57	53	50	47	41
$\frac{3}{8}$	440	278	210	178	157	116	100	76	64	56	54	51	48	42	37
$\frac{1}{2}$	430	275	205	175	155	113	98	73	61	52	49	47	45	40	34
$\frac{3}{4}$	428	273	200	171	150	110	95	71	58	49	45	42	40	36	30
1	424	261	199	170	148	107	92	70	57	48	42	41	38	32	27

TABLE 39. ROUGH-TURNING B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. 30° APPROACH ANGLE. $\frac{1}{8}$-IN. NOSE-RADIUS. SIDE RAKE 14°. TOP RAKE 8°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	940	605	450	385	330	254	225	170	146	130	120	118	115	110	103
$\frac{1}{16}$	660	440	320	280	250	184	160	115	98	90	88	82	80	78	71
$\frac{1}{8}$	570	365	280	250	210	154	135	102	88	75	71	68	66	60	54
$\frac{1}{4}$	520	325	245	210	185	136	118	90	73	65	61	58	56	50	44
$\frac{3}{8}$	500	315	225	200	165	130	110	83	70	60	55	51	49	44	38
$\frac{1}{2}$	490	310	210	194	163	126	105	80	65	57	52	49	47	40	35
$\frac{3}{4}$	475	300	205	188	160	122	100	76	62	52	49	48	45	39	34
1	470	295	205	187	155	119	100	75	61	50	47	45	40	38	30

TABLE 40.—ROUGH-TURNING B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. 30° APPROACH ANGLE. ¼-IN. NOSE-RADIUS. SIDE RAKE 14°. TOP RAKE 8°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	1065	680	490	430	380	283	250	188	160	140	130	127	122	115	103
$\frac{1}{16}$	941	600	450	380	330	246	215	161	138	122	110	108	103	94	81
$\frac{1}{8}$	667	435	310	275	240	178	155	117	100	87	80	77	72	67	58
$\frac{1}{4}$	574	365	270	230	200	148	130	97	80	70	65	60	58	51	45
$\frac{3}{8}$	536	330	240	215	180	138	120	89	74	64	58	55	51	46	40
$\frac{1}{2}$	517	325	235	205	180	131	116	85	70	60	55	53	49	42	37
$\frac{3}{4}$	496	313	230	196	178	126	105	81	66	55	51	49	46	41	33
1	482	305	225	191	170	123	100	76	62	52	48	46	42	35	30

TABLE 41.—FORMING B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. NO RAKE. TOOL-LIFE 1 HOUR CUTTING DRY.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed f.p.m.	155	97	75	62	53	48	43	40	37	35	33	32

TABLE 42.—PARTING OFF B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. 8° RAKE. CORNERS $\frac{1}{64}$-IN. RADIUS.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed f.p.m.	700	490	370	305	270	240	220	200	185	175	165	156

TABLE 43.—FINISH-TURNING B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. $\frac{1}{8}$-IN. NOSE-RADIUS. $\frac{1}{8}$-IN. FLAT BEFORE TRAILING ANGLE. 20° TOP RAKE. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·030	·040	·050	·060
·005	1300	760	660	590	540	500	470	430	400	350	330	315	290
·010	1020	670	520	445	400	365	340	320	290	250	230	210	195
·015	890	570	460	390	350	320	295	280	240	200	185	175	170
·020	780	500	400	340	300	275	255	235	205	165	155	145	135

TABLE 44.—FINISH-TURNING B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. $\frac{1}{16}$-IN. NOSE-RADIUS. $\frac{1}{8}$-IN. FLAT BEFORE TRAILING ANGLE. 15° TOP RAKE. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·030	·040	·050	·060
·005	900	550	480	435	400	370	350	320	300	260	245	220	220
·010	700	490	395	330	300	270	250	230	210	185	160	150	145
·015	600	420	350	290	260	240	220	200	180	150	140	130	125
·020	550	360	300	250	235	210	195	180	160	125	120	110	100

TABLE 45.—FINISH-TURNING B.S. 970 EN 2 C STEEL, H.R. H.S.S. TOOL 18 . 4 . 1. NO APPROACH ANGLE. NO NOSE-RADIUS. 15° RAKE. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·030	·040	·050	·060
·005	540	350	300	265	240	220	205	195	180	160	150	142	136
·010	420	300	230	200	180	165	150	142	130	115	108	100	90
·015	370	255	200	175	160	145	135	125	115	95	85	80	75
·020	335	225	180	155	140	130	120	110	95	80	76	75	72

Table 46.—Rough-turning B.S. 970 En 2 C Steel, H.R. Tool Stellite J. No Approach Angle. No Nose-radius. Side Rake 14°. Top Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	460	327	270	235	210	175	160	142	140	140	138	138	138	138	137
$\frac{1}{16}$	458	321	250	229	205	170	155	133	130	120	115	110	110	110	105
$\frac{1}{8}$	455	318	245	226	200	164	150	126	110	105	98	97	96	95	93
$\frac{1}{4}$	453	316	240	221	195	159	145	118	105	95	88	85	83	80	76
$\frac{3}{8}$	451	314	235	218	190	155	140	113	100	90	83	80	78	74	67
$\frac{1}{2}$	451	313	233	217	187	152	135	109	95	85	78	75	70	65	60
$\frac{3}{4}$	450	310	230	214	185	150	130	104	92	84	73	70	68	63	51
1	448	309	230	212	182	147	128	102	90	82	69	64	60	55	46

Table 47.—Rough-turning B.S. 970 En 2 C Steel, H.R. Tool Stellite J. No Approach Angle. $\frac{1}{16}$-in. Nose-radius. Side Rake 14°. Top Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	608	421	370	341	300	251	230	197	180	175	163	160	158	150	145
$\frac{1}{16}$	577	407	320	287	260	213	195	164	150	145	134	131	130	125	116
$\frac{1}{8}$	519	352	290	255	230	188	170	143	130	125	115	112	110	105	99
$\frac{1}{4}$	494	344	280	245	215	171	150	127	110	105	99	95	90	87	82
$\frac{3}{8}$	474	331	250	231	210	165	145	119	105	95	90	87	83	78	72
$\frac{1}{2}$	469	324	245	226	205	160	140	115	100	92	85	80	77	72	65
$\frac{3}{4}$	458	319	240	221	200	154	137	110	97	87	77	75	72	65	56
1	452	314	235	217	195	151	135	104	92	82	72	70	65	60	49

Table 48.—Rough-turning B.S. 970 En 2 C Steel, H.R. Tool Stellite J. 30° Approach Angle. ⅛-in. Nose-radius. Side Rake 14°. Top Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	881	615	500	426	380	301	270	226	205	190	172	170	168	164	160
1/16	677	472	400	330	300	240	220	177	160	150	138	137	130	120	115
⅛	590	411	330	289	260	207	190	152	137	125	118	112	110	105	98
¼	536	373	300	261	240	186	170	135	120	110	102	100	98	90	82
⅜	520	359	290	252	230	178	160	127	115	105	93	91	90	80	72
½	512	354	270	245	220	173	155	122	108	98	88	85	80	72	65
¾	503	345	260	238	220	167	150	116	100	90	79	73	70	65	57
1	498	344	260	238	220	164	145	112	97	85	76	70	67	60	51

Table 49.—Rough-turning B.S. 970 En 2 C Steel, H.R. Tool Stellite J. 30° Approach Angle. ¼-in. Nose-radius. Side Rake 14°. Top Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	968	670	520	467	410	334	305	243	220	200	184	180	175	165	156
1/16	828	603	470	421	380	298	270	214	190	170	159	150	147	140	127
⅛	674	468	400	325	300	232	210	167	150	135	125	120	115	110	100
¼	590	404	320	282	250	200	180	143	130	115	105	100	95	90	82
⅜	550	383	300	265	230	188	170	133	120	105	98	90	85	80	72
½	540	370	280	256	220	180	160	126	112	100	90	85	80	75	68
¾	518	356	270	246	215	172	150	119	105	93	82	76	73	67	57
1	464	349	260	240	210	167	145	114	100	85	77	70	68	60	51

Table 50.—Forming B.S. 970 En 2 C Steel, H.R. Tool Stellite J. No Rake. Tool-life 1 hour Cutting Dry. (Feed = Depth of Cut.)

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed f.p.m.	185	115	90	72	62	56	50	46	42	39	37	36

TABLE 51.—PARTING OFF B.S. 970 EN 2 C STEEL, H.R. TOOL STELLITE J. 8° RAKE. $\frac{1}{64}$-IN. CORNER RADIUS. TOOL-LIFE 1 HOUR CUTTING DRY.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed f.p.m.	430	350	280	240	217	200	185	177	167	158	153	145

TABLE 52.—FINISH-TURNING B.S. 970 EN 2 C STEEL, H.R. TOOL STELLITE J. NOSE-RADIUS $\frac{1}{8}$ IN. $\frac{1}{8}$-IN. FLAT BEFORE TRAILING ANGLE. RAKE 80°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·030	·040	·050	·060
·005	1620	1050	880	795	720	670	620	585	540	480	450	425	408
·010	1320	900	700	600	510	470	440	426	390	345	310	290	270
·015	1110	765	600	525	465	430	400	375	340	285	255	240	225
·020	1000	650	520	450	400	375	350	330	290	230	210	200	190

If using Stellite No. 3, multiply Tables 46-52 by 0·52.

TABLE 53.—ROUGH-TURNING B.S. 970 EN 2 C STEEL, H.R. TOOL TIPPED WITH A CEMENTED CARBIDE, TUNGSTEN AND TANTALUM, OR TUNGSTEN AND TITANIUM. NO APPROACH ANGLE. NO NOSE-RADIUS. TRUE RAKE ANGLE 8°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	1325	838	650	537	480	349	285	236	235	236	244	245	250	252	258
$\frac{1}{16}$	1325	835	650	537	478	346	283	226	200	175	156	155	154	153	150
$\frac{1}{8}$	1322	835	650	532	478	344	280	222	190	165	146	135	130	110	101
$\frac{1}{4}$	1322	830	640	530	450	340	275	218	185	160	142	130	120	110	94
$\frac{3}{8}$	1322	829	637	527	447	338	273	216	182	156	138	128	117	106	91
$\frac{1}{2}$	1316	829	637	526	446	336	271	214	180	155	137	127	115	104	88
$\frac{3}{4}$	1316	828	635	524	445	334	271	211	175	153	134	123	115	105	86
1	1316	828	635	524	443	334	270	207	170	150	131	120	110	100	82

Table 54.—Rough-turning B.S. 970 En 2 C Steel, H.R. Tool tipped with a Cemented Carbide, Tungsten and Tantalum, or Tungsten and Titanium. No Approach Angle. $\frac{1}{16}$-in. Nose-radius. True Rake Angle 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	0156	·020	·031	·040	050	·062	·070	·080	·100	·125
$\frac{1}{32}$	2182	1392	1100	900	800	600	530	426	360	345	330	320	310	300	284
$\frac{1}{16}$	1780	1134	850	730	630	485	425	334	295	265	242	235	225	210	193
$\frac{1}{8}$	1565	1000	750	635	550	416	370	282	250	235	194	185	175	160	148
$\frac{1}{4}$	1441	938	700	585	490	379	330	249	215	185	168	155	145	135	119
$\frac{3}{8}$	1395	886	650	564	470	366	320	239	200	177	161	145	135	120	108
$\frac{1}{2}$	1375	875	630	551	450	352	305	229	190	165	150	135	125	115	101
$\frac{3}{4}$	1366	862	630	540	440	346	300	220	185	160	143	130	120	105	93
1	1321	831	630	540	440	342	295	218	180	155	138	125	115	100	86

Table 55.—Rough-turning B.S. 970 En 2 C Steel, H.R. Tool tipped with Cemented Carbide, Tungsten and Tantalum, or Tungsten and Titanium. 30° Approach Angle. $\frac{1}{8}$-in. Nose-radius. True Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	050	·062	·070	·080	·100	·125
$\frac{1}{32}$	3020	1930	1450	1220	1100	800	730	535	470	420	371	360	355	335	313
$\frac{1}{16}$	2100	1390	1040	986	820	575	520	379	320	290	263	258	250	235	211
$\frac{1}{8}$	1820	1160	900	787	680	482	435	313	290	250	212	205	195	175	157
$\frac{1}{4}$	1640	1035	800	661	600	426	390	275	240	210	182	178	170	150	135
$\frac{3}{8}$	1586	995	730	636	540	408	360	262	230	190	169	160	150	130	115
$\frac{1}{2}$	1540	976	680	615	530	396	345	252	215	185	163	155	147	125	110
$\frac{3}{4}$	1520	950	670	600	520	386	330	245	207	170	157	150	140	120	101
1	1500	945	665	595	510	381	330	240	200	168	150	142	132	115	97

Table 56.—Rough-turning B.S. 970 En 2 C Steel, H.R. Tool tipped with Cemented Carbide, Tungsten and Tantalum, or Tungsten and Titanium. 30° Approach Angle. $\frac{1}{4}$-in. Nose-radius. True Rake 8°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	006	·008	·010	·0156	·020	031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	3340	2180	1580	1360	1240	890	810	587	520	450	400	390	375	350	315
$\frac{1}{16}$	2990	1900	1450	1200	1100	776	700	502	445	400	334	317	305	290	245
$\frac{1}{8}$	2120	1380	1010	870	780	562	500	364	325	280	242	230	220	198	172
$\frac{1}{4}$	1825	1152	880	725	650	470	420	310	260	230	197	180	175	155	135
$\frac{3}{8}$	1700	1040	780	681	580	436	390	280	245	210	181	165	155	138	121
$\frac{1}{2}$	1645	1028	770	655	570	420	375	267	225	195	171	160	147	125	113
$\frac{3}{4}$	1580	995	760	626	560	402	340	254	215	180	160	150	140	120	104
1	1540	980	745	610	550	392	325	247	205	170	155	143	132	115	99

Table 57.—Forming B.S. 970 En 2 C Steel, H.R. Tool tipped with either Tungsten and Tantalum, or Tungsten and Titanium Carbide. No Rake. Tool-life 1 hour Cutting Dry.
(Feed = Depth of Cut.)

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed, f.p.m.	548	344	263	216	186	167	150	137	126	118	110	105

Table 58.—Parting off B.S. 970 En 2 C Steel, H.R. Tool tipped with either Tungsten and Tantalum, or Tungsten and Titanium Carbide. 8° Rake. $\frac{1}{64}$-in. Corner Radius. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·011	·012
Speed, f.p.m.	1300	1000	750	629	550	485	440	400	380	347	320	309

TABLE 59.—FINISH-TURNING B.S. 970 EN 2 C STEEL, H.R. TOOL TIPPED WITH EITHER TUNGSTEN AND TANTALUM, OR TUNGSTEN AND TITANIUM CARBIDE. RAKE 8°. NOSE-RADIUS $\frac{1}{8}$ IN. FLAT BEFORE TRAILING ANGLE $\frac{1}{8}$ IN. LONG.

Depth of Cut, in.	Speed, f.p.m.													
	Feed, in.													
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·030	·040	·050	·060	·125
·005	3450	2000	1860	1560	1400	1300	1200	1130	1050	900	830	780	750	690
·010	2700	1760	1400	1160	1040	940	880	830	760	630	580	550	520	460
·015	2360	1520	1200	1010	900	820	750	700	630	520	470	440	420	360
·020	2100	1330	1060	900	800	730	680	630	550	440	420	390	370	330

If using tungsten carbide tips, multiply the above Tables 53–59 by ·67.

TABLE 59A.—VALUES FOR C_r

Rake degrees	C_r
0	·97
3	·98
8	1·00
10	1·01
15	1·07
20	1·03

When the rake varies from that given above for turning with tipped tools, use the values in Table 59a.

TABLE 60.—SPEC. NO. B.S. 970: 1947 EN SERIES. CARBON STEELS FOR

In the following tables, these contractions are used: A = annealed or softened. A.C. = as C.W. = cold worked. H.R. = hot rolled.

Spec. No.	Designation	Composition					U.T.S. tons per sq. in.	Ruling Section, in.
		C	Si	Mn	S	P		
En 1 A	Free-cutting steel bars for machining.	·07–·15	<·1	·8–1·2	·2–·3	<·07	32	$<\frac{17}{32}$
							28	$\frac{17}{32}$–1⅛
							25	1⅛–2⅛
							23	
							23	2½–4
							28	<4
En 1 B	Free-cutting steel bars for machining.	·07–·15	<·1	1·0–1·4	·3–·6	<·06	27	$\frac{17}{32}$
							25	$\frac{17}{32}$–1⅛
							23	1⅛–2⅛
							23	
							28	<2⅛
En 2	General purpose cold-forming steel.	<·2		<·8	<·06	<·06	>20	
En 2 A		<·12		<·5	<·05	<·05		
En 2 A1		<·1		<·5	<·04	<·04		
En 2 B		<·15		<–·5	<·05	<·05		
En 2 C		·15–·25		·4–·6	<·05	<·05		
En 2 D		·15–·3		·4–·7	<·05	<·05		
En 3	"20" carbon steel.	<·25	·05–·35	<1·0	<·06	<·06	28–35	
En 3 A	"20" carbon steel, normalized.	·15–·25	·05–·35	·4–·9	<·06	<·06		
En 3 B	"20" carbon steel, C.D.	<·25	<·35	<1·0	<·06	<·06		$<\frac{17}{32}$
								$\frac{17}{32}$–1⅛
								1⅛–2⅛
								>2⅛
En 4	"25" carbon steel, bright normalized.	<·3	·05–·35	<1·0	<·06	<·06	28–38	
En 4 A	"25" carbon steel, bright C.D.	<·3	·05–·35	<1·0	<·06	<·06	32–42	

BARS, BILLETS, LIGHT FORGINGS AND STAMPINGS, UP TO 6 IN. RULING SECTION

cast. A.F. = as forged. A.R. = as rolled. C.D. = cold drawn. C.H. = case hardened. H.T. = hardened and tempered. N = normalized.

Spec. No.	How supplied		Condition	B.H. No.	Constants			Force for cutting C_p, lb. in thousands	Remarks
	Bar	Forgings			Machining constant M	H.P. index P	Speed C_v		
En 1 A	Bright.		C.D.	153	1·76	1·23	21·1	85	For ⅛ in. dia. bar.
				140	2·2	1·48	26·4	82	For 17/32 ,, ,,
	,,		C.D.	140	2·2	1·48	26·4	82	For 17/32 ,, ,,
				121	2·6	1·55	31·2	73	For 1½ ,, ,,
	,,		C.D.	121	2·6	1·55	31·2	73	For 1½ ,, ,,
				105	2·89	1·66	34·7	70	For 2½ ,, ,,
	,,		C.D.	105	2·89	1·66	34·7	70	For 4 ,, ,, and over.
	,,		H.R.	101	2·89	1·66	34·7	70	
			C.H.		2·00	1·34	24·0	82	For core of case-hardened components.
	Black or A.R., or bright.		H.R.	101	2·89	1·66	34·7	70	
En 1 B	Bright.		C.D.		1·76	1·23	21·1	85	For ⅛ in. dia. bars.
					2·2	1·48	26·4	82	For 17/32 ,, ,,
	,,		C.D.		2·2	1·48	26·4	82	For 17/32 ,, ,,
					2·6	1·55	31·2	73	For 1½ ,, ,,
	,,		C.D.		2·6	1·55	31·2	73	For 1½ ,, ,,
					2·89	1·66	34·7	70	For 2½ ,, ,,
	,,		H.R.		2·89	1·66	34·7	70	
			C.H.		2·00	1·34	24·0	82	For core of case-hardened components.
	Black or bright.		H.R.	101	2 89	1·66	34·7	70	
En 2	A.R.		H.R.	125	1 05	1·10	12·6	128	Steels of this type may be had in the form of bar, plate, sheet, and strip suitable for cold-working and deep-drawing.
En 2 A	A.R.		H.R.	100	1·42	1·32	17·0	114	
En 2 A1	A.R.		H.R.	100	1·42	1·32	17·0	114	
En 2 B	A.R.		H.R.	125	1·33	1·27	16·0	116	
En 2 C	A.R.		H.R.	127	1·00	1·00	12·0	122	
En 2 D	A.R.		H.R.	150	·97	1·00	11·7	122	
En 3	A.R.	A.F.	H.R.	127	·97	1·00	11·7	122	
			A.	106	1·20	1·00	14·4	100	
En 3 A	A.R.		N.	140	·95	1·03	11·4	124	
	A.R.		H.R.	127	1·00	1·00	12·0	122	
	Bright.		H.R.	127	1·00	1·00	12·0	122	
En 3 B	Bright.		C.D.	190	·54	·62	6·5	140	⅛ in. dia. bar.
				170	·66	·73	7·9	135	For 17/32 ,, ,,
	,,		C.D.	170	·66	·73	7·9	135	For 17/32 ,, ,,
				150	·78	·83	9·4	130	For 1½ ,, ,,
	,,		C.D.	150	·78	·83	9·4	130	For 1½ ,, ,,
				121	1·00	1·0	12·0	122	For 2½ ,, ,,
	,,		C.D.	121	1·00	1·0	12·0	122	All bars 2½ in. dia. and over.
	A.R.		H.R.	130	·98	·98	11·7	122	
En 4	Bright.		N.	126	·95	·98	11·4	125	
	,,		N.	179	·70	·76	8·4	133	
En 4 A	Bright.		C.D.		·62	·70	7·4	137	For ½ in. dia. bar, *M* factor.
	,,		C.D.		·71	·79	8·4	135	For 1 ,, ,, ,,
	,,		C.D.		·78	·81	9·4	133	For 1½ ,, ,, ,,
	,,		C.D.		·82	·84	9·8	130	For 2 ,, ,, ,,
	,,		H.R.	148	·78	·84	9·4	132	
	,,		A.	122	1·0	1·0	12·0	122	

TABLE 60.—

Spec. No.	Designation	Composition					U.T.S. tons per sq. in.	Ruling Section, in.
		C	Si	Mn	S	P		
En 5	"30" carbon steel, hardened and tempered.	·25–·35	·05–·35	·6–1·0	<·06	<·06	30	2½
							35	2½
							40	¾
							45	½
En 5 A	"30" carbon steel.	·25–·30	·05–·35	·7–·9	<·06	<·06		
En 5 B	"30" carbon steel.	·28–·33	·05–·35	·7–·9	<·06	<·06		
En 5 C	"30" carbon steel.	·30–·35	·05–·35	·7–·9	<·06	<·06		
En 5 D	"30" carbon steel, hardened and tempered.	·25–·35	·05–·35	·6–1·0	<·06	<·06	45 40 35 35	<½ ½–¾ ¾–1½ 1½–2½
En 6 En 6 A	35–45-ton bright carbon steel bars.	<·4	·05–·35	·5–·9	<·06	<·06	35–45	
En 7	35–45-ton bright carbon steel semi-free cutting.	·1–·3	<·35	·7–1·3	·1–·18	·06	35–45 30–40	1¾ 1¾–2½
En 8	"40" carbon steel.	·35–·45	·05–·35	·6–1·0	<·06	<·06	45	½
							40	2
							35	6
							38	1½

(Continued)

Spec. No.	How supplied: Bar	How supplied: Forgings	Condition	B.H. No.	Constants: Machining constant M	Constants: H.P. index P	Constants: Speed C_r	Force for cutting C_p, lb. in thousands	Remarks
En 5	Bright.		H.T.	131	·93	·97	11·1	127	
				187	·67	·82	8·0	150	
	,,		H.T.	152	·84	·94	10·1	135	
				207	·54	·67	6·5	152	
	,,		H.T.	179	·70	·83	8·4	145	
				229	·48	·62	5·8	158	
	,,		H.T.	201	·65	·81	7·8	152	
				255	·39	·53	4·7	165	
	,,		N.	153	·75	·86	9·0	140	
En 5 A	Bright.		H.R.	137	·85	·89	10·2	127	Steel for special purposes.
	,,		A.	134	·92	·93	11·0	123	Supplied to composition only.
	,,		C.D.		·61	·70	7·3	141	M factor for ½ in. dia. bar.
	,,		C.D.		·70	·79	8·4	137	,, ,, 1 ,, ,,
	,,		C.D.		·77	·83	9·2	133	,, ,, 1½ ,, ,,
	,,		C.D.		·8	·85	9·6	130	,, ,, 2 ,, ,,
En 5 B	Bright.		H.R.	145	·80	·84	9·6	128	Steel for special purpose sup-
	,,		A.	140	·89	·93	10·7	127	plied to composition only.
	,,		C.D.		·58	·68	7·0	142	M factor for ½ in. dia. bar.
	,,		C.D.		·68	·76	7·9	137	,, ,, 1 ,, ,,
	,,		C.D.		·74	·82	8·9	135	,, ,, 1½ ,, ,,
	,,		C.D.		·78	·85	9·4	132	,, ,, 2 ,, ,,
En 5 C	Bright.		C.D.		·57	·67	6·9	143	M factor for ½ in. dia. bar.
	,,		C.D.		·63	·72	7·4	140	,, ,, ¾ ,, ,,
	,,		C.D.		·67	·75	8·3	136	,, ,, 1 ,, ,,
	,,		C.D.		·74	·82	8·9	134	,, ,, 1½ ,, ,,
	,,		C.D.		·77	·83	9·3	132	,, ,, 2 ,, ,,
	,,		H.R.	155	·75	·81	9·0	131	
	,,		A.	145	·86	·90	10·3	128	
En 5 D	Bright.		H.T.	255	·37	·48	4·4	160	
	,,		H.T.	229	·43	·55	5·2	155	
	,,		H.T.	229	·43	·55	5·2	155	
	,,		H.T.	229	·43	·55	5·2	155	
En 6	Bright .		C.D.	207	·52	·62	6·2	146	May be partially annealed after cold-working up to 620° C.
En 6 A	,,		C.D.	180	·62	·69	7·4	137	
	,,		C.D.	160	·73	·79	8·8	132	
	,,		C.D.	150	·78	·83	9·4	129	
	,,		H.R.	174	·69	·71	8·3	135	
	,,		A.	145	·82	·86	9·8	127	
En 7	Bright.		C.D.	210	·67	·50	8·0	91	May be partially annealed after cold-working up to 620° C. Not recommended for case-hardening.
	,,		C.D.	195	·75	·54	9·0	88	
	,,		C.D.	180	·83	·58	10·0	85	
	,,		C.D.	165	·92	·62	11·0	82	
	,,		C.D.	150	1·00	·63	12·0	79	
	,,		H.R.	133	1·22	·75	14·7	75	
En 8	Bright.	H.T.	H.T.	255	·36	·49	4·3	165	,, ,, ,, ,,
	,,		H.T.	229	·44	·57	5·3	158	
	,,		H.T.	201	·54	·69	6·5	155	
	,,		H.T.	229	·44	·57	5·3	158	
	,,		H.T.	201	·54	·69	6·5	155	
	,,		H.T.	179	·62	·70	7·5	138	
	,,		N.	207	·54	·64	6·5	144	
	,,		N.	152	·73	·79	8·8	131	
	,,		H.R.	153	·73	·79	8·8	131	
	,,		A.	140	·8	·85	9·6	130	
	,,		C.D.	229	·39	·49	4·7	153	
	,,		C.D.	210	·48	·58	6·8	147	
	,,		C.D.	195	·56	·65	6·7	142	
	,,		C.D.	180	·64	·72	7·7	138	
	,,		C.D.	167	·71	·78	8·5	134	

TABLE 60.-

Spec. No.	Designation	Composition					U.T.S. tons per sq. in.	Ruling Section, in.
		C	Si	Mn	S	P		
En 8 A	" 40 " carbon steel.	·33–·38	·05–·35	·7–·9	<·06	<·06		
En 8 B		·35–·40	·05–·35	·7–·9	<·06	<·06		
En 8 C		·38–·43	·05–·35	·7–·9	<·06	<·06		
En 8 D		·4–·45	·05–·35	·7–·9	<·06	<·06		
En 8 E		·35–·40	·05–·35	·9–1·1	<·06	<·06		
En 8 M	" 40 " carbon free-cutting steel.	·35–·45	<·25	·9–1·1	·12–·2	<·07	45	½
							40	2
							35	6
							38	1⅛
En 9	" 55 " carbon steel.	·5–·6	·05–·35	·5–·8	<·06	<·06	55	1⅛
							50	1⅛
							45	4
							50	2
En 43 A	" 50 " carbon steel.	·45–·55	·05–·35	·7–1·0	<·06	<·06	50	1⅛
							40	1⅛
							45–60	
En 43 B	" 50 " carbon steel.	·45–·5	·05–·35	·7–1·0	<·06	<·06		
En 43 C		·5–·55	·05–·35	·7–1·0	<·06	<·06		
En 43 D		·6–·65	·05–·35	·4–·6	<·06	<·06		
En 43 E		·65–·75	·05–·35	·7–·9	<·06	<·06		

(*Continued*)

Spec. No.	How supplied		Condition	B.H. No.	Constants			Force for cutting C_p, lb. in thousands	Remarks
	Bar	Forgings			Machining constant M	H.P. index P	Speed C_v		
En 8 A En 8 B En 8 C En 8 D En 8 E					As En 8		As En 8	As En 8	Steels for special application.
En 8 M	Black or	H.T.	H.T.	255	·53	·50	6·4	115	Cold work may be given the bright bars after heat treatment at the option of the manufacturer, unless otherwise stated on order.
	bright.		H.T.	229	·60	·52	7·2	105	
	,,		H.T.	201	·70	·38	8·4	94	
	,,	H.T.	H.T.	229	·60	·52	7·2	105	
	,,		H.T.	201	·70	·38	8·4	94	
	,,		H.T.	179	·90	·61	10·8	83	
				152	1·09	·70	13·2	78	
	,,		N.	207	·78	·60	9·4	94	
	Bright.		C.D.	229	·58	·48	7·0	100	
	,,		C.D.	210	·66	·52	7·9	96	
	,,		C.D.	195	·72	·53	8·6	89	
	,,		C.D.	180	·78	·53	9·4	83	
	,,		C.D.	167	·84	·55	10·1	80	
	,,		H.R.	187	·85	·59	10·2	84	
En 9	Black or		H.T.	302	·24	·35	2·9	175	,, ,, ,, ,,
	bright.		H.T.	277	·32	·45	3·8	171	
	,,		H.T.	248	·37	·50	4·5	165	
	,,		H.T.	277	·32	·45	3·8	171	
	,,		H.T.	248	·37	·50	4·5	165	
	,,		H.T.	223	·43	·57	5·2	162	
	,,		N.	255	·36	·53	4·3	180	
	,,		N.	229	·43	·58	5·2	166	
	,,		N.	201	·50	·64	6·0	156	
	Bright.		C.D.	298	·32	·45	3·8	174	
	,,		C.D.	277	·36	·50	4·3	171	
	,,		C.D.	255	·40	·59	4·8	180	
	,,		C.D.	228	·46	·63	5·5	166	
	,,		A.	197	·53	·65	6·4	150	
En 43 A	Black or		H.T.	277	·32	·45	3·9	171	
	bright		H.T.	248	·37	·50	4·4	167	
	as		H.T.	223	·43	·57	5·2	162	
	ordered.		N.	229	·44	·59	5·3	163	
	,,		N.	201	·54	·66	6·5	150	
	,,		N.	179	·64	·74	7·7	138	
	Bright.		C.D.	277	·32	·45	3·8	171	
	,,		C.D.	255	·37	·49	4·4	163	
	,,		C.D.	228	·46	·59	5·5	153	
	,,		C.D.	201	·50	·61	6·0	149	
	Black or		A.	181	·64	·74	7·7	138	
	bright.		H.R.	200	·52	·64	6·2	150	
En 43 B En 43 C En 43 D En 43 E					As En43A		As En43A	As En43A	Steels for special purposes.

TABLE 61.—B.S. 970 EN SERIES. ALLOY STEELS
HARDENED AND TEMPERED TO GIVE

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	P
En 10	"55" carbon ¾% nickel steel.	·5–·6	·05–·35	·5–·8	·5–·8				<·06	<·06
En 11	"60" carbon-chromium steel.	·5–·7	·1–·35	·5–·8		·5–·8			<·05	<·05
En 12	1% nickel steel.	·35–·45	·1–·35	<1·5	·6–1·0				<·05	<·05
En 13	Manganese-nickel-molybdenum steel.	·15–·25	·1–·35	1·4–1·8	·4–·7		·15–·35		<·05	<·05
En 14 A	Carbon-manganese steel.	·15–·25	·1–·35	1·3–1·7	<·4	<·25			<·06	<·06
En 14 B	Carbon-manganese steel.	·2–·3	·1–·35	1·3–1·7	<·4				<·06	<·06

for Bars, Billets, Light Forgings and Stampings
40 to 100 tons per sq. in. U.T.S.

Spec. No	How supplied		Properties				Constants				Remarks
	Bar	Forgings	U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 10	As En 9	As En 9									Machining constants identical with those for En 9, Table 60.
En 11	Black or bright as ordered.	H.T.	65	2½	H.T.	341	·28	·38	3·4	168	Bright bars may be subjected to cold work after heat treatment unless specified.
						321	·30	·39	3·6	159	
						293	·33	·40	4·0	150	
			55	2½	H.T.	302	·32	·41	3·8	157	
						277	·35	·44	4·2	152	
						248	·37	·44	4·4	144	
					A.	229	·42	·45	5·0	131	
					A.	201	·5	·48	6·0	118	
En 12	Black or bright as ordered.	H.T.	40	6	H.T.	229	·44	·57	5·3	158	,, ,, ,, ,,
					H.T.	201	·54	·64	6·5	146	
					H.T.	179	·62	·70	7·5	138	
			35	6	N.	207	·54	·64	6·5	144	
					N.	179	·64	·72	7·7	137	
					N.	152	·73	·79	8·8	131	
					H.R.	177	·66	·73	7·9	135	
En 13	Black or bright as ordered.	H.T.	40	6	H.T.	229	·44	·57	5·3	158	,, ,, ,, ,,
					H.T.	201	·54	·65	6·5	147	
					H.T.	179	·62	·70	7·5	138	
					H.R.	180	·66	·76	8·2	140	
					N.	207	·54	·65	6·5	144	
					N.	150	·74	·80	8·8	131	
En 14 A	Black or bright as ordered.	H.T.	45	1½	H.T.	255	·54	·74	6·5	166	,, ,, ,, ,,
					H.T.	229	·58	·77	7·0	162	
					H.T.	201	·65	·85	7·8	160	
			40	4	H.T.	229	·58	·77	7·0	162	
					H.T.	201	·65	·85	7·8	160	
					H.T.	179	·70	·90	8·4	156	
			35	6	N.	207	·62	·83	7·5	164	
					N.	177	·69	·88	8·3	156	
					N.	152	·75	·92	9·0	150	
	Bright.		45	2	C.D.	210	·46	·60	5·4	160	
					C.D.	195	·54	·70	6·5	157	
					C.D.	180	·62	·79	7·4	154	
					C.D.	165	·70	·85	8·4	150	
					C.D.	150	·78	·94	9·3	147	
					H.R.	155	·75	·91	9·0	148	
					A.	145	·81	·94	9·7	143	
En 14 B	Black or bright.	H.T.	45	2½	H.T.	255	·54	·74	6·5	168	Bright bars may be cold worked after heat treatment unless otherwise specified on order.
					H.T.	227	·58	·79	7·0	166	
					H.T.	201	·65	·85	7·8	160	
			40	4	H.T.	229	·58	·79	7·0	166	
					H.T.	201	·65	·85	7·8	160	
					H.T.	189	·70	·90	8·4	156	
			38	6	N.	229	·61	·82	7·8	162	
					N.	201	·68	·89	8·2	159	
					N.	179	·73	·93	8·8	156	
	Bright.		45	2	C.D.	210	·43	·56	5·2	160	
					C.D.	195	·51	·66	6·1	157	
					C.D.	180	·59	·74	7·1	154	
					C.D.	170	·67	·83	8·0	151	
					H.R.	166	·73	·89	8·8	149	
					A.	152	·78	·93	9·4	146	

TABLE 61.—

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	P
En 15	Carbon-manganese steel.	·3–·4	·1–·35	1·3–1·7					<·05	<·05
En 15 A		·3–·4	·05–·35	1·3–1·7					<·06	<·06
En 15 B	Carbon-manganese steel.	·35–·4	·05–·35	1·1–1·3					<·06	<·06
En 16	Manganese-molybdenum steel.	·25–·4	·1–·35	1·3–1·8			·2–·35		<·05	<·05
En 16 A	Manganese-molybdenum steel.	·25–·3	·1–·35	1·3–1·8			·2–·35			
En 16 B		·3–·35	·1–·35	1·3–1·8			·2–·35			
En 16 C		·35–·4	·1–·35	1·3–1·8			·2–·35			

(*Continued*)

Spec. No.	How supplied		Properties				Constants				Remarks
	Bar	Forgings	U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 15	Black or bright.	H.T.	50	⅞	H.T.	277	·49	·68	5·9	170	Bright bars may be cold worked after heat treatment unless otherwise specified on order.
En 15 A			50	⅞	H.T.	255	·53	·73	6·4	168	
						223	·57	·77	6·8	166	
			45	2½	H.T.	255	·53	·73	6·4	168	
						223	·57	·77	6·8	166	
						201	·62	·81	7·4	160	
			40	*	H.T.	229	·56	·76	5·7	166	* 6 in. for En 15; 4 in. for En 15 A.
						201	·62	·81	7·4	160	
						179	·68	·88	8·2	157	
					H.R.	180	·71	·91	8·5	157	
					A.	160	·75	·94	9·0	153	
En 15 B	Black or bright.	H.T.	55	½	H.T.	302	·38	·57	4·6	184	Bright bars may be cold worked after heat treatment unless otherwise specified.
					H.T.	277	·48	·68	6·0	170	
					H.T.	248	·54	·74	6·5	167	
			50	⅞	H.T.	277	·48	·68	6·0	170	
					H.T.	255	·53	·73	6·4	168	
					H.T.	223	·57	·77	6·8	166	
			45	2½	H.T.	255	·53	·73	6·4	168	
					H.T.	229	·56	·76	5·7	166	
					H.T.	201	·62	·81	7·4	160	
			40	4	H.T.	229	·56	·76	5·7	166	
					H.T.	201	·62	·81	7·4	160	
					H.T.	179	·68	·88	8·2	157	
					H.R.	180	·71	·91	8·5	157	
					A.	160	·75	·94	9·0	153	
En 16	Black or bright.	H.T.	65	⅞	H.T.	341	·31	·44	3·7	172	,, ,, ,, ,,
					H.T.	321	·34	·46	4·0	170	
					H.T.	293	·42	·58	5·1	167	
			60	1⅛	H.T.	321	·34	·46	4·0	170	
						293	·42	·58	5·1	167	
						269	·50	·68	6·0	166	
			55	2½	H.T.	302	·38	·57	4·6	184	
						277	·49	·68	6·0	170	
						248	·55	·75	6·6	166	
			50	4	H.T.	277	·49	·68	6·0	170	
						255	·54	·74	6·5	166	
						223	·60	·81	7·2	165	
			45	6	H.T.	255	·54	·74	6·5	166	
						229	·59	·79	7·1	164	
						201	·65	·85	7·8	163	
					H.R.	201	·66	·87	7·9	163	
					A.	190	·70	·91	8·4	160	
En 16 A											Steels for special purposes. M factor as for En 16.
En 16 B											
En 16 C											

TABLE 61.—

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	P
En 17	Manganese-molybdenum steel (higher molybdenum).	·3–·4	·1–·35	1·3–1·8			·35–·55		<·05	<·05
En 18	1% chromium steel.	·35–·45	·1–·35	·6–·95		·8–1·1			<·05	<·05
En 18 A	1% chromium steels.	·27–·3	·1–·35	·65–·8		·8–·1·1				
En 18 B		·3–·35	·1–·35	·65–·8		·8–1·1				
En 18 C		·35–·38	·1–·35	·65–·8		·8–1·1				
En 18 D		·38–·43	·1–·35	·65–·8		·8–1·1				
En 19	1% chromium-molybdenum steel.	·35–·45	·1–·35	·5–·8		·9–1·5	·2–·4		<·05	<·05
En 19 A		·35–·45	·1–·35	·5–·8		·9–1·5	·2–·4		<·05	<·05

(*Continued*)

Spec. No.	How supplied		Properties				Constants				Remarks
	Bar	Forgings	U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 17	Black or bright.	H.T.	65	1⅛	H.T.	341	·31	·44	3·7	172	Bright bars may be subjected to cold working after heat treatment unless otherwise stated.
					H.T.	321	·34	·46	4·0	170	
					H.T.	293	·42	·58	5·1	167	
			60	2½	H.T.	321	·34	·46	4·0	170	
					H.T.	293	·42	·58	5·1	167	
					H.T.	269	·50	·68	6·0	166	
			55	4	H.T.	302	·38	·57	4·6	184	
					H.T.	277	·49	·68	6·0	170	
					H.T.	248	·55	·75	6·6	166	
			50	6	H.T.	277	·49	·68	6·0	170	
					H.T'	255	·54	·74	6·5	166	
					H.T.	223	·60	·81	7·2	165	
			45	6	H.T.	255	·54	·74	6·5	166	
					H.T.	223	·60	·81	7·2	165	
					H.T.	201	·65	·85	7·8	163	
					H.R.	201	·66	·87	7·9	163	
					A.	190	·70	·91	8·4	160	
En 18	Black or bright.	H.T.	55	1⅛	H.T.	302	·30	·39	3·6	157	„ „ „ „
					H.T.	277	·34	·41	4·1	145	
					H.T.	248	·38	·43	4·6	138	
			50	2½	H.T.	277	·34	·41	4·1	145	
					H.T.	255	·37	·43	4·4	141	
					H.T.	223	·42	·45	5·0	131	
			45	4	H.T.	255	·37	·43	4·4	141	
					H.T.	223	·42	·45	5·0	131	
					H.T.	201	·45	·47	5·4	127	
					H.R.	201	·47	·48	5·6	125	
					H.R.	223	·44	·47	5·3	131	
					H.R.	255	·39	·45	4·7	141	
					A.	201	·46	·44	5·5	116	
En 18 A											Steels for special applications. M factor as for En 18.
En 18 B											
En 18 C											
En 18 D											
En 19	Black or bright.	H.T.	70	1⅛	H.T.	375	·22	·34	2·6	190	Bright bars may be subjected to cold work after heat treatment unless otherwise specified. Note.—The 70-ton range only applies to En 19.
En 19 A					H.T.	341	·25	·35	3·0	171	
					H.T.	311	·28	·37	3·4	161	
			65	1⅛	H.T.	341	·25	·35	3·0	171	
					H T.	311	·28	·37	3·4	161	
					H.T.	293	·30	·38	3·6	154	
			60	2½	H.T.	321	·27	·37	3·2	166	
					H.T.	293	·30	·38	3·6	154	
					H.T.	269	·34	·40	4·1	144	
			55	2½	H.T.	302	·29	·37	3·5	156	
					H.T.	277	·33	·40	4·0	146	
					H.T.	248	·36	·41	4·3	138	
			50	4	H.T.	277	·33	·40	4·0	146	
					H.T.	255	·34	·39	4·3	138	
					H.T.	223	·38	·41	4·9	131	
			45	6	H.T.	255	·34	·39	4·3	146	
					H.T.	223	·38	·41	4·9	131	
					H.T.	201	·40	·43	4·8	128	
					A.	190	·45	·45	5·4	122	

TABLE 61.—

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	P
En 19 B	1% chromium-molybdenum steel.	·35–·4	·1–·35	·5–·8		·9–1·2	·2–·35			
En 19 C		·4–·45	·1–·35	·5–·8		·9–1·2	·2–·35			
En 20	1% chromium-molybdenum steel for high-temperature bolts.	·22–·5	·1–·35	·4–·7	<·3	·5–1·5	·4–1·0		<·05	<·05
En 21	3% nickel steel	·25–·35	·1–·35	·35–·75	2·75–3·5	<·3			<·05	<·05
En 22	3½% nickel steel.	·35–·45	·1–·35	·5–·8	3·25–3·75	<·3			<·05	<·05
En 23	3% nickel-chromium steel.	·25–·35	·1–·35	·45–·7	2·75–3·5	·5–1·0	optional <·65		<·05	<·05

(*Continued*)

Spec. No.	How supplied		Properties				Constants				Remarks
	Bar	Forgings	U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 19 B											Steels for special application. *M* factor as for En 19.
En 19 C											
En 20	Black or bright.	H.T.	65	1½	H.T.	341	·25	·34	3·0	171	Bright bars may be subjected to cold work after H.T. unless otherwise stated.
					H.T.	321	·27	·37	3·2	166	
					H.T.	293	·30	·38	3·6	154	
			55	2½	H.T.	302	·29	·37	3·5	156	
					H.T.	277	·33	·40	4·0	146	
					H.T.	248	·36	·41	4·3	138	
					A.	190	·45	·45	5·4	122	
En 21	Black or bright.	H.T.	50	2½	H.T.	277	·42	·49	5·0	142	Bright. Heat-treated bars may be cold worked after treatment.
					H.T.	255	·45	·51	5·4	138	
					H.T.	223	·51	·56	6·1	134	
			45	4	H.T.	255	·45	·51	5·4	138	
					H.T.	227	·50	·55	6·0	135	
					H.T.	201	·55	·59	6·7	131	
					A.	190	·58	·61	6·9	129	
En 22	Black or bright.	H.T.	55	2½	H.T.	302	·38	·46	4·6	147	" " " "
					H.T.	277	·42	·49	5·0	142	
					H.T.	248	·46	·52	5·5	137	
			50	4	H.T.	277	·42	·49	5·0	142	
					H.T.	255	·45	·51	5·4	138	
					H.T.	223	·51	·56	6·1	134	
					H.R.	277	·42	·49	5·0	142	
					H.R.	223	·51	·56	6·1	134	
					A.	210	·54	·57	6·4	129	
En 23	Black or bright.	H.T.	65	2½	H.T.	341	·25	·39	3·0	191	" " " "
					H.T.	321	·28	·43	3·3	186	
					H.T.	293	·32	·42	3·8	160	
			60	6	H.T.	321	·28	·43	3·3	186	
					H.T.	302	·31	·41	3·7	162	
					H.T.	269	·36	·43	4·3	145	
			55	6	H.T.	302	·31	·41	3·7	162	
					H.T.	277	·34	·41	4·1	148	
					H.T.	248	·39	·45	4·7	140	
			50	6	H.T.	277	·34	·41	4·1	148	
					H.T.	255	·38	·44	4·6	141	
					H.T.	223	·43	·47	5·2	132	
					H.R.	321	·28	·43	3·3	186	
					H.R.	223	·43	·46	5·2	132	
					A.	269	·36	·43	4·3	145	
					A.	210	·50	·57	6·2	129	

TABLE 61.—

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	
En 24	1½% nickel-chromium-molybdenum steel.	·35–·45	·1–·35	·45–·70	1·3–1·8	·9–1·4	·2–·35		$<$·05	$<$·05
En 25	2½% nickel-chromium-molybdenum steel.	·27–·35	·1–·35	·5–·7	2·3–2·8	·5–·8	·4–·7		$<$·05	$<$0·5

(*Continued*)

Spec. No.	How supplied		Properties				Constants				Remarks
	Bar	Forgings	U.T.S. Tons sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_f lb., thousands	
En 24	H.T. if bright, softened if black.	H.T.	100	1⅛	H.T.	>444	·19	·39	2·3	250	Bright bars may be subject to cold work after heat treatment unless otherwise specified.
			80	1⅛	H.T.	415	·21	·36	2·5	210	
					H.T.	388	·23	·36	2·8	190	
					H.T.	363	·25	·27	3·0	180	
			75	1⅛	H.T.	388	·23	·36	2·8	190	
					H.T.	363	·25	·27	3·0	180	
					H.T.	341	·27	·38	3·3	170	
			70	1⅛	H.T.	375	·24	·36	2·9	185	
					H.T.	341	·27	·38	3·3	170	
					H.T.	311	·29	·37	3·5	157	
			65	2½	H.T.	341	·27	·38	3·3	170	
					H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
			60	4	H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
					H.T.	269	·33	·39	4·0	145	
			55	6	H.T.	302	·30	·38	3·6	155	
					H.T.	277	·32	·39	3·8	148	
					H.T.	248	·34	·39	4·1	140	
			50	6	H.T.	277	·32	·39	3·8	148	
				6	H.T.	255	·34	·40	4·1	142	
				6	H.T.	223	·36	·40	4·3	135	
					A.	269	·34	·40	4·1	145	
					A.	210	·48	·50	5·8	127	
En 25	H.T. if bright, softened if black.	H.T.	100	2½	H.T.	>444	·19	·39	2·3	250	,, ,, ,, ,,
			80	2½	H.T.	415	·21	·36	2·5	210	
					H.T.	388	·23	·36	2·8	190	
					H.T.	363	·25	·27	3·0	180	
			75	2½	H.T.	388	·23	·36	2·8	190	
					H.T.	363	·25	·27	3·0	180	
					H.T.	341	·27	·38	3·3	170	
			70	4	H.T.	375	·24	·36	2·9	185	
					H.T.	341	·27	·38	3·3	170	
					H.T.	311	·29	·37	3·5	157	
			65	6	H.T.	341	·27	·38	3·3	170	
					H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
			60	6	H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
					H.T.	269	·33	·39	4·0	145	
			55	6	H.T.	302	·30	·38	3·6	155	
					H.T.	277	·32	·39	3·8	148	
					H.T.	248	·34	·39	4·1	140	
					A.	277	·32	·39	3·8	148	
					A.	210	·48	·50	5·8	127	

TABLE 61.—

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	P
En 26	2½% nickel-chromium steel.	·36–·44	·1–·35	·5–·7	2·3–2·8	·5–·8	·4–·7		<·05	<·05
En 27	3% nickel-chromium-molybdenum steel.	·25–·35	·1–·35	<·7	3·0–3·75	·3–1·3	·2–·65		<·05	<·05
En 28	3½% nickel-chromium-molybdenum steel.	·25–·4	·1–·35	<·7	3·0–4·5	·75–1·5	·2–·65		<·05	<·05

(*Continued*)

Spec. No.	How supplied		Properties				Constants				Remarks
	Bar	Forgings	U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 26	Black bars softened, bright bars H.T.	H.T.	100	4	H.T.	>444	·19	·39	2·3	250	Bright bars may be subject to cold work after heat treatment unless otherwise specified.
			80	6	H.T.	415	·21	·36	2·5	210	
					H.T.	388	·23	·36	2·8	190	
					H.T.	363	·25	·27	3·0	180	
			75	6	H.T.	388	·23	·36	2·8	190	
					H.T.	363	·25	·27	3·0	180	
					H.T.	341	·27	·38	3·3	170	
			70	6	H.T.	375	·24	·36	2·9	185	
					H.T.	341	·27	·38	3·3	170	
					H.T.	311	·29	·37	3·5	157	
			65	6	H.T.	341	·27	·38	3·3	170	
					H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
			60	6	H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
					H.T.	269	·33	·39	4·0	145	
					A.	277	·32	·39	3·8	148	
					A.	217	·46	·47	5·5	126	
En 27	Black or bright.	H.T.	70	4	H.T.	375	·24	·36	2·9	185	,, ,, ,, ,,
					H.T.	341	·27	·38	3·3	170	
					H.T.	311	·29	·37	3·5	157	
			65	6	H.T.	341	·27	·38	3·3	170	
					H.T.	311	·29	·37	3·5	157	
					H.T.	293	·31	·40	3·7	157	
			60	6	H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
					H.T.	269	·33	·39	4·0	145	
			55	6	H.T.	302	·30	·38	3·6	155	
					H.T.	277	·32	·39	3·8	148	
					H.T.	248	·34	·39	4·1	140	
					A.	277	·32	·39	3·8	148	
					A.	210	·50	·56	6·0	128	
En 28	Black bars H.T. up to 71 tons; black bars soft over 70 tons; bright bars H.T.	H.T.	80	2½	H.T.	415	·21	·36	2·5	210	
					H.T.	388	·23	·36	2·8	190	
					H.T.	363	·25	·27	3·0	180	
			70	4	H.T.	375	·24	·36	2·9	185	
					H.T.	341	·27	·38	3·3	170	
					H.T.	311	·29	·37	3·5	157	
			65	6	H.T.	341	·27	·38	3·3	170	
					H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
			60	6	H.T.	321	·28	·38	3·4	165	
					H.T.	293	·31	·40	3·7	157	
					H.T.	269	·33	·39	4·0	145	
					A.	277	·32	·41	3·8	156	
					A.	210	·51	·57	6·2	129	

TABLE 61.—

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	P
En 29	3% chromium-molybdenum steel.	·15–·35	·1–·35	<·65	<·4	2·5–3·5	·3–·7		<·05	<·05
En 30 A	4¼% nickel-chromium steel.	·26–·34	·1–·35	·4–·6	3·9–4·3	1·1–1·4			<·05	<·05
En 30 B	4¼% nickel-chromium-molybdenum steel.	·26–·34	·1–·35	·4–·6	3·9–4·3	1·1–1·4	·2–·4		<·05	<·05
En 31	1% carbon chromium steel.	·9–1·2	·1–·35	·3–·75		1·0–1·6			<·05	<·05
En 100	Low alloy steel.	·35–·45	<·5	1·2–1·5	·5–1·0	·3–·6	·15–·25		<·05	<·05
En 100 A	Low alloy steel.	·25–·3	·1–·35	1·2–1·5	·5–1·0	·3–·6	·15–·25			
En 100 B		·3–·35	·1–·35	1·2–1·5	·5–1·0	·3–·6	·15–·25			
En 100 C		·35–·4	·1–·35	1·2–1·5	·5–1·0	·3–·6	·15–·25			
En 100 D		·4–·45	·1–·35	1·2–1·5	·5–1·0	·3–·6	·15–·25			

(*Continued*)

Spec. No.	How supplied		Properties				Constants				Remarks
	Bar	Forgings	U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 29	Black bars H.T. up to 71 tons; black bars soft over 70 tons; bright bars H.T.	H.T.	100	2½	H.T.	>444	·18	·38	2·2	252	Bright bars may be subject to cold work unless otherwise specified.
			80	2½	H.T.	415	·21	·44	2·5	242	
					H.T.	388	·22	·42	2·6	230	
					H.T.	363	·24	·40	2·9	205	
			70	4	H.T.	375	·23	·40	2·7	215	
					H.T.	341	·26	·40	3·1	187	
					H.T.	311	·29	·40	3·5	166	
			65	6	H.T.	341	·26	·40	3·1	187	
					H.T.	321	·28	·39	3·3	174	
					H.T.	293	·31	·40	3·7	159	
			60	6	H.T.	321	·28	·39	3·3	174	
					H.T.	293	·31	·40	3 7	159	
					H.T.	269	·34	·40	4·1	145	
					A.	277	·33	·43	4·0	159	
					A.	220	·46	·47	5 5	128	
En 30 A	Black soft.	Soft.	100	6	H.T.	>444	·18	·38	2·2	250	
					A.	285	·32	·41	3·8	158	
					A.	220	·46	·47	5·5	129	
En 30 B	Black soft.	Soft.	100	6	H.T.	>444	·18	·38	2·2	250	
					A.	285	·32	·41	3·8	158	
					A.	220	·46	·47	5·5	129	
En 31	Black soft.	Soft.			A.	229	·42	·45	5·2	130	
					A.	187	·52	·53	6·2	125	
En 100	Black or bright.	H.T.	65	1⅛	H.T.	341	·26	·47	3·1	220	
					H.T.	321	·28	·46	3·4	200	
					H.T.	293	·32	·43	3·9	165	
			60	1⅛	H.T.	321	·28	·46	3·4	200	
					H.T.	293	·32	·43	3·9	165	
					H.T.	269	·34	·42	4·1	151	
			55	2½	H.T.	302	·30	·43	3·6	173	
					H.T.	277	·33	·42	4·0	156	
					H.T.	248	·38	·43	4·6	139	
			50	4	H.T.	277	·33	·42	4·0	156	
					H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
			45	6	H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
					H.T.	201	·50	·51	6·0	124	
					H.R.	201	·47	·50	5·6	128	
					A.	207	·48	·51	5·8	125	
					A.	183	·54	·51	6·4	123	
En 100 A En 100 B En 100 C En 100 D					A.	183	·54	·51	6·4	123	Steels for special application. M factor as for En 100.

TABLE 61.—

Spec. No.	Description	C	Si	Mn	Ni	Cr	Mo	V	S	P
En 110	Low nickel-chromium-molybdenum steel.	·35–·45	·1–·35	·4–·8	1·2–1·6	·9–1·4	·1–·2		<·05	<·05
En 111	Low nickel-chromium steel.	·3–·4	·1–·35	·6–·9	1·0–1·5	·45–·75			<·05	<·05
En 111 A	Low nickel-chromium steel.	·33–·38	·1–·35	·6–·9	1·0–1·5	·45–·75			<·05	<·05
En 160	2% nickel-molybdenum steel.	·35–·45	·1–·35	·3–·6	1·5–2·0		·2–·35		<·05	<·05
En 160 A	2% nickel-molybdenum steel.	·38–·43	·1–·35	·3–·6	1·5–2·0		·2–·35			

(Continued)

	How supplied		Properties				Constants				
Spec. No.	Bar	Forgings	U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	Remarks
En 110	Black or bright.	H.T.	70	1⅛	H.T.	375	·23	·41	2·7	245	Cold work may be given to heat-treated bars unless otherwise specified.
					H.T.	341	·26	·47	3·1	220	
					H.T.	311	·29	·40	3·5	166	
			65	1⅛	H.T.	341	·26	·47	3·1	220	
					H.T.	321	·28	·46	3·4	200	
					H.T.	293	·32	·43	3·9	165	
			60	2½	H.T.	321	·28	·46	3·4	200	
					H.T.	293	·32	·43	3·9	165	
					H.T.	269	·34	·42	4·1	151	
			55	4	H.T.	302	·30	·43	3·6	173	
					H.T.	277	·33	·42	4·0	156	
					H.T.	248	·38	·43	4·6	139	
			50	6	H.T.	277	·33	·42	4·0	156	
					H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
			45	6	H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
					H.T.	201	·50	·51	6·0	124	
					H.R.	210	·47	·49	5·6	128	
					A.	269	·34	·42	4·1	151	
					A.	180	·56	·52	6·7	125	
En 111	Black or bright.	H.T	60	1⅛	H.T.	321	·28	·46	3·4	200	Cold work may be given the bars after heat treatment unless otherwise specified.
					H.T.	302	·30	·43	3·6	173	
					H.T.	269	·34	·42	4·1	151	
			55	2½	H.T.	302	·30	·43	3·6	173	
					H.T.	277	·33	·42	4·0	156	
					H.T.	248	·38	·43	4·6	139	
			50	4	H.T.	277	·33	·42	4·0	156	
					H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
			45	6	H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
					H.T.	201	·50	·51	6·0	124	
					H.R.	210	·47	·49	5·6	128	
					A.	197	·52	·52	6·2	122	
En 111 A					A.	207	·48	·50	5·8	125	Steel for special applications. M factor as for En 111.
En 160	Black or bright.	H.T.	60	1⅛	H.T.	321	·28	·46	3·4	200	Cold work may be given the bright bars after heat treatment unless otherwise specified.
					H.T.	302	·30	·43	3·6	173	
					H.T.	269	·34	·42	4·1	151	
			55	2½	H.T.	302	·30	·43	3·6	173	
					H.T.	277	·33	·42	4·0	156	
					H.T.	248	·38	·43	4·6	139	
			50	4	H.T.	277	·33	·42	4·0	156	
					H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
			45	6	H.T.	255	·37	·43	4·3	142	
					H.T.	223	·44	·47	5·3	129	
					H.T.	201	·50	·51	6·0	124	
					H.R.	210	·47	·49	5·6	128	
					A.	201	·51	·51	6·1	122	
En 160 A					A.	201	·51	·51	6·1	122	Steel for special applications. M factor as for En 160.
					N.	248	·38	·41	4·2	122	

TABLE 62.—B.S. 970 EN SERIES. CASE-HARDENING AND

Spec. No.	Description	Composition								
		C	Si	Mn	Ni	Cr	Mo	V	S	P
En 32 A	Carbon case-hardening steel.	<·15	·05–·35	·4–·7					<·05	<·05
En 32 B	Carbon case-hardening steel.	·1–·18	·05–·35	·7–1·1					<·07	<·05
En 32 M	Carbon case-hardening steel, semi-free-cutting.	·1–·18	·05–·35	·7–1·1					·1–·15	<·05
En 33	3% nickel case-hardening steel.	·1–·15	·1–·35	·3–·6	2·75–3·5	<·3			<·05	<·05
En 34	2% nickel-molybdenum case-hardening steel.	·14–·2	·1–·35	·3–·6	1·5–2·0		·2–·3		<·05	<·05
En 35	2% nickel-molybdenum case-hardening steel.	·2–·28	·1–·35	·3–·6	1·5–2·0		·2–·3		<·05	<·05
En 35 A	2% nickel-molybdenum C.H. steel.	·2–·25	·1–·35	·3–·6	1·5–2·0		·2–·3			
En 35 B	2% nickel-molybdenum C.H. steel.	·23–·28	·1–·35	·3–·6	1·5–2·0		·2–·3			

NITRIDING STEELS. CORE STRENGTH 32-85 TONS/SQ. IN.

Spec. No.	How supplied		U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Constants				Remarks
	Bar	Forgings					Machining M	H.P. index P	Speed index C_v	Cutting force C_p lb. thousands	
En 32 A	Black or bright C.D. or machined.	A.F.			H.R.	127	1·00	1·00	12	122	For sections ½″ or below.
					C.D.		·66	·73	7·9	135	For ¼ in. dia. bar *M* factor.
					C.D.		·72	·78	8·6	132	For ⅜ ,, ,, ,,
					C.D.		·76	·81	9·1	130	For ½ ,, ,, ,,
			32	½	H.T.	150	·80	·85	9·6	129	Core only.
En 32 B	Black or bright C.D. or machined.	A.F.			H.R.	126	1·00	1·00	12	122	For sections over ½ in.
					C.D.		·76	·81	9·1	130	For ½ in. dia. bar *M* factor.
					C.D.		·87	·89	10·5	125	For 1 ,, ,, ,,
					C.D.		·96	·95	11·5	120	For 1½ ,, ,, ,,
					C.D.		1·00	·95	12·0	115	For 2 ,, ,, ,,
			32	over ½	H.T.	150	·80	·85	9·6	129	Core only.
En 32 M	Black or bright C.D. or machined.	A.F.			H.R.	145	1·87	1·15	22·2	75	
					C.D.		1·23	·84	14·8	84	For ¼ in. dia. bar *M* factor.
					C.D.		1·40	·95	16·8	83	For ½ ,, ,, ,,
					C.D.		1·53	1·03	18·2	82	For ¾ ,, ,, ,,
					C.D.		1·62	1·07	19·4	81	For 1 ,, ,, ,,
					C.D.		1·71	1·11	20·5	79	For 1¼ ,, ,, ,,
					C.D.		1·80	1·12	21·5	77	For 1½ ,, ,, ,,
					C.D.		1·87	1·15	22·2	75	For 2 ,, ,, ,,
			32		H.T.		1·12	·83	13·4	86	Core only.
En 33	Black or bright C.D.	A.F.	45		H.T.	235	·50	·55	6·0	134	Core only.
					H.R.	163	·88	·88	10·6	122	
					C.D.		·60	·66	7·2	134	For ¼ in. dia. bar *M* factor.
					C.D.		·73	·78	8·7	131	For ¾ ,, ,, ,,
					C.D.		·78	·82	9·4	128	For 1 ,, ,, ,,
					C.D.		·86	·88	10·3	125	For 1½ ,, ,, ,,
					C.D.		·90	·90	10·8	122	For 2 ,, ,, ,,
En 34	Black or bright C.D.	A.F.	45		H.T.	229	·42	·44	5·0	128	Core only.
					H.R.	183	·58	·52	7·0	110	
					C.D.		·44	·45	5·3	125	For ½ in. dia. bars.
					C.D.		·50	·49	6·0	120	For 1 ,, ,,
					C.D.		·55	·56	6·6	125	For 1½ ,, ,,
					C.D.		·58	·52	7·0	110	For 2 ,, ,,
En 35	Black or bright C.D.	A.F.	55		H.T.	250	·38	·41	4·6	131	Core only.
					H.R.	167	·60	·53	7·2	108	
					C.D.		·44	·45	5·3	125	For ½ in. dia. bars.
					C.D.		·50	·49	6·0	120	For 1 ,, ,,
					C.D.		·55	·51	6·6	125	For 1½ ,, ,,
					C.D.		·58	·52	7·0	111	For 2 ,, ,,
En 35 A					A.	153	·65	·56	7·8	105	Steels for special application. *M* factor as for En 35.
En 35 B					A.	153	·65	·56	7·8	105	

Table 62.—

Spec. No.	Description	Composition								
		C	Si	Mn	Ni	Cr	Mo	V	S	P
En 36	3% nickel-chromium case-hardening steel.	<·18	·1–·35	·3–·6	3·00–3·75	·6–1·1			<·05	<·05
En 37	5% nickel case-hardening steel.	<·16	·1–·35	·45	4·5–5·2	·3			<·05	<·05
En 38	5% nickel case-hardening steel.	<·16	·1–·35	<·6	4·5–5·5	·3	Optional ·15–·3		<·05	<·05
En 39 A	4¼% nickel-chromium case-hardening steel.	·12–·18	·1–·35	<·5	3·8–4·5	1·0–1·4			<·05	<·05
En 39 B	4¼% nickel-chromium-molybdenum case-hardening steel.	·12–·18	·1–·35	<·5	3·8–4·5	1·0–1·4	·15–·35		<·05	<·05
En 40 A	3% chromium-molybdenum.	·1–·2	·1–·35	·4–·65	<·4	2·9–3·5	·4–·7		<·05	<·05
En 40 B	Nitriding steels.	·2–·3	·1–·35	·4–·65	<·4	2·9–3·5	·4–·7		<·05	<·05
En 40 C	3% chromium-molybdenum-vanadium nitriding steel.	·3–·5	·1–·35	·4–·8	<·4	2·5–3·5	·7–1·2	·1–·3	<·05	<·05

(*Continued*)

Spec. No.	How supplied		U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Constants				Remarks
	Bar	Forgings					Machining M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 36	Black or bright C.D.	A.F.	80		H.T.	360	·24	·40	2·9	042	Core only.
			75		H.T.	330	·27	·37	3·3	175	,, ,,
			65		H.T.	290	·33	·40	3·9	146	,, ,,
			55		H.T.	260	·36	·41	4·3	138	,, ,,
					A.	153	·71	·53	8·5	91	
					C.D.		·42	·43	5·0	126	For ½ in. dia. bars.
					C.D.		·49	·50	5·9	125	For 1 ,, ,,
					C.D.		·52	·53	6·2	123	For 1½ ,, ,,
					C.D.		·56	·56	6·7	122	For 2 ,, ,,
En 37	Black A.R., bright C.D.	A.F.	60		H.T.	286	·41	·48	4·9	142	The hardness of the C.D. bars can, upon agreement, be varied to suit buyers' requirements.
			50		H.T.	240	·48	·54	5·8	137	
			40		H.T.	180	·60	·61	7·0	123	
					A.	160	·68	·57	8·2	120	
					H.R.	179	·63	·63	7·5	123	
					C.D.		·42	·49	5·0	142	For ½ in. dia. bars.
					C.D.		·48	·54	5·8	137	For 1 ,, ,,
					C.D.		·53	·57	6·4	132	For 1½ ,, ,,
					C.D.		·55	·59	6·6	130	For 2 ,, ,,
En 38	Black as rolled, bright C.D.	A.F.	>65		H.T.	302	·38	·47	4·8	150	Core only.
			55		H.T.	229	·50	·55	6·0	135	C.D. bars can have, by agreement, the B.H. No. varied to suit requirements.
			40		H.T.	180	·60	·61	7·0	123	
					H.R.	180	·63	·63	7·5	123	
					N.	179	·63	·63	7·5	123	
					C.D.		·42	·49	5·0	142	For ½ in. dia. bars.
					C.D.		·48	·54	5·8	137	For 1 ,, ,,
					C.D.		·53	·57	6·4	132	For 1½ ,, ,,
					C.D.		·55	·59	6·6	130	For 2 ,, ,,
En 39 A	Black bars soft, bright bars C.D.	Soft	>85		H.T.	388	·23	·44	2·7	232	Core only.
			75		H.T.	350	·25	·41	3·0	200	
			70		H.T.	326	·28	·39	3·4	172	
En 39 B					A.	277	·33	·45	4·0	168	
					A.	219	·47	·49	5·5	130	
					C.D.		·30	·50	3·6	170	For ½ in. dia. bar.
					C.D.		·35	·46	4·2	160	For 1 ,, ,,
					C.D.		·38	·45	4·6	145	For 1½ ,, ,,
					C.D.		·40	·43	4·8	130	For 2 ,, ,,
En 40 A	Black and bright bars H.T.	H.T.	60	4	H.T.	302	·32	·45	3·8	173	The bright H.T. bars may be cold worked after treatment unless otherwise specified.
			55	6	H.T.	248	·38	·43	4·6	139	
En 40 B			50	6	H.T.	223	·40	·42	4·8	129	
			45	6	H.T.	201	·45	·46	5·4	124	
					A.	180	·56	·52	6·7	122	
En 40 C	Black bars soft, bright bars H.T.	Soft	70		H.T.	401	·22	·41	2·6	216	,, ,, ,, ,,
					H.T.	341	·26	·47	3·1	208	
					H.T.	311	·29	·40	3·5	166	
			65		H.T.	341	·26	·47	3·1	208	
					H.T.	311	·29	·40	3·5	166	
					H.T.	293	·31	·41	3·7	161	
			60		H.T.	321	·28	·46	3·4	200	
					H.T.	293	·31	·41	3·7	161	
					H.T.	269	·34	·42	4·1	151	
			55		H.T.	302	·30	·43	3·6	163	
					H.T.	277	·33	·42	4·0	156	
					H.T.	248	·38	·43	4·6	139	

TABLE 62.—

Spec. No.	Description	Composition								
		C	Si	Mn	Ni	Cr	Mo	S	P	Al
En 41	1½% chromium-aluminium-molybdenum nitriding steel.	·18–·45	·1–·45	<·65	<·4	1·4–1·8	·1–·25	<·05	<·05	·9–1·3
En 201	Carbon-manganese case-hardening steel.	<·18	·05–·35	1·1–1·5				<·05	<·05	
En 202	Carbon-manganese case-hardening steel, semi-free-cutting.	<·18	·05–·35	1·1–1·5				·1–·18	<·05	
En 206	Low-chromium case-hardening steel.	·12–·17	·1–·35	·3–·5		·3–·5		<·05	<·05	
En 207	Low-chromium case-hardening steel.	·16–·21	·1–·35	·6–·8		·6–·8		<·05	<·05	
En 320	2% nickel-chromium-molybdenum case-hardening steel.	·14–·20	·1–·35	·4–·7	1·8–2·2	1·8–2·2	·15–·25	<·05	<·05	
En 325	Low-nickel-chromium-molybdenum case-hardening steel.	·17–·22	·1–·35	·45–·65	1·5–2·0	·4–·6	·2–·3	<·05	<·05	

(*Continued*)

Spec. No.	How supplied		U.T.S. Tons sq. in.	Ruling section	Condition	B.H. No.	Constants				Remarks
	Bar	Forgings					Machining M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 41	Black and bright bars H.T.	H.T.	55		H.T.	302	·30	·39	3·6	159	Bright bars may be subject to cold work after H.T. unless otherwise specified.
					H.T.	277	·33	·40	4·0	148	
					H.T.	248	·37	·42	4·4	137	
			45		H.T.	255	·37	·42	4·4	137	
					H.T.	225	·43	·46	5·2	129	
					H.T.	201	·50	·50	6·0	122	
			35		H.T.	207	·49	·50	5·9	125	
					H.T.	179	·59	·57	7·1	118	
					H.T.	152	·70	·63	8·4	110	
En 201	Black as rolled, bright C.D. or machined.	A.F.	40		H.T.	180	·7	·93	8·4	161	Core only.
					H.R.	153	·75	·90	9·0	147	
					A.	130	·97	1·00	11·7	122	
					C.D.		·57	·75	6·8	162	For ½ in. dia. bars.
					C.D.		·65	·84	7·8	158	For 1 ,, ,,
					C.D.		·72	·92	8·6	155	For 1½ ,, ,,
					C.D.		·75	·93	9·0	152	For 2 ,, ,,
En 202	Black as rolled, bright C.D. or machined.	A.F.	38		H.T.	180	·87	·66	10·5	93	Core only.
					H.R.	166	1·15	·85	13·8	85	
					A.	130	1·30	·83	15·6	79	
					C.D.		·87	·66	10·5	93	For ½ in. dia. bar.
					C.D.		1·0	·74	12·0	90	For 1 ,, ,,
					C.D.		1·1	·78	13·2	87	For 1½ ,, ,,
					C.D.		1·15	·85	13·8	85	For 2 ,, ,,
En 206	Black as rolled, bright C.D.	A.F.	45		H.T.	210	·45	·45	5·4	122	Core only.
					H.R.	143	·66	·56	7·8	105	
					A.	130	·98	1·00	11·7	122	
					C.D.		·49	·48	5·9	120	For ½ in. dia. bar.
					C.D.		·57	·53	6·8	112	For 1 ,, ,,
					C.D.		·62	·58	7·4	112	For 1½ ,, ,,
					C.D.		·65	·59	7·8	110	For 2 ,, ,,
En 207	Black as rolled, bright C.D.	A.F.	70		H.T.	335	·27	·36	3·2	160	Core only.
			45		H.T.	210	·46	·46	5·5	122	,, ,,
					H.R.	170	·61	·55	7·3	110	
					A.	135	·95	1·00	11·4	122	
					C.D.		·48	·48	5·8	121	For ½ in. dia. bar.
					C.D.		·55	·53	6·6	117	For 1 ,, ,,
					C.D.		·60	·57	7·2	115	For 1½ ,, ,,
					C.D.		·63	·58	7·6	112	For 2 ,, ,,
En 320	Black bars soft, bright bars C.D.	Softened	85		H.T.	375	·23	·42	2·8	220	Core only.
					H.T.	230	·44	·51	5·3	140	,, ,,
					A.	241	·43	·49	5·2	140	
					A.	200	·50	·53	6·0	130	
					C.D.		·32	·41	3·8	156	For ½ in. dia. bar.
					C.D.		·36	·45	4·3	152	For 1 ,, ,,
					C.D.		·40	·47	4·8	144	For 1½ ,, ,,
					C.D.		·42	·48	5·0	140	For 2 ,, ,,
En 325	Black bars as rolled, bright bars C.D.	A.F.	55		H.T.	235	·36	·40	4·4	137	Core only.
					H.R.	167	·60	·53	7·2	108	
					A.	153	·78	·64	9·3	100	
					C.D.		·44	·45	5·3	125	For ½ in. dia. bar.
					C.D.		·50	·49	6·0	120	For 1 ,, ,,
					C.D.		·55	·52	6·6	115	For 1½ ,, ,,
					C.D.		·58	·53	7·0	111	For 2 ,, ,,

TABLE 63.—B.S. 970[16] En

Spec. No.	Description	C	Si	Mn	Cr	V	S	P
En 42	Carbon spring steel oil-hardening and tempering.	·7–·85	·1–·4	·55–·75			<·05	<·05
En 42 A	,, ,, ,, ,, ,,	·6–·9	<·35	·35–·9			<·05	<·05
En 43	,, ,, water-hardening.	·45–·6	·1–·4	·6–·8			<·05	<·05
En 43 F	,, ,, ,, ,, ,,	·45–·6	<·35	·35–·9			<·05	<·05
En 44	Carbon steel oil-hardening and tempering.	·9–1·2	<·3	·45–·7			<·05	<·05
En 44 A	,, ,, ,, ,, ,,	·9–1·25	<·35	·35–·9			<·05	<·05
En 45	Silicon-manganese spring steel oil-hardening and tempering.	·5–·65	1·5–2·0	·7–1·0			<·05	<·05
En 45 A	Silicon-manganese spring steel oil-hardening and tempering.	·53–·63	1·7–2·0	·7–1·0			<·05	<·05
En 46	Silicon-manganese spring steel water-hardening and tempering.	·35–·45	1·5–2·0	·6–1·0			<·05	<·05
En 47	1% chromium-vanadium steel oil-hardening and tempering.	·45–·55	<·5	·5–·8	·8–1·2	<·15	<·05	<·05
En 48	1% chromium steel oil-hardening and tempering.	·45–·55	·1–·5	·5–·8	1·0–1·4		<·05	<·05
En 49	Carbon steel for hard-drawn wire.	·4–·85	·3	<1·0			<·05	<·05
En 49 A	,, ,, ,, ,, ,,	·4–·85	·3	<1·0			<·05	<·05
En 49 B	,, ,, ,, ,, ,,	·4–·85	·3	<1·0			<·05	<·05
En 49 C	,, ,, ,, ,, ,,	·55–·85	·3	<·75			<·04	<·04
En 49 D	,, ,, ,, ,, ,,	·65–·85	·3	·4–·75			<·04	<·04
En 50	Chromium-vanadium steel wire for valve spring.	·4–·5	·1–·35	·5–·7	1–1·5	·15	<·04	<·04

SERIES. SPRING STEELS

Spec. No.	How supplied		U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Constants				Remarks
	Bars for machining	Forgings					Machining index M	H.P. index P	Speed index C_v	Cutting force C_p, lb., thou.	
En 42					H.T.	375 340	·22 ·28	·41 ·46	2·6 3·4	216 200	Laminated spring plate.
En 42 A											Cold-rolled strip and flat wire, special applications.
En 43					H.T.	532 336	·28	·46	3·4	200	Laminated spring steel. See also under B.S. 970 En 43 A, p. 122.
En 43 F											Cold-rolled strip and flat wire, special application.
En 44					H.T.	335	·28	·46	3·4	200	
En 44 A											Cold-rolled strip and flat-wire steel for special application.
En 45					H.T.	496 324	·29	·40	3·5	166	Laminated spring steel.
En 45 A											Laminated spring steel.
En 46					H.T.	461 363	·23	·44	2·7	232	Laminated spring steel.
En 47					H.T.	482 377	·22	·41	2·6	216	” ” ” ”
En 48					H.T.	477 321	·29	·4	3·5	166	” ” ” ”
En 49			85 to 150								
En 49 A											
En 49 B											
En 49 C											
En 49 D											
En 50	Wire.		90–110		Soft.	·187	·52	·53	6·2	125	

TABLE 64.—B.S. 970[16]

Spec. No.	Description	C	Si	Mn	Ni	Cr	W	S	P
En 51	3 % nickel valve steel.	·25–·35	·1–·35	·35–·75	2·75–3·5	<·3		<·05	<·05
En 52	Silicon-chromium valve steel.	·4–·5	3·0–3·75	·3–·6	<·5	7·5–9·5		<·04	<·04
En 53	Silicon-chromium valve steel.	·55–·65	1·4–1·7	·3–·6	<·5	5·75–6·75		<·05	<·05
En 54	High nickel-chromium-tungsten valve steel.	·35–·5	1·0–2·5	<1·5	>10·0	12·0–16·0	2·0–4·0	<·05	<·05
En 55	High chromium-nickel-tungsten valve steel.	·18–·45	1·0–2·5	<1·0	6·0–12·0	17·0	2·0–4·0	<·05	<·05
En 59	Chromium-nickel valve steel.	·74–·84	1·75–2·25	·2–·6	1·15–1·65	19·0–20·5		<·03	<·03

TABLE 65—B.S. 970[16] EN SERIES.

Spec. No.	Description	C	Si	Mn	Ni	Cr	W	S	P
En 56 A	Chromium rust-resisting steel.	<·12	<1·0	<1·0	<1·0	12–14	<·05	<·05	
En 56 B	,, ,, ,, ,,	·12–·18	<1·0	<1·0	<1·0	12–14	<·05	<·05	
En 56 C	,, ,, ,, ,,	·18–·25	<1·0	<1·0	<1·0	12–14	<·05	<·05	
En 56 D	,, ,, ,, ,,	·25–·35	<1·0	<1·0	<1·0	12–14	<·05	<·05	
En 56 M	,, ,, free-cutting.								
En 57	High-tensile chromium rust-resisting steel.	<·25	·1–1·0	<1·0	>1·0	15·5–20·0	<·05	<·05	
En 58	Austenitic chromium-nickel rust- and acid-resisting steel.	<·2	>·2	<1·0	6·0–20·0	>12	<·05	<·05	*
En 58 A	,, ,, ,, ,,	<·2	>·2	<1·0	8·0–10·0	16·0–20·0	<·05	<·05	
En 58 B	,, ,, ,, ,,	<·2	>·2	<1·0	8·0–10·0	16·0–20·0	<·05	<·05	*
En 58 D	,, ,, ,, ,,	Agreed	composi	tion.					
En 58 M	,, ,, ,, ,,	Agreed	composi	tion.					

* May contain

EN SERIES. VALVE STEELS

Spec. No.	How supplied		U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Constants				Remarks
	Bars for Machining	Forgings					Machining M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 51	Black bars H.T., bright bars as ordered.	H.T.			H.T.	229	·45	·48	5·4	130	
En 52	Black bars H.T., bright bars as ordered.	H.T.			H.T.	293 255	·32 ·37	·43 ·43	3·9 4·3	165 142	
En 53	Black bars H.T., bright bars as ordered.	H.T.			H.T.	285 235	·32 ·42	·43 ·46	3·9 5·0	165 134	
En 54	Black bars H.T., bright bars as ordered.	H.T.			H.T.	302 277	·30 ·33	·43 ·42	3·6 4·0	173 156	
En 55	Black bars H.T., bright bars as ordered.	H.T.			H.T.	302 277	·30 ·33	·43 ·42	3·6 4·0	173 156	
En 59	Black bars H.T., bright bars as ordered.	H.T.			H.T.	269 207	·34 ·49	·42 ·50	4·1 5·9	151 124	

RUST- AND ACID-RESISTING STEELS

Spec. No.	How supplied		U.T.S. Tons/sq. in.	Ruling section	Condition	B.H. No.	Constants				Remarks
	Bars for Machining	Forgings					Machining index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands	
En 56 A	Black bars H.T., bright bars H.T.	H.T.	35 45		H.T.	255	·20	·22	4·8	137	Bright bars may be subjected to cold work after H.T. unless otherwise specified.
En 56 B						201	·33	·33	4·1	122	
En 56 C						152	·42	·38	5·1	110	
En 56 D											
En 56 M					H.T. H.T.	255 201 152	·30 ·49 ·63	·34 ·49 ·63	3·6 5·9 7·6	137 122 110	Composition adjusted to give free cutting.
En 57	Black and bright bars H.T.	H.T.	55		H.T.	248	·2	·2	4·8	137	Bright bars may be subjected to cold work unless otherwise specified.
En 58	Black and bright bars H.T.	H.T.	35		H.T.		·27	·28	3·3	126	
En 58 A		H.T.	45		H.T.		·23	·25	3·4	130	
En 58 B			50		H.T.		·21	·23	2·5	136	Welding quality.
En 58 D			55		H.T.		·20	·2	4·8	137	Deep-drawing quality.
En 58 M					H.T. H.T. H.T.	255 201 152	·30 ·49 ·63	·34 ·49 ·63	3·6 5·9 7·6	137 122 110	Free-cutting quality.

other elements

TABLE 65A.—STEEL CASTINGS

Spec. No.	Description	B.H. No.	U.T.S. tons/sq. in.	*M* factor
Carbon Steels.				
B.S. 592 B.S. 24/4/10	·2% carbon steel castings.		26–30	·66
B.S. 5028/1 B.S. 5028/2 B.S. 592 B.S. 24/4/10	·3% carbon steel castings.		30–35	·55
B.S. 150 B.S. 592 B.S. 24/4/10	·4% carbon steel castings.		38–40	·42
B.S. 150 B.S. 24	·6% carbon steel castings.		40–45	·30
Alloy Steels.				
	·25% carbon-manganese steel.		35–40	·42
	·45% carbon-manganese steel.		40–50	·40
	Nickel-chromium steels.		40–50	·37
	Nickel-chromium-molybdenum steels.		50–60	·25
	Manganese-molybdenum steels.		40–50	·37
	Carbon-chromium steel.		45–50	·32
	·2% carbon-molybdenum steel.		32–38	·42
	·3% carbon-molybdenum steel.		36–44	·30
	Stainless steel.		40–50	·30
	Austenitic stainless steel.		35–45	·22
	High-manganese steel (12% Mn).	200–240		·15
	1% carbon-chromium-molybdenum steel.	300–320		·22
	·5% carbon-chromium steel.	200–260		·28
	·7% carbon-chromium steel.	240–300		·24
	·75% carbon-chromium steel.	280–330		·22
	·7% carbon-chromium-molybdenum steel.	320–400		·16

Table 65B.—Railway and Tramway Axles and Tyres

Spec. No.	Description	Constants				
		U.T.S. tons/sq. in.	Machining index *M*	H.P. index *P*	Speed index C_v	Cutting force C_p lb., thous.
B.S. 24/3	See similar material under B.S. 970 or S.A.E. lists.					
B.S. 102/A	Carbon steel.	35–40	See	En 5.		
B.S. 102/B	Low-carbon alloy steel.	40–45	See	En 5.		
B.S. 102/C	3½% nickel steel.	45–50	·38	·46	4·6	147
			·51	·56	6·1	134
B.S. 102/C	Medium-carbon alloy steel.	45–50	·38	·46	4·6	147
			·51	·56	6·1	134
	3½% nickel-molybdenum steel.	55–65	·25	·39	3·0	191
			·39	·45	4·7	140
	Medium-carbon nickel-chromium-molybdenum steel.	55–65	·25	·39	3·0	191
			·39	·45	4·7	140
B.S. 24/2/5B	·45–·5% carbon steel.	42–48	See	En 43	A.	
B.S. 24/2/4C /5C	·55–·6% carbon steel.	50–56	See	En 9.		
B.S. 24/2/4D	·67–·7% carbon steel.	56–62	·28	·38	3·4	168
/5D			·37	·44	4·4	144
B.S. 24/2/4C	·50–·55% carbon-chromium steel.	50–55	·32	·41	3·8	157
B.S. 24/2/5C			·37	·5	4·5	165
B.S. 24/2/4D	·55–·65% carbon-chromium steel.	56–62	·28	·38	3·4	168
B.S. 24/2/5D			·37	·44	4·4	144
B.S. 24/2/4E	·6–·7% carbon-chromium steel	63–69	·24	·36	2·9	185
B.S. 24/2/5E			·31	·40	3·7	157
B.S. 101/X	·65–·75% carbon chromium steel.	70–80	·21	·36	2·5	210
/Y		65–75	·31	·40	3·7	157
B.S. 24/2/D	Manganese-chromium-molybdenum steel.	56–62	·28	·38	3·4	168
			·37	·44	4·4	144
	·65–·75% carbon 1¼% nickel-chromium steel.	70	·23	·36	2·8	190

Table 66.—Tool Steels and Sundry Materials

Description	Approx tensile lb., th.	Condition	B.H. No.	*M*	H.P. index *P*	C_v	C_p lb., thous.
Wrought iron.	36	H.R.	65	·65	·64	7·8	120
Manganese steel 11–14% Mn.		Forged		·17	1·47	2·0	182
Tool steels:—							
Carbon tool-steels.	96	A.	200	·41	·48	4·9	143
Low-alloy tool steels.	96	A.	200	·41	·48	4·9	143
Manganese oil-hardening steel.	96	A.	200	·41	·48	4·9	143
Low-tungsten chromium steel.	96	A.	200	·41	·48	4·9	143
Tungsten-alloy chisel steel.	91	A.	185	·62	·71	7·4	143
High-chromium high-carbon steel.	104	A.	210	·32	·40	3·8	152
High-speed steels.	91	A.	185	·62	·71	7·4	143
Bakelite (moulded).				·4			
Hard rubber (moulded).				1·0			

AMERICAN STEEL SPECIFICATIONS

There are a number of American steel specifications, but probably the best known are the S.A.E. and A.I.S.I. lists. In these series the system of numbering is as follows:

Carbon steels	1xxx
Plain carbon	10xx
Free-cutting	11xx
Manganese steel	13xx
Nickel steels	2xxx
3·5% nickel	23xx
5% nickel	25xx
Nickel-chromium steels	3xxx
1·25 Ni ·6 Cr	31xx
1·75 Ni 1·0 Cr	32xx
3·5 Ni 1·5 Cr	33xx
Corrosion- and heat-resisting steels	30xxx
Molybdenum steels	4xxx
C Mo	40xx
Cr Mo	41xx
Cr Ni Mo	43xx
1·75 Ni Mo	46xx
3·5 Ni Mo	48xxx
Chromium steels	5xxx
Low-chromium	51xx
Low-chromium (bearing)	501xx
Medium-chromium (bearing)	511xx

Chromium steels—*continued*	
High-chromium (bearing)	521xx
Corrosion- and heat-resisting steel	51xxx
Chromium-vanadium steel	6xxx
1% chromium	61xx
Silicon-manganese steel	9xxx
2% Si	92xx
Triple alloy steels	
Ni ·4–·7 Cr ·4–·6 Mo ·15–·25	86xx
Ni ·4–·7 Cr ·4–·6 Mo ·2–·3	87xx
Ni 3·0–3·5 Cr 1·0–1·4 Mo ·08–·15	93xx
Ni ·3–·6 Cr ·3–·5 Mo ·08–·15	94xx
Ni ·4–·7 Cr ·1–·25 Mo ·15–·25	97xx
Ni ·85–1·15 Cr ·7–·9 Mo ·2–·30	98xx
Low-alloy high-tensile steel	9xx
Austenitic steels (Cr, Ni)	303xx
Castings, steel	
Corrosion-resisting	60xxx
Heat-resisting	70xxx
Carbon and low-alloy	00x 00xx
High-strength	01xx

The general composition and the *M* factor for the various classes of steels are given in Tables 67 to 76. Use can also be made of the tables listing the British Standard steels when the two steels have roughly the same composition.

In Tables 60–76 (pp. 118–63) for steel and Table 106 (p. 179) for cast iron, in addition to the *M* factor, values are given for the speed index C_v, the cutting force constant C_p and the h.p. index *P*. The latter is of value when estimating the approximate h.p. requirements for a specific machining operation, working on the assumption that the actual cutting speed agrees with that given when using the various tables. At other speeds the relationship does not hold good. A general expression to cover all conditions is given on p. 245. The values of C_v and C_p are those used in the expressions on pp. 101 and 238.

TABLE 67.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS, *M* FACTORS, &c., FOR CARBON STEELS

Specification		General composition					Physical Properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	S	P	Tensile strength, thousand lb./sq. in.	Condition	B.H. No.	Machine index *M*	H.P. index *P*	Speed index C_r	Cutting force C_p lb., in thousands
1008	C 1008	·07		·25			51	H.R.	101	1·50	1·37	18·0	110
		·1		·5			56	C.D.	113	1·30	1·22	15·6	115
1010	C 1010	·08		·3			55	H.R.	110	1·42	1·32	17·0	114
		·13		·5			66	C.D.	141	·93	·96	11·2	125
1015	C 1015	·13		·3			57	H.R.	143	1·33	1·27	16·0	116
		·18		·6			73	C.D.	150	·78	·82	9·4	127
1020	C 1020	·18		·3			66	H.R.	127	1·00	1·00	12·0	122
		·23		·6			69	C.D.	143	·85	·87	10·3	126
							78	C.D.	160	·71	·76	8·5	131
1022	C 1022	·18		·7			61	H.R.	126	1·18	1·15	13·6	119
		·23		1·0			86	C.D.	156	1·04	1·18	12·5	138
1025	C 1025	·22		·3			66	H.R.	160	·98	1·00	11·7	122
		·28		·6			82	C.D.	168	·66	·73	7·9	135
							80	H.T.	168	·73	·79	8·7	133
1030	C 1030	·28		·6			75	H.R.	168	·78	·83	9·4	129
		·34		·9			85	C.D.	180	·62	·69	7·4	137
							89	H.T.	185	·63	·72	7·5	140
1035	C 1035	·32		·6			82	H.R.	174	·69	·77	8·3	135
		·38		·9			88	C.D.	180	·62	·69	7·4	137
							85	H.T.	174	·68	·76	8·1	137
							105	H.T.	212	·48	·60	5·8	152
1040	C 1040	·37		·6			90	H.R.	187	·61	·70	7·3	141
		·44		·9			92	C.D.	195	·56	·65	6·7	142
							100	C.D.	225	·43	·55	5·1	158
							92	H.T.	186	·59	·69	7·1	142
							113	H.T.	230	·43	·55	5·1	158
1045	C 1045	·43		·6	<·04	<·05	93	H.R.	187	·60	·69	7·2	143
		·50		·9			95	C.D.	200	·54	·63	6·5	143
							105	C.D.	225	·42	·55	5·1	160
							93	N.	185	·61	·71	7·3	143
							98	H.T.	197	·62	·74	7·4	147
							121	H.T.	248	·38	·51	4·5	165

Continued over

TABLE 67.—(*Continued*)

Specification		General composition					Physical Properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	S	P	Tensile strength, thousand lb./sq. in.	Condition	B.H. No.	Machine index M	H.P. index P	Speed index C_v	Cutting force C_p lb., in thousands
1050	C 1050	·48		·6			103	H.R.	201	·49	·60	5·9	150
		·55		·9			110	C.D.	235	·40	·52	4·8	160
							95	N.	190	·60	·70	7·2	143
							104	H.T.	208	·46	·57	5·5	151
							129	H.T.	266	·33	·46	3·9	171
1052	C 1052	·47		1·2			115	H.R.	210	·45	·59	5·4	160
		·55		1·5			97	N.	200	·53	·65	6·4	150
							135	H.T.	277	·31	·45	3·7	176
1055	C 1055	·5		·6			117	H.R.	217	·42	·55	5·0	162
		·6		·9			95	A.	197	·62	·72	7·5	143
							105	N.	210	·50	·63	6·0	152
							116	H.T.	230	·38	·50	4·5	161
							122	H.T.	255	·36	·49	4·4	167
1060	C 1060	·55		·6			117	H.R.	217	·42	·55	5·0	162
		·65		·9			96	A.	200	·61	·74	7·3	147
							110	N.	225	·46	·59	5·5	156
							116	H.T.	230	·38	·50	4·5	161
							144	H.T.	315	·22	·32	2·6	182
1070	C 1070	·65		·6				A.	200	·54	·64	6·4	144
		·75		·9									
1080	C 1080	·75		·6				A.	200	·49	·58	5·9	144
		·88		·9									
1085	C 1085	·8		·7				A.	200	·44	·52	5·3	144
		·93		1·0									
1095	C 1095	·9		·3			147	H.R.	280	·30	·45	3·6	184
		1·05		·5			93	A.	207	·41	·48	4·9	143
							121	H.T.	250	·36	·49	4·3	168
							144	H.T.	315	·22	·32	2·6	182

TABLE 68.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS, *M* FACTORS, &C., FOR FREE-CUTTING CARBON STEELS

Specification		General composition					Physical properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	S	P	Tensile strength, thousand lb./sq. in.	Condition	B.H. No.	Machine index M	H.P. index P	Speed index C_v	Cutting force C_p, lb., thousands
Bessemer Steels.													
1111	B 1111	·08		·6	·08	·07	67	H.R.	130	1·87	1·15	20·0	75
		·13		·9	·15	·12	88	C.D.	167	1·12	·83	13·4	86
1112	B 1112	·08		·7	·16	·07	68	H.R.	130	2·13	1·22	25·5	70
		·13		1·0	·23	·12	88	C.D.	167	1·37	·94	16·4	84
1113	B 1113	·08		·7	·24	·07	67	H.R.	130	2·89	1·66	34·7	70
		·13		1·0	·33	·12	88	C.D.	183	1·86	1·28	22·3	84
Open-hearth Steels.													
1115	C 1115	·13		·6	·08	·045	75	H.R.	145	1·87	1·15	20·0	75
		·18		·9	·13		91	C.D.	187	1·12	·83	13·4	86
1117	C 1117	·14		1·0	·08	·045	80	H.R.	167	1·02	·66	12·2	79
		·20		1·3	·13			C.D.		·89	·70	10·7	95
1118	C 1118	·14		1·3	·08	·045	67	H.R.	120	1·61	·93	10·4	70
		·20		1·6	·13		90	C.D.	161	·96	·67	11·7	85
1132	C 1132	·27		1·35	·08	·045	83	H.R.	165	·95	·63	11·3	81
		·34		1·65	·13		90	C.D.	200	·67	·51	8·1	91
1137	C 1137	·32		1·35	·08	·045	92	H.R.	197	·71	·70	8·4	87
		·39		1·65	·13		90	C.D.	197	·71	·70	8·4	86
							114	H.T.	229	·55	·46	6·6	101
1141	C 1141	·37		1·35	·08	·045	90	H.R.	179	·85	·59	10·2	85
		·45		1·67	·13		100	C.D.	207	·65	·49	7·8	93
1145	C 1145	·42		·7	·04	·045	95	H.R.	190	·80	·56	9·6	85
		·49		1·0	·07		105	C.D.	220	·58	·46	7·0	97
1151	C 1151	·48		·7	·08	·045	100	H.R.	200	·75	·55	9·0	90
		·55		1·0	·13		110	C.D.	230	·56	·44	6·7	95

TABLE 69.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS, M FACTORS, &C., FOR MANGANESE STEELS

Specification		General composition					Physical properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	S	P	Tensile strength, thousand lb./sq. in.	Condition	B.H. No.	Machine index M	H.P. index P	Speed index C_v	Cutting force C_p, lb., thousands
1320	A 1320	·18	·2	1·6	·04	·04	76	H.R.	153	·75	·9	9·0	147
		·23	·35	1·9			90	N.	180	·71	·94	8·5	161
							89	C.D.	179	·71	·95	8·5	163
							95	H.T.	180	·70	·93	8·4	161
							126	H.T.	255	·54	·74	6·5	166
1330	A 1330	·28	·2	1·6	·04	·04	111	H.R.	212	·71	·91	8·5	157
		·33	·35	1·9			93	N.	190	·70	·89	8·6	154
							122	H.T.	229	·58	·79	7·0	166
							139	H.T.	277	·46	·67	5·5	178
1335	A 1335	·33	·2	1·6	·04	·04	107	H.R.	205	·68	·87	8·2	156
		·38	·35	1·9			100	N.	200	·68	·89	8·2	159
							122	H.T.	229	·58	·79	7·0	166
							129	H.T.	262	·50	·70	6·0	171
1340	A 1340	·38	·2	1·6	·04	·04	115	H.R.	217	·68	·90	8·2	160
		·43	·35	1·9			107	N.	205	·67	·90	8·2	160
							122	H.T.	229	·58	·80	7·0	168
							135	H.T.	277	·46	·66	5·5	176

TABLE 70.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS, *M* FACTORS, &c., FOR NICKEL STEELS

Specification		General composition					Physical properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	Ni	S and P	Tensile strength, thousand lb. sq. in.	Condition	B.H. No.	Machine index *M*	H.P. index *P*	Speed index C_v	Cutting force C_p, lb., thousands
2317	A 2317	·15	·2	·4	3·25	Each ·04 max.	76	H.R.	153	·88	·88	10·6	121
		·2	·35	·6	3·75		75	N.	150	·82	·81	9·8	121
							87	C.D.	192	·58	·58	6·9	123
							168	H.T.	363	·30	·48	3·7	190
2330	A 2330	·28	·2	·6	3·25		105	H.R.	207	·50	·52	6·0	126
		·33	·35	·8	3·75		102	N.	205	·53	·54	6·4	124
							124	C.D.	223	·36	·40	4·3	136
							129	H.T.	271	·40	·46	4·8	139
							160	H.T.	324	·33	·46	3·9	172
2340	A 2340	·38	·2	·7	3·25		114	H.R.	240	·45	·48	5·4	129
		·43	·35	·9	3·75		106	N.	223	·50	·55	6·0	134
							115	C.D.	235	·42	·48	5·0	140
							136	H.T.	300	·38	·46	4·6	147
							180	H.T.	376	·30	·49	3·6	200
2345	A 2345	·43	·2	·7	3·25		129	H.R.	260	·42	·48	5·0	140
		·48	·35	·9	3·75		116	A.	235	·50	·55	6·0	134
							126	N.	250	·41	·46	4·9	137
							119	C.D.	255	·37	·44	4·5	144
							125	H.T.	273	·43	·48	5·1	137
							160	H.T.	340	·31	·44	3·7	172
2515	A 2515	·12	·2	·4	4·75		91	H.R.	179	·63	·63	7·5	123
		·17	·35	·6	5·25		91	N.	179	·63	·63	7·5	123
							115	C.D.	226	·48	·52	5·8	130
							115	H.T.	286	·38	·46	4·3	147

TABLE 71.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS, *M*, &c., FOR NICKEL-CHROMIUM STEELS

Specification		General composition							Physical properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	Ni	Cr	S	P	Tensile strength, thousand lb./sq. in.	Condition	H.B. No.	Machine index M	H.P. index P	Speed index C_s	Cutting force C_p lb., thousands
3115	A 3115	·13	·2	·4	1·1	·55	·04	·04	71	H.R.	134	·78	·57	9·3	90
		·18	·35	·6	1·4	·75			72	N.	128	·78	·58	9·4	90
									77	C.D.	163	·66	·50	7·9	92
									130	H.T.	270	·36	·41	4·3	140
3120	A 3120	·17	,,	·6	,,	,,	,,	,,	88	H.R.	149	·57	·44	6·8	95
		·22		·8					85	N.	144	·65	·50	7·8	94
									98	C.D.	174	·47	·46	5·6	119
									132	H.T.	280	·34	·40	4·0	141
3130	A 3130	·28	,,	·6	,,	,,	,,	,,	99	H.R.	178	·48	·48	5·8	122
		·33		·8					97	N.	176	·50	·48	6·0	116
									118	C.D.	210	·35	·38	4·2	132
									130	H.T.	267	·35	·40	4·2	141
									166	H.T.	335	·26	·38	3·1	180
3135	A 3135	·33	,,	·6	,,	,,	,,	,,	106	H.R.	195	·43	·45	5·1	128
		·38		·8					105	N.	185	·45	·45	5·4	122
									115	C.D.	210	·35	·38	4·2	132
									130	H.T.	270	·35	·40	4·2	141
									170	H.T.	350	·25	·38	3·0	187
3140	A 3140	·38	,,	·7	,,	,,	,,	,,	112	H.R.	228	·41	·43	4·9	128
		·43		·9					108	A.	205	·44	·46	5·3	127
									110	N.	207	·42	·41	5·0	127
									125	C.D.	241	·33	·37	3·9	137
									143	H.T.	285	·32	·40	3·8	155
									175	H.T.	370	·24	·39	2·9	195
3141	A 3141	·38	·2	·7	1·1	·7	·04	·04	112	H.R.	210	·47	·49	5·6	128
		·43	·35	·9	1·4	·9			102	A.	207	·48	·50	5·8	125
										C.D.	215	·37	·41	4·4	137
									130	H.T.	255	·38	·43	4·5	140
									167	H.T.	320	·28	·39	3·3	172
									190	H.T.	384	·23	·40	2·8	213
3145	A 3145	·43	,,	,,	,,	,,	,,	,,	116	H.R.	225	·38	·42	4·5	137
		·48							104	A.	210	·48	·50	5·8	129
									117	N.	223	·38	·41	4·6	131
									128	H.T.	259	·35	·40	4·2	139
									170	H.T.	332	·26	·39	3·1	186
3150	A 3150	·48	,,	,,	,,	,,	,,	,,	120	H.R.	240	·35	·38	4·2	133
		·53							97	A.	179	·51	·38	6·1	91
									120	N.	239	·36	·39	4·3	133
									132	H.T.	262	·34	·39	4·1	142
									173	H.T.	342	·26	·40	3·1	191
3240	A 3240	·38	,,	·4	1·65	·9	,,	,,	144	H.R.	285	·32	·41	3·8	157
		·45		·6	2·0	1·2			90	A.	170	·58	·46	7·0	96
									146	N.	285	·32	·41	3·8	158
									107	C.D.	207	·45	·47	5·4	126
									160	H.T.	330	·28	·39	3·3	172
									198	H.T.	400	·22	·41	2·6	228
3310	E 3310	·08	,,	·45	3·25	1·4	·025	·025	133	H.R.	296	·32	·38	3·8	144
		·13		·6	3·75	1·75			160	N.	321	·28	·39	3·3	172
									105	A.	212	·47	·48	5·6	126
									111	H.T.	228	·43	·45	5·1	128

TABLE 72.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS [17] FOR MOLYBDENUM STEELS

S.A.E.	A.I.S.I.	C	Si	Mn	Mo	S	P	U.T.S.	Condition	B.H. No.	Constants			
											Machine index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thous.
4023	A 4023	·2	All ·2–·35	·7	·2	<·04	<·04		H.R.	160	·88	1·00	10·7	122
		·25		·9	·3				C.D.	168	·66	·73	7·9	135
									H.T.	168	·73	·79	8·7	133
4027	A 4027	·25		·7	All				H.R.	168	·78	·83	9·4	129
		·30		·9					C.D.	180	·62	·69	7·4	137
									H.T.	185	·63	·72	7·5	140
4032	A 4032	·3		·7					H.R.	174	·69	·77	8·3	135
		·35		·9					C.D.	180	·62	·69	7·4	137
									H.T.	212	·48	·60	5·8	152
4037	A 4037	·35		·7					H.R.	187	·61	·70	7·3	141
		·40		·9					C.D.	225	·43	·55	5·1	158
									H.T.	230	·43	·55	5·1	158
4042	A 4042	·4		·7					H.R.	187	·6	·69	7·2	143
		·45		·9					C.D.	225	·42	·55	5·1	160
									H.T.	248	·38	·51	4·5	165
4047	A 4047	·45		·7					H.R.	201	·49	·60	5·9	150
		·50		·9					C.D.	235	·40	·52	4·8	160
									H.T.	208	·46	·57	5·5	151
									H.T.	266	·33	·46	3·9	171
4063	A 4063	·6		·75					H.R.	217	·42	·55	5·0	162
		·67		1·0					N.	210	·5	·63	6·0	152
									H.T.	230	·38	·50	4·5	161
									H.T.	255	·36	·49	4·4	167
4068	A 4068	·64		·75					H.R.	217	·42	·55	5·0	162
		·72		1·0					N.	225	·46	·59	5·5	156
									H.T.	230	·38	·50	4·5	161
									H.T.	315	·22	·32	2·6	182

TABLE 73.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS, *M* FACTORS, &c., FOR CHROMIUM-MOLYBDENUM STEELS

Specification		General composition							Physical properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	Cr	Mo	S	P	Tensile strength, thousand lb./sq. in.	Condition	B.H. No.	Machine index M	H.P. index P	Speed index C_v	Cutting force C_p lb., thousands
4119	A 4119	·17	·2	·7	·4	·2	·04	·04	91	H.R.	179	·65	·53	7·8	100
		·22	·35	·9	·6	·3			87	N.	160	·67	·52	8·0	95
									97	C.D.	207	·46	·46	5·7	118
									137	H.T.	302	·31	·36	3·7	142
4125	A 4125	·23	·2	·7	·4	·2	·04	·04	93	H.R.	185	·56	·51	5·7	110
		·28	·35	·9	·6	·3			88	N.	169	·64	·52	7·7	98
									135	H.T.	290	·32	·36	3·8	138
4130	A 4130	·28	,,	·4	·8	·15	,,	,,	95	H.R.	192	·51	·46	6·1	111
		·33		·6	1·1	·25			89	A.	179	·65	·53	7·8	100
									112	N.	217	·47	·46	5·7	118
									112	C.D.	241	·35	·41	4·2	142
									141	H.T.	293	·32	·36	3·8	138
4137	A 4137	·35	,,	·7	·8	·15	,,	,,	131	H.R.	272	·34	·40	4·1	142
		·40		·9	1·1	·25			114	N.	230	·38	·40	4·6	127
									90	A.	187	·58	·54	7·0	113
									183	H.T.	364	·25	·38	3·0	185
									219	H.T.	444	·19	·35	2·3	225
4140	A 4140	·38	,,	·75	·8	·15	,,	,,	134	H.R.	269	·34	·40	4·1	142
		·43		1·0	1·1	·25			137	N.	277	·33	·40	4·0	145
									90	A.	187	·58	·54	7·0	113
									114	C.D.	241	·35	·41	4·2	142
									183	H.T.	363	·23	·35	2·7	191
									216	H.T.	444	·19	·35	2·3	222
4145	A 4145	·43	·2	·75	·8	·15			136	H.R.	270	·34	·40	4·1	142
		·48	·35	1·0	1·1	·25			138	N.	278	·33	·4	4·0	145
									187	H.T.	363	·23	·35	2·7	191
									215	H.T.	444	·19	·35	2·3	220
4150	A 4150	·48	·2	·75	·8	·15			144	H.R.	287	·31	·39	3·7	156
		·53	·35	1·00	1·1	·25			105	A.	220	·40	·40	4·8	122
									153	N.	300	·28	·37	3·4	158
									180	H.T.	365	·23	·35	2·7	191
									215	H.T.	444	·19	·35	2·3	220

TABLE 74.—AMERICAN SPECIFICATIONS, *M* FACTORS, &c., FOR NICKEL-CHROMIUM-MOLYBDENUM AND NICKEL-MOLYBDENUM STEELS

Specification		General Composition								Physical Properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	Ni	Cr	Mo	S	P	Tensile, thousand lb./sq. in.	Condition	B.H. No.	Machining index *M*	H.P. index *P*	Speed index C_v	Cutting force C_p lb., thousands
4320	A 4320	·17	·2	·45	1·65	·4	·2	·04	·04	87	H.R.	179	·58	·52	6·9	111
		·22	·35	·65	2·0	·6	·3			99	C.D.	207	·43	·43	5·2	122
										185	H.T.	415	·21	·36	2·5	212
4340	A 4340	·38	·2	·6	1·65	·7	·2	·04	·04	198	H.R.	401	·20	·33	2·4	202
		·43	·35	·8	2·0	·9	·3			149	A.	302	·29	·37	3·5	154
										203	N.	415	·21	·35	2·5	207
										150	H.T.	302	·31	·39	3·7	155
										184	H.T.	375	·24	·37	2·9	136
										213	H.T.	429	·20	·36	2·4	217
4615	A 4615	·13	·2	·45	1·65		·2			82	H.R.	183	·58	·52	7·0	109
		·18	·35	·65	2·0		·3			83	N.	170	·58	·53	7·0	110
										107	C.D.	212	·42	·42	5·0	125
										115	H.T.	229	·42	·44	5·0	128
										129	H.T.	251	·37	·41	4·4	138
										141	H.T.	271	·33	·40	4·0	147
4620	A 4620	·17	·2	·45	1·65		·2	·04	·04	82	H.R.	167	·60	·53	7·2	108
		·22	·35	·65	2·00		·3			85	N.	179	·58	·52	6·9	111
										89	C.D.	203	·44	·44	5·3	122
										120	H.T.	246	·38	·41	4·6	131
										139	H.T.	280	·33	·40	4·0	147
										178	H.T.	345	·25	·37	3·0	182
4640	A 4640	·38	·2	·6	1·65		·2			119	H.R.	241	·36	·38	4·3	130
		·43	·35	·8	2·00		·3			122	N.	248	·38	·41	4·2	132
										100	A.	201	·46	·45	5·2	118
										145	H.T.	320	·30	·37	3·6	151
										182	H.T.	392	·23	·35	2·8	182
4815	A 4815	·13	·2	·4	3·25		·2			105	H.R.	212	·44	·46	5·3	127
		·18	·35	·6	3·75		·3			94	N.	187	·52	·50	6·2	118
										110	C.D.	217	·40	·42	4·8	128
										203	H.T.	415	·21	·36	2·5	207
4820	A 4820	·18	·2	·5	3·25		·2			105	H.R.	212	·44	·46	5·3	127
		·23	·35	·7	3·75		·3			94	N.	187	·52	·50	6·2	118
										110	C.D.	217	·40	·42	4·8	128
										200	H.T.	390	·23	·37	2·7	203

TABLE 75.—AMERICAN S.A.E. AND A.I.S.I. SPECIFICATIONS, *M* FACTORS, &C., FOR CHROMIUM AND CHROMIUM-VANADIUM STEELS

Specification		General composition							Physical properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	Cr	V	S	P	Tensile strength, thousand lb./sq. in.	Condition	B.H. No.	Machine index *M*	H.P. index *P*	Speed index C_v	Cutting force C_p lb., thousands
5120	A 5120	·17	·2	·7	·7		·04	·04	82	H.R.	160	·61	·55	7·3	110
		·2	·35	·9	·9				73	N.	149	·67	·57	8·0	105
									79	C.D.	165	·61	·54	7·3	108
									98	H.T.	210	·46	·46	5·5	122
									155	H.T.	335	·27	·35	3·2	160
5140	A 5140	·38	·2	·7	·7		·04	·04	114	H.R.	223	·42	·45	5·0	131
		·43	·35	·9	·9				110	N.	212	·43	·46	5·2	128
									103	A.	201	·50	·48	6·0	118
									115	C.D.	248	·36	·42	4·3	144
									124	H.T.	241	·38	·43	4·6	138
									152	H.T.	302	·30	·39	3·6	157
									180	H.T.	363	·25	·37	3·0	182
5150	A 5150	·48	·2	·7	·7		·04	·04	135	H.R.	277	·33	·40	4·0	145
		·55	·35	·9	·9				103	A.	201	·50	·48	6·0	118
									136	N.	285	·32	·38	3·8	145
									115	C.D.	248	·36	·42	4·3	144
									133	H.T.	269	·36	·42	4·3	144
									168	H.T.	352	·27	·37	3·2	171
									220	H.T.	461	·18	·34	2·2	226
50100	E 50100	·95	·2	·25	·4		·025	·025		A.	229	·42	·45	5·2	130
		1·1	·35	·45	·6					A.	187	·52	·53	6·2	125
51100	E 52098	·95	·2	·25	·9		·025	·025		A.	229	·42	·45	5·2	130
		1·1	·35	·45	1·15					A.	187	·52	·53	6·2	125
52100	E 52100	·95	·2	·25	1·3		·025	·025	185	H.T.	415	·21	·36	2·5	207
		1·1	·35	·45	1·6				109	A.	235	·39	·44	4·6	136
6150	6150	·48	·2	·7	·8	·15	·04	·04	141	H.R.	285	·34	·50	4·1	177
		·53	·35	·9	1·1				103	A.	217	·41	·48	4·9	144
									136	N.	277	·36	·47	4·3	159
									118	C.D.	255	·37	·48	4·4	158
									133	H.T.	262	·37	·48	4·4	158
									171	H.T.	341	·27	·58	3·2	265
									228	H.T.	461	·19	·46	2·3	300

TABLE 76.—AMERICAN SPECIFICATIONS, *M* FACTORS, &C., FOR STEELS

Specification		General composition						Physical properties			Constants			
S.A.E.	A.I.S.I.	C	Si	Mn	Cr	Ni	Mo	Tensile, 1000 lb. per sq. in.	Condition	B.H. No.	Machining index M	Horse-power factor P	Speed index C_v	Cutting force C_p lb., thous.
Silicon Steel.														
9260	A.	·55 ·60	1·8 2·2	·7 ·9						324	·29	·40	3·5	166
Chromium-nickel Austenitic Steels.														
30303/F	303	·08 ·15	1·0	2	17 19	8 10	·6				·70			
30302	302	·08 ·15	1·0	·2	17 19	7 10	·6				·70			
30321	321	·08	1·5	2·5	17 19	8 12					·50			
30316	316	·08	1·0	2·0	16 18	10 14	3				·50			
30304	304	·08	1·0	2·0	20 18	8 11			H.T.	187	·28	·29	3·3	126
									A.C.		·22			
									A.	142	·35	·35	4·2	122
30310	310	·25	1·5	2·0	24 26	19 22								
Stainless Chromium Irons.														
51410	410	·08 ·15	1·0	1·0	11·5 13·5						·50	·50	6·3	118
51410	414	·08 ·15	1·0	1·0	11·5 13·5	1·25 2·5					·50			
51420	420	·30 ·40	1·0	1·0	12 14						·50			
51416/F	416	·15	1·0	1·25	12 14		·6				·70			
51430	430	·12	1·0	1·0	14 18						·50			
High-manganese Steel.														
		1·0		11				45	Forged	198	·52	·50	6·3	118
		1·0		14				95	Cast	230	·17	·25	2·0	182
Wrought Iron.														
									H.R.		·65		7·8	
		·35							Steel Casting		·42	·47	5·0	135

4. Machining Lead-bearing Free-cutting Steels.

In order to improve the machining qualities of the various grades of steel (i.e. give a good surface-finish, avoid clogging and the fouling of the tools with long chips without seriously affecting the physical properties of the material), the proportions of sulphur and manganese are increased, whilst in some proprietary steels a small addition of lead is made. When this is done the lead gives rise to a much shorter chip, which can be easily removed and is often washed away by the force of the cutting oil. The adjusting of the composition in this manner leads to the use of higher cutting-speeds, a better surface-finish, a longer tool-life, whilst the power requirements for a given size of chip are less. One important feature that an estimator must note is the reaction of cold-work upon the cutting speeds. A typical example taken in part and indirectly from information given by the manufacturers of " Ledloy "[18] shows this—Table 77 below—using a knife tool having no nose-radius.

TABLE 77.—SHOWING THE EFFECTS OF COLD-WORK UPON THE CUTTING SPEEDS FOR "LEDLOY" FREE-CUTTING STEEL APPROXIMATING TO EN 1 A

Bar dia., in.	Cutting speed, f.p.m.	Increase as dia. grows	Size factor, 2 in. dia. bar as unity
2	340	1·51	1·00
1·5	325	1·44	·96
1·0	295	1·31	·87
·75	280	1·24	·82
·50	260	1·16	·77
·25	225	1·00	·66

Putting it another way, it means that a 50 per cent increase in the cutting speed—see also Tables 30 to 59—is possible when the material is free from the effects of heavy cold-work, and this compares very closely with the data given for En 1 A, H.R. and C.D. in Table 60, and the S.A.E. steels in Table 68. Alternatively a longer tool-life is obtained. The remarks as to the general effects of work-hardening also apply with equal force to the lead-free steels and non-ferrous metals. Fig. 8.2 (p. 105) enables the cutting speed, or the " Bar Size Factor ", to be obtained for other bar dimensions.

Comparison.—Before any suggestions can be made as to the cutting speed applicable to the free-cutting lead-bearing alloy-steels a comparison is necessary because of the lack of other experimental data. This is made below using the data listed by the manufacturers of

" Ledloy " and those computed from the Tables for S.A.E. 1113 or En 1 A. The tools are of 18 . 4 . 1 h.s.s. ground to have approximately the same top-rake and cutting under a flood of a suitable cutting-oil.

For cutting " Ledloy " 2-in dia. bar. Tool-life 1 hour.

Knife tool. Top rake 15°. Depth of cut unstated.

Feed, in.	·004	·006	·008	·010	·012
Speed, f.p.m.	600	470	375	340	300

Tool having a 30° approach angle. Depth of cut and nose-radius unstated.

Feed, in.	·005	·006	·008	·010	·012	·015
Speed, f.p.m.	570	500	410	380	320	275

Parting-off tool. Top rake unstated.

Feed, in.	·0015	·002	·003	·004
Speed, f.p.m.	600	525	375	320

Form tool. Top rake unstated.

Feed, in.	·0005	·00075	·001	·002
Speed, f.p.m.	475	350	300	175

For cutting S.A.E. 1113 (Table 68) or its equivalent En 1 A, C.D., assuming a 1-hour tool-life, with a machining factor of 1·86, a lubricating factor of 1·16, and using Tables 37 to 47, then:

Knife tool. No approach angle. No nose-radius.

Feed, in.	·004	·006	·008	·010	·012	
Speed, f.p.m.	580	435	374	326	302	for $\frac{1}{32}$ in. depth of cut.

Tool having 30° approach angle. $\frac{1}{8}$-in. nose-radius.

Feed, in.	·005	·006	·008	·010	·012	
Speed, f.p.m.	650	604	540	455	412	for $\frac{1}{8}$ in. depth of cut.
Speed, f.p.m.	583	540	455	396	354	for $\frac{1}{4}$ in. depth of cut.

Parting-off tool. 8° rake.

Feed, in.	·0015	·002	·003	·004
Speed, f.p.m.	1190	1060	800	660

Forming to close dimensions. Little or no rake on tool.

Feed, in.	·0005	·0075	·001	·002
Speed, f.p.m.	430	380	335	209

Having gathered the data together it will be noticed:

Knife Tool.—When using the knife tool with no approach angle and no nose-radius, the two sets of figures are, for practical purposes, identical. If the tool is used for a deeper cut than is given, the effect (see p. 92) is, for bar work on the capstan and automatic lathes, to take the extreme point of the tool out of the danger zone.

Tool with a 30° Approach Angle and ⅛-in. Radius.—The tables on p. 165 show that the cutting speeds given by the manufacturers of "Ledloy" are, for the shallow cuts, less than the computed speeds when due allowance has been made for the class of material (in this instance free-cutting steel En 1 A). It is only when the cut is around ¼ in. deep that the two sets of figures show a very close measure of agreement.

Forming to Close Limits.—When the two sets of cutting speeds are examined a good measure of agreement is found.

Parting-off Tools.—The figures as listed above for "Ledloy" are to say the least on the conservative side when compared with those listed for En 1 A operating under the same conditions. One does not find with this set of figures the same measure of agreement as is found with the knife tool, the rough-turning tool having a 30° approach angle, or the forming tool. This may be due to the tool-shape or the need to reduce the speed (f.p.m.) to suit the machine speed (r.p.m.); the tables for the parting tool are on the basis of a small corner radius.

When a similar analysis is made for the other lead-bearing steels conforming generally to B.S. 970 En series, the cutting speeds as recommended by the makers of "Ledloy" also agree closely with those for the free-cutting or semi-free-cutting non-lead-bearing steels operating under the same conditions. Hence in every instance it is suggested that, as a starting-point, the cutting speed for a known chip-size be computed as for the free- or semi-free-cutting equivalent non-lead-bearing steel, making, of course, due allowance for changes in the hardness caused by cold-work or heat treatment. As sufficient accurately recorded operating or experimental data become available, the cutting speed can be modified by the introduction of a new machining factor M.

CHAPTER IX

Cutting-speed Data for Cast Iron and the Non-Ferrous Metals

1. Machining Cast Iron.

When machining cast iron the difference between its structure and that of a normal steel is quickly noted in the formation of the chip along with the dust and dirt. Steel normally gives, with a suitable tool and speed, a continuous chip formation; cast iron, on the other hand, has a very short chip. This is due to the graphitic carbon which lies between the crystals, and thus acts in a similar way to lead in a free-cutting brass. Arising out of this comes the need to adapt the composition of the iron to suit the wall thickness; thin castings require a higher percentage of silicon, or the addition of a graphitizer, such as nickel and copper, along with sufficient manganese to prevent the formation of " white iron ".

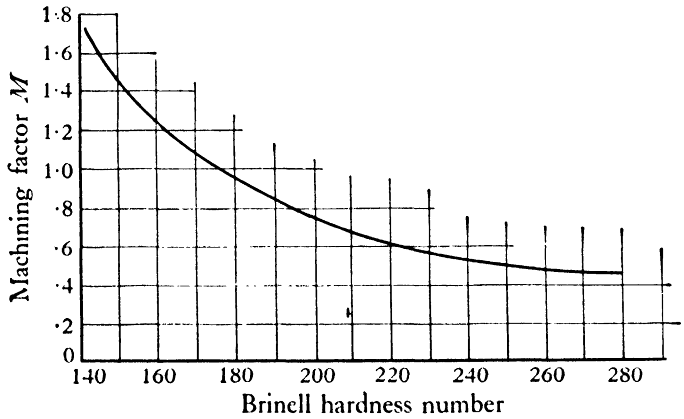


Fig. 9.1.—Change in machining factor (M) with hardness for plain grey cast iron

Tables are given below for the machining of a cast iron having the following properties:

Analysis: Total carbon, 2·88. Combined carbon, ·32. Silicon, 1·47. Manganese, ·6.

Physical properties: Brinell hardness, 177. Tensile strength, 13·4 tons/sq. in.

The cutting medium is carbon steel, high-speed steel of 18 . 4 . 1 composition, Stellite J, and cemented carbide of titanium or tantalum plus tungsten. The tables are based on a tool-life of one hour. The machining is done dry, which is usual for cast iron, as a lubricant has the tendency to carry the grit and sand into the machine slides, and thus ruin its accuracy. The given speeds apply only to the rake angle

TABLE 78.—ROUGH-TURNING CAST IRON, BRINELL 177. CARBON-STEEL TOOLS. NO APPROACH ANGLE. NO NOSE-RADIUS. TOP RAKE 8°. SIDE RAKE 14°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	58	45	40	37	35	32	31	31	30	30	29	29	28	27	26
$\frac{1}{16}$	57	44	38	35	33	30	29	29	28	28	27	27	27	27	26
$\frac{1}{8}$	57	44	37	34	31	28	27	26	25	25	24	24	24	23	22
$\frac{1}{4}$	56	43	36	33	30	26	25	23	22	22	21	21	21	20	20
$\frac{3}{8}$	56	42	35	32	29	25	23	21	20	20	19	19	19	18	17
$\frac{1}{2}$	55	42	35	32	29	25	23	20	18	17	16	16	16	15	14
$\frac{3}{4}$	55	41	34	31	29	24	21	18	16	15	14	13	13	12	10
1	55	41	34	30	28	23	21	17	15	14	12	11	11	9	8

TABLE 79.—ROUGH-TURNING CAST IRON, BRINELL 177. CARBON-STEEL TOOLS. NO APPROACH ANGLE. $\frac{1}{16}$-IN. NOSE-RADIUS. TOP RAKE 8°. SIDE RAKE 14°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	77	59	50	46	42	37	35	32	31	30	29	28	28	27	27
$\frac{1}{16}$	69	52	45	41	38	33	31	29	28	28	27	27	26	26	25
$\frac{1}{8}$	62	48	41	37	35	30	28	26	25	24	24	24	24	23	23
$\frac{1}{4}$	59	45	38	34	32	27	26	23	22	21	21	21	21	21	20
$\frac{3}{8}$	58	44	36	33	30	26	24	21	20	19	18	18	18	18	17
$\frac{1}{2}$	57	43	35	32	30	25	23	20	19	18	17	17	16	15	14
$\frac{3}{4}$	57	42	35	31	29	24	22	19	18	16	14	14	13	13	11
1	56	41	35	31	23	23	21	17	16	15	13	13	12	11	9

stated at the top of each table; modifications to the rake will lead to the speed being altered. It is assumed that the data given by the L.T.R.C. also apply to the machining of cast iron.

For irons having different characteristics to those in Tables 78 to 105,[15] the machining factors listed in Table 106, and suitable for the iron, should be chosen, or use made of the graph in fig. 9.1 (p. 167), which gives the approximate machining index *M* on the basis of the B.H. No.

Table 80.—Rough-turning Cast Iron, Brinell 177. Carbon-steel Tools. 30° Approach Angle. ⅛-in. Nose-radius. Top Rake 8°. Side Rake 14°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	95	71	65	59	54	49	39	33	32	30	29	29	28	28	27
$\frac{1}{16}$	77	58	50	45	42	36	34	29	27	26	26	26	25	25	24
$\frac{1}{8}$	69	52	45	42	38	32	30	26	25	24	23	23	23	23	22
$\frac{1}{4}$	64	48	42	37	34	29	27	24	22	21	20	20	20	19	18
$\frac{3}{8}$	63	47	40	35	32	27	25	22	20	19	18	18	18	16	15
$\frac{1}{2}$	62	46	37	34	30	26	23	20	19	17	16	16	15	14	13
$\frac{3}{4}$	60	45	36	33	30	25	23	19	17	16	14	14	13	12	11
1	60	44	36	33	30	24	22	18	16	14	13	13	12	10	9

Table 81.—Rough-turning Cast Iron, Brinell 177. Carbon-steel Tools. 30° Approach Angle. ¼-in. Nose-radius. Top Rake 8°. Side Rake 14°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	101	77	67	58	52	45	42	36	34	32	30	29	28	27	26
$\frac{1}{16}$	94	70	58	53	48	41	38	32	30	28	27	26	26	25	23
$\frac{1}{8}$	77	57	54	44	40	34	31	27	25	24	23	23	22	22	21
$\frac{1}{4}$	69	51	44	39	36	30	27	24	22	20	19	19	18	18	17
$\frac{3}{8}$	65	49	43	37	33	28	26	22	21	19	18	17	17	16	15
$\frac{1}{2}$	63	48	42	36	32	27	25	21	19	17	16	16	15	14	13
$\frac{3}{4}$	62	46	40	34	31	26	23	19	17	16	14	13	13	11	10
1	61	45	40	34	29	24	22	18	16	15	13	12	11	10	9

TABLE 82.—FORMING CAST IRON, BRINELL 177. CARBON-STEEL TOOLS. NO RAKE. TOOL-LIFE 1 HOUR CUTTING DRY.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012
Speed, f.p.m.	16	11	10	9	8	8	7	7	7	6	5

TABLE 83.—PARTING-OFF CAST IRON, BRINELL 177. CARBON-STEEL TOOLS. 8° Rake. $\frac{1}{64}$-IN. CORNER RADIUS. TOOL-LIFE 1 HOUR CUTTING DRY.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·015
Speed, f.p.m.	37	35	33	29	27	25	24	23	23	22	20

TABLE 84.—FINISH-TURNING CAST IRON, BRINELL 177. CARBON-STEEL TOOLS. NOSE-RADIUS $\frac{1}{8}$ IN. TRAILING FLAT $\frac{1}{8}$ IN. TOP RAKE 15°.

Depth of cut, in.	Speed, f.p.m.													
	Feed, in.													
	·002	·004	·006	·008	·010	·012	·014	·0156	·020	·031	·040	·050	·062	·125
·005	104	75	68	64	60	57	55	53	50	46	44	42	41	39
·010	89	69	59	54	50	47	45	44	42	38	36	35	34	31
·015	82	63	53	49	45	43	41	40	38	34	32	31	30	28
·020	75	57	47	44	40	39	37	36	34	30	28	27	26	25

TABLE 85.—ROUGH-TURNING CAST IRON, BRINELL 177. H.S.S. TOOLS 18 . 4 . 1. NO APPROACH ANGLE. NO NOSE-RADIUS. TOP RAKE 8°. SIDE RAKE 14°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	169	127	110	97	88	77	71	63	62	62	62	62	62	62	62
$\frac{1}{16}$	168	126	104	96	87	76	70	61	58	54	52	52	51	50	49
$\frac{1}{8}$	168	126	104	96	86	74	68	58	54	51	48	47	46	44	41
$\frac{1}{4}$	166	126	104	94	85	73	66	56	52	48	45	44	43	40	37
$\frac{3}{8}$	166	125	103	93	84	71	65	54	49	46	43	42	40	38	34
$\frac{1}{2}$	165	124	103	93	84	71	64	53	48	44	41	40	38	36	32
$\frac{3}{4}$	165	124	102	92	83	69	64	52	48	43	39	38	37	34	29
1	165	123	102	92	82	68	63	51	47	41	37	36	35	32	28

TABLE 86.—ROUGH-TURNING CAST IRON, BRINELL 177. H.S.S. TOOLS 18 . 4 . 1. NO APPROACH ANGLE. $\frac{1}{16}$-IN. NOSE-RADIUS. TOP RAKE 8°. SIDE RAKE 14°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	227	174	150	131	120	103	96	84	79	75	73	72	71	69	66
$\frac{1}{16}$	203	153	126	116	105	91	85	73	67	62	58	56	56	55	54
$\frac{1}{8}$	186	140	120	107	98	82	76	66	61	57	54	52	51	48	47
$\frac{1}{4}$	178	132	112	100	90	77	70	60	55	51	48	47	46	44	41
$\frac{3}{8}$	173	131	110	97	88	74	68	58	52	48	45	44	42	40	37
$\frac{1}{2}$	171	128	107	96	86	73	66	56	50	46	43	42	40	38	35
$\frac{3}{4}$	170	127	104	95	84	71	64	53	48	44	41	40	38	35	31
1	168	125	102	93	83	70	64	52	47	43	39	38	36	32	28

TABLE 87.—ROUGH-TURNING CAST IRON, BRINELL 177. H.S.S. TOOLS 18 . 4 . 1. 30° APPROACH ANGLE. $\frac{1}{8}$-IN. NOSE-RADIUS. TOP RAKE 8°. SIDE RAKE 14°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	282	212	180	159	145	122	112	96	90	80	77	76	75	72	69
$\frac{1}{16}$	230	172	150	130	120	100	93	78	73	70	63	62	61	59	56
$\frac{1}{8}$	206	154	135	122	110	89	78	69	65	60	56	55	54	50	47
$\frac{1}{4}$	192	143	120	107	100	82	74	63	58	54	50	49	48	45	41
$\frac{3}{8}$	187	140	115	104	95	79	70	60	55	52	47	45	44	40	37
$\frac{1}{2}$	185	137	115	102	92	77	68	58	53	50	45	44	42	39	35
$\frac{3}{4}$	181	135	113	100	92	76	68	56	53	49	43	42	40	37	33
1	180	134	113	99	91	74	67	55	51	47	41	40	38	35	30

Table 88.—Rough-turning Cast Iron, Brinell 177. H.S.S. Tools 18 . 4 . 1. 30° Approach Angle. ¼-in. Nose-radius. Top Rake 8°. Side Rake 14°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	302	226	190	171	157	131	120	101	95	90	80	78	77	74	69
1/16	281	210	175	157	145	120	110	92	85	80	71	70	68	65	60
⅛	255	171	145	128	120	97	90	75	68	63	59	58	56	52	48
¼	205	153	130	114	105	88	80	67	60	55	52	50	49	46	41
⅜	196	146	123	109	100	82	75	62	55	50	48	47	45	42	38
½	191	143	117	105	96	80	73	60	52	49	46	44	43	40	36
¾	187	139	115	103	95	77	70	58	50	47	43	42	40	37	32
1	183	136	113	101	93	76	69	56	48	47	41	39	37	34	30

Table 89.—Forming Cast Iron, Brinell 177. H.S.S. Tools 18 . 4 . 1. No Rake. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012
Speed, f.p.m.	47	35	29	26	23	22	20	19	18	17	16

Table 90.—Parting-off Cast Iron, Brinell 177. H.S.S. Tools. 8° Rake. 1/64-in. Corner Radius.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012	·015
Speed, f.p.m.	150	110	94	79	76	70	67	63	60	58	53	50

Table 91.—Finish-turning Cast Iron, Brinell 177. H.S.S. Tools 18 . 4 . 1. ⅛-in. Nose-radius. ⅛-in. Trailing Flat. Top Rake 15°.

Depth of cut, in.	Speed, f.p.m.													
	Feed, in.													
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·031	·040	·050	·060	·125
·005	309	219	200	187	175	165	160	154	145	133	126	123	117	115
·010	263	202	175	156	147	140	133	127	120	106	100	96	93	87
·015	242	181	155	142	130	125	120	114	107	95	90	85	82	75
·020	225	160	140	125	117	110	105	100	95	85	78	75	70	67

TABLE 91A.—FINISH-TURNING CAST IRON, BRINELL 177. H.S.S. TOOLS 18.4.1. NO APPROACH ANGLE. $\frac{1}{16}$-IN. NOSE-RADIUS. TOP RAKE 15°.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·031	·040	·050	·060
·005	215	140	120	105	95	90	85	80	75	70	65	60	55
·010	165	120	95	80	75	70	65	60	55	50	45	42	40
·015	150	105	80	70	65	60	55	50	45	40	35	35	35
·020	135	90	75	65	60	55	50	45	40	35	30	30	30

TABLE 92.—ROUGH-TURNING CAST IRON, BRINELL 177. TOOL STELLITE J. NO APPROACH ANGLE. NO NOSE-RADIUS. TOP RAKE 8°. SIDE RAKE 14°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	304	234	200	182	172	146	140	126	123	123	123	123	122	121	120
$\frac{1}{16}$	303	230	195	177	167	142	135	120	115	112	109	108	105	103	100
$\frac{1}{8}$	301	228	195	174	163	137	130	113	107	103	95	94	94	93	93
$\frac{1}{4}$	299	226	190	171	158	132	123	106	98	93	86	85	83	81	79
$\frac{3}{8}$	299	225	190	168	157	130	120	101	95	87	80	78	75	73	69
$\frac{1}{2}$	299	224	190	168	156	128	118	98	92	84	76	74	71	68	62
$\frac{3}{4}$	297	223	189	166	154	125	115	94	87	80	71	69	66	60	53
1	296	221	187	164	153	123	113	91	83	75	67	64	61	55	48

TABLE 93.—ROUGH-TURNING CAST IRON, BRINELL 177. TOOL STELLITE J. NO APPROACH ANGLE. $\frac{1}{16}$-IN. NOSE-RADIUS. TOP RAKE 8°. SIDE RAKE 14°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	403	308	265	239	220	188	178	158	150	143	137	136	134	130	125
$\frac{1}{16}$	366	276	235	211	195	167	155	137	130	125	118	116	115	110	106
$\frac{1}{8}$	333	254	215	192	180	151	143	124	117	110	105	104	102	98	94
$\frac{1}{4}$	319	238	205	181	167	140	130	111	105	100	93	91	89	86	81
$\frac{3}{8}$	311	236	195	175	160	135	125	106	97	93	86	85	82	78	73
$\frac{1}{2}$	308	230	190	172	157	132	123	102	96	92	81	79	76	72	66
$\frac{3}{4}$	306	227	187	169	155	128	120	98	91	85	73	71	68	63	57
1	301	224	185	166	152	125	117	93	86	78	69	67	64	58	51

Table 94.—Rough-turning Cast Iron, Brinell 177. Tool Stellite J. 30° Approach Angle. ⅛-in. Nose-radius. Top Rake 8°. Side Rake 14°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	511	382	325	286	263	220	205	175	163	151	141	140	138	134	130
$\frac{1}{16}$	413	364	280	234	215	182	170	145	133	128	120	118	116	111	105
$\frac{1}{8}$	371	278	235	211	195	162	150	128	120	115	106	104	102	98	93
$\frac{1}{4}$	343	257	220	194	178	149	137	116	107	100	94	92	90	85	80
$\frac{3}{8}$	335	250	210	188	173	143	132	110	100	93	87	85	83	78	72
$\frac{1}{2}$	332	247	206	183	167	140	129	107	97	89	82	80	77	72	66
$\frac{3}{4}$	323	242	203	180	165	135	124	101	93	84	76	73	71	65	57
1	322	239	200	177	163	133	120	98	87	80	71	69	65	59	51

Table 95.—Rough-turning Cast Iron, Brinell 177. Tool Stellite J. 30° Approach Angle. ¼-in. Nose-radius. Top Rake 8°. Side Rake 14°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	545	410	345	309	280	237	223	184	175	163	148	146	142	136	129
$\frac{1}{16}$	504	378	315	284	260	217	200	166	153	143	132	129	125	119	111
$\frac{1}{8}$	401	308	260	232	215	178	163	138	125	120	110	108	105	100	93
$\frac{1}{4}$	370	275	235	206	185	157	145	121	113	105	96	94	91	86	80
$\frac{3}{8}$	352	262	220	196	180	149	136	114	103	95	89	86	84	78	71
$\frac{1}{2}$	342	256	210	190	173	144	135	109	97	90	84	82	78	72	65
$\frac{3}{4}$	335	248	205	185	167	139	128	103	94	85	77	74	71	65	57
1	328	244	201	180	163	135	124	99	90	80	72	68	66	60	52

Table 96.—Forming Cast Iron, Brinell 177. Tool Stellite J. No Rake.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012
Speed, f.p.m.	150	110	95	83	75	68	66	62	58	56	53

Table 97.—Parting-off Cast Iron, Brinell 177. Tool Stellite J. Rake 8°. $\frac{1}{64}$-in. Corner Radius.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012
Speed, f.p.m.	320	280	240	210	180	177	165	158	151	145	135

Table 98.—Finish-turning Cast Iron, Brinell 177. Tool Stellite J. $\frac{1}{8}$-in. Nose-radius. $\frac{1}{8}$-in. Trailing Flat. 15° Rake.

Depth of cut, in.	Speed, f.p.m.													
	Feed, in.													
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·031	·040	·050	·062	·125
·005	600	440	400	375	350	330	320	310	290	270	255	245	235	220
·010	520	400	350	315	300	280	265	250	235	210	200	192	185	175
·015	480	360	320	285	268	250	240	230	212	186	175	170	165	150
·020	440	320	280	255	240	225	215	205	190	166	150	143	140	125

If using Stellite No. 3, multiply the above by ·52.

If using a rake smaller than given in the tables (approx. 15°), use the C_r factor.

Rake degrees	C_r
·0	·89
5	·9
10	·93

TABLE 99.—ROUGH-TURNING CAST IRON, BRINELL 177. CEMENTED-CARBIDE-TIPPED TOOL. NO APPROACH ANGLE. NO NOSE-RADIUS. RAKE 3°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	532	400	340	301	275	229	210	181	182	183	183	184	185	186	187
$\frac{1}{16}$	531	399	340	301	272	228	203	175	160	150	140	140	140	140	139
$\frac{1}{8}$	530	398	340	298	271	226	201	172	158	143	136	133	130	120	108
$\frac{1}{4}$	529	397	330	295	270	224	200	169	155	142	130	127	122	112	101
$\frac{3}{8}$	529	396	330	294	268	222	197	167	155	140	127	123	118	109	98
$\frac{1}{2}$	528	395	329	293	267	221	196	165	153	138	125	122	117	107	95
$\frac{3}{4}$	528	395	328	292	266	220	195	164	152	137	123	120	116	104	91
1	527	394	327	292	266	219	194	162	150	135	122	117	112	101	88

TABLE 100.—ROUGH-TURNING CAST IRON, BRINELL 177. CEMENTED-CARBIDE-TIPPED TOOL. NO APPROACH ANGLE. $\frac{1}{16}$-IN. NOSE-RADIUS. RAKE 3°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
$\frac{1}{32}$	732	550	460	415	390	343	310	260	245	230	218	215	214	207	200
$\frac{1}{16}$	634	482	415	364	337	280	255	222	205	195	182	178	174	166	158
$\frac{1}{8}$	592	444	375	333	305	254	235	199	180	170	159	155	151	143	133
$\frac{1}{4}$	565	420	360	314	290	238	218	183	167	150	143	140	136	126	116
$\frac{3}{8}$	552	417	350	307	280	231	210	177	160	145	138	136	129	120	109
$\frac{1}{2}$	547	410	340	303	275	229	205	174	155	140	132	128	124	114	104
$\frac{3}{4}$	545	405	339	300	270	225	203	172	153	136	128	123	119	109	97
1	538	400	338	298	268	223	200	167	150	132	124	120	115	105	94

TABLE 101.—ROUGH-TURNING CAST IRON, BRINELL 177. CEMENTED-CARBIDE-TIPPED TOOL. 30° APPROACH ANGLE. ⅛-IN. NOSE-RADIUS. RAKE 3°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	930	676	560	506	460	384	350	297	270	250	237	234	230	222	212
1/16	732	548	470	410	380	313	285	240	220	205	192	189	185	178	168
⅛	657	490	430	388	360	298	270	213	200	187	167	163	159	150	139
¼	614	456	390	341	315	259	230	195	180	165	151	149	144	134	122
⅜	597	443	370	330	300	251	220	188	170	157	144	140	135	125	113
½	588	438	360	324	295	246	200	185	165	150	140	136	131	121	108
¾	575	431	355	320	290	242	215	179	163	148	134	130	126	116	102
1	568	428	350	318	288	238	213	177	160	145	132	127	122	111	98

TABLE 102.—ROUGH-TURNING CAST IRON, BRINELL 177. CEMENTED-CARBIDE-TIPPED TOOL. 30° APPROACH ANGLE. ¼-IN. NOSE-RADIUS. RAKE 3°. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	970	725	610	546	500	414	380	318	285	265	248	243	238	227	213
1/16	895	670	570	500	455	380	350	287	260	235	221	216	211	198	182
⅛	720	545	455	406	380	308	280	234	210	195	180	175	170	159	146
¼	654	486	410	362	330	275	250	207	185	170	158	154	148	143	125
⅜	628	465	390	347	315	261	240	196	178	160	149	146	140	129	116
½	607	455	380	337	308	254	230	191	170	155	144	139	136	123	109
¾	597	443	370	329	303	247	225	185	165	152	137	132	127	116	104
1	584	436	360	324	295	243	220	180	160	148	134	128	123	112	100

Table 103.—Forming Cast Iron, Brinell 177. Cemented-carbide-tipped Tool. No Rake. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012
Speed, f.p.m.	167	123	105	92	83	77	73	69	65	62	58

Table 104.—Parting-off Cast Iron, Brinell 177. Cemented-carbide-tipped Tool. 3° Rake. $\frac{1}{64}$-in. Corner Radius. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012
Speed, f.p.m.	350	297	265	237	220	208	190	180	165	151	134

Table 105.—Finish-turning Cast Iron, Brinell 177. Cemented-carbide-tipped Tool. Rake 3°. $\frac{1}{8}$-in. Nose-radius. $\frac{1}{8}$-in. Trailing Flat. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.													
	Feed, in.													
	·002	·004	·006	·008	·010	·012	·014	·0156	·020	·031	·040	·050	·062	·125
·005	990	700	640	594	560	535	510	488	470	422	400	387	372	355
·010	845	645	550	490	455	430	415	400	380	345	330	310	293	272
·015	775	590	500	455	420	400	375	358	335	295	280	270	255	235
·020	725	550	480	425	390	367	343	325	305	265	250	240	230	210

If using other rake angles with cemented-carbide-tipped tools:

Multiply by 1·072 for 10°.
„ „ 1·12 for 15°.

TABLE 106.—MACHINABILITY OF CAST IRONS[15]

General composition								Physical properties		Constants			
Total C	Combined C	Si	Mn	Ni	Cr	Cu	Mo	Tensile, thous. lb./sq. in.	B.H. No.	Machining index M	H.P. index P	Speed index, C_v	Cutting force C_p lb., thousand
Plain Cast Irons.													
3·71		1·8	·91					17	127	1·67	·88	32·0	37
									141	1·11	·71	21·4	37
									143	1·65	·98	31·7	37
2·98	·24	2·41	·14						144	1·20	·74	23·1	38
3·37	·18	2·34	·50					19	156	1·32	·97	25·4	44
3·39	·80	1·60	·52					30	161	1·10	1·10	21·2	52
2·88	·32	1·47	·60					30	177	1·00	1·00	19·2	52
3·03		1·68	·98					33	181	1·03	1·28	19·8	59
3·10		1·89	·80					36	182	1·04	1·25	19·9	57
3·20		2·01	·79					33	182	1·05	1·35	20·2	59
3·13		1·57	1·06					33	183	·91	1·02	17·4	55
3·16		2·50	·79					37	194	·81	·88	13·6	58
2·92	·88	1·57	·36					41	195	·80	1·24	15·3	65
3·04		1·70	·69					40	198	·71	·48	13·6	62
3·30	1·05	·88	·94					36	199	·70	·78	13·4	55
2·70	·65	2·00	·60					38	204	·76	1·12	14·6	64
2·65		2·34	1·05					38	205	·71	1·01	13·6	62
2·9		1·12	·71					44	218	·66	1·16	12·7	71
2·8	·9	2·85	·41					50	224	·59	1·11	11·4	73
Alloy Irons.													
3·43		1·13	·53	1·44				29	165	1·29	1·25	24·9	42
3·38		1·99		·36	·28	·35		46	205	·81	1·43	15·4	92
3·52		1·07	·56	2·26	·49			34	206	·81	·98	15·5	72
3·4		1·97		2·00	·51	·20		45	215	·72	1·54	13·9	100
3·54		1·07	·61	·61	·80			33	249	·46	·72	8·9	93
3·25		1·92		·30	·40	·20	·80	56	270	·49	1·0	9·4	120
Malleable Iron.													
2·46		1·00	·26						137	1·10	1·31	21·2	36

For clean metal only. With scale reduce speeds 10–20 per cent according to conditions.

2. Machining Copper and its Alloys.

To-day there are many copper alloys the composition of which is adjusted to suit the functional requirements of the particular article. As the characteristics of these alloys[15, 19] must cover parts produced from free-cutting brass, the brasses for forging and hot-pressing, deep-drawn articles such as cartridge cases, to the heat- and corrosion-resisting alloys containing nickel, the speed of machining varies considerably.

When dealing with these alloys the same problem arises as with the many classes of steel in that the cutting speed for each alloy is altered by cold-work and heat treatment. The former, whilst hardening the metal and greatly increasing its strength, assists in the machining process, as it places the metal in a better condition to withstand the torsional stresses set up during the cutting operation. Hence bars which have been cold-worked enable deeper cuts and heavier feeds to be taken without the same risk that an unfinished component will be prematurely wrenched off the end. Then again the hard cold-work bar has a different arrangement of the crystals, as during the drawing process they have been made to flow axially. The combined action of work-hardening and the directional layout of the crystals is such that the chips are removed from the parent body without the damaging or tearing effect that accompanies the softer metals. None of the normal copper alloys are heat-treated to improve their machining qualities.

As is the case with cold-drawn steel bars, the size has an important influence upon the cutting speed. On the smaller sizes cold-drawing has a greater effect upon the hardness figures which often calls for a lower machining speed in f.p.m. Extruded bar has roughly the same hardness throughout the section. These remarks also apply to the annealed or hot-rolled bar.

When, as is often the case, the main consideration is economic production and a reasonably good surface-finish, strength and corrosion resistance being secondary, the call is for the free-cutting alloys. These contain a small percentage of lead, or, as in the case of copper, selenium or telurium. Free-cutting alloys may be obtained in brass, copper, nickel brass, nickel silver, Monel metal, phosphor bronze and silicon bronze. The composition of each of these free-cutting metals is adjusted to meet the requirements associated with production and use. When the main requirement is high-speed machining, without a thought as to any other operation, then for free-cutting brass rod the lead content is around 3 per cent; if a certain amount of cold-work has to be performed, say, knurling or slightly spinning an edge over to retain a component, then the lead content has to be reduced. Similar adjustments are called for when producing contact pins for electrical components which must have some spring.

A point to bear in mind when considering the term " free-cutting " is that it covers surface finish, dimensional accuracy, the ease with which the swarf can be handled, the question as to whether or not the swarf fouls the tools, and the speed of cutting. The latter, in every instance, has to be adjusted to suit the alloy and its condition.

Cutting Speeds.

On the basis of the available data, Tables 107–122 are compiled on the assumption that the tools cutting brass act in a similar manner as when cutting steel. This covers the question of tool-life, the effect of a lubricant, the tool-shape taken in plan, also changes in rake angles. The relative machinability of free-cutting steel (B.S. 970 En 1 A, H.R.) and free-cutting brass (B.S. 249) is taken as 1 to 1·1. Tables 107–113 are on the basis of dry cutting with an 18 . 4 . 1 h.s.s. tool; for other alloys Tables 114–122 give the suggested *M* factor. Owing to the many slight variations in the composition and physical state in which the component or metal is sent forward to the machine shop, the suggested figures are only a basis upon which to work. In everyday practice, circumstances will arise where modifications are necessary. Then the *M* factor should be adjusted to meet the specific conditions. The need for a reduction in speed quickly makes itself known; the tools require frequent resharpening. On the other hand, the possibility of using higher speeds, deeper cuts, and heavier feeds, along with fixing specific times for changing the tools, so that production per shift can be improved, is normally the result of (*a*) a close and accurately recorded series of experiments, or (*b*) checking the present cutting speeds, feeds, and h.p. requirements against existing data.

When the tables are closely examined and the speeds for a given chip size compared with those used on the general run of high-speed automatic lathes, it will be noticed that, in the smaller bar sizes, full use cannot be taken of the excellent machining properties of the leaded brasses. Taking a well-known make of automatic supplied with machine bars of $\frac{5}{16}$, $\frac{1}{2}$ and 1 in. dia. and running at speeds of 5000, 3600 and 2400 r.p.m. respectively, the maximum surface speed for each machine is:

Lathe taking $\frac{5}{16}$ in. dia. bar $= \cdot 262dR = \cdot 3125 \times \cdot 262 \times 5000$
$= 410$ f.p.m.
,, ,, $\frac{1}{2}$,, ,, $= \cdot 5 \times \cdot 262 \times 3600 = 470$ f.p.m.
,, ,, 1 ,, ,, $= 1 \times \cdot 262 \times 2400 = 628$ f.p.m.

Thus, in spite of the high spindle speeds in r.p.m. of the two smaller machines, they fail to give the necessary linear speed which would lead to a rapid breakdown of the edge on an h.s.s. tool when cutting dry. If, as is usual, the tools are flooded with a cutting oil, then the position is such that a long tool-life is assured. This is also favoured by the rapid change in the linear speed between the two extremities of the cutting edge (see pp. 92, 165). Then again, it is important to note that the optimum spindle speed for turning often has to be reduced to suit, say, a screwing or tapping operation. Such procedure, of course, again favours a long tool-life. It also raises the question as to whether any of the slower operations could or should be transferred to another machine.

Table 107.—Rough-turning Free-cutting Brass Rod, B.S. 249. H.S.S. Tool 18 . 4 . 1. No Approach Angle. No Nose-radius. True Rake 5°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.										
	Feed, in.										
	·002	·004	·006	·008	·010	·012	·014	·016	·031	·062	·125
$\frac{1}{32}$	1320	850	640	555	480	445	405	372	260		
$\frac{1}{16}$	1320	840	635	555	475	440	400	369	250		
$\frac{1}{8}$	1320	837	632	550	473	435	390	360	240	166	
$\frac{1}{4}$	1320	835	630	545	470	430	385	355	230	156	110
$\frac{3}{8}$	1320	830	630	540	470	426	380	350	225	150	100
$\frac{1}{2}$	1320	830	630	535	470	422	375	345	220	143	96
$\frac{3}{4}$	1320	827	630	530	468	418	370	340	210	140	87
1	1320	827	630	525	465	415	365	335	205	130	80

Table 108.—Rough-turning Free-cutting Brass Rod, B.S. 249. H.S.S. Tool 18 . 4 . 1. No Approach Angle. $\frac{1}{16}$-in. Nose-radius. True Rake 5°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.										
	Feed, in.										
	·002	·004	·006	·008	·010	·012	·014	·016	·031	·062	·125
$\frac{1}{32}$	2200	1400	1020	905	780	715	660	605	445	350	300
$\frac{1}{16}$	1780	1150	890	740	670	605	540	500	340	260	210
$\frac{1}{8}$	1575	1000	765	645	590	510	460	430	300	210	165
$\frac{1}{4}$	1450	925	715	590	525	480	400	390	260	180	130
$\frac{3}{8}$	1440	885	670	570	500	445	390	370	245	175	120
$\frac{1}{2}$	1370	875	650	560	495	435	380	360	235	155	110
$\frac{3}{4}$	1360	870	635	550	480	425	375	350	230	145	96
1	1350	865	635	540	470	415	370	340	225	135	86

Table 109.—Rough-turning Free-cutting Brass Rod, B.S. 249. H.S.S. Tool 18 . 4 . 1. 30° Approach Angle. ⅛-in. Nose-radius. True Rake 5°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.										
	Feed, in.										
	·002	·004	·006	·008	·010	·012	014	·016	·031	·062	·125
1/32	3000	1920	1430	1230	1050	960	875	810	540	382	330
1/16	2100	1400	1050	890	795	715	640	585	365	280	225
⅛	1810	1160	860	795	670	605	540	490	325	225	175
¼	1660	1030	780	670	590	525	460	430	285	195	145
⅜	1590	1000	720	635	525	480	445	415	265	175	120
½	1560	990	700	620	529	470	435	400	255	165	110
¾	1510	960	685	600	510	460	425	395	243	155	105
1	1500	940	670	595	495	450	415	380	240	150	100

Table 110.—Rough-turning Free-cutting Brass Rod, B.S. 249. H.S.S. Tool 18 . 4 . 1. 30° Approach Angle. ¼-in. Nose-radius. True Rake 5°. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.										
	Feed, in.										
	·002	·004	·006	·008	·010	·012	·014	·016	·031	·062	·125
1/32	3400	2170	1560	1370	1210	1080	970	900	600	415	330
1/16	3000	1910	1430	1200	1050	970	860	785	515	350	260
⅛	2120	1385	980	880	765	700	640	565	375	255	185
¼	1830	1160	860	730	640	580	525	475	310	205	145
⅜	1710	1050	765	685	575	510	480	440	285	185	130
½	1650	1030	750	655	570	500	460	420	270	175	120
¾	1580	1000	735	625	565	495	440	400	260	165	105
1	1540	975	715	610	545	480	420	390	245	155	95

Table 111.—Forming Free-cutting Brass Rod, B.S. 249. H.S.S. Tool 18 . 4 . 1. No Rake. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010
Speed, f.p.m.	495	310	240	200	170	155	140	130	120	110

Table 112.—Parting-off Free-cutting Brass Rod, B.S. 249. H.S.S. Tool 18 . 4 . 1. 5° Rake. $\frac{1}{64}$-in. Corner Radius. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010
Speed, f.p.m.	2220	1560	1180	970	860	760	700	635	590	555

Table 113.—Finish-turning Free-cutting Brass Rod, B.S. 249. H.S.S. Tool 18 . 4 . 1. 5° Rake. $\frac{1}{8}$-in. Nose-radius. $\frac{1}{4}$-in. Trailing Flat. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·030	·040	·050	·060
·005	4130	2400	2100	1880	1720	1590	1500	1330	1270	1110	1050	1000	920
·010	3240	2120	1650	1420	1270	1160	1080	1020	920	790	730	670	620
·015	2820	1800	1460	1240	1110	1020	940	890	760	640	590	560	540
·020	2500	1600	1270	1080	950	875	810	750	650	525	490	460	430

For rake angles on turning tools other than those given in Tables 107-113 use the factor C_r, Table 113a.

Table 113a.—Values of C_r for Cutting Brass

Rake, degrees.	0	5	10	15	20	25	30
Value of C_r.	1·00	1·00	1·02	1·11	1·05	·91	·83

The tables 107–113 are based on the supposition that the brass acts similarly to steel.

If using other cutting media than 18 . 4 . 1 h.s.s. introduce the T_m factor, Table 26, p. 96.

Table 114.—Copper. British Standards and *M* Factors

Spec. No.	Designation	Cu	Pb	Te	As	V.D.H.*	Condition	*M* factor
B.S. 24/Pt. 5	Copper bars. Loco stay bolts.	99·2			·3–·5	55 85 110	Soft ½ Hard Hard	·875 ·67 ·55
B.S. 143	Copper castings.						A.C.	·31
B.S. 1433 1434	Copper rod and sections.	99·9				55 85 110	Soft ½ Hard Hard	·875 ·67 ·55
	Copper.	99·4	$<$·04					
	Free-cutting copper bar.	99·2		·75		55 85 110	Soft ½ Hard Hard	·875 ·67 ·55

* V.D.H. = Vickers Diamond Hardness. For use with Tables 107–113, pp. 182–4.

TABLE 115.—BRASSES. BRITISH STANDARDS AND *M* FACTORS

Spec. No.	Designation	Ni	Min. tensile, tons/in.²	Cu	Zn	Pb	Sn	Fe	Mn	Mg	Al	Impurities, &c.	Other elements	V.D.H.	Condition	*M* factor
	"A" Cast.															
B.S. 208/1	Special brass castings (mang. brass).		28	54	Remainder	·5							5		A.C.	·25
B.S. 208/2	" " " " "		32	54		·5							5		A.C.	·19
B.S. 208/3	" " " " "		34	54		·5							8		A.C.	·18
B.S. 208/4	" " " " "		38	50		·5							10		A.C.	·16
B.S. 208/5	" " " " "		45	50		·5							13		A.C.	·12
B.S. 1026	Brass castings.	1·0		75		2·5	2	·75			·01				A.C.	·8
B.S. 1028	" "	1·0		66		2·5	2	·75	·25		·25				A.C.	·8
	Yellow brass.			60	40										A.C.	·31
	High tensile.			57	37			·8	2		3·2				A.C.	·12
B.S. 920	Brass die castings (naval brass)·			62	37		1							60	A.C.	·3
B.S. 932	" " " (ordinary).			60	40									70	A.C.	·27
														80		·24
	"B" Wrought Forms.															
B.S. 218	Hot stamping bar.			58	40·5	1·5								80	Extruded	·75
														100		·64
														120		·5
														140		·45
B.S. 249	Free-cutting brass rod.			58	39	3·0								80	Extruded	1·000
														95		·86
														110		·72
														120		·66
														130		·6

For use with Tables 107-113, pp. 182-4.

TABLE 115.—(*Continued*)

Spec. No.	Designation	Min. tensile tons/in.^{2}	Cu	Zn	Pb	Sn	Fe	Mn	Mg	Al	Impurities, &c.	Other elements	V.D.H.	Condition	*M* factor
	"B" Wrought Forms—(*Cont.*).														
B.S. 250	High-tensile brass bars.	30	54	Rem.								up to	80	C.W.	·31
			62									7·0	100	,,	·27
													120	,,	·23
													140	,,	·19
B.S. 251	Admiralty naval brass bars.	26	61	Rem		1							80	,,	·31
						1·5							100	,,	·27
													120	,,	·23
B.S. 252	,, ,, ,, ,, (special)		57·5	Rem		·6							80	,,	·31
			60·5			1·25							100	,,	·27
													120	,,	·23
	,, ,, ,, ,, (leaded)		61	Rem.	·5	1							80	,,	·75
					2·0								100	,,	·62
													120	,,	·5
B.S. 264	Yellow brass (Muntz metal).	22	60	40									75	Sheet, Strip, &c.	·4
													100		·35
													125		·3
													150		·24
B.S. 265	Basis brass.	10	63	37									65	Sheet, Strip, &c.	·41
													90		·37
													115		·32
													150		·24
													180		·18

B.S. 266	65/35.	18	65	35									65 90 115 150 185	Sheet, Strip, &c.	·41 ·37 ·32 ·24 ·18
B.S. 267	Cartridge metal 70/30.	18	70	30									65 90 115 150 185	Sheet, Strip, &c.	·41 ·37 ·32 ·24 ·18
B.S. 409	Naval brass.	22	62	37		1							80	Plate	·39
B.S. 885	Brass tube 70/30.	25	70	30									65 90 115 150 175	Tube	·41 ·37 ·32 ·24 ·19
B.S. 886	Admiralty brass.	18	70	29		1							65 90 115 150 175	Tube	·41 ·37 ·32 ·24 ·19
B.S. 1001	High-tensile brass forgings.	30	56·8 62	Rem.	1·5					·2		6	90 110 130		·25 ·19 ·18

For use with Tables 107–113, pp. 182–4.

TABLE 115.—(*Continued*)

Spec. No.	Designation	Min. tensile tons/in.²	Cu	Zn	Pb	Sn	Fe	Mn	Mg	Al	Impurities, &c.	Other elements	V.D.H.	Condition	*M* factor
	“B” Wrought Forms—(*Cont.*).														
	Semi-free-cutting brass rod.		59	40	1·0								80		·75
													100		·62
													120		·5
													140		·4
	” ” ” (nipple wire rod).		63·5	35	1·5								75		·78
													100		·62
													120		·5
													140		·4
	Free-cutting brass tube.		63	35·5	1·5								65	Tube	·85
													90		·68
													115		·53
													150		·34
	Brass wire (for screws, rivets, &c.).		61	30	·0								65		·41
			75	38	·5								90		·37
													125		·3
													150		·24
													200		·12
	Brass wire or gilding metal wire.		75	10									60		·44
			90	25									80		·39
													100		·35
													120		·31
													180		·18

For use with Tables 107–113, pp. 182–4.

The *M* factor for the alloys to specification B.S. 1400 are equivalent to those listed above having the same general composition.

TABLE 116.—GILDING METALS. BRITISH STANDARDS AND *M* FACTORS

Spec. No.	Designation	Cu	Zn	Pb	V.D.H.	Condition	*M* factor
B.S. 711	Gilding metal.	80	20		60	Sheet,	·44
712	,, ,,	85	15		80	Strip,	·39
713	,, ,,	90	10		100	&c.	·35
					120		·31
					140		·27
					170		·20
	Gilding metal, leaded.	89	9	2	65	Bars,	·85
	,, ,, ,,	84	14	2	90	Section,	·69
					115	&c.	·53
					140		·4
					160		·3

For use with Tables 107-113, pp. 182-4.

TABLE 117.—NICKEL SILVERS. BRITISH STANDARDS AND *M* FACTORS

Spec. No.	Designation	Cu	Ni	Zn	Pb	V.D.H.	Condition	*M* factor
B.S. 790	10% Nickel silver.	63	10	27		65	Sheet,	·28
B.S. 790	12% ,, ,,	63	12	25		80	Strip,	·26
B.S. 790	15% ,, ,,	63	15	22		100	Bars,	·23
B.S. 790	18% ,, ,,	62	18	20		120	Wire	·21
B.S. 790	20% ,, ,,	62	20	18		140		·19
B.S. 790	25% ,, ,,	57	25	18		160		·16
	30% ,, ,,	57	30	13		200		·13
	,, ,, for springs	55	18	27		240		·11
	Nickel silver for machining.	60	12	Rem	1	72	,,	·45
			18		2	90		·42
						105		·39
						130		·36
						150		·33
						180		·3
	Nickel silver for hot working.	44	10	44	2	100	Rods,	·62
						125	pressings	·5
						150		·4

TABLE 118.—B.S. 374 CUPRO-NICKELS. *M* FACTORS

Designation	Cu	Ni	V.D.H.	Condition	*M* factor
Cupro-nickel.	70	30	65	Strip,	·28
,,	75	25	85	Sheet,	·25
,,	80	20	105	Tube,	·23
,,	85	15	125	Rods,	·2
,,	95	5	160	&c.	·16

TABLE 119.—BRONZES. BRITISH STANDARDS AND *M* FACTORS

Spec. No.	Designation	Cu	Zn	Pb	Sn	P	Ni	Si	Al	Fe	Mn	Cr	V.D.H.	Condition	*M* factor
	(A) Wrought Forms.														
B.S. 369	Phosphor-bronze rod.	94			5·5	·1							65		·30
													85	Rod	·26
													105		·23
													125		·20
													150		·17
													175		·15
													200		·14
D.T.D. 265 A	Bronze high tin for bearings.	91·5			8·25	·25							140		·18
B.S. 384	Phosphor-bronze wire for springs.	94			5·75	·1							60	Sheet	·31
B.S. 407/1	Phosphor-bronze sheet and strip.	96·0			3·75	·1							85	and	·26
B.S. 407/2	,, ,, ,,	94·5			5·25	·1							105	strip	·23
B.S. 407/3	,, ,, ,,	93·0			6·75	·1							125		·20
													150		·17
													175		·15
													200		·14
													260		·12
D.T.D. 155	Wrought gunmetal bar.	88	2		10								70	Bar	·29
													90		·25
													110		·22
													130		·19
													150		·17
													180		·15
D.T.D. 135	Aluminium-bronze rods.	88·75					1·25		10·0				160	Forged	·16
D.T.D. 160	,, ,,	90·0											185		·14
D.T.D. 164	,, ,,	87·5					2·0		10·0				210		·12
	,, ,,	86·5					2·0		10·0	1·5			245		·11

(B) Cast Forms.

B.S. 382	Admiralty gunmetal.	88	2		10								70	A.C.	·24
B.S. 383													80		·22
													90		·21
													100		·20
B.S. 421	Phosphor-bronze for worm gears. Sand, chill, and spun cast.	87·5			12	·15							80	A.C.	·23
													100		·20
													120		·17
													140		·15
													160		·14
													180		·12
													200		·11
													250		·10
													300		·09
B.S. 897	Leaded gunmetal.	85	5	5	5								60	A.C.	1·0
B.S. 898													70		1·0
B.S. 900	Leaded gunmetal.	87	3	1	9								70	A.C.	·25
B.S. 901													80		·23
													90		·22
													100		·20
B.S. 960	Leaded bronze.	85		5	10								70	A.C.	1·0
B.S. 961	,, ,,														
B.S. 962	Leaded bronze.	80		10	10								65	A.C.	1·0
B.S. 963	,, ,,														
B.S. 964	Leaded bronze.	76		15	9								60	A.C.	1·0
B.S. 965	,, ,,														

For use with Tables 107-113, pp. 182-4.

TABLF 119.—(*Continued*)

Spec. No.	Designation	Cu	Zn	Pb	Sn	P	Ni	Si	Al	Fe	Mn	Cr	V.D.H.	Condition	*M* factor
	(B) Cast Forms.—(*Cont.*).														
B.S. 1024	Leaded gunmetal.	Rem	5	2	7		1							A.C.	·8
B.S. 1030	Silicon bronze.	„	5					2·5		2·5	1·5		60	A.C.	·25
B.S. 1032	Aluminium-bronze.	„	·5				1		9·5	2·5	1·0		90	A.C.	·21
													115	A.C.	·18
													140	A.C.	·15
B.S. 1059	Phosphor-bronze.	„			10	·5	1							A.C.	
B.S. 1061	Leaded phosphor-bronze.	„	2	2 5	7·5	·5								A.C.	·8
B.S. 1073	Aluminium bronze.	„	·5				4		9·5	9·25	3		90	A.C.	·21
													115	A.C.	·18
													140	A.C.	·15
	Lead (electrical) bronze.	87	3	3	7								60–70	A.C.	·80
D.T.D. 174 A	Aluminium bronze.	Rem					*		9	2·5			90	A.C.	·21
													115		·18
													140		·15
D.T.D. 412	Aluminium bronze.	„					4·5		10	4·5	>2·5		150		·14
	Aluminium bronze.	„					†						175		·12
													200		·11
													250		·10
													300		·09

For use with Tables 107-113, pp. 182-4.

* Ni up to 4·0. Mn up to 3·5. † Fe and Ni each between 3·0 to 6·0. Mn up to 2·5.

The *M* factors for the alloys to specification B.S. 1400 are equivalent to those listed above having the same general composition.

TABLE 120.—NICKEL, MONEL METAL, ICONEL. *M* FACTORS

The non-ferrous metals and alloys of nickel, Monel metal, and Iconel have a very wide range of physical properties imparted by (*a*) cold-work or (*b*) heat treatment. The range of tensile strength varies from, say, 20 tons per sq. in. to 76 tons per sq. in. and the B.H. No. from, say, 80 to 375. Suggestions as to the *M* factors for use with Tables 107–113 are:

Strength per sq. in.		*M* factor
Tons	Lb.	
20	44,800	·220
25	56,000	·190
30	67,200	·170
35	78,400	·150
40	89,600	·132
45	100,800	·120
50	112,000	·104
55	123,200	·096
60	134,400	·088
65	145,600	·080
70	156,000	·072
75	168,000	·066
80	179,200	·060

TABLE 121.—AMERICAN (S.A.E.) COPPER-BASED CASTING ALLOYS

S.A.E. No.	Description	Cu	Sn	Pb	Zn	Fe	Ni	P	Al	Si	Sb	Mn	M factor
40	Red brass, leaded.	84–86	4–6	4–6	4–6	·3	1·0						1·00
41	Yellow brass.	65–70	1·5	1·5–3·75	Bal.	·75			·3				1·00
43	Manganese-bronze.	55–60	1·0	·4	Bal.	·4–2·0	·5		·5–1·5			1·5	·25
430 A	High-tensile manganese-bronze.	60–68	·2	·2	Bal.	2–4	·5		3–7·5			2·5–5·0	·2
430 B	,, ,, ,, ,,												·18
62	Gunmetal.	86–89	9–11·0	·3	1–3	·15	1·0						·32
620	Navy "G".	86–89	7·5–9	·3	3–5	·15	1·0						·19
621	Navy "G", leaded.	85–89	7·5–9	1·0	3–5	·25	1·0						·20
622	Navy "M".	86–89	5·5–6·5	1–2	3–5	·25	1·0						·75
63	Leaded gunmetal.	86–89	9–11	1–2·5	·75	·15	1·0	·25					·75
64	Phosphor-bronze.	78–82	9–11	8–11	·75	·15	·5	·25			·5		1·00
640	Nickel phosphor-bronze.	85–88	10–12	1–1·5	·5	·3	·75–1·5	·2–3					·75
65	Phosphor gear bronze.	88–90	10–12	·5	·5	·15		·1–3					·22
66	Bronze bearings.	83–86	4·5–6·0	8–10	2	·2	·5				·3		1·00
660	Bronze bearings.	81–85	6·25–7·5	6–8	2–4	·2	·5	·15			·25		1·00
68 A	Aluminium-bronze, as cast.	86–89	·5			2·5–4			8·5–9·5				·31
68 B	,, ,, ,,	86–89	·2			1–2			10–11·5				·30
	,, heat-treated.												·20

Take basic speed V_c from Tables 107–113.

The M factor in Tables 121, 122 is of a general character inasmuch as variations in strength and hardness due to methods of casting and cold-work have not been dealt with. If the hardness of material is known, the adjusted M factor can be estimated by combining Tables 114–120.

Table 122.—American Copper-based Wrought Alloys

S.A.E. No.	Description	Cu	Pb	Fe	Zn	Sn	Al	P	*M* factor
70 A	Cartridge brass sheet.	68·5–71·5	·07	·05	Rem.				·4
70 B	,, ,, ,,								·4
70 C	High brass sheet.	64–68	·15	·05	Rem.				·36
701 A	Aluminium-bronze rods, &c.	92–96		·5			4–7		
701 B	,, ,, *	80–93		4·0		·6	9·0–11·0		
71	Copper sheet.	99·9							·70
72	Free-cutting brass, rods.	60–63	2·5–3·75	·15	Rem.				1·0
73	Naval brass, rods, forgings.	59–62	·2	·1	Rem.	·5–1·0			·3
74 A	Brass tubes. Muntz metal.	59–63	·8	·07	Rem.				·3
74 B	,, ,, Yellow brass.	65–68	·8	·07	Rem.				·36
74 C	,, ,, Cartridge brass.	68·5–71·5	·07	·05	Rem.				·4
74 D	Red brass.	83–86	·06	·05	Rem.				·3
75	Copper tubing.	99·9							·7
76	Naval brass tubes.	59–62	·3	·1	Rem.	·5–1·0			·3
77 A	Phosphor-bronze strip.	Rem.	·05	·1	·3	3·5–5·8		·03–·35	·29
77 C	,, ,,	Rem.	·05	·1	·2	7·0–9·0		·03–2·5	·27
79 A	Red brass sheet.	84–86	·05	·05	Rem.				·3
79 B	Low ,, ,,	78·5–81·5	·05	·05	Rem.				·35
791	Rolled bronze bushing.	Rem.	3·5–4·5	·1	1·5–4	3·5–4·5			1·00
795	Rolled bronze bushing.	88–92			Rem.	·5			·25
80 A	Brass wire.	68·5–71·5	·07	·05	Rem.				·4
81	Phosphor-bronze, rods and wire.	†	·05	·1	·3	3·5–5·8		·03–·35	·29
83	Copper wire, annealed.	‡							·7
88	Forging brass.	58–62	1·5–2·5	·3	Rem.				·75

* Composition varies. When nickel is 5·5, silicon to be ·25. If silicon is 2·25, then nickel to be ·25.

† Copper + tin + phosphorus = 99·5. ‡ Copper of such purity as to give the desired physical and electrical qualities.

Take basic speeds from Tables 107–113.

3. Machining Aluminium and its Alloys.

The machining of aluminium and its alloys follows the same general procedure as is used for the various classes of steel, namely, that one must make due allowance for the different physical characteristics of each alloy. In practice the metals to be handled vary from pure aluminium or free-cutting alloy bars, to the high-duty forgings, sand- and die-castings. In addition, due allowance must be made for cold-working and heat treatment. When using old machines, the question of speed is relatively unimportant, the equipment being unsuitable for the highest cutting speed; if modern machines are available, then speed in f.p.m. needs careful consideration in order to obtain the optimum efficiency.

Commercially pure aluminium gives, on being turned, a long chip,[21,22] which on automatic and kindred machines fouls the tools. This is a drawback and has led to the development of the free-cutting alloys. Owing to the low strength of the metal, thick chips, as they leave the parent body, tear and carry away with them small unsheared pieces of metal. This action gives a very rough surface; hence on all operations which call for the removal of a large volume of material, particular care must be given to the chip dimensions and the amount left on for the finishing cuts.

In order that aluminium alloys may be used in a similar manner to the free-cutting brasses on capstan and automatic lathes, free-cutting types of aluminium alloy bars [21,23] are now available. These metals have small additions of such elements as copper, lead, bismuth, and antimony, which function in a similar manner to lead in brass, i.e. they prevent the formation of long chips. Thus the swarf given by the free-cutting alloys is in the form of small chips that are easily washed away by the stream of suds or other cutting lubricants.

With the alloys falling within the " non-heat-treating " group, cold-working improves the machining qualities of the metal, as to a marked extent it removes the tendency for the material to tear or build up on the cutting edge of the tool.

Aluminium alloys amenable to heat treatment are in the best condition, so far as producing a short chip is concerned, when heated to bring about the maximum strength. Then the production of a short chip gives a good finished surface. When machined in the untreated condition their machining qualities, i.e. ability to give a short chip and a smooth surface, may be poorer than some of the alloys in the non-heat-treating category.

Casting alloys,[20] particularly those with a high silicon-content, have a greater abrasive action upon the cutting edge, and the result is that cutting tools made from high-speed steel, which give excellent service in terms of tool-life on the non-silicon alloys, fail rapidly when used to machine an alloy having a high percentage of silicon. Hence the usual instruction to choose cemented carbide-tipped tools for such metals, as, owing to their greater resistance to abrasion, they last much longer.

The life of a standard h.s.s. tool cutting aluminium is from 3 to 5 times greater than when engaged on steels, whilst the cemented carbide-tipped tools have a life varying from 5 to 7 times greater than when machining ferrous metals. Bars of the free-cutting types of aluminium give a slightly greater tool-wear than is experienced with the free-cutting brasses. Comparing the cutting life for the free-cutting aluminium alloys with that for cutting Duralumin, tools engaged on the former metal last roughly twice as long as when engaged on the latter. Moreover, the cutting speed is higher and the cutting force for a known chip-area is lower. High-silicon alloys reduce the tool-life by, say, 30–50 per cent or more.

Rough-machining aluminium alloys is best done at high cutting speed and a moderate to fine feed. This is different to the conditions governing the rough machining of steel, where the usual combination is a heavy cut and a moderate to slow cutting speed. The reason for this combination has been mentioned above, the tearing of metal away from the machined face. Surface-finish is favoured by a fine feed and a high cutting speed, whilst the smaller chip area reduces the forces acting upon the machine. The power input should, however, be watched, as the higher cutting speed may call for a greater power-input than is possessed by the machine. The following points also need attention when engaged in planning machining operations on aluminium alloys:

(*a*) The feed must be small when a good surface-finish is desired.

(*b*) Owing to the high rate of linear expansion, all finish-machining must be done on aluminium alloys with the metal quite cool.

(*c*) If the work becomes hot, the surface-finish becomes rough, owing to the combination of a reduction in strength at an elevated temperature and the tearing action of the chips.

(*d*) The work must be adequately supported, keeping in mind the lower strength of some of the aluminium alloys when compared with steel.

(*e*) Vibration must be absent, and this may affect the choice of a cutting speed.

(*f*) A suitable cutting liquid is necessary on some alloys in order to give a good surface-finish.

(*g*) The top rake on all cutting tools should be adjusted to suit the alloy[24] and the class of tool to be used. The graphs (figs. 9.2 and 9.3) give the general run of rake angles.

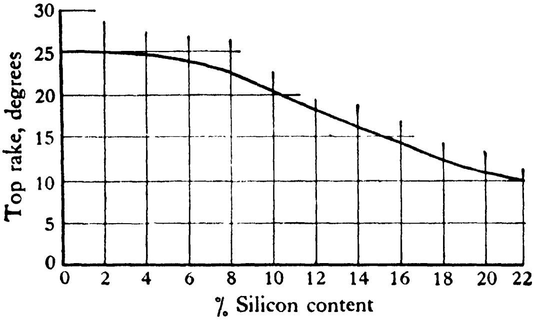


Fig. 9.2.—Top rake for carbide-tipped tool when machining silicon-aluminium alloys

(*h*) In order to keep the number of tool shapes[12] down, it may be necessary to standardize on one or two rake angles. This should not give rise to any difficulty provided that the cutting edges are keen, the surfaces excellently ground and lapped smooth, so that the chips flow readily across the tool-face, thus lessening the tendency to form a " built-up edge ".

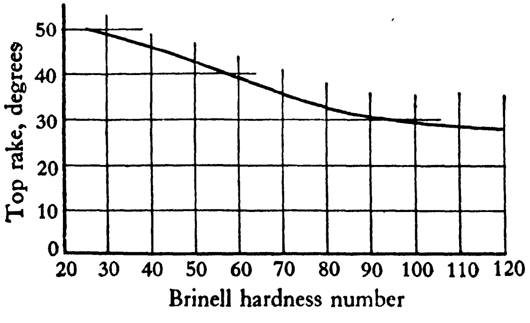


Fig. 9.3.—Top rake for aluminium alloys excluding silicon types

Cutting-speed Tables for Aluminium and its Alloys.

Tables 123–132 are for wrought aluminium bars to B.S. 386 and S.A.E. 25. It must be realized that, owing to the lack of sufficient experimental data, which may be years in forthcoming, the speeds and feeds are subject to such modification as experience, under the given set of conditions, dictates. There cannot be any hard-and-fast ruling. For other alloys the material factor *M* is listed in Tables 133–136 and is brought into the cutting-speed formula in a similar way to that outlined for steel (p. 218). In quite a few instances the computed cutting speeds are beyond those practicable on machines dating back before, say, the year 1930.

Basis of the Tables.—When constructing the tables the relative machinability of En 2 C and pure aluminium for 15° and 40° rake angles has been taken as 12 and 40 respectively; the tool-life for aluminium has been taken at three times that when cutting a similar chip from steel, and thus, assuming a tool-life factor of ·83 (Table 21, for h.s.s. cutting non-ferrous metals), the relative machinability of aluminium becomes:

$$\left.\begin{array}{r}\text{Relative machinability of aluminium}\\ \text{for a 1-hour run when compared}\\ \text{with B.S. En 2 C, or S.A.E. 1020}\end{array}\right\} = \frac{40}{12} \times \frac{1}{\cdot 83} = \text{say, } 4.$$

To cope with the varying hardness of the alloys due to either cold-work or heat treatment, the graph in fig. 9.4 may be used to determine the approximate machining factor *M* for non-silicon alloys only.

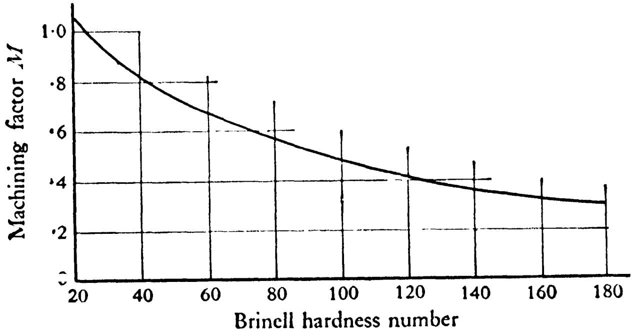


Fig. 9.4.—Machining factors (*M*) for aluminium alloys

With the high-silicon alloys the basis of the factor *M* is on the assumption that the tool-life is only one-third that when machining pure aluminium bar.

Magnesium Alloys.—The basic speed for magnesium alloys is taken at an increase of one-third on that for pure aluminium bars, and the *M* factors are listed in Tables 137–140, pp. 210–213.

TABLE 123.—ROUGH-TURNING SOFT ALUMINIUM BARS, B.S. 386. H.S.S. TOOLS 18 . 4 . 1. TRUE RAKE 40°. NO APPROACH ANGLE. NO NOSE-RADIUS. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	1680	1068	806	696	604	468	408	328	328	328	332	332	336	340	344
1/16	1672	1056	800	692	600	464	400	308	276	252	228	228	224	220	216
1/8	1672	1052	800	684	596	448	380	300	256	228	208	200	188	176	160
1/4	1664	1052	795	668	592	440	372	288	244	220	196	184	176	152	136
3/8	1664	1044	795	668	592	436	372	284	240	216	188	180	172	148	124
1/2	1648	1044	795	668	592	428	368	276	236	208	180	172	160	140	120
3/4	1648	1040	790	660	585	424	364	264	224	200	176	160	148	132	108
1	1648	1040	790	656	585	420	360	260	220	188	164	148	140	124	100

TABLE 124.—ROUGH-TURNING SOFT ALUMINIUM BARS, B.S. 386. H.S.S. TOOLS 18 . 4 . 1. TRUE RAKE 40°. NO APPROACH ANGLE 1/16-IN. NOSE-RADIUS. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	2760	1760	1280	1140	980	760	700	560	500	460	440	432	420	400	372
1/16	2240	1440	1120	928	840	628	560	440	392	356	328	320	231	292	264
1/8	1980	1260	960	808	744	540	480	364	320	280	264	256	248	232	204
1/4	1820	1160	900	740	660	488	432	328	280	240	228	212	200	188	164
3/8	1760	1112	840	712	628	464	400	304	256	224	216	204	192	168	148
1/2	1720	1100	820	700	620	452	392	292	244	208	196	188	180	160	136
3/4	1712	1092	800	684	600	440	380	284	232	196	180	168	160	144	120
1	1696	1044	796	680	592	428	368	280	228	192	168	164	152	128	108

TABLE 125.—ROUGH-TURNING SOFT ALUMINIUM BARS, B.S. 386. H.S.S. TOOL 18 . 4 . 1. 30° APPROACH ANGLE. 1/8-IN. NOSE-RADIUS. 40° TRUE RAKE. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	3760	2420	1800	1540	1320	1016	900	680	584	520	480	472	460	440	412
1/16	2640	1752	1280	1120	1000	736	640	456	392	360	352	328	320	312	288
1/8	2280	1460	1120	1000	840	616	540	408	352	300	284	272	264	240	216
1/4	2080	1300	980	840	740	544	472	356	292	260	244	232	224	200	176
3/8	2000	1260	900	800	660	520	440	332	280	240	220	204	196	176	152
1/2	1960	1240	840	776	652	504	420	320	260	228	208	196	188	160	140
3/4	1900	1200	820	752	640	488	400	304	248	208	196	192	180	156	136
1	1880	1180	820	748	620	476	400	300	244	200	188	180	160	152	120

Table 126.—Rough-turning Soft Aluminium Bars, B.S. 386. H.S.S. Tool 18 . 4 . 1. 30° Approach Angle. ¼-in. Nose-radius. 40° True Rake. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.														
	Feed, in.														
	·002	·004	·006	·008	·010	·0156	·020	·031	·040	·050	·062	·070	·080	·100	·125
1/32	4260	2720	1960	1720	1520	1132	1000	752	640	560	520	508	488	460	412
1/16	3764	2400	1800	1520	1320	974	860	644	552	488	440	432	412	376	324
⅛	2668	1740	1240	1110	960	712	620	468	400	348	320	308	288	268	232
¼	2296	1460	1080	920	800	592	520	388	320	280	260	240	232	204	180
⅜	2144	1320	960	860	720	552	480	356	296	256	232	220	204	184	160
½	2068	1300	940	824	720	524	464	340	280	240	220	212	196	168	148
¾	1984	1252	920	784	718	504	420	324	264	220	204	196	184	164	132
1	1928	1220	900	764	680	482	400	304	248	208	192	184	168	140	120

Table 127.—Forming Soft Aluminium Bars, B.S. 386. H.S.S. Tool 18 . 4 . 1. No Rake. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	·012
Speed, f.p.m.	620	388	300	248	212	192	172	160	148	140	128

Table 128.—Parting-off Soft Aluminium Bars, B.S. 386. H.S.S. Tool 18 . 4 . 1. 15° Rake. 1/64-in. Corner Radius. Tool-life 1 hour Cutting Dry.

Feed, in.	·001	·002	·003	·004	·005	·006	·007	·008	·009	·010	0·12
Speed, f.p.m.	2800	1960	1480	1220	1080	960	880	800	740	700	632

Table 129.—Finish-turning Soft Aluminium Bars, B.S. 386. H.S.S. Tool 18 . 4 . 1. Rake 40°. ⅛-in. Nose-radius. ⅛-in. Trailing Flat. Tool-life 1 hour Cutting Dry.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·031	·040	·050	·062
·005	5200	3040	2640	2360	2160	2000	1880	1680	1600	1400	1320	1260	1160
·010	4080	2680	2080	1780	1600	1460	1360	1280	1160	1000	920	840	780
·015	3560	2280	1840	1560	1400	1280	1180	1120	960	800	740	700	680
·020	3120	2000	1600	1360	1200	1100	1020	940	820	660	620	580	540

TABLE 130.—FINISH-TURNING SOFT ALUMINIUM BARS, B.S. 386. H.S.S. TOOL 18 . 4 . 1. 40° RAKE. $\frac{1}{16}$-IN. NOSE-RADIUS. $\frac{1}{8}$-IN. TRAILING FLAT. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·031	·040	·050	·062
·005	3600	2200	1920	1740	1600	1480	1400	1280	1200	1040	980	880	880
·010	2800	1960	1580	1320	1200	1080	1000	920	840	740	640	600	580
·015	2400	1680	1400	1160	1040	960	880	800	720	600	560	520	500
·020	2200	1460	1200	1000	940	840	780	720	640	500	480	440	400

TABLE 131.—FINISH-TURNING SOFT ALUMINIUM BAR, B.S. 386. H.S.S. TOOL 18 . 4 . 1. 40° RAKE. NO APPROACH ANGLE. NO NOSE-RADIUS. TOOL-LIFE 1 HOUR CUTTING DRY.

Depth of cut, in.	Speed, f.p.m.												
	Feed, in.												
	·002	·004	·006	·008	·010	·012	·014	·016	·020	·031	·040	·050	·0625
·005	2160	1400	1200	1060	960	880	820	780	720	640	600	568	544
·010	1680	1200	920	800	720	660	600	568	520	460	432	400	360
·015	1480	1020	800	700	640	580	540	500	460	380	340	320	300
·020	1340	900	720	620	560	520	480	440	380	320	304	300	288

If using carbon steel tools, multiply by ·25.
If using Stellite J, multiply by 1·5–2.
If using cemented-carbide-tipped tool, multiply by 3–6.

Working on the data given in the L.T.R.C. 1922 Report, it is necessary to alter the above figures when the rake angle differs from that listed in Tables 123–131. To cover this correction values for C_r are shown in Table 132.

TABLE 132.—VALUES FOR C_r

Rake, degrees.	0	5	10	15	20	25	30	35	40
Value of C_r	1·49	1·52	1·59	1·70	1·61	1·39	1·27	1·11	1·0
Ratio of C_r value at 0° = 1·0.	1·00	1·03	1·07	1·14	1·08	·93	·86	·75	·67

TABLE 133.—BRITISH STANDARD CAST-ALUMINIUM ALLOYS. MACHINING FACTOR *M* AND COMPOSITION

Spec. No.	Designation	Approx. composition									*M* factor		
		Cu	Mn	Mg	Si	Fe	Ni	Zn	Ti	Al	S.C.	D.C	H.T.
B.S. 361	7% copper-aluminium casting.	6·0 8·0			1·0	1·0				Remainder (excluding small percentage for impurities).	·58	·56	
362	12% „ „	11·0 13·0			1·0	1·0					·68	·65	
363	13% zinc-copper-aluminium casting.	2·5 3·0			1·0	1·0		12·5 14·5			·64	·60	
702	Silicon-aluminium casting.	·1	·5		10·0 13·0	·6		·2	·1		·47	·42	
703	Y-alloy casting.	3·5 4·5		1·2 1·7	·6	·6	1·8 2·3				·56	·53	·45
704	Y-alloy „ heat-treated.	3·5 4·5		1·2 1·7	·6	·6	1·8 2·3						·45
B.S. 3L5	13% zinc-copper-aluminium casting.	2·5 3·0			·7	·8		12·5 14·5			·64	·6	
3 L8	12% copper-aluminium casting.	11·0 13·0			1·0	1·0					·58	·56	
4 L11	7% „ „	6·0 8·0			·7	·8			Sn 1·0		·68	·65	
2 L24	Y-alloy casting.	3·5 4·5		1·2 1·7	·6	·6	1·8 2·3				·56	·53	·45
3 L33	Silicon-copper-aluminium casting.	1·0	·5		10·0 13·0	·6		·2	·1		·47	·42	
3 L35	Y-alloy casting, H.T., 110 B.H. No.	3·5 4·5		1·2 1·7	·6	·6	1·8 2·3						·45
	140 B.H. No.												·38
D.T.D. 131 A	R.R. 53.	2·25		1·3	2	1	1·3		·1		·62	·52	·42
D.T.D. 133 B	R.R. 50.	1·8		1·2	1·25	1	1·3		·18		·65	·63	·56
	Alpax Alpha.										·39	·37	
D.T.D. 240	„ Beta.										·35	·31	
D.T.D. 245	„ Gamma.		·5								·28	·27	
D.T.D. 165	Birmabright.			4·5							·68	·66	
D.T.D. 264	Birmasil spec.				11·5		3·0				·42	·34	

Note.—S.C. = sand cast. D.C. = die cast. H.T. = heat-treated to give full strength and hardness.

TABLE 134.—BRITISH STANDARD WROUGHT ALUMINIUM ALLOYS. MACHINING FACTOR *M* AND COMPOSITION

Spec. No.	Designation	Approx. composition									*M* factor		
		Cu	Mn	Mg	Si	Fe	Ni	Zn	Ti	Al	A.	C.W.	H.T.
B.S. 385	Pure aluminium tube.									Remainder (excluding small percentage of impurities).	1·0		
386	Pure aluminium bars and sections.										1·0		
	¼ hard.											·92	
	½ hard.											·88	
	¾ hard.											·82	
	hard.											·76	
414	Y-alloy sheet and strip.	3·5 4·5		1·2 1·7	·6	·5	1·8 2·3						
477	Duralumin bars and sections.	3·5 4·5	·4 ·7	·4 ·7	·7	·7			·3		·75		·46
478	Y-alloy bars and sections.	3·5 4·5		1·2 1·7	·6	·5	1·8 2·3				·78		·47
532	Duralumin forgings.	3·5 4·5	·4 ·7	·4 ·7	·7	·7			·3		·75		·46
533	Y-alloy forgings.	3·5 4·5		1·2 1·7	·6	·5	1·8 2·3						·45
1080	Bars for fuse parts: Sb ·3–1·0; Sn ·1–·5.	2·5 4·0	·2	·25 ·75		·75	·05	·2			·75	·65	

	Aircraft.												
B.S. 6 L1	Aluminium-alloy bars, forgings, sections.	3·5 4·5	·4 ·7	·4 ·7	·7	·7			·3	Remainder (excluding small percentage of impurities).	·75		·46
5 L3	Aluminium-alloy sheet and coil.	3·5 4·5	·4 ·7	·4 ·7	·7	·7			·3		·75		·46
2 L4	Aluminium sheet, hard.											·76	
	½ hard.											·88	
	soft.										1·0		
L34	99% aluminium bars and sections.				·5	·6					1·0		
	¼ hard.											·92	
	½ hard.											·88	
	¾ hard.											·82	
	hard.											·76	
2 L38	Aluminium-alloy coated with aluminium sheet and coil.	3·5 4·5	·4 ·7	·4 ·9	·7	·7							·46
B.S. 2 L39	Aluminium-alloy bars and forgings.	3·5 4·5	·4 ·7	·4 ·9	·7	·7			·3		·75		·46
2 L40	„ bars, forgings, sections.	1·5 4·0	1·0	·3 1·5	1·5	·3 1·5	2	Cr. ·2	·2		·75		·46
2 L42	„ forgings.	1·5 3·0		1·2 1·8	1·3	1·0 1·5	·5 1·5		·2				·52
L44	„ bars and sections, soft.	1·0 3·0	1·5		·7	·7	·35	Cr ·5	·2		·75		
L45	„ bars, forgings and sections.	1·5 4·5	1·0	·3 1·5	1·5	·3 1·5	2	Cr ·2	·2		·75		·45
	Free-cutting aluminium-alloy bars.										·75		·46

Note.—A = annealed or soft. C.W. = cold worked. H.T. = fully heat-treated to give maximum strength and requisite hardness.

TABLE 135.—STANDARD AMERICAN (S.A.E.)[17] ALUMINIUM CASTING ALLOYS

S.A.E. No.	Type of Casting	Approx. composition										*M* Factor	
		Cu	Fe	Si	Mn	Mg	Zn	Ti	Ni	Cr	Sn	A.C.	H.T.
300	Permanent mould casting.	5·5 7·5	1·5	5·0 6·0	·8	·2 ·6	·8	·2				·53	·40
304	Die casting.	·6	2·0	4·5 6·0	·3	·1	·5		·5		·1	·55	
305	,, ,,	·6	2·0	11·0 13·0	·3	·1	·5		·5		·1	·4	
306	,, ,,	3·0 4·0	1·3	7·5 9·5	·5	·1	·6		·5		·3	·42	
307	,, ,,	3·0 4·5	2·0	4·5 5·5	·5	·1	1·0		·5		·3	·54	
308	,, ,,	3·0 4·0	2·0	7·5 9·5	·5	·1	1·0		·5		·3	·41	
310	Sand casting.	·3	1·0	·25	·3	·5 ·65	5·0 6·0	·1 ·3		·4 ·6		·63	
320	,, ,,	·1	·5	·3	·3	3·5 4·5	·1	·2				·8	
321	Permanent mould casting.	·5 1·5	1·3	11 13	1	·7 1·3	·1	·2	2·0 3·0			·4	·35
322	Sand casting.	1·0 1·5	·8	4·5 5·5	·5	·4 ·6	·3	·2		·2			·55
323	Permanent mould casting. Sand casting.	·2	·6	6·5 7·5	·3	·2 ·4	·3	·2					·52 ·41
324	Permanent mould casting. Sand casting.	·2	·3	·2	·1	9·5 10·6	·1						·38 ·6

326	Sand casting.	3·3	1·0	5·5	·5	·1	1·0	·2	·3			·63	·52
		4·3		7·0									
	Permanent mould casting.											·62	·5
327	Sand casting.	1·0	1·0	7·0	·2	·2	1·0	·3	·2	·3		·6	·52
		2·0		8·6	·6	·6							
328	Permanent mould casting.	1·0	·9	11·0	·5	·4	·4	·2	·05			·4	·35
		2·0		13·0	·9	1·0							
33	Sand casting.	6·0	1·0	1·0	·5	·07	2·5	·2	·3			·78	
		8·0		4·0									
	Permanent mould casting.											·74	
34	Sand casting.	9·2	1·5	2·0	·5	·15	·5	·2	·3			·75	·64
		10·8				·25							
	Permanent mould casting.											·64	·59
35	Sand casting.	·6	·8	4·5	·3	·05	·3	·2				·84	
				6·0									
	Permanent mould casting.											·78	
38	Sand casting.	4·0	1·0	1·5	·3	·03	·3	·2				·67	·62
		5·0											
380	Permanent mould casting.	4·0	1·2	2·0	·3	·05	·3	·2	·3			·65	·61
		5·0		3·0									
39	Sand casting.	3·5	1·0	·07	·3	1·2	·3	·2	1·7	·2		·56	·45
		4·5				1·8			2·3				
	Permanent mould casting.											·53	·45

A.C. = as cast. H.T. = heat-treated to give full hardness and strength. Permanent mould casting = gravity die casting.
Die casting = pressure die casting.

TABLE 136.—STANDARD AMERICAN (S.A.E.) WROUGHT-ALUMINIUM ALLOYS

S.A.E. No.	Type	Approx. composition										M factor		
		Cu	Fe	Si	Mn	Mg	Cr	Ti	Ni	Zn		A.	C.W.	H.T.
20		·2	·7	·3	1·0 1·5	·8 1·3				·1	Remainder aluminium			
201	Sheet, plate, bar, tube, wire.	·1	Fe + Si = ·45 max.		·1	2·2 2·8	·15 ·35			·1		·75		
	¼ hard.											·64		
	½ hard.											·62		
	¾ hard.											·58		
	hard.											·54		
24	” ” ” ” ”	3·8 4·9	·5	·5	·3 ·9	1·2 1·8	·1			·1		·78		·48
240	Alloy sheet and plate coated with aluminium.	3·9 4·9	·5	·5	·3 ·9	1·2 1·8	·1			·1		·78		·48
25	Commercial aluminium, all wrought forms.	·2	Fe + Si = 1 max.		·1					·1		1		
	¼ hard.												·92	
	½ hard.												·88	
	¾ hard.												·82	
	hard.												·76	
26	Bar, rod, rivets.	3·5 4·7	1·0	·8	·4 1·0	·2 ·8	·25	·1		·25		·75		·46

260	Bar, rod, forgings.	3·9 5·0	1·0	·5 1·2	·4 1·2	·2 ·8	·10	·15		·25				·45
27	Forgings.	3·9 5·0	1·0	·5 1·2	·4 1·2		·10	·15		·25				·47
270	„	3·5 4·5	1·0	·9	·2	·45 ·9	·10	·15		·25				·47
280	„	·35	1·0	·6 1·2	·2	·45 ·8	·15 ·35	·15		·25				·58
281	Sheet, plate, bar, tube, wire.	·15 ·4	·7	·4 ·8	·15	·8 1·2	·15 ·35	·15		·2		·63		·54
282	Extrusions and wire.	·1	·35	·45 ·7	·10	1·1 1·4	·15 ·35	·15		·1		·73		·65
29	Most wrought forms.	·2	·7	·6	1·0 1·5					·1		·92		
	¼ hard.												·84	
	½ hard.												·80	
	¾ hard.												·74	
	hard.												·68	
290	Forgings.	·5 1·3	1·0	11·5 13·5	·2	·8 1·3	·10	·15	·5 1·3	·25		·4		·3

A = annealed or in a soft state. C.W. = cold worked. H.T. = heat-treated to give full hardness and strength.

TABLE 137.—COMPOSITION AND *M* FACTOR FOR BRITISH STANDARD[16] MAGNESIUM CASTING ALLOYS

Spec. No.		Approx. composition							*M* factor
		Al	Mn	Zn	Cu	Si	Mg	Impurities	
D.T.D. 59 A	Magnesium casting alloy (A.Z.G.) A.C.	8·5	·5	3·5			Remainder	1·7	·95
D.T.D. 59 A	,, ,, .. (A.B.) A.C.	8·5	·5	3·5				1·7	·95
D.T.D. 59 A	,, ,, .. (A.Z. 31) A.C.	8·5	·5	3·5				1·7	1·03
D.T.D. 136 A	,, ,, ,, (A.Z. 91) A.C.	9 11	·5	3·5				1·5	·92
D.T.D. 140 A	,, ,, ,, (A.M. 503) A.C.	·2	2·5	·2	·2	·4		·5	1·08
D.T.D. 281	,, ,, ,, (A.Z. 91) S.T.	9 11	·5	1				1·0	·92
D.T.D. 285	,, ,, ,, (A.Z. 91) S.P.T.	9 11	·5	1				1·0	·77
D.T.D. 289	,, ,, ,, (A.B.) S.T.	8·5	·5	3·5				1·0	·95
D.T.D. 289	,, ,, ,, (A.Z. G.) S.T.	8·5	·5	3·5				1·0	1·00
B.S. 1273	*M* factor as for D.T.D. 136 A								
B.S. 1274	,, ,, ,, D.T.D. 281								
B.S. 1275	,, ,, ,, D.T.D. 285								
B.S. 1277	,, ,, ,, D.T.D. 59								
B.S. 1278	,, ,, ,, D.T.D. 289								
B.S. 1280	,, ,, ,, D.T.D. 140								

A.C. = as cast. S.T. = solution treatment. S.P.T. = solution and precipitation treatment.

TABLE 138.—COMPOSITION AND *M* FACTOR FOR BRITISH STANDARD [16] MAGNESIUM WROUGHT ALLOYS

Spec. No.		Approx. composition							*M* factor
		Al	Mn	Zn	Cu	Si	Mg	Impurities	
D.T.D. 88 B	Forgings.	11	1·0	1·5			Remainder	1·5	·85
D.T.D. 118	Sheet for welding.	·2	2·5	·2	·2	·4		·5	1·05
D.T.D. 120 A	Sheet rolled.	9	1·0	1·5	·3	·4			1·05
D.T.D. 142	Extruded alloy bar.	·2	2·5	·2	·2	·4		·5	1·05
D.T.D. 259	Alloy bars, sections, tube, sheet.	11	1·0	1·5				1·5	·92
	Forging (A.Z. 855).	7·5	·15	·4					·84
		8·5	·25	·55					
B.S. 1350	*M* factor as for D.T.D. 88 B								
B.S. 1353	,, ,, ,, D.T.D. 118								
B.S. 1352	,, ,, ,, D.T.D. 142								
B.S. 1354	,, ,, ,, D.T.D. 88 B								

Note: The *M* factor is to be used in conjunction with Tables 123–131 listed for Aluminium Bars.

TABLE 137.—COMPOSITION AND *M* FACTOR FOR BRITISH STANDARD[16] MAGNESIUM CASTING ALLOYS

Spec. No.		Approx. composition							*M* factor
		Al	Mn	Zn	Cu	Si	Mg	Impurities	
D.T.D. 59 A	Magnesium casting alloy (A.Z.G.) A.C.	8·5	·5	3·5			Remainder	1·7	·95
D.T.D. 59 A	,, ,, .. (A.B.) A.C.	8·5	·5	3·5				1·7	·95
D.T.D. 59 A	,, ,, .. (A.Z. 31) A.C.	8·5	·5	3·5				1·7	1·03
D.T.D. 136 A	,, ,, ,, (A.Z. 91) A.C.	9 11	·5	3·5				1·5	·92
D.T.D. 140 A	,, ,, ,, (A.M. 503) A.C.	·2	2·5	·2	·2	·4		·5	1·08
D.T.D. 281	,, ,, ,, (A.Z. 91) S.T.	9 11	·5	1				1·0	·92
D.T.D. 285	,, ,, ,, (A.Z. 91) S.P.T.	9 11	·5	1				1·0	·77
D.T.D. 289	,, ,, ,, (A.B.) S.T.	8·5	·5	3·5				1·0	·95
D.T.D. 289	,, ,, ,, (A.Z. G.) S.T.	8·5	·5	3·5				1·0	1·00
B.S. 1273	*M* factor as for D.T.D. 136 A								
B.S. 1274	.. .. .. D.T.D. 281								
B.S. 1275	,, ,, .. D.T.D. 285								
B.S. 1277	,, ,, ,, D.T.D. 59								
B.S. 1278	.. ,, ,, D.T.D. 289								
B.S. 1280	.. .. ,, D.T.D. 140								

A.C. = as cast. S.T. = solution treatment. S.P.T. = solution and precipitation treatment.

TABLE 138.—COMPOSITION AND *M* FACTOR FOR BRITISH STANDARD [16] MAGNESIUM WROUGHT ALLOYS

Spec. No.		Approx. composition							*M* factor
		Al	Mn	Zn	Cu	Si	Mg	Impurities	
D.T.D. 88 B	Forgings.	11	1·0	1·5			Remainder	1·5	·85
D.T.D. 118	Sheet for welding.	·2	2·5	·2	·2	·4		·5	1·05
D.T.D. 120 A	Sheet rolled.	9	1·0	1·5	·3	·4			1·05
D.T.D. 142	Extruded alloy bar.	·2	2·5	·2	·2	·4		·5	1·05
D.T.D. 259	Alloy bars, sections, tube, sheet.	11	1·0	1·5				1·5	·92
	Forging (A.Z. 855).	7·5 8·5	·15 ·25	·4 ·55					·84
B.S. 1350	*M* factor as for D.T.D. 88 B								
B.S. 1353	,, ,, ,, D.T.D. 118								
B.S. 1352	,, ,, ,, D.T.D. 142								
B.S. 1354	,, ,, ,, D.T.D. 88 B								

Note: The *M* factor is to be used in conjunction with Tables 123–131 listed for Aluminium Bars.

TABLE 139.—AMERICAN STANDARD (S.A.E.)[17] FOR MAGNESIUM CASTING ALLOYS

S.A.E. No.	Description		Al	Mn	Zn	Cu	Si	Mg	Ni	*M* factor
50	Magnesium-alloy casting, - -	A.C.	5·3 6·7	·15	2·5 3·5	·25	·3	Remainder	·03	1·08
		H.T.								·85
500	,, ,, - -	A.C.	8·3 9·7	·1	1·7 2·3	·25	·3		·03	1·03
		H.T.								·85
501	,, die casting		8·3 9·7	·13	·4 1·0	·1	·5		·03	·95
502	Magnesium permanent-mould casting,	A.C.	9 11	·1	·3	·1	·3		·03	1·08
		H.T.								·85
503	,, ,, ,,	A.C.	8·3 9·7	·1	1·7 2·3	·25	·3		·05	1·08
		H.T.								·85

A.C. = as cast. H.T. = heat-treated.

TABLE 140.—AMERICAN STANDARD (S.A.E.)[17] for MAGNESIUM WROUGHT ALLOYS

S.A.E. No.	Description	Al	Mn	Zn	Cu	Si	Mg	Ni	*M* Factor
51	Sheet and strip.†		1·2		·05	·3	Remainder	·01	1·00
510	„ „ †	2·5 3·5	·2	·6 1·4	·05	·3		·005	·95
512	„ „	4·1 5·5	·15	·4 1·3	·05	·3		·005	·8
52	Bars, rods, tubes, sections.	2·5 3·5	·2	·6 1·4	·05	·3		·005	·95
520	„ „ „ „	5·8 7·2	·15	·4 1·5	·05	·3		·005	·95
522	„ „ „ „ †		1·2		·05	·3		·01	1·02
523	„ „ „ „	7·8 9·2	·12	·2 ·8	·05	·3		·005	·85
	H.T.								·8
53	Forgings.*	3·0 4·0	·2	·3	·05	·3		·03	·89
531	„	5·8 7·2	·15	·4 1·5	·05	·3		·005	·85
532	„	7·8 9·2	·12	·2 ·8	·05	·3		·005	·84
533	„ †		1·2		·05	·3		·01	1·00

* Sn 4·0–6·0. † Ca = ·3.

4. Rigidity of Tool and Component.

The figures given in all the above Tables apply only to conditions where the component is of such proportions as to withstand the cutting force, and is securely held. The tool is assumed to be adequately supported and free from excessive overhang. The machine itself must be in good condition and so designed that it runs at the required speed without " chatter ". Moreover, the h.p. input must be adequate for the chosen chip dimensions (see Chapter XI, p. 234). Often the shape of the article and the method of holding will determine the size of the cut and the speed. In a number of instances the r.p.m. of the machine will be the limiting factor, particularly when using the cemented carbides on light alloys.

CHAPTER X

Estimating Machining Speeds

1. Choosing a Cutting Speed.

Briefly summarizing what has been already discussed it is necessary when deciding upon a suitable cutting speed, using data given in the tables, to take into account the following factors:

(*a*) The profile of the cutting edge.

(*b*) The duration of the cutting period.

(*c*) The material used to form the cutting edge.

(*d*) The rake placed upon the tool.

(*e*) The use or otherwise of a lubricant or coolant.

(*f*) The material to be cut, the shape of the component, and the condition in which it is sent to the machine shop.

(*g*) The class of machining, which may require an operational factor. (See Table 27, p. 98.)

(*h*) The h.p. input of the machine and its efficiency.

Figs. 7.1, 7.2, 7.3 and 8.2 indicate how the machining speed varies with changes in the B.H.N. for plain carbon steels, H.R., C.D., and H.T. In the nature of things the data shown graphically cannot be absolute, but illustrate only the general tendency. When planning operation schedules they can be of great value, forming as they do a basis upon which to work that may be modified as circumstances demand.

2. Feeds.

The decision as to what feed to choose for turning, boring, facing, shaping, planing or milling depends upon the class of finish required. In turn this depends upon whether or not the operation is to be regarded as roughing or finishing; other factors are the condition of the material, the size, shape, strength and method of holding the component; the tool-shape and its setting as regards overhang; the design of the machine; the power available; the depth of cut and the chosen speed. Because of so many variables it is impossible to give any definite ruling, hence Table 141 is a suggestion only and is given to meet the various shop conditions.

TABLE 141.—SUGGESTED RANGE OF FEEDS

Dia. of bar or workpiece, inches	Feed, in.			
	Very fine	Fine	Medium	Coarse
Up to 1.	·001–·003	·004–·008	·009–·015	·016–·032
Over 1 to 2.	·001–·004	·005–·010	·011–·020	·021–·045
Over 2 to 3.	·001–·005	·006–·012	·013–·025	·026–·062
Over 3 to 4.	·001–·006	·007–·015	·016–·035	·036–·093
Over 4.	·001–·007	·008–·020	·021–·045	·046–·125

It is assumed that the above suggestions will be adjusted to meet the given machine capacity. For automatic bar work the cam will probably have to be made to suit the job, and this gives greater freedom. The feeds coming under the heading " Very Fine " and " Fine " are chosen for fine turning and boring, finish-turning on capstan and turret lathes, and when producing articles from bar on automatic and capstan lathes. When rough-machining, i.e. removing the bulk of the surplus material as quickly as is economically possible without undue attention to surface finish, the feeds under the headings " medium " and " coarse " would be chosen, the actual feed depending upon the size of the article, how held, its shape, and the h.p. input.

If milling, then the chosen feed is as for a bar, say, 3 to 4 in. dia. and would be taken from the first three columns, the coarse feed normally being too great for a milling cutter.

For work on the shaper and planer the feeds for a bar over 4 in. dia. are suggested. In many instances these feeds may be greatly exceeded.

It should be noted that when a finishing cut only has to be taken and there is ample power available, blending a large nose-radius on to a flat, say, $\frac{1}{8}$ to $\frac{3}{8}$ in. wide, before the trailing angle, permits the same class of finish to be obtained with a much coarser feed and a corresponding reduction in operational time.

Basic Data.

Tables 30 to 59, 78 to 105, 107 to 113, and 123 to 131, give the appropriate cutting speeds for varying shapes of tools, depth of cut, feed per revolution, for machining respectively steel, cast iron, brass, aluminium for a tool-life of one hour, using the four standard cutting-media, carbon steel, h.s.s., Stellite, and the cemented carbides. These data may be regarded as basic inasmuch as they are used to determine the cutting speeds for other alloys. To permit this, use is made of the M factor given in Tables 60 to 66 for the B.S. 970 En series of steels, in Tables 67–76 for the S.A.E. steels, in Tables 114–122 for copper-based alloys, and in Tables 133–139 for the light metals.

3. Lubricant.

When a lubricant or coolant is to be used, the speed increase is given by the factor L_u in Table 25, p. 94.

4. Tool-life.

The life of a cutting tool may either be increased or decreased by changes in the cutting speed. The data as listed in Tables 30 to 59, &c., are for a tool-life of one hour. To meet known machining problems the speed has often to be modified so as to obtain an economic run. Under these conditions any computation for a cutting speed must introduce the appropriate tool-life factor T_l from Table 21, p. 85. When dealing with any questions of tool-life it should be realized that it represents the actual time the tool is engaged removing metal under the stated condition of cut, speed and lubricant. " Idle " time, whether inherent in the work cycle, due to setting, the operator, or the machine not running at the stated speed, is ignored. Hence on a wide range of work, as is done on capstan, turret and automatic lathes, the tool-life must be estimated before proceeding to compute the cutting speed. Where a series of tools are engaged cutting at the same time the tool-life is based upon the one doing the heaviest work.

5. Tool-shape.

The tool-shape also affects the cutting speed, and when the chosen profile differs from that given at the head of the appropriate table, adjustments must be made. The tool-shape factor T_s listed in Table 24 (p. 91) assists here.

6. Tool Material.

The steady development in metallurgical science has given a variety of cutting media and, in all calculations appertaining to metal-cutting speeds, due provision must be made for the different types of cutting material. At the head of each table the chosen cutting medium is given. If using other materials, the T_m factor listed in Table 26 (p. 96) must be introduced into the cutting-speed expression as shown on p. 218.

7. Rake.

The L.T.R.C. 1922 Report clearly shows that the rake angle has an important influence upon the cutting speed, hence departures from that given at the head of the appropriate table calls for the introduction of the rake correction factor C_r as listed in the appropriate tables.

8. Cutting-speed Expression.

Bringing together the data as outlined above, the cutting speed for any metal can be determined using the expression

$$V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r.$$

Owing to the wide range of operating conditions encountered in industry it is anticipated that at times the various machining constants will need adjustment. Therefore, when the conditions differ from those stated in the appropriate table, the required value must be estimated; alternatively a graph may be drawn from the known data and the desired value thus taken from the chart, or an operational factor (see p. 98) may be introduced. When working through the various examples several instances of such adjustment will be noticed.

Example 1.—The speed is required for machining a forging B.H. No. 183, in En 8 using a knee tool made from 18 . 4 . 1 h.s.s. having a 15° rake but without any approach angle or nose-radius. The diameter of the work is 9 in. and the cut will be ¼ in. deep with ·010-in. feed. A tool-life of 1 hour is required when cutting dry.

For this example the general remarks relating to the various points of interest associated with abstracting the required data from the various tables are given below:

Basic Cutting Speed (V_b).—With the work diameter 9 in. the difference between the cutting speed in f.p.m. at the extremities of the chip will be 10 per cent (see p. 92) and may be safely ignored. As the desired feed is already given in Table 37 the basic cutting speed may be obtained without the need for a graph or interpolation.

Material Factor (M).—The steel is assumed to be H.T. and have a B.H. No. of 183. The precise value of M is not shown in Table 60, hence a slight adjustment becomes necessary. Here, it is suggested that an M value of ·61 meets the case.

Cutting Lubricant (L_u).—As the cutting is to be done dry, the value of L_u is unity or 1·0.

Tool-life (T_l).—The required tool-life is 1 hour and this is identical with the cutting period upon which the tables were based. Hence T_l is 1·0.

Tool-shape (T_s).—The suggested tool-shape is the same as that upon which the tables were based. Because of this the tool-shape factor is equal to 1·0.

Tool Material (T_m).—The tool to be used is an 18 . 4 . 1 h.s.s. and is the same as that upon which the table is based. Hence the tool material factor is unity.

Rake Factor (C_r).—The tool is to have a 15° rake. This is very close to that upon which the table is constructed. Hence, for purposes of estimating the cutting speed, the rake factor may be taken as 1·0.

Gathering the data from the tables:

The basic speed or V_b from Table 37 (p. 108) is 148.
The material factor M from Table 60 (p. 121) is ·61.
The lubricating factor L_u from Table 25 (p. 94) is 1·0.
The tool-life factor T_l from Table 21 (p. 85) is 1·0.
The tool-material factor T_m from Table 37 (p. 108) is 1·0.
The tool-shape factor T_s from Table 37 (p. 108) is 1·0.
The rake factor C_r from Table 37 is 1·0.

Hence $V_c = 148 \times \cdot 61 \times 1 \times 1 \times 1 \times 1 \times 1 =$ say, 90 f.p.m.

Example 2.—An alloy steel forging in En 11 heat-treated within the 60–70-ton range is to be machined, and the maximum chip dimensions are known to be $\frac{3}{16}$ in. deep and ·008 in. feed. Suggest the rake angle, tool material and cutting speed, assuming the tool will have a $\frac{1}{8}$-in. nose-radius and a 30° approach angle. The cutting is to be done dry. A tool-life of 4 hr. is suggested.

With a steel heat-treated to give the desired strength, the B.H. No. will be around 290 to 350 (see pp. 78, 100); this suggests that a cemented-carbide-tipped tool should be used. To give strength to the cutting edge no rake is suggested. Now the machining is to be done dry, whilst the tool shape and material are identical with those listed at the head of the appropriate table (55); because of this no modification is needed and L_u, T_s and T_m are each equal to 1·0. Using a tipped tool with no rake calls for adjustment to the value of the basic cutting speed, and the value for C_r is obtained from Table 59 A. Knowing that the M factor is to be based upon the machining of steel coming within the 60- to 70-ton range, the values listed in Table 61 need a slight adjustment. The specified chip size does not feature in Table 55, hence the need to interpolate or construct a graph based upon the tabulated data. For a tool-life of 4 hours the basic cutting speed requires adjustment, and to do this the T_l factor from Table 21 is used. Gathering the information:

V_b (Table 55, p. 115) = 710.
L_u (Table 25, p. 94) = 1·0.
T_s (Table 55, p. 115) = 1·0.
C_r (Table 59A, p. 117) = ·97.
M (Table 61, p. 125) = ·27.
T_l (Table 21, p. 85) = ·84.
T_m (Table 55, p. 115) = 1·0.

$$\text{And } V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r$$
$$= 710 \times \cdot 27 \times 1\cdot 0 \times \cdot 84 \times 1\cdot 0 \times 1\cdot 0 \times \cdot 97 = 155 \text{ f.p.m.}$$

Example 3.—A roughing cut is to be taken on some large iron castings, Brinell 195. The chip dimension is known to be $\frac{1}{4}$ in. deep and a feed of ·0625 in. is suggested. No cutting lubricant is to be used. The tool is to have a rake of 5°, an approach angle of 20°, and a nose-radius of $\frac{1}{8}$ in.; it is made from a 12 per cent cobalt steel and is expected to have a life, between grinding, of $1\frac{1}{2}$ hr.

Given the conditions as outlined, it is necessary to take into account the use of (*a*) a cobalt h.s.s. tool; (*b*) a different approach angle; (*c*) a smaller rake angle; (*d*) a tool-life of 90 minutes. Keeping these factors in mind, the data from the various tables may readily be gathered:

V_b (Table 87, p. 171) = 50.
M (Table 106, p. 179) = ·8.
T_m (Table 26, p. 96) = 1·12.
T_s (Table 24, p. 91) $= \dfrac{1\cdot 15}{1\cdot 21} = \cdot 95.$
T_l (Table 21, p. 85) = ·96.
L_u (Table 87, p. 171) = 1·0.
C_r (Table 22, p. 89) = ·9.

$$V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r$$
$$= 50 \times \cdot 8 \times 1\cdot 0 \times \cdot 96 \times 1\cdot 12 \times \cdot 95 \times \cdot 9 = \text{ say, } 37 \text{ f.p.m.}$$

Example 4.—Some phosphor-bronze castings (V.D.H., say, 160) are to be machined with a cemented-carbide tool having a 3° rake, 30° approach, and $\frac{1}{8}$-in. nose-radius. The cut is $\frac{1}{4}$ in. deep and the feed is ·016 in. Give the cutting speed for a tool-life equal to 5 hr. when using a cutting liquid.

Gathering the data from the Tables:

V_b (Table 109, p. 183) = 430.
T_s (Table 109, p. 183) = 1·0.
T_m (Table 26, p. 96) = 5.
L_u (Table 25, p. 94) = 1·18.
T_l (Table 21, p. 85) = ·7.
M (Table 119, p. 191) = ·14.
C_r (Table 109, p. 183) = 1·0.

$$V_c = V_b \,.\, L_u \,.\, M \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r$$
$$= 430 \times 1\cdot 18 \times \cdot 14 \times \cdot 7 \times 5 \times 1\cdot 0 \times 1\cdot 0 = \text{ say, } 250 \text{ f.p.m.}$$

Example 5.—A duralumin forging is to be machined using a tool of 18 . 4 . 1 h.s.s. having a 30° approach angle and a ⅛-in. nose-radius. The hardness of the material is known to be 105 Brinell, hence using the graph in fig. 9.3, p. 198, the maximum top rake should be 30°. The feed for the roughing cut is to be ·016 in. and the maximum depth of cut is ⅜ in. Give the suggested speed on the basis of cutting with a lubricant and a tool-life of 1½ hr.

Gathering the data:

V_b (Table 125, p. 200) = 520.
L_u (Table 25, p. 94) = 1·18.
T_m (Table 125, p. 200) = 1·0.
C_r (Table 132, p. 202) = 1·27.
M (Table 134, p. 204) = ·46.
T_l (Table 21, p. 85) = ·94.
T_s (Table 125, p. 200) = 1·0.

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= 520 \times {\cdot}46 \times 1{\cdot}18 \times {\cdot}94 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}27 = \text{say, } 340 \text{ f.p.m.} \end{aligned}$$

Example 6.—A cut ⅜ in. deep is to be taken on an automatic lathe using a feed of ·008 in. The tool, made from 18 . 4 . 1 h.s.s., is of the knife type having no nose-radius or approach angle. The bar, 1¾ in. dia., supplied in the cold-drawn state, is a free-cutting lead-bearing steel approximating to B.S. 970 En 1 A.

The point to note when using this class of tool on bar work is that the point operates in a zone having a much lower cutting speed than that measured at the periphery of the bar. Hence the tool is not subjected to the same operating conditions as would be the case given much larger work (see p. 92). Owing to these changed conditions one may reasonably take the basic speed as given in Table 37 on the assumption that the tool is engaged for the shallowest depth of cut, namely $\frac{1}{32}$ in. Then, using a 18 . 4 . 1 h.s.s. tool with 15° rake, and expecting a tool-life of 4 hours with the tool flooded with a cutting liquid, the cutting-speed data are:

V_b (Table 37, p. 108) = 174.
T_s (Table 37, p. 108) = 1·0.
L_u (Table 25, p. 94) = 1·16.
T_m (Table 37, p. 108) = 1·0.
T_l (Table 21, p. 85) = ·84.
M (Table 60, p. 119) = 2·6.
C_r (Table 37, p. 108) = 1·0

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= 174 \times 2{\cdot}6 \times 1{\cdot}16 \times {\cdot}84 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 = \text{say, } 440 \text{ f.p.m.} \end{aligned}$$

Example 7.—A Duralumin forging has been machined so that the bulk of the material is removed. The last operation on the component is to face to length and bore the hole to suit the fitting of a ball race. The previous operation has brought the hole through the article to 1·10 plus or minus ·003 in. The bore has to be finished to 1·37795 − 1·37765 in. dia. to a depth of ⅞ in.

The actual work to be done is face to length; open the bore to remove bulk of the material; final bore to size. The conditions are such that the maximum radius on the nose of the boring tool is $\frac{1}{32}$ in. The machine, a Herbert 2B capstan, has, in the top range, the following spindle speeds: 1050, 1355 and 2034 r.p.m. Suggest the cutting speeds for the various operations on the basis of the tool lasting 1 hour.

Facing.—The amount to remove is $\frac{1}{32}$ in. The tool is to be made from 18 . 4 . 1 h.s.s. In order to keep the article cool a feed of, say, ·008 in. is suggested using a tool having a 30° rake, a $\frac{1}{8}$-in. nose-radius and a trailing flat of $\frac{1}{8}$ in. One cut is to be taken and the work will be flooded with a cutting compound. As the cut is shallow and the radius on the tool is to be $\frac{1}{8}$ in. the speed may be taken from Table 125. Under the given conditions the size of the radius governs the appropriate cutting speed. The factors T_l, T_m, T_s are each equal to 1·0, hence will not influence the computed cutting speed. It is, however, necessary to choose the M factor appropriate to the material to be cut, introduce the L_u factor because a cutting lubricant is to be used, and take care of the change in the rake from 40°, as listed at the head of Table 125, to the proposed 30° deemed necessary when machining a stronger alloy (see figs. 9.3 and 9.4), then relate the rake to the M factor. Gathering the data:

V_b (Table 125, p. 200) = 1540.
T_m (Table 125, p. 200) = 1·0.
T_s (Table 125, p. 200) = 1·0.
C_r (Table 132, p. 202) = 1·27.
M (Table 134, p. 204) = ·46.
T_l (Table 125, p. 200) = 1·0.
L_u (Table 25, p. 94) = 1·16.

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_m \,.\, T_l \,.\, T_s \,.\, C_r \\ &= 1540 \times {\cdot}46 \times 1{\cdot}16 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}27 = \text{say, } 1050 \text{ f.p.m.} \end{aligned}$$

The outside diameter of the component, given as 2·75 in., will be the governing factor for speed; then

$$\text{Speed in r.p.m.} = \frac{1050 \times 12}{\text{O/S dia.} \times 3{\cdot}14} = \frac{1050 \times 12}{2{\cdot}75 \times 3{\cdot}14} = \text{say, } 1460.$$

Hence the spindle speed of 1355 is suggested, providing that it suit the speed for boring, as it is proposed to face and rough out the bore at the same time.

Boring.—Simple inspection shows that for a cut $\frac{1}{8}$ in. deep, ·006 in. feed, boring a hole 1·370 in. dia. at 1355 r.p.m. is possible; enough is to be left in for a light finishing skin. For this the graph of fig. 5.1 comes into use, and the proposals are that the rough boring dimensions shall be 1·368 – 1·370 in. dia., thus leaving, say, ·005 in. for the last cut. So that a good surface is produced and the work kept cool the finest feed is chosen, being ·0018 in. Gathering the data for fine boring:

V_b (Table 131, p. 202) = 2160.	M (Table 134, p. 204) = ·46.
L_u (Table 25, p. 94) = 1·16.	T_l (Table 131, p. 202) = 1.
T_m (Table 131, p. 202) = 1.	T_s (Table 131, p. 202) = 1.
C_r (Table 132, p. 202) = 1·27.	

Hence $V_c = 2160 \times \cdot 46 \times 1{\cdot}16 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}27 =$ say, 1470 f.p.m.

$$\therefore\ R = \frac{1470 \times 12}{1{\cdot}375 \times 3{\cdot}14} = 4100 \text{ r.p.m.}$$

The highest spindle-speed available is 2034 r.p.m., hence this will be chosen, giving an increased tool-life.

9. Shaping and Planing.

The tables and associated data listed above for turning apply also to shaping and planing operations without any modification. In practice the question of adjusting the available machine speeds to those arrived at by computation has to be faced. For large-batch production it is desirable to see that the machines run as near as possible to the computed speeds, modified, if need be, to suit the conditions as experience dictates. Though this may involve alteration to the drive, the saving will normally outweigh the cost of making such changes. With " one off " such changes are out of the question, and then the computed speeds have to be reduced to suit the nearest existing speed.

10. Drilling.

The data listed in the various tables are also useful for computing the speeds for drilling, using the standard twist-drills. They are valuable because the cutting speed may be adjusted to suit the required tool-life, and the class of material to be drilled. However, when drilling, one must choose the feed so that the drill is not subjected to excessive torsional strains, and a very rough rule for steel is to base the feed in terms of the drill diameter. Thus, for the standard drill, the feed may be given as $\cdot 01D$; for a short, stubby drill this may be increased to read $\cdot 015D$. In order to take into account the question of rake, Table 142 gives the values for C_r when using drills designed for the particular material and using the respective tables.

TABLE 142.—RAKE AND POINT ANGLES ON DRILLS, AND C_r VALUES

Material to drill	Rake angle, degrees	C_r value	Point angle, degrees
Aluminium.	40	1·0	140
Brass and soft bronze.	10	1·02	118
Brass and hard bronze.	0	1·0	118
Cast iron, soft.	10	·93	90
Cast iron, hard.	0	·89	90
Copper.	30	·83	100
Magnesium.	10	1·59	130
Plastic mouldings, &c.	20		90
Steel, low and medium carbon.	20	·95	118
high-tensile.	10	·93	125
manganese.	5	·90	150

Using the expression as given for a lathe tool, and introducing the operation factor given in Table 27, the expression for the drilling speed becomes

$$V_c = 0{\cdot}8 V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r.$$

The value for V_b is taken from the tool having no nose-radius or approach angle.

Example 8.—A heat-treated forging in En 8, having a B.H. No. of 176, is to be drilled $\frac{3}{4}$ in. dia. The aim is to have a tool-life of 60 minutes with the tool flooded with a cutting compound. An 18 . 4 . 1 drill with a 20° helix is to be used. Give a suggested feed and cutting speed. Note that the depth of cut is taken as equal to half the drill diameter.

$$\text{Feed} = {\cdot}01D = {\cdot}01 \times {\cdot}75 = {\cdot}0075 \text{ in.}$$

In order to obtain a value for V_b we use Table 37 for a knife tool having no approach angle or nose-radius. Hence it is necessary to introduce a tool-shape factor to take care of the alteration arising from the point angle on the drill. For steel the latter is 118° and therefore may be regarded as equivalent to a 30° approach angle. Table 24 gives a value of 1·21 for a tool with such a shape. Table 60 does not give an M factor for a B.H. No. of 176, hence an estimated figure is used. As the rake on the drill is greater than that given at the head of Table 37, it is necessary to introduce the C_r value for a 20° rake from Table 132. Drilling with the cutting edge flooded with a lubricant gives a higher speed or longer tool-life, hence the need for the L_u value from Table 25.

Grouping the data from the tables:

V_b (Table 37, p. 108) = 167.
L_u (Table 25, p. 94) = 1·16.
T_m (Table 37, p. 108) = 1·00.
C_r (Table 22, p. 89) = ·95.
M (Table 60, p. 121) = ·63.
T_l (Table 37, p. 108) = 1·00.
T_s (Table 24, p. 91) = 1·21.

Then $V_c = \cdot 8 \times 167 \times \cdot 63 \times 1{\cdot}16 \times 1{\cdot}21 \times \cdot 95 = 112$ f.p.m.

Example 9.—A ·75 in. dia. drill is to be used on free-cutting aluminium-alloy bar. The operating conditions permit a good flow of the cutting lubricant on to the point of the drill, which has a 25° helix angle and is made from 18 . 4 . 1 h.s.s. Suggest a feed and speed for a tool-life of 1 hour. The point angle is to be 140°, Table 142.

Feed for a standard length drill = say, $\cdot 01D$ = say, ·008 in. The example is similar to (8) above and it is necessary to take into account the point angle of 140°, which gives the equivalent of a 20° approach angle. As the helix of the drill is given as 25° the C_r value is obtained from Table 132, and the cutting speed V_b is based on half the drill diameter.

Gathering data from the various tables so as to compute the cutting speed:

V_b (Table 123, p. 200) = 668.
L_u (Table 25, p. 94) = 1·16.
T_m (Table 123, p. 200) = 1.
C_r (Table 132, p. 202) = 1·39.
M (Table 134, p. 205) = ·46.
T_l (Table 123, p. 200) = 1.
T_s (Table 24, p. 91) = 1·15.

$$\begin{aligned} V_c &= \cdot 8 V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= \cdot 8 \times 668 \times \cdot 46 \times 1{\cdot}16 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}15 \times 1{\cdot}39 = \text{say, } 455 \text{ f.p.m.} \end{aligned}$$

11. Milling Speeds.

The tables given above for turning with a single-point tool can also be adapted for milling operations, thus relating the cutting speed to the tool-life, depth of cut, and feed per tooth. Before this can be done, it is necessary to take into account any changes that may be inherent in the method of cutting.

Face-mills.

The cutting action of a face-mill is very similar to that of a single-point turning-tool, and the same general remarks as to the effects of the nose-radius and approach angle apply to face-milling. The chief difference between the face-mill and a lathe tool is that normally the latter has a continuous cutting-action, whereas the former is intermittent. Arising from the intermittent action a face-mill has these features:

(*a*) As each tooth makes contact there is an impact load on the cutting edge.

(*b*) Each tooth is brought repeatedly into contact with the outer surface of the article, hence may have to cut through a hard skin, scale or fused sand.

(*c*) Dividing the cutting action over a number of teeth the work is not so concentrated, hence the heat generated is less.

(*d*) Each time the tooth swings clear of the work it is cooled by the action of the atmosphere and coolant.

Effects of the Changes.—The effects of the changes in the cutting are briefly as follows.

The impact force has the tendency to destroy the cutting edge, but how great this potential destructive force will be, depends upon the resistance offered by the material and the cutting speed. The former is, of course, dependent upon the chip dimensions and the strength or hardness of the material to be cut. With the soft and easily machinable metals, e.g. aluminium and magnesium, the effects of any impact loading arising from a chip of the usual proportions can be ignored. When milling steel and cast iron the effect is greater, but by regulating the thickness no trouble need be expected. Under the heading (*b*) the teeth on a face-mill are placed in a worse condition than those on a single-point tool engaged on a continuous roughing cut, as the latter moves in what may be regarded as a low-pressure zone, but the cutting edge of a face-mill has to be forced through the surface metal, and anything that may be adhering to it. The effect of this action is to dull the cutting edge; to what extent this takes place depends solely upon the material to be machined. Thus, when cutting clean metal, such as aluminium or a previously machined forging, the effects are slight; on the other hand, in face-milling sand-castings or forgings which have a dirty scaled surface the effect will be pronounced. The effects of (*c*) and (*d*) are to increase the tool-life as each cutting edge is engaged only a fraction of the time the mill is removing metal. Hence, when computing an hour's cutting life for a face-mill, the speed must be adjusted to suit the computed, effective cutting-time of the individual tooth.

Face-mill summary.—Summarizing the above, for a well-supported face-mill, the speed formula as given for turning may be used for face-milling operation. Where hard skin, scale or fused sand is encountered, then the cutting speed must be reduced to suit the operation conditions, and this may involve a reduction from 10 to 25%. The best proposition, of course, would be either to anneal or clean the surface by pickling or shot-blasting.

Example 10.—*Computing the Speeds for Face-milling.*

A cast-iron article of 187 B.H. No. is to be face-milled before seasoning. The job is 6 in. wide and a $\frac{1}{8}$ in. depth of cut is to be allowed for. Choose a suitable diameter mill and cutting speed on the basis that a two-hour tool-life for each tooth will enable the batch to be machined at one setting of the cutter.

Suggested cutter dimensions: 8 in. dia., 16 teeth, approach angle 30°, nose-radius $\frac{1}{8}$ in., rake 10°, feed ·031 in. per tooth, cutting medium Stellite J; machining cast iron is done dry.

Now $V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r.$

Grouping the data:

V_b (Table 94, p. 174) = 128.

L_u (Table 94, p. 174) = 1·0.

T_m (Table 94, p. 174) = 1·0.

C_r (Table 22, p. 89) = ·93.

M (Fig. 9.1, p. 167) = ·89.

T_l (Table 21, p. 85) = ·91.

T_s (Table 94, p. 174) = 1·0.

Hence $V_c = 128 \times \cdot 89 \times \cdot 91 \times \cdot 93 = 96$ f.p.m.

Example 11.—*Face-milling an Aluminium Alloy.*

A cut $\frac{1}{4}$ in. deep is to be taken with a face-mill, 8 in. dia., having a $\frac{1}{8}$-in. nose-radius and a 30° approach angle, across a sand-cast article in B.S. 702, Brinell 55. The feed is ·008 in. per tooth and machining will be done dry. The cutting period per blade is taken at 1 hour, and the shape conforms to that of a single-pointed lathe tool. The material chosen for the blades is a cemented carbide. Using the graph (fig. 9.2, p. 198), a rake of, say, 18° is suggested.

Gathering the data,

V_b (Table 125, p. 200) = 840.

T_s (Table 125, p. 200) = 1·0.

T_m (Table 26, p. 96) = 3·0.

C_r (Table 132, p. 202) = 1·65.

T_l (Table 125, p. 200) = 1·0.

M (Table 133, p. 203) = ·47.

L_u (Table 25, p. 94) = 1·0.

then

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r. \\ &= 840 \times \cdot 47 \times 1\cdot 0 \times 3\cdot 0 \times 1\cdot 0 \times 1\cdot 0 \times 1\cdot 65 \\ &= \text{say, } 1950 \text{ f.p.m.} \end{aligned}$$

Side-and-face or Straddle Mills.

The action of this class of cutter is very similar to that of the face-mill, particularly when machining the inner and outer faces of a component. Hence the expression given above for face-mills may be used to compute the speed for straddle mills. In some instances it may be necessary to use an operational factor (see Table 27, p. 98).

Cylindrical Mills.

The cutting speeds may be computed using the expression given for face-mills when arranging the cutting speed for cylindrical cutters. Of course, it is recognized that such speeds are suggestions, and that the power of the machine, and its condition, will have a great effect upon tool-life and cutting speed.

12. Form Cutters and Hobs.

When using form cutters, hobs and similar tools on the milling machine, the cutting speed has to be adjusted to suit the new conditions of operating. The factors which have to be taken into account arise from the contour of the cutting edge, for:

(*a*) The section may be such that there is little or no metal at the back to absorb the heat generated or withstand any shock.

(*b*) The cutting action may be such that the work is done by one particular portion of the cutting edge, which results in heavy wear at that point.

(*c*) The high standard of accuracy that is called for on the machined surfaces, and the need to hold wear in check, may demand that the cutters be run at a lower speed for a given tool-life. To cover these contingencies it may be necessary to use operational factors; a few are listed in Table 27, p. 98; others should be introduced where necessary. Alternatively, the operation may be regarded as akin to form-turning, and therefore the cutting speed (V_c) may be based upon the data listed in the appropriate tables.

Example 12.—Suggest a cutting speed when milling a spur gear having a 5 D.P. tooth produced in En 8 H.T. to 186 B.H.N. A feed per tooth on the cutter of ·003 in. is suggested, which gives a chip thickness of, say, ·002 in., with the life of the individual teeth to be 3 hours. During cutting, the cutter and component will be flooded with a soluble oil.

Now this operation may be regarded as a forming one, hence the basic speed for a form-relieved gear-cutter in 18 . 4 . 1 h.s.s. is taken from

Table 41, p. 110. Grouping the data as given in the various tables, the following values are obtained:

V_b (Table 41, p. 110) = 97.
L_u (Table 25, p. 94) = 1·16.
T_m (Table 41, p. 110) = 1·0.
C_r (Table 41, p. 110) = 1·00.
M (Table 60, p. 121) = ·59.
T_l (Table 21, p. 85) = ·89.
T_s (Table 41, p. 110) = 1·0.

$$\begin{aligned} V_c &= V_b \cdot M \cdot L_u \cdot T_l \cdot T_m \cdot T_s \cdot C_r \\ &= 97 \times \cdot 59 \times 1\cdot 16 \times \cdot 89 \times 1\cdot 0 \times 1\cdot 0 \times 1\cdot 00 \\ &= \text{say, } 60 \text{ f.p.m.} \end{aligned}$$

Similar examples are given in Chap. XII dealing with estimating production times for milling, gear-hobbing and threadmilling.

13. Broaching.

The speed for broaching may be determined in a similar manner to that outlined for form-turning. As an example, assume that a 1½ in. dia. splined hole is to be broached in En 36, annealed.

Broach Details.—Increment rise per tooth ·0015 in., rake 5°, and the broach is made from h.s.s., but, owing to the need for strength, the heat treatment is such that the maximum cutting efficiency cannot be achieved. For this reason a material factor of, say, ·75 is assumed.

Operating Conditions.—The work is expected to be flooded with a sulphurized cutting liquid.

Tool-life.—The actual cutting time per tooth is estimated to be 18 min. per day, and on this basis it is assumed that the cutting speed should be based upon an hour's cutting. This means regrinding every 3 to 4 days.

Cutting Speed.—The chip thickness is known to be ·0015 in., hence the basic cutting speed (Table 41) may be estimated at 120 f.p.m.; taking the remaining data from the appropriate tables,

$$\begin{aligned} V_c &= V_b \cdot M \cdot L_u \cdot T_l \cdot T_m \cdot T_s \cdot C_r \\ &= 120 \times \cdot 71 \times 1\cdot 16 \times 1\cdot 0 \times \cdot 75 \times 1\cdot 0 \times 1\cdot 01 = \text{say, } 75 \text{ f.p.m.} \end{aligned}$$

This figure is much higher than is found in practice and explains why a broach lasts so long between each regrind. The normal cutting speeds for broaching vary from 3 to 35 f.p.m.

14. Reaming.

The speed to use when reaming can be determined in the same way as outlined above for form-turning with the thickness of the chip being measured normal to the cutting edge.

Take the simple case of reaming a hole in a component made from En 32 A, annealed, in which ·010 in. is left for the sizing operation.

Assuming a feed of ·005 in. per revolution, this gives, for square cutting, a chip thickness of ·005 in.; with the rose reamer made from 18 . 4 . 1 h.s.s. and a good flow of suds, then, for a tool-life of 1 hour's cutting,

$$V_c = 53 \times 1{\cdot}0 \times 1{\cdot}16 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 = 62 \text{ f.p.m.}$$

15. Screw-cutting.

The speeds for screw-cutting and chasing on centre and turret lathes may be determined in the same manner as outlined above for reaming, but due regard must be given to the time needed for withdrawing the tool. This may, on small and medium-sized work, call for a large reduction in the computed cutting speed.

Tapping and Screwing Speeds.

The speeds for tapping and screwing may also be based upon the tables given for form-turning. It will be realized that, by working upon the chip thickness, due allowance is made for the use of serial taps taking more than one cut with a die-head, and the number of cutting edges in action. The chip thickness is measured normal to the lead angle. Where the appropriate chip thickness and speed are not listed in the tables, they are easy to obtain by constructing a graph.

The chip thickness can be readily computed from the expression:

$$\text{Chip thickness or } T = \frac{\sin(\text{lead angle}) \times \text{pitch}}{\text{number of edges cutting}}$$

$$= \frac{\sin(\text{lead angle})}{N} \times \frac{1}{(\text{T.P.I.})}.$$

16. Fine Boring and Turning.

Fine boring and turning is a finishing operation used to give high-grade precision work. In some instances the process has superseded reaming, broaching, and grinding. Normally, it is poor economy to attempt the fine-boring or turning operation immediately after any rough machining. The best practice calls for all finishing stages to be performed after the bulk of the surplus material has been removed, and a sufficient period given so that the heat generated by the heavy cutting has had time to be lost. Moreover, a time-lag is required, so that the material may reach a stable condition. In order to ensure accuracy, the operations previous to fine boring should be held to fairly close limits. The work must run true. These conditions are essential so that the cutting force on the diamond or tipped tool remains fairly constant.

A wide range of work is finished by the fine-boring process, covering cast-iron cylinders, gudgeon-pin holes in pistons, the outside diameter of aluminium-alloy pistons, boring white-metal-lined bearings for various types of engines, turning or boring various non-ferrous valve parts.

TABLE 142A.—CUTTING SPEEDS FOR FINE (DIAMOND) TURNING AND BORING (F.P.M.)

Aluminium and its alloys	600–1000 f.p.m.
Magnesium and its alloys	1000–2000 f.p.m.
Bronze	500–1000 f.p.m.
Leaded bronzes	1500–2000 f.p.m.
Lined white-metal bearings	800–1200 f.p.m.

The feed, when fine boring, is around ·001 to ·004 in. with the depth of cut varying from ·002 to ·005 in. Where necessary the cutting speed may be computed using the data in the various tables and assuming a diamond is equivalent to the hardest cemented-carbide-tipped tool, thus giving for the diamond a T_m factor of 6.

17. Negative-rake Turning and Milling.[25, 26]

When negative-rake tools are chosen for turning and milling operations, the appropriate cutting-speeds and feeds are normally listed in the following manner:

TABLE 143.—CUTTING SPEEDS FOR NEGATIVE-RAKE TURNING AND BORING

Material to cut	Roughing, f.p.m.	Finishing, f.p.m.	Material to cut	Roughing, f.p.m.	Finishing, f.p.m.
·15% C steel.	770	1000	Ni Cr oil-hardening steel.	550	900
·3% C ”	700	900	Ni Cr C.H.S.	600	900
·4% C ”	550	700	M.S. castings.	300	350
·45% C ”	400	500	Gun-metal.	1000	1400
·8% C ”	400	450	Phosphor-bronze.	1000	1400
1% Carbon and Cr steel.	400	450	Copper.	1500	1800
3% Ni C.H.S.	600	1000	Brass.	2000	3000
Ni Cr air-hardening steel.	500	800	Aluminium.	3000	4000

The feeds for negative-rake carbide-tipped tools are:

Roughing, ·010–·032 in.
Finishing, ·002–·015 in.

The depth of cut varies roughly as follows:

Roughing from ·06 to, say, ·5 in.
Finishing from ·002 to, say, ·015 in.

TABLE 144.—CUTTING SPEED WHEN MILLING WITH A NEGATIVE-RAKE CUTTER

Material to cut	Roughing, f.p.m.	Finishing, f.p.m.	Material to cut	Roughing, f.p.m.	Finishing, f.p.m.
·15% C steel.	700	900	Ni Cr oil-hardening steel.	500	800
·30% C "	630	800	Ni Cr C.H.S.	540	800
·40% C "	500	630	M.S. castings.	270	320
·45% C "	360	450	Gun-metal.	900	1250
1% C and C Cr steels.	360	400	Phosphor-bronze.	900	1250
3% Ni C.H.S.	540	900	Copper.	1350	1600
Ni Cr air-hardening steel.	450	720	Brass.	1800	2700
			Aluminium.	2700	3700
Ni Cr oil-hardening steel.	500	800	Cast iron.	600	750

The feed per tooth when milling with a negative-rake cutter is:

Soft steel	·004–·015 in.
Hard steel	·002–·010 in.
Cast iron	·010–·025 in.
Non-ferrous metals	·006–·030 in.

The drawback with Tables 143, 144 is that they do not relate the speed of cutting to the dimensions of the chip and the contour of the cutting edge. If the reasons underlying the success of negative-rake cutting be examined, the following points emerge:

(*a*) The cross-section of the tool permits it to withstand shock loading with less risk of the cutting edge being damaged.

(*b*) It permits the harder carbides to be successfully used, and thus increases the tool-life for the same speed of cutting, or gives a higher speed for the same life.

(*c*) A cutting fluid is normally unnecessary (i) because of the speed of cutting and the associated difficulties; (ii) with negative-rake cutting the feed is comparatively fine, hence the heat due to the chip thickness is low, but that arising from the speed of removal is high. The latter only affects the chip and tool. As the metal is removed so quickly the heat generated by the cutting action has very little effect upon the component, hence the risk of distortion is slight.

Hence, failing adequate experimental data, the suggested procedure for computing the speed when cutting with negative-rake tools is:

(*a*) Use the tables as listed for h.s.s. tools.

(*b*) Take the T_m factor as 6, as the hardest carbides can be chosen.

(*c*) As negative-rake cutting is usually done dry, the L_u factor can be dropped from the expression giving the cutting speed.

(*d*) With comparatively light feeds, the rake factor C_r may be taken as unity, and need not feature in the expression.

On this basis the speed formula for negative-rake cutting becomes

$$V_c\,(\text{neg.}) = 6V_b\,.\,M\,.\,T_l\,.\,T_s.$$

The question of introducing negative-rake cutting should be carefully considered, for it is of little value to do so unless a saving in the production time is achieved, or unless difficulties associated with the cutting edge failing under shock loadings are prevented. The speed and feed[12] will have to be adjusted finally to suit the horse-power and spindle-speed of the machine chosen for the operation.

CHAPTER XI

Control and Horse-power Requirements

1. Control Requirements.

To ensure easy production of a given article, and to control expenditure, it may be necessary on an estimate to:

(*a*) List all patterns, gauges, and tools required.

(*b*) Give the estimated cost of all new equipment required, whether made in or purchased.

(*c*) Indicate which gauges, tools, and patterns are to be duplicated, &c., in order to reach the required daily output.

(*d*) Indicate which machines are allocated for the various operations.

(*e*) Determine the hours of work required from each machine per week.

(*f*) Indicate the probable reaction of the new line on existing production.

(*g*) State the additional plant required to cope with the proposed output.

(*h*) Make provision for the normal wear and tear on tooling and pattern equipment.

2. Patterns, Tools and Gauges.

The patterns, tools and gauges required for the production of a given article will be related to the process schedule. When the equipment is to be made in, the estimator must have a first-hand knowledge of the work, as the range to be covered is wide. It may be necessary to draw upon the knowledge gained by the time-study and rate-fixing officials.

3. Daily Machine Efficiency.

The daily machine efficiency, or the number of hours each machine is actually working each day, must be carefully considered when estimating the daily output. Due allowance must be made for the inevitable delays and hold-ups which are encountered in a manufacturing concern. Setters and operators may occasionally be away because of failure to get up in time, transport difficulties, illness, or private business; material or parts may not be to hand just when required; patterns, tools, and gauges, also machines, need renovation at awkward moments, whilst a power unit may give rise to an unexpected delay. Then again, there is the fluctuation in output between different members of the operating staff. Because of so many variations it is impossible to reckon on a daily machine efficiency of 100 per cent, and it is more prudent to assume one around 67 to 75 per cent.

4. Machine Capacity.

Associated with the equipment is the need to have full details of the capacity of each machine, also the power, spindle speeds, and feeds available; on a planer or shaper, the minimum strokes; for a press, the shut height, stroke, &c. To ensure that these data are to hand when required a chart should be prepared for each machine within the establishment (see figs. 2.13, 2.20 and 11.5).

5. H.P. Requirements for Turning.

Under normal production conditions the h.p. requirements to remove a given volume of material when turning or boring depends upon the material to be cut; the rigidity of the component; how it is held; the class of machine used and its general condition; the type of cutting tool, the keenness of the edge and its shape, along with the depth of cut, feed and speed. With so many variables any simple expression can only be in the nature of a suggestion.

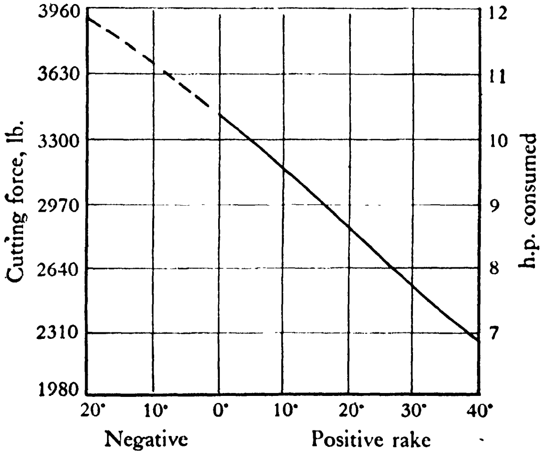


Fig. 11.1.—Effect of rake on cutting force and horse-power when cutting steel (based on L.T.R.C. 1922 Report)

Results of Changing the Rake Angle.

The general run of experiments conclusively prove what a competent turner has learned by experience, namely, that the h.p. required for a given cut decreases as the rake angle is increased, and increases as the chip area is made greater. The results of the L.T.R.C.'s 1922 [2] findings are given in fig. 11.1 for cutting steel of 29·7 tons per sq. in. tensile strength, elongation 30% on 4 in., and a B.H. No. of 137; the chip gave a cross-sectional area of ·01 sq. in., being ·375 in. deep and ·031 in. thick.

When the results of the experiments are expressed algebraically the following expression is given:

$$\text{h.p.} = C + {\cdot}09\phi.$$

$\phi = 40° -$ (true rake on the tool). $C =$ constant for the material to be cut and a tool having a 40° true rake.

Example 1.—It is known that, for a given cut, a tool having a 40° rake has a power consumption of 6·9 h.p. Give the h.p. if the rake is altered to 15°.

Now $\phi = 40° - 15° = 25°.$

$$\therefore \text{h.p.} = 6{\cdot}9 + ({\cdot}09 \times 25) = 9{\cdot}15.$$

The data given in the L.T.R.C. report are shown below.

TABLE 145.—INDICATING HOW THE RAKE ANGLE AFFECTS THE H.P. REQUIREMENTS.

Approx. h.p.	Rake angle, deg.	Cutting speed, f.p.m.	Cutting force, lb.	% increase in power, per step	% H.P. requirement for changes in rake angle
6·9	40	100	2275		100
7·8	30	100	2570	11·3	113
8·7	20	100	2870	11·3	126
9·6	10	100	3170	11	139
10·4	0	100	3450	11	151

Hence from the above figures it may be said that, starting from a rake angle of 40° and decreasing the rake in increments of 10°, the effect is to push up the h.p. requirements 11·1 per cent per step.

By extending the curve, as shown dotted in fig. 11.1, the general tendency when using a negative rake in the direction of the chip flow may be roughly determined.

Effect of Altering the Approach Angle.

The experiments of the L.T.R.C. seem to prove that little or no alteration takes place in the h.p. requirements for a given chip area as the approach angle or tool profile is modified.

6. Cutting Force.

The force on a single-point tool is not exactly proportional to the increase in the cross-sectional area. The results of many published experiments indicate that, for a number of metals, a slight fall per unit area is experienced as the chip area is enlarged. It also varies with the material to be cut, the top rake on the tool, the ratio of the depth to the feed, the finish given to the top face of the tool, and the use or otherwise of a suitable cutting compound or oil. The expression given by F. W. Taylor[13] was

$$F = Cdf^{\cdot 934},$$

where C = a constant depending upon the material, f = feed,
d = depth of cut.

That by Kronenberg[14] is $F = C_p(1000A)^r$, where $r = 1 + \frac{1}{E_p}$,

C_p = a constant for cutting pressure depending upon the material to be cut,
E_p = an exponent depending upon the components,
A = cross-sectional area of chip.

The various values for C_p and A are given in the tables below.

TABLE 146.—VALUES OF C_p WHEN DETERMINING THE CUTTING FORCE

Rake angle normal to cutting edge, degrees	Cast steel 135/150 Brinell	Steel (S.A.E.)					Cast iron, Brinell No.						Light alloy, Brinell 53	Brass, 85% Co, 9% Sn, 6% Zn
		1015	1025	1035	1045	1060								
		B.S. 970 equivalents												
		En 2B	En 3	En 5	En 8	En 43	100	120	140	160	180	200		
40													35	
35		270	312	358	406	473	92	98	105	111	116	121		
30		284	328	378	426	496	97	104	112	118	124	128		
25		296	342	391	445	516	103	110	118	125	131	136		
21														129
20		308	357	408	464	538	108	116	125	132	138	143		
18	268													
15		320	370	424	481	560	113	122	131	139	144	150		
10		330	383	439	498	579	119	127	137	145	151	157		

TABLE 147.—MULTIPLICATION FACTOR FOR CALCULATING THE CUTTING FORCE F

A Chip cross-sectional area, sq. in.	$(1000\,A)^r$ Multiply C_p as given in Table 146 for the different metals by the following:				
	Steel	Cast iron	Cast steel	Brass	Light alloys
·001	1·00	1·00	1·00	1·00	1·00
·002	1·75	1·80	1·80	1·68	1·92
·003	2·4	2·6	2·55	2·28	2·82
·004	3·1	3·3	3·25	2·83	3·70
·005	3·6	4·0	3·9	3·35	4·55
·008	5·3	6·0	5·9	4·8	7·1
·010	6·4	7·3	7·1	5·6	8·7
·015	8·8	10·4	10·0	7·6	12·8
·020	11·2	13·3	12·7	9·4	16·6
·025	13·3	16·0	15·4	11·2	20·5
·030	15·2	19·0	18·0	12·8	24·5
·040	19·3	24·4	23·0	15·7	32·0

Example 2.—Give the approximate cutting force when machining a light-metal alloy with a cut ·375 in. deep and a feed of ·025 in. The tool has a rake angle of 20°.

C_p (from Table 146) = 35.

Chip area = ·375 × ·025 = ·009375 sq. in.

Then the factor from Table 147 is, say, 8·7.

Correction factor for change in rake (Table 145) is, for a 20° alteration in the rake angle away from the basic 40°, say, 1·22. Note that each 10° alteration in the rake gives rise to an 11 per cent alteration. See paragraph 5 on p. 236.

Hence estimated cutting force = 35 × 8·7 × 1·22 = say, 370 lb.

A.S.M.E. Cutting-force Expression.[15]

The expression as given by the A.S.M.E. is

$$F = C_p C_r T^c L^d.$$

Notation: F = force on tool. C_p = material constant for pressure on tool. C_r = rake constant depending on R = rake angle, as shown in Table 148. T = mean length of chip. L = length of tool contact with component.

The values for the different constants are listed below.

TABLE 148.—GIVING THE CONSTANTS IN THE A.S.M.E. FORCE EXPRESSION

Material to be cut	c	d	C_p	C_r
Steel.	·78	1·1		1–·0075 R
Cast iron.	·68	1·0		1–·0115 R
Brass, unleaded, B.S. 266 and 267.	·92	1·1	207,000	1–·0115 R
Brass, free-cutting, B.S. 249.	·92	1·1	102,500	1–·0115 R
Brass, yellow, B.S. 264.	·92	1·1	110,000	1–·0115 R
Gilding metal, B.S. 711.	·92	1·1	110,000	1–·0115 R
Leaded bronze, B.S. 964.	·92	1·1	68,000	1–·0115 R
Leaded bronze, B.S. 962.	·92	1·1	90,000	1–·0115 R
Manganese bronze, B.S. 208.	·92	1·1	134,000	1–·0115 R
Gun-metal, B.S. 382.	·92	1·1	101,000	1–·0115 R
Copper, annealed, B.S. 128.	·92	1·1	336,000	1–·0115 R
Nickel, rolled.	·78	1·1	273,000	1–·0075 R
Monel metal, rolled.	·78	1·1	290,000	1–·0075 R
Aluminium castings, B.S. 363.	·83	1·1	71,000	1–·0075 R
Aluminium castings, B.S. 361.	·83	1·1	61,000	1–·0075 R
Magnesium castings, D.T.D. 59 A.	·83	1·1	27,500	1–·0075 R

Note C_p for cast iron and steel is given in Tables 60 to 76.

Example 3.—A cut is to be taken with a knife tool having a 15° top rake, no approach angle or nose-radius. The depth is ·250 in. with a feed of ·015625 in. when cutting steel to En 2 C; compute the cutting force F.

Gathering the data from the tables:

$$C_p \text{ (Table 60)} = 122{,}000.$$

$$C_r = (1 - \cdot0075R).$$

$$R = 15^\circ. \quad T = \cdot015625. \quad L = \cdot250.$$

$$c = \cdot78. \quad d = 1\cdot1.$$

$$\therefore \; F = C_p C_r T^c L^d$$

$$= 122{,}000 \times (1 - \cdot0075 \times 15) \times \cdot015625^{\cdot78} \times \cdot250^{1\cdot1}$$

$$= 122{,}000 \times \cdot8875 \times \cdot0390 \times \cdot218 = \text{say, } 920 \text{ lb.}$$

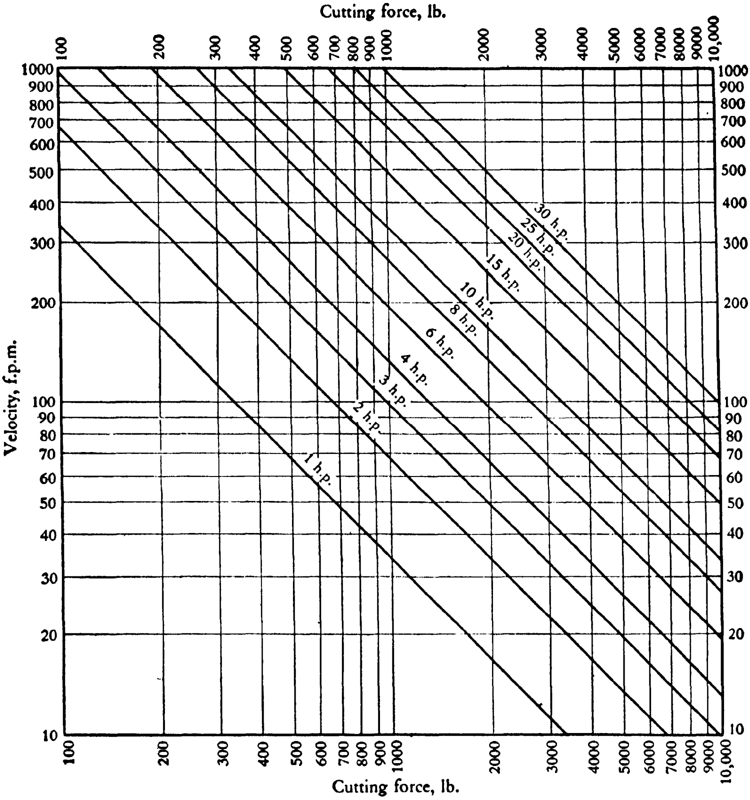


Fig. 11.2.—Relationship between cutting force and velocity for different horse-powers

CUTTING FORCE (A.S.M.E.)

Tables 149–156 give the estimated cutting force in pounds for various depths of cut and feed per revolution. The graph in fig. 11.3 shows how the force varies as the feed is increased for a given depth of cut, whilst fig. 11.4 indicates the change when the depth is varied, but the feed remains constant. With the given data similar graphs can be constructed for intermediate values. Alternatively, these may be obtained by interpolation. The tables become very useful when the need arises to estimate the approximate power required for a known machining operation. Examples may be found on pp. 246–252.

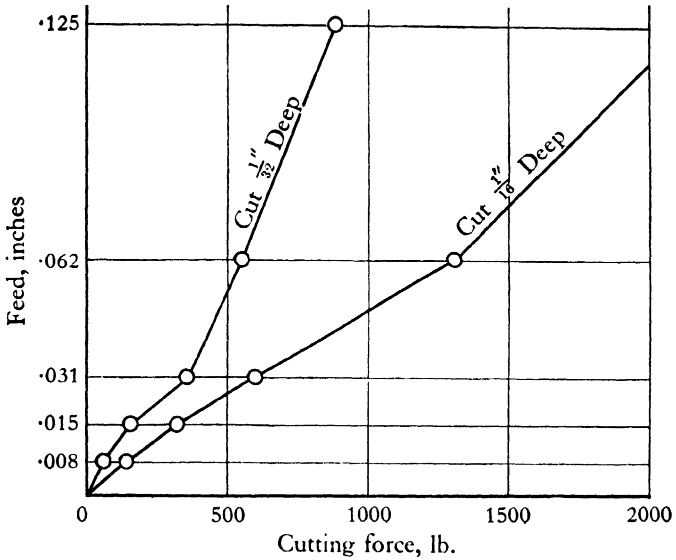


Fig. 11.3.—Variation of cutting force with feed when cutting B.S. 970 EN 2 C steel (zero approach angle and nose-radius)

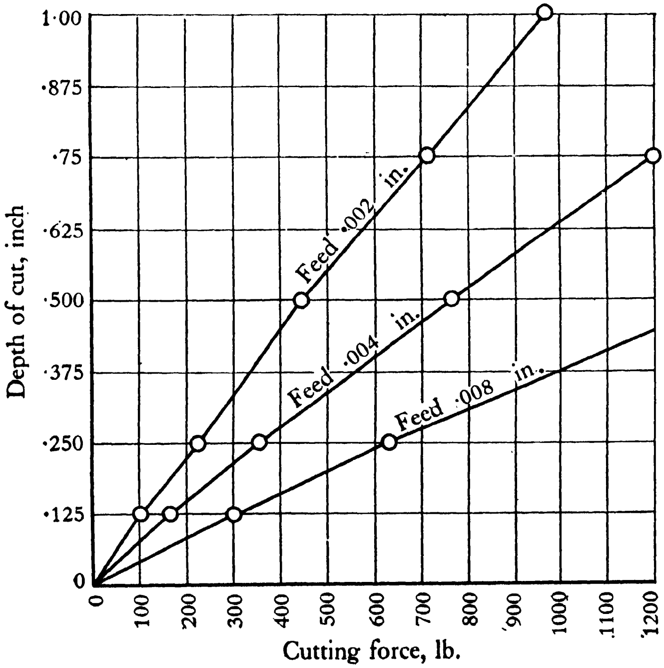


Fig. 11.4.—Variation of cutting force with depth of cut for given feeds

Tables 149–152. Cutting Force when Machining Steel B.S. 970 En 2 C. Top Rake 14°. Side Rake 8°. H.S.S. Tool. Based on A.S.M.E.[15] Data.

(149) Tool with no Approach Angle and no Nose-radius

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·062	·125
$\frac{1}{32}$	24	37	76	169	362	558	880
$\frac{1}{16}$	47	88	153	285	593	1,330	2,140
$\frac{1}{8}$	103	176	308	531	1058	2,220	5,050
$\frac{1}{4}$	213	364	630	1080	2020	3,970	8,260
$\frac{3}{8}$	326	570	990	1630	3020	5,620	11,280
$\frac{1}{2}$	448	772	1360	2280	4120	7,500	14,350
$\frac{3}{4}$	710	1205	2080	3520	6310	10,480	20,800
1	960	1650	2860	4750	8490	15,080	27,900

(150) Tool with no Approach Angle and $\frac{1}{16}$-in. Nose-radius

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·0625	·125
$\frac{1}{32}$	29	45	81	138	259	426	781
$\frac{1}{16}$	53	92	156	274	480	845	1,500
$\frac{1}{8}$	107	179	327	542	957	1,650	2,910
$\frac{1}{4}$	218	368	643	1080	1890	3,300	5,880
$\frac{3}{8}$	339	583	1000	1675	2910	5,020	8,850
$\frac{1}{2}$	458	789	1360	2280	3990	6,880	13,600
$\frac{3}{4}$	718	1220	2100	3550	6060	10,620	18,100
1	935	1685	2870	4850	8340	14,480	25,600

(151) Tool with 30° Approach Angle and $\frac{1}{8}$-in. Nose-radius

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·062	·125
$\frac{1}{32}$	32	55	95	156	289	495	864
$\frac{1}{16}$	60	98	176	288	550	910	1,630
$\frac{1}{8}$	110	200	342	578	1000	1,770	3,120
$\frac{1}{4}$	234	406	695	1163	2000	3,460	6,180
$\frac{3}{8}$	357	620	1050	1780	3100	5,340	9,470
$\frac{1}{2}$	486	869	1545	2400	4280	7,250	13,200
$\frac{3}{4}$	750	1290	2218	3720	6450	11,000	19,200
1	1025	1755	3020	5080	8740	15,000	26,000

(152) Tool with 30° Approach Angle and ¼-in. Nose-radius

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·062	·125
$\frac{1}{32}$	34	58	100	164	300	534	900
$\frac{1}{16}$	67	110	200	335	595	1,056	1,750
$\frac{1}{8}$	124	213	360	630	1070	1,875	3,240
$\frac{1}{4}$	240	416	721	1225	2110	3,710	6,470
$\frac{3}{8}$	357	638	1105	1840	3200	5,460	9,500
$\frac{1}{2}$	498	832	1470	2470	4280	7,350	12,880
$\frac{3}{4}$	760	1315	2260	3810	6540	11,350	19,200
1	1030	1780	3060	5170	8930	15,250	26,000

Tables 153–156.—Cutting Force when Machining Cast Iron, Brinell 177. Top Rake 14°. Side Rake 8°. 18 . 4 . 1 H.S.S. Tool. Based on A.S.M.E.[15] Data.

(153) Tool with no Approach Angle and no Nose-radius

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·062	·125
$\frac{1}{32}$	20	52	68	129	320	480	746
$\frac{1}{16}$	39	78	172	260	488	950	1,075
$\frac{1}{8}$	118	183	275	447	855	1580	3,050
$\frac{1}{4}$	218	368	564	860	1475	2570	4,820
$\frac{3}{8}$	318	503	815	1250	2070	3450	6,300
$\frac{1}{2}$	460	692	1060	1670	2740	4500	8,050
$\frac{3}{4}$	658	1010	1615	2530	4020	6620	11,130
1	860	1365	2120	3340	5570	9030	13,950

(154) Tool with no Approach Angle and $\frac{1}{16}$-in. Nose-radius

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·0625	·125
$\frac{1}{32}$	29	57	126	192	236	362	600
$\frac{1}{16}$	49	108	170	254	407	630	1,100
$\frac{1}{8}$	106	188	277	443	750	1160	1,890
$\frac{1}{4}$	222	375	562	857	1370	2270	3,540
$\frac{3}{8}$	342	530	818	1250	1990	3230	5,260
$\frac{1}{2}$	444	694	1100	1670	2660	4220	6,800
$\frac{3}{4}$	660	1015	1620	2460	3980	6280	9,760
1	864	1370	2170	3300	5220	8400	13,420

(155) TOOL WITH 30° APPROACH ANGLE AND ⅛-IN. NOSE-RADIUS

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·062	·125
$\frac{1}{32}$	35	78	124	162	275	428	718
$\frac{1}{16}$	72	115	178	264	423	735	1,178
$\frac{1}{8}$	128	193	325	522	815	1230	2,100
$\frac{1}{4}$	257	394	586	925	1470	2310	3,780
$\frac{3}{8}$	352	605	890	1378	2150	3370	5,640
$\frac{1}{2}$	464	723	1165	1790	2840	4500	7,180
$\frac{3}{4}$	692	1100	1745	2660	4180	6520	10,600
1	934	1450	2270	3530	5460	8620	13,750

(156) TOOL WITH 30° APPROACH ANGLE AND ¼-IN. NOSE-RADIUS

Depth of cut, in.	Cutting force, lb.						
	Feed, in.						
	·002	·004	·008	·0156	·031	·062	·125
$\frac{1}{32}$	54	73	115	176	294	413	718
$\frac{1}{16}$	82	126	210	300	468	840	1,320
$\frac{1}{8}$	147	216	362	545	840	1400	2,220
$\frac{1}{4}$	257	410	608	970	1580	2420	4,040
$\frac{3}{8}$	387	587	907	1408	2240	3570	5,640
$\frac{1}{2}$	485	760	1190	1860	2910	4600	7,250
$\frac{3}{4}$	724	1110	1760	2700	4220	6780	10,800
1	936	1480	2320	3560	5600	9020	10,950

7. Horse-power.

The horse-power to overcome a given chip resistance is indicated by one of the basic expressions of mechanics, namely

$$\text{h.p. at tool point} = \frac{\text{force} \times \text{velocity}}{33{,}000}.$$

The above formula does not take into account the efficiency of the machine itself, hence due allowance must be made for the latter. In practice the efficiency of a lathe may be taken around 67% for an old-type machine, whilst a newer model would have a higher efficiency of, say, 75%.

For a belt drive the power input is given by the expression

$$\text{h.p. input} = \frac{\pi DRPW}{12 \times 33{,}000}.$$

D = dia. of pulley, in. R = r.p.m. P = pull per in. width, lb. W = width of belt, in.

Assuming that the machine is only 75% efficient,

$$\text{h.p. available at tool point} = \frac{\pi DRPW \times 75}{12 \times 33{,}000 \times 100}.$$

If the belt is taken to have a pull of 50 lb. per inch width, then, for 75% efficiency,

$$\text{h.p. available at tool point} = \frac{DRW}{3370}.$$

Where a machine is directly driven by an electric motor, then meter readings, if possible, should be taken with the gear trains engaged as for a cut, and the power to drive the machine when idling determined with some degree of accuracy.

The bilogarithmic chart (fig. 11.2) gives the horse-power for varying cutting forces, for speeds up to 1000 f.p.m. and cutting force up to 10,000 lb.

H.P. using Kronenberg's Data.

If, using the data given by Kronenberg for computing the power requirements for a given cut, the expression is

$$\text{h.p.} = \frac{C_p F V_c}{33{,}000}.$$

C_p is obtained from Table 146. F is obtained from Table 147.

H.P. using the A.S.M.E. Data.

If choosing the data as given by the A.S.M.E. for computing the h.p. requirements when cutting steel (and this takes into account the changes in the contour of the tool), then the expression is

$$\text{h.p.} = \frac{F P_c V_c}{33{,}000}.$$

Now (for steel) the cutting force factor

$$P_c = \frac{\text{cutting force for the material}}{\text{cutting force for B.S. 970 En 2 C or S.A.E. 1020}} = \frac{C_p}{122{,}000},$$

and the cutting force is given as C_p in Tables 60 to 76.

Adjusting the expression for P_c to suit the machining of cast iron, we have:

$$\text{For cast iron } P_c = \frac{C_p \text{ for material (Table 106)}}{C_p \text{ for cast iron having a B.H. No. of 177}}$$

$$= \frac{C_p \text{ from Table 106}}{52{,}000}.$$

H.P. for Negative-rake Cutting.

The above data given for tools having positive rake can be readily adapted to suit the needs of cutting with tools having negative rake by the introduction of a suitable constant. Using the data given in fig. 11.1, p. 235 and Table 145, it appears necessary to increase the power, say, 11% for each 10° movement away from the given datum of 15° positive rake. Hence the correction factor C_r for negative-rake tools can be written

$$C_r = 1 + \frac{\text{degrees movement away from datum}}{10} \times \frac{11}{100}.$$

Hence, using a tool having a 10° negative rake, and working on the Tables 149–152 which are for tools having approximately 15° positive rake, the difference in the rake angle is 25° and the value of C_r is

$$C_r = 1 + \left(\frac{25}{10} \times \frac{11}{100}\right) = 1{\cdot}28.$$

Hence, amending the A.S.M.E. expression to suit, the power requirement for a 10° negative-rake tool is given by the formula:

$$\text{h.p. for a 10° negative-rake tool} = \frac{1{\cdot}28 F P_c V_c}{33{,}000}.$$

Example 4.—A crankshaft from a ·45 per cent C steel forging is to be rough-turned on a lathe driven by a 10 h.p. motor. The proposed chip dimension is $\frac{3}{8}$ in. deep, the feed ·04 in., and the tool is to have a 10° rake. Check the h.p. requirements using Kronenberg's expression if cutting at 80 f.p.m.

$$\text{Chip area} = {\cdot}375 \times {\cdot}04 = {\cdot}015 \text{ sq. in.}$$

From Tables 146, 147 the values of C_p and F are given as 498 and 8·8.

Hence $$\text{h.p.} = \frac{C_p F V_c}{33{,}000} = \frac{498 \times 8{\cdot}8 \times 80}{33{,}000} = \text{say, } 10{\cdot}6.$$

From this rough check the power of the motor is inadequate for the drive, inasmuch as for cutting alone, approximately 11 h.p. is necessary; thus, taking into account the efficiency of the machine, a motor having a rating of, say, 15 h.p. is required. The alternatives open to the engineer are obvious: reduce the size of the chip, or fit a larger motor on the machine.

Example 5.—A cut $\frac{1}{4}$ in. deep with a feed of ·015 in. is to be taken on En 1, using a capstan lathe with a knife tool having no nose-radius or approach angle. The cutting speed has been fixed at 205 f.p.m. Check the h.p. requirements.

Using the A.S.M.E. data,

$$P_c \text{ (from Table 60)} = \frac{73{,}000}{122{,}000} = \cdot 598.$$

$$F \text{ (Table 149) is 1080.}$$

$$\therefore \text{ h.p.} = \frac{FP_cV_c}{33{,}000} = \frac{1080 \times \cdot 598 \times 205}{33{,}000} = \text{say, } 4.$$

Example 6.—A cut is to be taken on a series of nickel-chromium steel forgings to B.S. 970 En 23, having a B.H. No. of 230. The tool will have a 10° negative rake, $\frac{1}{16}$-in. nose-radius, 30° approach angle; the depth of cut is to be $\frac{1}{8}$ in. with a feed of ·01 in. A suggested tool-life of 2 hours is required. Compute the speed and power requirements.

The nearest tool having a $\frac{1}{16}$-in. nose-radius is a knife tool, hence a correction is required to take care of the approach angle, which gives a thinner chip and hence permits a higher speed for the same tool-life. The cutting speed expression, p. 233, is

$$V_c \text{ (neg.)} = 6V_b \,.\, M \,.\, T_l \,.\, T_s.$$

Gathering the data from the various tables,

V_b (Table 38, p. 109) = 186. M (Table 61, p. 131) = ·41.

T_l (Table 21, p. 85) = ·9. T_s (Table 24, p. 91) = 1·21.

Then $V_c = 6 \times 186 \times \cdot 41 \times \cdot 9 \times 1{\cdot}21 =$ say, 500 f.p.m.

Using the A.S.M.E. data for h.p. adjusted to suit negative-rake cutting,

$$\text{h.p.} = \frac{1{\cdot}28FP_cV_c}{33{,}000}.$$

$$F \text{ (Table 151)} = \text{say, } 400.$$

$$P_c = \frac{136{,}000}{122{,}000} = 1{\cdot}11,$$

hence $$\text{h.p.} = \frac{1{\cdot}28 \times 400 \times 1{\cdot}11 \times 500}{33{,}000} = \text{say, } 8{\cdot}7.$$

8. Cutting Force and Rigidity of Component.

At all times the cutting force must be related to (*a*) the means of holding, (*b*) the strength of the component, so that undue torsional stresses are not created during the machining operation. This latter phase becomes of great importance when machining on multi-tool lathes, where up to a dozen tools may be cutting at the same moment. Often, in order to reduce the torsional stresses, the layout is on the basis of a high cutting speed and a very fine feed which favours the cemented carbides.

9. Combined Cutting Speed, Chip-dimension and H.P. Chart.

When planning a machining operation, a chart giving the speed and power requirements for a known chip-dimension proves to be of

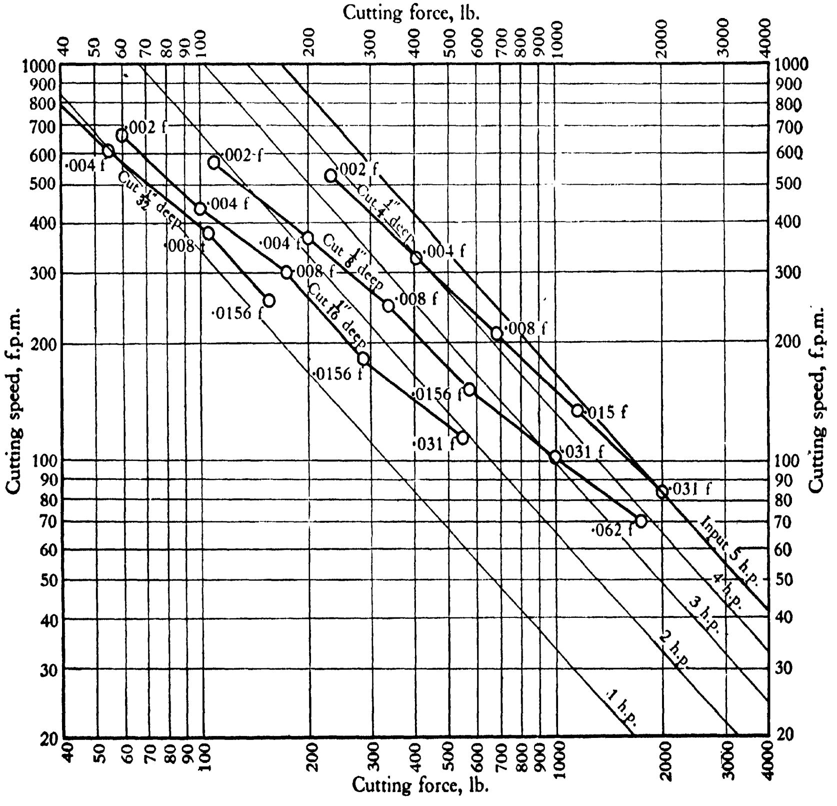


Fig. 11.5.—Diagram combining horse-power available with cutting force for EN 2 C H.R. steel. Tool, 18.4.1. h.s.s. 30° approach angle. $\frac{1}{8}$-in. nose-radius. 15° Rake. Tool-life one hour cutting dry.

great assistance, as it removes much uncertainty as to the capability of the machine to take the proposed cut or cuts. Such a chart is best planned to suit a given tool-life for each cutting medium, carbon steel, h.s.s., Stellite, or the cemented carbides. The chart should give the maximum power input, the power required for various depths and feeds, the cutting speed and force. A chart of this type (and there are others [14, 12]) is given in fig. 11.5 and is set out on a bilogarithmic basis. It is based upon the machining of B.S. 970 En 2 C, H.R. On the Y axis is given the cutting speed; on the X axis, the cutting force. The heavy line running at 45° to the base gives the maximum h.p. input, in this instance 5, whilst the thin lines running parallel to the thick sloping line give respectively 1, 2, 3 and 4 h.p. Curves for cuts $\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$ and $\frac{1}{4}$ in. deep are shown. On each of the curves the various feeds are marked off. This permits different combinations to be chosen to meet the known requirements of the many jobs that must be handled. A point brought out by the chart is that for cuts greater than $\frac{1}{4}$ in. deep, sufficient power is not available for the optimum cutting speeds.

Example 7.—Determine the best feed and speed if machining a job with two cuts, $\frac{1}{16}$ in. and $\frac{1}{8}$ in. deep respectively, operating simultaneously.

Combined h.p. = 5.

Cutting at 150 f.p.m. with a feed of, say, ·020 in. and a cut $\frac{1}{8}$ in. deep requires 3 h.p.

Cutting at 150 f.p.m. with a feed of, say, ·020 in. and a cut of $\frac{1}{16}$ in. deep needs, say, 1·9 h.p.

Hence, ignoring machine efficiency, the suggested best combination to use the available power is one running at 150 f.p.m. and a feed of ·020 in.

An examination of the chart also illustrates the two general tendencies:

(*a*) A high cutting speed and a small chip-area are general when finishing operations are necessary.

(*b*) Low cutting speed and a large chip-area are chosen for roughing stages.

In the former the steady decrease in the cutting force as the speed is increased is clearly indicated when the h.p. curves are examined. The results are:

1. A reduction in the cutting stresses in the component.
2. A reduction in the force necessary to hold the article during the machining stages and prevent it from moving during the cutting

period. The higher speed has the tendency to take the tool outside the range where a built-up edge may be expected.

3. Less risk of distortion.

4. Low deflection stresses.

5. As the chip dimensions are small the surface finish is good.

6. With the lower cutting stresses required for machining, the reactions upon the machine itself are smaller and not so destructive to its accuracy.

7. The grouping together of all these factors gives, over a longer period, greater accuracy in the work as it passes through the shops.

10. H.P. for Milling.

The h.p. requirements for milling are much the same as when turning, and a rough estimation of the power required may be based upon the volume of material removed per minute. On this basis,

$$\text{h.p.} = \frac{V}{C}.$$

Table travel $= fNR$.

Hence $$V = WdfNR,$$

and $$\text{h.p.} = \frac{WdfNR}{C}.$$

Notation: $V =$ volume. $C =$ a power constant. $W =$ width of work. $d =$ depth of cut. $f =$ feed per tooth. $N =$ number of teeth in cutter. $R =$ r.p.m. of cutter.

TABLE 157.—POWER FACTOR WHEN MILLING WITH POSITIVE-RAKE MILLS

Material being Cut	C	
Cast iron (grey)	1·22	For face-mills these values may in some instances be increased 50%.
Carbon steels up to, say, 45 tons	·61	
Alloy steels from 45 to, say, 70 tons	·37	
Malleable iron	·73	
Brass	1·95	
Bronze	·92	
Aluminium	3·1	

For negative-rake milling the values of C are as follows:

TABLE 158.—POWER FACTOR WHEN MILLING WITH NEGATIVE-RAKE CUTTERS

Low-carbon steels up to, say, 30 tons	·75
Medium-carbon steels up to, say, 45 tons	·875
High-tensile steels from 45 to 60 tons	·875
Cast iron up to, say, 20 tons	·875
Cast iron from 20 to 30 tons	1·000

The horse-power required when milling may also be estimated using the figures given in Tables 146 to 156 for turning when the chip dimensions are known. Owing to a milling cutter having teeth around the periphery, it is necessary to take into account the maximum number of teeth in contact with the work at any one time. Moreover, a factor P_c as mentioned on pp. 245–6 above should be introduced into the expression to take care of variations in the physical properties of the material to be cut; these may be due to slight changes in the constituents, or to the treatment. Working on this basis the expression may be written:

h.p. at cutting edge = velocity of cutting × number of teeth in contact × force for chip size × power factor ÷ 33,000

$$= \frac{V_c N F P_c}{33{,}000}.$$

This expression can be modified to suit the needs of negative-rake milling by introducing a constant to cover the change in the cutting angle, and using the data as shown in Table 145. Assuming that the rake is 10° negative, the change in the rake angle from that giving the cutting force in Tables 149 to 156 is 25°.

Then $$C_r = 1 + \left(\frac{25}{10} \times \frac{11}{100}\right) = \text{say, } 1{\cdot}28.$$

For other rake angles the value can be similarly computed. On the basis of using a 10° negative-rake tool,

$$\text{h.p. at cutting edge} = \frac{1{\cdot}28 V_c N F P_c}{33{,}000}.$$

Example 8.—A facing cutter having no approach angle is chosen to mill a cast-iron block $4\frac{1}{2}$ in. wide. The cutter is 6 in. dia. and has 15 teeth with a $\frac{1}{16}$-in. nose-radius. The cut is $\frac{1}{8}$ in. deep and the feed is ·008 in. per tooth. The chosen speed is 55 f.p.m. Estimate the h.p. requirements using the volume formula.

Volume of metal removed per minute $V = WdfNR$,

$$\text{and h.p.} = \frac{V}{C}.$$

A 6 in. dia. cutter at 55 f.p.m. makes 35 r.p.m.

Hence $V = 4{\cdot}5 \times {\cdot}125 \times {\cdot}008 \times 15 \times 35 = 2{\cdot}37$ c. in.,

and $$\text{h.p.} = \frac{V}{C} = \frac{2{\cdot}37}{1{\cdot}22} = \text{say, } 1{\cdot}94.$$

Example 9.—Using the same data as in the above example, and assuming the material has a B.H. No. of 194, compute the h.p. requirements using the A.S.M.E. cutting force listed in Tables 149–152.

$$\text{H.P.} = \frac{V_c N F P_c}{33{,}000}.$$

From a rough sketch N is found to be 4.

Table 154 gives F as 277 lb.

$$\text{For cast iron } P_c = \frac{C_p}{52{,}000} = \frac{58{,}000}{52{,}000} = 1{\cdot}11. \text{ (Table 106.)}$$

$$\text{H.P.} = \frac{55 \times 4 \times 277 \times 1{\cdot}11}{33{,}000} = 2{\cdot}05.$$

Example 10.—Assume now that the cutter has a 10° negative rake; the cutting speed is 400 f.p.m., and the number of teeth cutting at any one moment is 2. All other data as for Example 9.

$$\text{Then} \quad \text{h.p.} = \frac{1{\cdot}28 V_c N F P_c}{33{,}000}$$

$$= \frac{1{\cdot}28 \times 400 \times 2 \times 277 \times 1{\cdot}11}{33{,}000} = \text{say, } 9{\cdot}6.$$

If using the volume expression

$$\text{h.p.} = \frac{V}{C},$$

the working is as follows:

For two teeth to be cutting at any one time the cutter would have 8 teeth.

$$\text{r.p.m. of cutter} = \frac{12V_c}{\pi d} = \frac{12 \times 400}{3{\cdot}1416 \times 6} = 254.$$

$$\begin{aligned} \text{Volume of metal cut per minute} &= V = WdfNR \\ &= 4{\cdot}5 \times {\cdot}125 \times {\cdot}008 \times 8 \times 254 \\ &= 9{\cdot}144 \text{ c. in.} \\ C \text{ from above} &= \text{say, } 1{\cdot}0. \\ \therefore \text{h.p.} &= \frac{9{\cdot}14}{1{\cdot}0} = 9{\cdot}14, \end{aligned}$$

which is close to the above figure.

In Examples 9 and 10 it has been assumed that each tooth is engaged removing a chip of the maximum thickness. In practice this is not so, but the above results are usually of sufficient accuracy for checking the h.p. requirements. If greater accuracy is desired, then the average chip thickness for the given conditions should be determined from a large-scale drawing. Better still, take readings of the power consumed by the motor during the cutting and idling periods.

CHAPTER XII

Estimating Machining Times

When dealing with the machining of bar, forgings, castings, and hot-pressings, the preparation of the operation schedule is similar to that outlined on pp. 65, 66, 342, 343, for press work, namely, the subdivision into suitable stages.

Special Features.—With all machining jobs attention should be paid to such features as:

(*a*) The need to do the roughing stages before attempting final machining.

(*b*) The need to introduce an annealing, normalizing, or seasoning operation after the roughing stage, to remove (1) any tendency to distortion, (2) the internal stresses which may lead to trouble during hardening or service.

(*c*) Giving a time-lag between the machining operations to permit the work to " stabilize " where it is impossible to heat-treat as suggested in (*b*); then finishing operatings can be performed with less risk of distortion.

(*d*) Arranging the work cycle so that the operations are based upon one or two well-chosen datum faces.

Use of Formulæ.—Knowing the material to be cut, and having full details of the operations, including the amount of material to be removed, one may pass along to estimating the actual machining times. What follows excludes handling, setting, tool-sharpening, and the other incidental times associated with the work. When determining the machining times, use is made of the information on speeds and feeds given in Chap. X, and the basic formulæ listed below for different classes of machining.

Approach and Over-run.—With a number of machining operations it is essential to take into account the approach and over-run of the tool. The former is the distance the tool must travel just prior to making contact, before the full depth of cut is reached; the latter is the distance it must travel to clear the work, after the cut has been completed. The effect of the approach and over-run upon the machining times depends upon the length of the component, the class of tool, and the depth of the cut.

1. Turning and Boring.

The machining times for turning and boring can be estimated if use is made of the expressions listed below, after the most suitable cutting speed, depth of cut, and feed have been determined for the machine.

$$R = \text{r.p.m.} = \frac{\text{cutting speed} \times 12}{\pi d} = \frac{3{\cdot}82 V_c}{d}.$$

$$\text{Tool travel in one minute} = \text{feed} \times R = \frac{3{\cdot}82 f V_c}{d}.$$

Time in minutes for turning or boring

$$= \frac{L + A + O}{R \times f}.$$

$$\text{Time for facing} = \frac{\text{outside dia.} - \text{inside dia.}}{f \times R \times 2}.$$

Notation: V_c = cutting speed, f.p.m. R.P.M. = R. d = diameter. f = feed per rev. A = approach. O = over-run. L = length of component—all in inches.

When a job has to be faced on the lathe it is often necessary to base the cutting speed on the largest diameter, as with a finishing cut it is unwise to stop and change speeds. To do so would give a poor surface.

Example 1.—Estimate roughly the time for turning a steel component, 2 in. dia., which is to be machined to $1\frac{3}{4}$ in. dia., for a length of $11\frac{1}{2}$ in. at one cut. The approach and over-run are each assumed to be $\frac{1}{4}$ in. The tool is made from 18 per cent h.s.s.

Suggested cutting speed = 150 f.p.m.

Depth of cut = $\frac{1}{8}$ in.

Feed = $\frac{1}{64}$ in.

R.P.M. of machine $= \dfrac{3{\cdot}82 V_c}{d} = \dfrac{3{\cdot}82 \times 150}{2} = 287.$

Turning time $= \dfrac{L + A + O}{R \times f} = \dfrac{11\frac{1}{2} + \frac{1}{4} + \frac{1}{4}}{{\cdot}015 \times 287}$ = say, 2·8 minutes.

The alignment and intersection charts of figs. 2.7, 2.13 and 2.20 given on pp. 23, 29 and 39 should also be examined.

2. Economic Considerations.

In the example above no consideration has been given to economic considerations, nor has a comparison been made between the machining times for various combinations. Yet, in practice, this should be done.

Example 2.—Take a series of ·4 per cent C steel forgings, say B.H. No. 183, which are to be turned from the rough forging diameter of 4$\frac{1}{2}$ in. to 4·000–3·997 in. dia. in two stages. The operation schedule calls for rough-turning to 4·125–4·093 in. before heat treatment and finish-turning to the final diameter after heat treatment to a B.H. No. of, say, 190. The shape of the article is such that it can be firmly held and well supported during machining, whilst the length of the turned portion is 6 in.; the article does not require any special tools as a cut can be taken straight across the surface; a lubricant is to be used.

Type of Tool.—The combinations available are:

(*a*) Rough- and finish-turn with an h.s.s. tool.

(*b*) Rough- and finish-turn using a carbide-tipped tool.

(*c*) Rough-turn with an h.s.s. tool and finish with a carbide-tipped one.

Chip Size.—The combination here is to use a thick chip with the h.s.s. roughing tool, and a finer feed on finishing. The feed using the carbide-tipped tool would be fairly small.

Tool-shape.—As there are no machining difficulties, the tool giving the highest cutting speed is to be chosen for roughing, namely one having a $\frac{1}{4}$-in. radius and a 30° approach angle. The finishing tool is to have a $\frac{1}{4}$-in. radius.

Tool-life.—The work to be done is plain turning, giving easy tool-setting, hence the maximum tool-life can be quite low, say, 1$\frac{1}{2}$ hours.

Using h.s.s. Tools.—The suggested depth of cut for roughing is $\frac{3}{16}$ in. and a feed of ·040 in. giving a ratio of, say, 5 to 1. For finishing, the depth of cut is ·062 in., and the feed ·0156 in. A high-cobalt-steel tool is to be used. Grouping the data relative to the cuts, and bearing in mind that heat treatment will toughen the material, we have:

Factor	Table	Page	Roughing cut, 30° approach, 15° top rake, $\frac{1}{4}$-in. rad.	Finishing cut, $\frac{1}{4}$-in. rad., 15° top rake
V_b	40	110	90	246
M	60 or 67	121 or 153	·61	·59
L_u	25	94	1·40	1·16
T_l	21	85	·95	·96
T_s	40	110	1·0	1·0
T_m	26	96	1·12	1·12
C_r	40	110	1·0	1·0

Now $$V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_s \,.\, T_m \,.\, C_r.$$

For roughing $V_c = 90 \times {\cdot}61 \times 1{\cdot}4 \times {\cdot}95 \times 1{\cdot}0 \times 1{\cdot}12 \times 1 = 82$ f.p.m.

For finishing $V_c = 246 \times {\cdot}59 \times 1{\cdot}16 \times {\cdot}96 \times 1{\cdot}0 \times 1{\cdot}12 \times 1{\cdot}0$
$= 181$ f.p.m.

Then r.p.m. for roughing (from fig. 2.7) = 70,
and r.p.m. for finishing (from fig. 2.7) = 168.

$$\text{Cutting time} = \frac{L + A + O}{Rf}.$$

Taking the approach and over-run for roughing as ¾ in., and for finishing as ⅜ in., then time for rough cut

$$= \frac{6{\cdot}75}{70 \times {\cdot}040} = 2{\cdot}4 \text{ min.},$$

and for finish cut $$= \frac{6{\cdot}375}{168 \times {\cdot}0156} = \text{say, } 2{\cdot}44 \text{ min.}$$

Hence machining time only, for the two cuts is, say, 4·84 min.

Using Cemented-carbide Tools.—The suggested feeds are, for roughing ·020 in., finishing with ·0156 in. Grouping the data then:

Factor	Table	Page	Roughing cut, 30° approach, ⅛-in. nose-radius, 8° top rake.	Finishing cut, ⅛-in. nose-radius, 8° top rake
V_b	55	115	400	575
M	60 and 67	121 and 153	·61	·59
L_u	25	94	say, 1·25	1·16
T_l	21	85	·94	·95
T_s	55	115	1·0	1·0
T_m	55	115	1·0	1·0
C_r	55	115	1·0	1·0

$$V_c \text{ (roughing)} = 400 \times {\cdot}61 \times 1{\cdot}25 \times {\cdot}94 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0$$
$$= 287 \text{ f.p.m.}$$
$$V_c \text{ (finishing)} = 575 \times {\cdot}59 \times 1{\cdot}16 \times {\cdot}95 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0$$
$$= 374 \text{ f.p.m.}$$

Then r.p.m. for roughing (from fig. 2.7) is, say, 240,
for finishing, say, 350.

Then time for rough-turning $= \dfrac{6{\cdot}75}{240 \times {\cdot}020} =$ say, 1·4 min.,

and for finish-turning $= \dfrac{6{\cdot}375}{350 \times {\cdot}0156} =$ say, 1·18 min.

Hence machining time only, for the two cuts is, say, 2·58 min.

Simple inspection indicates that the third combination would not give a better time than that obtained by the use of the cemented carbides for both roughing and finishing.

As the use of the carbide-tipped tools indicates a saving in machining times of, say, 87 per cent, it would be better, if possible, to use them. The decision is, of course, made on the assumption that the power and a suitable machine are available.

3. Drilling.

The time taken to drill a hole depends upon the cutting speed and feed used. As the speed in r.p.m. must depend upon the design of the machine, it is imperative that a detailed examination of the latter is made before attempting to determine any cutting times. Then, assuming that full information is available, due allowance must be made for the distance the drill must travel before it commences to cut the full diameter. (See also p. 224.)

$$\text{Cutting speed in r.p.m.} = \frac{3{\cdot}82V_c}{d}.$$

$$\text{Drill travel per minute} = \text{feed} \times \text{r.p.m.}$$

Distance of drill travel before cutting full diameter

$$= {\cdot}5d \tan\left[90^\circ - \tfrac{1}{2}(\text{cutting angle})\right].$$

A series of times for drilling a hole 1 in. deep is given in the table below, but they do not take into account any setting, marking out, or jigging allowances.

TABLE 159.—TIME, IN MINUTES, TO DRILL A HOLE 1 IN. DEEP

Dia. of drill, in.	Cutting					
	M.S.	C.S.	C.I.	Brass	Ph. Br.	Aluminium
·25	·25	·37	·75	·12	·16	·12
·50	·3	·45	·9	·15	·2	·15
·75	·45	·7	1·4	·22	·3	·22
1·00	·5	·76	1·52	·25	·33	·25
1·25	·6	·9	1·8	·3	·4	·3
1·50	·66	1·0	2·0	·33	·44	·33
1·75	·75	1·12	2·25	·38	·51	·38
2·00	·84	1·24	2·5	·42	·57	·42

4. Tapping and Screwing.

When tapping and screwing on the machine, the time necessary to cut a thread with either taps or dies depends upon the chosen cutting speed, the number of threads per inch, the number of cuts or taps required to give the necessary finish and accuracy, and whether or not the cutting tool has to be run off the component. For hand-tapping the table below may be used. (See p. 334.)

TABLE 160.—TIME, IN MINUTES, TO HAND-TAP A B.S. WHITWORTH THREAD

Dia., in.	Depth of thread, in.				
	⅜	¾	1⅛	1½	2
¼	2·7	3·3			
5/16	2·8	3·7			
⅜	3·1	3·9	5·4		
½		4·4	6·0	7·3	
⅝		4·8	6·7	8·5	9·8
¾		5·4	7·5	9·5	10·6
⅞		6·1	8·5	10·6	11·6
1			9·0	11·5	12·0

5. Estimating for Grinding.

When estimating the production times for grinding, the general procedure is very similar to that adopted for turning and boring. To cover all the types of machine encountered in practice there cannot be any hard-and-fast ruling. Hence any estimate must be based upon a specific machine, and full details should be available in the form of a machine chart.

Wheel Speeds.—An important factor when grinding is the speed of the wheel, and this must be adjusted to maintain a free cutting-action. If the speed in f.p.m. is too high, the wheel will appear to be too hard and there will be overheating of the work; if it is too low, the wheel will appear soft and wear rapidly. In all cases of doubt it is wise to consult the wheel makers. The normal linear speeds for several types of grinding are:

Cylindrical external grinding	5500–6500 f.p.m.
Cylindrical internal grinding	2000–6000 f.p.m.
Surface grinding	4000–5000 f.p.m.
Cutting-off wheels	7000–16,000 f.p.m.

Work Speeds.—The work speeds for various types of grinding are listed below:

External cylindrical grinding	30–60 f.p.m.
Internal cylindrical grinding	80–120 f.p.m.
Surface grinding with a reciprocating table	25–50 f.p.m.
Surface grinding with a rotating table ..	15–50 f.p.m.

The above figures are subject to modification according to operating conditions. When rough-grinding, a fast table travel is favoured with a slow work speed; for finishing, a slower table travel and a higher work speed are chosen.

Feed for Cylindrical Work.—The feed (f) of the grinding wheel per revolution depends upon its width. In order that the wheel shall wear evenly, the feed should be between half and two-thirds the width with modifications to meet the operating conditions.

Table Traverse per Minute.—The table traverse per minute is often used in preference to the feed per revolution, and is equal to the feed per rev. multiplied by the r.p.m. of the work-piece.

Feed of Centreless Grinders.—When using a centreless grinder the feed per minute is governed by three variables—the size, speed, and angle of inclination of the control wheel. The size of the control wheel is usually 12 in. diameter; the speed for rough-grinding, say, 110 f.p.m., and for finishing, say, 75 f.p.m.; the angle of inclination is around 4° when roughing and $2\frac{1}{2}$° for finishing.

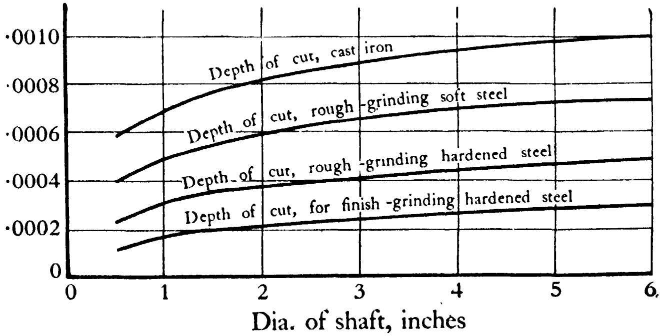


Fig. 12.1.—Depth of cut for cylindrical grinding

Depth of Cut.—At each reversal of the machine table the cut (d') should be adjusted so as to give an even distribution of the work over the whole width of the wheel. In general, the depth of cut or infeed (see fig. 12.1) per pass of the wheel lies between ·0002 and ·0015 in., the lighter cuts being chosen for finishing and the heavier for roughing.

Allowances for Grinding.—The allowances must be related to the size of the article and the manufacturing processes which have been done prior to grinding. In some instances the article is ground as the first operation from the foundry or forge. On the other hand, a wide range of articles are ground after machining and heat treatment. Dealing with the latter, the limiting sizes for final grinding must be related to:

(*a*) The finish given by the turning or boring operation.

(*b*) The possibility of any contraction caused by heat treatment.

(*c*) The possibility of distortion that cannot be rectified before attempting grinding.

(*d*) The accuracy demanded on the unground portion of the finished component.

When deciding the turning sizes for any job which has to be ground, the aim should be to avoid too close a machining limit, which would send up the machining costs unnecessarily; at the same time the chosen feed must not produce a very rough surface.

With any boring or reaming size, due attention must be paid to the possibility of shrinkage during heat treatment. Failure to do so leads to an excessive amount being left in the hole for grinding, and a reduced output per hour.

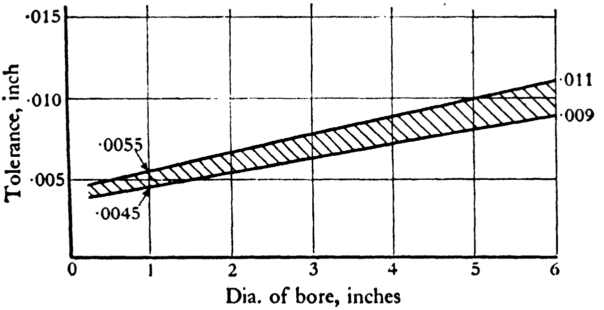


Fig. 12.2.—Tolerances minus limits on holes for fine work (compontent hard for grinding)

If the shape of the article is such that distortion takes place that cannot be rectified by a straightening operation, an additional amount must be left on the component.

Assuming that great accuracy as regards concentricity is demanded on the unground portion, the machining limits prior to grinding should be very fine, so that the grinding time is reasonable and the work is concentric. Suggestions for grinding allowances designed to meet the range of work normally encountered are given in the graphs in figs. 12.2 to 12.6.

The question of the heat treatment given to the steel must be carefully considered, for when case-hardening is involved too great a grinding allowance may result in the case being removed altogether, or only a very thin shell being left. Under such conditions trouble could be expected when the component is placed in service. For these reasons it is usual to restrict the grinding allowance on case-hardened work to between, say, ·010 and ·020 in. on the diameter, according to size.

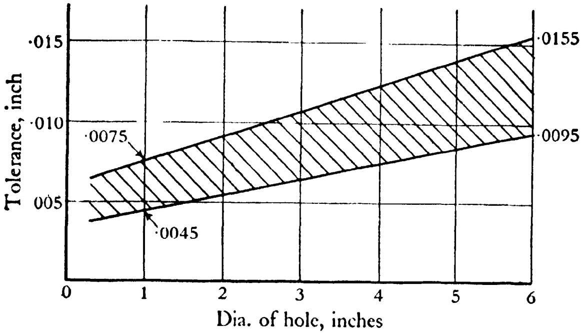


Fig. 12.3.—Tolerances minus limits on holes for average work (hard component)

When the component is left soft, or only heat-treated to bring about the most favourable structure throughout the mass, then a greater

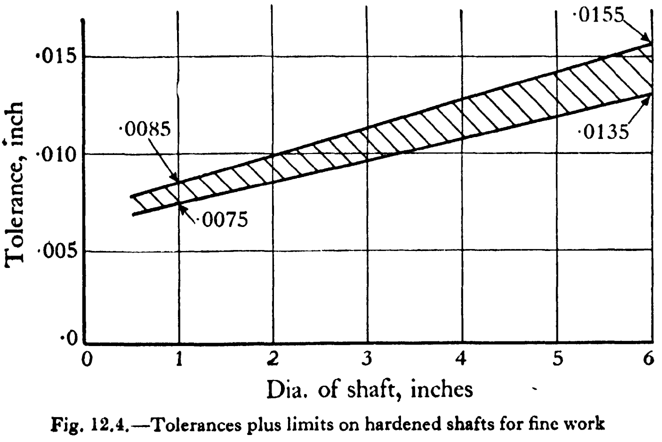


Fig. 12.4.—Tolerances plus limits on hardened shafts for fine work

amount can be left for grinding, and a wider tolerance granted (see fig. 12.6), as it is normally quicker to remove the surplus material and obtain the desired accuracy by grinding than to attempt machining to fine limits with a single-point tool.

Centreless Straight-through Grinding.—When using the straight-through feed method of centreless grinding for steel components, the maximum amount of metal removed per pass is around ·006 to ·007 in. A greater amount than this quickly breaks down the leading edges of the wheels, which then require frequent dressing with a diamond.

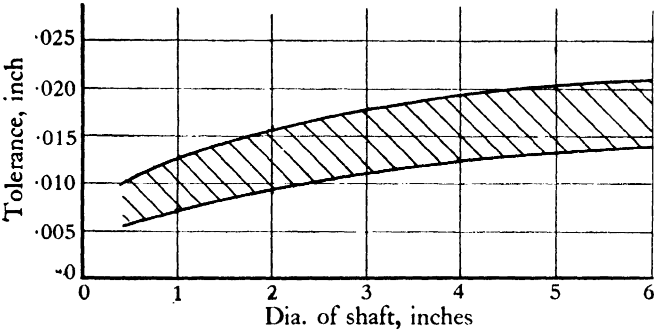


Fig. 12.5.—Tolerances plus limits on shafts for general work

Approach and Over-run.—When determining the length of stroke or travel of the wheel, it is necessary to take into account the distance by which the edge of the wheel must clear the work, as the approach and over-run have an important influence upon the grinding times. No pre-

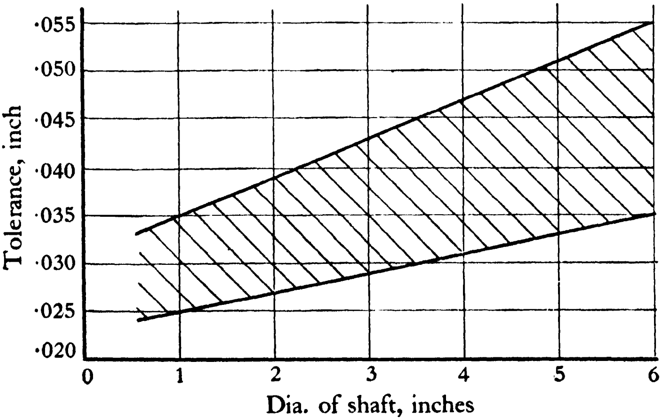


Fig. 12.6.—Grinding allowance on shafts, soft or heat-treated, when more economical to grind to size after rough-turning

cise ruling is possible as each set-up should be considered on its merits.

For cylindrical work, both internal and external, the wheel should never leave the component during the grinding operation. The over-run at each end should not exceed, say, one-third of the width of the wheels. Running clear of the work at each pass destroys the wheel face and may lead to a hole being bell-mouthed.

Incidental Times.—The total time to allow for any grinding job must make due provision for the various incidental stages in, or associated with, the complete working cycle. Thus the allowed grinding times will include provision for handling the work to and from the machine, gauging, reading the drawing, truing the wheel at periodic intervals during the day, and, when batch production is encountered, the time to break down one set-up and arrange the next.

Grinding Times.

The grinding time can be computed only when the operating conditions are known. For cylindrical grinding, the time equation is built up in the following manner:

Work speed, f.p.m. $V_c = \dfrac{\text{dia. of work} \times \pi \times \text{r.p.m.}}{12} = \cdot 262dR.$

Work speed, r.p.m. $= R = \dfrac{V_c \times 12}{\pi d} = \dfrac{3 \cdot 82 V_c}{d}.$

Axial feed per rev. of work $= f = xW$, where W is the width of the wheel, in inches, and x a ratio of up to ·67.

Table travel, f.p.m. $= F = \dfrac{fR}{12}.$

Cross feed or depth of cut $= d'.$

Number of Cuts.—When rough-grinding to size, the number of single passes of the wheel may be given by the expression:

$$N_r = \frac{\text{actual amount left for grinding} + C}{2\ (\text{cross feed or } d')} = \frac{A + C}{2d'}.$$

In the above expression a constant has been introduced to allow for any slight distortion on the work that may lead to a heavy cut coming suddenly upon the wheel and destroying its surface, and also to permit the wheel and work to make contact smoothly. The suggested values of C are given in graphical form in fig. 12.7 for different diameters and lengths.

For finish-grinding after a rough-grinding operation, or on rough-turned articles which have not been heat-treated, the above expression holds good, but the value of C is smaller as the risk of eccentricity should no longer exist.

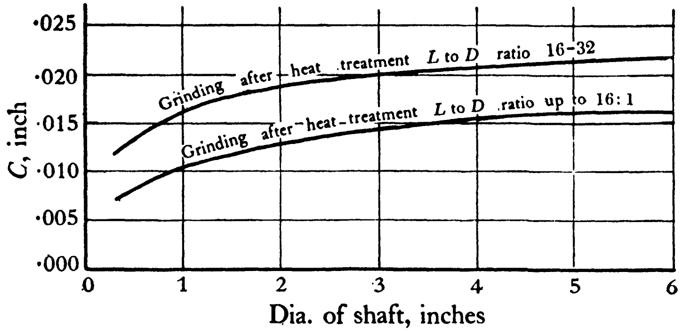


Fig. 12.7.—Value of grinding constant C for different work diameters

Assuming that the grinding operation is a composite one, rough- and finish-grinding being done at the same setting of the work-piece between the centres or in the chuck, it becomes essential to take into account the finer cross-feed or depth of cut used during the last stages. As the work is not removed from the centres, it is necessary to give the allowance for C only once. Thus:

For roughing $N_r = \dfrac{A_r + C}{2d'_r}$.

For finishing $N_f = \dfrac{A_f}{2d'_f}$.

And the total number of passes for composite grinding

$$= N = \frac{A_r + C}{2d'_r} + \frac{A_f}{2d'_f}.$$

$$\text{Grinding time (min.)} = \frac{LN}{F}.$$

If rough-grinding, $N = N_r$; if finish-grinding only, $N = N_f$.

Work travel per minute for centreless grinding,

$F = 3{\cdot}1416 D_{cw} R \sin \phi$.

D_{cw} = dia. of control wheel.

ϕ = angle of inclination of control wheel.

When thread grinding, form wheels are used and, so that the contour will not require dressing after each cut, the cross feed is fine. The table travel per revolution of the work-piece is governed by the pitch or lead of the thread and the speed of the component, which is reduced somewhat, e.g.

$$F = \frac{PR}{12},$$

where F = feed or travel of table per min., ft.,
P = pitch or lead of thread,
R = revolutions per min. of work-piece.

The remaining data are similar to those used when finish-grinding cylindrical work and need adjustment to suit the individual machine.

Example 3.—A c.h. steel shaft is to be ground, the diameter before heat treatment being held between 1·509 and 1·514 in. The final size is to be between 1·4982 and 1·497 in., with the ground length $11\frac{1}{2}$ in. The grinding wheel is known to be 2 in. wide. Estimate a grinding time to give a fine finish.

Length plus approach and over-run = $11\frac{1}{2}$ + say, $\frac{1}{2}$ = 12 in.
Feed of wheel = $f = xW = \cdot 67 \times 2 = 1{\cdot}34$.

If we assume a linear work-speed of 40 f.p.m. then the work speed in r.p.m. from fig. 2.7 = say, 100 r.p.m.

$$\text{Table travel (f.p.m.)} = F = \frac{1{\cdot}34 \times 100}{12} = 11{\cdot}2.$$

The value of C for rough-grinding a $1\frac{1}{2}$ in. shaft is given in fig. 12.7 as ·012 inch.

Actual amount left for grinding = A_r = 1·514 − 1·498 = ·016 in. max.
Amount for finish-grinding = A_f = say, ·004 in. on diameter.
Depth of roughing cuts for hardened steel = d'_r = say, ·00035 in.
Depth of finishing cuts for hardened steel = d'_f = say, ·0002 in.

Then
$$N_r = \frac{A_r + C}{2d'_r} = \frac{(\cdot 016 - \cdot 004) + \cdot 012}{2 \times \cdot 00035} = 34.$$

$$N_f = \frac{A_f}{2d'_f} = \frac{\cdot 004}{2 \times \cdot 0002} = 10.$$

Hence $N = 34 + 10 = 44$.

$$\text{Grinding time} = \frac{LN}{F} = \frac{1 \times 44}{11{\cdot}2} = \text{say, 4 minutes.}$$

Note L, the length of the component plus approach and over-run, is given in feet, i.e. in the same units as F.

To this figure must be added time for loading and unloading the machine, gauging, wheel truing, and other incidental factors.

6. Estimating for Shaping, Slotting and Planing.

The actual machining times depend upon the number of strokes made per minute; the length of the stroke, which must take into account the approach and over-run; the ratio of the cutting to the return stroke; the width of the component where it is also necessary to provide for the approach and over-run of the tool. In all cases the feed per stroke should be as coarse as possible consistent with a satisfactory surface-finish.

In practice the cutting speed varies considerably; at the commencement of the stroke it is zero, it reaches its maximum at the middle, and falls to zero at the finish. The time taken to reach the maximum cutting speed varies according to the class of drive. With a geared machine the increase is more gradual than when an hydraulic drive is fitted.

When determining the cutting times for a shaper or slotter the following expressions may be used:

$$\text{Tool travel (f.p.m.)} = T$$

$$= \frac{2 \times \text{number of strokes/min.} \times \text{length of stroke (in.)}}{12}$$

$$= \cdot 167NL.$$

Ratio of segment on driving gear for forward stroke $= x$.

Ratio of segment on driving gear for return stroke $= y$.

Now with the Whitworth quick-return motion the return segment on the large driving-gear is less than the forward segment, hence the cutting speed is lower than the speed with which the ram is returned.

Therefore the cutting speed $= V_c = \cdot 167yNL$.

Hence $N = \dfrac{V_c}{\cdot 167yL}$.

Then time for forward stroke (minutes) $= \dfrac{1}{N} \times x$.

Time for return stroke (minutes) $= \dfrac{1}{N} \times y$.

$$\text{Cutting time in minutes} = \frac{\text{width of article} + \text{approach} + \text{over-run}}{f \times N}$$

$$= \frac{\text{Table travel}}{fN}.$$

Example 4.—A number of cast-iron components $5\frac{1}{4}$ in. long and 4 in. wide with a B.H. No. of 177 are to be machined. The cutting is to be done with a single-point tool having a $\frac{1}{8}$-in. nose-radius, a 30° approach angle, and a life of one hour. It is proposed to machine the face in two cuts, one roughing, the other finishing; the first is to be $\frac{1}{8}$ in. deep and have a feed of ·031 in., the second cut will have a depth of ·06 in. and a feed of ·008 in. The proposed cutting speeds are to be based, if possible, on Table 87, which gives 69 and 130 f.p.m. respectively. The ratio of the forward to the return stroke for that particular machine and setting is known to be 3 to 2, whilst the strokes per minute as given by the machine capacity chart are 13, 16, 18, 23, 27, 50, 75 and 150 respectively.

Then:

The ratio of forward stroke = ·6.
The ratio of return stroke = ·4.
Length of stroke $= 5\frac{1}{4} + \frac{1}{2} + \frac{1}{4} = 6$ in.
Cross-movement of table $= 4 + \frac{1}{8} + \frac{1}{8} = 4\frac{1}{4}$ in.

From above, $N = \dfrac{V_c}{\cdot 167yL}$.

Hence for the proposed rough cut,

$$N = \frac{69}{\cdot 167 \times \cdot 4 \times 6} = 172 \text{ strokes per min.}$$

And for the final cut,

$$N = \frac{130}{\cdot 167 \times \cdot 4 \times 6} = 325 \text{ strokes per min.}$$

Cross-checking for the rough cut only:

$$\text{Time for the forward stroke} = \frac{1}{172} \times \cdot 6 = \cdot 00349 \text{ min.}$$

$$\text{Time for the return stroke} = \frac{1}{172} \times \cdot 4 = \cdot 00233 \text{ min.}$$

$$\text{Time for one complete stroke} = \cdot 00582 \text{ min.}$$

$$\text{No. of strokes per min.} = \frac{1}{\cdot 00582} = 172.$$

This confirms the general working.

Now, comparing the computed strokes per minute with those given on the machine capacity chart, it is at once observed that, for roughing, the top speed of the machine is fairly near, but for the final cut the machine cannot be run at the speed sufficiently high to give an estimated tool-life of one hour. In this direction it is necessary to bear in mind that the weight and reciprocating motion of the ram places very definite limits upon the speed in strokes per minute, if the working stresses of a shaper or slotter are to be held within safe limits, and the size of the parts to be reasonable when examined for the viewpoint of the general machine details. Indirectly, the few simple calculations above have demonstrated that under some conditions a shaper, slotter, or planer is a less efficient remover of surplus metal than a lathe. Moreover, it raises the question as to the value of using h.s.s. tools on the shaper or slotter when, at the slow cutting speeds, the plain carbon or low-alloy steels may be just as efficient.

Adjusting the cutting speeds for the component to suit the machine capacity, the final suggestions are to take the two cuts at the same speed of 75 strokes per minute and feed of ·031 in. The suggested speed is put forward to remove the possibility of vibration spoiling the surface finish. The tool for finishing is to have a flat to cover up the feed marks.

$$\text{Cutting time} = \frac{\text{Table travel}}{fN}.$$

Then for the 2 cuts at the same speed and feed,

$$\text{Actual machining time} = \frac{2 \times 4{\cdot}25}{{\cdot}031 \times 75} = 3{\cdot}66 \text{ or, say, } 4 \text{ min.}$$

7. Planing.

The operation of planing is identical with that of shaping, but the design of the machine differs greatly. On the old-type belt-driven machine usually there is only one cutting speed; some of the newer types have a gearbox giving two or more cutting and reverse speeds; the modern electric-driven planer has a number of cutting and reverse speeds. For accurate results each machine should be studied individually under the known shop conditions, but this is not always possible, and one has sometimes to work from the information given by the maker.

Example 5.—A planer has a cutting speed of 40 f.p.m. and a return speed of 100 f.p.m. A casting 3 ft. 9 in. long and 20 in. wide is to be machined, and two cuts are required, one roughing with a depth of $\frac{1}{8}$ in. and a feed of, say, ·04 in., the other finishing with a depth of ·05 in. and using a feed of ·01 in. Estimate the cutting times.

Length of stroke = Length of article + Approach + Over-run
= 3 ft. 9 in. + 2 in. + 1 in. = 4 ft.

Cross-feed = Width of component + Approach + Over-run
= $20 + \frac{1}{4} + \frac{1}{4} = 20\frac{1}{2}$ in.

Time for 1 cutting stroke $= \frac{4}{40} = \cdot 1$ min.

Time for return stroke $= \frac{4}{100} = \cdot 04$ min.

∴ Time for 1 complete stroke $= \cdot 14$ min.

Number of strokes, roughing $= \frac{\text{Travel}}{f} = \frac{20 \cdot 5}{\cdot 04} = 512 \cdot 5$.

Number of strokes, finishing $= \frac{20 \cdot 5}{\cdot 01} = 2050$.

Cutting time, roughing $= 512 \cdot 5 \times \cdot 14 = 72$ min.

Cutting time, finishing $= 2050 \times \cdot 14 = 287$ min.

∴ Total cutting time (estimated) $= 359$ min., say, 6 hours.

To the above times must be added those for setting, tool grinding, reading the drawings, obtaining the clamping equipment, and any other incidentals relevant to the job and shop.

Arising out of the estimated time for planing the bedplate come the questions: "Is it possible to use 2 roughing tools on the cross rail each travelling, say, 10½ in.? Could not the same surface finish be obtained by using coarser feeds with tools having a trailing flat to smooth down the feed marks?" Whether or not these suggestions are practical depends upon the power and feed mechanism of the machine. Providing that sufficient power is available and a suitable shaped tool used, the suggested feeds should be greatly increased and thus conform with modern practice. In this way the machining time may be drastically reduced.

CHAPTER XIII

Estimating Cutting Speeds

1. Estimating for Cutting Speeds for Milling and Gear-cutting Operations.

When estimating for a milling operation[27] the same general procedure is followed as for a turned article. In order to ascertain the cutting speed it becomes necessary to know the chip thickness per tooth, which may vary from ·001 to, say, ·032 in. The difference between the feed and chip thickness for a cylindrical cutter is shown in fig. 13.1, while fig. 13.2 gives it for a face-mill with and without an approach angle.

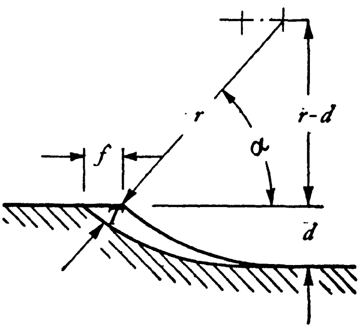


Fig. 13.1.— Difference between chip thickness and feed for a plain mill.

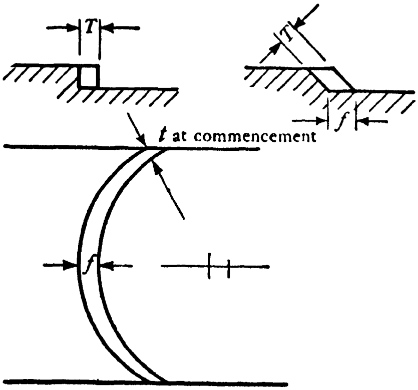


Fig. 13.2.— Difference between feed and chip thickness at beginning of cut using a face-mill. (*Above*: effect of approach angle.)

Whilst the chip thickness is used to determine the cutting speed, the feed per tooth is necessary to determine the time to machine a given article. As is to be expected, the chosen feed will be dependent upon the class of cutter, the rigidity of the machine, the material to be cut and the required surface-finish. When deciding upon the combination of cutting speed, feed, and depth of cut, due regard must be given to the chip thickness, and its effect upon the feed, for at all times there should be sufficient metal for each tooth to remove. Failure to provide this causes the cutter to slide over and work-harden the surface; this leads to high machining times, waste power, and unnecessary dulling of the cutting edges.

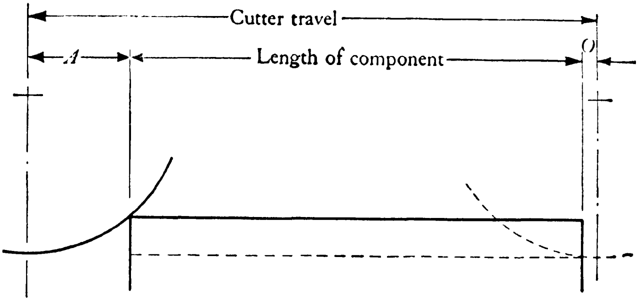


Fig. 13.3.—Approach and over-run for a plain cylindrical mill

Cutting Speeds and Operational Factor.

When computing the cutting speed for a milling operation the same general procedure as outlined for turning is followed. In many instances there is no need to use an operational factor from Table 27, although conditions may arise where it is prudent to do so. The circumstances as they exist within each concern largely determine the need for, and the value to assign to, an operational factor. Much will depend upon the rigidity of the machine and work-piece, the tool set-up and method of clamping, along with the h.p. input. In Examples 1 to 24 below no attempt has been made to relate the proposed cutting speeds and feed to suit the known characteristics of any machine.

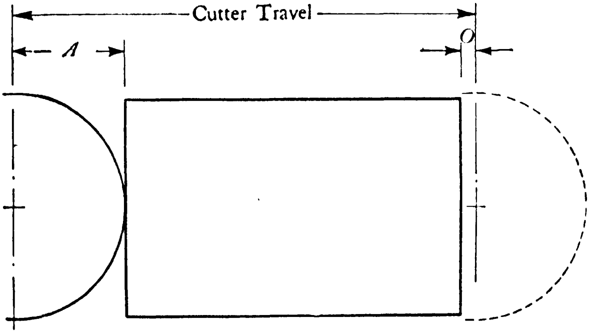


Fig. 13.4.—Approach and over-run for face-mill. Cutter and workpiece approx. the same size

Approach and Over-run.—The approach and over-run of a milling cutter are illustrated in figs. 13.3–13.6 for a plain cylindrical mill, also a facing cutter. The distances may be computed, scaled, or taken from Tables 182 and 183 on pp. 355–6.

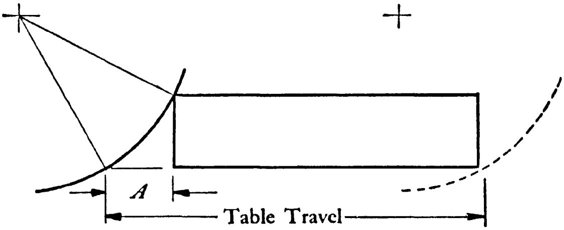


Fig. 13.5.—Approach and over-run for face-mill with work offset

Examples.—A number of examples planning the cutting speed and estimating the necessary machining times for various types of milling and kindred operations are given below. They cover face-milling and cylindrical milling, threadmilling, gear hobbing, and gear shaping.

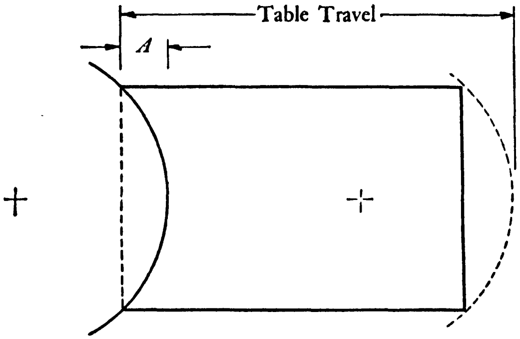


Fig. 13.6.—Approach and over-run for face-mill with larger diameter than width of component

Example 1.—A face-mill is to be used to machine a batch of 100 iron castings 6 in. wide and 24 in. long. The material has a Brinell number 180. $\frac{1}{8}$ in. is to be removed and the aim is to set a cutting speed which will enable the batch to be machined at one setting of the cutter.

Cutter Details.—Face-mill, 8 in. dia., 16 teeth, approach angle 30°, with a $\frac{1}{8}$-in. nose-radius and 10° rake; material, Stellite J.

Operating Details.—The cutting of cast iron will be done dry. The feed per tooth is taken at ·031 in. The approach from Table 183, p. 356, is 1·36 in. with an over-run of, say, ½ in. Maximum number of teeth engaged at any one moment, 5.

Tool-life.—The tentative calculations are:

Approx. angular contact of one tooth,

$$\Delta = 2\sin^{-1}\frac{w}{r}, \text{ where } r = \text{radius of cutter, } w = \tfrac{1}{2} \text{ width of work-piece with cutter central}$$

$$= 2\sin^{-1}\tfrac{3}{4} = \text{say, } 100^\circ.$$

Ratio of tooth engagement per rev. of cutter $= \frac{100}{360} = {\cdot}28$.

Assuming a tentative cutting speed of 75 f.p.m. the cutter makes, say, 36 r.p.m. Then, approximately,

$$\text{Cutting time per article} = \frac{L + A + O}{f \times N \times R} = \frac{24 + 1{\cdot}36 + {\cdot}5}{{\cdot}031 \times 16 \times 36}$$

$$= \text{say, } 1{\cdot}45 \text{ min.}$$

$$\text{Time for batch} = 1{\cdot}45 \times 100 = 145 \text{ min.}$$

$$\text{Cutting time per tooth} = 145 \times {\cdot}28 = \text{say, } 41 \text{ min.}$$

Hence the suggested tooth life is, say, 60 min.

Cutting Speed.—Assuming chip thickness equals feed and grouping the appropriate data from the various tables,

V_b (Table 94, p. 174) = 128.
M (fig. 9.1, p. 167) = ·94.
L_u (Table 25, p. 94) = 1·0.
T_l (Table 94, p. 174) = 1·0.
T_m (Table 94, p. 174) = 1·0.
T_s (Table 94, p. 174) = 1·0.
C_r (Table 98, p. 175) = ·93.

$$V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r$$

$$= 128 \times {\cdot}94 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 \times {\cdot}93 = \text{say, } 112 \text{ f.p.m.}$$

Machining Time.

$$\text{R.P.M. of cutter} = \frac{3{\cdot}82 V_c}{d} = \frac{3{\cdot}82 \times 112}{8} = \text{say, } 53.$$

$$\text{Then machining time per article} = \frac{24 + 1{\cdot}36 + {\cdot}5}{{\cdot}031 \times 16 \times 53} = \text{say, } 1 \text{ min.}$$

Checking Tool-life.

Total estimated cutting time = 1 × 100 = 100 min.

Cutting time per tooth for the batch = ·28 × 100 = 28 min.

But the estimated cutting speed of 112 f.p.m. was based upon a tool-life of 60 minutes, hence the speed could be slightly increased. Whether or not this should be done depends upon the details of the machine used. Minor adjustments are certain to be necessary.

Example 2.—A gang of cutters is to be used for milling a large number of annealed steel forgings in En 8 (B.H. No., say, 179) on the sides and top. The amount of metal to remove is $\frac{1}{8}$ in. on each face and down the sides to a depth of $\frac{3}{4}$ in. The articles are 4 in. long, 2 in. wide, and the proposal is to cut 5 at a time in a milling fixture.

With a set-up of this type the question of the most suitable material for the cutting edges of the side and face cutters and the cylindrical mill is of importance owing to the wide difference in the linear cutting speeds. Hence the suggestion below to use Stellite J for the side-mill and face-mill and the standard 18 . 4 . 1 h.s.s. cylindrical cutter.

Cutter Details.—For the sides it is proposed to use 6 in. dia. half-side and face-mills with the teeth set to give a rake of 10° and also a helix which has the opposite hand on the respective cutters, so as to neutralize the end thrust; 12 teeth are suggested, made from Stellite J. A 4-in. dia. slab-mill also having 12 teeth is suggested: rake 10°; helix 25° to 30° so as to lessen the shock as each tooth makes contact.

Operating Conditions.—The cutters and work are to be flooded with a sulphurized cutting compound. A feed per tooth of ·016 in. is desired for the straddle-mills; depth of cut $\frac{1}{8}$ in.; approach for the 6-in. mills (from Table 182) cutting down $\frac{3}{4}$ in. is, say, 2 in.

Tool-life.—The tentative calculations for the tool-life upon which the cutting speeds are based, are for cutters lasting a full 9-hour working shift.

Approximate angular contact made by each tooth on the side- and face-mills

$$= \cos^{-1} \frac{r - d}{r},$$

where d = depth of cut,

$$= \cos^{-1} \frac{2\frac{1}{4}}{3} = \text{say, } 41^\circ.$$

Ditto on the slab-mill $= \cos^{-1} \frac{1\frac{7}{8}}{2} = \text{say, } 20^\circ.$

Hence engagement factor per tooth on side- and face-mill

$$= \frac{41}{360} = \text{say, } \cdot 11.$$

Ditto for the cylindrical mill

$$= \frac{20}{360} = \text{say, } \cdot 05.$$

From these figures it becomes evident that the side- and face-mills are the governing factor for the resharpening period. Now assuming a tentative cutting speed of 100 f.p.m. for the Stellite-tipped side- and face-mills, the cutting time for each loading of the fixture is found roughly thus:

$$\text{R.P.M. of cutter} = \frac{3{\cdot}82V_c}{d} = \frac{3{\cdot}82 \times 100}{6} = 64.$$

$$\text{Cutting time} = \frac{L + A + O}{fNR} = \frac{20 + 2 + 1\frac{1}{2}}{{\cdot}016 \times 12 \times 64} = \text{say, 2 min.}$$

$$= \text{say, } {\cdot}4 \text{ min. each article.}$$

Note O also covers the gap between each component; for A see Table 182, p. 355.

Take loading and unloading, &c., at $2\frac{1}{2}$ min., then the actual cutting time of the mills is roughly:

$$\text{Daily cutting time of mills} = \frac{9 \times 2}{4\frac{1}{2}} = 4 \text{ hours.}$$

Hence cutting time per tooth on the face-mills = 4 × ·11 = ·44 hour. Therefore assume the cutting life of each tooth on the mill is ·5 hour.

Chip Dimensions.—In order to ascertain the cutting speed it is necessary to know the chip dimensions. From fig. 13.1, p. 270,

Chip thickness $= T = f \cos \alpha$.

Now $\sin \alpha = \dfrac{r - d}{r}$.

For straddle-mills, $\sin \alpha = \dfrac{3 - \frac{3}{4}}{3} = {\cdot}75$.

For slab-mills, $\sin \alpha = \dfrac{2 - \frac{1}{8}}{2} = {\cdot}9375$.

Hence for straddle-mills $\alpha = 48^\circ\ 36'$.
Hence for slab-mill $\alpha = 69^\circ\ 38'$.
T for straddle-mills $= {\cdot}016 \cos 48^\circ\ 36' = {\cdot}0106$ in.
T for slab-mill $= {\cdot}016 \cos 69^\circ\ 38' = {\cdot}0056$ in.

Now the length of chip at any one moment for the slab-mill depends upon the helix angle H of the cutter.

$$\therefore \text{Length of chip} = d \operatorname{cosec} H$$
$$= \tfrac{1}{8} \operatorname{cosec} 25^\circ = \text{say, } {\cdot}3.$$

Hence the chip dimensions upon which to base the speed are:

Straddle-mill: ·010 in. thick, ·125 in. long.

Slab-mill: ·0056 or, say, for estimating, ·006 in. thick, ·3 in. long.

Cutting Speed.—Gathering the associated data for the straddle-mills from the tables above:

V_b (Table 46, p. 112) = 200.
M (Table 60, p. 121) = ·62.
L_u (Table 25, p. 94) = 1·18.
T_l (Table 21, p. 85) = 1·13.
T_m (Table 46, p. 112) = 1·0.
T_s (Table 46, p. 112) = 1·0.
C_r (Table 22, p. 89) = ·93.

Then cutting speed for the side- and face- or straddle-mills

$$\begin{aligned} &= V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &\quad = 200 \times \cdot 62 \times 1\cdot 18 \times 1\cdot 13 \times 1 \times 1 \times \cdot 93 \\ &\quad = 154 \text{ f.p.m.} \end{aligned}$$

And in R.P.M. $= \dfrac{3\cdot 82 V_c}{6} = 96.$

The slab-mill having 96 r.p.m. makes the following linear speed:

Cutting speed of slab-mill $= \cdot 262 dR = \cdot 262 \times 4 \times 96 = 100$ f.p.m.

Comparing this with the computed speed, and ignoring the question of using an operational factor, we can group the data for the slab-mill thus:

V_b (Table 37, p. 108) = 198.
M (Table 60, p. 121) = ·62.
L_u (Table 25, p. 94) = 1·16.
T_l (Table 21, p. 85) = 1·07.
T_m (Table 37, p. 108) = 1·0.
T_s (Table 37, p. 108) = 1·0.
C_r (Table 22, p. 89) = ·93.

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= 198 \times \cdot 62 \times 1\cdot 16 \times 1\cdot 07 \times 1 \times 1 \times \cdot 93 = 142 \text{ f.p.m.} \end{aligned}$$

The check indicates that the slab-mill is to run far below the optimum computed speed but under the given conditions it will be difficult to obtain a better combination.

Cutting Time.—The cutting time for slab-milling is given by the expression:

$$\begin{array}{c}\text{Cutting}\\ \text{time}\end{array} = \frac{\text{length of work} + \text{approach} + \text{over-run}}{\text{feed per tooth} \times \text{number of teeth in cutter} \times \text{r.p.m. of cutter}}$$

$$= \frac{L + A + O}{fNR} = \frac{20 + 2 + 1\frac{1}{2}}{\cdot 016 \times 12 \times 95} = 1\cdot 285 \text{ min.}$$

There are 5 components in the fixture, hence time each = ·258 min.

To the above cutting time must be added the time required for loading, unloading, cleaning the fixture, gauging, personal conveniences, and other incidentals.

Checking.—Cutting time per cycle = 1·285 minutes. Taking the various incidentals at 2½ min. per cycle, then

Estimated cutting time per day for mills

$$= \frac{1\cdot285}{1\cdot285 + 2\cdot5} \times 9 = \text{say, } 3\tfrac{1}{2} \text{ hours.}$$

On this basis the estimated cutting time per day is ½ hour less than the tool-life was tentatively based upon, hence the cutting speeds of 154 f.p.m. for the side- and face-mills, with 100 f.p.m. for the slab-mill should meet the operating conditions.

Comments.—Commenting upon the above, it is essential to point out that no operational factor (Table 27, p. 98) has been used in these calculations, nor has the h.p. input or rigidity of the machine been considered. In practice this may be necessary; a trial will quickly give the necessary information.

Another point is that when planning milling schedules and designing gang cutters for long runs, the aim should be to have every cutter in the group working near to its optimum speed so that each needs resharpening at the same time. To achieve this end it is first necessary to make a detailed analysis of the operating conditions. Upon the results of such an investigation should be based the material for the cutting edges and the design of the cutter, e.g. the number of teeth and the helix angle.

2. Form Cutters and Hobs, &c.

When using form cutters, hobs, and similar tools on the milling machine, the cutting speed must be adjusted to suit the new operating conditions.

The factors which have to be taken into account are: (*a*) The section of the tooth may be such that there is very little metal behind the cutting edge to absorb the heat generated during the cutting action or to take care of shock. (*b*) The action of cutting may lead to the concentration of the load at one particular portion, and therefore give rise to excessive wear at that point. (*c*) To maintain a given form usually calls for cutters having no rake, and this gives rise to a higher temperature for a given chip size at the cutting edge. (*d*) The accuracy and surface finish called for is usually of the highest standard. (*e*) Owing to (*d*), abrasion on the cutting edge is more readily noted.

The combined effect is to demand a lower cutting speed, so that the desired tool-life may be achieved. To meet such contingencies the ordinary cutting speed may be chosen and then modified with suitable operational factors, some of which are listed in Table 27, p. 98; alternatively, use may be made of the cutting speeds as given in the various tables for forming operations. Naturally, when experience indicates that such cutting speeds can be increased or should be reduced, this should be done, and in order to relate the new cutting speed with the basic speed, a new operational factor should be introduced, or the one above altered.

3. Threadmilling.

Example 3.—A large number of forgings En 4 or S.A.E. 1030 having a B.H. No. of 148 are to be machined to 2·000 in. dia., 14 t.p.i., the depth of thread being ·046 in. Compute the cutting speed for the hob, and give the operating time.

The Cutter.—The proposed threadmilling hob is of the shell type, 1·40 in. dia., having 8 teeth; material 18 . 4 . 1 h.s.s.

Operating Conditions.—The work is to be held in a chuck with soft jaws. A feed of ·001 in. per tooth is suggested so as to give a good finish, and the cutter is expected to last a full 9-hour shift. The approach and over-run of the cutter are taken at ·115 in.

Then travel of cutter $= \pi D + A + O = (2 \times 3{\cdot}14) + {\cdot}115 =$ say, 6·4 in.

Note $D =$ dia. of thread.

The cutter will be flooded with a soluble cutting oil.

Tool-life.—With a cutter having 8 teeth each tooth is engaged approximately only one-eighth of the total cutting time. For purposes of determining the tool-life tentatively assume:

Cutting time per article = 3 min.
Then time each tooth is engaged = ·375 min. approx.
Total time including loading, unloading, gauging, &c. = 4 min.
Then output per day $= \dfrac{60 \times 9}{4} = 135$.

Hence daily cutting time per tooth $= {\cdot}375 \times 135 =$ say, 51 min. Then base cutting life on 1 hour.

Cutting Speed.—The operation of threadmilling may be likened to forming, hence the tool is given little or no rake. Checking for chip thickness, as a rough approximation which ignores the curvatures on the component, one may use the expression:

$$\sin \alpha = \frac{r - d}{r}, \text{ where } d = \text{depth of thread}, r = \text{radius of cutter},$$

$$= \frac{{\cdot}7 - {\cdot}046}{{\cdot}7} = {\cdot}93;$$

$$\therefore \quad \alpha = \text{say, } 69^\circ.$$

Now $T = f \cos \alpha = {\cdot}001 \cos 69^\circ = {\cdot}001 \times {\cdot}358 = {\cdot}000358.$

Checking Table 41, it will be noted that the thinnest chip is ·001 in., and, as abrasion is perhaps the most important factor in tool wear for this operation, the proposal is to base the speed upon a chip thickness of ·001 in. This, of course, raises a question as to the advisability of increasing the feed per tooth to ·003 and so bring the chip to ·001 in. thick. Surface finish would be the most important factor here. In practice, it should be tried out; for the purpose of the example, it is ignored.

Gathering the data together:

V_b (Table 41, p. 110) = 155.
M (Table 60, p. 119) = ·78.
L_u (Table 25, p. 94) = 1·16.
T_l (Table 41, p. 110) = 1·0.
T_m (Table 41, p. 110) = 1·0.
T_s (Table 41, p. 110) = 1·0.
C_r (Table 41, p. 110) = 1·0.

$$V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r$$
$$= 155 \times \cdot 78 \times 1\cdot 16 \times 1\cdot 0 \times 1\cdot 0 \times 1\cdot 0 \times 1\cdot 0 = 140 \text{ f.p.m.}$$

$$\text{R.P.M. of cutter} = \frac{3\cdot 82 V_c}{d} = \frac{3\cdot 82 \times 140}{1\cdot 4} = 382.$$

Hence number of cutting edges in action per minute = 382 × 8 = 3056.

Cutting Time.—The expression for cutting time is:

$$\text{Cutting time} = \frac{L + A + O}{fNR} = \frac{6\cdot 4}{\cdot 001 \times 382 \times 8} = \text{say, } 2\cdot 0 \text{ min.}$$

Loading time, &c., say, ·5 min.

Hence output per shift of one machine with due allowance for the various incidentals, say, 180.

Checking.—Cutting time, 2 min. per article, or ·25 min. per tooth per article.

Approx. time each tooth is cutting per shift = 180 × ·25 = 45 min.

But the tool-life was based upon cutting for an hour each shift, hence the suggested speed of 140 f.p.m. is safe.

Example 4.—Threadmilling a worm using a form-ground milling cutter. The details of the worm are 2·5 in. pitch dia., axial pitch ·625 in., depth of thread ·45 in., length 3·25 in., helix angle, say, $4\frac{1}{2}°$, material ·4 per cent C steel having a Brinell number 176.

Cutter Details.—A cylindrical form-ground cutter, $5\frac{1}{2}$ in. dia., having 15 teeth, no rake, and made from 18 . 4 . 1 h.s.s.

Operating Conditions.—When cutting steel a cutting liquid can be used, thus keeping the cutting edges cool. In order to get a good output, it is not sure whether a feed of ·002 or ·003 in. per tooth will prove more satisfactory from the viewpoints of surface finish and machining time. Hence a trial is suggested. Only one component can be held in the machine at a time.

Tool-life.—This class of cutter needs care when grinding, hence the proposal to adjust the cutting speed so that the cutter may last over two working shifts of 9 hours each. As the cutter has 15 teeth, a reasonable assumption is that each tooth will be engaged for $\frac{1}{15}$ of the total cutting time. The latter is estimated to be, say, 480 minutes per day. Hence,

$$\text{Cutting time per tooth per day} = \tfrac{480}{15} = 32 \text{ min.,}$$

and the suggestion is to base the tool-life on 30 minutes' cutting per day, or 60 minutes between each regrinding.

Cutting Speed.—This class of milling may be regarded in the same light as form turning. Hence Table 41, p. 110, may be used when computing the cutting speed. Alternatively one may use the finish-turning speed and bring in an operational factor, but this procedure is ignored here. Before the cutting speed can be calculated, it is necessary to determine the chip thickness.

Now $r = {\cdot}5$ cutter dia., $d =$ depth of thread on worm,

whilst $\sin\alpha = \dfrac{r-d}{r}$ and $T = f\cos\alpha$.

$$\therefore \sin\alpha = \frac{2\frac{3}{4} - {\cdot}45}{2\frac{3}{4}} = {\cdot}836. \text{ Hence } \alpha = 56^\circ\ 44'.$$

When $f = {\cdot}002,\ T = {\cdot}002 \times {\cdot}548 = {\cdot}001,$

and when $f = {\cdot}003,\ T = {\cdot}003 \times {\cdot}548 = {\cdot}0016.$

The cutting speed should be based on these chip thicknesses. Gathering the data from the various tables and interpolating where necessary, the values for V_b are respectively 155 and 115. Tabulating:

V_b (Table 41, p. 110) = 155, 115. T_m (Table 41, p. 110) = 1·0.
M (Table 60, p. 121) = say, ·63. T_s (Table 41, p. 110) = 1·0.
L_u (Table 25, p. 94) = 1·16. C_r (Table 41, p. 110) = 1·0.
T_l (Table 41, p. 110) = 1·0.

Now $V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r.$
For ·002 feed, $V_c = 113$ f.p.m. or 78 r.p.m.
For ·003 feed, $V_c = 84$ f.p.m. or 58 r.p.m.

Cutting Time.—When threadmilling, the approach of the cutter for a full-depth thread may be taken as equal to one pitch. When two or more cuts are taken, then the approach for the second and succeeding cuts is reduced. In order to take into account the helix angle H, the expression for the total length of thread to be cut reads:

$$\text{Total length of milling} = \frac{(L + A + O)}{\text{D}}\,\pi(\text{PD}) \sec H$$

$$= \left(\frac{L}{P_a} + 1\right) .\ \pi(\text{PD}) \sec H.$$

Travel of cutter per minute $= fNR$.

Cutting time $= \left(\frac{L}{P_a} + 1\right) \frac{\pi(\text{PD}) \sec H}{fNR}$.

Notation:

L = length of thread, P.D. = pitch dia.,
P_a = axial pitch, H = helix angle,
f = feed per tooth, N_c = number of teeth in cutter.

For ·002 feed, it is $\left(\frac{3{\cdot}25}{{\cdot}625} + 1\right) \frac{3{\cdot}14 \times 2{\cdot}5 \times 1{\cdot}003}{{\cdot}002 \times 15 \times 78}$ = say, 22 min.

For ·003 feed, it is $\left(\frac{3{\cdot}25}{{\cdot}625} + 1\right) \frac{3{\cdot}14 \times 2{\cdot}5 \times 1{\cdot}003}{{\cdot}003 \times 15 \times 58}$ = say, 20 min.

Estimated daily output (·002 feed), say, 21.

Estimated daily output (·003 feed), say, 23.

These estimated output figures (based on a 9-hour shift and 3 min. on each article for incidentals) indicate, as they were intended to, the possible advantage of using a slightly lower cutting speed, but a greater feed. Of course, the governing factor will be the surface finish required, but on the above basis the advantage lies with the slower speed and coarser feed.

Checking Tool-life.—The daily cutting time is:

For the ·002 feed, cutting time per day for the individual tooth

$$= \frac{22 \times 21}{15} = \text{say, 30 min.}$$

For the ·003 feed, it is $\frac{20 \times 23}{15}$ = say, 30 min.

The actual tool-life was based upon a two-day cutting, therefore the cutting speed from this angle appears satisfactory.

Example 5.—Cutting a gear 5 D.P., 24 teeth, 2 in. width, in steel to specification En 8, Brinell 186.

Cutter Details.—A standard-form, relieved, milling cutter, 3¾ in. dia. is to be used. It is assumed to have 8 teeth and be made in 18 . 4 . 1 h.s.s.

Operating Conditions.—Only one article is to be machined, hence the cutting is assumed to be done dry. The feed per tooth is taken at ·003 in., whilst the depth of tooth is given as ·45 in. The approach from Table 182, p. 355, is known to be 1¼ in.

Tool-life.—The cutting speed is to be based upon cutting one article only.

Approx. angular contact of each cutting tooth

$$= \sin^{-1}\left(\frac{1{\cdot}425}{1{\cdot}875}\right) = \text{say, } 49\tfrac{1}{2}^{\circ}.$$

Tooth engagement per rev. of cutter

$$= \frac{49\frac{1}{2}}{360} = \cdot 138.$$

Assuming that the cutting time will be 1½ hours, then the tooth is engaged for 1·5 × ·138, say, 12½ min. The suggestion is therefore to base the cutting speed upon a tool-life per tooth of 15 min., or a cutter life of 2 hours.

Cutting Speed.—This class of milling, as explained for Example 3, may be treated like form turning, hence the basic cutting speed may be taken from Table 41, p. 110. The chip thickness when calculated (see fig. 13.1) will be found to be roughly ·002 in., and the cutting speed is based upon this value. The value for M is obtained by interpolation. Grouping the data:

V_b (Table 41, p. 110) = 97.
M (Table 60, p. 120) = ·59.
L_u (Table 41, p. 110) = 1·0.
T_l (Table 21, p. 85) = 1·15.
T_m (Table 41, p. 110) = 1·0.
T_s (Table 41, p. 110) = 1·0.
C_r (Table 41, p. 110) = 1·0.

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= \text{say, 65 f.p.m. or 66 r.p.m.} \end{aligned}$$

Cutting Time.—The cutting time for the gear is given by the expression:

$$\begin{aligned} \text{Cutting time} &= \frac{N_g(L + A + O)}{fN_cR} \\ &= \frac{24 \times (2 + 1\frac{1}{4} + \frac{1}{4})}{\cdot 003 \times 8 \times 66} = 53 \text{ min.} \end{aligned}$$

Checking Tool-life.—The tool-life was based upon a two-hour run, hence the cutting speed should prove adequate. If circumstances require an operational factor, then this should be introduced.

The tools used on such machines as the Gleason Spiral Bevel Gear Machine or the Gleason Revacycle may be examined in the same manner, so that the best combination of cutting speed, feed per tooth, and tool-life for each class of materials is achieved.

Example 6.—Cutting a worm using a pinion-type cutter.

Details of the component are: tooth size 7 D.P., length 3¾ in., pitch dia. 1·2 5in., outside dia. 1·536 in., 2-start thread, material Ni-Cr steel En 39, annealed.

Cutter Details.—Pinion-type cutter having 30 teeth, and a 5° rake. The material is 18 . 4 . 1 h.s.s.

Operating Conditions.—The worm is mounted on the hob slide and the cutter on the normal work spindle of a gear hobber. A good flow of cutting oil is available.

Tool-life.—The cutter is expected to last for one shift of 9 hours and during this period to be cutting for, say, 7½ hours. Hence cutting time per tooth is:

$$\text{Daily cutting time per tooth} = \frac{7{\cdot}5 \times 60}{30} = \text{say, 15 min.}$$

Then the suggestion is to base the tool-life on a 20-minute run per tooth.

Cutting Speed.—Normally this class of machining is akin to form turning, as the aim is to give a fine feed which will ensure a long tool-life and accurate production. The feed of the cutter is parallel to the axis of the component; usually it is stated as a decimal fraction of an inch per revolution of the cutter itself. However, in order to ascertain the appropriate cutting speed the feed per tooth has to be known.

Then axial feed of cutter per rev. $= f_c = fN_c$,

where N_c = number of teeth in cutter.

Working on a basis of a feed per tooth of ·002 in., the feed per rev. of cutter becomes

$$f_c = {\cdot}002 \times 30 = {\cdot}060 \text{ in.}$$

The cutting action is rather a complex one, but for simplicity the chip thickness is assumed to equal the axial feed per tooth.

Gathering the data from the tables:

V_b (Table 41, p. 110) = 97.
T_s (Table 41, p. 110) = 1·0.
T_m (Table 41, p. 110) = 1·0.
L_u (Table 25, p. 94) = 1·16.
T_l (Table 21, p. 85) = say, 1·15.
M (Table 62, p. 143) = ·47.
C_r (Table 22, p. 89) = 1·01.

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= 97 \times {\cdot}47 \times 1{\cdot}16 \times 1{\cdot}15 \times 1{\cdot}0 \times 1{\cdot}01 = \text{say, 62 f.p.m.} \end{aligned}$$

With this process the work revolves at the cutting speed, whilst the tool is geared to rotate according to the number of starts in the worm, and teeth in the cutter.

$$R \text{ (for work)} = \frac{3{\cdot}82V_c}{d} = \frac{3{\cdot}82 \times 62}{1{\cdot}536} = \text{say, 155 r.p.m.}$$

Cutting Time.—When estimating the cutting time, it is essential to make allowance for the approach and over-run of the cutter. Moreover, the worm may be of the multistart type, and this must be taken into account when computing the cutting times. Hence, where S equals the number of starts, L the length of thread, and R the r.p.m. of the work-piece, the cutting time in terms of the feed per revolution of the cutter may be written:

$$\text{Cutting time} = \frac{(L + A + O)N_c}{f_c RS},$$

and substituting the above algebraic value of f_c,

$$\text{Cutting time} = \frac{(L + A + O)N_c}{fN_c RS} = \frac{(L + A + O)}{fRS}$$

$$= \frac{(3\frac{3}{4} + \frac{7}{8} + \frac{1}{8})}{\cdot 002 \times 155 \times 2} = 7{\cdot}6 \text{ min.}$$

Checking Tool-life.—Given a cutting time of 7·6 min., the daily output can be assumed to be 68 articles. On this basis the cutting time per tooth is:

$$\text{Cutting time per tooth} = \frac{68 \times 7{\cdot}6}{30} = 17 \text{ min.}$$

The cutting time is therefore slightly less than the figure upon which the cutting speed was based, hence the given combination of speed and feed should meet the needs of the case.

Example 7.—Cutting gears on a Fellows gear-shaper.

The details of thegears are: number of teeth 48, tooth size 6 D.P., face width 1 in., material cast iron of 177 Brinell, pitch dia. 8·00 in., tooth depth (T_d) ·375 in.

Cutter Details.—The pinion-type cutter has 24 teeth, pitch dia. 4·00 in., outside dia. 4·375 in., rake 5°, material 18 . 4 . 1 h.s.s.

Operating Conditions.—With cast iron the cutting is to be done dry. Three gears at a time will be mounted upon the work mandrel. Tool sharpening is to take place once each shift of 9 hours.

Tool-life.—On the assumption that the cutter will be operating for 7½ hours each shift, cutting time per tooth is:

$$\text{Cutting time per tooth} = \frac{7{\cdot}5 \times 60}{24} = \text{say, } 18 \text{ min.}$$

The suggestion is therefore to base the cutting speed upon a tool-life of 20 min.

Cutting Speed.—The problem here is to determine the chip thickness so that the appropriate basic cutting speed may be chosen from the tables above. When using a pinion type of cutter the feed per tooth is a complex one as there are two feed motions: (*a*) the radial or in-feed which takes the cutter to the desired depth; during this period the work-piece is stationary and the cutter has a reciprocating motion only. (*b*) The rotary feed motion; just before each stroke the cutter and work-piece are given, through a gear train, a slight rotation. With the in-feed the chip thickness is governed by a cam action and is known or can be readily obtained, hence no difficulty is experienced with this. The rotary feed depends upon (i) a gear train which may be adjusted to suit specific needs; (ii) the diameter of the cutter, for, as the number of strokes remain constant and the cutter diameter is increased, the rotary feed per stroke is increased; (iii) the pitch diameter of the work. The two usual ways of giving the rotary feed are:

(1) the number of strokes for one revolution of the cutter,
(2) the number of strokes per inch of the pitch diameter of the cutter.

Neither give the feed per tooth, hence

Rotary feed per tooth measuring on pitch circle [for (1) above]

$$= \frac{\pi(PD_c)}{N}. \qquad PD_c = \text{pitch dia. of cutter.}$$

Ditto for (2) above

$$= \frac{1}{\pi N}. \qquad N = \text{No. of strokes.}$$

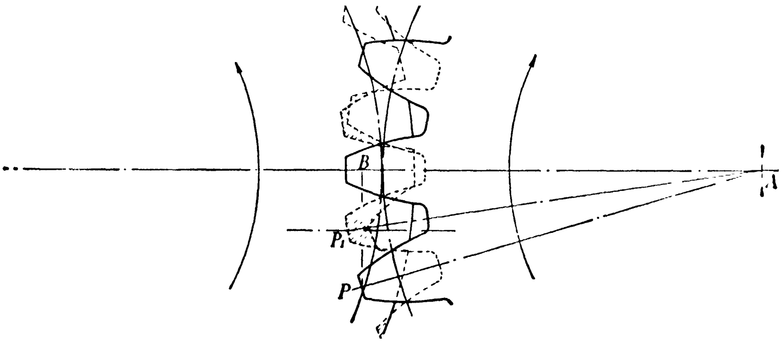


Fig. 13.7.—Showing chip thickness when gear shaping

As shown in fig. 13.7, the bulk of the work is done by the teeth on the entering side, and the shaded areas indicate the chips for varying positions of the cutter and work-piece as they revolve and the cutting teeth enter deeper into mesh. Analysing, for the above combination, the positions after the in-feed has been completed, the centre of the incoming tooth is at P and

$$AP = \cdot 5 \text{ O.S. dia.} = 2{\cdot}188,$$

whilst $$AB = AP \cos\left(\frac{360}{N}\right)^\circ = AP \cos\left(\frac{360}{24}\right)^\circ = AP \cos 15^\circ$$

$$= 2{\cdot}188 \times \cdot 96593 = 2{\cdot}113.$$

Now the proposition is to arrange the number of strokes per revolution of the pinion cutter so that the overlap of the cutting teeth in relation to the work-piece, measuring parallel to the line of centres, gives approximately the same chip thickness as that obtained by the radial in-feed. Assuming that the number of strokes per revolution of the cutter (S_c) is 955, the angular movement of the cutter is:

$$\text{Angular movement of cutter} = \frac{360}{955} = \text{say, } 0^\circ\ 23'.$$

Tabulating the varying positions of P, the information in Table 161 is obtained.

TABLE 161.—CHIP THICKNESS WITH PINION CUTTER AS TOOTH IS FORMED

No. of strokes after completion of in-feed	Angular movement of cutter (approx.)		Approx. average chip thickness measuring parallel to centre line
	Deg.	Min.	
1	0	23	·004
2	0	45	·004
3	1	8	·004
4	1	31	·003
5	1	53	·003
6	2	14	·003
7	2	38	·003
8	3	1	·002
9	3	24	·002

These figures indicate clearly how the chip thickness is steadily decreasing as the cutting tooth works towards the central position. Knowing from the above data that the chip thickness around the 7th to 8th stroke is approximately equal to that for the radial in-feed, it is suggested that the cutting speed be based upon a chip ·002 in. thick, and that the machine be set to give 955 strokes per revolution of the cutter, or 238·8 strokes per inch of cutter diameter. If a coarser feed is chosen, then the cutting speed would probably require adjustment.

Gathering the data from the various tables:

V_b (Table 89, p. 172) = 35.
T_s (Table 89) = 1·0.
T_m (Table 89) = 1·0.
L_u (Table 89) = 1·0.
T_l (Table 21, p. 85) = 1·15.
M (Table 106, p.179) = 1·0.
C_r (Table 22, p. 89) = $\frac{\cdot 95}{\cdot 93}$ = 1·01.

$$V_c = V_b \cdot M \cdot L_u \cdot T_l \cdot T_m \cdot T_s \cdot C_r$$
$$= \text{say, } 41 \text{ f.p.m.}$$

Cutting Time.—Knowing the cutting speed, it is necessary to determine the strokes per minute before the estimated cutting time can be computed. The position is very similar to that for shaping, as the cutting speed at the two extremities of the stroke is zero, being at the maximum at the centre. When determining the strokes per minute it is necessary to take into account the idle or return portion. A equals the approach for in-feed, say, ·010 in. on cutting stroke $\frac{3}{32}$ in. $A = O$. Now

Distance travelled per complete stroke $= 2(L + A + O)$.

$$\text{Then strokes per minute} = S = \frac{V_c \times 12}{2(L + A + O)}$$

$$= \frac{41 \times 12}{2(3 + \frac{3}{32} + \frac{3}{32})} = \text{say, } 77.$$

Movement of cutter around pitch diameter per stroke

$$= \frac{\pi(\text{PD}_c)}{S_c} = \frac{3{\cdot}1416 \times 4}{955} = {\cdot}0132 \text{ in.}$$

Cutting time = in-feed cutting + rotary cutting.

$$\therefore \text{ In-feed cutting time} = \frac{T_d + A}{fS} = \frac{{\cdot}375 + {\cdot}010}{{\cdot}002 \times 77} = 2{\cdot}5 \text{ min.}$$

$$\text{Cutting time for rotary feed} = \frac{\pi(\text{PD}_g)}{\text{Rotary feed in in.} \times S} \text{ or } \frac{S_c(\text{PD}_g)}{S(\text{PD}_c)}$$

$$= \frac{955 \times 8}{77 \times 4} = 24{\cdot}8 \text{ min.}$$

Then total time for one cut (3 gears) $= 2{\cdot}5 + 24{\cdot}8 = 27{\cdot}3$ min.

Checking for Tool-life.—Assuming the number of set-ups per day is 18, then the total cutting time is 18 × 27·3, say 491 min., which is slightly in excess of the time upon which the tool-life was based. A trial will indicate if the cutting speed is too high.

General Remarks.

The number of strokes the cutter makes per revolution have also a marked effect upon the resultant surface finish. For smooth running of any gear it is desirable that the facets left by the cutting tool shall be very short and shallow so that each cut blends in to form a good involute curve. The position is that the functional requirements of gears, and to some extent the tool-life, favour a fine rotary feed. Hence arises the question as to the advisability of first roughing with a coarse feed and finishing the second cut with a finer one. It is necessary to strike a mean between the inspection demands and the need for economic production. The tendency is to use a fine feed, that is a high number of strokes per revolution of the cutter, and complete each gear, if possible, with one cut.

Strokes per Tooth Formed.

In order to have an idea of the surface finish of the tooth profile the cutting action may be analysed in the following manner. It involves computing the number of strokes made from the entry of a cutting tooth into the gear blank until the time it breaks engagement. This rough analysis is useful when the finish has to be decided for gears which are to be shaved after the main cutting process.

For the present example the centre distance $= \dfrac{4 + 8}{2} = 6.$

Outside diameters of cutting pinion and work-piece are respectively 4·375 and 8·333 in.

Using the cosine formula, the angle PAB (fig. 13.7) may be proved to be approximately 26° for a cutter 6 D.P. having 24 teeth, and a gear with 48. The cutter makes 955 strokes per revolution.

Hence strokes per tooth formation

$$= 955 \times \frac{2 \times 26}{360} = \text{say, } 138.$$

Approx. length of tooth flank and face of a 6 D.P. tooth ignoring curvature

$$= \frac{2 \sec 20}{\text{D.P.}} = \frac{2 \times 1{\cdot}064}{6} = {\cdot}355.$$

Therefore approx. length of facet

$$= \frac{{\cdot}355}{138} = {\cdot}0025 \text{ in.}$$

Assuming a shaving operation is to follow, the question of whether or not the number of strokes per revolution of the cutter should not be adjusted warrants serious consideration.

Other Gear-shaping and Planing Machines.

With other gear-shaping, hobbing, and planing machines such as the Parkinson, Gleason or Pfauter the conditions relating to the actual cutting operation should be examined to ensure that the best combination of speed, feed per stroke, and tool-life is achieved consistent with a satisfactory surface-finish.

Example 8.—Hobbing spur gears.

A pinion with 14 teeth, tooth size 2 D.P., tooth form corrected, face width 4½ in., material case-hardening steel En 32 as sent from forge, is to be cut on a gear hobber.

Hob Details.—The standard outside diameter is 5¾ in., length 8 in.; the design gives a single-start hob with 9 gashes milled around the perimeter to form the cutting teeth, no rake is placed on the cutting face; material 18 . 4 . 1 h.s.s.

Operating Conditions.—A good flow of suds is to be used; the design of the pinion permits two components being mounted upon the work mandrel.

Tool-life.—Assuming that the hob is cutting for 8 hours during a 9-hour shift, the cutting time for the tooth section engaged may be taken as one hour. The length of the hob is such that it is feasible to assume that 3 sections will be available, hence the hob, on this basis, will last for 3 days between each regrinding.

Cutting Speed.—Knowing the operating conditions along with full information as to the material to be cut, leaves only the chip thickness to be decided before commencing to compute the cutting speed. Now hobbing is very similar to form milling, hence the suggestion to base the cutting speed upon the chip thickness as given by the axial feed.

As shown in fig. 13.1, p. 270, the feed does not always represent the chip thickness, and here

$$\text{Chip thickness} = f \cos \alpha.$$

Hence $$f = \text{chip thickness} \times \sec \alpha.$$

Hence, on the assumption that a chip of ·003 in. is desired,

$$\begin{aligned} f &= {\cdot}003 \sec 40^\circ \text{ (say)} \\ &= {\cdot}003 \times 1{\cdot}305 = {\cdot}00392 \text{ in.} \end{aligned}$$

Grouping the data together from the various tables:

V_b (Table 41, p. 110)	= 75.	M (Table 62, p. 142)	= 1·0.
L_u (Table 25, p. 85)	= 1·16.	T_l (Table 41, p. 110)	= 1·0
T_m (Table 41)	= 1·0.	T_s (Table 41)	= 1·0.
C_r (Table 41)	= 1·0.		

Now $$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= 87 \text{ f.p.m. or } 58 \text{ r.p.m.} \end{aligned}$$

Cutting Time.—As with all machining operations, due attention is needed so that the approach and over-run of the hob features in the estimate. If the slight influence of the helix angle on the single-start hob be ignored, the same expression as is used for plain milling may be adopted. Then

$$A = \sqrt{{\cdot}5d^2 - ({\cdot}5d - T_d)^2}.$$

Alternatively Table 182, p. 355, may be used, and A then is, say, $2\frac{3}{16}$ in.

Example 5 (p. 282) gives the time required to mill the teeth on a gear blank using a formed relieved cutter by the expression:

$$\text{Cutting time} \quad \frac{N_g(L + A + O)}{fN_cR}.$$

However, when hobbing, the cutting time is often expressed in the following manner:

$$\text{Cutting time} = \frac{N_g(L + A + O)}{FRS}.$$

Here F is equal to the feed per revolution of the cutter whilst S is the number of starts on the hob. Hence the need to relate the expression based upon the feed per revolution of the cutter to that made by the individual tooth.

Spur gears are always finished with a single-start hob, hence under such conditions the symbol S may be omitted from the standard formula, which then reads:

$$\text{Cutting time} = \frac{N_g(L + A + O)}{FR}.$$

Examining a single-start hob set at the correct depth in the workpiece for cutting the required tooth thickness, it will be observed that the teeth which lie either side of a perpendicular line off the hob axis and passing through the centre of the gear blank, give the required size to the tooth, measuring at the pitch line. Moreover, the teeth are confined to a distance equal to half a pitch on either side of the perpendicular line, that is over a distance equal to one axial pitch.

But the number of tooth gashes around the hob perimeter

= number of teeth on hob over the axial distance of 1 pitch

= N_c.

Feed per tooth $= f$.

Then feed per revolution of hob $= F = fN_c$.

Substituting the value of F in the above equation,

$$\text{Cutting time for a single-start hob} = \frac{N_g(L + A + O)}{fN_cR}.$$

This is identical with the expression for cutting with a form-relieved cutter.

When cutting spur gears multi-start hobs are only used for the roughing stages, because for a given tooth size and hob diameter an increase in the number of starts gives a greater helix angle, and this affects the accuracy of the tooth profile. Moreover, the greater helix angle alters the spacing of the teeth on each start when working off the hob axis. The effect is such that the sizing of the gear teeth is controlled by the cutting teeth on each of the starts or threads lying within the active portion of the hob. They do not all lie on the same helix as is the case when using a hob with a single start.

When an examination is made of the profile of the teeth on a multi-start hob meshing at the correct distance with a gear blank, it is at once observed that the cutting action is similar to that experienced with the hob having a single start, the zone of effective cutting being covered by the axial distance of one pitch. From above:

Number of tooth gashes around the single-start hob perimeter
= number of cutting teeth on the individual thread covered by the lead
= N_c.

Hence the number of cutting teeth on the perimeter of the multi-start hob covered by the axial distance of the lead of the thread

= number of teeth on each thread × number of starts,
= N_cS,

and lead = axial pitch × number of starts.

From above it is known that the effective cutting is done by the teeth lying within one axial pitch. Hence the number of teeth upon which to base the cutting per revolution of the hob becomes

$$\text{Teeth cutting per rev. of hob} = \frac{N_cS}{S} \text{ or } N_c.$$

With a feed per tooth equal to f,

$$\text{Feed per rev. of a multi-start hob} = fN_c.$$

This is identical with the formula already given for a single-start hob. Hence the general expression for the cutting time when hobbing gears, if based upon the feed per individual tooth, is the same for either a single- or multi-start hob.

Using the above general expression:

$$\text{Cutting time} = \frac{N_g(L + A + O)}{fN_cR}$$

$$= \frac{14(4{\cdot}5 \times 2 + 2\tfrac{3}{16} + \tfrac{1}{16})}{{\cdot}00392 \times 9 \times 58} = 77 \text{ min.}$$

Hence each pinion requires 38·5 min. for cutting the teeth. With this set-up it is assumed that the surface finish will meet the inspection requirements, otherwise a roughing and finishing cut may become necessary.

Checking Tool-life.—With a cutting time of 38·5 min. each, the number of components produced each shift would be, say, 12. Hence,

Total cutting time per shift = 38·5 × 12 = 462 min.

This is very close to the figure upon which the cutting speed was based.

Serrated and Spline Shafts.

The above formula is also applicable when hobbing spline or serrated shafts.

Example 9.—Hobbing helical gears.

A gear has 64 teeth, 3 D.P., outside dia. 22 in., pitch dia. 21·333 in., face width 3¼ in., tooth depth ·73 in., and a helix angle of 20°. The material is En 8 steel, Brinell 186.

Cutter Details.—The o/s. dia. of the hob is known to be 5 in., its length 7 in., and 8 gashes are cut around the perimeter for the teeth; material 18 . 4 . 1 h.s.s. single start.

Operating Condition.—The desire is to have a very good finish, hence the suggestion is to take two cuts with the same hob and at the same setting of the work-piece, one to rough out the tooth space, and the other to clean up the form. As the material is steel a good flow of a sulphurized cutting liquid will be used.

The next point is to determine the feed; for roughing, no difficulty arises, as there will be ample metal to remove; with the finishing cut it is essential that care be taken to ensure that each tooth has enough metal under it to avoid slipping over the surface, and at the same time produce a well-machined face. Using fig. 13.1, p. 270,

$$f = T \sec \alpha,$$

and when the angle α equals, say, 70°, the feed is 3 times the chip thickness and steadily becomes greater as the angle moves towards 90°. Hence if a chip ·001 in. thick is desired for the final cut with a feed of ·003 in. per tooth, the amount to leave at the bottom becomes:

$$\text{Amount left in at the bottom of tooth} = {\cdot}5d - {\cdot}5d \sin 70^\circ$$

$$= 2{\cdot}5 - 2{\cdot}5 \times {\cdot}940 = {\cdot}15 \text{ in.}$$

$$\text{Then sine of angle } \alpha \text{ for roughing} = \frac{2{\cdot}5 - ({\cdot}73 - {\cdot}15)}{2{\cdot}5} = \frac{1{\cdot}92}{2{\cdot}5} = {\cdot}77.$$

$$\text{Angle } \alpha = \text{say, } 50^\circ\, 24',$$

$$\therefore \sec 50^\circ\, 24' = 1{\cdot}5689.$$

Hence if a chip of ·003 in. is assumed for roughing, the feed is:

$$f \text{ for roughing} = {\cdot}003 \sec 50^\circ\, 24' = {\cdot}003 \times 1{\cdot}5689 = {\cdot}0047 \text{ in.}$$

The tool-life per tooth is assumed to be ½ hour; one section of the hob is to be used for roughing, the other for the finish cut.

Gathering the data from the respective tables:

V_b (Table 41, p. 110) = 155 and 75.
L_u (Table 25, p. 85) = 1·16.
T_m (Table 41, p. 110) = 1·0.
T_s (Table 41) = 1·0.
M (Table 60, p. 121) = ·58.
T_l (Table 21, p. 85) = 1·07.
C_r (Table 41, p. 110) = 1·0.

Now $V_c = V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r.$

$$\begin{aligned}\text{For roughing } V_c &= 75 \times \cdot 58 \times 1{\cdot}16 \times 1{\cdot}07 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0\\ &= 54 \text{ f.p.m.}\\ \text{For finishing } V_c &= 155 \times \cdot 58 \times 1{\cdot}16 \times 1{\cdot}07 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0\\ &= 112 \text{ f.p.m.}\\ R \text{ for finishing} &= \frac{3{\cdot}82V_c}{d} = \frac{3{\cdot}82 \times 112}{5} = 86 \text{ r.p.m.}\\ R \text{ for roughing} &= \frac{3{\cdot}82 \times 54}{5} = \text{say, } 41 \text{ r.p.m.}\end{aligned}$$

Cutting Times.—The question of the approach is important because of the helix on the teeth which increases the distance the hob has to travel before fully engaging the component. It is difficult to compute the approach or to use graphical methods. Accurate data are best obtained by checking an actual set-up. As a safe figure the values listed in Table 182, p. 355, may be used and multiplied by the constant 1·4 or the value of the approach calculated from

$$A = 1{\cdot}4\sqrt{\cdot 5d^2 - (\cdot 5d - T_d)^2}.$$

When taking the finishing cut the same general remarks apply. Then

$$\begin{aligned}A \text{ for roughing} &= 1{\cdot}4 \times 1{\cdot}15 = \text{say, } 1{\cdot}61 \text{ in.}\\ A \text{ for finishing} &= 1{\cdot}4 \times \cdot 66 = \cdot 93 \text{ in.}\end{aligned}$$

With the teeth being in the form of a helix it is necessary to adjust the expression used for spur gears to give effect to the longer tooth. For a helical gear:

$$\text{Tooth length} = L \sec H,$$

where L = face length parallel to axis, H = helix angle.

$$\text{Now} \quad \text{Cutting time} = \frac{N_g(L \sec H + A + O)}{fN_cR},$$

$$\begin{aligned}\text{Cutting time roughing} &= \frac{64(3{\cdot}25 \sec 20^\circ + 1{\cdot}61 + \cdot 15)}{\cdot 0047 \times 8 \times 41}\\ &= \frac{64(3{\cdot}25 \times 1{\cdot}06 + 1{\cdot}76)}{\cdot 0047 \times 8 \times 41} = \frac{332}{1{\cdot}54} = \text{say, } 216 \text{ min.,}\end{aligned}$$

Cutting time for finishing

$$= \frac{64(3{\cdot}25 \times 1{\cdot}06 + \cdot 93 + \cdot 15)}{\cdot 003 \times 8 \times 86} = \frac{290}{2{\cdot}06} = 140 \text{ min.}$$

Checking the Tool-life.—The roughing cut takes 216 min., hence with 8 teeth around the perimeter the life for each becomes, say, 30 min., whilst the tool-life for the teeth engaged finishing is, say, 20 min. These figures agree very well with those upon which the tool-life was based.

Example 10.—Hobbing a coarse-pitch worm, outside dia. 4·00 in., pitch dia. 3·125 in., pitch 1·375 in., tooth depth 985 in., length $5\frac{1}{2}$ in., 4 starts, helix angles, say, 29° 15′, material Ni-Cr En 39 steel annealed.

Cutter Details.—Similar to Example 9.

Operating Conditions.—Also similar to Example 9.

Cutting Speed.—The cutting speed is to be based upon a chip thickness of ·002 in.

From fig. 13.1, $\sin \alpha = \dfrac{2{\cdot}5 - {\cdot}985}{2{\cdot}5} = {\cdot}606.$

Hence $\alpha =$ say, 37°.

$$\therefore f = {\cdot}002 \sec 37^\circ = {\cdot}002 \times 1{\cdot}25 = {\cdot}0025 \text{ in.}$$

Gathering the data:

V_b (Table 41, p. 110) = 97.
L_u (Table 25, p. 94) = 1·16.
T_m (Table 41) = 1·0.
C_r (Table 41) = 1·0.
M (Table 62, p. 143) = ·47.
T_l (Table 41) = 1·0.
T_s (Table 41) = 1·0.

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_l \,.\, T_m \,.\, T_s \,.\, C_r \\ &= 53 \text{ f.p.m. or } 41 \text{ r.p.m.} \end{aligned}$$

Cutting Time.—This is identical with the expression for cutting helical gears.

$$\begin{aligned} \text{Cutting time} &= \frac{N_g(L \sec H + A + O)}{fN_cR} \\ &= \frac{4(5{\cdot}5 \sec 29^\circ\, 15' + 1{\cdot}4 \times 1{\cdot}22 + \frac{1}{8})}{{\cdot}0025 \times 8 \times 41} \\ &= \frac{4(6{\cdot}32 + 1{\cdot}71 + {\cdot}125)}{{\cdot}02 \times 41} = 41 \text{ min.} \end{aligned}$$

Checking Tool-life.—Assuming that 10 worms are cut per shift, then the total cutting time is just under the figure upon which the cutting speed was based.

Comments.—With a cutting time of 41 min. each it would be worth while checking the possibility of using a coarser feed and using an h.s.s. tool having, say, 3 to 5 per cent vanadium.

Grinding Allowance.

After hobbing many worms are case-hardened and ground. The general allowance on the surface may be based upon the following:

Tooth designation	Allowance, in.
12 to 7	·0025
6	·0035
5	·005
4	·006
3½	·0075
3 to 2½	·01
2¼ to 2	·012

In all instances the grinding allowance should be viewed in the light of possible distortion, the permissible depth of the case, and the surface finish of the hobbing process. Care should be exercised so that the hard abrasive-resisting surface is not made too thin or entirely removed whilst grinding.

Example 11.—Hobbing a wormwheel using the in-feed method of cutting.

Details of the wheel are: 110 teeth of 1 in. pitch mating with a single-start worm of 4 in. dia.; the material cast iron of Brinell 184.

Cutter Details.—The general dimensions of the hob are identical with those for the worm excepting that provision is made for the necessary clearance. Its length is 7 in.; there are 9 gashes for teeth around the perimeter and the material is 18 . 4 . 1 h.s.s.

Operating Conditions.—The gear material is cast iron, hence no liquid coolant will be used. The radial in-feed method is to be adopted, and only one component can be mounted on the work mandrel at a time.

Cutting Speed.—A chip thickness of ·002 in. is decided upon, and with this particular set-up the chip thickness is equal to the radial in-feed per tooth. A rough check on the hob indicates that the hob life may be based on two cutting positions. Assuming that each is to last a day of 8 hours actual machining, then the cutting period for each tooth is:

$$\text{Cutting time for tooth} = \tfrac{8}{9} = 53 \text{ min., say, 1 hour.}$$

Gathering the data from the tables:

V_b (Table 89, p. 172) = 35.
M (fig. 9.1, p. 167) = ·92.
L_u (Table 89) = 1·0.
T_l (Table 89) = 1·0.
T_m (Table 89) = 1·0.
T_s (Table 89) = 1·0.
C_r (Table 89) = 1·0.

$$V_c = V_b \cdot M \cdot L_u \cdot T_l \cdot T_m \cdot T_s \cdot C_r$$
$$= 32 \text{ f.p.m. or } 30 \text{ r.p.m.}$$

Cutting Time.—When cutting a wormwheel using the radial in-feed, the general expression for the cutting time is:

$$\text{Cutting time} = \frac{T_r N_g}{FRS},$$

where T_r = the radial travel of the hob (this may be scaled from a drawing), N_g = number of teeth on the wheel, F = feed per rev. of the hob, S = number of starts on the hob.

The drawback of this expression is that it does not give the feed per tooth cutting, hence in its present form it is unsuitable for use with the various tables. However, before the formula may be rewritten it is necessary to know something of the cutting action and the effect of a multi-start hob. This has been briefly touched upon for spur gears, and when hobbing wormwheels it will be found that the same general conditions exist, i.e. the zone of effective cutting on any hob is spread over the teeth lying within one axial pitch. Then, using the same station as above:

$$\text{Teeth cutting per rev. of hob} = \frac{N_c S}{S} = N_c.$$

With the feed per individual tooth equal to f,

Feed per rev. of hob $= fN_c$.

Rewriting the above expression so that the feed may be based upon that assigned to the individual tooth:

$$\text{Cutting time} = \frac{T_r N_g}{fN_c R}.$$

For the given example

$$N_c = 9,\ N_g = 110,\ f = \cdot002,\ R = 30.$$

From a drawing T_r is scaled and found to be ·812 in.

Then $$\text{Cutting time} = \frac{\cdot812 \times 110}{\cdot002 \times 9 \times 30} = 165 \text{ min.}$$

Checking Tool-life.—Assuming 3 gears are cut per shift, the total cutting time would be 495 minutes. This is slightly greater than the estimated figure, but unless other factors operate the cutting speed of 32 f.p.m. could be retained.

Example 12.—Rough and finish-hobbing a bronze wormwheel the main details of which are: 39 teeth, 1 in. pitch, mating a five-start worm, the lead of which is approximately 4·5 in., the pitch dia. 3·375 in., outside dia. approximately 4·00 in.

Method of Operating.—When using two machines as proposed here, the first operation gashes out the tooth space and the finishing operation skims up the tooth surface. The usual practice with coarse pitches is to cut down to the root diameter with the roughing hob, leaving the finishing hob to cut only on the sides. Another point arising out of taking two cuts is the method of feeding: (*a*) radial, or (*b*) axial. The choice depends upon two main considerations: (i) chip thickness, (ii) machine capacity. In this example the conditions are such that the roughing is to be done using the radial in-feed method; for finishing, the axial feed is chosen as it gives the best tooth-form.

Roughing.

Cutter Details.—The general details of the hob are identical with the worm except for the necessary clearances, whilst the length is such that it permits two settings. Around the perimeter 8 gashes are cut for the teeth which gives around the hob, and covering one axial pitch, 8 cutting edges. The hob has no rake and the material is 18 . 4 . 1 h.s.s.

Tool-life.—The estimated cutting time per day is 8 hours. As the hob is engaged roughing the aim is that each cutting section should require resharpening after a day's run. Hence the hob needs sharpening once every two days. The tooth-life on this basis is one hour.

Cutting Speed.—With this set-up the chip thickness is regarded as equal to the radial in-feed per tooth, and for roughing the chip is assumed to be ·003 in. thick. The data for the cutting speed will be taken on the basis that gear hobbing is akin to form turning. Gathering the data:

V_b (Table 111, p. 183) = 240.
L_u (Table 25, p. 94) = 1·16.
T_m (Table 111) = 1·0.
C_r (Table 111) = 1·0.

M (Table 119, p. 191) = ·2.
T_l (Table 111) = 1·0.
T_s (Table 111) = 1·0.

$$V_c = V_b \, . \, M \, . \, L_u \, . \, T_l \, . \, T_m \, . \, T_s \, . \, C_r$$
$$= 240 \times {\cdot}2 \times 1{\cdot}16 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 = \text{say, } 56 \text{ f.p.m.}$$

$$\text{R.P.M.} = \frac{3{\cdot}82 V_c}{d} = \frac{3{\cdot}82 \times 56}{4} = \text{say, } 54.$$

Cutting Time.—The general expression for the cutting time when hobbing wormwheels using the radial in-feed method is, from Example 11 above, given thus:

$$\text{Cutting time, in-feed method} = \frac{T_r N_g}{f N_c R}.$$

$$= \frac{{\cdot}875 \times 39}{{\cdot}003 \times 8 \times 54} = \text{say, } 26{\cdot}5 \text{ min.}$$

Note: T_r by scaling is found to be ·875.

Checking Tool-life.—On the basis of a cutting time equal to 26·5 min. per component the daily output would be, say, 18.

Hence daily cutting time = 18 × 26·5 = say, 480 min.

This gives a tooth-life of 1 hour per day.

Hence, as the figures agree with those upon which the cutting speed is based, they may be regarded as satisfactory.

Finishing Cut.

This operation is to be done using the axial feed, and the hob to use is assumed to be of the short, tapered type. Working on the same basis as above, the general work when estimating the cutting speed and times is as follows:

Hob Details.—The general size of the hob will, except for the cutting edges, be similar to the worm itself. It will be of the short, tapered, shell type having the standard 36° inclusive taper lead; 8 gashes are to be cut giving 8 cutting teeth over an axial distance of one pitch; the material will be 18 . 4 . 1 h.s.s.

Operating Conditions.—The aim is to sharpen the hob only once during a working week consisting of 5 shifts, each of 9 hours' duration. This long run is suggested for two reasons: (*a*) to give an extended period between each regrind so that no rapid change shall take place in the pitch diameter and tooth thickness between the various batches of work; (*b*) because with so many teeth cutting the work is well distributed.

With the axial feed the teeth enter into engagement and cut, afterwards they move clear of the cutting zone. Hence the calculation of the time each tooth will be engaged is somewhat more difficult than when the radial in-feed method is chosen. In this instance the basis of the tool-life is on the assumption that any one section of the hob is cutting, as a maximum, not more than one-third of the time the hob is engaged cutting. Thus, if the actual time the hobbing machine is working comes out at 7½ hours per day, the cutting time on which to base the tool-life is:

$$\text{Cutting time of hob per week} = 7{\cdot}5 \times 5 = 37{\cdot}5 \text{ hours.}$$

$$\text{Cutting time per tooth per week} = \frac{37{\cdot}5 \times 60}{3 \times 8} = \text{say, } 94 \text{ min.}$$

Hence the suggestion is to base the tool-life upon a 1½-hour run.

Cutting Speed.—The deciding factor here is the chip thickness; each tooth should be given sufficient metal to remove, so that the tendency to slide over the surface is eliminated. In this instance it is assumed that the previous operation has cut a tooth between ·010 and ·014 in. thick, so as to provide a fair finish-machining allowance of, say, ·006 in. on each surface.

When using a tapered hob for the final hobbing the actual cutting is done by the corners of the truncated teeth. Expressing the chip thickness as measured normal to the sides and truncated portions of the tapered teeth for a standard tooth-form having a 20° pressure angle and a tapered hob with an inclusive nose-angle of 36°, the chip thickness in both directions may be written:

Chip thickness normal to leading edge

$$= \text{axial feed per tooth} \times \cos 20^\circ$$
$$= f_a \times \cdot 93969.$$

Chip thickness normal to truncated face

$$= \text{axial feed per tooth} \times \sin 18^\circ$$
$$= f_a \times \cdot 309.$$

The cutting action of the finishing hob, ignoring the rotary movement of the work-piece, gives a very small chip the thickness of which may, for purposes of computing the cutting speed, be taken as equal to the machining allowance on a tooth face. As the action takes place only upon the corners of the cutting teeth it becomes necessary to decide upon what basis the cutting speed shall be computed. It is difficult to regard the operation as akin to forming, and the nearest approach to the conditions that exist when finish-hobbing with the axial feed motion occurs when parting off; then two corners of a comparatively narrow tool are in action. Basing the cutting-speed data upon a chip ·006 in. thick, i.e. half the mean allowance on the tooth, and abstracting the information from the various tables:

V_b (Table 112, p. 184) = 760.
L_u (Table 25, p. 94) = 1·16.
T_m (Table 112) = 1·0.
C_r (Table 112) = 1·0.
M (Table 119, p. 191) = ·2.
T_l (Table 21, p. 85) = ·92.
T_s (Table 112, p. 184) = 1·0.

$$V_c = V_b \,.\, M \,.\, T_l \,.\, T_m \,.\, T_s \,.\, L_u \,.\, C_r$$
$$= 760 \times \cdot 2 \times \cdot 92 \times 1\cdot 0 \times 1\cdot 0 \times 1\cdot 16 \times 1\cdot 0 = \text{say, } 162.$$
$$R = \frac{3\cdot 82 V_c}{d} = \frac{3\cdot 82 \times 162}{4} = \text{say, } 155.$$

Cutting Time.—When hobbing wormwheels with the axial or tangential feed, the expression for the cutting time is normally given in the following manner:

$$\text{Cutting time} = \frac{T_a N_a}{FRS},$$

where T_a is the axial feed per revolution of the hob. The meaning of the remaining symbols is the same as in the previous examples.

The drawback to this expression is that it does not directly give the number of teeth cutting, nor the chosen feed per tooth. Hence it becomes necessary to partially rewrite the formula so that the feed per tooth (f)

and the number of teeth (N_c) within the effective cutting zone may be introduced and the symbols F and S dropped.

When hobbing wormwheels with the axial or tangential feed, the number of teeth within the effective cutting zone is restricted to those lying within the axial distance of one pitch. For spur gears it was found equal to the number of tooth gashes around the perimeter of the hob and was denoted by the symbol N_c; this was true for both single and multi-start hobs. Hence, when basing the cutting times upon the feed of the individual tooth, the number of starts in the above expression drops out and the feed per revolution of the hob is

$$F = fN_c.$$

Substituting for the value of F in the above expression and noting that S is dropped, the hobbing time using the axial cross-feed is given by

$$\text{Cutting time with axial feed} = \frac{T_a N_g}{fN_c R}.$$

Checking off the data required for computing the cutting time, it will be noticed that the axial feed per tooth has yet to be decided. Here the governing factor is the thickness of chip required and, as the machining allowance on the face has been fixed at ·006 in., the suggestion is to use the same thickness on the truncated face of the hob teeth. Then,

$$\text{Axial travel per tooth} = \frac{\cdot 006}{\sin 18^\circ} = \frac{\cdot 006}{\cdot 309} = \text{say, } \cdot 020 \text{ in.}$$

From a rough drawing T_a is found to be 4·5 in. Hence

$$\text{Cutting time} = \frac{T_a N_g}{fN_c R} = \frac{4{\cdot}5 \times 39}{\cdot 020 \times 8 \times 155}$$
$$= \text{say, } 7 \text{ min.}$$

Checking Tool-life.—With an estimated cutting time of 7 min. the weekly output should be around 300 components. Then

$$\text{Estimated time cutting per tooth} = \frac{300 \times 7}{8 \times 3} = 88 \text{ min.}$$

Being slightly under the basis upon which the cutting speed was calculated, the figures may be regarded as satisfactory.

Example 13.—Cutting a wormwheel from the solid using the axial or tangential feed.

The details of the wormwheel are that it has 24 teeth, ·5 in. circular pitch, and mates a two-start worm. The material is a nickel-chromium steel to, say, B.S. 970 En 39 or S.A.E. 3310.

Hob Details.—The general dimensions of the hob are: outside dia. 2·5 in.; the front teeth have a truncated form, the inclusive taper on the hob being 36°; 8 tooth gashes are given around the perimeter. The material is known to be an h.s.s. having approximately 3 per cent vanadium.

Operating Conditions.—The aim is for the hob to operate one full shift of 9 hours between each resharpening period. Then assuming that the teeth on each effective cutting zone are engaged for $\frac{1}{3}$ of the working time, and the teeth are in action for $\frac{1}{8}$ of each revolution of the hob, the working period desired may be taken as $\frac{1}{2}$ hour. As steel is being cut, a suitable cutting lubricant will be used.

Cutting Speed.—When using the axial or tangential-feed method of hobbing direct from the blank, the bulk of the cutting action takes place on the truncated portion of the leading teeth. In this example it is desired to operate with a chip ·002 in. thick. Working on this basis, and regarding the cutting action as akin to forming, the data from the various tables are:

V_b (Table 41, p. 110) = 97.
T_l (Table 21, p. 85) = 1·07.
T_s (Table 41) = 1·0.
C_r (Table 41) = 1·0.

M (Table 62 or 71, pp. 143 or 158) = ·47.
T_m (Table 26, p. 96) = 1·06.
L_u (Table 25, p. 94) = 1·16.

Then

$$
\begin{aligned}
V_c &= V_b \,.\, M \,.\, T_l \,.\, T_m \,.\, T_s \,.\, L_u \,.\, C_r \\
&= 97 \times {\cdot}47 \times 1{\cdot}07 \times 1{\cdot}06 \times 1{\cdot}0 \times 1{\cdot}16 \times 1{\cdot}0 \\
&= \text{say, } 60 \text{ f.p.m.}
\end{aligned}
$$

$$
R = \frac{3{\cdot}82 V_c}{d} = \frac{3{\cdot}82 \times 60}{2{\cdot}25} = \text{say, } 100.
$$

Cutting Time.—The cutting time for the axial or tangential-feed method is given above by the following equation:

$$
\text{Cutting time} = \frac{T_a N_g}{f N_c R}.
$$

From a rough layout on the drawing board T_a is found to be, say, 2·5 in. The axial feed in terms of the chip thickness is given by the expression:

$$
\text{Axial feed per tooth} = \frac{\text{chip thickness}}{\sin\,(\cdot 5 \text{ inclusive lead angle on hob})}
$$

$$
= \frac{{\cdot}002}{\sin\,({\cdot}5 \times 36^\circ)} = \frac{{\cdot}002}{\sin 18^\circ} = \frac{{\cdot}002}{{\cdot}309} = {\cdot}0066 \text{ in.}
$$

Putting the known values in the equation,

$$
\text{Cutting time} = \frac{2{\cdot}5 \times 24}{{\cdot}0066 \times 8 \times 100} = \text{say, } 11{\cdot}5 \text{ min.}
$$

Example 14.—Hobbing a splined shaft.

Hobbing a splined shaft is similar to cutting the teeth on a spur gear. Take a 1·5 in. dia. shaft, 6 splines $\frac{1}{16}$ in. deep whose length including approach and over-run is 3 in., material Ni-Cr En 39 or S.A.E. 3310 steel, annealed.

Cutter Details.—The hob is of 3½ in. dia., having 9 teeth around the perimeter, and is made from 18 . 4 . 1 h.s.s.

Operating Conditions.—Mount one at a time and flood the tool with a sulphurized cutting oil. Effective life of tooth is 1 hour.

Cutting Speed.—With a shallow cut of this type the feed in relation to the chip thickness is comparatively large. Using fig. 13.1, p. 270,

$$\sin \alpha = \frac{1{\cdot}625}{1{\cdot}750} = \text{say, } {\cdot}93,$$

$$\therefore \alpha = \text{say, } 70°.$$

And

$$f \text{ per tooth} = \text{chip thickness} \times \sec 70°$$
$$= {\cdot}001 \times 2{\cdot}924 = \text{say, } {\cdot}003 \text{ in.}$$

Collecting the data from the tables:

V_b (Table 41, p. 110) = 155.

L_u (Table 25, p. 94) = 1·16.

T_m (Table 41) = 1·0.

C_r (Table 41) = 1·0.

M (Table 62 or 71, pp. 143 or 158) = ·47.

T_l (Table 41) = 1·0.

T_s (Table 41) = 1·0.

$$V_c = V_b \,.\, M \,.\, L_u \,.\, T_m \,.\, T_l \,.\, T_s \,.\, C_r$$
$$= 85 \text{ f.p.m. or } 92 \text{ r.p.m.}$$

Cutting Time.

The time for hobbing a spline shaft is given by the expression used for spur gears (Example 8, p. 288), and in this instance N_g equals the number of splines on the shaft.

$$\text{Cutting time} = \frac{N_g(L + A + O)}{fN_cR}$$
$$= \frac{6 \times 3}{{\cdot}003 \times 9 \times 92} = 7{\cdot}3 \text{ min.}$$

4. Comparison with Published Data.

The above examples illustrate how to compute the cutting speed using the various tables. As mentioned in the opening paragraph, no attempt was made to use an operational factor or to adjust the data to suit a specific machine, the aim being with Examples 1–14 above to illustrate the value of the data and how to relate the various machining operations to the information listed in the many tables.

Below, a comparison is made between the cutting speed actually used for machining, and that arrived at by working from the principles outlined. In this way the value of the data listed in this work to the personnel actively engaged in planning and production is clearly demonstrated.

Example 15.—An aluminium-alloy piston casting is to be rough-machined on a capstan lathe. The spindle speed[29] is given as 900 r.p.m. and the tool is carbide-tipped. The finished diameter of the piston is 110 mm. or 4·3307 in. The feed used for the rough machining is stated to be 5 in. in $1\frac{1}{2}$ minutes. Allowing, say, $\frac{1}{8}$ in. on the article for machining, the cutting speed is, say,

$$V_c = \frac{4{\cdot}625 \times 3{\cdot}14 \times 900}{12} = 1090 \text{ f.p.m.}$$

$$f = \frac{5}{900 \times 1{\cdot}5} = {\cdot}0037 \text{ in.}$$

To compute the cutting speed, the tool-shape must be known. This is not given, hence, as the tool is used in the turret, a knife tool having a rake of 40°, no approach angle or nose-radius, is assumed. Owing to the high cutting speed and knowing that a tipped tool is used, it is taken for granted that the cutting is done dry. Moreover, as the tool is cutting for the greater part of the actual work-cycle, a tool-life of 6 hours is assumed to be necessary if changes are to be made but once a shift. Gathering the data on this basis:

V_b (Table 123, p. 200) = 1052.
T_l (Table 21, p. 85) = ·79.
L_u (Table 123) = 1.
C_r (Table 123) = 1.
M (Table 133, p. 203) = ·42.
T_m (Table 26, p. 96) = 3.
T_s (Table 123, p. 200) = 1.

$$\begin{aligned} V_c &= V_b \,.\, M \,.\, L_u \,.\, T_m \,.\, T_l \,.\, T_s \,.\, C_r \\ &= 1052 \times {\cdot}42 \times 1{\cdot}0 \times 3 \times {\cdot}79 \times 1{\cdot}0 \times 1{\cdot}0 = 1050 \text{ f.p.m.} \end{aligned}$$

The computed figure of 1050 f.p.m. is very close to that actually used even though full allowance has been made for, say, a six-hour tool-life.

Example 16.—Brake shoes made from steel stampings in En 3 and having a Brinell of 130 after normalizing are machined on a turning-mill to 16 in. dia. The cutting speed is given as 28 r.p.m. with a feed of 48 cuts per in., or, say, ·02 in. Allowing $\frac{1}{8}$ in. for machining, the cutting speed is:

Actual $$V_c = \frac{16\frac{1}{4} \times 3{\cdot}14 \times 28}{12} = \text{say, } 119 \text{ f.p.m.}$$

No details of the material for the cutting tools are given, nor is any mention made of the shape of the tool. Hence it is assumed that a knife tool having, say, a $\frac{1}{16}$-in. nose-radius is used, without any approach angle. Setting is comparatively easy, hence a tool-life of one hour is taken, using a coolant. Gathering data for a normal 18 . 4 . 1 h.s.s. tool, the values for M, T_s, T_m, T_l and C_r each are equal to unity. Hence the computed cutting speed may be written:

$$V_c = V_b \, . \, L_u = 120 \times 1{\cdot}16 = \text{say, } 139 \text{ f.p.m}$$

Reducing these figures to suit the machine capacity, they are of sufficient accuracy to justify the use of the tables.

Example 17.—A cast-iron cylinder block[31] is milled on its faces using a 15 in. dia. cutter with 40 teeth tipped with Stellite. The cutting speed is given as 54 r.p.m. and the feed as $7\frac{1}{2}$ in. per minute.

Then $$\text{Actual } V_c = \frac{15 \times 3{\cdot}14 \times 54}{12} = 212 \text{ f.p.m.,}$$

and $$f = \frac{7{\cdot}5}{40 \times 54} = \text{say, } {\cdot}0035 \text{ in.}$$

No details of the shape of the cutter are given, hence it is assumed that there is no approach angle or nose-radius. A life of one hour is suggested for each tooth. Taking the chip dimensions as $\frac{1}{8}$ in. deep with a feed of ·004 in., the nearest given in Table 92, a cutting speed of 228 f.p.m. is obtained, which is very close to that used.

Example 18.—The rear axle as fitted to a commercial vehicle[32] is turned at 110 f.p.m. with a cut at the maximum $\frac{1}{8}$ in. deep and ·011 in. feed. The work is done on a multi-tool lathe with the tools flooded with a cutting oil. The material specification is close to En 25 with B.H. No. of 352–375.

No details are available as to the exact tool-shapes, so it is assumed that a cemented-carbide-tipped tool having no approach angle, but a $\frac{1}{16}$-in. nose-radius, is chosen. With this class of machine the tool-life is rather high and it is assumed that it will operate for a day's run or, say, 6 hours of actual cutting. Then

V_b (Table 54, p. 115) = 550. L_u (Table 25, p. 94) = 1·18.

M (Table 61, p. 133) = ·23. T_l (Table 21, p. 85) = 0·75.

And T_s, T_m and C_r each equal 1.

Hence $$V_c = 550 \times {\cdot}23 \times 1{\cdot}18 \times {\cdot}75 = 112 \text{ f.p.m.}$$

The computed figures are very close to those used in practice, and when the adjustments are made to suit the given machine the use of the data given here is amply justified.

Example 19.—The swivel axle for the Morris 8 h.p. car is made from a 3–3½ per cent nickel-steel stamping, heat-treated to give a tensile strength of 55 tons minimum. A milling operation[33] is necessary on the lugs and the cutting speed is given as 70 r.p.m., with a feed of ¾ in. per minute using cutters of 5 in. dia. flooded with a lubricant.

$$V_c = \frac{5 \times 3{\cdot}14 \times 70}{12} = \text{say, } 92 \text{ f.p.m.}$$

$$f = \frac{{\cdot}75}{10 \times 70} = \text{say, } {\cdot}001 \text{ in.}$$

Note when computing the feed per tooth it has been assumed that the cutter had 10 teeth[12] and the material is standard high-speed steel; these data were not published.

In order to compute the cutting speed it is necessary to point out that the design of the fixture is such that no correction is required for the chip thickness. The chip itself is assumed to be ⅛ in. long. The tool-life is taken at 1 hour per tooth cutting. With a chip dimension of ·125 × ·001 in. the data in Table 37 are hardly applicable unless use is made of an operational factor from Table 27, as the life of the tool depends more upon its resistance to abrasion than its red hardness value. The suggestion is to use the maximum speed in the table, e.g. the speed for a chip ·002 in. thick along with an operational factor of ·5, and, assuming the steel is roughly equal to En 22, base the M factor upon a B.H. No. of 302. As the factors for T_m, T_s, T_l and C_r are taken as each equal to 1, the expression in this example for the cutting speed becomes

$$V_c = {\cdot}5 \,.\, V_b \,.\, M \,.\, L_u.$$

Gathering the data:

V_b (Table 37, p. 108) = 418. L_u (Table 25, p. 94) = 1·16.

M (Table 61, p. 131) = ·38.

$$V_c = {\cdot}5 \times 418 \times {\cdot}38 \times 1{\cdot}16 = \text{say, } 92 \text{ f.p.m.}$$

Again these figures demonstrate how close good practice is to the computed data, when judicious use is made of the appropriate tables.

The above detailed examination of the cutting conditions raises the question as to the wisdom of using such a fine feed. It is highly probable that a coarser feed with a lower speed would give the same output per hour, and at the same time reduce the risk of the cutting edges sliding across the surface and work-hardening the material.

Example 20.—Information published[34] relating to heavy cutting on nickel-chromium-molybdenum steel heat-treated to 55–65 tons is:

Dia., in.	Cutting speed	Chip dimensions, in.	
	f.p.m.	*d*	*f*
< 2½	65	·25–·375	·0125
2½–6	40	·25	·05
6–11	35	·3	·1
11–24	24	·5	·1
24–48	15 to 18	·5–·625	·125

Details as to the tool-life, tool material or shape are not given, nor is any mention made of a suitable cutting lubricant. Owing to the lack of this information the check calculations are on the assumption that a super h.s.s. tool will be used with an approach angle of 30°, and for the feed of ·0125 in., a nose-radius of $\frac{1}{8}$ in.; for the coarser feeds a nose-radius of $\frac{1}{4}$ in. is assumed. For purposes of determining the M factor the material is taken as En 24 with a B.H. No. of 248. Using the data from Tables 25, 26, 39, 40 and 61, then assuming T_l, T_s and C_r each equal 1, the required data may be tabulated:

Chip dimensions, in.		Data from Tables				Cutting speeds, f.p.m.	
d	*f*	V_b	M	T_m	L_u	Dry	Using coolant
·25	·0125	160	·34	1·2	1·18	65	77
·25	·05	70	·34	1·2	1·42	28·5	40
·3	·1	49	·34	1·2	1·55	20	30
·5	·1	42	·34	1·2	1·58	17	26
·5 to ·625	·125	35	·34	1·2	1·58	14	22

Comparing the computed figures with those given as used in practice, it will be noticed that for dry cutting the extremes for the two sets of figures almost agree whilst the intermediate computed speeds are lower than those given as used in practice. Such differences are to be expected, but the use of the tables is justified in that they permit an engineer to plan with the certainty that the job can be done. Improvements in the cutting times would be the result of close and detailed examination of the existing operating conditions.

Example 21.—Details as to the milling of splines[35] in an airscrew shaft produced in S.81, say, En 28, heat-treated to give 65–75 tons tensile strength, are that a 3 in. dia. form-cutter makes 51 r.p.m. and has a feed of 1·0 in. per minute.

Then
$$V_c = \frac{3 \times 3{\cdot}14 \times 51}{12} = 40 \text{ f.p.m.}$$

Feed per tooth, on the assumption that the cutter has 8 teeth, is

$$f = \frac{1}{51 \times 8} = \text{say, } {\cdot}00245 \text{ in.}$$

With the shallow cut necessary to produce the spline the chip at its maximum cannot be more than, say, ·001 in. thick (see fig. 13.1, p. 270), and it is suggested that the basic cutting speed be based upon a chip ·001 in. thick. The operation is regarded as similar to form-turning.

Checking the speed with the data from the tables:

M (Table 61, p. 135) = ·23. V_b (Table 41, p. 110) = 155.
L_u (Table 25, p. 94) = 1·16.

The other factors are each assumed to be equal to 1,

$$\therefore\ V_c = 155 \times {\cdot}23 \times 1{\cdot}16 = \text{say, } 41 \text{ f.p.m.}$$

Hence the computed figure compares favourably with that used in practice.

Example 22.—Details[36] are given of rough-turning Ni-Cr annealed forgings to B.S. 970 En 34 or, say, S.A.E. 4620 at a speed of 80 f.p.m. with a feed of ·012 in. A cutting compound is used, but no mention is made of the depth of cut, the shape of the cutting edge, or the tool-life required.

For purposes of a check, and to show the value of the various tables, the assumptions made are:

(*a*) For roughing the maximum depth of cut is taken as $\frac{1}{8}$ in.
(*b*) A 12 per cent super h.s.s. tool will be used.
(*c*) The tool is to have a nose-radius of $\frac{1}{8}$ in.
(*d*) As the machine is of the special-purpose type, and production is continuous, a tool-life of, say, 8 hours or one complete day or night shift is expected.

The above assumptions agree with the usual practice.

Abstracting the data from the various tables, and in the case of the basic speed constructing a graph to obtain V_b, we have:

V_b (Table 39, p. 109) = 185. T_s (Table 39, p. 109) = 1.
T_l (Table 21, p. 85) = ·77. T_m (Table 26, p. 96) = 1·12.
L_u (Table 25, p. 94) = 1·18. C_r (Table 39, p. 109) = 1.
M (Table 62, p. 141) = ·52.

And
$$\begin{aligned} V_c &= V_b \,.\, M \,.\, T_l \,.\, T_m \,.\, T_s \,.\, L_u \,.\, C_r \\ &= 185 \times {\cdot}52 \times {\cdot}77 \times 1{\cdot}12 \times 1 \times 1{\cdot}18 \times 1 = \text{say, } 98 \text{ f.p.m.} \end{aligned}$$

This is above the given speed. However, if the nose-radius is reduced to $\frac{1}{16}$ in., a cutting-speed of, say, 83 f.p.m. is obtained. This illustrates two factors—the value of the tables, and the effect of changing the profile of the cutting edge.

Example 23.—A cast-iron gear wheel having 216 teeth, 8 D.P., is cut on a Fellows type gear-shaper.[37] The work is mounted in pairs, and the total cutting time is given for the two gears as 90 minutes.

Checking for Cutting Speed and Strokes per Minute.—No other data beyond those given are known, hence, in order to check the production time and illustrate the use of the tables, the following reasonable assumptions are made:

(*a*) Width of gear face is roughly 4 times the circular pitch and equal to $1\frac{1}{2}$ in.

(*b*) The material has a B.H. No. of 190.

(*c*) Cutting is done dry.

(*d*) The average chip thickness of, say, ·002 in. is desired.

(*e*) The life of the cutting edge in action will be 1 hour.

Working on the basis that gear shaping with a pinion cutter is akin to form turning, the data from the tables may be listed:

V_b (Table 89, p. 172) = 35.
L_u (Table 25, p. 94) = 1.
T_m (Table 89) = 1.
C_r (Table 89) = 1.
M (fig. 9.1, p. 167) = ·82.
T_l (Table 89) = 1.
T_s (Table 89) = 1.

Then $V_c = 35 \times \cdot 82 =$ say, 29 f.p.m.

Length of machine stroke $= L + A + O = 3 + \frac{1}{8} + \frac{1}{8} = 3\frac{1}{4}$ in.

Tool travel per stroke $= 2 \times 3\frac{1}{4} = 6\frac{1}{2}$ in.

Hence strokes per minute $= \dfrac{29 \times 12}{6\cdot 5} =$ say, 54.

Checking for Surface Finish.

The general details of the cutter and work-piece are taken as:

Cutter pitch dia. = 4 in.

Cutter outside dia. = 4·300 in. (This includes bottom clearance or work-piece.)

Work-piece pitch dia. = 27 in.

Work-piece outside dia. = 27·25 in.

Work-piece pitch-circle circumference = 3·1416 × 27 = say, 85 in.

Centre distance of cutter and work-piece $= \dfrac{4 + 27}{2} = 15\cdot 5$ in.

With the cutter at the full depth the triangle ABC made by the centre line and the point where the outside diameters of the cutter and work-piece just make contact has the following dimensions:

AB or side $c = 2{\cdot}15$.
AC or side $b = 13{\cdot}625$.
BC or side $a = 15{\cdot}5$.

Using the cosine formula to obtain angle B,

$$\cos B = \frac{a^2 + c^2 - b^2}{2ac} = \frac{15{\cdot}5^2 + 2{\cdot}15^2 - 13{\cdot}625^2}{2 \times 15{\cdot}5 \times 2{\cdot}15} = {\cdot}899.$$

Hence angle $B = 25^\circ\ 58'$.

Tentatively assuming that the cutter rotates 0° 30′ after each stroke, the approximate number of strokes to form each tooth from entry into until the breaking of engagement is given by:

$$\text{Number of strokes to form tooth} = \frac{\text{arc of contact of cutter}}{\text{angular movement per stroke}}$$

$$= \frac{2 \times 25^\circ\ 58'}{0^\circ\ 30'} = \text{say, } 104.$$

Length of flank and face for 8 D.P. size tooth, and pressure angle 20°, ignoring curvature,

$$= \frac{2 \sec 20^\circ}{8} = \frac{2 \times 1{\cdot}064}{8} = {\cdot}266 \text{ in.}$$

Then approx. length of each facet cut on profile

$$= \frac{{\cdot}266}{104} = \text{say, } {\cdot}0025.$$

Checking for Chip Thickness.—What is required is some indication of the chip thickness; where possible enlarged drawings of each chip formed by the various cutting strokes are advisable when conducting a detailed analysis into the cutting capacity of the machine. Often this procedure is impossible, and to some extent the chip size may be roughly determined in the following way.

With the in-feed completed, assume that the pinion tooth lies on the line of centres. With this combination there are on either side of the line of centres two other teeth in contact with the work-piece. As the 4 in. dia. cutter has 32 teeth, the angle made by the outer-tooth centre line off the line of centres is $22\frac{1}{2}^\circ$. Now it is very difficult with a tooth profile to readily give the relation of the tip of the tooth to the centre line, hence for purposes of computing the chip thickness the point P on the tip of the in-swinging tooth is taken as 21°. Working on this basis (and using fig. 13.7, p. 285), we have:

At finish of in-feed P from the line of centres

$$= 2{\cdot}15 \sin 21°$$
$$= {\cdot}770 \text{ in.}$$

O_cO_g the centre distance between the cutter and work-piece

$$= 15{\cdot}5 \text{ in.}$$

And it can be proved that O_gP the distance of P from the centre of the work-piece

$$= 13{\cdot}513 \text{ in.},$$

whilst the angle made by O_cO_gP can be proved = 3° 16′.

On the first in-swing of the cutter point, P moves towards the line of centres.

And P from line of centres

$$= 2{\cdot}15 \sin (21° - 0°\ 30') = 2{\cdot}15 \sin 20°\ 30'$$
$$= 2{\cdot}15 \times {\cdot}3502 = {\cdot}7529.$$

But the work-piece also has a rotary motion, and this is proportional to the respective pitch diameter, hence

Angular movement of work-piece

$$= \frac{4}{27} \times 0°\ 30' = 0°\ 4{\cdot}45'.$$

And the new angular position of work-piece becomes

$$= 3°\ 16' - 0°\ 4{\cdot}45' = 3°\ 11{\cdot}55'.$$

Then distance of P on the work-piece measuring off the line of centres

$$= 13{\cdot}513 \sin 3°\ 11{\cdot}55'$$
$$= 13{\cdot}513 \times {\cdot}05579 = {\cdot}7538$$

Therefore overlap of pinion cutter on workpiece

$$= {\cdot}7538 - {\cdot}7529 = {\cdot}0009 \text{ in.}$$

Thus the chip thickness at this position is very thin and below that upon which the cutting speed was based. This tends to ensure a somewhat long tool-life.

Cutting Time.

The cutting time is given on p. 287 as = in-feed cutting + rotary cutting.

$$\text{In-feed cutting} = \frac{T_a + A}{fS} = \frac{\cdot 275 + \cdot 010}{\cdot 002 \times 54} = 2\cdot 64 \text{ min.}$$

$$\text{Rotary cutting} = \frac{\pi(\text{PD}_g)}{\text{rotary feed in in.} \times S} = \frac{S_c(\text{PD}_g)}{S(\text{PD}_c)}.$$

$$\text{Strokes per rev. of cutter} = \frac{360}{0^\circ\ 30'} = 720.$$

$$\text{Strokes per inch of cutter} = \frac{720}{4 \times 3\cdot 1416} = \text{say, } 58.$$

$$\text{Rotary cutting time} = \frac{720}{58} \times \frac{27}{4} = 84.$$

Then total cutting time

$$= 84 + 2\cdot 64 = 86\cdot 64 \text{ min., say } 44 \text{ min. each gear.}$$

Comments.—From this detailed examination it appears that cutting speed as determined from the tables is very close to that used for cutting these gears. Passing to the rotary feed, one is driven to the conclusion that, using 720 strokes per revolution of the pinion cutter, the feed is very fine and improved machining times could be reasonably expected by a reduction between, say, 5 and 10 per cent. This should operate without seriously interfering with the finish on the tooth face. If a shaving operation is to follow the rough gear-shaping, then the higher figure should be tried out under controlled conditions.

Example 24.—Cutting the teeth on a straight-tooth bevel gear.[38]

The given details are that a straight-tooth bevel gear having 33 teeth has an outside diameter of 3·872 in. and a pitch diameter of 3·666 in. The machine used is a Gleason No. 7 Revex with a cutter diameter of 18 in. and 40 cutting teeth. The production time is given as four minutes for cutting the 33 teeth.

Assumptions.—Before a detailed examination can be made as to the cutting time based upon the data listed in the various tables it is essential to make a number of assumptions. These are:

(*a*) As the gears are known to be used in an aero-engine, it is assumed that the material used will, when fully heat-treated, be within the 100-ton range, say, B.S. 970 En 26 or S.A.E. 4340.

(*b*) Cutting on a Revex machine implies a non-standard tooth form, but for purposes of computing the machining speed the standard tooth-dimensions are assumed.

(*c*) With a circular pitch of approximately ·35 in., the tooth depth is taken at ·25 in. measuring at the big end.

Chip Thickness.—Using a Revex machine cutting with 40 teeth per revolution carries with it the implication that 20 are used to cut one face, and the other 20 the opposite. Moreover, some of the back teeth are designed for finishing, hence take a thinner chip. As the cutter has 20 pairs of teeth and the distance it is to sink into the blank is ·25 in. maximum, the average depth of cut may be taken as ·0125 in. Allowing for the finer finishing cuts taken by the last series of teeth, the suggestion is to assume a maximum chip thickness of, say, ·016 in.; the length of the chip is taken as $\frac{1}{3}$ the circular pitch, say $\frac{1}{8}$ in.

Operating Conditions.—Only one component can be mounted at a time on the machine spindle, and, as the material to be cut is steel, a good flow of a suitable cutting lubricant is assumed. The annealed material is assumed to have a B.H. No. of 277.

Tool-life.—With 40 teeth cutting around the cutter perimeter, the tooth engagement in the blank may be taken as $\frac{1}{40}$ of a revolution. Assuming that the cutter runs for 5 working shifts, each of 8 hours actual working, the estimated tool-life between regrinding becomes 1 hour. The suggestion is to work on this figure.

Cutting Speed.—The next stage is to determine the cutting speed and decide which of the cutting tools covered by Tables 37–45 has an action similar to or identical with that of the cutting segments on a Revex cutter. With an estimated chip ·016 in. thick and $\frac{1}{8}$ in. long, the suggestion is to base the cutting speed upon the first teeth cutting. These are of the roughing type, and it is assumed that the blades will have a small corner radius, hence the proposal to base the cutting speed upon rough-turning with a knife tool having no approach angle but a $\frac{1}{16}$-in. nose-radius. Assuming that the annealed metal has a B.H. No. of 277, and that the cutting blades are of an 18 . 4 . 1 h.s.s., the following data may be abstracted from the various tables:

V_b (Table 38, p. 109) = 135. M (Table 61, p. 135) = ·32.
L_u (Table 25, p. 94) = 1·16.

The remaining data are assumed equal, in each instance, to 1·0.

Then
$$V_c = 135 \times \cdot 32 \times 1\cdot 16 = 50 \text{ f.p.m.}$$
$$R = \frac{3\cdot 82 V_c}{d} = \frac{3\cdot 82 \times 50}{18} = \text{say, } 10.$$

Cutting Time.—It is known that each revolution of the cutter completes one tooth space. Hence

$$\text{Cutting time} = \frac{N_g}{R} = \frac{33}{10} = 3\cdot 3 \text{ min.}$$

Allow for chucking and removing the work, say 4 min. These estimated figures agree very well with those actually reported, and more than justify the use of the data listed above when determining the cutting speeds. The point to bear in mind is that the above analysis is on the rough side; it is advisable, wherever possible, to make a more detailed examination of the actual cutting action of the teeth on the perimeter of the cutter. For simplicity this has been ignored.

CHAPTER XIV

The Indirect Expenses and Economics of Estimating

1. The Indirect Expenses.

When estimates are being prepared so that the selling price may be decided, the question arises: "What are the indirect expenses associated with each stage in the production cycle, and how shall they be allocated?" The two extremes encountered in practice are (*a*) using an overall percentage on direct labour, and (*b*) subdividing the work done according to the operation and class of machine used, and then placing an oncost or overhead rate on each stage in the manufacturing cycle.

2. Subdivision of Expenses.

When convenient it is suggested that the best way of allocating the various indirect expenses is to subdivide them into the following grouping, so that each facet of the works activities is clearly represented:

Production or Works Oncost.—All the indirect expenses incurred by the works from the time the raw material is received until the completed article is forwarded to the warehouse or dispatch bay are grouped under the heading Production or Works Oncosts.

Selling Overheads or Oncosts.—The many expenses incurred in getting orders, advertising, travellers' expenses, and commission; the office expenses in dealing with the customers' orders, invoicing, crediting returns, and keeping sales ledgers, are included in the general term Selling Oncosts.

Distribution Oncosts.—This is the expenditure incurred from the time the goods are received by the stores or warehouse until they reach the customer. It also includes the cost of all package; outward cost of transporting the goods to the customer, and the return of empty casks and boxes; the cost of repairing the casks, &c.; and the expense incurred in keeping outlying service and sale depots.

Administrative Oncosts.—All the expenditure incurred in formulating, directing, controlling the policy, organization, and operations of the business come under the heading Administrative Oncosts.

In a small concern the above divisions are rarely found, the general policy being to split the indirect expenses into two sections, one dealing with all the indirect charges associated with running the works, the second comprising the costs due to the stock room, offices, selling and distribution. Alternatively, one inclusive figure may cover the whole of the indirect expense associated with the job.

3. Allocating the Oncosts.

Assuming that the various indirect expenses are known, the question arises as to how they shall be allocated, so that each article made bears its share. In an establishment where there is a wide range of production machinery, this is not an easy matter. Machines vary in their first cost, the space occupied, repairs, useful life, depreciation charges, running costs, time required for setting, along with the tooling equipment. With the aim of allocating the indirect expenses on the most accurate basis it is necessary to divide those associated with running the works into groups, which gives (*a*) the cost of running each batch of similar machines, (*b*) an inclusive figure to cover the management and other indirect expenses associated with the running of the works.

Then follow the decisions as to how the expense shall be based. It may be placed as a percentage on direct labour or upon the time taken to do the job. When the necessary preliminary work has been done the latter would probably be chosen.

Selling Charges.—This charge would be dealt with in the same way as (*b*) above, when a separate figure is used in the adopted scheme of costing.

Distribution Charges.—When dealing with this class of charge it is necessary to ascertain just which of the charges are regarded as direct in the costing system used. In some instances cartons and packing cases are charged direct on the article; this may also be the case with the transport charges. To ensure reasonable accuracy it is important that no expense is dealt with as both indirect and direct. The actual distribution charge would be handled in a similar way to the indirect works charges.

Administrative Expenses.—When handled as a separate expense these are treated in a similar manner to the distribution charges. Hence they feature as a percentage on direct labour or as an hourly rate.

4. Accuracy of Data.

When dealing with the various indirect charges it must be clearly understood that under the best conditions they are only an estimate, for it is impossible with so many variables to obtain an exact figure. In order that the concern can quote reasonable prices, the recovery of the various indirect expenses should be based upon what is regarded as the normal works charges. It is unwise to base them upon a period of great activity or those existing during a slump.

5. Economics of Estimating.

On all estimates it is important to give careful attention to the economics of each job, as under the known or stated conditions it is the layout which gives the lowest all-in costs that is required. Normally it is a question of balancing a low capital expenditure with a high labour charge, against a high capital expenditure and low labour cost, in both production and maintenance. The former is chosen when producing only a few articles, erecting a temporary structure, or making a roadway which is not to be used extensively either at the present time or in the future; the latter is the choice when large quantities are to be produced, with the labour cost and production times brought down to a minimum, or a roadway is expected to carry an increasing amount of heavy traffic and the maintenance charges must be light.

It will be appreciated that the economics of the job may affect both material chosen and the allocating of the various indirect expenses. Ignoring the question of material, a low capital expenditure on equipment means that the ratio of the indirect to the direct expenses will be low; with a high capital expenditure and a low labour charge, the ratio of indirect to direct expenses changes so much that the indirect expenses often form the greater part of the manufacturing costs.

Another point to make clear is that an estimate should be based upon the use of machines normally chosen for the job. If, owing to the pressure of work upon a department, larger and more expensive machines which carry a higher oncost rate have to be used, it is unwise in face of competition to base the selling price upon the use of the larger equipment; similar remarks apply when unsuitable machinery has to be used owing to unforeseen circumstances.

Wage allocations on every estimate should be based upon the normal day-shift operations. The extra wage allowance for overtime or working on nights should not feature in the estimate, but should be regarded as an additional running expense to be recovered by the oncosts. The exception to this is when a customer requires an exceptionally quick delivery, and is known to be willing to pay for overtime. It must be realized that continuous overtime leads quickly to a fall in the hourly output, which may be as much as 20 per cent. At the same time, the expenses are increased as more lighting and power are required. With two shifts running, the average hourly output by night will normally be less than by day, but owing to the greater use of the machines the oncost per unit manufactured should show a fall, even though more lighting, heating, and power be consumed. Hence, running two shifts gives a compensatory effect, but the exact effect is often difficult to assess. Overtime has no corresponding compensations.

Basing the various oncosts as a percentage on direct labour is not altogether satisfactory, and only suitable when operating on a flat day-rate basis. The drawback is, of course, that it does not show any reduction in the indirect charges, no matter how quickly the work is done. Hence, in order to take full advantage of piecework it is wise to base the oncost rates upon an hourly basis, not as a percentage of the wages paid.

The handling of bought-out goods is another feature which concerns the estimator, and the question is just how to allocate the various indirect expenses connected with purchasing and storing the components or units until required for erection or sending to the customer. The normal oncost rates as used to cover the manufacturing sections are unsuitable. Hence, a special oncost rate to cover such items may have to be introduced.

When dealing with the selling price it is important, in addition to the items given in various places above, to take into account the question of any royalty or commission due to an agent; for these and similar items have a very important effect upon the actual profits. This may be seen from the following examples.

(*a*) An estimate gives the total manufacturing cost of a component as 6*s*. and a 10 per cent profit is required on the sale.

Then 6*s*. equals 90 per cent of the selling price, and the

$$\text{Selling price} = 6s. \times \tfrac{10}{9} = 6s.\ 8d.$$

Note that in order to obtain 10 per cent profit on the manufacturing price it is necessary to add to the manufacturing price 11·1 per cent.

(*b*) The same article is assumed to carry a patent royalty of 6*d*. per article, and an agent's commission of 5 per cent. A profit of 10 per cent is required on the net selling price. Then the selling price is made up as follows:

	s.	*d.*
Manufacturing costs	6	
Royalty		6
Total costs	6	6
Profit on total costs at 11%, say		9
Net selling price	7	3
Agent's fee 5%, say		4½
Actual selling price	7*s.*	7½*d.*

Purchases.—When arranging for the purchase of material the lowest price should be carefully examined to ensure that it gives the minimum all-in cost. The latter calls for attention to the manufacturing and process scrap that will be produced, and also the possibility of extra work because the material may not be up to the required standard. In this direction an up-to-date knowledge of the works activities, based upon the combination of personal experience and accurate cost records, is of the utmost value.

CHAPTER XV

Pricing and Kindred Matters

1. Conditions of Contract.

The " Conditions of Contract " usually forms one of the most important documents associated with any tender, dealing as it does with the commercial and legal sides of the proposed transaction. In practice, it will be found that the general tendency is to give the Conditions of Contract separate from the other details associated with the tender.

When considering the clauses to be inserted in any Conditions of Contract, the fundamental idea is to ensure that the general interests of the particular party are thoroughly safeguarded. Care and foresight are necessary so that all contingencies may be covered in a concise manner that is free from any ambiguity. The actual terms must depend on whether or not the interests of a buyer or seller are to be given the first consideration. In the case of the former, the draft must be done so as to ensure efficient results with a low maintenance charge. If the latter, then care must be exercised so that no undue claims can be put forward which would turn a profitable transaction into a loss. Owing to the difference in the viewpoint of a buyer and seller there may, at times, be conflicting opinions, and the main aim is to arrange for the procedure to follow under such conditions.

With the wide range of commercial activities associated with engineering it is impossible to give any representative Conditions of Contract that would cover all circumstances. Some of the more usual features are those associated with the duties and responsibilities of the supervising engineer and his staff: provisions for arbitration; specifying the tests to be carried out before the work is finally accepted; clearing sites, excavations, filling in and making good any damage to property; sanitation, drainage, shoring up, or under-pinning; protection against frost, weather and traffic; control of labour, fair wages, overtime and nightwork rates; and, say, details as to general maintenance of the site.

The actual terms to embody in the Conditions of Contract can only be decided when a complete analysis of the work to be done, and of the effects of the proposals on other parties, has been duly considered. As no engineer can hope to have more than a working knowledge of the law, it is generally wise to seek the assistance of a solicitor, particularly when large sums are at stake.

2. Conditions of Sale.

When a quotation is sent to a customer giving the price at which one is willing to supply a given article, or undertake to perform a known task, it is highly desirable that the " Conditions of Sale ", such as are applicable to the industry, and agreed upon by the representative trade association, are attached to or printed on the quotation form. The information coming under the above heading covers all relevant details that are not listed in the quotation proper. It may cover such items as transport; the liability for damage or breakage during transit; responsibility for defective work and replacements; defining the liability for any loss suffered by the customer due to articles being found defective; charges for casks, packing cases, and battens; overtime and nightwork rates; the quantity at which any order will be deemed completed; responsibility for repairs to damaged property; terms of payment; the period for which any quotation holds good; claims for shortage; pattern, tool and setting charges; cancellation of orders and the consent required; the effect of any wage increases on quotations and current prices.

3. Specifications.

With many classes of engineering it is impossible to list on a drawing full details of what a given tender or quotation is to cover. Hence, to clarify the position and give a clear conception of what is required, or will be supplied, it is usual to attach to the drawings a specification list. In practice this may be drawn up by either the buyer or the supplier. The data given will include a description of the work to be done or the machine to be supplied along with the main dimensions; they will refer to the materials chosen, their composition, quality, methods of testing, and probably the general finish; they will give a brief outline of the constructional details and list all incidental equipment which is required or will be supplied at the stated price. Mention may also be made of such B.S., A.S.T.M. or S.A.E. specifications as are relevant to the work to be done or the machine being discussed. Concise details will also be given as to the performance, fuel or power consumption, loading and running conditions, accuracy or alignment tests, factors of safety, overload margins, and power rating.

4. Selling Price.

The determination of a selling price or that at which a given work will be performed, follows on the completion of the estimate for material, direct labour, and the other direct charges. In this direction it must be realized that price-fixing is governed by policy. Much will of necessity depend upon the many factors operating within and without the concern, such as the class of goods being manufactured, the state of the order book, the possibility of achieving the same ends by other means, the general economic trends, the competition offered by other concerns within the industry, along with the existence of any price-fixing agreement operating through a trade association.

Naturally, every concern desires to make a reasonable profit on each transaction, but in the rough and tumble of competitive industry this is not always possible. Often, when a decision has to be made, it is necessary to consider carefully what profit margin, if any, is obtainable. Under the conditions existing during trade depressions, when price-cutting is rife, the decision may have to be taken to cut into what are regarded as the normal indirect expenses so that the order may be obtained and the various departments found some work. The point is then, " Just how far shall the price be cut?" No precise ruling can be given. Each case must be judged in the light of existing circumstances.

Then again there may be the balancing of one article selling at a good profit against another which must be sold at a loss. The conditions surrounding the person responsible for fixing the price, the value he places on the necessity to retain the customers' goodwill, his experience, training, views on the future trends, and his temperament, will collectively and separately have an influence on the decision. In spite of the above it is essential that the estimate itself be based upon up-to-date information, accurately drafted, so that the responsible person has a clear idea of the results arising from the decision he must make.

5. Graphs.

Often when determining the selling price for a given article use is made of graphs; a typical example is given in fig. 15.1. Here, the selling prices for a number of sizes have been determined at various times by estimates, and have been found satisfactory when the job has been costed. Hence, in order to save time, the prices for the other sizes are determined graphically. In the example the known prices are shown by a small circle.

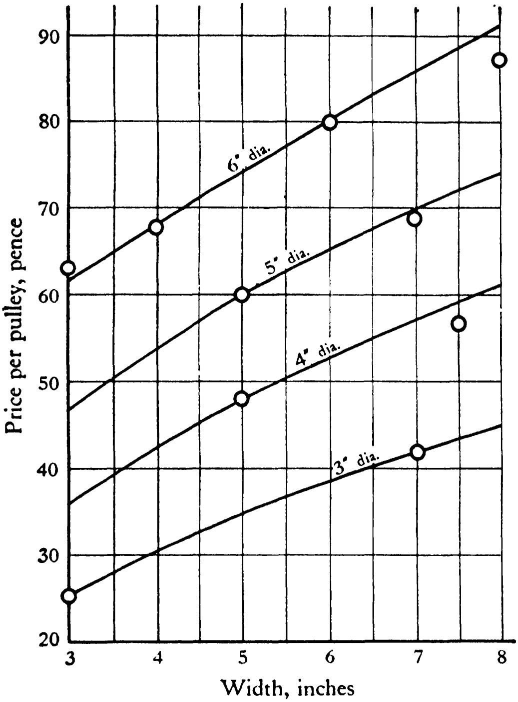


Fig. 15.1.—Price determination from a graph

6. Tentative Prices.

On some classes of work it is exceedingly difficult to estimate the selling price as a considerable amount of experimenting is necessary before the desired results can be achieved. Under such conditions a price may be quoted with a proviso, " The quotation is tentative only and subject to modification when the final costs are known ". Under such conditions the buyer must be very much on the alert, otherwise he may be in for a cost far greater than was expected.

7. Submission of Tenders or Quotations.

The submission of a quotation or the filling in of a tender is the last stage in the work of estimating. The details required must vary according to the known conditions, but such of the following items as are applicable, and any others special to the class of work, should be given.

(*a*) A description of the machine part or job.
(*b*) The quantity.
(*c*) The price for the work, each article, or per dozen, &c.
(*d*) Delivery date or the date on which it is anticipated the work will commence and finish.

In every instance the quotation or tender must be read in conjunction with the other documents attached thereto. According to the circumstances these may be " Conditions of Contract " or " Conditions of Sale ", the specification and all relevant drawings. It is, therefore, very important that no conflicting instructions or information be given. Moreover, the wording should be concise and capable of only one meaning.

Occasions arise where a concern will, after its representatives have visited the site or otherwise made themselves familiar with the job, submit a quotation, and the necessary specification to do a given class of work. Under such conditions the submission of a specification does not exonerate the suppliers from supplying a satisfactory machine or structure. The fact that the firm has, under these conditions, tendered for the job, carries with it the implication that the work will be effectively performed.

8. Destructive Test Allowance.

The conditions of a tender may be such that a percentage of the goods supplied have to be submitted to a destructive test. Under such terms it is important that this be included in the estimate, as the allowance is additional to the normal manufacturing scrap. Failure to take the components required for testing purposes into account means that the desired percentage profit will not be realized.

CHAPTER XVI

Examples of Estimating

A few examples of estimating for a range of articles made in the foundry, machine shop, and finishing sections are given below.

Estimating for Plant Required.

Under some conditions it is necessary to estimate for the plant required to produce a specified daily or weekly output of a given article. Under such conditions the preliminary stages of the work are identical with process planning, and a detailed schedule of all operations and the times must be prepared for the sub-assembly and final assembly of each component. Along with this information the machines necessary for each operation must be specified.

1. **Example.**—A small domestic article is chosen as an example of this phase of estimating, and the information available along with the sample is that a weekly output of 100 gross is desired. The various forming and assembly work is to be done in a small factory which is to be established. All finishing operations of plating, spraying, and similar work are to be done by outside specialist firms.

Part List.—On checking the sample the following part list is drafted:

Part No.	Part	Material	Quantity per set	Finish	Remarks
1	Coil handle.	M.S.	1	B.N.P.	B/O.
2	Rivet.	M.S.	2	B.N.P.	B/O.
3	Handle.	Wood.	1	Sprayed green.	B/O.
4	Eyelet.	Brass.	2	B.N.P.	B/O.
5	Washers.	M.S.	4	B.N.P.	B/O.
6	Small gear.	B.R.M.S.	2	B.N.P.	Made in.
7	Large gear.	B.R.M.S.	1	B.N.P.	Made in.
8	Blades.	B.R.M.S.	4	Hot tinned.	Made in.
9	Bracket.	B.R.M.S.	1	B.N.P.	Made in.
10	Handle wire.	B.D.M.S.	1	B.N.P.	Made in.
11	Frame wire.	B.D.M.S.	1	B.N.P.	Made in.

Estimated Operation Schedule.—A careful examination of each component and the various sub-assembly stages enables one to condense from a mass of detail the following chart. The information listed covers each stage in the production cycle, the class of machine required, the estimated output per machine, the machines required, the number of sets of tools necessary, and indicates where a stand-by set is desirable to ensure continuity of production.

Component	Quantity P/M gross	Operation	Machine required	Output per machine	No. of machines	No. of tools in use	Stand-by sets
Small gear.	800	Blank and pierce.	P.P.	See machine loading chart, fig. 16.1	1	1	1
		Turn up.	No. 2 H.P.		1	1	
Large gear.	400	Blank and pierce.	P.P.		1	1	1
		Turn up.	No. 4 H.P.		1	1	
Bracket.	400	Blank and pierce.	P.P.	As large	for gear.	1	1
		Bend 1st.	No. 4 H.P.		1	1	
		Bend 2nd.	No. 4 H.P.		1	1	
Blades.	1600	Pierce and crop.	Foot press.		1	1	1
		Bend 1st.	No. 4 H.P.		2	2	
		Bend 2nd.	Fixture.			1	
Handle wire.	400	Crop.	No. 4 H.P.		1	1	
		Bend 1st.	No. 4 H.P.		1	1	
		Bend 2nd.	No. 4 H.P.		1	1	
Frame wire.	400	Crop.	No. 4 H.P.		As fo	r handle	wire.
		Bend.	Fixture.			1	

SUB-ASSEMBLY.

1. Blades to eyelet.	200	Fit and close eyelet.	Foot press.	See machine loading chart, fig. 16.1	1	1	1
2. Wood handle to wire.	200	Close in wire on handle.	Fixture.		1	1	
3. Blades, small gears and frame wires.		Thread together.	By ha	nd.			
4. Wood handles and wires to bracket.		Place in position.	By ha	nd.			
5. Sub-assemblies (3) and (4) brought together.		Close bracket down on wires.	No. 4 H.P.		2	2	1
6. Rivet handle on large gear.		Rivet.	No. 4 H.P.		2	2	1
7. Final assembly (5) to (7).		Rivet over.	Fixture.		2	2	1

Machine Loading Chart.—A machine loading chart constructed from the above data is shown in fig. 16.1 and indicates how many hours each machine is expected to work per week in order to give the desired output of 100 gross. It does not require a very careful examination to ascertain

MACHINE LOADING CHART

MACHINE NUMBER	MACHINE	COMPONENT	OPERATION	WEEK'S REQUIREMENTS	DAILY MACHINE LOADINGS				
					M	T	W	TH	F
1	2" A/S POWER PRESS	SMALL GEAR	BLANK AND PIERCE	200 GROSS	←→				
3			TURN UP	200 "	←	—	—	—	→
2	4" S/S POWER PRESS	LARGE GEAR	BLANK AND PIERCE	100 "	←	—	→		
4			TURN UP	100 "		←	—	→	
2	4" S/S POWER PRESS	BRACKET	BLANK AND PIERCE	100 "			←	—	→
5			1st BEND	100 "	←	—	—	—	→
6			2nd BEND	100 "	←	—	—	—	→
7	FOOT PRESS	BLADES	CROP AND PIERCE	400 "	←	—	—	—	→
8	No. 4 H.P.	"	BEND 1st WAY	400 "	←	—	—	—	→
9	FIXTURE	"	BEND 2nd WAY	400 "	←	—	—	—	→
10	No. 4 H.P.	HANDLE WIRES	CROP	100 "	←	→			
11	No. 4 H.P.	" "	BEND 1st WAY	100 "			←	—	→
12	No. 4 H.P.	"	BEND 2nd WAY	100 "			←	—	→
10	No. 4 H.P.	FRAME WIRES	CROP	100 "			←	→	
13	No. 6 H.P.	" "	BEND	100 "	←→		←	—	→
	SUB-ASSEMBLIES								
14	FOOT PRESS	EYELET TO BLADES		200 GROSS	←	—	—	—	→
	BENCH FIXTURE	WIRE TO HANDLE		100 "	←	—	—	—	→
	HAND	THREAD BLADES AND GEARS ON FRAME		200 "	←	—	—	—	→
	HAND	HANDLES IN BRACKETS		100 "	←	—	—	—	→
15	No. 4 H.P.	CLOSE BRACKET		100 "	←	—	—	—	→
16	No. 3 H.P.	GEAR TO HANDLE	RIVET	50 "	←	—	—	—	→
17	No. 3 H.P.	GEAR TO HANDLE	RIVET	50 "	←	—	—	—	→
	FIXTURE	FINAL ASSEMBLY	RIVET	50 "	←	—	—	—	→
	FIXTURE	FINAL ASSEMBLY	RIVET	50 "	←	—	—	—	→

Fig. 16.1

Note:—A/S = Adjustable stroke, S/S = Single stroke, H.P. = Hand press.

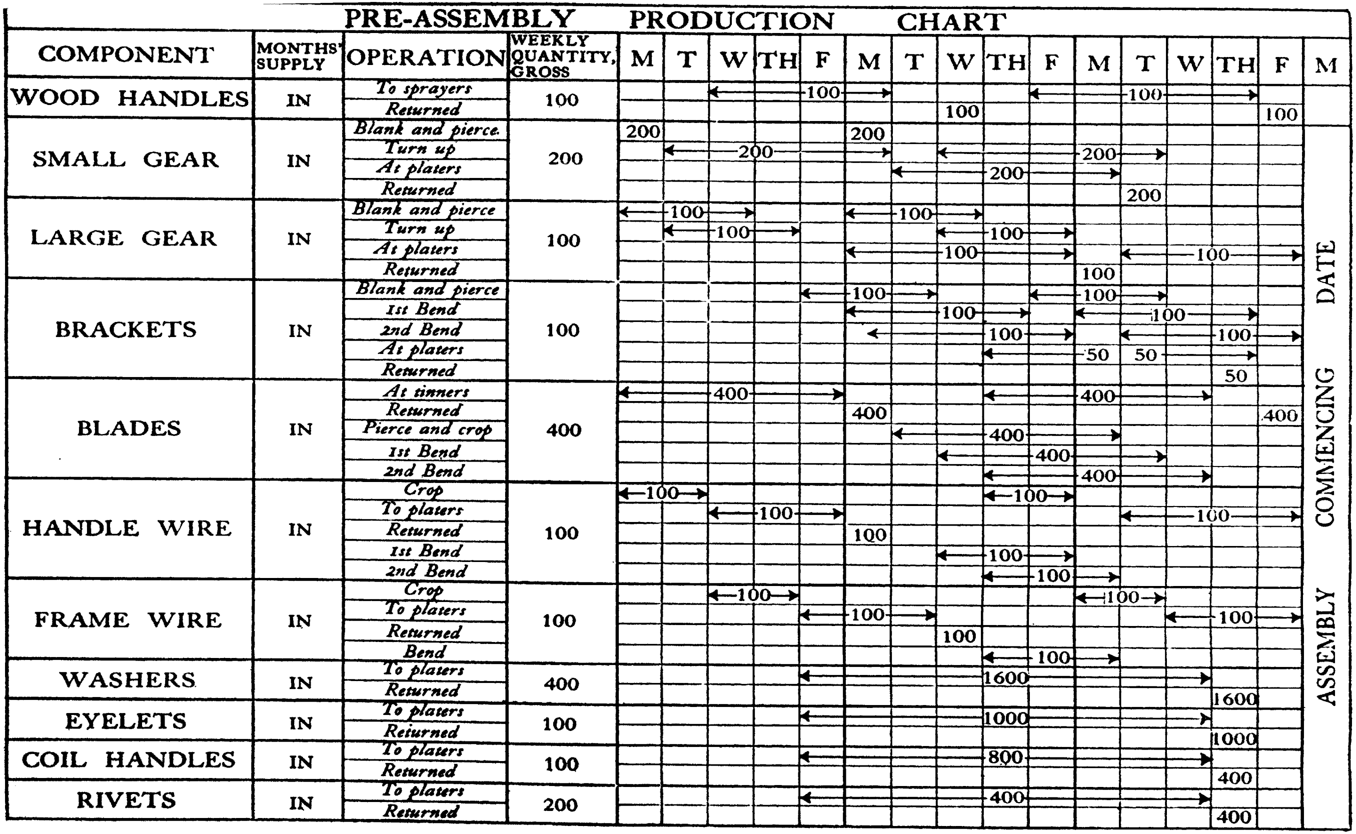


FIG. 16.2

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which has a low estimated machine-hour efficiency. The chart is laid out on the basis of competent operators, with due allowance for contingencies.

Time Lag and Outwork.—In order that the daily output may be achieved a careful study indicates that the material required must be to hand at least 4 weeks before it reaches the assembly stage. This is to cover the time required to manipulate the material under the press, send it out to and bring it back from the platers, tinners, and sprayers. Given that the material is available as stated, it is estimated that there should be a slight build-up of finished components and thus provide a buffer stock to cover contingencies.

Production Chart.—A production chart showing how the material is required and the necessary steps to build up at least a week's supply of parts before assembly is commenced is shown in fig. 16.2. It indicates the quantities to be made and sent to the platers; the amounts received back; the time when cutting the blades should commence. As the blades are made from hot-tinned strip purchased with a rolled edge and in coils, they can pass through each stage from cropping to the final assembly without leaving the premises. The chart shows that the material is bought in the " as-rolled " condition and is sent to an outside concern for tinning.

2. Example from the Foundry.

A small fuse box 10 in. long, 7 in. wide and 2 in. deep with a lid 1 in. deep is to be produced in grey iron. It has the usual lugs and ears with an average thickness of ·156 in. The pattern, supplied by the customer, is of the " loose " type, hence bench moulding is to be followed. The articles will be taken in one-gross batches.

The points to note with this estimate are (*a*) the customer supplies the patterns, hence there cannot be any pattern charge; (*b*) ordering in gross batches gives the moulder a chance to get into his stride, hence so long as the orders keep on this basis the question of small quantities does not arise; (*c*) the buying concern lies within the motor transport area, hence no transport charges have to be considered; (*d*) an agent is paid 5 per cent commission.

The work of estimating the selling price for this article is as follows:

Weights of Parts.

Box. Volume of base $= 10 \times 7 \times {\cdot}156 \qquad = 10{\cdot}9$ c. in.
Volume of sides $= 2 \times 10 \times 2 \times {\cdot}156 +$
$2 \times 7 \times 2 \times {\cdot}156 \qquad = 10{\cdot}6$ c. in.
Volume of lugs $= 4 \times 1 \times 1 \times \frac{1}{2} + 2 \times \frac{1}{2} \times 1 \times 1 = 3.$
Lid. Volume of top $= 10 \times 7 \times {\cdot}156 \qquad = 10{\cdot}9.$
Volume of sides $= 2 \times 10 \times 1 \times {\cdot}156 +$
$2 \times 7 \times 1 \times {\cdot}156 \qquad = 5{\cdot}3.$
Volume of lugs $= 2 \times \frac{1}{2} \times 1 \times 1 \qquad = 1.$
Total estimated volume $\qquad 41{\cdot}7$ c. in.
Estimated weight of box and lid $= 41{\cdot}7 \times {\cdot}26 \qquad =$ say, 11 lb.

Weight of Process Scrap.

With this class of article the problem is to get sufficient hot metal into the mould quickly, so as to avoid the loss of heat as the molten metal passes across the sand. For this reason " double " pouring is suggested as a preventative against " white iron " or " cold shut ". The rough details of the gate and runner are:

Down gate 2 in. deep and ¾ in. dia.	·88 c. in.
Runner ¾ wide, 9 in. long, and ¼ in. deep	1·69 c. in.
Volume of 1 runner	2·56 c. in.,
say, 3 c. in. with basin.	

Hence total volume of the 4 gates and runners is 12 c. in. Note there are two on the box and two on the lid.

Weight of process scrap = 12 × ·26 = say, 3½ lb.

Operations.

The conditions operating in the foundry are such that each moulder pours his own moulds and attends to the milling and damping down of the sand. Hence, when estimating the time, due allowance must be made for the various incidental jobs. Under these conditions the operation schedule is:

Mould drag for box.
Mould cope for box and cut gate.
Close mould.
Mould drag for lid.
Mould cope for lid and cut gate.
Close mould.
Pour, say, six completed boxes at a time.
Open mould and remove gates and runners.
Shot blast.
Fettle.

Estimated Production Times.

With the above schedule prepared the production times can be determined, and for each box and lid they are, inclusive of all incidentals, as follows:

Moulding and pouring	20 min.
Shot blasting	3 min.
Fettling	1 min.

Estimated Cost.

The details as to the cost of the iron at the cupola spout have been computed to be 1¾*d.* per lb., whilst the scrap returns are valued at a 1*d.* per lb. Each section in the foundry has its own oncost rate with a general rate to cover the administration, laboratory, and selling sections. Using the known data, the estimated cost and then the selling price are determined.

Material.

		s.	d.
Gross 14½ lb. at 1¾*d.*/lb.	25½*d.*		
Process scrap 3½ lb. at 1*d.*/lb.	3½*d.*		
Net metal cost		1	10

Operations.

	Labour s.	Labour d.	Oncost rate	Oncost s.	Oncost d.
Mould and pour	1		3*s.* per hour	1	
Shot blast		1·5	6*s.* ,, ,,		3·6
Fettle		·6	3*s.* ,, ,,		·6
	1*s.* 2·1*d.*			1*s.* 4·2*d.*	

	s.	d.
Labour	1	2·1
Works oncosts	1	4·2
	4	4·3
Administrative oncosts at 2*s.* per hour		9·6
Total costs	5*s.* 1·9*d.*	

Selling Price.

With the estimated cost known, the next stage is to determine the selling price. This must ultimately depend upon policy and outside conditions, but assuming that at least 10 per cent is looked for on the selling price and an agent's commission of 5 per cent is to be taken into account, then the selling price is made up as follows:

	s.	d.
Estimated cost, say	5	2
Profit, say,		9
Agent's commission		3½
Total selling price	6*s.* 2½*d.*	

Given very keen competition, the possibility of cutting down the profit margin must be considered.

3. Example of Capstan Lathe Work.

A ½-in. B.S.W. bolt 2 in. U.H is to be made from 35-ton bright hexagon bar, B.S. 970 En 6, C.D., B.H. No., say, 190, on a capstan lathe and it becomes necessary to estimate the cost of production. Taking the work in the logical manner the following layout is obtained.

Material Requirements.

Material: bright drawn hexagon bar ·920–·915 in. across flats, 1·06 in. across corners. Lengths to be 6 ft. long.

Net length of article, 2·437 in.
Allowance for parting tool, ·125 in.
Gross length of article, 2·562 in.
Allowance for stub end, say, 2 in.

$$\text{Then number of articles per bar} = \frac{72-2}{2\cdot562} = 27.$$

$$\text{Number of bars per gross (150)} = \frac{150}{27} = 5\cdot6.$$

$$\text{Length of bar per gross} = 5\cdot6 \times 6 = 33\cdot6 \text{ ft.}$$

$$\text{Weight per gross using Table 171, p. 349} = 33\cdot6 \times 2\cdot40 = 81 \text{ lb.}$$

If using the expression

$$\text{Weight of bar} = 12\cdot5LW \text{ (p. 49)}$$

and assuming that the gross length of the bar per article is, say, 2·75 (taking a rough figure), then

$$\text{Estimated weight} = 12\cdot5 \times 2\cdot75 \times 2\cdot40$$
$$= \text{say, 83 lb.}$$

Given the use of random lengths, there may be a rather wide difference between the estimated and actual weights, and this point needs watching when ordering material. Owing to the low value of steel swarf the question of process scrap is ignored.

Determining the Machining Speeds.

The next stage is to arrange the operation cycle and determine the appropriate machining speeds. In the example the cutting medium is taken as a 18 . 4 . 1 h.s.s. When rough-breaking the bar down to size, a tool having a 30° approach angle and a nose-radius of $\frac{1}{8}$ in. is used; for finish-turning one having a $\frac{1}{16}$-in. nose-radius is chosen. A sulphurized cutting compound is to be used.

The tentative operation-cycle, feeds, &c., are listed:

Rough turn: feed ·010 in., depth of cut, say, ·29 in.
Finish turn: feed ·004 in., depth of cut, say, ·020–·015 in.
Form head and radius: feed, say, ·0015 in.
Part off: feed, say, ·002 in.

Using the tables and charts given above, the cutting speeds can now be computed. But first it is necessary to fix the required tool-life. The chosen basis is resharpening once every 9-hour shift. Assuming the component takes three minutes to make and a tool is cutting, say, half a minute at a time, then

$$\text{Time tool works per shift} = \frac{\cdot5 \times 9 \times 60}{3} = 90 \text{ min.}$$

Known data:

V_b or rough-cutting speed from Table 39, p. 109	185 f.p.m.
V_b or finish-cutting speed from Table 44, p. 111	360 f.p.m.
T_l or tool-life factor from Table 21, p. 85, roughing	·95
finishing	·96
L_u or lubricating factor from Table 25, p. 94	1·18
M or machining index for En 6 from Table 60, p. 121	say, ·56
T_m or tool-material factor from Tables 39, 44, p. 109, 111	1·0
T_s and C_r are both	1·0

Now V_c for roughing $= V_b \times M \times L_u \times T_l \times T_m \times T_s \times C_r$

$$= 185 \times {\cdot}56 \times 1{\cdot}18 \times {\cdot}95 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 = \text{say, } 116 \text{ f.p.m.}$$

and the chart, fig. 2.7, for a bar, say 1·06 across corners gives, say, 415 r.p.m.

V_c finishing $= 360 \times {\cdot}56 \times 1{\cdot}16 \times {\cdot}96 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 =$ say, 225 f.p.m., giving, for a $\frac{17}{32}$ in. dia. bar, say, 1620 r.p.m.

Forming.—The speed for the forming operation is computed in much the same way and the known data are:

V_b is taken from Table 41, p. 110	130
L_u is taken from Table 25, p. 94	1·16
T_l comes from Table 21, p. 85	·96
T_m comes from Table 41, p. 110	1·0
T_s comes from Table 41, p. 110	1·0
M the material factor is taken from Table 60, p. 121	·56
C_r for rake is taken from Table 41, p. 110	1·0

Then the speed whilst forming $= 130 \times {\cdot}56 \times 1{\cdot}16 \times {\cdot}96 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0$ say, 81 f.p.m. or, with a hexagon bar, say 1·06 in. across corners, 300 r.p.m.

Parting Off.—This operation commences at a diameter of ·750 in. after the forming; the data to use are:

V_b (Table 42, p. 110)	490
M (Table 60, p. 121)	·56
L_u (Table 25, p. 94)	1·16
T_l (Table 21, p. 85)	·96
T_m (Table 42, p. 110)	1·00
T_s (Table 42, p. 110)	1·00
C_r (Table 42, p. 110)	1·0

Speed for parting off $= 490 \times {\cdot}56 \times 1{\cdot}16 \times {\cdot}96 \times 1{\cdot}0 \times 1{\cdot}0 \times 1{\cdot}0 =$ say, 300 f.p.m. or, say, 1540 r.p.m. at ·750 in. diameter.

Screwing.—The speed for screwing (see Table 28 p. 98) is taken at, say, ·2 of the speed chosen for the roughing operation, hence

Screwing speed $= 116 \times {\cdot}2 =$ say, 23 f.p.m. or, say, 175 r.p.m.

Checking Machine Data.—The next stage is to bring the above figures into line with those available on the machines chosen for the work. An examination gives the following r.p.m. and feeds; for comparison the computed figures are given alongside.

Operation	Machine data		Estimated data	
	Speed, r.p.m.	Feed, in.	Speed, r.p.m.	Feed, in.
Rough-turning.	332	·01	415	·01
Finish-turning.	1500	·004	1620	·004
Forming.	245	·002	300	·0015
Parting off.	1500	·002	1540	·002
Screwing.	188		175	

The speeds and feeds fit in fairly closely with those estimated, hence no great change is called for.

Power Requirements.—The machine is driven by a 5-h.p. motor and a rough check is required to ensure that sufficient power is available for the heaviest cut.

Force (estimated from Table 151, p. 242, for En 2 C) is, say, 900.

Cutting force factor P_c (p. 245) for En 6 is, say, $\frac{142,000}{122,000} = 1{\cdot}16$.

Actual cutting speed is, say, 93 f.p.m.

$$\text{H.P. required} = \frac{FP_cV_c}{33,000} = \frac{900 \times 1{\cdot}16 \times 93}{33,000} = \text{say, } 3.$$

On this basis the proposed cut is satisfactory, but the question may be raised, " Why not use the full h.p. available?" This may be done when the machine efficiency is known, by changing the cutting medium or slightly increasing the feed. It is ignored here.

Machining Times.

Using the given data, the time for each operation can be computed and estimates or time studies used for indexing the turret, &c. A list of times for the production of the component is given below.

Operation.	Time, min.
Feed to stop	·2
Index and bring tool to work	·15
Rough-turn to ·540–·530 in. dia., 2 in. along	·61
Index and bring tool to work	·15
Finish-turn to ·499–·496 in. dia., 2 in. along	·33
Index and bring tool to work	·15
Form head cross traverse, say, ·3 in.	·61
Screw first pass	·06
Index and bring die head to work	·15
Screw second pass	·06
Part off	·13
Index	·15
Machining time	2·75
Fatigue, gauging, and incidentals, say, 20%	·55
Total time, each	3·3 min.

Time per gross, say, 8 hours.

Works Costs.

From the above data the desired information is now assembled so that the works cost may be ascertained.

	£.	s.	d.
Material.			
Total weight per gross: 81 lb. at 3·16*d.* per lb.	1	1	4
Process scrap (return value nil)			
Total cost per gross	£1	1	4
Labour.			
Turning: 8 hours at 1*s.* 8*d.* an hour		13	4
Cleaning, 15 min.			6
Oncosts.			
Works: 8 hours at 7*s.* 6*d.* per hour	3		
Works, cleaning, ¼ hour at 2*s.* 6*d.*			6
Selling and administrative, &c., 8¼ hours at 2*s.* per hour		16	6
Cost per gross	£5	12*s.*	2*d.*

If the job had been done on an automatic, the direct labour costs would have been nearly non-existent but the oncosts must have been much higher. This may be seen in the following example.

4. Example of Estimating for Automatic Lathe Bar Work.

In order to outline the work involved when estimating for work off automatic lathes the simple example of a $\frac{5}{16}$ in. dia. Whitworth bolt is chosen. The material is to be 35–45 ton steel and the dimension under the head is 1¼ in.; the head is ·275 in. thick and ·601 in. across flats, say ·7 in. across corners.

Material Weight.—The hexagon bar is assumed to be purchased in 6-ft. lengths. During machining an allowance for parting off of ⅛ in. is required. Hence:

Length of bar for 1 article $= 1{\cdot}25 + {\cdot}275 + {\cdot}125 = 1{\cdot}650$ in.

Number of articles per length allowing 2 in. stub end $= \dfrac{72 - 2}{1{\cdot}650} =$ say, 42.

Length of bar per manufacturing gross $= 6 \times \dfrac{150}{42} = 21{\cdot}5$ ft.

Weight of bar (Table 171, p. 349) $= 21{\cdot}5 \times 1{\cdot}03 = 22{\cdot}2$ lb.

Or using the expression

$$\text{Weight of bar} = 12{\cdot}5LW \text{ (p. 49),}$$

and assuming $L = 1{\cdot}75$ in.,

$$\begin{aligned}\text{Weight of bar} &= 12{\cdot}5 \times 1{\cdot}75 \times 1{\cdot}03\\ &= 22{\cdot}6 \text{ lb.}\end{aligned}$$

Operation Schedule and Feeds.—The next stage is to list the operations required, and give the prospective feeds. The tentative suggestions in this direction are:

Operation.	Feed, in.	Tool position
Chamfer bar at 45° for turning tool	·006	Turret
Turn ·312–·310 in. dia., $1\frac{1}{4}$ in. along	·008	Turret
Form head and gap for parting	·001	Rear cross-slide
Screw: T.P.I. = 18; cutting edges in die head, 4, and chip thickness (p. 230) is given by $T =$ sin (throat angle) × pitch/N $= \dfrac{\sin 33^\circ \times 1}{4 \times 18} = \dfrac{\cdot544}{72} =$	·00755	Turret
Part off	·002	Front cross-slide

Tool Material and Life.—The tool material is assumed to be the standard 18 . 4 . 1 h.s.s. and the life between each sharpening is to cover one complete shift. Assuming that the shift is one of 9 hours and that experience shows that in this particular department a 15 per cent allowance is necessary to take care of the many incidentals, the actual working-time per shift is reduced to $7\frac{1}{2}$ hours. Knowing this, the various tools are estimated to be working per day:

Chamfering tool	1 hour.
Turning tool	3 hours.
Forming tool	1 hour.
Screwing die	1 hour.
Parting-off tool	1 hour.

The above figures are in the nature of suggestions and subject to modification after the estimate has been developed.

Cutting Speeds.—Knowing the tool-life and material, the feed and material to be cut, the cutting speed for the respective tools can be computed using the expression

$$V_c = V_b \, . \, M \, . \, L_u \, . \, T_l \, . \, T_m \, . \, T_s \, . \, C_r,$$

the data being abstracted from Tables 21, 24, 25, 37 to 45, and 60.

Chamfering $V_c = 199 \times \cdot62 \times 1\cdot16 \times 1\cdot0 \times 1\cdot0 \times 1\cdot48 \times 1\cdot0 = 212$ f.p.m.
Turning $V_c = 190 \times \cdot62 \times 1\cdot16 \times \cdot89 \times 1\cdot0 \times 1\cdot0 \times 1\cdot0 = 123$ f.p.m.
Form head $V_c = 155 \times \cdot62 \times 1\cdot16 \times 1\cdot0 \times 1\cdot0 \times 1\cdot0 \times 1\cdot0 = 111$ f.p.m.
Screw $V_c = 41 \times \cdot62 \times 1\cdot16 \times 1\cdot0 \times 1\cdot0 \times 1\cdot0 \times 1\cdot0 = 30$ f.p.m.
Part off $V_c = 490 \times \cdot62 \times 1\cdot16 \times 1\cdot0 \times 1\cdot0 \times 1\cdot0 \times 1\cdot0 = 350$ f.p.m.

Converting these speeds into the appropriate r.p.m.:

$$\text{Chamfering} = \frac{3{\cdot}82 \times 212}{{\cdot}694} = 1168.$$

$$\text{Turning} = \frac{3{\cdot}82 \times 123}{{\cdot}694} = 677.$$

$$\text{Form head} = \frac{3{\cdot}82 \times 111}{{\cdot}694} = 611.$$

$$\text{Screw} = \frac{3{\cdot}82 \times 30}{{\cdot}312} = 367.$$

$$\text{Part off} = \frac{3{\cdot}82 \times 350}{{\cdot}312} = \text{say, } 4280.$$

On checking the machine capacity chart the nearest speeds are found to be 665 and 245 r.p.m. respectively. This means that turning the shank governs the production cycle, and the other stages must be reduced in speed to suit the main operation.

Time Schedule.—When engaged on this class of work it is wise to draft a schedule similar to that given below so that operations which overlap may be taken into account when computing the production times.

Operation	Actual op.		Overlapped op.		Remarks
	Time, sec.	Rev.	Time, sec.	Rev.	
Chamfer.	3·32	36·7			Travel ·22 in., feed ·006 in.
Index.	1·00	11·1			
Turn.	14·4	159			Travel 1·27 in., feed ·008 in.
Index.	1·00				
Change speed.			·5		
Screw.	4·9	20			Slow speed $\frac{20 \times 60}{245} = 4{\cdot}9$ sec.
Change speed.	·5				
Index.			1·0	11·1	
Form head.	18·5	205			Travel ·205 in., feed ·001 in.
Part off.	9·00	100			Travel ·200 in., feed ·002 in.
Total machining time.	52·62 sec.				

Then the estimated output per shift is, say, 476, or 3 gross 4 dozen.

Checking Tool-life.

$$\text{Chamfering} = \frac{3{\cdot}32}{60} \times 476 = 26{\cdot}4 \text{ min.}$$

$$\text{Turning} = \frac{14{\cdot}4}{60} \times 476 = 115 \text{ min.}$$

$$\text{Screwing} = \frac{4{\cdot}9}{60} \times 476 = 39 \text{ min.}$$

$$\text{Forming} = \frac{18{\cdot}5}{60} \times 476 = 147 \text{ min.}$$

$$\text{Parting off} = \frac{9}{60} \times 476 = 72 \text{ min.}$$

Arising out of the above analysis, and omitting a check on the h.p. input, the following comments must be given:

(*a*) The chamfering tool having a cutting period of, say, ½ hour is quite safe, as both cutting speed and tool-life are less than the preliminary estimates.

(*b*) The life of the turning tool, on checking, comes out at, say, 2 hours, in place of the 3 as given in the preliminary estimate. As the spindle speed of the machine is the governing factor, the tool-life, whilst on the safe side, may be regarded as satisfactory, although the possibility of increasing the feed should not be overlooked.

(*c*) The screwing diehead is used for a shorter period than that upon which the cutting speed was based. Moreover, the cutting speed itself is reduced. Thus, assuming that other things are satisfactory, the lower machine speed and shorter cutting period ensures a good tool-life.

(*d*) The time the forming tool will be engaged during the day is twice that upon which the cutting speed was based. This factor combined with the increase in speed from 611 to 665 r.p.m. necessary to suit the machine speed gives rise to unsatisfactory conditions. To avoid trouble it would be better to use a cemented-carbide tool for this operation and keep the turning speed at the present figure.

(*e*) The period of cutting for the parting tool is slightly in excess of that upon which the cutting speed was based. Yet, in order to accommodate the other operations, the optimum speed has to be reduced considerably. Hence there should be no trouble due to the period between each resharpening being increased from 60 to 72 min. In practice the tool should be found to last, say, two full shifts.

Cost Summary.—The final stage in the estimate is to give the cost summary. With a battery of machines to set and attend, there is no direct labour; the machine oncost figures are adjusted to cover these. The cost summary is:

	£.	s.	d.
Material at 28*s*. 6*d*. per cwt.		5	8
Note no allowance is made for any process scrap as the value of steel scrap is very small			
Machine oncosts, gross, 2·7 hours at £1 per hour	2	14	
Cleaning labour and shop oncosts			9
Administrative oncosts at 3*s*. per hour		8	3
Total cost per gross	£3	8*s*.	8*d*.

To this figure would be added the necessary selling expenses, carriage and commission, if any.

5. Example Relating to Moulded Goods.

When estimating for moulded goods the various stages in the work are very similar to the previous examples. As with the foundry the question as to the most economic method must be carefully considered. This depends upon the quantity required and size. The latter governs the possibility of using multi-impression moulds. In this direction it may be necessary to point out that the curing time is roughly the same whether the mould has one or twenty impressions. There is, however, a marked difference in the labour and associated charges per unit produced.

Take as a simple example an ash tray, 4½ in. dia. with a well 3 in. dia. and ½ in. deep; the wall thickness is to be ·08 in. The given details are that a minimum of 200 gross will be required during the first twelve months' run.

Mould Design.—Dealing first with the mould design, the capacity of the press needs checking. In this instance it is a 200-ton machine and the platens are 18 in. square. Assuming that the maximum pressure required is 1 ton per sq. in., then:

$$\text{Pressure per article} = \cdot 7854D^2 = \cdot 7854 \times 4{\cdot}5^2 = 16 \text{ tons.}$$

$$\text{Number of impressions possible} = \frac{200}{16} = 12.$$

Platen size 18 in. square.

Number of impressions = 3 each way or 9 in all.

Given a 200-ton press, there should be no difficulty in working with a 9-impression mould.

Weight of Powder.—The process of curing leads to little or no loss in weight so long as the powder is kept dry. For flash a 5 per cent allowance is usually sufficient; for manufacturing scrap the gross is taken at 150. Then

$$\text{Weight per gross in lb.} = \text{volume of article} \times \frac{\text{wt. (oz./c. in.)}}{16} \times 150 \times 1{\cdot}05$$

$$= 9{\cdot}86VW \text{ (see Table 173, p. 351, for values of } W\text{).}$$

$$\text{Volume of article} = (\cdot 7854D^2 + \cdot 5\pi d) \times \cdot 08$$

$$= (\cdot 7854 \times 4{\cdot}5^2 + \cdot 5 \times 3{\cdot}1416 \times 3) \times \cdot 08$$

$$= 1{\cdot}656 \text{ c. in.}$$

$$\text{Weight per gross} = 9{\cdot}86 \times 1{\cdot}656 \times 1{\cdot}07 = \text{say, } 17\tfrac{1}{2} \text{ lb.}$$

Tool or Mould Cost.—The moulds are assumed to be made out to suit a standard 9-impression bolster. The cost per impression is given as £20. Spreading the mould cost of £180 over the first 200 gross gives a cost per article of:

Tool cost per article on the basis of recovery on 200 gross

$$= \frac{180 \times 240}{200 \times 144} = 1\tfrac{1}{2}d. \text{ each.}$$

Operations—The operation cycle for this class of work is given below with fictitious details of the labour and overhead charges.

Op. No.	Operation	Details per cure 9 articles				
		Quantity	Time, min.	Labour cost, pence	Works oncosts, pence	
					Per hour	For job
1	Make pellets.	36	2·0	·75	60	2·0
2	Clean mould with blast.	9	·2			
3	Place in pellets.	36	1·0			
4	Close press.		·2			
5	Cure.	9	3·0	3·0	180	16·8
6	Open press.		·2			
7	Remove articles.	9	1·0			
8	Fraze.	9	1·5	·5	30	·75
9	Barrel burnish (in 2-gross lots).	9	4·0	·5	30	2·0
10	Inspect.	9	1·0	·5	15	·125
Summary for 1 heat.		9	14·1	5·25		21·675

Cost summary per gross:

	£.	s.	d.
Powder at 3*s*. per lb. . . . 17½ lb.	2	12	6
Labour		7	3½
Shop oncosts	1	10	0
Administrative oncosts at 3*s*. per hour for 3·93 hours ..		11	9
Tool cost		18	0
	£5	19	6½
Cost each			10

6. Example of Press Work Estimating.[5]

As an example of estimating for press work the brass shaving-stick container (fig. 16.3) is chosen; the production involves cut and cupping, drawing, trimming, and threadrolling. The article is assumed to be made in fairly large quantities, hence use is made of roll and other feeding devices.

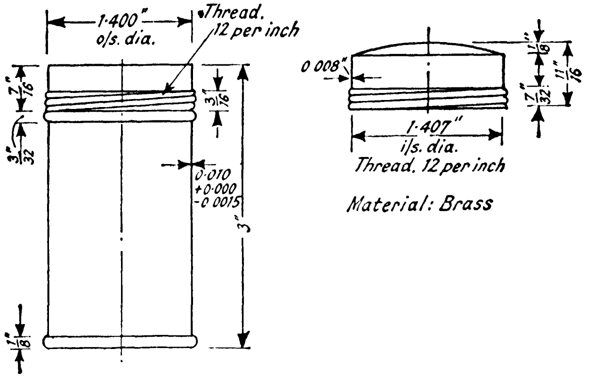

Fig. 16.3.—Brass shaving-stick container

Material.

Now the work of forming the metal to the required size and shape is in the nature of deep drawing, therefore the brass alloy should be on the following basis:

(*a*) For the lid the lowest quality would be a 67/33 mixture; it would be better if costs permit the use of a 70/30 mixture.

(*b*) The body should be made from a 70/30 mixture, that is cartridge metal, failing this then the 67/33 alloy.

Condition.—The metal should be supplied annealed, in coils weighing up to 35 lb. so that they may be handled by women operators. The surface finish must be of the best quality and free from any trace of " orange peel ".

Blank and Strip Sizes.—The calculations for determining the blank and strip sizes are (p. 51) as follows:

Lid.

Blank dia. for finished component

$$= \sqrt{(d^2 + 4dH)}$$
$$= \sqrt{(1{\cdot}407^2 + 4 \times 1{\cdot}407 \times {\cdot}69)}$$
$$= 2{\cdot}42 \text{ in.}$$

Blank dia. with trimming allowance of $\frac{1}{8}$ in.

$$= \sqrt{(1{\cdot}407^2 + 4 \times 1{\cdot}407 \times {\cdot}81)}$$
$$= 2{\cdot}56 \text{ in.}$$

Body.

The general outline of the body indicates that several drawing operations must follow the blanking and cupping stage. To ensure a clean surface for the subsequent polishing operations it is essential that the material be "ironed" during the drawing operations. To ensure this the initial thickness must be adjusted and, assuming three drawing stages, the initial metal is taken as ·020 in. thick.

$$\text{Then the equivalent height } H = \frac{ht}{T}$$
$$= 3 \times \frac{10}{20} = 1{\cdot}5 \text{ in.}$$

$$\text{Blank diameter} = \sqrt{(d^2 + 4dH)}$$
$$= \sqrt{(1{\cdot}4^2 + 4 \times 1{\cdot}4 \times 1{\cdot}5)}$$
$$= 3{\cdot}3 \text{ in.}$$

The next stage is tentatively to plan out the drawing diameters and wall thickness so that the scrap produced by the trimming operations may be taken into account. Working from a blank of roughly 3⅜ in. dia., the prospective production stages for cupping and drawing along with the proposed wall thickness may be listed:

Cup to 1⅞ in. dia. with a wall thickness of ·020 in.
1st draw to 1·7 in. dia. to a wall thickness of ·017 in.
2nd ,, 1·56 in. ,, ,, ,, ·014 in.
3rd ,, 1·4 in. ,, ,, ,, ·010 in.

Allowance for 1st trim, ⅛ in., then metal removed in terms of original thickness $= {\cdot}125 \times 1{\cdot}562 \times 3{\cdot}14 \times \frac{17}{20} = {\cdot}52$ sq. in.

Final trimming allowance ¼ in., then metal removed in terms of original thickness $= {\cdot}25 \times 1{\cdot}4 \times 3{\cdot}14 \times \frac{10}{20} = {\cdot}55$ sq. in.

Hence total area of blank

$$= (3{\cdot}3^2 \times {\cdot}7854) + {\cdot}55 + {\cdot}52 = 9{\cdot}62 \text{ sq. in.}$$

$$\text{Blank dia.} = \sqrt{(9{\cdot}62 \times 1{\cdot}272)} = 3\tfrac{1}{2} \text{ in.}$$

Strip Width and Metal Weights.

The blank diameter for the cap is known to be $2\frac{9}{16}$ in. and, allowing a web width of $\frac{3}{32}$ in., the strip becomes $2\frac{3}{4}$ in. wide. The bridge between the blanks is, say, ⅛ in., which gives a pitch of $2\frac{11}{16}$ in. Table 168, on p. 347, gives the weight of brass ·008 in. thick as ·357 lb. per sq. ft. On p. 53 the weight per manufacturing gross for sheet-metal components is given as:

$$\text{Weight in lb.} = 1{\cdot}04\,AW.$$

$$\text{Hence total weight of strip per gross} = 1{\cdot}04AW$$
$$= 1{\cdot}04 \times 2\tfrac{3}{4} \times 2\tfrac{11}{16} \times {\cdot}357$$
$$= 2{\cdot}75 \text{ lb.}$$

ESTIMATE For Shaving Stick Case
Quantity 1200 Gross during 12 mths.
Mark None
Special Remarks Delivery by own lorry

Material Brass
Req. per Week 25 Gross
Commence Dely. 18 weeks.

Drg. No.

Comp. No. 4321
Finish N.P. and Polish
Promised per Week 15 Gross
Complete Order

Est. No.	1346
Date	2.10.7
To Est. Dept.	2.10.7
To Sales	5.10.7
Cust. No.	376
Issued by	E.C.

Material per Gross

Part	Cap			Body					
Material.	Brass 67/33			Brass 67/33					
Size.	2¾ × ·008			3¾ × ·020					
How Required.	Coil.			Coil.					
Condition.	Annealed.			Annealed.					
	Lb.	@ per lb.	Cost	Lb.	@ per lb.	Cost	Lb.	@ per lb.	Cost
Total Weight.	2·75	1/2	38·6	12·7	1/1	165·1			
Less Process Scrap.	1·04	5	5·2	4·75	5	23·7			
Net Cost (pence)			33·4			141·4			

Material per Gross

Part									
Material. Size. How Required. Condition.									
	Lb.	@ per lb.	Cost	Lb.	@ per lb.	Cost	Lb.	@ per lb.	Cost
Total Weight Less Process Scrap.									
Net Cost									

Estimated by A.E.W. Date 3.10.7

Estimate Summary per Gross (pence)

Part	Cap	Body				
Material.	33·4	141·4				
Labour (direct).	134·06	236·9				
Set up.						
Process Mat.						
Works o/c.	168·1	511·8				
Works Costs.	335·56	890·1				
Admin. o/c.	33·55	89·2				
Selling o/c.	67·10	178·0				
Commission.						
Discount.						
Carriage.						
Works, Admin. and Selling charges.	436·21	1157·3				
Pattern charge.						
Tool charges.						
Small Qty. Set-up charge.						
Total.	436·21	1157·3				

Part	Total cost per gross
	£ s. d.
Cap	1 16 5
Body	4 16 6
Tools	3 2
	£6 16 1

Quot. No. - 2365

Price
Per gross £8, 5s.

Date - 7 10 7

General Remarks

Tool cost spread over the first estimated 1000 G. For first set of tools only. Tools remain our property.

Sheet No. 1

No. of Sheets, 4

Approved C.R.S.

$$\begin{aligned}\text{Weight of article per gross} &= 1{\cdot}04 \times 2{\cdot}42^2 \times {\cdot}7854 \times {\cdot}357\\ &= 1{\cdot}71 \text{ lb.}\\ \therefore \text{ Process scrap} &= 1{\cdot}04 \text{ lb.}\end{aligned}$$

The size of the blank for the body is given at $3\frac{1}{2}$ in., hence allowing a side web of $\frac{1}{8}$ in. the width of the strip becomes $3\frac{3}{4}$ in.; with a bridge of $\frac{1}{8}$ in. the pitch is $3\frac{5}{8}$in. The weight per sq. ft. for brass ·020 in. thick is given in Table 168, p. 347, as ·894 lb.

$$\begin{aligned}\text{Then total weight per gross} &= 3\tfrac{3}{4} \times 3\tfrac{5}{8} \times 1{\cdot}04 \times {\cdot}894 = 12{\cdot}7 \text{ lb.}\\ \text{Net weight per gross} &= 3{\cdot}3^2 \times {\cdot}7854 \times 1{\cdot}04 \times {\cdot}894 = 7{\cdot}95 \text{ lb.}\\ \therefore \text{ Process scrap} &= 4{\cdot}75 \text{ lb.}\end{aligned}$$

Operation Schedule.

The next stage is to draft the operation schedule. In practice this article is polished and plated and the full list of operations is given. It must, however, be understood, that the times and prices are fictitious. The details are given on the estimate forms illustrated in the folders and on pp. 342–3.

7. Estimating Forms.

With all estimating it is essential that the work is done and recorded in a manner which permits the various details to be understood readily by all concerned. For this purpose forms should be drafted to suit the class of work handled. One set as used for light engineering production is given for Example 6 above, and is made up of three sheets; the first (folder) is used for recording details of the article, delivery requirements, material costs and weights, and the final estimate summary. The second (folder, p. 342) is used to list all the new equipment required to produce the articles, whilst the third (pp. 342–3) is used to give all details appertaining to production. Calculations as to material weights, operating times and wage rates are omitted, as the understanding is that each estimator keeps the working sheets in a loose-leaf folder so that quick reference can be made as and when necessary. Where possible, full use should be made of any available accounting machines. The number of copies of each estimate will depend upon the size of the establishment. Normally, two copies are sufficient, one remaining in the estimate department, the other going to the cost or sales office. For civil engineering the recommendations of the I.C.E. should be followed.

PRODUCTION ESTIMATE For Shaving-stick Container (Cap) Date 3.10.7 Est. No. 1346

Op. No.	Operations	Labour		Shop oncosts		Process material		Plant		Production		
		P/W rate per gross	D/W rate per	Rate P/H	Cost P/Gr.	Qty. per gross	Cost	Type and size	Mc. No.	Set-up time	Hourly production	Est. scrap percentage
1	Blank and cup.	·6		5/-	2·4			S.A. press	1	1 hour	25 G.	·01
2	Trim.	·48		4/-	1·6			T.L.	1	½ hour	30 G.	·01
3	Threadroll.	·48		4/-	1·6			T.R.	1	1 hour	30 G.	·01
4	Clean.	3·5		3/-	4·5			Vats			8 G.	
5	Grease mop.	48·0	Nil	3/6	56·	Nil	Nil	P.S.	1		8 doz.	
6	Colour off.	36·0		3/6	42·			P.S.	1		1 G.	
7	Wire up.	1·5		2/-	4·			Bench			6 G.	
8	N.P. and dry.	6·0		5/-	10·			Vats and oven			6 G.	
9	Unwire.	1·5		2/-	4·			Bench			6 G.	
10	Polish.	36·0		3/6	42·			P.S.	2	1 hour	1 G.	
	Assembly (inspect, assemble, wrap in tissue).		Indirect					Note: Additional polishing plant required to give 25 G. per week.			2 G.	
	Labour, pence	134·06		Shop oncosts, pence	168·1	Process mat		Plant				

Sheet No. 3 No. of Sheets, 4 Estimated by E.F.R. Date 3.10.7 App. C.R.S.

TOOL AND PATTERN ESTIMATE FOR CASE, SHAVING STICK BODY AND COVER. DATE 3.10.7 EST. NO. 1346

Op. No.	Operation	Material costs		Direct Labour on Tools, Patterns and Gauges															
		Patterns	Tools and gauges	Patterns		Lathes		Shapers		Planers		Millers		Jig borer		Bench		Grinding	
				Hr.	Cost	Hr.	Cost	Hr.	Cost	Hr.	Cost	Hr.	Cost	Hr.	Cost	Hr.	Cost	Hr.	Cost
	CAP.	£ s. d.	£ s. d.		£ s. d.		£ s. d.		£ s. d.		£ s. d.		£ s. d.		£ s. d.		£ s. d.		£ s. d.
1	Cut and cup.	1 10 -	2 - -	8	1 10 -	60	9 - -							6	1 4 -	5	1 - -	20	3 10 -
2	Trim.		3 -			3	4 6											1	2 -
3	Threadroll.		5 -			28	3 10 -									6	1 4 -		
	BODY.																		
1	Cut and cup.	1 10 -	2 5 -	12	2 5 -	80	12 - -							10	2 - -	10	1 - -	20	3 10 -
2	Draw 1st way.		4 -			6	18 -									1	2 6	2	6 -
3	Trim.		4 -			3	4 6									1	2 6	2	6 -
4	Draw 2nd way.		4 -			6	18 -									1	2 6	2	6 -
5	Draw 3rd way.		4 -			6	18 -									1	2 6	2	6 -
6	Trim.		3 -			4	6 -									1	2 6	2	6 -
7	Bead.		5 -			12	1 16 -									3	7 6	1	2 6
8	Threadroll		7 -			28	3 10 -									8	1 10 -	5	12 6
10	Polish.		8 -			36	4 10 -					16	2 10 -			2	5 -	8	1 8 -
			1 set of tools only																
	TOTALS	3 - -	6 12 -		3 15 -		37 15 -						2 10 -		3 4 -		5 19 -		10 15 -

Pattern and tool cost summary	Direct labour	Shop oncosts
	£ s. d.	£ s. d.
PATTERNS.	3 15 -	4 - -
LATHES.	37 15 -	45 - -
SHAPERS.		
PLANERS.		
MILLERS.	2 10 -	4 - -
JIG BORERS.	3 4 -	10 - -
BENCH.	5 19 -	6 - -
GRINDING.	10 15 -	10 - -
TOTAL	63 18 -	
MATERIAL.	9 12 -	
SUNDRIES.	1 10 -	
B/O GOODS.		
TOTALS	75 - -	79 - -

ESTIMATED BY E.F.R. DATE 3.10.7 SHEET NO. 2 NO. OF SHEETS, 4 APPROVED E.S.W.

Facing p. 342

PRODUCTION ESTIMATE FOR SHAVING-STICK CONTAINER (BODY) DATE 3.10.7 EST. NO. 1346

Op. No.	Operations	Labour		Shop oncosts		Process material		Plant		Production		
		P/W rate per gross	D/W rate per	Rate P/H	Cost P/Gr.	Qty. per gross	Cost	Type and size	Mc. No.	Set-up time	Hourly production	Est. scrap percentage
1	Blank and cup.	1·0		10/-	6·0			D/A press	2	1 hour	20 G.	·01
2	Draw 1st way.	1·0		6/-	3·6			Dial feed press	3	¾ hour	20 G.	·01
3	Trim.	4·0		3/-	7·2			T.L.	2	½ hour	5 G.	·01
301	Anneal.	2·0		6/-	4·8			Furnace	7		15 G.	·01
302	Clean.	3·0		3/-	4·5			Vats			8 G.	·01
4	Draw 2nd way.	1·2		5/-	4·0			H/Drawing press	4	¾ hour	15 G.	·01
401	Anneal.	2·5		6/-	6·0			Furnace	7		12 G	·01
402	Clean.	3·0		3/-	4·5	Nil	Nil	Vats			8 G.	·01
5	Draw 3rd way.	1·2	Nil	5/-	4·0			H/Drawing press	5	¾ hour	15 G	·01
6	Trim.	4·0		3/-	7·2			T.L.	3	½ hour	5 G.	·01
7	Bead.	4·0		3/-	7·2			T.L.	4	½ hour	5 G.	·01
8	Threadroll.	4·0		3/2	7·6			T.R.	2	1 hour	5 G.	·01
9	Clean.	4·0		3/-	7·2			Vats			5 G.	·01
10	Polish (machine)	60·0		6/6	156·0			P. Mc.	1	1 hour	6 doz.	·01
11	Colour off (machine).	60·0		6/6	156·0			P. Mc.	2	1 hour	6 doz.	·01
12	Wire up.	3·0		2/-	6·0			Bench			4 G.	·01
13	N. plate and dry.	16·0		5/-	30·0			Vats and oven			2 G.	·01
14	Unwire.	3·0		2/-	6·0			Bench			4 G.	·01
15	Polish (hand).	60·0		3/6	84·0			Polishing spindle	3		6 doz.	·01
	Labour, pence	236·9		Shop oncosts, pence	511·8	Process mat		Plant				

SHEET NO. 4 NO. OF SHEETS, 4 ESTIMATED BY E.F.R. APPROVED C.R.S. DATE 3.10.7

Note: Additional polishing and plating equipment required to cover requested deliveries.

TABLE 162.—MENSURATION

Perimeters

Circle	3·1416D or 6·2832R.
Square	4L.
Rectangle	2($L + B$).
Triangle	Sum of the three sides.
Regular polygon	$N \times L$.

Areas of flat surfaces

Circle	3·1416R^2 or ·7854D^2.
Square	L^2.
Rectangle	LB.
Triangle	·5BH.
Parabola	·667BH.
Area of ellipse	·7854 × major axis × minor axis.
Trapezium	·5 (sum of parallel sides) × H.

Areas of curved surfaces of solids

Cylinder	3·1416DH.
Cone	1·5708D × slant height.
Sphere	3·1416D^2.

Volumes

Cylinder	·7854D^2H.
Cone	$\frac{1}{3}$ × ·7854D^2 × perp. height = ·2618D^2 × perp. height.
Cube	L^3.
Sphere	·5236D^3.

Notation

D = Diameter.
R = Radius.
L = Length.
B = Breadth.
H = Height.
N = Number of sides.

TABLE 163.—TRIGONOMETRIC FORMULÆ

Trigonometric Ratios

$\frac{P}{H}$ = sine α written sin α
$\frac{B}{H}$ = cosine α „ cos α
$\frac{P}{B}$ = tangent α „ tan α
$\frac{B}{P}$ = cotangent α written cot α
$\frac{H}{B}$ = secant α „ sec α
$\frac{H}{P}$ = cosecant α „ cosec α

Note.—B = Base.
H = Hypotenuse.
P = Perpendicular.

TABLE 164

Solution of Right-angled Triangles

Parts given	Parts required			
	Hypotenuse	Base	Perpendicular	α
H and P.	—	$B = \sqrt{H^2 - P^2}$ or $B = H \cos \alpha$	—	$\sin \alpha = \frac{P}{H}$
H and B.	—	—	$P = \sqrt{H^2 - B^2}$ or $P = H \sin \alpha$	$\cos \alpha = \frac{B}{H}$
B and P.	$H = \sqrt{B^2 + P^2}$ or $H = B \sec \alpha$	—	—	$\tan \alpha = \frac{P}{B}$
H and α.	—	$B = H \cos \alpha$	$P = H \sin \alpha$	—
B and α.	$H = B \sec \alpha$	—	$P = B \tan \alpha$	—
P and α.	$H = P \operatorname{cosec} \alpha$	$B = P \cot \alpha$	—	—

Solution of Triangles using the Sine and Cosine Formula

Given data	Required to find	Expression to use
All sides abc.	Angle A	$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$
	,, B	$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$
	,, C	$\cos C = \frac{a^2 + b^2 - c^2}{2ab}$
All the angles and side a.	Side b	$b = \frac{a \sin B}{\sin A}$
	,, c	$c = \frac{a \sin C}{\sin A}$
Two sides a and b and the included angle C.	Side c	$c = \sqrt{a^2 + b^2 - 2ab \cos C}$
	Angle A	$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$
	,, B	$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$
Side a and the angles A, B.	Angle C	Angle $C = 180° - (A + B)$
	Side b	$b = \frac{a \sin B}{\sin A}$
	,, c	$c = \frac{a \sin C}{\sin A}$

TABLE 165.—COMMERCIAL TOLERANCES ON SHEET METAL

Thickness

Width, in.	Thickness, in.	Tolerance, in.
< 6	< ·010	±·0005
6–12	·010–·024	±·0015
12–24	·024–·040	±·0025
24–42	·040–·080	±·0035

Widths

< 6 in.	±·025 in.
6–12 in.	±·032 in.
> 12 in.	±·062.

Cut lengths

< 4 ft.	±·062 in.
4–8 ft.	±·125 in.
> 8 ft.	±·250 in.

Finer tolerances than the above can be obtained providing that the quantity is sufficient. The cost per pound comes out higher.

TABLE 166.—TOLERANCES ON BRIGHT-DRAWN BAR

Round		*Square*	
< ·875 in.	·003 in.	< ·5 in.	·003 in.
0·875–2·000	·004 in.	·5–·875	·004 in.
2·000–4·000	·005 in.	·875–2·000	·005 in.
4·000–5·000	·006 in.	2–3	·006 in.
> 5	·007 in.		

TABLE 167.—TIN PLATE SHEET SIZES

Sheet sizes, in.	Thicknesses to nearest ·001 in.									
18¾ × 14	·010	·012	·016							
20 × 10	·010	·012	·014	·016						
20 × 14	·006	·008	·009	·010	·012	·014	·016	·018	·020	·022
22 × 15	·024	·027					·016		·020	·022
25 × 17	·016	·021	·024	·027	·031	·038				
28 × 20	·006	·007	·008	·009	·010	·012	·016	·018	·020	·022
30 × 21	·008	·009	·011	·012	·016	·018	·020	·022		
30 × 22	·018	·020	·022	·024	·027					
34 × 25	·016	·020	·024	·027	·031	·038				

The general run of sheet metal sizes are:

6 ft. × 3 ft., 8 ft. × 3 ft., 8 ft. × 4 ft., 12 ft. × 4 ft.

TABLE 168.—WEIGHT PER SQUARE FOOT OF SHEET METAL, LB.

I.S.W.G.	Thickness, in.	Aluminium	Brass	Copper	Magnesium alloys	Nickel silver	Steel	Tin
40	·0048	·068	·214	·221	·045	·210	·20	·195
39	·0052	·073	·231	·239	·049	·227	·22	·210
38	·0060	·084	·266	·276	·056	·262	·25	·242
37	·0068	·094	·304	·313	·063	·298	·28	·276
36	·0076	·107	·340	·350	·072	·333	·32	·310
35	·0084	·118	·375	·386	·079	·368	·35	·341
34	·0092	·129	·411	·423	·087	·402	·39	·374
33	·0100	·147	·447	·460	·099	·437	·43	·410
32	·0108	·153	·482	·497	·103	·472	·45	·438
31	·0116	·163	·518	·534	·11	·507	·48	·47
30	·0124	·174	·554	·570	·12	·542	·51	·48
29	·0136	·191	·610	·626	·13	·596	·56	·52
28	·0148	·208	·662	·681	·14	·647	·61	·57
27	·0164	·230	·733	·754	·15	·717	·67	·63
26	·018	·253	·804	·828	·17	·787	·74	·70
25	·020	·281	·894	·920	·19	·874	·82	·77
24	·022	·309	·980	1·012	·21	·962	·90	·85
23	·024	·337	1·08	1·104	·23	1·049	·98	·92
22	·028	·393	1·25	1·288	·26	1·225	1·14	1·10
21	·032	·449	1·43	1·472	·31	1·400	1·32	1·23
20	·036	·506	1·61	1·656	·34	1·574	1·48	1·38
19	·040	·562	1·79	1·840	·38	1·750	1·63	1·54
18	·048	·675	2·15	2·208	·46	2·098	1·95	1·84
17	·056	·786	2·50	2·576	·54	2·450	2·30	2·15
16	·064	·900	2·86	2·944	·61	2·798	2·63	2·46
15	·072	1·01	3·22	3·312	·69	3·148	2·87	2·77
14	·080	1·12	3·58	3·680	·76	3·497	3·26	3·07
13	·092	1·29	4·12	4·232	·88	4·020	3·76	3·53
12	·104	1·46	4·65	4·784	1·00	4·546	4·24	4·00
11	·116	1·63	5·18	5·336	1·11	5·070	4·71	4·46
10	·128	1·80	5·72	5·888	1·22	5·600	5·22	4·92

Note.—The above table makes no allowance for rolling-mill tolerances, but in some instances it may be essential to take the extra thickness into account.

TABLE 169.—WEIGHTS OF METALS PER CUBIC INCH, LB.

Aluminium (pure)	·0975	Lead	·41
Aluminium (cast silicon alloy)	·094	Magnesium castings and extrusions	·0654
Aluminium alloy 3 L 5	·108	Nickel silver (18% Ni)	·313
Brass extruded or drawn	·31	Steel (plain carbon)	·283
Bronze, phosphor	·315	Steel (h.s.s.)	·32
Copper	·32	Tin	·26
Cast iron	·26	Zinc	·25
Cupro nickel	·32		
Duralumin	·103		

Table 170.—Weight of Bar per foot run, lb.

Round Bar

Dia.	Aluminium	Brass	Copper	Magnesium	Carbon steel
·062	·0036	·011	·012	·003	·011
·125	·0147	·044	·049	·010	·042
·187	·0323	·102	·106	·022	·094
·250	·057	·182	·189	·038	·167
·312	·0895	·284	·296	·060	261
·375	·127	·410	·426	·085	·376
·437	·176	·557	·579	·118	·511
·500	·231	·728	·757	·155	·668
·625	·358	1·14	1·18	·240	1·04
·750	·518	1·64	1·70	·347	1·50
·875	·702	2·23	2·32	·470	2·04
1·00	·922	2·91	3·03	·617	2·67
1·125	1·164	3·69	3·83	·781	3·38
1·250	1·430	4·55	4·73	·961	4·17
1·375	1·745	5·51	5·72	1·170	5·05
1·500	2·075	6·55	6·81	1·390	6·01
1·625	2·430	7·69	7·99	1·630	7·05
1·750	2·820	8·92	9·27	1·89	8·18
1·875	3·24	10·2	10·6	2·17	9·39
2·000	3·68	11·6	12·1	2·47	10·68

Square Bar

Side	Aluminium	Brass	Copper	Magnesium	Carbon steel
·0625	·005	·014	·016	·003	·014
·125	·019	·055	·061	·013	·053
·1875	·042	·131	·136	·028	·120
·250	·073	·220	·243	·050	·213
·3125	·115	·344	·379	·077	·332
·375	·164	·522	·545	·110	·478
·4375	·224	·718	·746	·150	·651
·5	·294	·905	·97	·197	·849
·625	·457	1·405	1·52	·307	1·328
·750	·660	2·063	2·18	·447	1·912
·875	·896	2·687	2·97	·602	2·603
1·000	1·170	3·687	3·88	·787	3·400
1·125	1·475	4·625	4·91	·994	4·303
1·250	1·832	5·750	6·06	1·220	5·312
1·375	2·220	7·000	7·34	1·440	6·428
1·500	2·640	8·250	8·73	1·780	7·750
1·625	3·080	9·625	10·25	2·110	8·978
1·750	3·590	11·250	11·89	2·410	10·412
1·875	4·120	12·875	13·65	2·750	11·953
2·000	4·680	14·750	15·63	3·145	13·600

TABLE 171.—STANDARD (BRITISH) HEXAGON ROD FOR BOLTS AND NUTS
APPROX. WEIGHT IN LB. PER FOOT RUN

Dimensions across Flats (approx.), in.	Nominal bolt dia.			Material				
	B.S.W.	B.S.F	B.A.	Magnesium	Aluminium	Brass	Copper	Carbon steel
·117			10	·009	·014	·043	·045	·040
·152			8	·016	·024	·073	·075	·067
·193			6	·026	·038	·119	·122	·108
·248			4	·042	·063	·194	·206	·178
·282			3	·055	·083	·250	·260	·228
·324			2	·071	·108	·330	·340	·300
·338	1/8			·080	·120	·372	·390	·34
·365			1	·092	·139	·430	·450	·390
·413			0	·116	·173	·540	·560	·490
·445	3/16	1/4		·136	·203	·640	·665	·585
·525	1/4	5/16		·188	·281	·880	·915	·805
·600	5/16	3/8		·242	·361	1·125	1·17	1·03
·710	3/8	7/16		·336	·504	1·563	1·63	1·43
·820	7/16	1/2		·457	·682	2·125	2·21	1·95
·920	1/2	9/16		·565	·844	2·625	2·73	2·40
1·01	9/16	5/8		·685	1·03	3·19	3·31	2·92
1·10	5/8			·806	1·21	3·75	3·90	3·43
1·20	11/16	3/4		·981	1·47	4·57	4·75	4·18
1·30	3/4	7/8		1·16	1·74	5·38	5·59	4·93
1·39	13/16			1·33	1·99	6·19	6·43	5·65
1·48	7/8	1		1·51	2·26	7·00	7·27	6·40
1·57	15/16			1·70	2·54	7·88	8·18	7·20
1·67	1	1 1/8		1·88	2·81	8·75	9·09	8·00
1·86	1 1/8	1 1/4		2·32	3·46	10·75	11·17	9·85
2·05	1 1/4	1 3/8		2·93	4·37	13·63	14·18	12·47
2·22	1 3/8	1 1/2		3·20	4·77	15·00	15·60	13·70
2·41	1 1/2			3·78	5·64	17·50	18·20	16·00
2·58	1 5/8	1 3/4		4·50	6·72	21·00	21·80	19·20
2·76	1 3/4	2		5·05	7·54	23·50	24·40	21·45
3·02	1 7/8			6·00	8·95	28·00	29·10	25·60
3·15	2			6·85	10·23	32·00	33·25	29·40

Note.—Under B.S. 1083: 1944, B.S.W. and B.S.F. bolts have the same small-sized head. Hence when computing weights care should be taken to work to the A/C flat dimensions, not on the nominal bolt size. For A/C corner dimensions multiply A/C flats size by 1·155.

Table 172.—Weight of Castings from Pattern Relationship

Pattern made from	Material for casting							
	Aluminium	Brass	Copper	Bronze or gunmetal	Cast iron	Magnesium	Carbon steel	Zinc
	Multiplication factor (approx.)							
Baywood.	3·2	9·9	10·5	10·3	8·8	2·22	9·6	8·5
Beechwood.	3·1	9·5	10·1	10·0	8·5	2·15	9·3	8·2
Mahogany.	3·1	9·5	10·1	10·0	8·5	2·15	9·3	8·2
Oak.	3·4	10·5	11·2	11·0	9·4	2·38	10·3	9·1
Pine, white.	5·3	16·5	17·5	17·3	14·7	3·7	16·0	14·2
Pine, yellow.	4·7	14·7	15·6	15·4	13·1	3·3	14·3	12·6
Steel.	·344	1·09	1·13	1·11	·92	·23	1·0	·89
Cast iron.	·375	1·19	1·23	1·21	1·0	·25	1·09	·96
Bronze.	·310	·99	1·02	1·0	·83	·21	·9	·8
Brass.	·315	1·0	1·03	1·01	·84	·21	·92	·81
Aluminium.	1·00	3·18	3·28	3·23	2·67	·67	2·9	2·57
Magnesium.	1·50	4·75	4·90	4·83	3·98	1·0	4·34	3·84

TABLE 173.—WEIGHT OF BAKELITE MOULDING POWDERS, &c.

Bakelite No.	Description	Uses	Bulk factor	Shrinkage per in.	Specific gravity	Curing time, min.	Moulding temp., °F.	Weight, oz./c. in.
X 20	General purpose	Articles needing	2·3–2·5	·005–·007	1·35	¼″ thick	300–340	·78
	material.	average strength and	2·3–2·5	·005–·007	1·40	3½	300–400	·78
X 20/5	” ” ”	electrical properties.	2·3–2·5	·005–·007	1·40	3½	300–400	·78
X 4996	” ” ”	” ” ”	2·3–2·5	·005–·007	1·40	Slightly faster as X 20	300–400	·78
X 30	” ” ”	” ” ”	2·3–2·5	·005–·007	1·40		300–400	·78
X 20/386	Telephone material.	Hand sets.	As X 20					
X 20/521	” ”	Ear caps.	As X 20					
XMB 261	Heat-resisting.	Handles, &c., for saucepans, kettles, &c.	2·5–3·0	·002–·003	2·00		300–320	1·16
B 250LF	”	” ” ”	6–9	·002–·003	1·85		290–310	1·07
ExX 4847	”	” ” ”	2·3–2·4	·002–·003	2·06		300–320	1·19
ExX 5072	”	” ” ”	2·7–3·1	·002–·004	1·74		290–320	1·01

[*Continued over*

TABLE 173.—(*Continued*)

Bakelite No.	Description	Uses	Bulk factor	Shrinkage per in.	Specific gravity	Curing time, min.	Moulding temp., °F.	Weight, oz./c. in.
XMB 199	Shock-resisting.	For goods requiring a good impact strength	12·15	·003–·005	1·37		290–310	·79
XMB 1957	”	” ” ”	4·5–5·5	·003–·005	1·37		300–320	·79
ExX 4980/SR	”	” ” ”	4·5–6·5	·004–·006	1·34		300–330	·77
ExX 5073	”	” ” ”	4·0–4·5	·004–·006	1·35		300–330	·78
XMB 262	Low-loss.	Electric mouldings having low power losses and good insulating properties.	2·1–2·4	·002–·003	1·87	7–10	290–310	1·08
ExX 4933	”	” ” ”	2·3–2·7	·004–·005	1·58		290–310	·93
X 543	Flexible.	Moulding on heavy inserts.	2·9–3·2	·007–·009	1·35		300–320	·78
ExX 4811	”	” ” ”	3·0–4·0	·006–·008	1·33		300–320	·77
XMB 53	Water-resisting.	Containers.	4·0–4·5	·001–·002	1·87 1·79	7	290–310	1·08
ExX 4892/4	”	”	2·5–3·0	·002–·004	1·86		290–320	1·07
ExX 4990	Alkali-resisting.	”	3–3·5	·004–·005	2·38		300–320	1·38
ExX 5080/SR	”	”	5–6	·006–·008	1·36		300–320	·79

TABLE 174.—CAPACITY MEASURE

Quarters	Bushels	Pecks	Gallons	Quarts	Pints	Gills	Metric equivalent, litres	Volume, cu. in.
1	8	32	64	256	512	2048	290·942	17,754·24
	1	4	8	32	64	256	36·368	2,219·28
		1	2	8	16	64	9·092	554·82
			1	4	8	32	4·546	277·41
				1	2	8	1·136	69·35
					1	4	·568	34·67
						1	·142	8·67

TABLE 175.—TROY WEIGHT

24 grains = 1 dwt.
480 „ = 20 „ = 1 oz.
5760 „ = 240 „ = 12 „ = 1 lb.

TABLE 176.—AVOIRDUPOIS WEIGHT

1 dram = 27·34375 grains.
16 drams = 1 oz. = 437·5 „
256 „ = 16 „ = 1 lb. = 7000 grains.
7168 „ = 448 „ = 28 „ = 1 quarter.
28672 „ = 1792 „ = 112 „ = 4 quarters = 1 cwt.
573440 „ = 35840 „ = 2240 „ = 80 „ = 20 „ = 1 (long) ton.
2000 lb. = 1 short ton (American).

TABLE 177.—APOTHECARIES' WEIGHT

20 grains = 1 scruple.
60 „ = 3 „ = 1 dram.
480 „ = 24 „ = 8 „ = 1 oz.
5760 „ = 288 „ = 96 „ = 12 „ = 1 lb.

TABLE 178.—DECIMAL SYSTEM OF WEIGHTS

By the Weights and Measures Act, 1875, the adoption of the decimal system of weights, with the ounce troy and grain as basis, is made compulsory for goldsmiths, jewellers, silversmiths, &c. The following table converts pennyweights (dwt.) and grains into decimals of an ounce:

Dwt.	Ounces	Dwt.	Ounces	Grains	Ounces	Grains	Ounces
1	·050	11	·550	1	·002	13	·027
2	·100	12	·600	2	·004	14	·029
3	·150	13	·650	3	·006	15	·031
4	·200	14	·700	4	·008	16	·033
5	·250	15	·750	5	·010	17	·035
6	·300	16	·800	6	·012	18	·037
7	·350	17	·850	7	·015	19	·040
8	·400	18	·900	8	·017	20	·042
9	·450	19	·950	9	·019	21	·044
10	·500	20	1·000	10	·021	22	·046
				11	·023	23	·048
				12	·025	24	·050

TABLE 179.—TO CONVERT AVOIRDUPOIS AND TROY WEIGHTS INTO METRIC WEIGHTS

As one grain is equal to 0·0648 gramme and one Avoirdupois ounce is equal to 28·3495 grammes and one Troy ounce is equal to 31·1035 grammes; to convert:

Grains	into grammes	multiply by	0·0648
Grains	,, centigrammes ..	,,	6·4799
Grains	,, milligrammes ..	,,	64·799
Avoirdupois ounces	kilogrammes ..	,,	0·02835
Avoirdupois ounces .. .,	grammes	.,	28·3495
Avoirdupois pounds .. .,	kilogrammes ..	,,	0·4536
Troy ounces .. .. .,	kilogrammes ..	,,	0·0311
Troy ounces .. .. .,	grammes	,,	31·1035

TABLE 180.—METRIC WEIGHT

	Grammes	Grains	Troy oz.	Troy lb.	Avoir. oz.	Avoir. lb.
1 Milligramme =	·001 =	·01543				
1 Centigramme =	·01 =	·15432				
1 Decigramme =	·1 =	1·54324				
1 Gramme =	1· =	15·43236 =	·032 =	·00268 =	·03527 =	·0022046
1 Decagramme =	10· =		·322 =	·02679 =	·35275 =	·0220462
1 Hectogramme =	100· =		3·215 =	·26792 =	3·52740 =	·2204622
1 Kilogramme =	1000· =		32·151 =	2·6792 =	35·27396 =	2·2046223
1 Myriagramme =	10000· =			26·792 =		22·046223
1 Quintal =	100000· =			267·92 =		220·46223
1 Tonneau =	1000000· =			2679·2 =		2204·6223

The unit of the metric system is the gramme (= 15·4323564 grains): the weight of 1 c.c. of distilled water at 4° C.

TABLE 181.—TO CONVERT METRIC WEIGHTS INTO AVOIRDUPOIS AND TROY WEIGHTS

As one gramme is equal to 15·432 grains, or ·03527 Avoirdupois ounce, or ·03215 Troy ounce; to convert:

Grammes	into grains	multiply by 15·432
Centigrammes	„ grains .. .	„ 0·15432
Milligrammes	„ grains	„ 0·01543
Kilogrammes	„ Avoirdupois ounces	„ 35·27396
Gramme	„ Avoirdupois ounces	„ ·03527
Kilogrammes	„ Avoirdupois pounds	„ 2·2046
Kilogrammes	„ Troy ounces ..	„ 32·1507
Grammes	„ Troy ounces ..	„ ·03215

TABLE 182.—CUTTER APPROACH FOR SLAB MILLS, &c.

Dia. of cutter, in.	Approach									
	Depth of cut, in.									
	1/16	1/8	3/16	1/4	3/8	1/2	3/4	1	1½	2
1¼	·27	·37	·44	·50	·57					
1½	·3	·41	·49	·56	·65	·71				
1¾	·32	·45	·54	·61	·72	·79	·87			
2	·35	·48	·58	·66	·78	·87	·97			
2¼	·37	·53	·62	·71	·84	·93	1·06	1·12		
2½	·39	·54	·66	·75	·89	1·00	1·15	1·22		
2¾	·41	·57	·69	·79	·94	1·06	1·22	1·32		
3	·43	·60	·73	·83	·99	1·12	1·30	1·41	1·50	
3¼	·45	·63	·76	·87	1·04	1·17	1·37	1·50	1·62	
3½	·46	·65	·79	·91	1·08	1·22	1·44	1·58	1·73	
3¾	·48	·67	·82	·93	1·13	1·28	1·50	1·66	1·84	
4	·49	·70	·85	·97	1·17	1·32	1·56	1·73	1·94	2·00
4¼	·51	·72	·87	1·00	1·21	1·37	1·62	1·80	2·03	2·12
4½	·53	·74	·90	1·03	1·24	1·41	1·67	1·87	2·12	2·24
4¾	·54	·76	·92	1·06	1·28	1·46	1·73	1·93	2·21	2·35
5	·56	·78	·95	1·09	1·32	1·50	1·79	2·00	2·29	2·45
5½	·58	·82	1·00	1·14	1·39	1·58	1·89	2·12	2·45	2·64
6	·61	·86	1·04	1·20	1·45	1·66	1·98	2·24	2·60	2·83
6½	·64	·89	1·09	1·25	1·51	1·73	2·08	2·35	2·74	3·00
7	·66	·93	1·13	1·30	1·58	1·80	2·17	2·45	2·87	3·16
7½	·68	·95	1·17	1·35	1·63	1·87	2·25	2·55	3·00	3·32
8	·71	·99	1·21	1·39	1·69	1·94	2·33	2·65	3·12	3·46
8½	·73	1·03	1·25	1·44	1·74	2·00	2·41	2·74	3·24	3·61
9	·75	1·05	1·28	1·48	1·80	2·06	2·49	2·83	3·36	3·74
9½	·77	1·08	1·32	1·52	1·85	2·12	2·56	2·92	3·47	3·88
10	·79	1·11	1·35	1·56	1·90	2·18	2·63	3·00	3·57	4·00

TABLE 183.—CUTTER APPROACH FOR END AND FACE MILLS

Dia. of Mill, in.	Approach Width of cut, in. 1	2	3	4	5	6	7	8	9	10	11	12
1	·5											
1½	·19											
2	·14	1·0										
2½	·11	·5										
3	·09	·37	1·5									
4	·07	·27	·68	2·00								
5	·05	·24	·5	1·00	2·50							
6	·04	·18	·4	·77	1·34	3·00						
7	·04	·14	·32	·59	·96	1·71	3·5					
8	·03	·13	·29	·54	·88	1·36	2·07	4·00				
10	·03	·10	·23	·43	·56	1·00	1·43	2·00	2·82	5·00		
12	·02	·08	·19	·35	·54	·81	1·13	1·53	2·04	2·69	3·6	6·00

TABLE 184.—DECIMAL EQUIVALENTS OF FRACTIONS

Fraction	Decimal equivalent	Fraction	Decimal equivalent	Fraction	Decimal equivalent
1/64	0·015625	11/32	0·34375	43/64	0·671875
1/32	0·03125	23/64	0·359375	11/16	0·6875
3/64	0·046875	3/8	0·375	45/64	0·703125
1/16	0·0625	25/64	0·390625	23/32	0·71875
5/64	0·078125	13/32	0·40625	47/64	0·734375
3/32	0·09375	27/64	0·421875	3/4	0·750
7/64	0·109375	7/16	0·4375	49/64	0·765625
1/8	0·125	29/64	0·453125	25/32	0·78125
9/64	0·140625	15/32	0·46875	51/64	0·796875
5/32	0·15625	31/64	0·484375	13/16	0·8125
11/64	0·171875	1/2	0·500	53/64	0·828125
3/16	0·1875	33/64	0·515625	27/32	0·84375
13/64	0·203125	17/32	0·53125	55/64	0·859375
7/32	0·21875	35/64	0·546875	7/8	0·875
15/64	0·234375	9/16	0·5625	57/64	0·890625
1/4	0·250	37/64	0·578125	29/32	0·90625
17/64	0·265625	19/32	0·59375	59/64	0·921875
9/32	0·28125	39/64	0·609375	15/16	0·9375
19/64	0·296875	5/8	0·625	61/64	0·953125
5/16	0·3125	41/64	0·640625	31/32	0·96875
21/64	0·328125	21/32	0·65625	63/64	0·984375

TABLE 185.—CONVERSION OF MILLIMETRES TO INCHES

M/M	Decimals	M/M	Decimals	M/M	Decimals	M/M	Decimals	M/M	Decimals
$\frac{1}{100}$	·00039	$\frac{61}{100}$	·02402	22	·86614	82	3·22835	142	5·59056
$\frac{2}{100}$	·00079	$\frac{62}{100}$	·02441	23	·90551	83	3·26772	143	5·62993
$\frac{3}{100}$	·00118	$\frac{63}{100}$	·02480	24	·94488	84	3·30709	144	5·66930
$\frac{4}{100}$	·00157	$\frac{64}{100}$	·02520	25	·98425	85	3·34646	145	5·70867
$\frac{5}{100}$	·00197	$\frac{65}{100}$	·02559	26	1·02362	86	3·38583	146	5·74804
$\frac{6}{100}$	·00236	$\frac{66}{100}$	·02598	27	1·06299	87	3·42520	147	5·78741
$\frac{7}{100}$	·00276	$\frac{67}{100}$	·02638	28	1·10236	88	3·46457	148	5·82678
$\frac{8}{100}$	·00315	$\frac{68}{100}$	·02677	29	1·14173	89	3·50394	149	5·86615
$\frac{9}{100}$	·00354	$\frac{69}{100}$	·02717	30	1·18110	90	3·54331	150	5·90552
$\frac{10}{100}$	·00394	$\frac{70}{100}$	·02756	31	1·22047	91	3·58268	151	5·94489
$\frac{11}{100}$	·00433	$\frac{71}{100}$	·02795	32	1·25984	92	3·62205	152	5·98426
$\frac{12}{100}$	·00472	$\frac{72}{100}$	·02835	33	1·29921	93	3·66142	153	6·02363
$\frac{13}{100}$	·00512	$\frac{73}{100}$	·02874	34	1·33858	94	3·70079	154	6·06300
$\frac{14}{100}$	·00551	$\frac{74}{100}$	·02913	35	1·37795	95	3·74016	155	6·10237
$\frac{15}{100}$	·00591	$\frac{75}{100}$	·02953	36	1·41732	96	3·77953	156	6·14174
$\frac{16}{100}$	·00630	$\frac{76}{100}$	·02992	37	1·45669	97	3·81890	157	6·18111
$\frac{17}{100}$	·00669	$\frac{77}{100}$	·03031	38	1·49606	98	3·85827	158	6·22048
$\frac{18}{100}$	·00709	$\frac{78}{100}$	·03071	39	1·53543	99	3·89764	159	6·25985
$\frac{19}{100}$	·00748	$\frac{79}{100}$	·03110	40	1·57480	100	3·93701	160	6·29922
$\frac{20}{100}$	·00787	$\frac{80}{100}$	·03150	41	1·61417	101	3·97638	161	6·33859
$\frac{21}{100}$	·00827	$\frac{81}{100}$	·03189	42	1·65354	102	4·01575	162	6·37796
$\frac{22}{100}$	·00866	$\frac{82}{100}$	·03228	43	1·69291	103	4·05512	163	6·41733
$\frac{23}{100}$	·00906	$\frac{83}{100}$	·03268	44	1·73228	104	4·09449	164	6·45670
$\frac{24}{100}$	·00945	$\frac{84}{100}$	·03307	45	1·77166	105	4·13386	165	6·49607
$\frac{25}{100}$	·00984	$\frac{85}{100}$	·03346	46	1·81103	106	4·17323	166	6·53544
$\frac{26}{100}$	·01024	$\frac{86}{100}$	·03386	47	1·85040	107	4·21260	167	6·57481
$\frac{27}{100}$	·01063	$\frac{87}{100}$	·03425	48	1·88977	108	4·25197	168	6·61418
$\frac{28}{100}$	·01102	$\frac{88}{100}$	·03465	49	1·92914	109	4·29134	169	6·65355
$\frac{29}{100}$	·01142	$\frac{89}{100}$	·03504	50	1·96851	110	4·33071	170	6·69292
$\frac{30}{100}$	·01181	$\frac{90}{100}$	·03543	51	2·00788	111	4·37008	171	6·73229
$\frac{31}{100}$	·01220	$\frac{91}{100}$	·03583	52	2·04725	112	4·40945	172	6·77166
$\frac{32}{100}$	·01260	$\frac{92}{100}$	·03622	53	2·08662	113	4·44882	173	6·81103
$\frac{33}{100}$	·01299	$\frac{93}{100}$	·03661	54	2·12599	114	4·48819	174	6·85040
$\frac{34}{100}$	·01339	$\frac{94}{100}$	·03701	55	2·16536	115	4·52756	175	6·88977
$\frac{35}{100}$	·01378	$\frac{95}{100}$	·03740	56	2·20473	116	4·56693	176	6·92914
$\frac{36}{100}$	·01417	$\frac{96}{100}$	·03780	57	2·24410	117	4·60630	177	6·96851
$\frac{37}{100}$	·01457	$\frac{97}{100}$	·03819	58	2·28347	118	4·64567	178	7·00788
$\frac{38}{100}$	·01496	$\frac{98}{100}$	·03858	59	2·32284	119	4·68504	179	7·04725
$\frac{39}{100}$	·01535	$\frac{99}{100}$	·03898	60	2·36221	120	4·72441	180	7·08662
$\frac{40}{100}$	·01575	1	·03937	61	2·40158	121	4·76378	181	7·12599
$\frac{41}{100}$	·01614	2	·07874	62	2·44095	122	4·80315	182	7·16536
$\frac{42}{100}$	·01654	3	·11811	63	2·48032	123	4·84252	183	7·20473
$\frac{43}{100}$	·01693	4	·15748	64	2·51969	124	4·88189	184	7·24410
$\frac{44}{100}$	·01732	5	·19685	65	2·55906	125	4·92126	185	7·28347
$\frac{45}{100}$	·01772	6	·23622	66	2·59843	126	4·96063	186	7·32284
$\frac{46}{100}$	·01811	7	·27559	67	2·63780	127	5·00000	187	7·36221
$\frac{47}{100}$	·01850	8	·31496	68	2·67717	128	5·03937	188	7·40158
$\frac{48}{100}$	·01890	9	·35433	69	2·71654	129	5·07874	189	7·44095
$\frac{49}{100}$	·01929	10	·39370	70	2·75591	130	5·11811	190	7·48032
$\frac{50}{100}$	·01969	11	·43307	71	2·79528	131	5·15748	191	7·51969
$\frac{51}{100}$	·02008	12	·47244	72	2·83465	132	5·19685	192	7·55906
$\frac{52}{100}$	·02047	13	·51181	73	2·87402	133	5·23623	193	7·59843
$\frac{53}{100}$	·02087	14	·55118	74	2·91339	134	5·27560	194	7·63780
$\frac{54}{100}$	·02126	15	·59055	75	2·95276	135	5·31497	195	7·67717
$\frac{55}{100}$	·02165	16	·62992	76	2·99213	136	5·35434	196	7·71654
$\frac{56}{100}$	·02205	17	·66929	77	3·03150	137	5·39371	197	7·75591
$\frac{57}{100}$	·02244	18	·70866	78	3·07087	138	5·43308	198	7·79528
$\frac{58}{100}$	·02283	19	·74803	79	3·11024	139	5·47245	199	7·83465
$\frac{59}{100}$	·02323	20	·78740	80	3·14961	140	5·51182	200	7·87402
$\frac{60}{100}$	·02362	21	·82677	81	3·18898	141	5·55119		

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