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ENGINEERING WORKSHOP MANUAL

ERNEST PULL

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ENGINEERING WORKSHOP MANUAL

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FOR

FITTERS, TURNERS, AND GENERAL MACHINISTS

CONTAINING

PRACTICAL INFORMATION ON THE MICROMETER, VERNIER, TOOLS, SCREW-CUTTING, WORKSHOP ARITHMETIC, GEOMETRY, MENSURATION, GEAR-CUTTING, PRECISION GRINDING, AND GENERAL MACHINE WORK. WITH NOTES, RULES, AND TABLES

BY

ERNEST PULL

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With 140 Illustrations and many Tables

SIXTH EDITION
REVISED AND ENLARGED OF
"THE ENGINEERING WORKSHOP HANDBOOK"

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PREFACE TO SIXTH EDITION

THE object of this book is to provide in as small a space as possible practical information that should be known by all apprentices, improvers, and journeymen engaged in engineering workshops.

It frequently happens that the book giving the desired information is not available at the moment it is required, or the data is difficult to find. A book of this size can be conveniently carried in the pocket, and is likely to be at hand when wanted.

The various chapters have been revised, and the information given will be found up-to-date and reliable.

It is understood that the London County Council accepts no responsibility for any opinions or conclusions appearing in the book.

The author would be glad to receive any criticism, or answer any questions relating to the matter appearing in the book.

E. P.

LONDON COUNTY COUNCIL
SCHOOL OF ENGINEERING,
HIGH STREET, POPLAR, E. 14.

CONTENTS.

Chapter I

WORKSHOP ARITHMETIC

Definition of the Terms used in Arithmetic

Integer.—A whole number, such as 1, 2, 3, 4.

Numerator.—The upper number of a fraction is called the numerator; in the fraction $\frac{2}{8}$, 2 is the numerator.

Denominator.—The lower number of a fraction is the denominator; in the fraction $\frac{2}{8}$, 8 is the denominator.

Fraction.—A fraction is part of an integer; thus 1 divided by 12 equals the fraction $\frac{1}{12}$. If an inch is divided into 64 parts and 7 of these parts are taken, then the parts taken would equal $\frac{7}{64}$ of the whole, and the fraction would be termed a vulgar fraction.

Proper Fraction.—A proper fraction is one in which the numerator is smaller than the denominator, thus $\frac{63}{64}$.

Improper Fraction.—An improper fraction is one in which the numerator is greater than the denominator; $\frac{65}{64}$ is an improper fraction.

Mixed Number.—A whole number and a fraction, such as $3\frac{1}{7}$, is called a mixed number.

Factors.—When a number is the product of two or more numbers, the numbers used to obtain the product are said to be its factors.

Prime Numbers.—A prime number is one which has no factors except itself and 1. Thus 1, 3, 5, 7, 11, etc. are prime numbers.

Multiplicand.—The number to be multiplied is called the multiplicand; thus in 36×7, 36 is the multiplicand.

Multiplier.—The multiplying number is called the multiplier; thus in 36×7, 7 is the multiplier.

Product.—The result of multiplication is called the product; thus 252 is the product of 36×7.

Dividend.—Is the number divided; thus in $21 \div 7$, 21 is the dividend.

Divisor.—The number by which another number is divided; thus in $21 \div 7$, 7 is the divisor.

Quotient.—The result of dividing; example $21 \div 7$ equals 3, then 3 is the quotient.

Common Denominator.—The product of all denominators; thus the common denominator of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$ is $2 \times 3 \times 4$ equals 24.

Least Common Denominator.—The smallest number all the denominators will divide into without a remainder; the least common denominator of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$ would be 12, that being the smallest number 2, 3, and 4 will divide into without a remainder.

Decimal Fraction.—A fraction in which the denominator is some power of 10; thus $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$ are decimal fractions.

Sum.—The result of addition; thus $3 + 4 + 5$ equals the sum of 12.

Ratio.—The ratio between two numbers is the quotient obtained by dividing the first number by the second; for example, the ratio between 3 and 12 is $\frac{1}{4}$, and the ratio between 12 and 3 is 4.

Reciprocal.—Is inverse ratio; thus the inverse ratio of 3 and 12 is 12 and 3.

Proportion.—Is the equality of ratios; thus $4 : 2 = 8 : 4$, or $4 : 2 :: 8 : 4$.

Percentage.—A ratio in which the denominator is 100, expressed by the symbol %.

Arithmetical Signs and Common Abbreviations

+	Plus or addition.	:	Is to.
−	Minus or subtraction.	: :	Equals (in proportion).
±	Plus or minus.	√	Square root.
∓	Minus or plus.	$\sqrt[3]{}$	Cube root.
÷	Division.	sin.	Sine.
×	Multiplication.	cos.	Cosine.
log.	Logarithm.	tan.	Tangent.
π	Pi (3·1416).	M.E.P.	Mean effective pressure.
B.H.P.	Brake horse-power.	R.P.M.	Revolutions per minute.
H.P.	Horse-power.	a^2	*a* squared.
I.H.P.	Indicated horse-power.	d^2	Diameter squared
K.W.	Kilowatt.	′	Feet.
°	Degree.	″	Inches.
□″	Square inch.	L.C.M.	Least common multiple.
Dia.	Diameter.		
∴	Therefore.		

Fractions

The unit of measurement in the United Kingdom is the Standard Imperial Yard; this length is divided into three equal parts, and each part is called a foot. A foot, then, is a fraction of a yard, and can be stated as one-third ($\frac{1}{3}$) of a yard. If two feet were taken instead of one, then the distance would be two-thirds ($\frac{2}{3}$) of a yard.

The foot is divided into twelve equal parts called inches, therefore one inch is obviously $\frac{1}{12}$ of a foot. Two inches $\frac{2}{12}$ or $\frac{1}{6}$ of a foot. Three inches $\frac{3}{12}$ or $\frac{1}{4}$ of a foot. Four inches $\frac{4}{12}$ or $\frac{1}{3}$ of a foot, and so on.

The inch has no special subdivisions, and in workshop practice it is divided into any number of divisions to suit the particular work on which it is to be used. If it is equally divided into sixty-four parts, then one part must be one sixty-fourth ($\frac{1}{64}$) of an inch. Two parts $\frac{2}{64}$ or $\frac{1}{32}$. Three parts $\frac{3}{64}$, and so on.

Addition of Fractions

If an inch is divided into eight parts, each part must be $\frac{1}{8}$ of an inch, and should it be necessary to add together, say, $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$, and $\frac{7}{8}$, it is only necessary to add together all the numerators, thus $1 + 3 + 5 + 7 = 16$, or $\frac{16}{8}$, which equals two whole numbers. The reason for this is that all the denominators are of the same power. When it is required to add together two fractions with different denominators such as $\frac{1}{6} + \frac{1}{8}$, then it is necessary to find a common denominator. The common denominator is found by multiplying the denominators together; thus the common denominator of 6 and 8 is 48, but as a smaller number can be found which can be divided equally by 6 and 8, it is usual to find the least common denominator, which in this case would be 24.

If the numerator and denominator of a fraction are both multiplied by the same number, then the value of the fraction is unaltered, thus:

$\frac{1}{6}$ is of exactly the same value as $\frac{2}{12}$, or $\frac{4}{24}$, or $\frac{8}{48}$, etc.

Improper Fractions

An improper fraction is a fraction in which the numerator is greater than the denominator, thus $\frac{17}{16}$ is an improper fraction. To bring an improper fraction to a proper fraction the numerator must be divided by the denominator, thus:

$$17 \div 16 = 1\frac{1}{16}.$$

Common Denominator

In order to add together, say, $\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{5}$, it is necessary to find a common denominator, and this is found by multiplying all the denominators together, thus $3 \times 4 \times 5 = 60$; then taking the first fraction and dividing 60 by 3, we get 20, taking the second we get 15, and the third 12. This would be put down thus:

$$\frac{1}{3} + \frac{1}{4} + \frac{1}{5}$$

$$\frac{20 + 15 + 12}{60} = \frac{47}{60}$$

When the numerators of the fractions to be added are greater than 1, then the common denominator is first divided by the denominator of the fraction, and the quotient multiplied by the numerator, thus $\frac{2}{3}+\frac{3}{4}+\frac{4}{5}$; here the common denominator is 60, and taking the first fraction $\frac{2}{3}$, we divide by 3 and multiply by 2, thus $60 \div 3 = 20$, and $20 \times 2 = 40$, giving $\frac{40}{60}$; the sum would be put down thus:

$$\frac{2}{3} + \frac{3}{4} + \frac{4}{5}$$

$$\frac{40 + 45 + 48}{60} = \frac{133}{60} = 2\frac{13}{60}$$

Least Common Denominator

The least common denominator of any numbers can be found by first striking out any numbers which are contained in all the other numbers, and then dividing any of the remaining numbers which have a common divisor. Multiply all the remaining numbers together, and by the numbers used as divisors.

Example.—Find the least common multiple of 2, 4, 8, 12, and 24. Here both 2 and 4 are contained in all numbers, so can be crossed out, leaving 8, 12, and 24; 4 can be divided into numbers 8, 12, and 24, and then 2 will divide into 2 and 6, and 3 will cancel into 3 and 3, leaving only the three divisors 4, 2, and 3, which multiplied together give 24, thus:

4	~~2~~,	~~4~~,	8,	12,	24
2			2	3	6
3			1	3	3
			1	1	1

Example.—Find the L.C.M. of 12, 16, 28, 42.

2	12	16	28	42
2	6	8	14	21
3	3	4	7	21
7	1	4	7	7
	1	4	1	1

The L.C.M. then is $2 \times 2 \times 3 \times 7 \times 4 = 336$.

Addition of Vulgar Fractions

Example.—Find the value of $\frac{1}{7}+\frac{1}{8}+\frac{1}{10}+\frac{1}{16}$.

$$\frac{1}{7}+\frac{1}{8}+\frac{1}{10}+\frac{1}{16}$$

$$\frac{80 + 70 + 56 + 35}{560} = \frac{241}{560}$$

Example.—Find the value of $1\frac{1}{3}+1\frac{5}{6}+2\frac{3}{4}+3\frac{5}{16}$. Here the integers are added separately, thus $1 + 1 + 2 + 3 = 7$, and then the fractions.

$$\frac{1}{3}+\frac{5}{6}+\frac{3}{4}+\frac{5}{16}$$

$$\frac{16+40+36+15}{48} = \frac{107}{48} = 2\frac{11}{48}$$

Which, with the whole numbers, equal $9\frac{11}{48}$.

Subtraction of Fractions

Proceed in exactly the same manner as for addition, and then find the difference in the numerators.

Example.—$\frac{1}{3} - \frac{1}{7}$.

$$\frac{1}{3} - \frac{1}{7}$$

$$\frac{7 - 3}{21} = \frac{4}{21}$$

Example.—$1\frac{1}{16} - \frac{5}{16}$.

$$\frac{17}{16} - \frac{5}{16}$$

$$\frac{17 - 5}{16} = \frac{12}{16} = \frac{3}{4}$$

Example.—$(\frac{1}{3} + \frac{1}{7}) - (\frac{1}{6} + \frac{1}{9})$. Proceed as for addition, and take the fractions in brackets separately.

$$(\frac{1}{3} + \frac{1}{7}) - (\frac{1}{6} + \frac{1}{9})$$

$$\frac{(42 + 18) - (21 + 14)}{126} = \frac{60 - 35}{126} = \frac{25}{126}$$

Multiplication of Fractions

To multiply fractions, multiply all the numerators to obtain a new numerator, and then all the denominators to obtain a new denominator.

Example.—Multiply $\frac{7}{16}$ by $\frac{5}{6}$; then $7 \times 5 = 35$, and $16 \times 6 = 96$, result $\frac{35}{96}$.

In multiplication the word "of" is frequently used in place of the word multiply, or the sign ×; thus $\frac{1}{3}$ of $\frac{1}{4}$ means $\frac{1}{3}$ multiplied by $\frac{1}{4}$, or $\frac{1}{3} \times \frac{1}{4}$, and which equals $\frac{1}{12}$.

Cancelling

Multiplication of fractions is often very much simplified by cancelling, thus $\frac{3}{4} \times \frac{2}{9}$; here it is possible to cancel by 3 and 2, thus:

$$\frac{\cancel{3}}{\underset{2}{\cancel{4}}} \times \frac{\cancel{2}}{\underset{3}{\cancel{9}}} = \frac{1}{6}$$

Without cancelling we should have $\frac{6}{36}$. Every advantage should be taken to cancel when possible.

Example.—$\frac{5}{16} \times \frac{4}{5} \times \frac{7}{8} \times \frac{32}{64} \times \frac{9}{21}$. Then

$$\frac{\cancel{5}}{\underset{4}{\cancel{16}}} \times \frac{\cancel{4}}{\cancel{5}} \times \frac{\cancel{7}}{\cancel{8}} \times \frac{\overset{4}{\cancel{32}}}{64} \times \frac{\overset{3}{\cancel{9}}}{\underset{3}{\cancel{21}}} = \frac{3}{64}$$

By cancelling in this sum no multiplication is necessary.

When adding or subtracting whole numbers and fractions, the whole numbers are in most cases added or subtracted separately, but in multiplication the whole numbers and fractions must be always brought to improper fractions.

Example. — Multiply $2\frac{3}{4}$ by $1\frac{1}{3}$. Converting these into improper fractions we get $\frac{11}{4}$ and $\frac{4}{3}$, then

$$\frac{11}{\cancel{4}} \times \frac{\cancel{4}}{3} = \frac{11}{3} = 3\frac{2}{3}.$$

Division of Fractions

In division of fractions the divisor is simply inverted and the fractions multiplied.

Example.—Divide $1\frac{1}{2}$ by $\frac{3}{4}$ or $1\frac{1}{2} \div \frac{3}{4}$; then inverting the divisor we get $\frac{3}{2} \times \frac{4}{3}$, cancelling by 2 and 3 we get

$$\frac{\cancel{3}}{\cancel{2}} \times \frac{\overset{2}{\cancel{4}}}{\cancel{3}} = 2.$$

Example.—Divide $11\frac{1}{4}$ by $2\frac{1}{2}$, then

$$\frac{\overset{9}{\cancel{45}}}{\underset{2}{\cancel{4}}} \times \frac{\cancel{2}}{\cancel{5}} = 4\frac{1}{2}.$$

Division is often represented thus $\frac{2\frac{1}{4}}{1\frac{1}{2}}$; proceed as before:

$$\frac{\overset{3}{\cancel{9}}}{\underset{2}{\cancel{4}}} \times \frac{\cancel{2}}{\cancel{3}} = 1\frac{1}{2}.$$

Example.—Divide 301 by $1\frac{3}{4}$, then

$$\frac{\overset{43}{\cancel{301}}}{1} \times \frac{4}{\cancel{7}} = 172.$$

Decimal Fractions

A decimal fraction is a fraction in which the denominator is 10 or some power of 10. A power of 10 means 10 multiplied by itself any number of times, such as $10 \times 10 = 100$, $10 \times 10 \times 10 = 1000$, and so on.

When we write a whole number such as 6666 we indicate the number six thousand six hundred and sixty-six. From right to left we have units, tens, hundreds, thousands. It is quite as easy to start from units and go to the right, adding more sixes and calling the digits tenths, hundredths, thousandths, etc., thus giving the figures the values $\frac{6}{10}$, $\frac{6}{100}$, $\frac{6}{1000}$, etc.; by doing this with our original figure we can get 6666666. To distinguish between the whole numbers and the fractions we put a dot called a decimal point, thus 6666·666, and the number would then read six thousand six hundred and sixty-six whole numbers, and six tenths, six hundredths, and six thousandths, or six hundred and sixty-six thousandths.

Example.—17·36 means 17 whole numbers and a fraction ·36, which is $\frac{3}{10} + \frac{6}{100}$ or $\frac{36}{100}$.

To bring a Decimal Fraction to a Vulgar Fraction

In every case of converting a simple decimal to a vulgar fraction, the denominator is a 1 followed by as many 0's as figures in the fraction.

Examples. ·5 = $\frac{5}{10} = \frac{1}{2}$. 1·75 = $1\frac{75}{100} = 1\frac{3}{4}$.
·25 = $\frac{25}{100} = \frac{1}{4}$. 1·625 = $1\frac{625}{1000} = 1\frac{5}{8}$.
·125 = $\frac{125}{1000} = \frac{1}{8}$. 1·0625 = $1\frac{625}{10000} = 1\frac{1}{16}$.

Reduction of Vulgar Fractions to Decimal Fractions

To convert a vulgar fraction into a decimal fraction, divide the numerator by the denominator, adding noughts as required, the decimal point being added to the quotient when the first nought is added to the numerator.

Example.—Convert $\frac{1}{2}$ into a decimal fraction. To divide 2 into 1 it is necessary to add a nought, therefore the decimal point must be placed in front of the first figure in the quotient, thus:

```
2)10(·5
  10
  —
   0
   ═
```

Example.—Convert $\frac{1}{16}$ into a decimal; then 16 into 1 will not go, so we add a nought and place the decimal point; 16 into 10 will not go, so we put a nought into the quotient, 16 into 100 goes 6 and 4 over, borrowing another nought 16 into 40 goes 2 and 8 over, borrow another nought, 16 into 80 goes 5, without a remainder.

This would be put down thus:

```
16)10000(·0625
    96
    —
     40
     32
     —
      80
      80
      —
       0   Answer ·0625.
       ═
```

Example.—Convert $\frac{1}{8}$ into a decimal, then

```
8)1000(·125
  8
  —
  20
  16
  —
   40
   40
   —
    0   Answer ·125.
    ═
```


Example.—Convert $\frac{1}{64}$ into a decimal, then

```
64)1000000(·015625
   64
   —
   360
   320
   —
    400
    384
    —
     160
     128
     —
      320
      320
      —
       0   Answer ·015625.
       ═
```

Examples.

$\frac{1}{4} = 1 \div 4 = 0{\cdot}25.$
$\frac{3}{8} = 3 \div 8 = 0{\cdot}375.$
$\frac{7}{8} = 7 \div 8 = 0{\cdot}875.$
$\frac{3}{16} = 3 \div 16 = 0{\cdot}1875.$
$\frac{15}{16} = 15 \div 16 = 0{\cdot}9375.$
$\frac{1}{32} = 1 \div 32 = 0{\cdot}03125.$
$\frac{3}{64} = 3 \div 64 = 0{\cdot}046875.$

Repeating Decimals

When a fraction such as $\frac{1}{3}$ is converted into a decimal fraction, it will be found that the figure in the quotient simply repeats, thus $1 \div 3 = {\cdot}333$; this is called a *recurring* or *repeating decimal*. In the case of $\frac{1}{7}$ being converted into a decimal fraction it will be found that a certain set of figures recurs, thus $1 \div 7 = {\cdot}142857$; these figures go on recurring indefinitely, and it is called a *circulating decimal*. In the case of a fraction like $\frac{21}{22}$ we get $21 \div 22 = {\cdot}95454$, with the figures 54 only repeating; this is called a *mixed circulating decimal*.

In the first case the decimal is expressed as ${\cdot}\dot{3}$, the point above the figure indicating that the figure repeats. In the second case the decimal would be indicated as ${\cdot}\dot{1}4285\dot{7}$, showing that all figures recur. In the last example, as ${\cdot}9\dot{5}\dot{4}$, showing that the figures 54 only repeat.

To bring Repeating Decimals to Vulgar Fractions

Pure recurring decimals such as $\cdot\dot{3}$ and $\cdot\dot{5}\dot{4}$ can be brought to vulgar fractions by making the recurring figures the numerator and placing a 9 or as many 9's as there are figures as the denominator, thus:

$\cdot\dot{3} = \frac{3}{9}$ or $\frac{1}{3}$. $\cdot\dot{5}\dot{4} = \frac{54}{99}$.

FRACTIONS AND DECIMAL EQUIVALENTS

$\frac{1}{64}$	·015625	$\frac{33}{64}$	·515625
$\frac{1}{32}$	·03125	$\frac{17}{32}$	·53125
$\frac{3}{64}$	·046875	$\frac{35}{64}$	·546875
$\frac{1}{16}$	·0625	$\frac{9}{16}$	·5625
$\frac{5}{64}$	·078125	$\frac{37}{64}$	·578125
$\frac{3}{32}$	·09375	$\frac{19}{32}$	·59375
$\frac{7}{64}$	·109375	$\frac{39}{64}$	·609375
$\frac{1}{8}$	·125	$\frac{5}{8}$	·625
$\frac{9}{64}$	·140625	$\frac{41}{64}$	·640625
$\frac{5}{32}$	·15625	$\frac{21}{32}$	·65625
$\frac{11}{64}$	·171875	$\frac{43}{64}$	·671875
$\frac{3}{16}$	·1875	$\frac{11}{16}$	·6875
$\frac{13}{64}$	·203125	$\frac{45}{64}$	·703125
$\frac{7}{32}$	·21875	$\frac{23}{32}$	·71875
$\frac{15}{64}$	·234375	$\frac{47}{64}$	·734375
$\frac{1}{4}$	·25	$\frac{3}{4}$	·75
$\frac{17}{64}$	·265625	$\frac{49}{64}$	·765625
$\frac{9}{32}$	·28125	$\frac{25}{32}$	·78125
$\frac{19}{64}$	·296875	$\frac{51}{64}$	·796875
$\frac{5}{16}$	·3125	$\frac{13}{16}$	·8125
$\frac{21}{64}$	·328125	$\frac{53}{64}$	·828125
$\frac{11}{32}$	·34375	$\frac{27}{32}$	·84375
$\frac{23}{64}$	·359375	$\frac{55}{64}$	·859375
$\frac{3}{8}$	·375	$\frac{7}{8}$	·875
$\frac{25}{64}$	·390625	$\frac{57}{64}$	·890625
$\frac{13}{32}$	·40625	$\frac{29}{32}$	·90625
$\frac{27}{64}$	·421875	$\frac{59}{64}$	·921875
$\frac{7}{16}$	·4375	$\frac{15}{16}$	·9375
$\frac{29}{64}$	·453125	$\frac{61}{64}$	·953125
$\frac{15}{32}$	·46875	$\frac{31}{32}$	·96875
$\frac{31}{64}$	·484375	$\frac{63}{64}$	·984375
$\frac{1}{2}$	·5	1	1·0

To bring Mixed Circulating Decimals to Fractions

To find the numerator subtract the digits which do not recur from the whole fraction, thus $\cdot 21\dot{3}\dot{6} = 2136 - 21 = 2115$.

To find the denominator place a 9 for every figure recurring and a 0 for each non-recurring figure, thus $\cdot 21\dot{3}\dot{6} = \frac{2115}{9900}$.

Example.—$\cdot 21\dot{3}\dot{6} = \frac{2115}{9900} = \frac{423}{1980} = \frac{47}{220}$.

Examples. $\cdot 12\dot{3}\dot{6} = \frac{1224}{9900} = \frac{34}{275}$.

$\cdot 0\dot{8}\dot{1} = \frac{81}{990} = \frac{9}{110}$.

$\cdot\dot{7} = \frac{7}{9}$.

$\cdot 09\dot{6}\dot{3} = \frac{954}{9900} = \frac{53}{550}$.

Decimals

Addition

The rule for the addition of decimals is: The decimal point must be placed directly under the preceding one.

Example.—Add 2·75, 1·0125, 14·7854, then

```
  2·75
  1·0125
 14·7854
 -------
 18·5479   Answer.
```

Example.—1·03 + ·125 + ·0002 + 84·5, then

```
  1·03
   ·125
   ·0002
 84·5
 -------
 85·6552   Answer.
```

Subtraction

Rule.—The same as for addition.

Example.—Subtract 1·025 from 6·1416, then

```
 6·1416
 1·025
 ------
 5·1166   Answer.
```

Example.—3·1854 − 2·973, then

```
 3·1854
 2·973
 ------
  ·2124   Answer.
```

Multiplication

Rule.—Put down the figures as for simple multiplication and multiply in the ordinary manner. The number of figures to be marked off in the product is the sum of the decimal places in the multiplier and the multiplicand.

Example.—Multiply 27·126 by 19·43, then

```
 27·126
  19·43
-------
  81378
 108504
244134
27126
-------
527·05818
```

We have three places of decimals in the multiplicand and two in the multiplier, so we mark off five places in the product.

Example.—3·1416 × ·015, then

```
 3·1416
   ·015
--------
 157080
 31416
--------
·0471240
```

Here we have four places in the multiplicand and three in the multiplier, so we must mark off seven figures in the product; as there are only six we add a 0 and place the decimal point.

Division

Rule.—Make the divisor a whole number by removing the decimal point. Shift the decimal point in the dividend as many places to the right as there were decimal places in the divisor, adding ciphers if necessary. Divide as for ordinary division. Then place the decimal point in the quotient when bringing down the first decimal place of the dividend.

Example.—Divide 11·65 by ·008, then

```
8 | 11650·00
    1456·25  Answer.
```


Example.—Divide ·0346 by ·09, then

```
9 | 3·460
     ·384̇  Answer.
```

Example.—93·576 ÷ 6·14, then

```
614)9357·600(15·2403
    614
    ---
    3217
    3070
    ----
     1476
     1228
     ----
      2480
      2456
      ----
       2400
       1842
       ----
        558  Answer 15·2403.
```

Example.—14·1 ÷ ·0037.

```
37)141000·00(3810·8̇10̇8
   111
   ---
   300
   296
   ---
     40
     37
     --
     300
     296
     ---
       40
       37
       --
       300
       296
       ---
         4  Answer 3810·8̇10̇.
```

Recurring and Circulating Decimals

Rule.—Carry the circulating decimal two places more than the required number of accurate decimals.

Example.—Subtract $1\cdot\dot{2}\dot{6}$ from $2\cdot9\dot{7}$ to three places of decimals, then

```
2·97777
1·26262
-------
1·71515   Answer 1·715.
```

Example.—Find the sum of $2\cdot51\dot{4}$ and $1\cdot\dot{6}\dot{3}$ to four places of decimals, then

```
2·514444
1·636363
--------
4·150807   Answer 4·1508.
```

Example.—Find the product of $2\cdot\dot{4}0\dot{3}$ and $1\cdot\dot{2}\dot{6}$ to three places of decimals, then

```
     2·40340
     1·26262
     -------
      480680
     1442040
    480680
   1442040
   480680
  240340
  ------------
  3·0345809080   Answer 3·034.
```

Example.—Divide $2\cdot\dot{4}0\dot{3}$ by $1\cdot\dot{6}$ to three places of decimals, then:

```
1·66666)2·40340(1·442
        1·66666
        -------
         736743
         666664
         ------
          700794
          666664
          ------
           341300
           333332
           ------
             7968   Answer 1·442
```


A more accurate and much quicker method of dealing with circulating decimals is to bring them to vulgar fractions, and then add, multiply, or divide as required.

Ratio and Proportion

Ratio is a term indicating the relationship that exists between two numbers or two quantities of the same kind, and can be ascertained by dividing the first quantity by the second. For example, if it is required to cut a screw having 24 threads per inch in a lathe having a lead screw of 4 threads per inch, the ratio would be $24 \div 4 = 6$, or 6 to 1.

A ratio is not altered if both of the terms are multiplied or divided by the same number. For example, the ratio of 24 to 4 is the same as 12 to 2 and 6 to 1.

Ratios can only be expressed between two quantities of the same kind. Thus it is not possible to compare yards with inches or pounds with tons.

Ratios are often conveniently expressed as fractions, especially when the first term is smaller than the second. Thus the ratio between 2 threads per inch and 4 threads per inch can be expressed as $\frac{1}{2}$.

Proportion

Proportion is the equality of ratios or the relationship between four quantities. Thus, as 8 is to 4 so is 10 to 5. The first and last terms in a proportion are called the extremes; the second and third are called the means. And the product of the extremes is equal to the product of the means. Thus

$$8 : 4 :: 10 : 5, \text{ then } 8 \times 5 = 40 \text{ and } 4 \times 10 = 40.$$

If three terms of a proportion are known, the remaining term can be found by the following rules:—

1. The first term is equal to the product of the second and third terms divided by the fourth.

Example.—Let x be the term to be found, then

$$x : 4 :: 5 : 15.$$

$$x = \frac{4 \times 5}{15} = 1\tfrac{1}{3}.$$

2. The second term is equal to the product of the first and fourth terms divided by the third.

Example.—$1\frac{1}{3} : x :: 5 : 15.$

$$x = \frac{1\frac{1}{3} \times 15}{5} = 4.$$

3. The third term is equal to the product of the first and fourth terms divided by the second.

Example.—$1\frac{1}{3} : 4 :: x : 15$.

$$x=\frac{1\frac{1}{3}\times 15}{4}=5.$$

4. The fourth term is equal to the product of the second and third terms divided by the first.

Example.—$1\frac{1}{3} : 4 :: 5 : x$.

$$x=\frac{4\times 5}{1\frac{1}{3}}=15.$$

Percentages

If 100 gauges are made and 3 are rejected as being under size, then it is said that 3 per cent were unsuitable. Percentage, then, is a ratio in which one term is a hundred, and the other term expresses the rate per hundred, or is the rate per cent.

Rule 1.—If the percentage is given, multiply the given quantity by the percentage and divide by 100.

Example.—What is 7 per cent of 95? Then

$$\frac{95\times 7}{100}=6\cdot 65.$$

Example.—If 2 per cent of 750 turning jobs are spoilt, how many are remaining? Then

$$\frac{750\times 2}{100}=15,\quad 750-15=735.$$

Rule 2.—If the percentage is required, multiply the part by 100 and divide by the whole.

Example.—What percentage of 95 is 6·65? Then

$$\frac{6\cdot 65\times 100}{95}=7\%.$$

Example.—If 15 jobs are spoilt out of 750, what is the percentage? Then

$$\frac{15\times 100}{750}=2\%.$$

Proportional Parts

When an alloy is composed of several metals and the total weight is given and also the proportion of its component parts, the weight or value of each metal can be found.

The number of parts of each metal will be the numerator of a fraction of the whole, and the total number of parts of all the metals will be the denominator.

Example.—White metal to the weight of 16 lb. is run into a bearing; the composition of the alloy is 25 parts tin, 2 parts antimony, and 1 part copper. Then, total number of parts 28.

$$\text{Weight of tin}=\frac{25\times 16}{28}=14\cdot 29\text{ lb.}$$

$$\text{Weight of antimony}=\frac{2\times 16}{28}=1\cdot 14\text{ lb.}$$

$$\text{Weight of copper}=\frac{1\times 16}{28}=0\cdot 57\text{ lb.}$$

Averages

If 3 jobs are spoilt out of 96 the average number of jobs spoilt would be 1 in 32. Thus the average of any number of quantities is the result of dividing the sum of the quantities by the number of them.

The average is also called the mean of the quantities.

Example.—If a turner finishes 16 jobs on Monday, 15 jobs on Tuesday, 17 Wednesday, 13 Thursday, 16 Friday, and 7 Saturday, the average number per day would be

$$(16+15+17+13+16+7)\div 6=14.$$

Formulæ

The term formulæ may be defined as a rule in which symbols or letters are used in the place of words; in fact, a formula is a shorthand method of condensing words or sentences into a small space.

The letters used in formulæ simply stand in place of figures, which are to be substituted when solving a problem.

Example.—Formulæ for finding the area of a circle.

$$A=\cdot 7854\times d^2.$$

Here A stands for area of the circle and d for the diameter of the circle in inches.

Example.—Formulæ used in gearing problems. To obtain outside diameter, having number of teeth and diametral pitch.

Let D = outside diameter.
,, N = number of teeth.
,, P = diametral pitch.

$$\text{Then } D=\frac{N+2}{P}$$

Example.—Number of teeth 22, diametral pitch 12. Find outside diameter. Substituting figures for letters, we get

$$D = \frac{22+2}{12} = 2.$$

Example.—To obtain diametral pitch having number of teeth and outside diameter.

$$\text{Formulæ } P = \frac{N+2}{D}$$

Example.—Number of teeth 22, outside diameter 2, then

$$P = \frac{22+2}{2} = 12.$$

When several numbers or quantities in formulæ are connected with signs indicating that multiplication, division, subtraction, or additions are to be made, generally multiplication should take place before any other operation. Division also precedes addition and subtraction if written in a line with these. The other operations are carried out in the order given.

Example.—Find the value of $42 - (27+14) + 7 \times (15-3)$.

$$\begin{aligned} \text{Then}\quad & 42 - (27+14) + 7 \times (15-3) \\ &= 42 - 41 + 7 \times 12 \\ &= 42 - 41 + 84 \\ &= 1 \quad + 84 \\ &= 85 \quad \text{Answer.} \end{aligned}$$

Example.—Find the value of $(3\frac{1}{4} + 2\frac{1}{2}) \div 5\frac{1}{2}$.

$$\begin{aligned} \text{Then}\quad & (3\tfrac{1}{4} + 2\tfrac{1}{2}) \div 5\tfrac{1}{2} \\ &= 5\tfrac{3}{4} \div 5\tfrac{1}{2} \\ &= 5\tfrac{3}{4} \times \tfrac{2}{11} = 1\tfrac{1}{22}. \end{aligned}$$

Example.—Find the value of $\dfrac{3\frac{1}{4} + 2\frac{1}{2}}{3\frac{1}{4} - 2\frac{1}{2}}$

$$\begin{aligned} \text{Then}\quad & \frac{3\frac{1}{4} + 2\frac{1}{2}}{3\frac{1}{4} - 2\frac{1}{2}} \\ &= (3\tfrac{1}{4} + 2\tfrac{1}{2}) \div (3\tfrac{1}{4} - 2\tfrac{1}{2}) \\ &= 7\tfrac{2}{3}. \end{aligned}$$

Figures shown in parentheses or brackets must always be calculated independent of all other figures, and if one bracket is placed inside of another the one inside must be calculated first.

Example.—Find the value of $5 - [\frac{5}{6} + \{3\frac{7}{8} - (2\frac{1}{3} - 1\frac{7}{8})\}]$

$$\begin{aligned} \text{Then}\quad & 5 - [\tfrac{5}{6} + \{3\tfrac{7}{8} - (2\tfrac{1}{3} - 1\tfrac{7}{8})\}] \\ &= 5 - [\tfrac{5}{6} + \{3\tfrac{7}{8} - (\tfrac{11}{24})\}] \\ &= 5 - [\tfrac{5}{6} + \{3\tfrac{7}{8} - \tfrac{11}{24}\}] \\ &= 5 - [\tfrac{5}{6} + \{3\tfrac{5}{12}\}] \\ &= 5 - [\tfrac{5}{6} + 3\tfrac{5}{12}] \\ &= 5 - 4\tfrac{1}{4} \\ &= \tfrac{3}{4}. \end{aligned}$$

Simplified Methods of Arithmetic

To multiply by 10, add a nought, or shift the decimal point to the right one place.

Example.—$7 \times 10 = 70$.
$187{\cdot}561 \times 10 = 1875{\cdot}61$.

To divide by 10, cross off the last figure, or shift the decimal point to the left one place.

Example.—$170 \div 10 = 17$.
$187{\cdot}561 \div 10 = 18{\cdot}7561$.

To multiply by 25, add two noughts, and divide by 4; if decimals, move decimal point to the right two places, and divide by 4.

Example.—$97 \times 100 = 9700$
$= 9700 \div 4 = 2425$.
$97{\cdot}65 \times 100 = 9765$.
$= 9765 \div 4 = 2441{\cdot}25$.

To divide by 25, cross off last two figures, or shift decimal point two places to the left, and multiply by 4.

Example.—$9700 \div 25 =$
$97 \times 4 = 388$.

To multiply by 5, add a nought, or remove the decimal point one place to the right, and then divide by 2.

Example.—$72{\cdot}6 \times 5 =$
$726 \div 2 = 363$.

To divide by 5, strike off last figure, or move the decimal point one place to the left, and multiply by 2.

Example.—$7{\cdot}26 \div 5 =$
${\cdot}726 \times 2 = 1{\cdot}452$.

To multiply by 9, add one cipher, or move the decimal point one place to the right, and subtract the original number.

Example.—7624 × 9 =
76240 − 7624 = 68616.

To multiply by 101, add two ciphers, and then add the original number.

Example.—5217 × 101 =
521700 + 5217 = 526917.

To multiply by 125, add three ciphers, and divide by 8.

Example.—274 × 125 =
274000 ÷ 8 = 34250.

To divide by 125, strike off last three figures, and multiply by 8.

Example.—875000 ÷ 125 =
875 × 8 = 7000.

Tables

Long Measure

English

12 (″)	inches	= 1 (′) foot.
3	feet	= 1 yard (yd.).
5½	yards	= 1 pole.
40	poles	= 1 furlong.
8	furlongs	= 1 mile.

Metric

10 (mm.) millimetres	= 1 centimetre.
10 (cm.) centimetres	= 1 decimetre.
10 (dm.) decimetres	= 1 metre.
10 (m.) metres	= 1 decametre.
10 (Dm.) decametres	= 1 hectometre.
10 (Hm.) hectometres	= 1 kilometre (km.).

English Equivalents of Metric Measures of Length

1 millimetre	= 0·03937 inch or about $\frac{1}{25}$ of an inch.
1 centimetre	= 0·3937 inch.
1 decimetre	= 3·937 inches.
1 metre	= 39·3707 inches.
1 decametre	= 32·8089 feet.
1 hectometre	= 19·927 poles.
1 kilometre	= 1093·61 yards or 0·6213 of a mile.

Square Measure

144 sq. in.	= 1 sq. ft.
9 sq. ft.	= 1 sq. yd.
30¼ sq. yds.	= 1 sq. pole.
40 sq. poles	= 1 rood.
4 roods	= 1 acre.
640 acres	= 1 sq. mile.

Cubic Measure

1728 cubic inches	= 1 cubic foot.
27 cubic feet	= 1 cubic yard.

Angular Measure

60 (″)	seconds	= 1 (′) minute.
60	minutes	= 1 (°) degree.
90	degrees	= 1 right angle.
4	right angles	= 1 complete circle.

Avoirdupois Weight

16 drams	= 1 ounce (oz.).
16 ounces	= 1 pound (lb.).
14 pounds	= 1 stone.
28 pounds	= 1 quarter (qr.).
4 qrs. or 112 lb.	= 1 hundredweight (cwt.).
20 hundredweights	= 1 ton.

Chapter II

MENSURATION AND GEOMETRY

Mensuration

Area of Surfaces

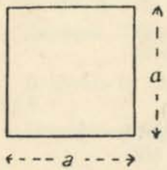


FIG. 1.—*Square.* Let a equal length of any side, then

$$\text{area} = a^2.$$

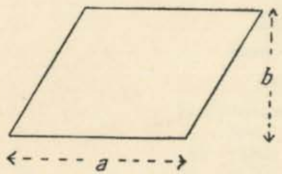


FIG. 2.—*Rhombus.* Area equals length of base, multiplied by the perpendicular height, then

$$\text{area} = a \times b.$$

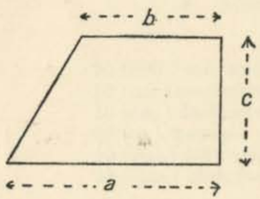


FIG. 3.—*Trapezoid.* Area equals half the sum of the two parallel sides, multiplied by the perpendicular distance between, then

$$\text{area} = \frac{a+b}{2} \times c.$$

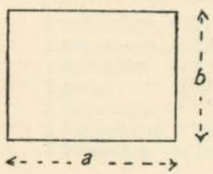
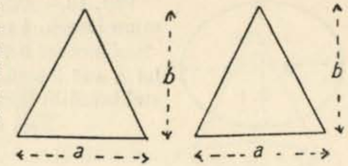


FIG. 4.—*Rectangle* or *Oblong.* Area equals length, multiplied by breadth, then

$$\text{area} = a \times b.$$



FIGS. 5 and 6.—*Triangles.* Area of a triangle, such as Figs. 5 and 6, equals length of base, multiplied by one-half of the perpendicular height, then

$$\text{area} = a \times \tfrac{1}{2} b.$$

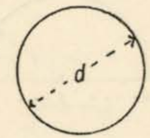


FIG. 7.—*Circle.*—Area equals diameter squared, multiplied by ·7854, then

$$\text{area} = d^2 \cdot 7854.$$

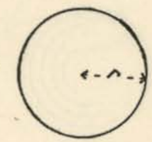


FIG. 8.—*Circle.* Area equals radius squared, multiplied by 3·1416, then

$$\text{area} = r^2 \pi.$$

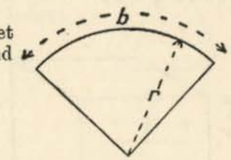


FIG. 9.—*Sector of a Circle.* Let b equal length of arc of circle, and r radius of circle, then

$$\text{area} = b \times \frac{r}{2}$$

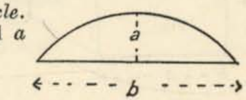


FIG. 10.—*Segment of a Circle.* Let b equal length of chord and a height of segment, then approx.

$$\text{area} = \frac{a \times 2 \times b}{3} + \frac{a^3}{2 \times b}$$

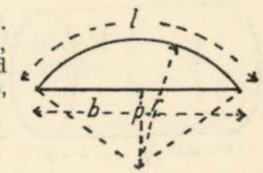


FIG. 11.—*Segment of a Circle.* Let r equal radius of circle, b length of arc of segment, and l breadth of base of segment, then

$$\text{area} = \left(l \times \frac{r}{2}\right) - \left(b \times \frac{p}{2}\right).$$

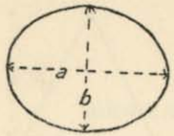


FIG. 12.—*Ellipse.* Let a equal maximum length, b maximum breadth, then

$$\text{area} = 0{\cdot}7854 \times a \times b\text{; or,}$$

let a and b equal half maximum length and breadth, then

$$\text{area} = a \times b \times \pi.$$

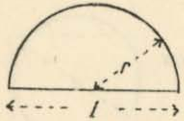


FIG. 13. — *Hemisphere.* Area of hemisphere equals half the area of a sphere of equal diameter.

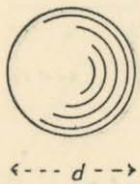


FIG. 14.—*Sphere.* Let d equal diameter of sphere, then

$$\text{area} = \pi d^2.$$

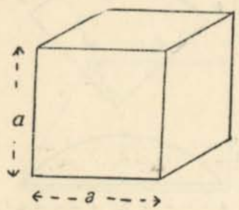


FIG. 15.—*Cube.* Let a equal length of any side, then

$$\text{area} = 6a^2.$$

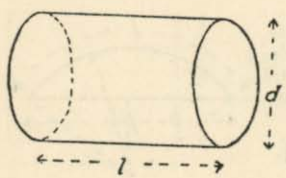


FIG. 16.—*Cylinder.* Let l equal length of cylinder, and d diameter, then total

$$\text{area} = (\pi d \times l) + 2\left(\frac{\pi}{4}d^2\right).$$

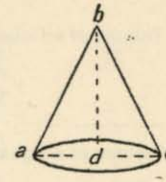


FIG. 17.—*Cone.* Area equals circumference of base, multiplied by one-half slant height, plus area of base; or,

Let a–b equal slant height, a–c diameter, a–d radius of base, then

$$\text{total area} = \frac{ac \times \pi \times ab}{2} + (dc)^2 \times \pi.$$

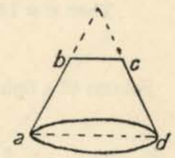


FIG. 18.—*Frustum of a Cone.* Area of the moved surface equals half the sum of the two ends, multiplied by π and multiplied by slant height.

Let a, b, c, d equal frustum, a–b = slant height, a–d and b–c = the two diameters, then

$$\text{area} = \frac{ad + bc}{2} \times \pi \times ab.$$

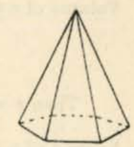


FIG. 19.—*Pyramid.* Area equals perimeter of base, multiplied by half slant height, plus area of base.

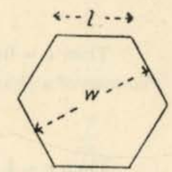


FIG. 20.—*Hexagon.* Let l equal length of one side, w width across flats, then

$$\text{area} = 2{\cdot}598 \times l^2 \text{ or area} = 0{\cdot}866 \times w^2.$$

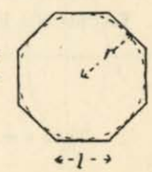


FIG. 21.—*Polygon.* Let r equal radius of inscribed circle, l length of one side, n number of sides, then

$$\text{area} = \tfrac{1}{2} r \times l \times n.$$

Volumes of Solids

Volume of a Cube—

Let v = volume.
l = length of side.
Then $v = l^3$, or
$l = \sqrt[3]{v}$.

Volume of a Square Prism—

Let v = volume.
l = length.
b = breadth, and width.

Then $v = lb^2$.

$$l = \frac{v}{b^2},\ b = \sqrt{\frac{v}{l}}$$

Volume of a Sphere—

Let v = volume.
d = diameter.

Then $v = \frac{\pi}{6} \times d^3$.

Volume of a Cone—

Let v = volume.
d = diameter of base.
h = slant height.

Then $v = \frac{\pi}{12} \times d^2 \times h$.

Volume of a Cylinder—

Let v = volume.
d = diameter.
l = length.

Then $v = 0{\cdot}7854 \times d^2 \times l$.

Volume of a Pyramid—

Let v = volume.
a = area of base.
h = height.

Then $v = \frac{1}{3} h \times a$.

Volume of a Frustum of a Pyramid—

Let v = volume.
a_1 = area of base.
a_2 = area of top.
h = height.

Then $v = \frac{h}{3}(a_1 + a_2 + \sqrt{a_1 \times a_2})$

Geometry

FIG. 22.—*To divide a line into two equal parts.* Let a–b represent the line to be bisected, then with a and b as centres and with a radius greater than one-half the length of the line draw arcs as shown. Through the intersections of the arcs draw a line. This line divides a–b into two equal parts and is perpendicular to the horizontal line.

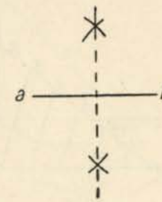


FIG. 23.—*To divide an angle into two equal parts.* Let b, a, c equal the angle, then with a as centre and any radius draw arcs at d and e. With d and e as centres, and a radius greater than one-half the angle, draw arcs at f. A line drawn through the intersections at f to a divides the angle into two equal parts.

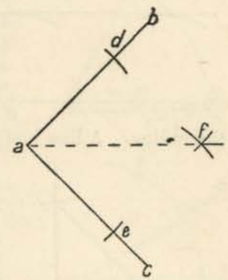


FIG. 24.—*To draw a line perpendicular to a straight line from a given point.* Let c be the point. Then with c as centre and any radius draw arcs at a and b, with a and b as centres and radius greater than a–c, draw intersecting arcs at d. Line d–c is then perpendicular to a–b.

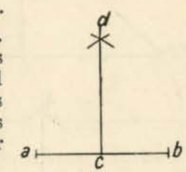
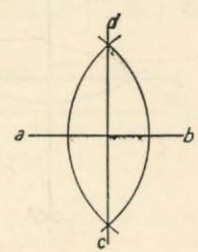


FIG. 25.—*To divide a line into two equal parts.* Let a–b represent the line. Then with a and b as centres and any radius greater than half the length of the line, draw circular arcs. A line drawn through the intersections at d and c divides a–b into equal parts.



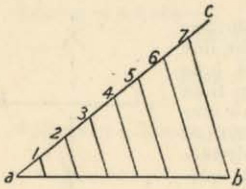


FIG. 26.—*To divide a straight line into any number of equal parts.* Let *a–b* represent the line and the number of parts 7. Draw the line *a–c* at an angle to *a–b*. Mark off on *a–c* seven equal divisions of any convenient length. From mark 7 draw a line to *b*, and then draw lines parallel to *b*–7 through 6, 5, 4, 3, 2, and 1.

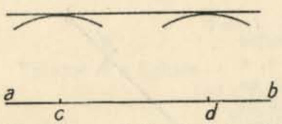


FIG. 27.—*To draw a line parallel to a given line at a given distance.* Let *a–b* represent the line. From any points, *c–d*, draw arcs with the given distance as the radius. A line just touching the arcs is parallel to *a–b*.

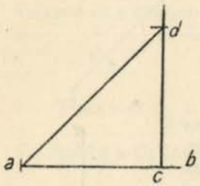


FIG. 28.—*To draw a 45° angle.* Let *a–b* represent the line. Then from *a*, set off any distance *a–c*. Draw the perpendicular *c–d*, and with a distance equal to *c–a* mark off *d*. Draw line from *d* to *a*. Then *c, a, d* equals angle.

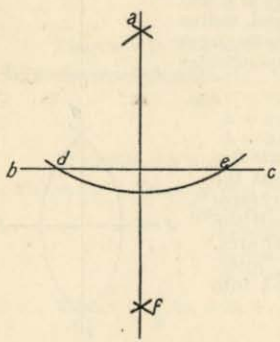


FIG. 29.—*To draw a perpendicular to a line from a point.* Let *b–c* represent the line and *a* the point. Then with *a* as centre draw an arc cutting the line at *d–e*, with *d* and *e* as centres, draw arcs with radius greater than one-half the distance between *d* and *e*. If the arcs intersect at *a* and *f*, then a line drawn through the intersections will be the required perpendicular.

FIG. 30.—*To draw a perpendicular line from a point at the end of a line.* Let *a–b* represent the line and *a* the point. Take any centre *c*, and with radius *c–a*, draw an arc cutting *a–b* at *d*. From *d* draw a line through *c* to *e*, and then join *a–e*. This line is the required perpendicular.

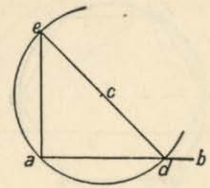


FIG. 31.—*To draw an angle of 60°.* With *a* as centre and any radius, draw arc *c–b*. With *b* as centre and *b–a* as radius, draw an arc intersecting the arc just drawn at *c*. Draw a line from *c* to *a*. Then *b, a, c* is the required angle.

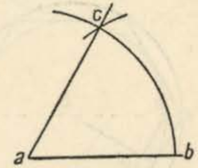


FIG. 32.—*To draw an angle of 30°.* Mark off as for an angle of 60°, then bisect arc *c–b*.

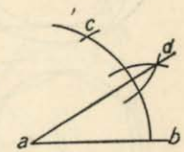


FIG. 33.—*To reproduce a given angle.* Let *a, d, c* represent angle to be reproduced. Then with *a* as centre draw arc *d–c* of any radius. With *e* as centre draw *f–g* with the same radius. Make *h–g* equal *c–d*, and draw *k–e* through *h*. Angle *e, k, g* will equal *a, c, d*.

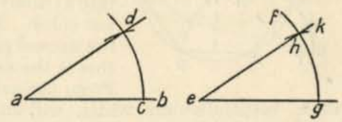
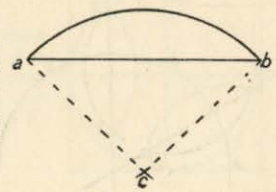


FIG. 34.—*To find the centre of the arc of the segment of a circle.* From points *a* and *b*, with length *a–b*, draw arcs at *c*. The point of intersection will be the centre of the arc.



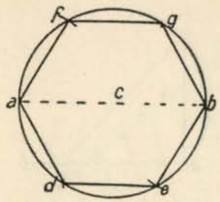


FIG. 35.—*To inscribe a hexagon in a circle.* Draw diameter *a–b* with *c* as the centre, with radius *a–c* mark off points intersecting at *d*, *e*, *b*, *g*, *f*. Then join *a–d*, *d e*, *e b*, *b g*, *g f*, and *a f* to form the hexagon.

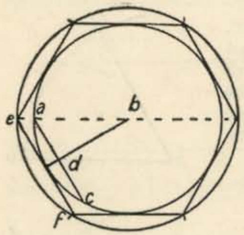


FIG. 36.—*To describe a hexagon about a circle.* Draw diameter from *b*, with *a–b* as radius cut the circle at *c*. Join *a–c* and bisect with a line drawn from *b*. Where this line touches the circle draw a line *e–f* parallel to *a–c*. With *b* as centre and *b–c* as radius draw a circle. Within this circle describe the hexagon.

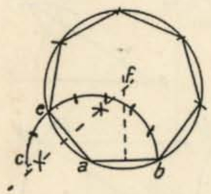


FIG. 37.—*Draw a regular polygon when one side is given.* Let *a–b* represent the given side. With *a* as centre, and *a–b* radius, draw the semi-circle *c*, *e*, *b*. Divide the semicircle into as many equal parts as the polygon has sides. This is done by trial. Join the second point of the division *e* to *a*: this is the second side of the polygon. From the centre of sides *e a* and *a b*, draw perpendiculars which will intersect at *f*. With *f* as centre, and radius *f a*, draw the circle containing the polygon, and with radius *a e* mark off the sides.

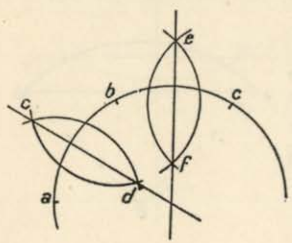


FIG. 38.—*To find the centre of an arc of a circle.* Mark off three points on the periphery of the arc *a*, *b*, *c*, and with each of these points as a centre and the same radius describe arcs intersecting each other. Through the points of intersection draw the lines *c d* and *e f*. The point where these lines intersect is the centre of the circle.

FIG. 39.—*To describe a circle about a triangle.* Divide the sides *a b* and *a c* into equal parts, and from the division points *d e* draw lines at right angles. The point of intersection is the centre of the circle.

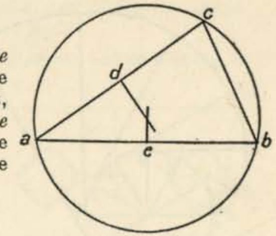


FIG. 40.—*To inscribe a circle in a triangle.* Bisect two of the angles *a* and *b*, and the point of intersection is the centre of the circle.

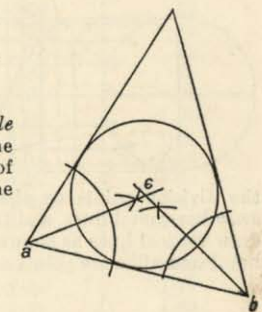
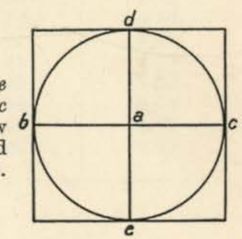


FIG. 41.—*To describe a square about a circle.* Draw line *b–c* through centre *a* of circle. Draw lines parallel to *b c* at *d* and *e*, and also lines at right angles at *c* and *b*.



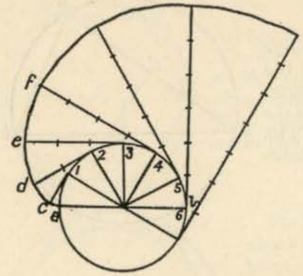


Fig. 42.—*To construct an involute.* Draw base circle a–b and divide into any number of equal parts. Through the division points 1, 2, 3, 4, etc., draw tangents to the circle and make the lengths c, d, e, f, etc., of these tangents equal the length of the arcs $a1$, $a2$, $a3$, $a4$, etc.

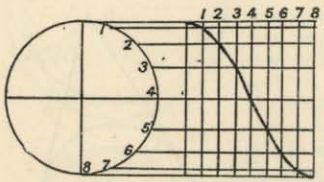


Fig. 43.—*To construct a helix.* Divide half the circumference of the cylinder on which the helix is to be described into a number of equal parts. Divide half the lead of the helix into the same number of equal parts. From the division points on the circle representing the cylinder draw horizontal lines, and from the division points on the lead draw vertical lines as shown. The intersection between lines numbered alike are points of the helix.

Distance across Corners of Squares and Hexagons, given distance across flats

Flats of hexagon × 1·155 equal distance across corners.
,, square × 1·414 ,, ,, ,, ,,

Across Flats.			
1/4	·29	·33	·36
5/16	·36	·41	·44
3/8	·43	·50	·53
7/16	·50	·58	·62
1/2	·57	·66	·71
9/16	·65	·75	·80
5/8	·72	·83	·88
11/16	·79	·91	·97
3/4	·86	1·00	1·06
13/16	·93	1·08	1·15
7/8	1·01	1·16	1·24
15/16	1·08	1·25	1·33
1	1·15	1·33	1·41
1 1/16	1·22	1·42	1·50
1 1/8	1·29	1·50	1·59
1 3/16	1·37	1·58	1·68
1 1/4	1·44	1·66	1·77
1 5/16	1·51	1·75	1·86
1 3/8	1·58	1·83	1·94
1 7/16	1·66	1·92	2·03
1 1/2	1·73	2·00	2·12
1 9/16	1·80	2·08	2·21
1 5/8	1·88	2·16	2·30
1 11/16	1·95	2·25	2·39
1 3/4	2·02	2·33	2·47
1 13/16	2·09	2·42	2·56
1 7/8	2·17	2·50	2·65
1 15/16	2·24	2·58	2·74
2	2·31	2·66	2·83

Chapter III

MATERIALS

Iron

It has been estimated that the earth's crust is composed of about 4½ to 5 per cent of iron. In many places stone containing up to 73 per cent of iron is found; seldom is the latter found in the free state, and therefore it requires to be smelted. Iron-ores are invariably found mixed with earthy matter, making them refractory, and requiring the addition of a flux to combine with the earthy matter and facilitate fusion.

The chief iron-ores are:—

Name of Ore.	Chemical Composition.	% of Ore.	Where found.
Red hematite.	Anhydrous ferric oxide.	60	Spain, Furness District, United States, Germany, Canada.
Magnetic ore.	Black oxide of iron.	62	Norway, Sweden.
Spathic iron-ore.	Ferrous carbonate.	35	Durham, Yorkshire, Derby, Somerset, Wales, Scotland.
Brown hematite.	Hydrated ferric oxide.	42	Lincolnshire, Forest of Dean, Spain, France, Germany.
Clay ironstone.	Ferrous carbonate.	33	England, Wales, Scotland, Germany, Russia, Hungary.

Iron is used in general engineering work in three varieties, cast iron, wrought iron, and steel, the difference being in the amount and the form of the carbon they each contain. The methods of obtaining these metals are:—

Pig Iron. The product of the blast furnace, obtained from iron-ore, by smelting with the aid of fluxes.

Cast Iron. Iron obtained by melting pig iron in the foundry cupola, and used for running into moulds for making iron castings.

Wrought Iron. Pig iron, refined, and then puddled in the puddling furnace, afterwards hammered and rolled into bars, plates, etc.

Steel. Compound of iron and carbon, obtained by first abstracting the whole of the carbon, and then adding more carbon to combine with the iron. Manufactured by the Siemens process, the Bessemer process, the Cementation process, the Basic process, and by crucible.

The Blast Furnace.—The blast furnace is usually constructed of wrought iron or steel plates, lined with fire-brick or some other refractory material. It takes the form of two truncated cones joined at their bases, with a short parallel part at the bottom forming the hearth; the whole being usually built on a foundation of sandstone, and supported by cast-iron pillars.

The size of the furnaces varies between 50 and 100 feet in height, the largest size producing as much as 3,000 tons of pig iron per week.

In order to produce 1 ton of pig iron it is necessary to use about 40 cwt. of iron-ore, 20 cwt. of coke, and 8 cwt. of limestone.

The charge, which consists of definite quantities of ore, coke, and limestone, is taken to the top of the furnace either by means of an hydraulic lift or else on an inclined hoist. It is then dropped into the hopper receiver, the ball of which is lowered to admit the charge into the furnace. Charging takes place about once every fifteen minutes, and forms a layer all round the furnace, keeping the mass at a constant level. The ball and hopper arrangement at the top of the furnace prevents the escape of hot gases during the charging process.

As the furnace is widest and largest in the centre and tapers downwards, it thereby prevents any large mass of metal falling on the hearth. The iron being heavier than the fuel gradually sinks, gaining more heat as it proceeds downwards, and at the same time becoming more liquid. As the molten mass falls it carries with it cinders and slag, which rise to the top and are allowed to pass off through an opening about 3 feet above the floor of the hearth, into cinder tubs. The amount of slag obtained is about equal to the amount of pig iron produced. To aid combustion, air previously heated to a temperature of about 1,200° Fahr. is blown in by means of a special blowing engine; the pressure of the air depends upon the height of the furnace, and varies between 3 and 12 lb. per square inch. The blast is admitted to the furnace through special water jacketed tuyeres.

The waste gases given off by the furnace, which are the product of the combustion of the fuel, are utilized for heating the air blast, working the blowing engine, and in some cases firing the boilers of the works.

When the hearth of the furnace is fully charged with molten metal, it is tapped, about eight hours being required to provide the full amount. The tapping simply consists of knocking in a plug of fire-clay, which allows the metal to run out into the sand channel ready to receive it. The main channel leads to a smaller channel called a sow, from which smaller channels lead into sand moulds, the latter being termed pigs. The pigs are about 3 feet long and 4 inches wide.

When pig iron is intended for conversion into steel, it is not run into pigs, but direct into ladles ready for transportation to the metal mixer, whence it goes direct to the converters or steel furnaces.

Pig iron contains from 3 to 4·5 per cent of carbon, about 3 per cent being in the form of graphite or blacklead, the remainder being chemically combined with the iron.

The Cupola.—The foundry cupola consists of a vertical cylindrical vessel constructed of steel plates and lined with fire-brick, a door near the top being provided for introducing the charge; at the bottom is the hearth upon which the molten liquid collects. In order to produce the necessary heat to melt the iron, air is blown into the mass of coke and iron through tuyeres placed at the bottom of the furnace.

The charge is made up of layers of broken pig iron, coke, and limestone, the usual amount of coke and limestone being about $2\frac{1}{2}$ cwt. of coke and $\frac{1}{2}$ cwt. of limestone to 1 ton of pig iron. The molten metal is tapped into a ladle and run into moulds as required.

The pig iron used for foundry purposes is termed grey iron, and is classified Nos. 1, 2, 3, and 4 (foundry); the amount of combined carbon increasing as the numbers rise, and the amount of silica decreasing.

The Puddling Furnace.—In order to produce wrought iron of good quality, pig iron from the blast furnace is first put through a refining process, the object of which is to convert or abstract the whole of the uncombined graphite. This object is accomplished by melting the metal, and forcing a blast of air on to the surface of the molten metal, and thereby oxidizing the carbon and producing what is known as white iron.

The puddling furnace is made up of cast-iron plates lined with fire-brick, with a dome-shaped roof to reflect the heat.

The hearth of the furnace is lined with oxide of iron or tap cinder, and the charge consists of about 4 cwt. of white iron; this amount requires about half an hour to become partly melted, and to form a pasty mass. When it is in this state it is thorougly rabbled with the tap cinder, in order to bring every part under the oxidizing influence of the oxide of iron; the carbon then combines with the oxygen and passes off as $C\,O_2$.

At this stage of the process jets of flames known as puddler's candles are formed, the slag begins to drop, and particles of malleable iron float on the surface, forming a spongy mass. These particles are worked together by the puddler and made into balls. The balls are taken to the shingling hammer and then hammered, so that the slag is squeezed out, and the iron welded together, forming what is known as blooms. To improve the quality of the iron, the blooms are reheated, piled four high, and welded into billets, and then again reheated and rolled into bars, plates, angles, etc.

Steel

Steel is a compound of iron and carbon, or iron, carbon, and some other element, forming an alloy or compound capable of being hardened by a sudden cooling. Carbon steels of the mild steel quality contain not more than 0·2 per cent of carbon, medium steels up to 0·5 per cent, hard or high carbon steels up to 1·6 per cent.

Alloy Steels.—Steels which owe their properties chiefly to the presence of an element other than carbon are called alloy steels.

Bessemer Steel.—Steel made by the Bessemer process.

Blister Steel.—Steel made by the Cementation process.

Crucible Steel.—Steel made by the Crucible process, irrespective of the carbon content.

Open Hearth Steel.—Steel made by the Open Hearth process, irrespective of the carbon content.

Shear Steel.—Steel usually made from blister steel by cutting bars into short lengths, then piling and welding them, by hammering or rolling at a white heat.

Double Shear Steel.—Made in the same manner as shear steel, only the process is repeated two or more times.

Alloy Steels

It has been found that by the addition of some of the rarer elements to the compound of iron and carbon very valuable properties are imparted to that metal. The elements chiefly used in alloying are chrome, manganese, molybdenum, nickel, silicon, tungsten, and vanadium. One very high class of alloy steel, greatly used in the manufacture of lathe tools, is said to have the following composition :—

Carbon .	0·68 per cent.	Tungsten .	18·0 per cent.
Chromium .	5·75 ,,	Manganese .	0·09 ,,
Vanadium .	0·30 ,,	Silicon . .	0·46 ,,

Bessemer Steel

The Bessemer process of making steel was patented in the year 1855 by Sir Henry Bessemer, and is a method by which air is blown through a molten mass of pig iron, whereby the carbon, silicon, and manganese are burnt out, sufficient heat being produced during the process to keep the metal in a liquid state and enable it to be poured into ingots. The required amount of carbon being added in the form of ferro-manganese, a variety of iron rich in carbon and manganese.

The Bessemer converter is a pear-shaped vessel lined with fire-brick, ganister, or dolomite, and constructed to rotate on trunnions, through one of which the air is blown. At the bottom of the converter a number of water-jacketed tuyeres are arranged to convey the air blast to the molten iron.

Before being run into the converter, pig iron free from phosphorus and sulphur is melted, and the inside of the converter prepared to receive it. When ready, the converter is rotated to the horizontal position, and the molten metal poured in from a ladle; air is then blown in for about twenty minutes. The metal during conversion really passes through three stages. In the first stage the air blast causes a shower of sparks with very little flame, and lasts for about four minutes; in that period the uncombined carbon is converted to the combined form, and the silicon is changed to silica. In the second stage the temperature rises, and for about ten minutes the whole mass appears to boil, this being due to the oxidization of the carbon and the escape of carbon monoxide, CO. In the third stage the air-pressure is reduced, and the remainder of the carbon and manganese is burnt out. The whole process of conversion takes about twenty minutes, and is indicated by a subsiding of the flames. The metal is still in the liquid stage, and the converter is then brought to the horizontal position, when the necessary amount of carbon is added in the form of spiegeleisen, which is white iron containing a known proportion of carbon and manganese. The steel is then poured into a ladle, and from

the ladle into iron ingot moulds, whence it goes to the soaking pits for about one hour, finally being run through the cogging mill, and rolled into bars, angles, tees, plates, etc.

Blister Steel

The production of blister steel by the Cementation process is the most important preliminary process employed in the manufacture of crucible cast steel. To produce blister steel by the Cementation process best selected bars of wrought iron are placed in a cementation furnace surrounded and packed in with charcoal, the furnace fire is lit, and in two days the conversion of the iron begins. A temperature sufficient to keep the bars at a blood-red heat is maintained for about nine days, the actual time being determined by the percentage of carbon required in the iron, and which ranges between 0·6 and 1·6 per cent.

At the end of the heating period the fire is withdrawn and the bars taken out, when they are found to be covered with blisters. The bars are broken into short pieces, piled, reheated, treated with a flux of borax and sand, and then welded together and drawn into bars; it is then called single shear steel.

When a better quality steel is required the single shear bars are broken into short lengths, selected for fracture, and then piled, reheated, welded, and drawn, and is then called double shear steel.

Crucible Steel

Tool steel, or what is sometimes called cast steel, is generally made from blister steel by cutting the bars into small pieces and melting them in a fireclay crucible, adding the necessary amount of carbon in the form of ferro-manganese.

Another method of making cast steel, or alloy steel, is to take small pieces of best Swedish bar iron and melt it in air-tight crucibles, adding oxide of manganese, charcoal, and any other elements required. The steel is run into iron moulds, forming ingots, which are hammered into bars or rolled into sectional shapes.

Open Hearth Steel

Several methods of producing open hearth steel are in vogue, the general principle being that a certain quantity of pig iron is melted in a reverberatory furnace, and red hematite added to oxidize the carbon, silicon, and manganese. Carbon then being added in the form of spiegeleisen and ferro-manganese.

It is somewhat similar to the process of puddling wrought iron, only on a larger scale. The furnaces have a capacity of 30 to 50 tons, and are heated by gas made from bituminous coal. The air and gas are passed through regenerative chambers before being allowed to enter the combustion chamber, and are heated to a temperature of about 1,200° Fahr. This preheating of the air and gas allows of an extremely high temperature being maintained in the furnace, and thereby keeps the metal in a liquid state.

The charge of molten metal has mixed with it red hematite ore or other oxides, which, owing to the chemical reactions, keep the molten iron in a continuous state of agitation. In the open hearth process it is usual to make use of scrap wrought iron or scrap steel, because the high temperatures obtained by the regenerative furnace allows of their being brought to a molten state. If the scrap contained too much phosphorus, then burnt lime is added to the charge, and when lime is used in order to keep the slag basic the process is called the "Basic process".

To melt a 30 ton charge of open hearth steel takes about five hours.

Malleable Iron

To produce a malleable iron casting, the casting is first cast in the ordinary manner from hard brittle white iron. The sand adhering to it is thoroughly removed by pickling. It is then packed in a cast-iron box with powdered red hematite ore, or rusty steel turning, then covered with fireclay, and brought to a blood-red heat, being kept at that temperature from two to seven days. The oxygen of the ore combines with the carbon in the iron, and reduces the carbon to less than 1·0 per cent. Malleable castings can be bent, but they cannot be forged in a similar manner to wrought iron.

NON-FERROUS METALS

Aluminium.—A metal used chiefly on account of its lightness; it has a specific gravity of 2·56, and weighs about 0·09 lb. per cubic inch. It is of bluish-white colour, and is seldom made use of in its commercially pure state. Aluminium resists the action of salt water much better than iron or steel, and does not corrode.

Antimony.—A white metal with a melting-point of about 1,150° Fahr. It is very brittle, and is chiefly used for hardening anti-friction metals.

Bismuth.—Grey-white in colour. Crystalline and brittle, and expands in solidifying. Melts at 520° Fahr. Sp. gravity 9·8

Copper.—A pink-coloured metal with a melting-point of about 1,900° Fahr. and a specific gravity of 8·82. It is very malleable, of high tenacity, and quickly becomes hard and brittle in working. When near its melting-point it is extremely brittle, and under the influence of sulphur, bismuth, or antimony, it deteriorates to a large extent. It is a very good conductor of heat, and for that reason is used in the manufacture of locomotive fire-boxes, etc. Its chief use is as a constituent with tin and zinc, in forming alloys.

Lead.—A blue-grey metal with a specific gravity of 11·37. It is highly malleable, can be rolled into sheets or formed into tubes or pipes. Owing to its low tenacity of 1·5 tons per square inch, it cannot be drawn. It is largely used as a constituent in the making of bronzes and fusible alloys.

Nickel.—A yellowish-white metal of about the same strength as copper, less ductile but harder. It melts at a temperature of about 2,600° Fahr., and in its pure state is very difficult to cast owing to the gas given off in cooling. Used to a considerable extent as a constituent in alloys of steel.

Tin.—A white-coloured metal with a yellow tinge and a melting-point of 445° Fahr. It is very soft and malleable, and can be rolled into very thin sheets. Seldom used in its pure state, but forms a valuable constituent in bronzes and special alloys.

Zinc.—A white metal with a greyish tint, melting at 785° Fahr., and having a specific gravity of 7·1. It can be rolled at a temperature between 212° and 300° Fahr. Largely used as a constituent in copper alloys.

STRENGTH AND PROPERTIES OF METALS

Definition of Terms

Compression.—A term used to indicate the state the particles of a body are in when a force tends to crush the particles together.

Ductility.—A metal is said to be ductile when it can be drawn and extended by a tensile or pulling force.

Elasticity.—The power of a metal to return to its original shape after a force has been applied and then released.

Elastic Limit.—If a metal is subjected to a gradually increasing strain, a certain limit is reached within which the stresses are proportional to the strains.

Elongation.—The amount a piece of metal stretches between two fixed points is called the elongation. It is made up of two parts, one due to the general stretch, the other to the contraction at the point of fracture.

Expansion.—Expansion is usually expressed as a coefficient, and which is the amount every unit of length expands for every degree of rise in temperature.

Fusibility.—The property of becoming liquid on the application of heat is termed the fusibility of the metal.

Hardness.—Hardness is the power of the surface of a metal to resist penetration by cutting or scratching. It can be expressed in relative terms.

Heat Conducting.—The property possessed in varying degree by metals for transmitting heat along or through them.

Malleability.—The changing of the shape by hammering, pressing, or rolling without causing fracture.

Shearing.—The shearing strength of a metal is equal to the force which, if applied at right angles to the line of axis, would cause the parts to separate.

Specific Gravity.—The ratio of a volume of metal to the weight of an equal volume of water is termed the specific gravity.

Specific Heat.—The relative amount of heat absorbed by metals, compared to the heat absorbed by an equal quantity of water when raised through the same temperature.

Tenacity.—The tenacity of a metal is the power to resist the effort of stretching or pulling apart.

Tensile Strength.—The equivalent to the amount of force applied to a piece of metal in a line with its axis, to just overcome the cohesion of particles and pull it into separate pieces.

Toughness.—A metal is said to be tough when it can be bent first in one direction, and then in the opposite, without developing a fracture.

Weldability. — The property possessed by a metal which renders it capable of being joined when in a state of fusion.

The Relative Hardness of Metals

Brinell Method

Lead . .	1·0	Wrought iron .	14·5
Tin . . .	2·5	Mild steel .	20·0
Zinc . . .	7·5	Cast iron (soft)	24·0
Copper (soft) .	8·0	Cast iron (hard)	35·0
Copper (hard) .	12·0	Steel (hardened)	93·0

Order of Malleability of Metals by Hammering

1. Aluminium.
2. Copper.
3. Tin.
4. Platinum.
5. Lead.
6. Zinc.
7. Iron.
8. Nickel.

Composition of Alloys

Percentage

	Copper	Zinc	Tin	Manganese	Phosphorus	Aluminium
Admiralty metal	75	25	...	...	...	...
Brass . . .	66	34	...	...	...	...
Bronze, phosphor	90	8	2	...	0·3	...
Bronze, manganese	60	38	1	0·3	...	0·5
Bronze, aluminium	90	...	...	...	...	10
Gun-metal .	88	2	10	...	...	...
Muntz metal	60	40	...	...	...	...
White metal	70	26	4	...	...	...

Allowance for Contraction

All the common metals expand when heated and contract in cooling, and it is owing to the expansion and contraction of metals before and after cooling that patterns used in the foundry are made larger than the required casting. The following figures give approximate allowances, but considerable judgment is required in order to decide the exact amount suitable for a particular job.

	per ft.		per ft.
Cast-iron large castings	$\frac{3}{32}$ in.	Cast-iron girders .	$\frac{1}{10}$ in.
,, small castings	$\frac{1}{10}$ in.	Castings in brass (large)	$\frac{5}{32}$ in.
,, pipes .	$\frac{1}{8}$ in.	,, ,, (small)	$\frac{1}{8}$ in.
Castings in zinc .	$\frac{5}{16}$ in.	,, copper .	$\frac{3}{16}$ in.
,, tin .	$\frac{1}{4}$ in.	,, lead .	$\frac{5}{16}$ in.

Order of Ductility of Metals in Wire Drawing

1. Platinum.
2. Iron.
3. Copper.
4. Aluminium.
5. Nickel.
6. Zinc.
7. Tin.
8. Lead.

Ultimate Strength of Metals

Metal	Tension lb. sq. in.	Compression lb. sq. in.	Shear lb. sq. in.
Aluminium	15,000	12,000	12,000
Brass, common... ...	22,000	30,000	36,000
Bronze, manganese ...	60,000	120,000	
Bronze, phosphor ...	58,000		
Copper, cast	24,000	40,000	30,000
Copper, rolled	36,000	58,000	
Iron, cast	15,000	80,000	18,000
Iron, wrought	48,000	46,000	40,000
Lead	2,000		
Steel castings	70,000	70,000	60,000
Steel wire	150,000		
Tin	3,500	6,000	
Zinc	5,000	20,000	

Approximate Weight of Metals

per Cubic Inch

	lb.		lb.		lb.
Aluminium	0·09	Iron, wrought	0·28	Steel . .	0·28
Antimony .	0·24	Lead . . .	0·41	Tin . . .	0·26
Brass . .	0·30	Nickel . . .	0·31	Tungsten .	0·67
Copper . .	0·31	Platinum . .	0·80	Vanadium .	0·19
Iron, cast .	0·26	Silver . . .	0·38	Zinc . . .	0·26

Melting-point of Metals

	Fahr.		Fahr.
Aluminium .	1,218°	Nickel . . .	2,600°
Antimony . .	1,160°	Platinum . .	3,200°
Brass . . .	1,750°	Silver . . .	1,750°
Bronze . . .	1,670°	Steel . . .	2,500°
Copper . . .	1,940°	Tin . . .	440°
Iron, cast . .	2,300°	Tungsten .	5,400°
Iron, wrought	2,900°	Vanadium . .	3,200°
Lead . . .	620°	Zinc . . .	780°

Weight of Round and Square Bars of Wrought Iron

in Pounds per Foot

(For Steel add 2 per cent.)

Thickness or diameter of metal in inches	Weight of one foot of square iron	Weight of one foot of round iron
$\frac{1}{8}$	0·052	0·041
$\frac{1}{4}$	0·208	0·164
$\frac{3}{8}$	0·469	0·368
$\frac{1}{2}$	0·833	0·654
$\frac{5}{8}$	1·302	1·023
$\frac{3}{4}$	1·875	1·473
$\frac{7}{8}$	2·552	2·004
1	3·333	2·618
$1\frac{1}{8}$	4·219	3·313
$1\frac{1}{4}$	5·208	4·091
$1\frac{3}{8}$	6·302	4·950
$1\frac{1}{2}$	7·500	5·890
$1\frac{5}{8}$	8·802	6·913
$1\frac{3}{4}$	10·21	8·018
$1\frac{7}{8}$	11·72	9·204
2	13·33	10·47
$2\frac{1}{8}$	15·05	11·82
$2\frac{1}{4}$	16·88	13·25
$2\frac{3}{8}$	18·80	14·77
$2\frac{1}{2}$	20·83	16·36
$2\frac{5}{8}$	22·97	18·04
$2\frac{3}{4}$	25·21	19·80
$2\frac{7}{8}$	27·55	21·64
3	30·00	23·59

Salt Baths for Hardening Purposes.

Pure Barium Chloride, 2000° to 2400° F.

Barium Chloride, 3 parts; Potassium Chloride, 2 parts } 1400° to 1650° F.

Potassium Nitrate, 1 part; Sodium Nitrate, 1 part } 560° to 1075° F.

CHAPTER IV

THE HEAT TREATMENT OF METALS

ANNEALING

The process of manufacture required to produce bars of steel, castings of steel, or forgings of steel must naturally set up some internal or external strains. All drawing, twisting, forging, rolling, bending, and welding operations tend to set up stresses, which, to a greater or less degree, cause brittleness.

To reduce the stresses and restore the metal to its normal condition, and at the same time soften it, it is necessary to put it through one of the annealing processes and thoroughly anneal it.

It is specially desirable that high carbon steel tools, which may require to be hardened after manufacture, should be annealed, and the necessity becomes greater when the metal is of intricate shape, or when holes of irregular shape pass through it.

The methods of annealing differ to some extent with the class of work requiring annealing. The ordinary shop method for annealing a small job is to bring the piece to a blood-red heat and place it in the hot ashes of the forge to gradually cool. This rough and ready method is suitable for some work, but should never be adopted for the more intricate work with carbon steels. For this class of work a cast-iron box is obtained, and the piece of work to be annealed is placed in and packed all round with charcoal, care being taken that it is evenly packed with not less than one inch of charcoal surrounding every part. The whole is then placed in a gas oven and brought to a temperature of 1,450° Fahr., corresponding to a cherry-red colour; it is kept at that temperature about one hour, after which the whole is allowed to gradually cool, and on no account must the work be taken out of the box until it is quite cold.

In annealing wrought or cast iron the same method is adopted, but in the place of the charcoal, cast-iron turnings can be used if desired.

Copper and Copper Alloys.—When copper is worked in any way it very quickly becomes hard and brittle, and during the

process of such operations as flanging or bending it is necessary to constantly anneal the metal.

The annealing of copper is a very simple operation; the metal is brought to a blood-red heat in a clean charcoal fire, and then plunged into cold water. Care must be taken not to overheat the metal, and the water used must be clean and quite free from grease.

HARDENING STEEL

Carbon can be found in steel in two forms, one known as pearlite or softening carbon, the other as cementite or hardening carbon. All varieties of carbon steel containing more than ·5 per cent of carbon can be made hard by bringing it to a certain temperature and then suddenly quenching in water. The temperature to which steel must be brought in order to bring about this change in the nature of the carbon is known as the point of decalescence.

It is found that steel slowly cooling from a high temperature, at a certain point, actually increases in temperature in spite of its surroundings being colder; this is the point where the carbon changed its form, and is the recalescence point.

It is also found that when a piece of steel has been heated to a certain point, it continues to absorb heat without showing a corresponding rise in temperature; this is called the point of decalescence. The decalescence point is from 100° to 200° Fahr. higher than the recalescence point.

To harden a piece of carbon steel it is necessary to bring it, first, to the point of decalescence, which corresponds to a temperature of about 1,450° Fahr., and then cool it suddenly before it reaches the point of recalescence, which corresponds to a temperature of about 1,280° Fahr.

TEMPERING STEEL

The object of tempering is to bring a piece of metal or a tool to a known degree of hardness, suitable to the requirements of the tool or part, for the work it may have to do.

The more heat imparted to the part during the tempering process the more the hardness will be reduced.

When a piece of hot steel with one face or edge made bright is exposed to the atmosphere, it will be found that various colours appear on the metal. These colours are caused by the formation of thin films of oxide, and are due to the action of the oxygen in the air and the carbon and heat in the metal. Each colour corresponds with a fixed temperature, which is shown in the following table :—

TEMPERATURE TABLE

Colour	Approx. Temp.	Colour	Approx. Temp.
	Degrees F.		Degrees F.
Light straw . .	430	Red . . .	1,080
Straw . . .	450	Dark red .	1,300
Dark straw . .	490	Cherry red .	1,450
Yellow . . .	500	Bright cherry	1,800
Brown purple . .	530	Light orange	2,000
Dark blue . .	580	White . .	2,400
Full blue . .	600	Brilliant white	2,550
Greenish blue .	630	Dazzling white	2,730

The methods adopted for tempering differ very greatly, and depend upon the class of steel, the size, and the nature of the work the piece of metal will be called upon to do. Two distinct methods are in use, one in which the work is first fully hardened and afterwards tempered, the other in which the hardening and tempering are done in one operation. The first method is generally adopted for high-class tool steel and intricate work, and the second for ordinary carbon steel cutting tools. In the former method the piece to be hardened and tempered is first hardened to the full extent, and then the temper is drawn by placing it in a bath of metal previously brought to the required temperature, or by holding it close to a flat piece of red-hot iron.

In the latter method the piece to be hardened and tempered is brought to a cherry-red about three inches, the end is then placed in water for about half this distance and cooled; one face is immediately rubbed with a piece of brick, and as the heat remaining in the metal conducts itself towards the one end the colours can be seen approaching. When the desired colour or temperature reaches the end, further reduction can be stopped by plunging it into cold water.

Alloy Steels.—The introduction of alloy steels in the shape of self-hardening and high-speed steels has altered the older methods of hardening and tempering. Many of the special tool steels require a special hardened method, and it is always advisable to consult tbe maker as to what is the correct method.

Mushet and tungsten steels are hardened by heating the cutting edge slowly to a bright red, and then rapidly to a white, cooling off in a blast of cool air, or plunging into cold oil. The following table gives the colours to which various tools should be tempered :—

COLOURS FOR TEMPERING

Colour	Tools to be Tempered
Light straw .	Scrapers, scribers, lathe tools.
Dark straw .	Chisels, drills, driffs, screwing tackle.
Brown purple .	Hack saws, flat drills, wood tools.
Dark blue . .	Springs, screw-drivers, wood saws.
Greenish blue .	Too soft for most purposes.

Case-hardening.— Case-hardening is a process whereby the skin of mild steel or wrought iron is converted into a form of carbon steel. The small percentage of carbon in mild steel does not allow of its being hardened, but by taking advantage of the case-hardening process it is possible to add sufficient carbon to allow the piece to be hardened.

The quickest method of case-hardening is by means of potassium ferro-cyanide. The cyanide is first crushed in a tray or melted in a ladle; the metal to be hardened is brought to a cherry red, and rolled in the powder or placed in the bath of liquid cyanide, after which it is plunged into cold water.

Various compounds are used for case-hardening, all of which contain in some form a carbon substance; the commonest of these substances are bone, charcoal, leather, and blood.

To case-harden castings of unequal form, the best material is perhaps granulated raw bone. The process requires the use of an iron box in which the metal is packed, surrounded by the bone. The whole is then placed in a gas oven or furnace, and kept at a cherry-red temperature for a period varying between two and twenty hours, after which the whole is plunged into cold water. By this means it is possible to case-harden from $\frac{1}{32}$ to $\frac{1}{8}$ of an inch in depth, but little advantage is gained by going deeper than $\frac{1}{8}$ of an inch.

CHAPTER V

COMMON WORKSHOP TOOLS

It is proposed in this chapter to deal with common engineering workshop tools in everyday use, and to indicate the name and the purpose of each tool.

Rules.—Engineers' steel rules are made in an infinite variety of lengths, widths, and thicknesses, both hardened and flexible. The usual graduations are 64ths, 32nds, 16ths, and 8ths, but any number of graduations of the inch can be either obtained or specially made. A most useful set of graduations are 100ths, 50ths, and 10ths.

When metric measurements are to be made, then a rule graduated in millimetres and centimetres is used, and as this is a frequent occurrence, rules are sold with millimetre graduations on one side and English measure on the other.

For accurately dividing rules special machines are used, and all reputable makers can be relied on to supply a rule of sufficient accuracy for all practical work.

Calipers.—Calipers of the ordinary type are not measuring tools, they are used simply to obtain a length, the actual measurement of which must be taken by some form of measuring instrument. An enormous variety of calipers are on the market; the best form perhaps are those in which the

FIG. 44.

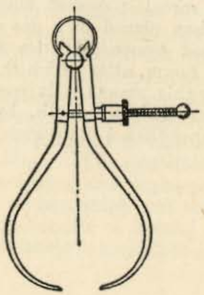
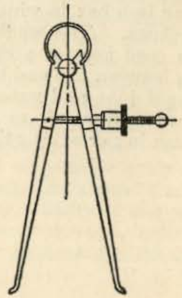


FIG. 45.



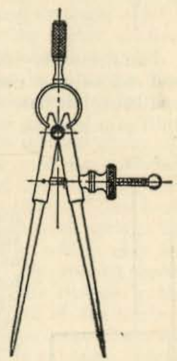
legs are opened and closed by means of a spring, the adjustment being made by a knurled nut. The simplest form of calipers are those used for inside and outside calipering, these are illustrated in Fig. 44 (outside calipers) and Fig. 45 (inside calipers). For special work, such as screw-cutting, calipers with suitable shaped ends are used; these may be very broad for taking the tops of external threads, or very thin for going to the bottom of threads, or, if for internal screw work, then with the ends coming to a point.

Using Calipers

Considerable practice is required before it is possible to caliper with any great degree of accuracy, especially when using the inside caliper. If it is desired to caliper a shaft held between the centres of a lathe, then proceed as follows: Hold the caliper by means of the thumb and first finger, with the second finger between the legs, keeping the caliper exactly vertical, adjust and test it on the work; when it passes over of its own weight, and at the same time can be felt to touch, it is set correctly.

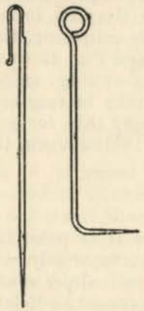
When using the inside caliper, one of the legs should be kept stationary, and with the other leg two small arcs should be made, first in a line with the hole and then at right angles to the hole; this will allow of the caliper being adjusted to the maximum size; for finer adjustment the caliper can be moved up and down the hole.

FIG. 46.



Dividers.—This tool is illustrated at Fig. 46. The points are hardened and tempered, and the tool is used for exactly the same purpose in workshop practice as the compasses are used in the drawing office, that is, marking out circles, arcs, and finding centres. When striking circles or arcs on metal with the dividers it is usual to make a very light centre dot mark for the fixed leg of the dividers to work in.

FIG. 47.



Scribers.—In order to mark the surface of metal, scribers made from cast steel with the ends pointed and hardened are used. In most cases the straight scriber can be used, but often it is not possible to make the straight scriber do, in which case the pointed end can be turned round to form a bent scriber. The straight and bent scriber are illustrated at Fig. 47.

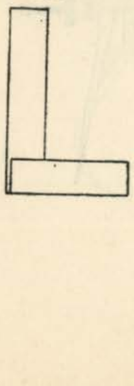
When the surface of the metal to be marked is polished or very bright, or when a scratch is objectionable, then a scriber made of brass can be used.

FIG. 48.

Centre Punch.—A tool made from cast steel, generally of hexagonal or octagonal section, one end being turned to an angle of 60°, with the point hardened and tempered. This tool is used for lining out work previous to machining and fitting. The dots made by the punch should be light, about $\frac{3}{8}''$ or $\frac{1}{2}''$ apart, and exactly on the line, so that when the machining is finished half the dot will be left in the work. This tool is shown at Fig. 48.

Pin Punches.—Made somewhat similar to the centre punch, one end being turned to the desired diameter and length, the end being left flat. This tool is used for driving out taper and split pins and for work of a similar character.

FIG. 49.



Try Square.—The best try squares are made from one piece of steel, machined to size, hardened, and then accurately finished by grinding. This important tool is used for testing the accuracy of two surfaces at right angles to each other, or for marking out work on the lining out table. It is shown at Fig. 49.

Thickness Gauge.—The thickness gauge generally takes the form of a small case containing a number of pieces of steel of a definite thickness, the actual thickness of each blade being shown in thousandths of an inch. The blades of metal can be used separately or collectively in testing the distance between two surfaces, or for obtaining clearances between two fixed parts of a machine.

Surface Plate.—A cast-iron plate with the face and edges accurately machined, and afterwards scraped by hand as near true as it is possible to make it. It is used for testing the flatness of a piece of work. When testing a job the surface plate is first very lightly rubbed over with a little blacklead or redlead and oil, and the piece of work to be tested is rubbed on the surface, the transference marks showing the high places.

Radius Gauge.—This tool consists of a number of pieces of steel held in a case, each piece having a definite radius at the end, and which may be either internal or external. The actual size of the radius is stamped on each piece of metal. It is used for testing the radius of a piece of work, or for finding the exact size of a radius.

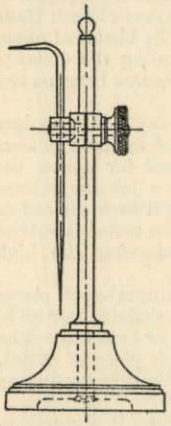
Marking-off Table.—All engineer shops contain a marking-off table. It consists of one or more cast-iron blocks mounted on legs, the faces of which have been machined flat and the edges square. The size of the table depends upon the class and size of work dealt with, and as the name implies it is used for lining or marking off work previous to machining.

Vee Blocks.—Vee blocks are made in pairs from oblong blocks of cast iron, a vee being cut out having an angle of 90°. These tools are used for lining out or centering round shafts, the metal being rotated in one or more vee blocks as required.

Hack Saws.—When metal is to be cut by hand power the hack saw is used. This tool consists of some form of frame, constructed to hold a renewable saw blade.

Scribing Block.—The scribing block or surface gauge is made in a variety of forms. It is a tool used for scribing lines at a given height from some face of the work or the continuation of lines around the several surfaces. The best form of surface gauge consists of a heavy base and upright to which is attached a scriber held by a clamp, which may be turned through a complete revolution. By resting both the surface gauge and the work upon a plane surface such as a surface plate it is possible to set the point of the scriber at a given height, either by use of a rule or some form of height gauge, and draw lines at this height on all faces of the

FIG. 50.

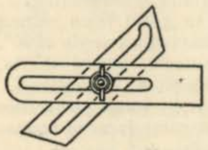


work, or on any number of pieces when duplicate parts are being made.

A simple form of surface gauge is illustrated at Fig. 50, the ends of the scriber being straight and bent as shown. The use of the surface gauge is not confined to scribing on vertical surfaces only, it may be used on other surfaces or as a height gauge as well. The bent end on the scriber permits lines to be drawn on horizontal surfaces.

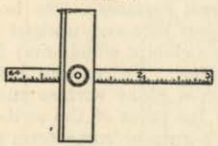
It is necessary in some cases to prepare the surface of the work so that the line made by the scriber will be sufficiently clean-cut to enable the workman to distinguish it quickly. This is done in the case of rough castings by chalking the surface and rubbing in with the finger. In the case of a highly finished surface some other method is necessary. The usual way is to use a solution containing copper sulphide and nitric acid in the proportions of one ounce of copper sulphide, four ounces of water, and a teaspoonful of acid. This solution gives a reddish-brown colour against which the lines will show.

FIG. 51.



Bevel Gauge.—The simplest form of bevel gauge is a tool similar to that illustrated at Fig. 51; it is used for transferring angles and for testing and marking off angles. It is constructed in a variety of shapes and forms, and requires to be set to the desired angle either by means of a protractor, from a standard gauge, or from the work it is intended to copy.

FIG. 52.



Depth Gauge.—The depthgauge is a tool, used as the name implies, for testing the distance between two surfaces, finding the depths of holes, and work of a similar character. Made in a large variety of forms, sometimes consisting of a narrow rule fitting in a cross-bar in such a manner as to be

adjustable; this tool is shown at Fig. 52. When great accuracy is required, it is fitted with a vernier attachment, by means of which it is possible to measure to thousandths of an inch.

Screw Cutting Gauge.—Screw cutting gauges are made for testing the tools used in cutting acme, vee, and square threads. They consist of flat pieces of steel, with pieces of the exact size of the thread cut out.

Wire Gauge.—A tool used for measuring the thickness of sheet metal. Cuts are made in the gauge of various thicknesses, each cut corresponding to a fixed and known size, the amount being stamped on the gauge.

Tapping and Drill Gauge.—This most useful tool is used for testing drills and round metal; it gives at once both tapping and drilling sizes, and is a great time-saver. It consists of a piece of hardened metal with two or more rows of holes of exact gauge at tapping size, each size being stamped in the gauge.

Keyseat Rules.—It is impossible to hold the ordinary steel rule on a cylindrical shaft and keep it parallel, and to overcome this difficulty, rules with flanges, similar in shape to angle bars, are used. The two edges of the rule form a box square when applied to a round piece of work, and permit a line or lines to be drawn parallel with its axis.

Centre or Screw-Cutting Gauges.—These useful little tools are used in grinding and setting screw-cutting tools.

Screw Pitch Gauges.—These consist of a number of spring temper leaves having sections of various standard screw threads. The leaves are stamped with the pitch or threads per inch, and are used to determine the actual pitch of a given thread.

Angle Gauge.—This gauge contains a number of leaves the ends of which are ground to an angle. It is a very convenient tool and frequently can be used in place of the protractor, saving considerable time.

Contraction Rule.—These rules are graduated in a similar manner to the ordinary rule, but allowance is made for various degrees of contraction.

Chapter VI

MEASURING TOOLS AND GAUGES

It is intended in this chapter to deal with fine measuring tools and gauges, or tools by means of which it is possible to measure to finer limits than with the ordinary rule.

The commonest form of measuring tool is, of course, the engineers' rule, and the unit of measurement for the greater part of the work done in the United Kingdom is the Standard Imperial Yard.

With the ordinary rule it will be found difficult to measure accurately to a smaller limit than $\frac{1}{64}$ of an inch; many rules are, however, graduated to $\frac{1}{100}$ of an inch, and it is certainly impossible to take readings smaller than $\frac{1}{100}$ of an inch on the ordinary rule.

The Micrometer

The micrometer caliper is an indispensable tool where very accurate measurements are required. It is constructed in several different shapes and forms, the measuring points in particular being formed to suit the special class of work on which it is to be used, and which may be for the purpose of measuring the depths of threads, the diameter of a piece of work, the size of a hole, or for some special purpose requiring specially designed anvils.

Principle of the Micrometer

Before the novice starts to study the working of the micrometer, he must first perfectly understand the meaning of the word pitch, as applied to a screw thread. This can be done to the best advantage by taking a screw and nut, and actually demonstrating that the nut, in one complete revolution, will move a distance equal to the pitch of the screw, that is to say, if the screw has sixteen complete threads per inch, then the nut would move in one complete revolution a distance of $\frac{1}{16}$ of an inch. It should also be proved that a nut turned half a revolution moves a distance equal to half the pitch, also that whatever fraction of a complete turn the nut is moved, so the distance will equal that fraction of the pitch.

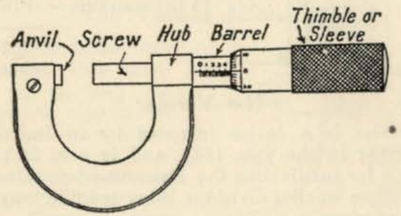
Example.—If a screw thread has twenty complete threads in one inch, then the pitch is $\frac{1}{20}$ of an inch, and if the nut is

moved $\frac{1}{10}$ of a turn, then the distance moved would be $\frac{1}{20}$ of $\frac{1}{10} = \frac{1}{200}$, or if the nut was turned $\frac{1}{20}$ of a turn the distance moved would be $\frac{1}{20}$ of $\frac{1}{20} = \frac{1}{400}$ of an inch.

Outside Micrometer Caliper

A micrometer graduated to read to $\frac{1}{1000}$ of an inch is illustrated at Fig. 53. The screw thread is quite enclosed and thus rendered dust-proof. The wearing parts are hardened,

Fig. 53.



and provision is made for taking up the wear. The various parts are named in the illustration for convenience of reference.

The pitch of the screw is forty complete threads to one inch, or $\frac{1}{40}$ of an inch. The graduations on the barrel in a line parallel to its axis are forty to one inch, and thus they agree exactly with the pitch of the screw; they are numbered at every fourth division, 0, 1, 2, 3, 4, etc. As these graduations conform to the pitch of the screw, each division must equal the longitudinal distance traversed by the screw in one complete revolution, and shows that the micrometer has been opened or closed $\frac{1}{40}$ or $\frac{25}{1000}$ or ·025 of an inch.

The bevelled edge of the thimble or sleeve is graduated into twenty-five parts, and figured every fifth figure, 0, 5, 10, 15, 20. Each division, when coincident with the line of graduations on the barrel, indicates that the screw has made $\frac{1}{25}$ of a revolution, and the opening or closing of the caliper increased or decreased $\frac{1}{25}$ of $\frac{1}{40} = \frac{1}{1000}$ or ·04 × ·025 = ·001.

To read the Caliper

Before proceeding to read the micrometer, particularly note the following:—

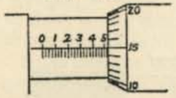
1	division on the	barrel equals		·025
2	,,	,,	,,	·05
3	,,	,,	,,	·075
4	,,	,,	,,	·1

Thus every fourth division equals a certain number of tenths. Also note that each division on the thimble represents a movement of ·001 of an inch.

To read the caliper, first read the numbers of tenths, then the number of fortieths coming after that figure, then the thousandths.

Taking Fig. 54 as an example, the reading would be :—

FIG. 54.



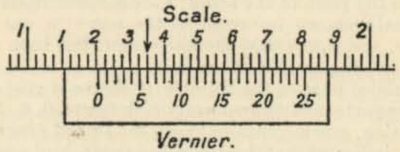
5 tenths	= ·5
1 fortieth	= ·025
15 thousandths	= ·015
	·540

The Vernier

The vernier is a device invented by an Italian named Pierre Vernier in the year 1631, and is used in measuring instruments for subdividing the divisions of a scale into finer divisions, these smaller divisions being too fine for reading in the ordinary manner.

The scale of the fixed portion of Fig. 55 is graduated in fortieths of an inch or ·025, every fourth division being figured, and representing a certain number of tenths. On the sliding vernier a length equalling twenty-four divisions on the fixed scale is divided into twenty-five equal parts; thus the width between one space on the vernier is less than the width between one space on the main scale by $\frac{1}{25}$ of $\frac{1}{40}$, which equals $\frac{1}{1000}$ or ·001 of an inch. If the zero mark on the vernier is set to coincide with the zero mark on the scale, then the next two lines will not coincide by $\frac{1}{1000}$ of an inch ; the next two lines will be $\frac{2}{1000}$ apart, the next two will be $\frac{3}{1000}$, and so on until the last two lines will be found to exactly coincide.

FIG. 55.



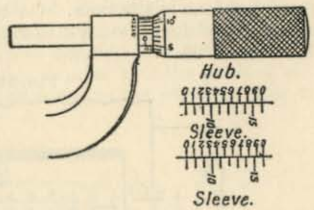
To read the Vernier

To read the vernier first read the tenths, then the fortieths, then the thousandths as indicated by the coinciding figure on the vernier. In the example shown at Fig. 55 the reading would be—

1 inch	1·0
2 tenths	= ·2
0 fortieths	= ·0
6 thousandths on vernier	= ·006
	1·206

The Vernier Micrometer

FIG. 56.



In order to make finer measurements than thousandths of an inch the micrometer is constructed with a vernier reading; this consists of a series of divisions on the barrel of the caliper as shown in Fig. 56. These divisions are ten in number, and occupy exactly the same length as nine divisions on the thimble, and for convenience in reading are numbered 0, 1, 2, etc., up to 10. The width between two lines on the vernier will be less than the distance between two lines on the thimble by $\frac{1}{10}$ of $\frac{1}{1000}$, which equals ·0001 of an inch. Accordingly, when a line on the thimble coincides with the first line on the vernier, the next two lines on the right differ from each other by $\frac{1}{10}$ of the length of a division on the thimble ; the next two differ by $\frac{2}{10}$, and so on.

To read the Vernier

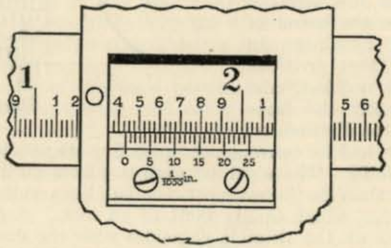
When the caliper is opened the thimble is turned to the left, and when a division passes a fixed point on the barrel it shows the caliper has been opened $\frac{1}{1000}$ of an inch. Hence, when the thimble is turned so that a line on the thimble coincides with the second line (end of the first division) of the vernier, the thimble has moved $\frac{1}{10}$ of the length of one of its divisions and the caliper opened $\frac{1}{10}$ of $\frac{1}{1000}$ or $\frac{1}{10000}$ of an inch. When a line on the thimble coincides with the third line (end of second division) of the vernier, the caliper has been opened $\frac{2}{10000}$ of an inch, etc. When a line on the thimble coincides with the fourth line (end of third division) of the vernier, and the reading is $\frac{3}{10000}$ of an inch, and so on.

To read the vernier micrometer, first note the tenths, fortieths, and thousandths as usual, then read the number of divisions on the vernier commencing at 0, until a line is reached with which a line on the thimble is coincident. If the second line (figured 1), add $\frac{1}{10000}$; if the third (figured 2), add $\frac{2}{10000}$, and so on.

The Vernier Sliding Caliper

The usual type of engineering workshop sliding vernier caliper has the bar of the instrument graduated into inches and numbered 0, 1, 2, etc., each inch being divided into ten parts, and each tenth part subdivided into four parts, making forty divisions to the inch. On the sliding jaw or vernier is a line of divisions, twenty-five in number, and marked 0, 5, 10, 15, 20, and 25.

FIG. 57.



To read the Sliding Caliper

Note the number of inches, then the tenths, then the fortieths, and lastly the thousandths on the vernier.

In Fig. 57 the reading would be

1·0
·4
·025
·009
1·434

The Vernier Bevel Protractor

A very useful and accurate tool for marking out angles, the vernier indicates every five minutes (5′) or one-twelfth of a degree.

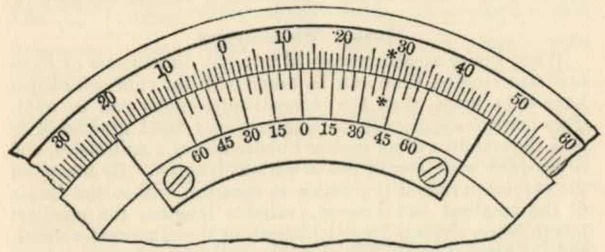
Every space upon the vernier is 5′ shorter than two spaces on the true scale.

When the line marked O on the vernier coincides with the line marked O on the true scale, the edges of the base and blade are parallel. When the swivel head is moved so the line on the vernier next to O coincides with the line next but one to O on the true scale, the included angle of the base and blade has been changed $\frac{1}{12}$ of a degree or 5′.

To read the Protractor Setting

Read off directly from the true scale the number of whole degrees between O and the O of the vernier scale. Then count, in the same direction, the number of spaces from the zero of the vernier scale to a line that coincides with a line on the true scale; multiplying this number by 5 the product will be the number of minutes to be added to the whole number of degrees.

FIG. 57A.

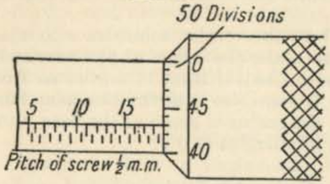


Example.—As the vernier is shown in Fig. 57A it has moved 12 whole degrees to the right of the O upon the true scale and the 8th line on the vernier coincides with a line upon the true scale as indicated by *. Multiplying 8 by 5 the product, 40, is the number of minutes to be added to the whole number of degrees, thus indicating a setting of 12 degrees and 40 minutes (12° 40′).

The Metric Micrometer Caliper

The metric reading micrometer is constructed on exactly the same principle as the micrometer for reading in inches.

FIG. 58.



The pitch of the screw is one-half a millimetre (½ mm.), and the graduations on the barrel 1 mm. and ½ mm., the thimble is divided into 50 parts, thus giving a reading of one hundredth of a millimetre. To read the micrometer first note the number of full millimetres, then see if one-half the millimetre shows or not, then note the number of hundredths on the thimble. Fig. 58 illustrates the method of graduating; in the example we see 18 millimetres, 1 one-half millimetre, and 43 hundredths of a millimetre, and which would be

$$\begin{array}{r} 18{\cdot}0 \\ 0{\cdot}5 \\ {\cdot}43 \\ \hline 18{\cdot}93 \end{array}$$

Inside Micrometers

When linear measurements of internal dimensions of more accurate lengths than can be taken with the rule and caliper have to be made, then the internal micrometer can be used. This instrument consists of a micrometer head graduated to read thousandths of an inch or hundredths of a millimetre, and is provided with sets of rod of various lengths. By means of the extension rods it is possible to measure within the limits of the smallest and longest available lengths, the smallest length being governed by the length of the micrometer head, and the longest by the length of the extension pieces.

Gauges

The advantages of working to gauge are so many that a great part of modern workshop practice is carried out under some system of working to limits. Interchangeability, rapidity of production, lessened supervision and inspection, the elimination of the human factor in judging sizes, and the reduction of the amount of spoiled work, are all factors tending to make the use of some means or methods for controlling sizes during the process of manufacture of utmost importance.

In a general limit system, that is a system that can be applied to all classes of work, it is necessary to decide on

what basis the limits are to be fixed. In the "Hole Basis" system provision is made in the size of the hole for error in workmanship only, and to obtain the quality of fit desired variation of size is allowed on the size of the shaft or journal. The variation is determined by the requirements of the job.

To serve as a guide, and to give some idea of the amount of tolerances allowable, the following table of running fits is given. A running fit is where a shaft is of such a diameter that it will revolve quite freely in a hole which it fits, and leave a space for a slight film of oil. Class X is suitable for running fits for engine and other work where easy fits are required. Class Y is suitable for high speed and good average machine work. Class Z for fine tool work.

ALLOWANCES FOR RUNNING FITS

Nominal Diameters	Up to ½ in.	$\frac{9}{16}$–1 in.	$1\frac{1}{16}$–2 in.	$2\frac{1}{16}$–3 in.	$3\frac{1}{16}$–4 in.	$4\frac{1}{16}$–5 in.	$5\frac{1}{16}$–6 in.
Class X							
High limit	−·00100	−·00125	−·00175	−·00200	−·00250	−·00300	−·00350
Low ,,	−·00200	−·00275	−·00350	−·00425	−·00500	−·00575	−·00650
Tolerance	·00100	·00150	·00175	·00225	·00250	·00275	·00300
Class Y							
High limit	−·00075	−·00100	−·00125	−·00150	−·00200	−·00225	−·00250
Low ,,	−·00125	−·00200	−·00250	−·00300	−·00350	−·00400	−·00450
Tolerance	·00050	·00100	·00125	·00150	·00150	·00175	·00200
Class Z							
High limit	−·00050	−·00075	−·00075	−·00100	−·00100	−·00125	−·00125
Low	−·00075	−·00125	−·00150	−·00200	−·00225	−·00250	−·00275
Tolerance	·00025	·00050	·00075	·00100	·00125	·00125	·00150

It will be seen from the above table that five places of decimals are used; the dimensions, however, actually run in thousandths and quarter thousandths.

Using Gauges

The fitter or turner is not concerned with the amount of tolerance allowed for any particular job. The only question for him is the turning or fitting of the work to suit the gauges.

In using limit gauges, either internal or external, it is intended that one end or one part of the gauge should pass over or go in the work, and the other end or part not go in or pass over the work. No force must be applied to any gauge, and the weight of the gauge alone should be sufficient to carry

FIG. 59.

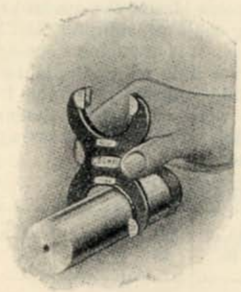


FIG. 60.

it over the work. The object to be aimed at in turning to limit gauge is to reduce the metal to such a size that the large end or plus end of the gauge goes over or in the work, and at the same time the work must be of such a size that the minus end or small end will not go over or in the work. The correct method of holding the external and internal limit gauge is shown in Figs. 59 and 60.

Calipers and measuring tools are entirely dispensed with when using limit gauges, and nothing is left to the judgment of the workman, except finding the quickest and best method for making one end of the gauge pass over the work, and at the same time leaving the work of such a size that the other end of the gauge will not go over the work.

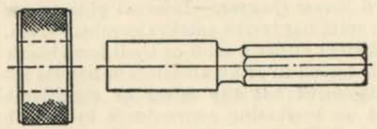
Classification of Gauges

The various gauges used in workshop practice may be classified as follows:—

Standard Internal Gauges
Standard External ,,
Internal Limit ,,
External Limit ,,
Caliper.
Standard Taper ,,
Standard Screw ,,
Adjustable External ,,
Adjustable Screw ,,
Position ,,

Standard Internal Gauges.—Fig. 61. Usually takes the form of a cylindrical gauge; it is used for the most accurate work, possesses large wearing surfaces, and is hardened, ground, and lapped to within ·0001 of the correct size.

FIG. 61.

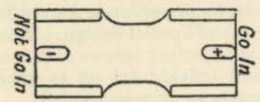


Standard External Gauges.—Fig. 61. Made in the form of a ring, very accurately finished to within the limit of ·0001.

Internal Limit Gauges.—The internal limit gauge is made in two forms, one as shown in Fig. 62, and which is

FIG. 62.

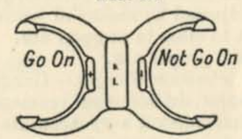
FIG. 63.



cylindrical, and the other as shown in Fig. 63. These gauges are made light and rigid, and are intended for general shop use.

External Limit Gauges.—This gauge usually takes the form shown in Fig. 64, and is the type of gauge intended for general shop use.

FIG. 64.



Caliper Gauges.—Caliper gauges as illustrated in Figs. 65 and 66 are frequently used for both roughing and finishing work.

FIG. 65.

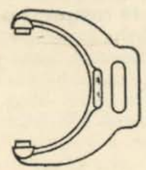
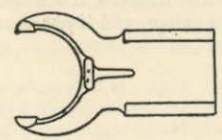


FIG. 66.



Standard Taper Gauges.—The object of using taper gauges is for the securing of correct taper holes in machine work and corresponding accuracy on the work intended to fit the hole. They are in the plug and ring form for external and internal work.

Standard Screw Gauges.—Internal plug screw gauges are made from solid bar in the smaller nominal sizes, and in the larger sizes from either a solid or shell form blank with a mild steel handle forced in or an aluminium handle fitted on ; this latter arrangement has the effect of considerably reducing weight and so increasing convenience in use, but it is not generally adopted except in the case of the largest sizes.

Adjustable External Gauges.—This type of gauge generally takes the form of a tool with two fixed anvils on one jaw and two movable anvils or adjusting screws on the other jaw, forming two pairs of measuring faces, the front pair being the "go" and the back pair the "not go" points ; the adjusting screws are securely locked in position by means of cotters and nuts of special design. Each gauge by the length of travel of its adjusting screws covers a range of sizes, and can be easily and quickly set up to such diameter and limits within its range as may be wanted.

Adjustable Screw Gauges.—Various types of adjustable screw gauges are made to suit special requirements. Generally the rings are rectangular in form, a cut being made through the centre of the screwed part in such a manner that it can be adjusted by means of screws, the spring of the metal causing it to close in or open out. Screw gauges require special care and proper use.

Position Gauges.—Gauges made from flat cast steel, with holes drilled and reamered, which show the position for marking off very accurate work.

Care of Gauges

The working surfaces of all gauges must always be kept perfectly cleaned and oiled. The dropping of a gauge may cause it to become inaccurate, and when a gauge has been accidentally dropped it should at once be compared with the standard gauge, and if necessary corrected.

Chapter VII

LATHE WORK AND TURNING

In order that the lathe hand or turner may be able to produce properly finished and accurate work, it is necessary that he should be provided with a lathe, accessories, and tools that will enable him to meet the following requirements :—

The lathe must be of suitable size and power.

Have accessories for doing various classes of work.

Have lathe tools of correct shape, ground to the proper cutting angle.

The work prepared and set up in a suitable manner.

The correct speed and feed.

By fulfilling the above requirements the turner will have gone the greater part of the way towards obtaining good results. Accuracy in turning comes with practice, and cannot be learnt through the medium of a book.

The Lathe

The types and designs of lathes are innumerable, special repetition work often demanding a special type of lathe. The tendency of recent years has been for the larger works to provide specially designed lathes for each operation ; this is particularly so in munition work. The size of a particular lathe is generally indicated by a distance taken from the lathe centre to the top of the lathe bed, and by the maximum distance between the fixed and movable centres. Two other important sizes are the amount of swing over the saddle and the greatest diameter that can be taken in the gap bed, if the lathe is so provided.

A good lathe should be strong and rigid enough to withstand the heaviest cuts without excessive strain, and in all cases the bed should have large broad surfaces to support the saddle.

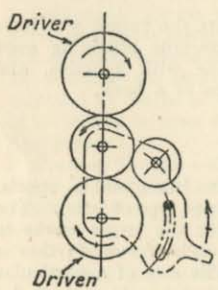
The headstock should be fitted with large bearings, have an efficient and well-designed back gear, and be provided with a cone pulley to take a wide belt.

The tailstock or poppet head should be proportionally rigid to the fast headstock; the tailstock spindle should be large, ground to size, and provided with an efficient locking gear. The screw is best left-handed, and lock nuts should be provided at the back of the hand wheel to take up wear between the collar and its bearings. An arrangement should be fitted by means of which it should be possible to set the tailstock centre out of line with the headstock centre, for the purpose of turning tapers.

The saddle or carriage should be provided with large bearing surfaces, and should move in the same direction as the handles.

The lead screw, or guide screw, being one of the most important parts of the lathe, should be accurately cut, and some simple and effective arrangement should be fitted in order that the saddle can be connected and disconnected as required.

FIG. 67.



Some good type of reversing action should be fitted. Fig. 67 illustrates a simple and common form of tumbler gear. When the lever is down as shown in the illustration, then a train of three wheels comes into operation, and therefore the first and last wheel revolve in the same direction. When the lever is lifted right up, then an even train of wheels comes into use and the direction of rotation of the lead screw is reversed; when the lever is half-way between right up and right down, then neither of the wheels gear with the one on the lathe mandrel, and therefore no movements take place.

Surfacing.—For automatic surfacing work, motion is often transmitted from the lead screw or from a special shaft by means of worm wheels and bevel wheels for surfacing work.

Automatic sliding feed is usually obtained by means of special shaft and gearing, but where this is not provided the lead screw can be used instead; to do this, all that is necessary, is to put on a compound train of wheels that will give a fine thread.

The Countershaft.—The majority of ordinary lathes are driven from a countershaft, which may be arranged to run at one or more speeds. The speed of the countershaft is determined by the size, power, and required speed of the lathe; it should be fitted with a simple and effective type of belt shifting gear.

The Lathe Back Gear.—In order to obtain sufficient power to take deep cuts on large or heavy work, and also to decrease the speed of the lathe, the back gear is used.

The following is a description of the common type of simple back gear:—

On the lathe mandrel one wheel is keyed called the plate wheel, the step-cone pulley and pinion wheel being free to revolve if desired. The back shaft has a wheel and pinion keyed on to it, and can be drawn into gear either by an eccentric motion or by sliding.

When using the back gear the pulley is free from the plate wheel, and the back shaft wheels put into gear.

When running without the back gear the back shaft wheels are taken out of gear, and the pulley is secured to the plate wheel by means of a bolt or pin. Thus, when running with the back gear the motion is transmitted from the countershaft to the cone pulley, which will run free on the lathe spindle and drive the back shaft through the medium of the pinion and wheel, this in turn driving the lathe spindle by means of the pinion and plate wheel.

The object of the back gear being to obtain a large range of speeds, and also to take heavy cuts, it is necessary to know what the reduction of the speed actually is.

To take an example. On an 8 in. lathe the speed cone has four speeds, the diameter of each speed being $3\frac{5}{8}$, $5\frac{1}{8}$, $6\frac{5}{8}$, and $8\frac{1}{8}$ inches. The countershaft pulley revolves at 100 revolutions per minute. The pinion wheel of the lathe spindle and back shaft have 16 teeth each, and the wheels themselves have 48 each. To find the ratio, then

$$\frac{16 \times 16}{48 \times 48} = \frac{1}{9}$$

or the back gear will reduce the velocity of the lathe mandrel compared with the cone pulley as 1 is to 9, the cone pulley revolving nine times as fast as the lathe mandrel.

The cone pulley having four speeds, by using the back gear eight different speeds can be obtained, these being—

Speed without back gear $\frac{100 \times 8\frac{1}{8}}{3\frac{5}{8}} = 224{\cdot}1.$

$$\frac{100 \times 6\frac{5}{8}}{5\frac{1}{8}} = 129{\cdot}2.$$

$$\frac{100 \times 5\frac{1}{8}}{6\frac{5}{8}} = 77{\cdot}3.$$

$$\frac{100 \times 3\frac{5}{8}}{8\frac{1}{8}} = 44{\cdot}6$$

Speed with back gear $\frac{224{\cdot}1}{9} = 24{\cdot}9.$

$$\frac{129{\cdot}2}{9} = 14{\cdot}3.$$

$$\frac{77{\cdot}3}{9} = 8{\cdot}5.$$

$$\frac{44{\cdot}6}{9} = 4{\cdot}5.$$

The eight speeds obtained being 4·5, 8·5, 14·3, 24·9, 44·6, 77·3, 129·2, and 224·1.

Lathe Accessories

General lathe work requires the use of quite a number of lathe accessories. Fig. 68 illustrates a 12 in. *independent jaw chuck*, and Fig. 69 shows a *two-jaw concentric chuck* with

Fig. 68.

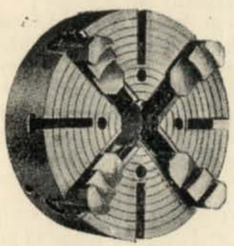
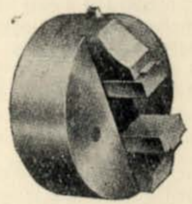


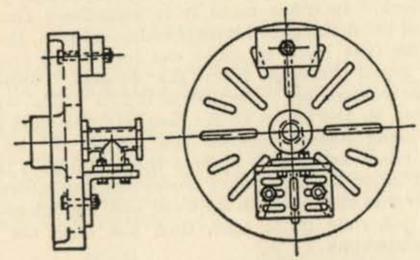
Fig. 69.



slip jaws; the jaws of this chuck are left blank, so they can be shaped to suit the work to be held. Where a variety of work is to be turned, then extra jaws can be made to suit the particular type of work.

The *face plate* is a circular cast-iron plate screwed to fit the lathe mandrel and then faced and turned on the edge perfectly true. Holes and slots are machined or cast in the plate, and it is used in boring and facing operations. The work to be bored or faced is screwed to the plate by means of bolts and

Fig. 70.



plates. Fig. 70 illustrates a face plate set up for boring a three-flange tee piece. In this example it is necessary to use an *angle plate*; here the angle plate is bolted to the face plate and the work secured to the angle plate with a piece of iron on the opposite side of the face plate to act as a counter-balance weight.

Stays.—When long slender jobs have to be turned in the lathe, unless some support is given to the work, it will spring as the tool runs along; to prevent this springing, stays are used. These may be either fixed or moving.

The fixed stay is chiefly used when turning short and stiff pieces of work. It will also be found convenient for supporting jobs requiring internal boring or screwing.

Generally the fixed stay is applied to some portion of the work which has previously been turned; when this is not possible, however, a sleeve can be sometimes fitted on the work, and the latter allowed to rotate in the steady.

The travelling stay or steady is mostly used when the work is parallel nearly its full length. It is secured to the saddle, and the chief advantage lies in the fact that support is given quite close to the tool.

Preparing and Setting-up Work

All work before it can be successfully turned between centres must be first properly prepared by having the ends centered. Many methods may be adopted for finding the centres, and it depends upon the size and shape of the metal as to which is the best method to adopt. For cylindrical work the simplest method is to use the vee blocks and the scribing block. In other cases it is sometimes simpler to make use of the dividers or hermaphrodite calipers, the object in the latter case being to strike out four small arcs, each being an equal distance from the outside. When the approximate centres are obtained a dot is made with the centre punch in the centre of the arcs, and the work is then tested by being rotated between the centres of the lathe, a piece of chalk being held against the metal as it is being rotated. If the metal runs out of truth, then the centres must be drawn over in the direction required and the job re-tested. When the job runs quite true, then the ends are drilled up and countersunk.

For the special purpose of centering work a drill is provided which drills and countersinks in one operation. The size of the hole depends upon the size and weight of the work; for light work $\frac{1}{16}$ of an inch in diameter or even less, with the outer end countersunk 60°.

In order to transfer the motion from the lathe mandrel to the work some form of carrier must be fixed on the work, the carrier being driven by means of a pin in the driving plate or a bolt in the face plate.

Setting Work.—The proper order of procedure for turning is as follows: Put a little oil on the moving centre of the work, and then adjust the tailstock and back centre so that the work will revolve quite freely and at the same time not be slack, and also leaving it in such a position as to allow the saddle and top slide rest to move the required amount. *Note.*—The tailstock spindle should always be as short as possible in order to obtain rigidity.

Procedure.—Select the tool and secure it to the tool holder in such a manner that the cutting edge is exactly level with the lathe centres.

Set the lathe to give the correct speed and feed by making the necessary adjustments to the belts and gears.

Try the lathe by giving a few turns on the belt by hand, and make quite sure that everything is clear and safe.

When commencing to turn, if much metal is to be removed, start by taking a deep cut. If straight centre work is being done, then rough down to within $\frac{1}{32}$ of an inch of full size, square the ends, and file off any excess of metal at the centres, and then re-countersink the holes.

Replace the work in the lathe and finish to the exact size all over. If the work is steel use a plentiful supply of soap and water, if cast iron use a broad-nosed tool.

Speeds and Feeds

The speed at which a piece of metal should be cut depends upon the hardness and shape of the metal, and also upon the rigidity of the lathe. It is very difficult to lay down any definite rule with regard to speed and feed. So much depends upon the job, the strength of the lathe, and the quality of the tool steel, that only approximate figures can be given. The following table can be taken as representing ordinary workshop practice :—

Metal.	*Cutting Speed.*
Hard steel . . .	20–50 feet per minute.
Mild steel . . .	35–150 ,, ,,
Wrought iron . .	40–120 ,, ,,
Cast iron . . .	35–80 ,, ,,
Brass	60–200 ,, ,,
Copper	130–180 ,, ,,

When taking heavy cuts on hard metal it is preferable to decrease the speed and increase the feed; when finishing on wrought iron or mild steel increase the speed and feed; finishing cast iron increase the speed and decrease the feed; when finishing on hard steel retain the speed and increase the feed.

To find Revolutions per minute for a given Cutting Speed

Multiply the cutting speed in feet by 12, and divide the product by the circumference of the work in inches.

Let R = revolutions per minute.
CS = cutting speed.
D = diameter of work.
$\pi = 3\frac{1}{7}$.

$$\text{Then } R = \frac{CS \times 12}{\pi \times D}$$

Example.—Find the number of revolutions per minute a piece of mild steel $3\frac{1}{2}$ inches in diameter should revolve at in order to cut at the rate of 95 feet per minute.

$$\text{Then } \frac{95 \times 12 \times 7 \times 2}{22 \times 7} = 103{\cdot}6.$$

Ans. 103·6 revolutions per minute.

Fig. 70A illustrates a 12 in. belt driven lathe by The American Tool Works Co., the swing over the bed is $13\frac{1}{2}$ in. The swing over the compound slide rest is $9\frac{1}{2}$ in. The hole in the mandrel is $2\frac{1}{16}$ in. The size of tool steel used is $\frac{7}{8} \times 1\frac{3}{4}$ in. Width of driving belt $4\frac{1}{2}$ in.

The following is a description of the various parts :—

Bed construction.—The bed is ribbed transversely with heavy double-walled cross girths spaced 2 feet apart. A rib is carried lengthwise in the centre of the bed, which has a rack cast integral with it. The tailstock is provided with a pawl which engages this rack for resisting the end thrust when heavy work is being turned.

The ways of the bed casting are carefully chilled, which produces a hard close-grained metal for the V bearings. As this provides a harder metal on the shears than on the carriage bearings, the wear which takes place will be largely confined to the carriage, where it will not impair the accuracy or alignment of the machine.

The carriage vees are wider and the bearings longer than are usually provided on other makes. The carriage bridge has also been widened and is of unusually great depth, due to the patented drop vee construction of the lathe bed.

The compound rest is rigidly designed, the swivel being made completely circular and is graduated in degrees. It is clamped to the cross slide by means of four bolts. Full-length taper gibs, having end screw adjustment are provided on both the cross and compound rest slides, these gibs being placed on the right-hand side, where they will not receive the thrust of the tool under ordinary working conditions.

The tailstock is of improved four bolt design, the rear bolts being carried to the top for convenience in clamping. The tailstock spindle is clamped in position by means of a double-plug binder which is so constructed as to securely clamp the spindle at any position without affecting its alignment.

The headstock spindle is made from a special ·75% carbon crucible steel, and all other shafts, including the lead-screw are made of a ·45% carbon special ground stock.

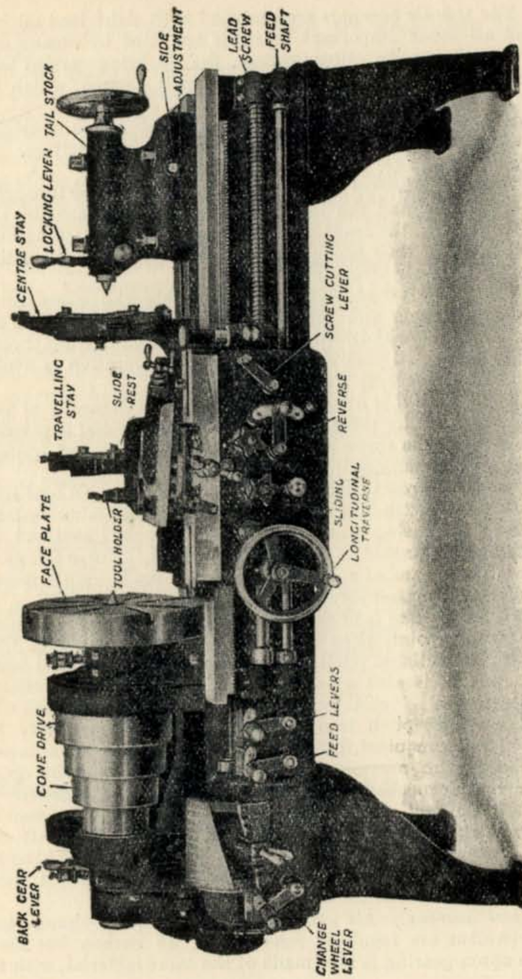


Fig. 70A.

The spindle bearings are equipped with sight feed oil cups, and all other important bearings are oiled by means of an improved gravity oiling system, the oil being carried to the bearings through oil pipes conspicuously located, which hold a generous supply of oil.

A standard thrust bearing is provided which consists of alternate bronze and hardened and ground steel collars. The bronze collars are provided with oil grooves.

Renewable bronze bushed bearings are furnished throughout the machine, and the loose gears in the apron are also lined with bronze ; the studs on which they run being case-hardened and ground, thus providing a hard bearing surface without impairing their strength.

The apron is made in a complete double wall or box section, giving all studs and shafts an outboard bearing. The rack pinion can be withdrawn from the rack when cutting threads, consequently all possibility of chatter or vibration is avoided when cutting coarse pitch screws.

A thread dial is fitted, thus obviating the necessity of using a backing belt for thread cutting. The thread dial is placed at the right of the apron and can be readily disengaged from the lead screw when not in use.

The lead screw is made from 45% carbon ground lead screw stock, and is 2 inches in diameter. The maximum variation allowed in chasing these screws is ·001 inch per lineal foot, and they are guaranteed to be within this limit. These screws are chased by means of a special lead screw made with a Browne and Sharpe master screw.

The ½ in. pitch lead screw permits engaging the half nuts at the proper point when chasing all threads, including those having a fractional pitch. This is not only a great time saving feature, but is also a safeguard against errors when chasing unit threads.

The coarse pitch lead screw and the comparatively low apron ratio required, provides the further great advantage of obviating the necessity of speeding up through the quick-change gear mechanism for the coarser pitches and feeds. As a matter of fact, no member of the quick-change mechanism does at any time run faster than the initial driving shaft, and the compounding gears are therefore only used for cutting the finer threads and feeds. Consequently, a very direct transmission is provided for heavy turning, etc.

Steel gearing.—All gears in the entire quick-change gear mechanism are regularly made from ·45 carbon bar steel. The apron gearing is also made of the same material, with the exception of two large gears which are made from steel castings.

The cone gears of the quick-change gear mechanism are cut with the improved Browne & Sharpe 20 degree involute cutters, which form a pointed tooth slightly rounded at the top. This is the only proper and satisfactory form of tooth to use in a tumbler gear mechanism, as it permits instantaneous engagement of the gears without clashing. The pointed tooth also has a wider and stronger section than the 14½ degree tooth.

The tumbler lever of the quick-change mechanism is cast steel and is bronze bushed. It is guided into its respective positions by means of a slotted plate attached to the front of the box. Consequently, the gears cannot be engaged before they are in their proper position for meshing.

The quick-change gear mechanism forms a complete unit in itself and is mounted on the front of the machine, being fixed to the bed by means of a tongue and groove which ensures permanently accurate alignment. This mechanism is also much more accessible for any necessary attention than where it is incorporated in the bed under the headstock. It provides a range of 48 threads and feeds, all of which are listed on a direct reading index plate located above the tumbler lever. Provision is made for cutting the following threads: ½, ⅝, ¾, ⅞, 1, 1⅛, 1¼, 1⅜, 1$\frac{7}{16}$, 1½, 1⅝, 1¾, 2, 2¼, 2½, 2¾, 2⅞, 3, 3¼, 3½, 4, 4½, 5, 5½, 5¾, 6, 6½, 7, 8, 9, 10, 11, 11½, 12, 13, 14, 16, 18, 20, 22, 23, 24, 26, 28.

All compounding in the feed-box is done by means of taper jaw clutches, which can be easily engaged. This construction is undoubtedly superior to that used on other designs, which have a compound mechanism of the tumbler gear type bolted on the end of the bed.

To find Cutting Speed given Revs. per Min.

$$\frac{\pi \times D'' \times R}{12} = \text{C.S.}$$

Example.—$D = 4\frac{1}{2}$ in. $R = 50$. Find C.S.

$$\text{Then } \frac{3\frac{1}{7} \times 4\frac{1}{2} \times 50}{12} = \frac{22 \times 9 \times 50}{7 \times 2 \times 2} = 58{\cdot}9$$

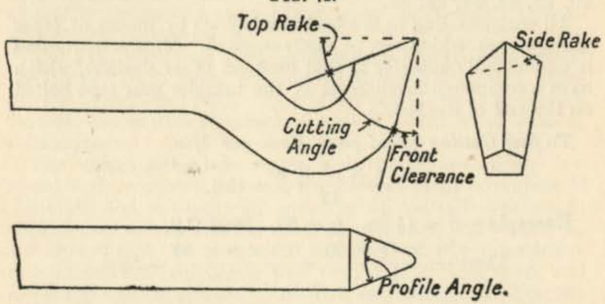
Chapter VIII

LATHE TOOLS

When a lathe is well designed, heavy and very rigid, it contributes in itself very much towards its own general efficiency as a cutting tool. The value and usefulness of a lathe depends almost entirely upon the amount of metal it will remove from a piece of work in a given time consistent with a finish and accuracy as good and as near as required. However, even when a lathe is well designed, successful and accurate work can only be done when tools of proper shape, having correct cutting edges and proper clearances, are used.

The fact that the tools being used are all that can be desired is not, of course, the only reason for rapid and accurate work: speeds, feeds, depth of cut, tool hardness, and the quality and nature of the metal being cut, are all factors which contribute towards the output and general efficiency of the lathe, but whatever the conditions and however good they may be, it is only possible to turn out satisfactory work when the tools are properly designed and correctly ground and fixed.

Fig. 71.



When studying the cutting action of lathe tools it is necessary to take into consideration the factors which go to make up a successful lathe tool. The action of the tool in cutting is similar to that of a wedge being driven into a piece of work, when obviously the more acute the angle of the wedge

the easier it will penetrate, but only within certain limits, because if the wedge is too acute it will be insufficiently supported at the cutting edge and will either break off or turn over, and if it is obtuse it would be difficult to make it penetrate at all.

Before considering the cutting action of tools further than this, it is necessary to be quite clear as to the meaning of the different terms used in describing the various angles and clearances that can be given to a tool. A common type of cranked front tool is shown in Fig. 71. Here the *Profile Angle* is the angle formed by the sides of the nose of the tool: the *Side Rake* is the side slope given to the top of the tool; the *Front Clearance* is the distance between a line at right angles to the body of the tool and the front of the tool; the *Cutting Angle*, which is perhaps the most important factor of all, is formed by the front of the tool and the top slope; and the *Top Rake* is the amount of slope from the cutting point of the tool back towards the body.

In the case of the wedge it is clear that the more acute the angle the easier the wedge will penetrate; this is true of the cutting angle of the lathe tool, but it is obviously necessary to support the cutting edge sufficient to prevent it breaking off or rapidly wearing away. The tool when in use must go on cutting for a considerable time, and therefore it must be well supported and backed up at the cutting edge.

Cutting Angle

The cutting angle depends first on the hardness and nature of the metal being cut, and then upon the amount of metal being removed. With cast iron, wrought iron, and steel, the harder the material the greater the cutting angle, also the heavier the cut the more the cutting edge must be supported by increasing the profile angle. For brass and most of the bronze alloys the cutting angle requires to be greater than for ferrous metal, the top of the tool in most cases being left quite flat with the body of the tool.

With cast iron in particular the metal will be found to vary very much; some will be very soft, some extremely hard. The same thing applies to forgings; here the same forging may have hard and soft places, and sometimes the metal will be extremely hard and dirty on the surface. Gunmetal and bronze also range between very soft metal and extremely hard metal.

In spite of the varying nature of the different metals the tendency of modern practice is to have the lathe tools ground by the tool room department and not by the turner. Repetition work, the improvements that have been made in the foundry and smithy and the advance in the knowledge of metallurgy, have made this to a great extent possible.

While it is not possible to give exact cutting angles for tools to be used on the general lathe, the following angles will serve as a guide and can be taken as being approximately correct.

Cutting Angles

Hard steel	75°	Cast iron	70°
Mild steel and wrought iron	65°	Brass .	85°

A considerable amount of practical experience will be found necessary before it is possible to decide upon the most suitable cutting angle and rake for the different classes of jobs commonly met with in the repair and general shop. The skilled man has frequently to alter the cutting angles of his lathe tools in order to deal with metal of varying degree of hardness and also for such considerations as large diameter work, springy work, and work of an intricate character.

Front Clearance

The question of front clearance is a comparatively simple one. Front clearance is the angle formed by the front of the tool and a line drawn at a tangent to the work at right angles to the centres. For hard ferrous metals the clearance is kept as small as possible in order to well support the cutting edge, but sufficient to just prevent the front of the tool, below the cutting edge, rubbing on the work. For mild steel and wrought iron, the clearance is increased in order to obtain a more acute cutting angle. This of course is possible because the metal being comparatively soft, the tool will stand up to the work with less support than would be necessary with a harder metal.

In the case of non-ferrous metals it will often be found possible and desirable to give a greater clearance than with either wrought iron or mild steel, and this is due to the peculiar nature of the metal.

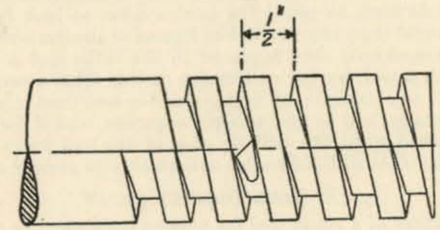
The diameter of the work has a considerable influence over the front clearance of a tool, and where on a small diameter job a tool might have sufficient clearance, on work of large diameter the front of the tool would probably rub.

Side Clearance

The side clearance of a lathe tool must be considered in relation to the feed. The amount given is usually about the

same as for front clearance, but when a coarse feed is being used it may be necessary to grind a side clearance to allow for the resulting tool advance. This will easily be seen in the case of cutting a coarse pitch thread, in which case the side clearance must be made to suit the angle formed by the side of the thread helix, as shown in Fig. 72.

Fig. 72.



Profile Angle

The profile angle of a tool is more often determined by the shape of the work and the character of the cut than by the nature of the metal. For front and side tools of the cranked type, 60° is generally given, but with other types of front tools the profile angle varies to suit not only the particular class of machine it is being used upon, but also the various kinds of metals being turned. Knife tools, screw-cutting tools, parting tools and all tools for special work have profile angles to agree with the conditions required.

Top Rake

The top rake of a tool is determined by the amount of the cutting angle plus the clearance. When turning wrought iron or mild steel the metal being removed should be in the form of a long shaving, and this can only be accomplished if the necessary amount of top rake is given. Insufficient top rake will cause the turning to drop off in short chips, and will also leave a rough finish on the work, therefore it is important that when fibrous metals are being turned as much top rake should be given as is consistent with cutting edge support.

When brass is being turned it is not usual to give any top rake, as with the peculiar nature of this metal all the turnings will be removed in the form of short chips.

Side Rake

It is impossible to give any definite angles for either top or side rake. So much depends upon the nature of the metal being turned, the amount of feed, and the class of finish required, that only practical experience and actual experiment can determine what is the best allowance in both cases. Top and side rake have a great deal to do with the rapid production of accurate work, and a little practical experience with cutting tools will do more to teach the novice what to look for and what to avoid than any amount of figures or illustrations.

If a piece of mild steel is placed in the lathe and a cut is taken with a tool, having neither top or side rake, a very poor finish will be obtained ; by first giving top and then side rake the advantages will be immediately apparent, and if the rakes are increased until the cutting edge of the tool wears away rapidly the most suitable angles will quickly be arrived at.

Tool Design

An example of a crank tool for cutting hard steel is shown in Fig. 73. This illustration is not given as being applicable to all cases, but is intended to act as a guide and a basis from which to start giving top and side rake. Fig. 74 gives the

Fig. 73.

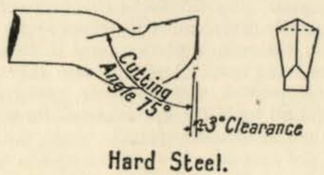
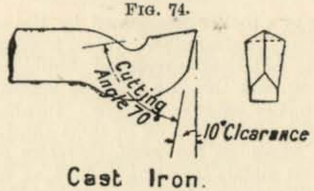


Fig. 74.

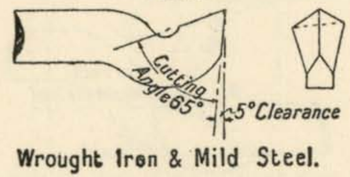


approximate cutting and clearing angles for cast iron turning, it will be seen that the clearance is increased. Cast iron, however, varies so much that in some cases the cutting angle

can be increased to the advantage of the cutting efficiency of the tool.

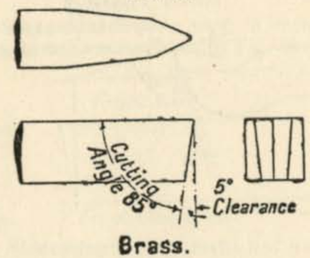
Cutting and clearing angles for front tools intended for turning wrought iron or mild steel are given in Fig. 75. The cutting angle can in many cases be decreased. Side rake is of more consequence here than in the two previous examples, and the correct amount can be determined best after a cut or two has been taken on the metal itself.

Fig. 75.



The example in Fig. 76 can be taken as correct for nearly all cases of brass turning. It is seldom necessary to give any top or side rake, and a flat top tool will be found to give a good finish and produce accurate work.

Fig. 76.



Tool Height

When tools are set in the lathe tool holder preparatory to cutting it is very important that after the tool is placed and held down in position that the cutting edge should be exactly in line with the lathe centres. This applies in all cases for all types of tools and all classes of metals. The correct position for a tool is shown in Fig. 77. It should be quite flat on the holder and dead in line when held down; the effect of raising the tool above the centre will be seen in Fig. 78. Here the clearance is decreased, causing the front of the tool to rub on the work, and the top rake is increased, making the point of the tool weak and liable to break off; lowering the tool as in

FIG. 77.

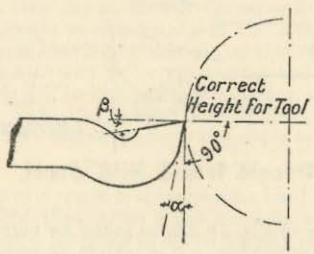


FIG. 78.

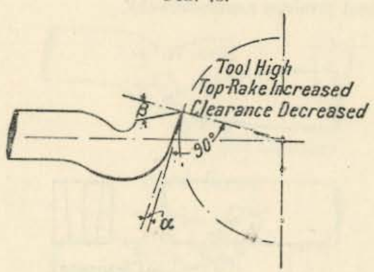
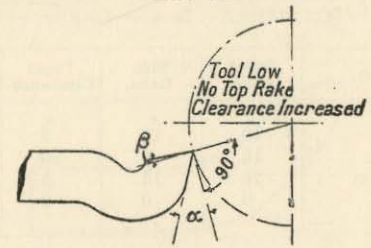


Fig. 79 also has a bad effect, as it considerably increases the front clearance and at the same time takes away the top rake so that instead of the tool cutting as it should do it simply grinds away rapidly at the point.

If the cutting edge of a tool is found to be above the centre of the lathe when it is laid on the tool holder, then the tool is unsuitable for use in that lathe; if on the other hand the cutting edge is below the centre, it can be packed up to the

correct height without any detriment, provided the packing is parallel and extends the full length of the tool and not at either of the ends.

FIG. 79.



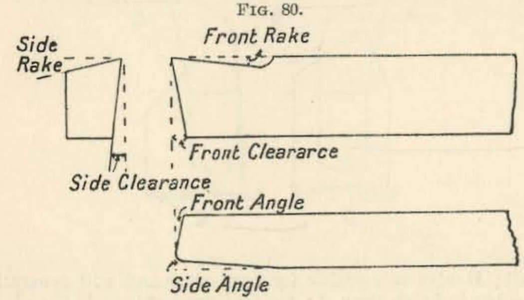
DIRECTION OF FEED

In most cases the feed given to front tools is from the tailstock to the fast headstock and the majority of tools have their side rake to suit this direction of feed. When, however, it is desired to feed with the ordinary front tool from left to right, the side rake must be altered accordingly. Such tools as knife and side tools have their cutting angles, clearances, and side rake ground to suit the altered conditions of cutting.

FRONT TOOLS

A type of front tool commonly used in repetition work in the modern machine shop is shown in Fig. 80. This class of

FIG. 80.



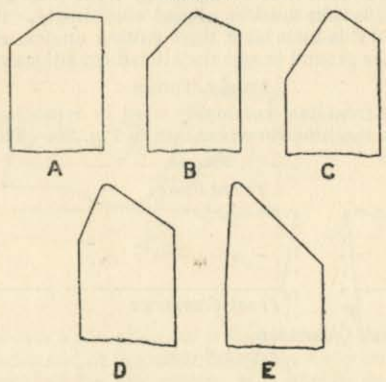
tool is very successful when used in conjunction with a rigid lathe and when a plentiful supply of cooling liquid is applied to the tool nose.

Approximate cutting angles for use on various classes of metals are given in the table below; the figures given can be modified to suit the various degrees of hardness of metals, and also to comply with the different conditions which may exist.

Material.	Front Rake.	Side Rake.	Front Clearance.	Side Clearance.
	°	°	°	°
Steel, Hard . .	10	12	3	6
Cast Iron . .	10	8	10	6
Wrought Iron .	20	15	5	6
Brass . . .	0	0	6	12

The front and side angles sometimes given to this type of tool are shown in Fig. 81. The profile at *A* will be found to stand up well to extremely hard steel when cutting from right

FIG. 81.



to left; *B* also is suitable for hard steel and will generally give a better finish than *A*; for medium hard steels *C* and *D* will both answer very well, and for soft fibrous metals and finishing cuts *E* gives good results.

SIDE TOOLS

Right and left hand side tools of the cranked type are illustrated in Fig. 82. These tools are practically front tools bent round to the angle desired. Another type of side tool is

FIG. 82.

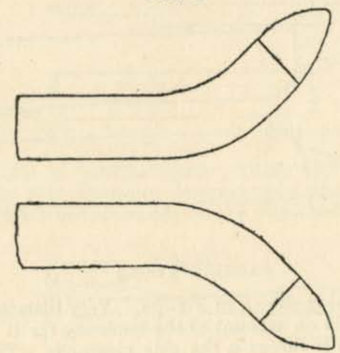
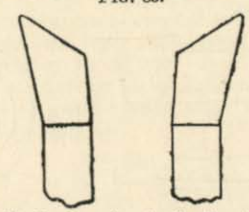


FIG. 83.

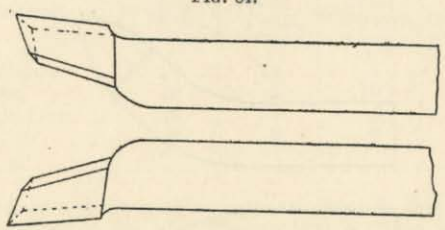


shown in Fig. 83. This tool occupies less room than the crank tool, is considerably stiffer, and is now more frequently used.

Knife Tools

Knife tools for right and left hand cutting are represented in Fig. 84. These tools are easily forged and can be kept in an efficient state without difficulty. They are very useful tools, and in many cases can be made to take the place of the ordinary front tool.

Fig. 84.



Parting Tools

A parting tool is shown in Fig. 85. Very little top rake is given to this tool on account of the tendency for it to dig in. The chief point to notice is the side clearance. This should be sufficient to prevent rubbing and friction on the metal being cut. When turning grooves in chuck or face plate

Fig. 85.

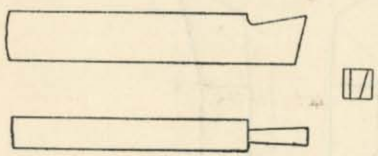
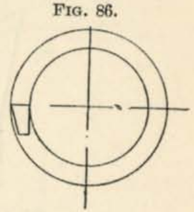


Fig. 86.



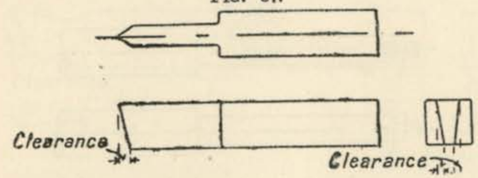
work a larger clearance is given to one side of the tool. The amount of this clearance can be found very easily by drawing full size circles representing the inner and outer edge of the groove as shown in Fig. 86.

One cut only is taken with the parting tool as a rule, the width of the tool cutting edge being slightly smaller than the width of the groove.

Screw-cutting Tools

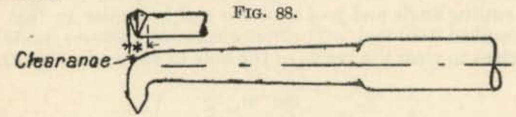
Externally V thread screw-cutting tools are generally made as shown in Fig. 87. The V is ground to gauge, and sufficient side clearance is given to allow the side of the tool to clear the edge of the thread helix.

Fig. 87.



A solid form of internal screw-cutting tool is shown in Fig. 88. The side clearance depends upon the pitch of the thread, and the front clearance on the diameter of the hole in the work.

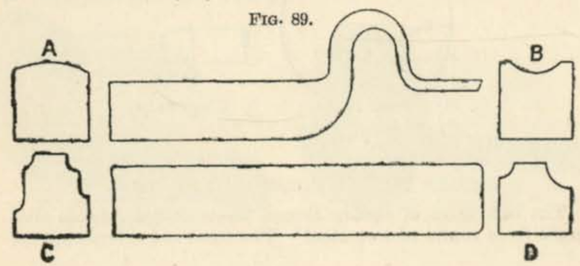
Fig. 88.



Spring Tools

The spring tool is used to produce a fine finish on work which does not require a great degree of accuracy. It takes a broad cut or scrape, and very little metal can be used on account of its tendency to dig in. It is most useful for turning a fillet or a radius on partly finished work. The tool is illustrated in Fig. 89, and cutting edges of various shapes are shown at *A*, *B*, *C*, and *D*.

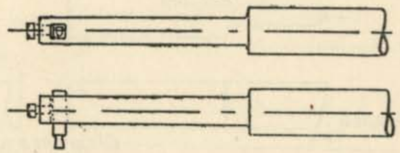
Fig. 89.



BORING TOOLS

The most convenient type of boring tool is shown in Fig. 90. The tool holder is made from square or oblong section metal with the end swayed or turned down as seen in the illustration.

FIG. 90.



A square section tool is fitted in the square hole at a convenient distance from the end and is secured by means of a set screw.

A solid one piece form of boring tool is shown in Fig. 91. The cutting angle and profile of this tool is similar to that of the cranked front tool. The front clearance, however, must be sufficient to clear the inside of the hole as shown in Fig. 92.

FIG. 91.

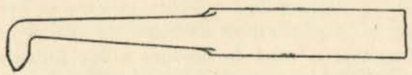
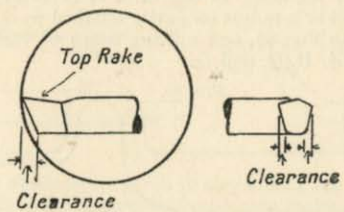


FIG. 92.



SQUARE THREAD SCREW-CUTTING TOOL

The best form of square thread screw-cutting tool is that made from round section steel. The front and side clearances

are normal, the tool being twisted to give the desired amount of clearance to suit the angle formed by the thread helix. This tool is illustrated in Fig. 93, and the most satisfactory method of holding the same is by means of some form of

FIG. 93.

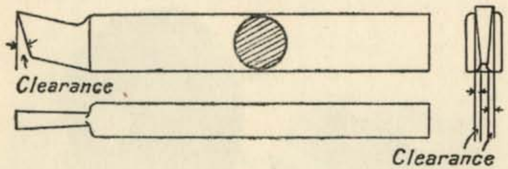
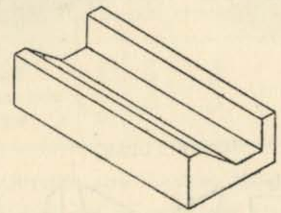


FIG. 94.



special holder similar to that shown in Fig. 94. Here the tool can be twisted to any angle and without difficulty held in position by the dogs of the lathe tool holder.

Examples of tools used in special capstan machines are illustrated in Figs. 95–8. Fig. 95 shows a tool turning a neck

FIG. 95.

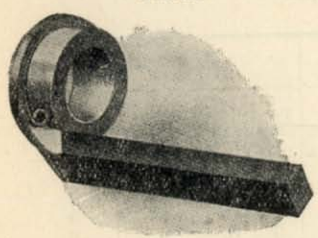
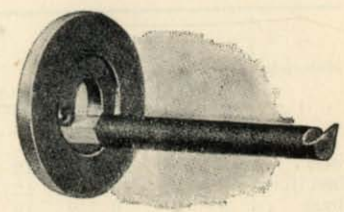


FIG. 96.



bush, Fig. 96 a round tool for counterboring, Fig. 97 a round tool boring a bush, and Fig. 98 a square section front turning tool.

FIG. 97.

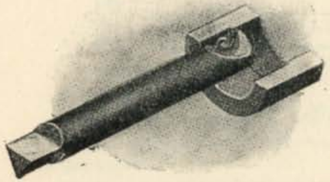
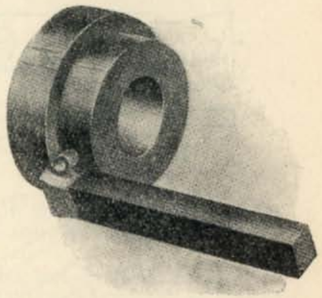
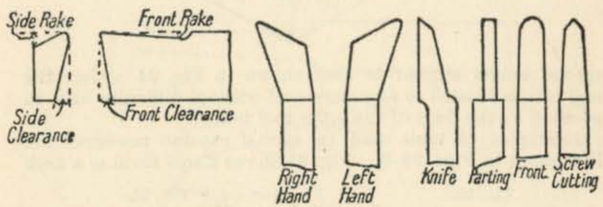


FIG. 98.



LATHE TOOLS



Materials	Front Tools				Side Tools			
	Top rake	Side rake	Side clearance	Front clearance	Top rake	Side rake	Side clearance	Front clearance
	°	°	°	°	°	°	°	°
Steel . .	10	15	6	12	7	13	6	8
Cast iron	8	8	6	12	8	8	6	8
Brass .	0	0	6	12	0	0	6	8

Materials	Knife Tools				Parting Tools			
	Top rake	Side rake	Side clearance	Front clearance	Side rake	Top rake	Side clearance	Front clearance
	°	°	°	°	°	°	°	°
Steel . .	3	8	8	10	12	0	3	12
Cast iron	0	3	8	10	1	0	3	12
Brass .	0	3	8	10	0	0	3	12

Materials	Screw-cutting Tools			
	Top rake	Side rake	Side clearance	Front clearance
	°			°
Steel . .	3	Varies	Varies	12
Cast iron	1			12
Brass .	0			12

CUTTING AND COOLING MIXTURE

For turning steel and wrought iron a suitable compound can be made by boiling together 10 gallons of water, 1 quart of lard oil, 2 lb. of washing soda, and 1 quart of soft soap.

Cast iron, brass, copper, and babbit metal are usually turned dry. Tool steel can be turned dry or with oil.

Chapter IX

SCREW-CUTTING

Geometrically the screw is the union of a plane cylinder having a circular base and a projecting ridge, of uniform shape throughout its length, wrapped on the surface of a cylinder in a regular spiral.

Pitch is the distance a nut would travel in one complete revolution if the screw had a single thread, or the distance between the centre of one thread and the centre of the next, measured in a line with its axis.

Lead is a term used when considering multiple threads, and is the distance a nut would travel in one complete revolution, or the distance from the centre of one thread to the centre of the same thread allowing for one complete turn.

Inclination of a thread is the angle formed by each of its superficial elements of depth, with a plane perpendicular to the axis of the screw. This inclination increases in proportion as the axis of the screw is approached. The pitch, on the contrary, remained constant.

The Whitworth Thread

Forms of screw threads vary according to the purpose for which they are to be used, and also according to the country in which they are manufactured. The form of thread most frequently used for general engineering work is probably that known as the Whitworth thread. In 1841 Sir Joseph Whitworth proposed the adoption of a standard thread for bolts, and this system is chiefly used in Great Britain, Germany, and the United States.

Fig. 99.

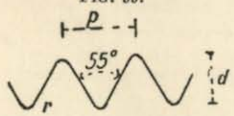
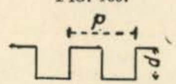


Fig. 100.



The depth of thread is equal to 0·64 of the pitch, the top and bottom of the thread is rounded off one-sixth of the depth, and the sides form an angle of 55°.

Fig. 99 shows the form of thread—

The formula being p = pitch $= \dfrac{1}{\text{Number threads per inch}}$

d = depth $= p \times 0{\cdot}6403$.

r = radius $= p \times 0{\cdot}1373$.

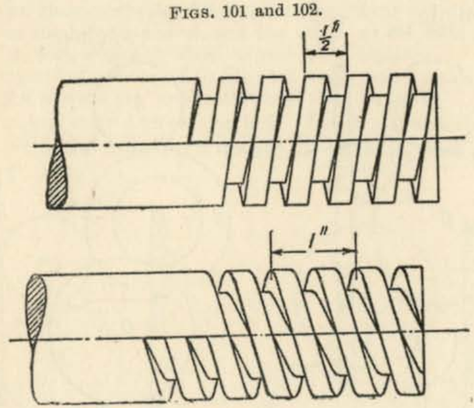
Square Threads

The form of the square thread is shown at Fig. 100. The depth and width is half the pitch.

Multiple Threads

Where coarse pitch threads are necessary, in order that the thread may be brought within workable size, multiple threads are used. The difference between a single and double thread is

Figs. 101 and 102.



shown in Figs. 101 and 102. Fig. 101 represents a single square thread of ½ inch pitch. Fig. 102 shows a double thread of ½ inch pitch, but having 1 inch lead.

Calculations for finding Change Wheels

In nearly all cases the calculations necessary for finding the wheels required in cutting a certain thread, is a very simple matter indeed. Three things have to be considered ; one the pitch of the lathe lead screw, which is a constant and can no possibly be altered, the other two are the speed of the job, and the speed of the lead screw. It needs very little consideration to see that if you start cutting a thread on a lathe in which the work revolved the same number of times per minute as the lead screw, then the thread cut will have exactly the same pitch as the lead screw.

A little further consideration will show that if the lead screw is made to revolve twice as fast as the work, then a screw will be cut having twice the pitch of the lead screw. Also, if the lead screw revolves at half the speed of the work, then the resulting screw will have a pitch only half that of the lead screw.

The whole question of screw-cutting resolves itself into a question of *ratio*—ratio between the number of revolutions made by the job, and the number of revolutions made by the lead screw. (See also p. 15.)

FIG. 103.

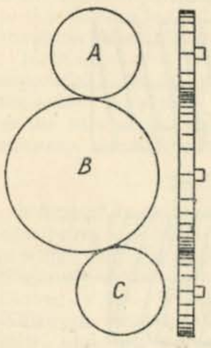
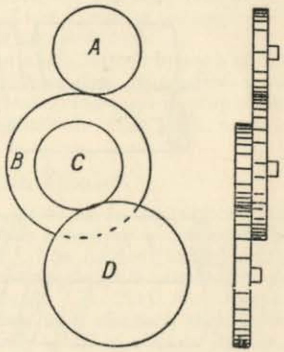


FIG. 104.



Before going into the question of finding the ratio, it is first necessary to thoroughly understand the names of the wheels used in either a simple or compound train. Taking the simple train of wheels first, shown at Fig. 103, here we have three wheels, *A* called the *mandrel wheel*, *C* called the *lead screw wheel*, and *B* the *intermediate wheel* gearing the two together. In the compound train of wheels, Fig. 104, we have *A*, *mandrel wheel*, and *D*, *lead screw wheel*, but instead of one intermediate wheel, we have two wheels on one stud; these are called stud wheels, the one going on first, *B*, is called the ***first stud wheel***, the one going on second, *C*, is called the ***second stud wheel***.

Ratio

Coming back to the question of ratio, this can always be expressed by the following rule: As the number of threads per inch of the lead screw is to the number of threads per inch of the screw to be cut, so is the number of teeth in the mandrel wheel to the number of teeth in the lead screw wheel, or in a fractional form:—

$$\frac{\text{Number of threads per inch of lead screw}}{\text{Number of threads per inch of screw to be cut}} = \frac{\text{Teeth in mandrel wheel.}}{\text{Teeth in lead screw wheel.}}$$

It can easily be seen that if the lead screw has, say 4 threads per inch, and it is required to cut a screw having 4 threads per inch, then the ratio will be as 4 is to 4, or as 1 to 1, in which case two change-wheels of equal size would be required, one to go on the lathe mandrel, and the other on the lead screw. See Fig. 103, with any wheel to gear them together.

If instead of a 4 thread to the inch screw being wanted, one having 8 threads per inch is required, then we get:—

$$\frac{\text{Pitch of lead screw 4 threads per inch}}{\text{Pitch of screw to be cut 8 threads per inch}} = \frac{\text{4 teeth in mandrel wheel.}}{\text{8 teeth in lead screw wheel.}}$$

FIG. 105.

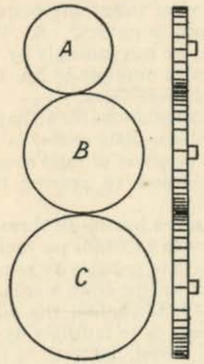
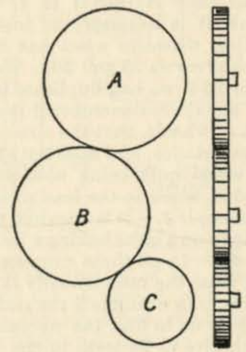


FIG. 106.



Here we see the ratio is 4 to 8, or 1 to 2, that is to say, the lead screw is travelling at half the speed of the lathe mandrel, and consequently a greater number of threads must be cut per inch than are on the lead screw. See Fig. 105.

Taking the example of cutting 2 threads per inch on the same lathe, then we get :—

$$\frac{\text{Pitch of lead screw 4 threads per inch}}{\text{Pitch of screw to be cut 2 threads per inch}} = \frac{\text{4 teeth in mandrel wheel.}}{\text{2 teeth in lead screw wheel.}}$$

In this case the ratio is as 4 is to 2, or 2 to 1, and the lead screw travels at twice the speed of the lathe mandrel. See Fig. 106.

Of course it is impossible to have a wheel with only two teeth, but these numbers represent the ratio, and if both numbers are multiplied by any other number, then the ratio will remain the same, thus the ratio of 4 to 2, is exactly the same as 80 to 40 or 40 to 20.

Change Wheel Examples

We will now take a few examples :—

Example 1.—It is required to cut a screw having 4 threads per inch, on a lathe with a lead screw having 4 threads per inch. Find the necessary wheels. Then :—

$$\frac{\text{Pitch of lead screw 4 threads per inch}}{\text{Pitch of screw to be cut 4 threads per inch}} = \frac{\text{4 teeth in mandrel wheel.}}{\text{4 teeth in lead screw wheel.}}$$

The ratio is then 4 to 4, and in order to get the correct wheels it is necessary to increase both numbers. As the smallest wheel in a set has 20 teeth, we can multiply by 5, which gives us 20 and 20. We could also multiply by 10, 15, 20, or 25 if we had duplicate wheels of those sizes.

It should be remembered that in all calculations for a simple train of wheels, that the size of the intermediate wheel is of no importance, and does not effect the question of ratio at all, the wheel only being used for the purpose of gearing the mandrel wheel to the lead screw wheel.

Example 2.—It is required to cut a screw having 18 threads per inch on a lathe having a lead screw with 4 threads per inch.

Note.—In all these simple examples it is possible to see at once what the ratio actually is, without writing down words or figures. In example 2 the ratio is as 4 is to 18, and the only thing to do to find the necessary wheels, is to multiply by 5, which give us 20 teeth in the mandrel wheel, 90 teeth in the lead screw wheel.

Example 3.—It is required to cut a screw having 9 threads per inch on a lathe having 2 threads per inch on the lead screw.

Here the ratio is as 2 is to 9, and by simply multiplying by 10, we get the wheels 20 and 90, the 20 being the mandrel wheel, and the 90 the lead screw wheel.

Example 4.—It is required to cut a screw having 1 thread per inch on a lathe having a lead screw with 2 threads per inch.

Here the ratio is as 2 is to 1, so that by multiplying by 20, we get 40 and 20, or multiplying by 25, we get 50 and 25 ; the former being mandrel wheels, and the latter the lead screw wheels.

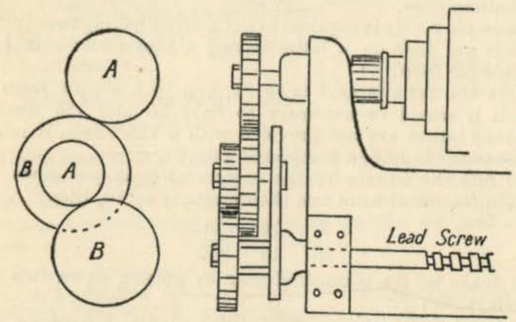
Example 5.—It is required to cut a screw having 2 threads per inch on a lathe with a lead screw having 6 threads per inch.

Here the ratio is as 6 is to 2, and by multiplying by 10, we get 60 and 20 ; then mandrel wheel 60, lead screw wheel 20.

Compound Gears

The calculations for finding the wheels of a compound gear, are exactly the same as for a simple gear. The ratio between the thread of the lead screw and the thread of the screw to be cut being first found.

FIG. 107.



It should be borne in mind that the product of the number of teeth in the mandrel wheel and the number of teeth in the second stud wheel, is equal to the top figure of the ratio fraction ; and the product of the number of teeth in the lead screw wheel and the number of teeth in the first stud wheel, is equal to the bottom figure of the ratio-fraction. In Fig. 107 the ratio is as the product of $A \times A$, is to the product of $B \times B$.

Example 6.—It is required to cut a screw having 4 threads per inch, on a lathe with a lead screw having 4 threads per inch, the lathe not being supplied with two wheels of the same size.

In this case the ratio is as 1 is to 1, and any two wheels of the same size would do in the ordinary course of events, but as we have no two wheels of the same size, it is necessary to use a compound gear. To find this gear, we start thus :—

$$\frac{2 \times 1}{1 \times 2}$$

by multiplying the first part of the fraction by 20, we can get

$$\frac{40 \times 1}{20 \times 2}$$

and by multiplying the second part by 50 we get

$$\frac{40 \times 50}{20 \times 100}$$

Then 40 mandrel wheel, 50 2nd stud wheel, 20 1st stud wheel, 100 lead screw wheel.

In all cases of compound gear, it is possible to multiply by any suitable number, provided you multiply one of the top figures by the same number that you use to multiply one of the bottom ones.

Example 7.—It is required to cut a screw having twenty-five threads per inch on a lathe having a lead screw with four threads per inch.

Here the ratio is as 4 is to 25, and in a simple train of wheels it would be necessary to have 20 and 125 wheels. As many lathes are not provided with a 125 wheel, it might be necessary to have a compound gear.

To find the wheels for the compound train put down the ratio in fractional form and then multiply by 10, thus :

$$\frac{4}{25} \times \frac{10}{10} = \frac{40}{250}$$

then make up the compound gear by putting down two 100 wheels, thus :

$$\frac{40}{250} \times \frac{100}{100}$$

cancel to obtain suitable by dividing by 5, thus :

$$\frac{40}{\underset{50}{\cancel{250}}} \times \frac{\overset{20}{\cancel{100}}}{100}$$

then we get 40 or 20 mandrel wheel, 20 or 40 2nd stud wheel, 50 or 100 lead screw wheel, 100 or 50 1st stud wheel.

Fractional Pitch Threads

It is common to have to cut threads of fractional pitch, thus : $7\frac{1}{4}$ threads per inch, or $1\frac{1}{8}$ inch pitch. In all these cases the ratio can be found very easily if the following rule is carried out.

Rule.—Find the distance in inches which contain the minimum number of complete threads in the screw to be cut, and also the number of threads in an equal distance on the lead screw.

Example A.—Find the minimum distance containing an equal number of threads on a screw having $7\frac{1}{4}$ threads per inch. By bringing this number to an improper fraction we get $\frac{29}{4}$, which gives 29 complete threads in 4 inches.

Example B.—Find the minimum distance containing an equal number of threads on a screw having a pitch of $1\frac{7}{8}$ inch. Bringing this figure to an improper fraction gives $\frac{15}{8}$, which shows that we have 8 complete threads in 15 inches.

Example 8.—It is required to cut a screw having $9\frac{1}{2}$ threads per inch on a lathe having 4 threads per inch on the lead screw. This is best expressed thus :

$$\frac{\frac{1}{4}'' \text{ pitch or 8 threads in 2 inches on lead screw}}{\frac{1''}{9\frac{1}{2}} \text{ pitch, or 19 threads in 2 inches on screw to be cut}} = \frac{\text{mandrel wheel}}{\text{lead screw wheel}} = \frac{8}{19}$$

giving a ratio of 8 to 19. Multiplying by five gives us 40 and 95. Then 40 mandrel wheel, 95 lead screw wheel.

Example 9.—It is required to cut a screw having $1\frac{3}{4}$ inch pitch on a lathe having 4 threads per inch on the lead screw, then :

$$\frac{\frac{1}{4}'' \text{ pitch or 28 threads in 7 inches on lead screw}}{1\frac{3}{4}'' \text{ pitch or 4 threads in 7 inches on screw to be cut}} = \frac{\text{mandrel wheel}}{\text{lead screw wheel}} = \frac{28}{4}$$

a ratio of 28 to 4 or 7 to 1. Multiplying by 20 we get 140 mandrel wheel and 20 lead screw wheel. If a 140 wheel is not available then a compound gear must be used ; in that case, split the fraction ratio into factors, thus :

$$\frac{4 \times 7}{2 \times 2}$$

then multiply each number by 10, which gives:

$$\frac{40 \times 70}{20 \times 20}$$

Multiply the 40 and one of the 20 by 2 gives:

$$\frac{80 \times 70}{20 \times 40}$$

then 80 mandrel wheel, 70 2nd stud wheel, 20 1st stud wheel, and 40 lead screw.

Approximations

If it is found that the threads of a screw to be cut will not factorize with the number of threads per inch on the lead screw, then it is necessary to adopt one of two methods. By the first method it is necessary to cut a special wheel: by the second an approximation is obtained by slightly altering the ratio.

Example 10.—It is required to cut a screw having 67·7 threads in 12 inches, on a lathe having a 2 thread per inch lead screw. The ratio is:

$$\frac{\text{Lead screw 24 threads in 12 inches}}{\text{Screw to be cut 67·7 threads in 12 inches}} = \frac{24}{67 \cdot 7}$$

or a ratio of 24 to 67·7 or 240 to 677. It will be seen that the ratio fraction will not factorize, but by adding ·3 to the bottom number we get the ratio of 240 to 680, and by breaking this into factors we can get:

$$\frac{12 \times 20}{17 \times 40}$$

and by multiplying the 12 and 17 by 5 we get:

$$\frac{60 \times 20}{85 \times 40}$$

then 60 mandrel wheel, 20 2nd stud wheel, 85 1st stud wheel, 40 lead screw wheel.

Millimetre Threads

The cutting of metric threads to approximate sizes is a very simple matter. The length of the metre is 39·37 inches, or about $\frac{1}{200}$ of an inch less than $39\frac{3}{8}$ inches; this small difference for most practical purposes can be neglected.

In a length of $39\frac{3}{8}$ inches we get exactly 1,000 millimetres, and in a length of $39\frac{3}{8} \times 8 = 315$ inches we get 8,000 millimetres, and assuming a lead screw with two threads per inch the ratio fraction would be 630 to 8,000. If it were necessary to cut a screw having a pitch of 1 mm. the ratio would be:

630 to 8,000, or 63 to 800.

As 1 mm. is less than the pitch of the lead screw, the smallest wheel would be the mandrel wheel, and the largest the lead screw wheel. Or to make a compound train, which would be necessary in this case, break into factors, thus:

$$\frac{63}{800} = \frac{9 \times 7}{160 \times 5}$$

Multiplying by 4 we get:

$$\frac{36 \times 7}{160 \times 20}$$

and multiplying by 5 we get:

$$\frac{36 \times 35}{160 \times 100}$$

Then 36 mandrel wheel, 35 2nd stud wheel, 100 1st stud wheel, 160 lead screw wheel.

Example 11.—It is required to cut a thread having a 5 mm. pitch on a lathe having $\frac{1}{2}$ in. pitch lead screw, then:

$$\frac{63}{800} \times 5 = \frac{63 \times 5}{80 \times 10}$$

By adding ciphers to 5 and 10 we get:

$$\frac{63 \times 50}{80 \times 100}$$

That is 50 mandrel wheel, 63 2nd stud wheel, 80 1st stud wheel, 100 lead screw wheel.

Catching Threads

It will be found in cutting certain threads that the screw-cutting tool will not always come in the same position when starting to cut the thread; in other words, the tool will sometimes cross thread.

If it were possible to cut a thread with one traverse of the tool no difficulty would be experienced by cross-threading, but as nearly all screws required several cuts to complete the thread, it is necessary to know when a thread can be cut without fear of cross-threading, and when not.

Rule.—When the number of threads per inch on the screw to be cut is a multiple of the number of threads per inch on the lead screw, then the tool will always pick up the thread in the correct place without marking the lathe.

Example 12.—On a lathe with a lead screw having two threads per inch it is possible to cut any even number of threads, such as 2, 4, 6, 8, 10, 12, etc., without any fear of cross-threading.

When the threads on the screw being cut are not a multiple of the threads per inch on lead screw, then it is necessary to take certain precautions. These precautions should be taken in the following manner. First, prepare the lathe by setting the tool and seeing everything is ready to start cutting, then come to the starting position and pull the lathe round until the engaging nut of the saddle drops into place; mark the position of the saddle either by bringing the loose headstock up against it or by some other convenient means. Next make a mark on the driving plate and a corresponding one on the lead screw; the lathe is then ready for work. Before starting each cut it is necessary to come to a position where all the marks agree.

When cutting short lengths of threads of odd pitch it is quicker and safer to leave the engaging nut in position, and at the end of each cut pull the lathe back by hand and thus do away with the trouble of marking the lathe and the possibility of cross-threading.

Multiple Threads

The calculations for finding the wheels for cutting multiple threads are the same as for single threads, the change wheels being found in the same manner, only being based on the fact that the mandrel wheel must have such a number of teeth that can be divided equally by the number of the separate threads to be cut on the screw. Thus, if a three-start thread had to be cut, then a mandrel wheel having 30, 45, 60 75, or 90 teeth would answer the purpose.

After the correct wheels have been found the method of procedure is then: One thread is nearly finished to the required depth, the lathe is then brought to the starting position. The mandrel wheel is divided into the number of parts corresponding with the number of separate threads to be cut; one of these marks must come between two marked teeth of the first stud wheel. The swing plate is then lowered and the lathe pulled round until the next mark gears with the two marked teeth of the stud wheel. The thread is then cut,

and the operation repeated until all threads are cut, a very light finishing cut is then taken along each thread, the tool being kept in the same position as regards depth throughout the operations.

Cutting Left-hand Threads

When the lathe is provided with some form of tumbler reverse gear, left-hand threads are cut by simply making the necessary alteration to the gear, the required change wheels being found in exactly the same manner as for a right-hand thread. When the lathe is not provided with a tumbler gear, then an extra wheel must be put either between the mandrel wheel and the intermediate wheel or between the lead screw wheel and the intermediate wheel. In a simple train of wheels, as shown in Fig. 108, *A* is the mandrel wheel, and

FIG. 108.

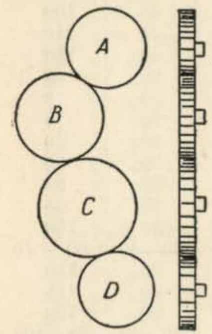
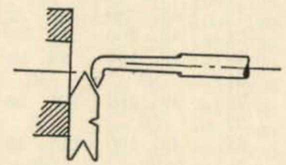


FIG. 109.



D the lead screw wheel, with *B* and *C* intermediate wheels; the size of *B* and *C* are of no consequence, and are only intended to gear the mandrel wheel and the lead screw wheel together and give the correct direction of rotation.

Setting Tools for Screw-cutting

In order to set screw-cutting tools in the correct position square with the work, the screw-cutting gauge shown in Fig. 109 is generally used. When internal work is being screwed it is used as illustrated; for external screw-cutting the small vee in the side is used.

Table of Change Wheels for Cutting various Pitch Threads

Lathe Lead Screw $\frac{1}{4}$ in. Pitch

Threads to be cut per inch.	Drivers.	Driven.	Threads to be cut per inch.	Drivers.	Driven.
1	100	25	$7\frac{1}{2}$	40	75
$1\frac{1}{8}$	60 80	45 30	8	40	80
$1\frac{1}{4}$	80	25	9	40	90
$1\frac{3}{8}$	80 120	110 30	10	40	100
$1\frac{1}{2}$	80	30	11	40	110
$1\frac{5}{8}$	60 80	65 30	12	40	120
$1\frac{3}{4}$	80	35	13	20	65
$1\frac{7}{8}$	40 80	50 30	14	20	70
$2\frac{1}{4}$	40 100	75 30	15	20	75
$2\frac{3}{8}$	40 100	95 25	16	20	80
$2\frac{1}{2}$	80	50	17	20	85
$2\frac{5}{8}$	40 100	105 25	18	20	90
$2\frac{3}{4}$	80	55	19	20	95
$2\frac{7}{8}$	40 100	115 25	20	20	100
3	80	60	21	20 40	60 70
$3\frac{1}{4}$	80	65	22	20	110
$3\frac{1}{2}$	40	35	23	20	115
4	40	40	24	20	120
$4\frac{1}{2}$	40	45	25	30 40	75 100
5	40	50	26	20 30	60 65
$5\frac{1}{2}$	40	55	28	20 30	40 105
6	30	45	30	20 60	90 100
$6\frac{1}{2}$	40	65	40	20 55	100 110
7	40	70	50	20 30	75 100

Table of Change Wheels for Cutting various Threads

Lead Screw $\frac{1}{2}$ in. Pitch

Threads to be cut per inch.	Drivers.	Driven.	Threads to be cut per inch.	Drivers.	Driven.
1	80	40	$7\frac{1}{2}$	20	75
$1\frac{1}{8}$	80	45	8	20	80
$1\frac{1}{4}$	80	50	9	20	90
$1\frac{3}{8}$	80	55	10	20	100
$1\frac{1}{2}$	80	60	11	20	110
$1\frac{5}{8}$	60 100	75 65	12	20	120
$1\frac{3}{4}$	80	70	13	20 50	65 100
$1\frac{7}{8}$	80	75	14	20 75	100 105
2	60	60	15	20 80	100 120
$2\frac{1}{4}$	40	45	16	25 30	50 120
$2\frac{3}{8}$	80	95	17	20 60	85 120
$2\frac{1}{2}$	40	50	18	25 40	75 120
$2\frac{5}{8}$	80	105	19	25 40	95 100
$2\frac{3}{4}$	40	55	20	20 40	80 100
$2\frac{7}{8}$	40 100	115 50	21	20 40	70 120
3	40	60	22	20 30	60 110
$3\frac{1}{4}$	40	65	23	20 50	100 115
$3\frac{1}{2}$	40	70	24	25 30	75 120
4	30	60	25	20 30	75 100
$4\frac{1}{2}$	40	90	26	20 25	65 100
5	30	75	28	20 25	70 100
$5\frac{1}{2}$	20	55	30	24 40	100 120
6	30	90	35	20 30	100 105
$6\frac{1}{2}$	20	65	40	20 30	100 120
7	20	70	50	20 20	100 100

CHANGE WHEELS FOR CUTTING MILLIMETRE PITCH

Lead Screw $\frac{1}{2}$ in. Pitch

Threads to be cut in Milli-metres.	Drivers.		Driven.		Threads to be cut in Milli-metres.	Drivers.		Driven.	
1	36	35	160	100	6	63	60	100	80
2	63	20	100	80	7	63	70	100	80
3	63	30	100	80	8	63	80	100	80
4	63	40	100	80	9	63	90	100	80
5	63	50	100	80	10	63	100	100	80

PROOF OF CHANGE WHEELS

Divide the number of teeth in driven wheel or the product of the teeth in the driven wheels, by the number of teeth in the driver or the product of the teeth in the drivers, and multiply by the number of threads per inch on the lead screw.

FINDING LATHE CONSTANT

Place wheels with an equal number of teeth on the first driver and lead-screw, and cut a thread. The pitch of this thread will be the lathe constant.

PRACTICAL PROOF OF CHANGE WHEELS

After the change gears have been placed on the lathe, drop in the lead-screw nut, mark the position of the saddle, and pull the lathe a number of complete turns equal to the number of threads to be cut per inch. The saddle should then have moved exactly one inch.

WHITWORTH STANDARD SCREW BOLTS AND NUTS

Diameter of bolt.	Threads per inch.	Diameter at bottom of thread.	Area at bottom of thread.	Hexagonal head and nut breadth over Flats.
Inches.	Threads.	Inches.	Square inches.	Inches.
$\frac{1}{8}$	40	...	...	...
$\frac{1}{4}$	20	·186	·0272	·525
$\frac{5}{16}$	18	·2414	·0458	·600
$\frac{3}{8}$	16	·2950	·0683	·710
$\frac{7}{16}$	14	·3460	·0940	·820
$\frac{1}{2}$	12	·3933	·1215	·920
$\frac{9}{16}$	12	·4558	·1632	1·010
$\frac{5}{8}$	11	·5086	·2032	1·100
$\frac{3}{4}$	10	·6219	·3038	1·300
$\frac{7}{8}$	9	·7327	·4216	1·480
1	8	·8399	·5540	1·670
$1\frac{1}{8}$	7	·9420	·6969	1·860
$1\frac{1}{4}$	7	1·067	·8942	2·050
$1\frac{3}{8}$	6	1·1616	1·0597	2·220
$1\frac{1}{2}$	6	1·2866	1·3001	2·410
$1\frac{5}{8}$	5	1·3689	1·4718	2·580
$1\frac{3}{4}$	5	1·4939	1·7528	2·760
2	$4\frac{1}{2}$	1·7154	2·3111	3·150
$2\frac{1}{8}$	$4\frac{1}{2}$	1·8404	2·6602	3·340
$2\frac{1}{4}$	4	1·9298	2·9249	3·550
$2\frac{3}{8}$	4	2·0548	3·3161	3·750
$2\frac{1}{2}$	4	2·1798	3·7318	3·890
$2\frac{5}{8}$	4	2·3048	4·1721	4·050
$2\frac{3}{4}$	$3\frac{1}{2}$	2·3841	4·4641	4·180
3	$3\frac{1}{2}$	2·6341	5·4496	4·530
$3\frac{1}{4}$	$3\frac{1}{4}$	2·8560	6·4063	4·850
$3\frac{1}{2}$	$3\frac{1}{4}$	3·1060	7·5769	5·180
$3\frac{3}{4}$	3	3·3231	8·6732	5·550
4	3	3·5731	10·0272	5·950
$4\frac{1}{4}$	$2\frac{7}{8}$	3·8046	11·3687	6·380
$4\frac{1}{2}$	$2\frac{7}{8}$	4·0546	12·9118	6·820
$4\frac{3}{4}$	$2\frac{3}{4}$	4·2843	14·4162	7·300

British Association Screws

For small work. Angle of thread $47\frac{1}{2}°$, rounded at top and bottom

No.	Diameter over thread (inch).	Diameter at bottom of thread (inch).	Threads per inch.
0	·2360	·1887	25·40
1	·2090	·1665	28·20
2	·1850	·1467	31·40
3	·1610	·1266	34·80
4	·1420	·1108	38·50
5	·1260	·0981	43·00
6	·1100	·0849	47·90
7	·0982	·0753	52·90
8	·0860	·0657	59·10
9	·0750	·0565	65·10
10	·0670	·0504	72·60
11	·0590	·0443	81·90
12	·0510	·0378	90·90
13	·0470	·0352	102·00
14	·0390	·0280	109·90
15	·0350	·0250	120·50
16	·0310	·0220	133·30

Bolts and Nuts

Table showing sizes of nuts. Flat to flat $= 1\frac{1}{2}\,D + \frac{1}{8}''$.
$D =$ diameter.

Diameter of Bolt.	Size of Nut.	Diameter of Bolt.	Size of Nut.
$\frac{1}{2}''$	$\frac{7}{8}''$	$1\frac{1}{2}''$	$2\frac{3}{8}''$
$\frac{5}{8}''$	$1\frac{1}{16}''$	$1\frac{5}{8}''$	$2\frac{9}{16}''$
$\frac{3}{4}''$	$1\frac{1}{4}''$	$1\frac{3}{4}''$	$2\frac{3}{4}''$
$\frac{7}{8}''$	$1\frac{7}{16}''$	$1\frac{7}{8}''$	$2\frac{15}{16}''$
$1''$	$1\frac{5}{8}''$	$2''$	$3\frac{1}{8}''$
$1\frac{1}{8}''$	$1\frac{13}{16}''$	$2\frac{1}{4}''$	$3\frac{1}{2}''$
$1\frac{1}{4}''$	$2''$	$2\frac{1}{2}''$	$3\frac{7}{8}''$
$1\frac{3}{8}''$	$2\frac{3}{16}''$	$2\frac{3}{4}''$	$4\frac{1}{4}''$

Diameter of washers $= 2\frac{1}{4}\,D$. Thickness of washers $= \frac{3}{20}\,D$.
Where $D =$ the diameter of bolt.

Iron and Steel Gas, Steam, and Water Pipes

Nominal Bore.	Diameter over screwed part.	Diameter at bottom of thread.	Number of threads per inch.
inches.	inches.	inches.	
$\frac{1}{8}$	·383	·336	28
$\frac{1}{4}$	·518	·451	19
$\frac{3}{8}$	·656	·589	19
$\frac{1}{2}$	·825	·734	14
$\frac{5}{8}$	·902	·811	14
$\frac{3}{4}$	1·041	·950	14
1	1·309	1·193	11
$1\frac{1}{4}$	1·650	1·534	11
$1\frac{1}{2}$	1·882	1·756	11
$1\frac{3}{4}$	2·116	2·000	11
2	2·347	2·231	11
$2\frac{1}{4}$	2·587	2·471	11
$2\frac{1}{2}$	2·960	2·844	11
$2\frac{3}{4}$	3·210	3·094	11
3	3·460	3·344	11
$3\frac{1}{2}$	3·950	3·834	11
4	4·450	4·334	11
$4\frac{1}{2}$	4·950	4·834	11
5	5·450	5·334	11
$5\frac{1}{2}$	5·950	5·834	11
6	6·450	6·334	11

Chapter X

DRILLING, TAPPING, AND SCREWING

Drilling machines are constructed in a very great variety of forms. They may be classified under the following heads :—

Vertical.
Horizontal.
Radial.
Multiple.
Sensitive.

In the *Vertical Drill*, a movable table is usually provided for altering the position of the work, and in addition the base is planed and fitted with tee-shaped slots in order that the job can be, if necessary, bolted down on to it. The larger sizes of vertical drills are provided with back gear for giving extra power, and also with automatic feeds, and in some cases with special arrangements for tapping.

The *Horizontal Drill* is chiefly used for work of too great a length to be taken in the vertical type of machine. Horizontal machines are provided with a movable drill-head, and in addition to drilling can be adapted for such work as boring, tapping, and reaming,

The *Radial Drill* is perhaps one of the best types of machine for general work. The movable arm can be swivelled to any part of the table, and with the universal machine the drill-head can be set to any desired angle. Thus any number of holes can be drilled in a job without having to move the work in any manner whatever after it has once been fixed.

Multiple Drills or gang drills have two or more drilling spindles in the same alignment, or in certain fixed positions. The belt-drive is generally taken from a common shaft, the speeds and feeds of the drills being variable. A simple type of multiple drill is illustrated at Fig. 110.

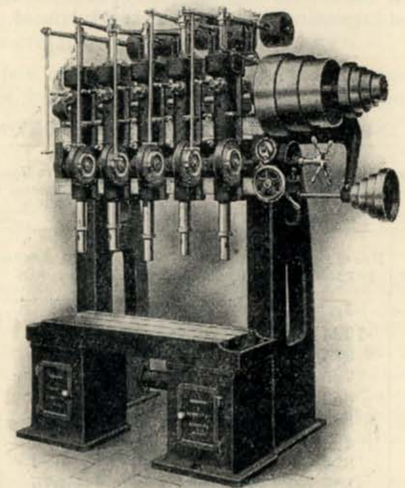
Sensitive Drills are constructed with one or more drilling spindles as desired. In this type of machine the feed is given to the drill by means of a simple lever.

Drills

Great improvements have been made in drills within the last few years ; the common or flat drill has practically disappeared, and its place taken by machine-made fluted drills.

The twist drill commonly used is made from high-speed steel, the fluting and backing off being done in the milling machine. A table on p. 114 gives the speeds for various size drills.

Fig. 110.



Grinding Drills

The grinding of the cutting edges of twist drills is of such importance that special twist drill grinders are provided ; these give an efficient and accurate method of grinding drills. The cutting edges should have the correct angle, and at the same time be uniform with the longitudinal axis of the drill, and the lips should be backed off or cleared. If the clearance is insufficient or imperfect the drill will not cut correctly, and when the feed is put on the probability is that the end of the drill will be crushed or split. Drills correctly made and ground have their cutting edges straight when at an angle of 59°. Care must be taken to see that the cutting edges are of exactly equal length, as any inequality doubles itself in the work.

Lubrication

The use of a good constant flow of cooling mixture to the drilling point undoubtedly prolongs the life of the drill, and enables the operator to run at a considerably higher speed and give an increased feed. For wrought iron and steel, a good mixture is made from soft soap, soda, and water. For very hard steel turpentine is perhaps the best lubricant.

Preparing Work for Drilling

In preparing work for drilling it is usual to first chalk the work, and then locate the centre by means of the scribing

SPEEDS AND FEEDS FOR HIGH-SPEED STEEL TWIST DRILLS

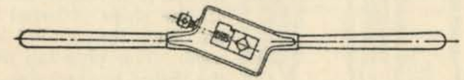
Approximate Speeds and Feeds for Wrought Iron and Mild Steel.			Approximate Speeds and Feeds for General Cast-iron Work.		
Drill Diameter.	No. of revs. per min.	Revs. per in. of feed.	Drill Diameter.	No. of revs. per min.	Revs. per in. of feed.
in.			in.		
$\frac{1}{4}$	1025	150	$\frac{1}{4}$	1200	165
$\frac{5}{16}$	875	150	$\frac{5}{16}$	900	160
$\frac{3}{8}$	750	150	$\frac{3}{8}$	865	160
$\frac{7}{16}$	650	150	$\frac{7}{16}$	750	160
$\frac{1}{2}$	550	100	$\frac{1}{2}$	630	110
$\frac{5}{8}$	450	100	$\frac{5}{8}$	520	110
$\frac{3}{4}$	375	100	$\frac{3}{4}$	430	110
$\frac{7}{8}$	325	100	$\frac{7}{8}$	375	110
1	275	75	1	320	85
$1\frac{1}{8}$	250	75	$1\frac{1}{8}$	290	85
$1\frac{1}{4}$	225	75	$1\frac{1}{4}$	260	85
$1\frac{3}{8}$	200	75	$1\frac{3}{8}$	230	85
$1\frac{1}{2}$	175	75	$1\frac{1}{2}$	200	85
$1\frac{3}{4}$	150	75	$1\frac{3}{4}$	175	85
2	135	75	2	155	85
$2\frac{1}{4}$	120	60	$2\frac{1}{4}$	140	65
$2\frac{1}{2}$	110	60	$2\frac{1}{2}$	125	65
$2\frac{3}{4}$	100	60	$2\frac{3}{4}$	115	65
3	90	60	3	100	65
$3\frac{1}{4}$	85	60	$3\frac{1}{4}$	95	65
$3\frac{1}{2}$	80	60	$3\frac{1}{2}$	90	60
$3\frac{3}{4}$	70	60	$3\frac{3}{4}$	80	60
4	60	60	4	70	60

block, dividers, or some other tool. The centre is marked with the centre punch, and from that mark a circle is scribed with the dividers, exactly the size of the hole; inside this circle another one is scribed somewhat smaller. These circles are dotted with the centre punch, and the work is then set up in the machine. Should the drill run out of truth, the smaller circle will show how much, and it may be necessary to draw it over with a bent round-nosed chisel.

Screwing by Hand

Threads are frequently cut by hand by means of the stocks and dies; these are shown in Fig. 111.

FIG. 111.



The stock is made from one piece of steel, the dies being in two parts, and usually fitting in a vee-shaped guide, being adjusted or screwed together by means of a set screw.

In using the stocks and dies, the metal that is to be screwed is first turned to the exact diameter of the outside of the thread. The dies are placed at the end of the metal and slightly tightened; they are then turned the distance required, and turned back. The process is repeated until a full-sized thread is cut.

In using the dies care should be taken to keep the clearance spaces free, and when cutting iron or steel to keep the metal well lubricated with oil. It should be remembered that dies cut in one direction only, therefore they should be only tightened up just previous to the cutting movement.

Screwing Gas Threads

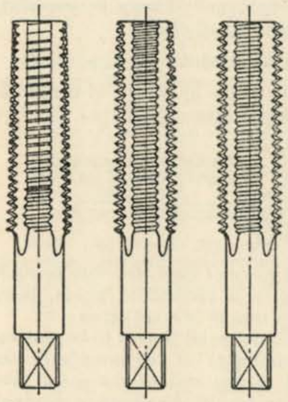
Stocks and dies for cutting gas threads or tubes are used to a far greater extent than the Whitworth dies. With sizes below 2 inches it is usual to find a solid, or one piece die used; above that size the split form of dies is more often used. In either case some form of guide is provided in order to keep the thread square with the axis of the tube.

Previous to using the gas dies it is necessary to grind or file the end of the tube slightly tapered, so as to allow the thread of the die to get a proper hold of the metal. With the solid form of die the thread is cut in one operation.

Cutting Internal Threads by Hand

Taps are used for the purpose of cutting internal threads. Two different systems are in use, the taper and parallel. Fig. 112 illustrates a set on the taper system. When using the taper set of taps, the first tap is inserted in the hole and carefully turned by means of a tap wrench; when the bottom of the hole is reached, or the tap has gone through the full length of the thread, it is turned back, and all the chips of metal blown out, and the second tap is used. The plug tap finishes the thread to exact size.

FIG. 112.



Taper. Second. Plug.
Hand Taps.

With the parallel system the same process is gone through, the difference being that the first tap used is not tapered, but simply smaller in diameter, and has a shallower thread; the second tap is slightly larger, and has a deeper thread; the last tap used is of full depth.

To find the correct diameter of a drill for drilling a hole to give a full Whitworth thread, multiply the pitch of the screw by 1·28, and subtract the product from the outside diameter.

Example.—To find the size of a drill to cut a hole for tapping a 1 in. Whitworth thread. Then—

$$\text{Eight threads per inch} = \tfrac{1}{8} \text{ inch pitch} = 0{\cdot}125.$$
$$0{\cdot}125 \times 1{\cdot}28 = 0{\cdot}16.$$
$$1{\cdot}0 - 0{\cdot}16 = 0{\cdot}84 \text{ or } \tfrac{27}{32}.$$

Size of drill required $\frac{27}{32}$, the nearest standard size being $\frac{27}{32}$ inch.

Taps for cutting square threads are occasionally made, but owing to inaccuracies caused during the hardening process they cannot be relied upon.

A small alteration of pitch in the vee-thread would not be noticeable, and if a slight difference were made in the diameter

of the nut and bolt they would screw together; but with the square thread, if the pitch is slightly altered, no difference of diameter would allow the nut to fit.

To overcome the difficulties of hardening, it is common practice to make the spaces of the tap slightly larger than the correct width, but this tap cannot produce a correctly fitting nut, as only the first and last thread would be bearing on the thread of the nut.

WHITWORTH'S STANDARD TAPS

Outside Diam.	Full Length.	Length of Screw.	Length of Square.	Size of Square.	Diam. at Bottom of Thread.	Threads per Inch.
$\frac{1}{16}$	$1\frac{1}{8}$	$\frac{5}{8}$	$\frac{3}{16}$	—	·0413	60
$\frac{3}{32}$	$1\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	—	·0671	48
$\frac{1}{8}$	$1\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{4}$	—	·093	40
$\frac{5}{32}$	$1\frac{7}{8}$	$\frac{7}{8}$	$\frac{1}{4}$	—	·112	32
$\frac{3}{16}$	2	1	$\frac{5}{16}$	—	·134	24
$\frac{7}{32}$	$2\frac{1}{8}$	$1\frac{1}{16}$	$\frac{5}{16}$	—	·165	24
$\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{1}{8}$	$\frac{3}{8}$	—	·186	20
$\frac{5}{16}$	$2\frac{1}{2}$	$1\frac{3}{8}$	$\frac{7}{16}$	$\frac{5}{32}$	·241	18
$\frac{3}{8}$	$2\frac{3}{4}$	$1\frac{1}{2}$	$\frac{1}{2}$	$\frac{7}{32}$	·295	16
$\frac{7}{16}$	$3\frac{1}{4}$	$1\frac{3}{4}$	$\frac{1}{2}$	$\frac{9}{32}$	·346	14
$\frac{1}{2}$	$3\frac{1}{2}$	2	$\frac{9}{16}$	$\frac{5}{16}$	·393	12
$\frac{9}{16}$	$3\frac{3}{4}$	$2\frac{1}{8}$	$\frac{9}{16}$	$\frac{5}{16}$	·456	12
$\frac{5}{8}$	4	$2\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{8}$	·508	11
$\frac{11}{16}$	$4\frac{1}{4}$	$2\frac{3}{8}$	$\frac{11}{16}$	$\frac{3}{8}$	·571	11
$\frac{3}{4}$	$4\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{4}$	$\frac{7}{16}$	·622	10
$\frac{13}{16}$	$4\frac{3}{4}$	$2\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{16}$	·684	10
$\frac{7}{8}$	5	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{1}{2}$	·732	9
$\frac{15}{16}$	$5\frac{1}{4}$	3	$\frac{13}{16}$	$\frac{1}{2}$	·795	9
1	$5\frac{1}{2}$	$3\frac{1}{4}$	$\frac{7}{8}$	$\frac{5}{8}$	·84	8
$1\frac{1}{8}$	6	$3\frac{3}{8}$	1	$\frac{11}{16}$	·942	7
$1\frac{1}{4}$	$6\frac{1}{2}$	$3\frac{3}{4}$	$1\frac{1}{8}$	$\frac{13}{16}$	1·067	7
$1\frac{3}{8}$	$7\frac{1}{2}$	$4\frac{1}{4}$	$1\frac{1}{8}$	1	1·161	6
$1\frac{1}{2}$	8	$4\frac{3}{4}$	$1\frac{1}{4}$		1 286	6
$1\frac{5}{8}$	$8\frac{1}{2}$	$5\frac{1}{4}$	$1\frac{1}{4}$	1	1·368	5
$1\frac{3}{4}$	9	$5\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$	1·494	5
$1\frac{7}{8}$	$9\frac{1}{2}$	$5\frac{3}{4}$	$1\frac{3}{8}$	$1\frac{1}{8}$	1·59	$4\frac{1}{2}$
2	10	6	$1\frac{1}{2}$	$1\frac{5}{16}$	1·715	$4\frac{1}{2}$
$2\frac{1}{8}$	$10\frac{1}{2}$	$6\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{8}$	1·84	$4\frac{1}{2}$
$2\frac{1}{4}$	11	$6\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$	1·93	4
$2\frac{3}{8}$	$11\frac{1}{2}$	$7\frac{1}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$	2·054	4
$2\frac{1}{2}$	12	$7\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{5}{8}$	2·18	4
$2\frac{5}{8}$	$12\frac{1}{2}$	$8\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	2·304	4
$2\frac{3}{4}$	13	$8\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{3}{4}$	2·384	$3\frac{1}{2}$
$2\frac{7}{8}$	$13\frac{1}{2}$	$9\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{7}{8}$	2·509	$3\frac{1}{2}$
3	14	$10\frac{3}{4}$	2	2	2·634	$3\frac{1}{2}$

Chapter XI

BENCH-WORK

Vices

The best type of vice is that with parallel jaws. It is of simple construction and can be obtained with hardened steel jaws varying between 2″ and 5″ in width.

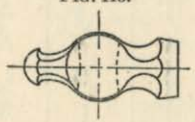
The *hand vice* is made in a variety of shapes and sizes, and is used for gripping objects too small to be held by hand, and which require the same manipulation as if held by hand.

Vice clamps are made from lead, copper, and tin, and are used to protect the work from damage by the hardened serrated faces of the vice jaws.

Hammers

Hammers are shaped to suit the particular work on which they are to be used. The engineers' chipping hammer is shown at Fig. 113; the usual weight is about 1½ lb. Lead,

Fig. 113.



copper, and hide hammers are used in cases where blows have to be struck, without bruising or damaging the metal.

Chipping.—Hand chipping is now seldom required in the modern shop. Before the general introduction of machine tools a great amount of work was accomplished by hand, but under modern conditions it is not economical to use the hand chisel. It is, however, very useful for a workman to be able to use the hammer and chisel in a quick and accurate manner, as in special circumstances, or when repairs are required in out-of-the-way places, this method may be the only one possible.

Chisels

Chisels are made from crucible steel and vary in length, section, and shape according to the particular work for which they are required. It is usual to forge chisels from bar steel of the same section as that required for the chisel, the ends

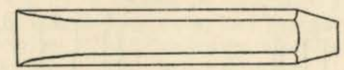
being heated and hammered to the shape required. The cutting edge is ground on the emery wheel, the angle being determined by the metal to be chipped.

The following may be taken as approximate cutting angles for chipping various metals :—

Cast steel 70°.	Wrought iron and mild steel 50°.
Cast iron 60°.	Copper and brass 45°.

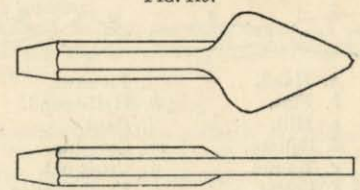
The flat chisel shown at Fig. 114 is used for general chipping work and for cutting large surfaces.

Fig. 114.



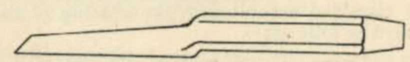
The cross-cut chisel shown at Fig. 115 is used for cutting channels on large flat surfaces, or for cutting keyway in wheels and shafts.

Fig. 115.



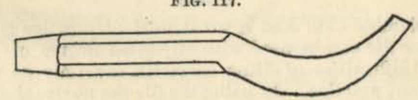
The side chisel, Fig. 116, is very useful in chipping and removing surplus metal in slots and cotter ways.

Fig. 116.



The round-nose chisel, Fig. 117, is chiefly used in cutting oil channels in bearings and pulley bushes, or for drawing over drill centres in drilling.

Fig. 117.

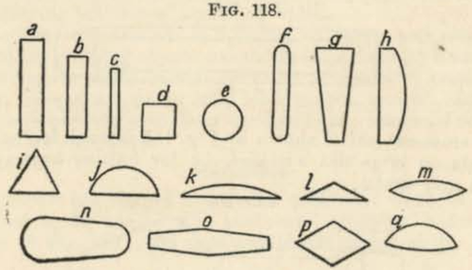


Files

Files are graded and classified according to their section, length, and pitch of teeth. They are forged by hand or power from crucible steel, annealed, ground to shape and size, the teeth cut, and then hardened by being brought to a cherry-red and dipped into salt and water.

Files vary in length between 3 and 16 inches. The various sections of files in general used in the engineers' shop are shown at Fig. 118.

FIG. 118.



a. Hand.
b. Flat.
c. Mill.
d. Square.
e. Round.
f. Cottar.
g. Knife.
h. Cabinet.
i. Three-square.
j. Pit saw.
k. Half-round.
l. Cant.
m. Crossing.
n. Cross-cut.
o. Feather edge.
p. Diamond.
q. Tumbler.

Files are classified according to the spacing of the teeth, and are named as follows:—

Rough.	20 teeth per inch.	Second cut.	30 to 40 teeth per inch.
Bastard.	20 to 25 ,, ,,	Smooth.	50 to 60 ,, ,, ,,

Special ward files and tool-maker's files have from 100 to 60 teeth per inch.

Filing

Considerable skill and a great deal of practice is required before the file can be used with any great degree of accuracy, and the difficulties of filing correctly can only be overcome by constant practice. In using the file the novice should stand

directly in front of the work, with the left foot advanced about 18 inches, holding the end of the file in the palm of the hand, with the handle up against the ball of the thumb. When using the file take long steady strokes, putting on weight on the forward stroke, and relaxing on the backward stroke, at the same time keeping the file perfectly horizontal.

Cross and diagonal filing should be used when large surfaces are being filed, or when a great amount of metal has to be removed.

When finishing long surfaces, draw filing is frequently done. In this method the file is grasped in both hands and drawn along the metal in one direction only, and generally parallel to the jaws of the vice. This often assists in getting the work flat, and brings all the scratches in one direction.

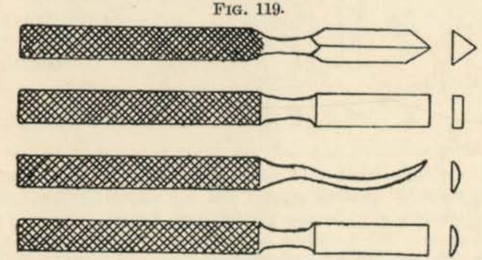
In using smooth files on soft metals, the teeth will be found to pin very quickly, and if the file is not cleaned it will scratch the job. Practical experience will overcome this to some extent, but the teeth must be cleared by means of a file card. A little chalk rubbed on the teeth of the file will help to keep the teeth from pinning.

New files should be kept for filing brass and copper, and when the cutting points have worn, the files can be taken for the harder metals.

Scraping

It is not possible to obtain a perfectly flat surface either by means of the file or by machine, and it is often necessary to finish work with the aid of the scraper. It is the only method by which true surfaces can be obtained, and is applied chiefly to the finishing of cast-iron surfaces.

FIG. 119.



Scrapers vary in size and shape according to the particular work for which they are required. A variety of scrapers are shown at Fig. 119, these consist of three square, flat, bent half-round, and flat half-round.

In using the scraper a very small amount of metal can be removed from any part of the work, and it is thus possible by making use of a surface plate to true the surface of any job to a fine degree of accuracy. In scraping curved surfaces, the three-square or half-round scraper is used, and when a very high degree of accuracy is required, the scraping must be continued until small transference spots are shown over the entire surface.

Proportions of Keys

Let D = the diameter of the shaft.
,, B = the breadth of the key.
,, T = the mean thickness of the key.

Then $B = \frac{D}{4} + \frac{1}{8}''$.

,, $T = \frac{D}{8} + \frac{1}{8}''$ for sunk keys.

,, $T = \frac{D}{10} + \frac{1}{16}''$ for keys on flat.

The taper of keys is $\frac{1}{8}''$ per foot in length, i.e. 1 in 96. Steel is the best material for ordinary keys.

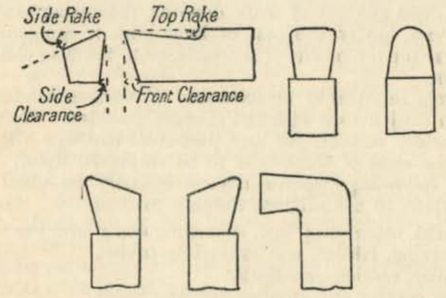
Colouring Solution for Bright Work

Sulphate of Copper (Saturated Solution)	4 oz.
Sulphuric Acid	1 oz.
Water	8 oz.

Chapter XII
PLANING AND SHAPING

The planer is constructed for the purpose of producing plane surfaces of larger area than that obtained by means of the shaper. The work to be operated upon is generally secured to a table which moves backwards and forwards, the tool being fed at right angles to the work by some suitable gear.

Planing and Shaping Tools



	Metal	Top rake	Side rake	Front clearance	Side clearance
Front and side tools for roughing and finishing	Steel Cast iron	12° 8	12° 1	10° 10	5° 5
Slotting tools . . .	—	3	—	5	5

The older form of planer has two fixed speeds, one for cutting and the other for the return stroke. Modern planers have a variable speed gear, which allows of a different speed being given for cutting different metals. On one particular type of machine the cutting speeds can be 30′, 40′, 50′, and 60′ per minute, with a return speed varying between 90′ and 140′ per minute.

For fixing and securing work on the planer the following accessories are required: angle plates, parallel packing, levelling wedges, holding down plates, hard wood blocks, stopping plates, vices, vee blocks, and many special devices.

Shaping

The shaper is designed to produce plane surfaces, but of smaller area than the planer. It differs from the planer inasmuch that the tool moves to give the cut. In some examples the work is made to revolve, so that it is possible to obtain semicircular work. The return stroke of the shaper is unproductive, so it is generally arranged to give the return stroke an increased speed.

The great amount of work done on the shaper can be held in the vice, but in the case of large work it can generally be bolted to the top or side of the table, or to the base plate of the machine.

A large number of attachments of various kinds can be used in conjunction with the shaping machine. The number and variety suitable for any particular machine will depend upon the class of work it is to be employed upon.

The following attachments can usually be obtained for application to the modern shaping machine :—

Parallel, taper, deep jaw, swivelling and round bar vices.
Revolving, tilting, and swivelling tables.
Circular motion mandrels.
Index centres and circular dividing heads.
Keyway cutting attachments.
Concave cutting attachments.

The cutting speeds of shapers vary between 30 to 50 feet per minute. The table on page 109 gives the cutting angles and clearances of both planer and shaper tools.

Chapter XIII

MILLING MACHINES AND MILLING

The universal type of milling machine is probably one of the most useful tools to be found in the tool-room of any engineering establishment. The wide range of operations, and the more general use of this type of machine, makes it worthy of careful study by the machine operator.

A very useful type of heavy universal milling machine is shown in Fig. 120. This machine is manufactured by Messrs. Brown & Sharpe, and the various parts are as follows :—

The Spindle.—Of crucible steel. Bearings ground. Phosphor bronze boxes with means of compensation for wear. Front end threaded $4\frac{1}{2}$ in. diameter, $2\frac{3}{4}$, L.H. Has No. 12 taper hole. Hole through, $\frac{3}{4}$ in. diameter. Recess in end and cap nut for arbor or collet with clutch collar.

The Drive.—One friction clutch pulley, 18 in. diameter, 6 in. belt. Runs at constant speed, 320 revolutions per minute. Enclosed by belt guard. Back geared. Ratio of gearing, 1 to 21·3 : 1. 16 changes of speed, 15 to 350 revolutions per minute in either direction. Changes made by adjustment of index slide and lever. Speeds in geometrical progression.

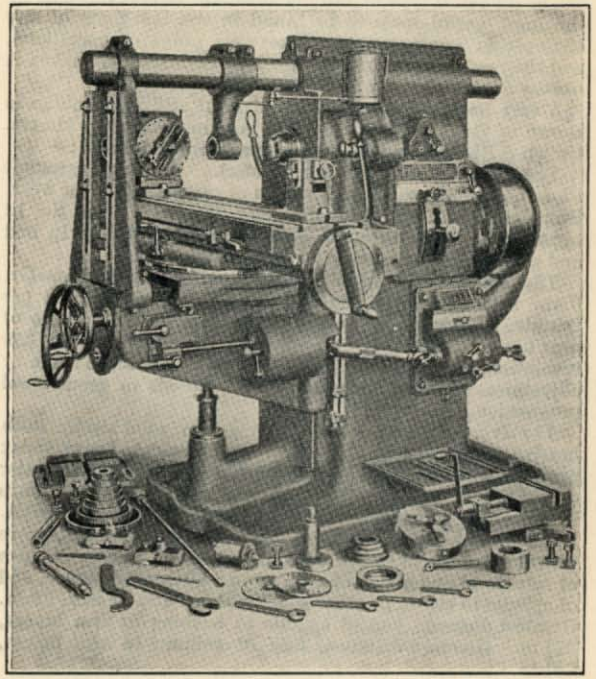
The Arbor Support.—Overhanging arm, solid steel. Both bearings clamped from one point. Arm braces, heavy type ; provided with phosphor bronze bushing for supporting outer end of arbor. Arbor yoke : provided with phosphor bronze bushing for supporting arbor at any intermediate point. Diameter of holes in bushings, $2\frac{9}{16}$ in. An adjustable centre provided for use in either arbor yoke or arm braces. Centre of spindle to under side of arm, $8\frac{3}{8}$ in. Greatest distance, end of spindle to centre in arbor yoke, without arm braces, 33 in. Greatest distance, end of spindle to bushing in arm braces, $27\frac{1}{2}$ in. Greatest distance, face of column to arm braces, $29\frac{1}{2}$ in.

The Table.—Including oil pans and channels, $64\frac{1}{2} \times 16$ in. Working surface, 59×16 in. 3 T slots, $\frac{3}{4}$ in. wide. Quick return by internal gear and pinion. Arc of swing, 276°. Elevating screw, telescopic.

Feeds.—Positive. All spur gears driven by chain. Sixteen changes varying in practically a geometrical progression, from

⅝ in. to 20 in. per minute. Independent of spindle speeds. Range for small mills, ·0018 in. to ·057 in. per revolution of spindle; for large mills, ·041 in. to 1·333 in. per revolution of spindle. An additional series of feeds of less than ⅝ in. per

FIG. 120.



minute is provided. No loose change gears. Changes made by adjustment of index slide and levers. Automatic feed can be used with table set to 48° either side of zero. Hand-wheels clutched.

Feed Tripping Mechanism.—Double plunger type. Sensitive. Can be set to prevent throwing in of wrong clutch.

Adjustable Dials.—Graduated to thousandths of an inch.

Spiral Head and Foot-stock Centres.—Swing 15 in. diameter; take 36 in. length. Head can be set at any angle from 10° below horizontal to 5° beyond perpendicular. Graduated to half degrees. Front end of spindle threaded, 2¾ in., 4, R. H. Has No. 12 taper hole. Hole through, 1½ in. diameter. Foot-stock centre adjustable in vertical plane. Index crank adjustable. Sector graduated.

Differential Indexing.—Provides for all divisions from 1 to 382, and many more beyond.

Vice.—Swivels. Base graduated. Jaws of tool steel, hardened. Capacity: 7½ in. wide, 2 in. deep, open 4½ in.

Counter-shaft.—Two friction pulleys, 18 in. diameter. 6 in. belts. Speed, 320 revolutions per minute.

Milling Cutters

The majority of cutters used on the milling machine have the teeth machined from the same material of which the body of the cutter is made. Very large cutters, and some specially formed cutters, are provided with a means of inserting teeth. In using the milling cutter each separate cutting edge acts as an ordinary machine tool having a single cutting edge. The cutter when revolving has the work fed to it, and only one tooth comes into contact with the work, and is then only in use for a small fraction of time. Thus the wear on the cutting edges is uniformly distributed between the whole of the cutting edges, and the intermittent cutting action preserves the keenness of the cutting edges.

Accurate milling can only be accomplished by the use of durable and correctly formed cutters, capable of doing a considerable amount of work without the need for regrinding.

The solid form of plain cutter is a disc of high carbon steel made with the front faces of the teeth radial. The angle of clearance given, is usually 5°, the land on top of the tooth being left about 0·03 in. wide. The tooth angle is approximately 50°. The side teeth and end teeth being formed with a 75° cutter. Cutters of this description vary from 1 to 4½ inches in diameter, and are made in widths up to 6 inches.

Plain milling cutters having straight axial teeth are made up to 5 inches in diameter, but the length seldom exceeds 1 inch.

The diameter of the cutter determines to a great degree the number of teeth. When the teeth are too closely spaced there is a tendency for the cuttings to clog in the cutter flutes and thereby reduce the cutting efficiency. A number of tests with cutters of similar diameter, but having teeth of different pitch, have been made, and it was found that by reducing the number of teeth 50 per cent the power required was reduced about 30 per cent. For roughing work a coarse tooth cutter gives a saving in power, is more durable, and allows of a much heavier feed than is possible with a closely-spaced cutter.

Cutters of various types are illustrated in Fig. 121.

Speeds and Feeds

The cutting speed is usually taken in feet per minute and can be found by multiplying the diameter of the cutter in inches by 3·1416, dividing by 12, and multiplying the quotient by the number of revolutions per minute of the cutter.

The following formula will give the number of revolutions per minute to be made by a cutter of a given diameter, in order to obtain a given cutting speed.

Let N = number of revolutions per minute.
,, C.S. = cutting speed.
,, D = diameter of cutter.
,, $\pi = 3\frac{1}{7}$.

$$\text{Then } \frac{\text{C.S.} \times 12}{\pi \times \text{D}} = \text{N}.$$

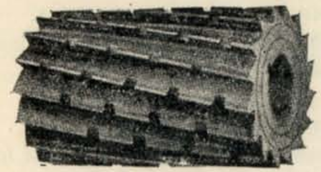
The feed or movement of the work towards the cutter is given as a rule in terms of feet per minute, and may in some cases be determined quite independent of the cutting speed. A large number of milling machines are constructed in such a manner that the feed is entirely dependent upon the speed of the machine, and consequently a very coarse feed with a very large cutter, or a fine feed with a small cutter, cannot be obtained, except within certain limits. This difficulty is often overcome by running the feed gear from an independent pulley.

The following rules will give approximate speeds for carbon steel cutter on plain straightforward work. With high speed steel cutters the speed can be increased up to 50 per cent.

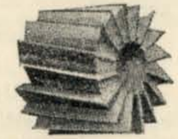
For brass $\frac{\text{200 to 300}}{\text{diam. cutter in inches}} =$ No. of revolutions per minute.

,, wrought-iron mild steel $\frac{\text{200 to 250}}{\text{diam. cutter in inches}} =$ No. of revolutions per minute.

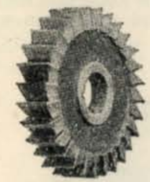
Fig. 121.



Plain Milling Cutter with Spiral Nicked Teeth



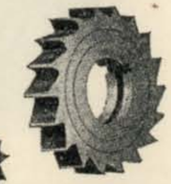
Shell End Mill with Spiral Teeth



Side Milling Cutter

Metal Slitting Saw

Centre Cut End Mill



Plain Milling Cutter

End Mill with Spiral Teeth

T Slot Cutter

Form Cutter. can be sharpened without changing Contour Teeth

Two-Lipped Slotting End Mill

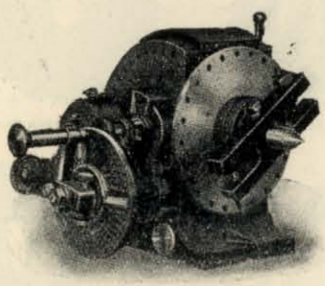
$$\text{For cast iron} \quad \frac{150 \text{ to } 200}{\text{diam. cutter in inches}} = \text{No. of revolutions per minute.}$$

$$\text{,, annealed tool steel} \quad \frac{80 \text{ to } 100}{\text{diam. cutter in inches}} = \text{No. of revolutions per minute.}$$

The Universal Dividing Head

The universal dividing head, or the spiral head, is used for indexing and cutting spirals. The Brown & Sharpe type of head is shown in Figs. 122 and 123. This consists of a hollow, semi-circular casting in which is mounted a spindle connected to an index crank through a worm and worm wheel. The worm has a single thread, and the worm wheel has 40 teeth.

Fig. 122.



Indexing

Indexing with the dividing head is a simple operation depending upon the ratio between the number of teeth in the worm wheel and the number of threads in the worm. The commonest ratio used is 40 to 1, thus every complete turn of the crank handle moves the worm wheel a distance equal to the advance of one tooth, or $\frac{1}{40}$ part of a complete revolution, and therefore 40 complete turns of the crank handle would be required to turn the head spindle one complete revolution.

It follows that to index a piece of work into 40 parts, one turn of the crank handle would be required for each division, and to index into 80 parts one-half of a turn would be required; also to index into 20 parts two turns of the crank handle would be necessary. To find the number of turns or fractions of

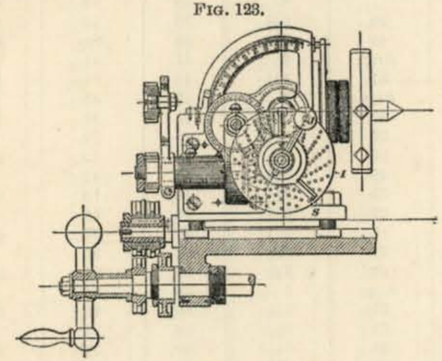
a turn the crank handle must be moved for a certain number of divisions; the following rule can be applied:—Divide 40 by the number of divisions to be made and the quotient will be the number of turns or parts of turns to be given to the crank handle.

Applying the Rule

When the quotient contains a fraction or is a fraction, then it will be necessary to give the crank handle a part of a complete turn when indexing.

The numerator of the fraction represents the number of holes that should be indexed for each division. If the fraction is so small that none of the plates contains the number of holes represented by the denominator, both numerator and denominator should be multiplied by a common multiplier that will give a fraction the denominator of which represents

Fig. 123.



a number of holes that are available. If on dividing the 40 by the number required the fraction is found to be too large, it can be reduced by dividing both the numerator and denominator by any suitable common number. For example, if seven divisions are required, $40 \div 7$, equals $5\frac{5}{7}$ turns of the index handle for each division. As no plate is provided with a circle containing 7 holes, this number can be raised by multiplying by the common multiplier 3, giving $7 \times 3 = 21$, and if the numerator is also multiplied by 3, then $5 \times 3 = 15$. Thus for one division of the work, the index crank pin is placed on the 21 hole circle, and is given five complete turns and then in addition 15 holes on the 21 circle. It would also be possible to use the 49 hole circle by taking 35 holes.

The following tables will be found useful in quickly finding the number of turns or parts of a turn to be given to the crank handle in order to index all possible numbers up to 360 by the plain method.

INDEX TABLE FOR USE WITH DIVIDING HEAD.—1

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.
2	Any	20	35	49	$1\frac{7}{49}$
3	39	$13\frac{13}{39}$	36	27	$1\frac{3}{27}$
4	Any	10	37	37	$1\frac{3}{37}$
5	,,	8	38	19	$1\frac{1}{19}$
6	39	$6\frac{26}{39}$	39	39	$1\frac{1}{39}$
7	49	$5\frac{35}{49}$	40	Any	1
8	Any	5	41	41	$\frac{40}{41}$
9	27	$4\frac{12}{27}$	42	21	$\frac{20}{21}$
10	Any	4	43	43	$\frac{40}{43}$
11	33	$3\frac{21}{33}$	44	33	$\frac{30}{33}$
12	39	$3\frac{13}{39}$	45	27	$\frac{24}{27}$
13	39	$3\frac{3}{39}$	46	23	$\frac{20}{23}$
14	49	$2\frac{42}{49}$	47	47	$\frac{40}{47}$
15	39	$2\frac{26}{39}$	48	18	$\frac{15}{18}$
16	20	$2\frac{10}{20}$	49	49	$\frac{40}{49}$
17	17	$2\frac{6}{17}$	50	20	$\frac{16}{20}$
18	27	$2\frac{6}{27}$	52	39	$\frac{30}{39}$
19	19	$2\frac{2}{19}$	54	27	$\frac{20}{27}$
20	Any	2	55	33	$\frac{24}{33}$
21	21	$1\frac{19}{21}$	56	49	$\frac{35}{49}$
22	33	$1\frac{27}{33}$	58	29	$\frac{20}{29}$
23	23	$1\frac{17}{23}$	60	39	$\frac{26}{39}$
24	39	$1\frac{26}{39}$	62	31	$\frac{20}{31}$
25	20	$1\frac{12}{20}$	64	16	$\frac{10}{16}$
26	39	$1\frac{21}{39}$	65	39	$\frac{24}{39}$
27	27	$1\frac{13}{27}$	66	33	$\frac{20}{33}$
28	49	$1\frac{21}{49}$	68	17	$\frac{10}{17}$
29	29	$1\frac{11}{29}$	70	49	$\frac{28}{49}$
30	39	$1\frac{13}{39}$	72	27	$\frac{15}{27}$
31	31	$1\frac{9}{31}$	74	37	$\frac{20}{37}$
32	20	$1\frac{5}{20}$	75	15	$\frac{8}{15}$
33	33	$1\frac{7}{33}$	76	19	$\frac{10}{19}$
34	17	$1\frac{3}{17}$	78	39	$\frac{20}{39}$

INDEX TABLE FOR USE WITH DIVIDING HEAD.—2

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.
80	20	$\frac{10}{20}$	164	41	$\frac{10}{41}$
82	41	$\frac{20}{41}$	165	33	$\frac{8}{33}$
84	21	$\frac{10}{21}$	168	21	$\frac{5}{21}$
85	17	$\frac{8}{17}$	170	17	$\frac{4}{17}$
86	43	$\frac{20}{43}$	172	43	$\frac{10}{43}$
88	33	$\frac{15}{33}$	180	27	$\frac{6}{27}$
90	27	$\frac{12}{27}$	184	23	$\frac{5}{23}$
92	23	$\frac{10}{23}$	185	37	$\frac{8}{37}$
94	47	$\frac{20}{47}$	188	47	$\frac{10}{47}$
95	19	$\frac{8}{19}$	190	19	$\frac{4}{19}$
98	49	$\frac{20}{49}$	195	39	$\frac{8}{39}$
100	20	$\frac{8}{20}$	196	49	$\frac{10}{49}$
104	39	$\frac{15}{39}$	200	20	$\frac{4}{20}$
105	21	$\frac{8}{21}$	205	41	$\frac{8}{41}$
108	27	$\frac{10}{27}$	210	21	$\frac{4}{21}$
110	33	$\frac{12}{33}$	215	43	$\frac{8}{43}$
115	23	$\frac{8}{23}$	216	27	$\frac{5}{27}$
116	29	$\frac{10}{29}$	220	33	$\frac{6}{33}$
120	39	$\frac{13}{39}$	230	23	$\frac{4}{23}$
124	31	$\frac{10}{31}$	232	29	$\frac{5}{29}$
128	16	$\frac{5}{16}$	235	47	$\frac{8}{47}$
130	39	$\frac{12}{39}$	240	18	$\frac{3}{18}$
132	33	$\frac{10}{33}$	245	49	$\frac{8}{49}$
135	27	$\frac{8}{27}$	248	31	$\frac{5}{31}$
136	17	$\frac{5}{17}$	260	39	$\frac{6}{39}$
140	49	$\frac{14}{49}$	264	33	$\frac{5}{33}$
144	18	$\frac{5}{18}$	270	27	$\frac{4}{27}$
145	29	$\frac{8}{29}$	280	49	$\frac{7}{49}$
148	37	$\frac{10}{37}$	290	29	$\frac{4}{29}$
150	15	$\frac{4}{15}$	296	37	$\frac{5}{37}$
152	19	$\frac{5}{19}$	300	15	$\frac{2}{15}$
155	31	$\frac{8}{31}$	310	31	$\frac{4}{31}$
156	39	$\frac{10}{39}$	312	39	$\frac{5}{39}$
160	20	$\frac{5}{20}$	360	18	$\frac{2}{18}$

Indexing Degrees

When it is necessary to divide the circumference of a piece of work into degrees, it can be frequently done by plain indexing. One complete turn of the index handle produces $\frac{1}{40}$ of a turn of the work, or $\frac{360}{40}$°, which equals 9 degrees. By this method it follows that :—

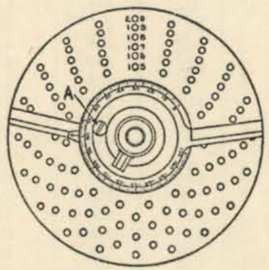
2 holes in the 18 circle = 1 degree.
2 holes in the 27 circle = $\frac{2}{3}$ degree.
1 hole in the 18 circle = $\frac{1}{2}$ degree.
1 hole in the 27 circle = $\frac{1}{3}$ degree.

Index Sector

With the Brown and Sharpe dividing head three index plates are provided, and contain circles with the following numbers of holes :—

No. 1 Plate—15, 16, 17, 18, 19, 20.
No. 2 Plate—21, 23, 27, 29, 31, 33.
No. 3 Plate—37, 39, 41, 43, 47, 49.

FIG. 124.



To facilitate the dividing of a given circle of holes the index sector shown at A in Fig. 124 is provided. Without the graduated index sector, care must be taken in counting the number of holes in an index plate when indexing to obtain a given number of divisions. The sector enables the correct number of holes to be obtained at each separate indexing with little chance of error. The sector consists of two arms which may be opened or closed by first slacking out the set screw at A, the correct number of holes may be counted, and the sector arms set to just enclose them.

CHAPTER XIV

GEAR CUTTING

Spur Gears

Spur gears are toothed wheels which give or receive motion from a parallel shaft. They have teeth parallel with the axis of the wheel, and when cut in the milling machine generally take the form of the involute.

In connection with the cutting of spur gears the word diameter is always understood to mean pitch diameter, and pitch diameter is represented by an imaginary circle termed the pitch circle which is intermediate between the top and bottom of the wheel tooth. The diametral pitch of a spur wheel is indicated by the number of complete teeth to each inch of pitch diameter. Circular pitch is the distance from the centre of one tooth to the centre of the next measured along the pitch circle.

Example : If a wheel has a pitch diameter of 3 inches and has 36 teeth, then the diametral pitch is $36 \div 3$, giving 12, and for each inch of pitch diameter the wheel has 12 teeth.

The diametral pitch of a spur wheel being equal to the number of teeth to each inch of pitch diameter, it follows that each unit will be represented on the pitch circle by that unit multiplied by 3·1416, and the number of teeth to each inch of diametral pitch equals the number of teeth to each 3·1416 inches of circumference. The circular pitch being the distance from the centre of one tooth to the centre of the next measured on the pitch circle, it follows that the circular pitch must be equal to 3·1416 divided by the number of teeth in 3·1416 of the circumference, and as the diametral pitch is equal to the numbers of teeth in each 3·1416 inches of circumference, the circular pitch must be equal to 3·1416 divided by the diametral pitch.

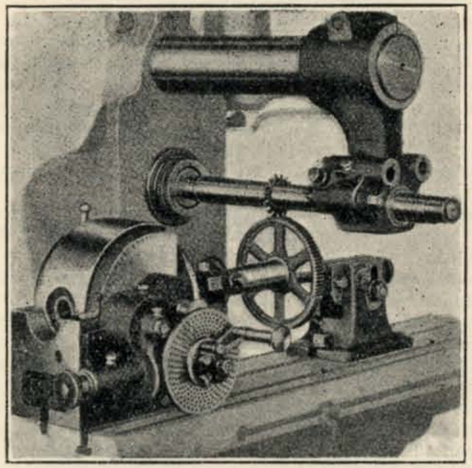
The diametral pitch is obtained from the circular pitch in a similar manner to the above; in each 3·1416 inches of circumference the wheel will have a certain number of teeth which must be the diametral pitch, and being given the circular pitch, by dividing 3·1416 by that, we obtain the number of teeth for 3·1416 of the circumference which must be the diametral pitch of the gear wheel.

When it is necessary to obtain the circular pitch, having already got the diametral pitch, all that is necessary is to divide 3·1416 by the diametral pitch and the result will be the circular pitch; or let P equal the diametral pitch and P^1 the circular pitch, then

$$\frac{3 \cdot 1416}{P} = P^1.$$

For example, if the diametral pitch is 6 and the circular pitch is required, then $3 \cdot 1416 \div 6$ gives 0·524, which is the circular pitch.

Fig. 125.



When the circular pitch is given and the diametral pitch is required, then we divide 3·1416 by the circular pitch, or using the same formula,

$$\frac{3 \cdot 1416}{P^1} = P.$$

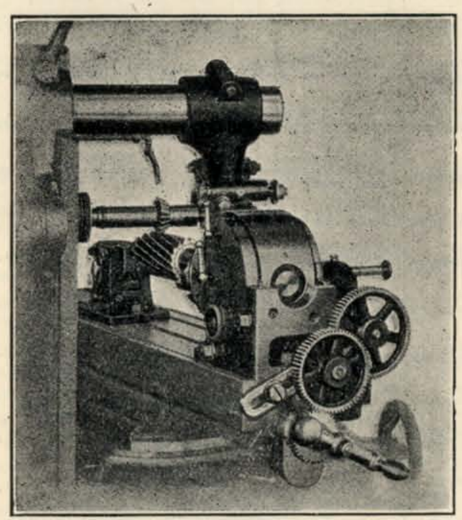
Tooth Relations in Diametral and Circular Pitch

The rules on pp. 138 and 139 give the formula for obtaining the various dimensions required when milling the teeth of spur wheels.

Setting up for cutting Spur Wheels

The method of setting up a wheel blank is clearly shown in Fig. 125. The cutter is placed on the machine arbor central with the head and tailstock centre, the wheel blank being driven on a suitable mandrel and held in position by means of a bent tailed carrier.

Fig. 126.



Spiral Milling

For spiral milling the milling machine is arranged as shown in Fig. 126. This operation shows the arrangement for cutting teeth in a right-hand spiral cutter.

The work is 6 inches long and 3 inches in diameter, and an angular cutter 3 inches in diameter is employed. An angle of $11\frac{1}{4}°$ is required and the saddle is accordingly set to that angle and the head geared to give a lead of 48 inches.

In considering spirals the distance the helix advances in one revolution is termed the lead, and in order to give the

DIAMETRAL PITCH.

Diametral Pitch is the Number of Teeth to Each Inch of the Pitch Diameter.

To Get	Having	Rule.	Formula.
The Diametral Pitch.	The Circular Pitch.	Divide 3.1416 by the Circular Pitch	$P=\frac{3.1416}{P'}$
The Diametral Pitch.	The Pitch Diameter and the Number of Teeth	Divide Number of Teeth by Pitch Diameter	$P=\frac{N}{D'}$
The Diametral Pitch.	The Outside Diameter and the Number of Teeth	Divide Number of Teeth plus 2 by Outside Diameter	$P=\frac{N+2}{D}$
Pitch Diameter.	The Number of Teeth and the Diametral Pitch	Divide Number of Teeth by the Diametral Pitch	$D'=\frac{N}{P}$
Pitch Diameter.	The Number of Teeth and Outside Diameter	Divide the product of Outside Diameter and Number of Teeth by Number of Teeth plus 2 .	$D'=\frac{D\,N}{N+2}$
Pitch Diameter.	The Outside Diameter and the Diametral Pitch . . .	Subtract from the Outside Diameter the quotient of 2 divided by the Diametral Pitch	$D'=D-\frac{2}{P}$
Pitch Diameter.	Addendum and the Number of Teeth.	Multiply Addendum by the Number of Teeth	$D'=s\,N$
Outside Diameter.	The Number of Teeth and the Diametral Pitch	Divide Number of Teeth plus 2 by the Diametral Pitch	$D=\frac{N+2}{P}$
Outside Diameter.	The Pitch Diameter and the Diametral Pitch	Add to the Pitch Diameter the quotient of 2 divided by the Diametral Pitch	$D=D'+\frac{2}{P}$
Outside Diameter.	The Pitch Diameter and the Number of Teeth	Divide the Number of Teeth plus 2 by the quotient of Number of Teeth and by the Pitch Diameter	$D=\frac{N+2}{\frac{N}{D'}}$
Outside Diameter.	The Number of Teeth and Addendum .	Multiply the Number of Teeth plus 2 by Addendum	$D=(N+2)\,s$
Number of Teeth.	The Pitch Diameter and the Diametral Pitch	Multiply Pitch Diameter by the Diametral Pitch	$N=D'P$
Number of Teeth.	The Outside Diameter and the Diametral Pitch . . .	Multiply Outside Diameter by the Diametral Pitch and subtract 2.	$N=DP-2$
Thickness of Tooth.	The Diametral Pitch.	Divide 1.5708 by the Diametral Pitch	$t=\frac{1.5708}{P}$
Addendum.	The Diametral Pitch.	Divide 1 by the Diametral Pitch, or $s=\frac{D'}{N}$	$s=\frac{1}{P}$
Root.	The Diametral Pitch.	Divide 1.157 by the Diametral Pitch	$s+f=\frac{1.157}{P}$
Working Depth.	The Diametral Pitch.	Divide 2 by the Diametral Pitch.	$D''=\frac{2}{P}$
Whole Depth.	The Diametral Pitch.	Divide 2.157 by the Diametral Pitch	$D''+f=\frac{2.157}{P}$
Clearance.	The Diametral Pitch.	Divide .157 by the Diametral Pitch	$f=\frac{.157}{P}$
Clearance.	Thickness of Tooth.	Divide Thickness of Tooth at pitch line by 10	$f=\frac{t}{10}$

CIRCULAR PITCH.

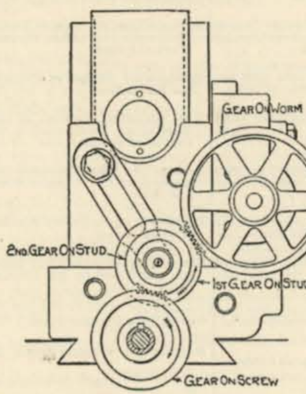
Circular Pitch is the Distance from the Centre of One Tooth to the Centre of the Next Tooth, Measured along the Pitch Line.

To Get	Having	Rule.	Formula.
The Circular Pitch.	The Diametral Pitch.	Divide 3.1416 by the Diametral Pitch	$P'=\frac{3.1416}{P}$
The Circular Pitch.	The Pitch Diameter and the Number of Teeth	Divide Pitch Diameter by the product of .3183 and Number of Teeth	$P'=\frac{D'}{.3183\,N}$
The Circular Pitch.	The Outside Diameter and the Number of Teeth	Divide Outside Diameter by the product of .3183 and Number of Teeth plus 2	$P'=\frac{D}{.3183\,N+2}$
Pitch Diameter.	The Number of Teeth and the Circular Pitch	The continued product of the Number of Teeth, the Circular Pitch and .3183	$D'=NP'.3183$
Pitch Diameter.	The Number of Teeth and the Outside Diameter	Divide the product of Number of Teeth and Outside Diameter by Number of Teeth plus 2 . . .	$D'=\frac{ND}{N+2}$
Pitch Diameter.	The Outside Diameter and the Circular Pitch	Subtract from the Outside Diameter the product of the Circular Pitch and .6366	$D'=D-(P'.6366)$
Pitch Diameter.	Addendum and the Number of Teeth.	Multiply the Number of Teeth by the Addendum	$D'=N\,s$
Outside Diameter.	The Number of Teeth and the Circular Pitch	The continued product of the Number of Teeth plus 2, the Circular Pitch and .3183 . . .	$D=(N+2)P'.3183$
Outside Diameter.	The Pitch Diameter and the Circular Pitch	Add to the Pitch Diameter the product of the Circular Pitch and .6366	$D=D'+(P'.6366)$
Outside Diameter.	The Number of Teeth and the Addendum	Multiply Addendum by Number of Teeth plus 2	$D=s\,(N+2)$
Number of Teeth.	The Pitch Diameter and the Circular Pitch	Divide the product of Pitch Diameter and 3.1416 by the Circular Pitch	$N=\frac{D'\,3.1416}{P'}$
Thickness of Tooth.	The Circular Pitch.	One-half the Circular Pitch . .	$t=\frac{P'}{2}$
Addendum.	The Circular Pitch.	Multiply the Circular Pitch by .3183, or $s=\frac{D'}{N}$	$s=P'.3183$
Root.	The Circular Pitch.	Multiply the Circular Pitch by .3683	$s+f=P'.3683$
Working Depth.	The Circular Pitch.	Multiply the Circular Pitch by .6366	$D''=P'.6366$
Whole Depth.	The Circular Pitch.	Multiply the Circular Pitch by .6866	$D''=P'.6866$
Clearance.	The Circular Pitch.	Multiply the Circular Pitch by .05	$f=P'.05$
Clearance.	Thickness of Tooth.	One-tenth the Thickness of Tooth at Pitch Line	$f=\frac{t}{10}$

necessary rotation to the work the spiral head is used. The feed screw of the machine generally has 4 threads per inch, and the spiral head is usually geared so that forty turns of the worm are required in order to make one complete turn of the spiral head spindle, and therefore if a train of change wheels are used which give a ratio of 1 to 1 then the spiral head will move a complete turn when the table has travelled a distance of 10 inches, and the work will have a lead of 10 inches.

The various wheels used are named: Gear on Worm, Second Stud Wheel, First Stud Wheel, and Gear on Screw. The wheel on the table screw and the first stud wheel are drivers, and the wheel on the worm and the second stud wheel are driven. The wheel arrangement is clearly shown in Fig. 127.

FIG. 127.



By taking advantage of the various combinations of wheels the ratio of the longitudinal movement of the table to the spiral movement of the work can be altered to suit nearly all requirements.

A table for finding the approximate angle and necessary wheels for cutting spirals will be found on pp. 142–4. This table is suitable for all Brown & Sharpe machines and for other machines geared in a similar manner.

Calculations for Change Wheels

The calculations necessary to find the required change wheels to give a desired spiral are practically the same as for finding lathe change wheels for screw cutting. In lathe work the ratio of the driving and driven wheels is the ratio between the number of threads to be cut per inch and the number of threads per inch on the lead screw. On the milling machine the ratio of the driving and driven wheels is the ratio of the lead of the spiral to be cut and the lead of the machine table; or the compound ratio of the driven to the driving wheels equals the lead of the required spiral to the lead of the machine table.

This expressed in fractional form would be—

$$\frac{\text{Lead of the required spiral}}{\text{Lead of machine table}} = \frac{\text{Driven gear}}{\text{Driving gear}}$$

and if the lead of the machine is 10 inches, then

$$\frac{\text{Product of driven gear}}{\text{Product of driving gear}} = \frac{\text{lead of the required spiral}}{10}$$

or ten times the product of the driven wheels divided by the product of the drivers will give the lead of the resulting spiral in one complete turn.

Ratio

If the required spiral has a lead of 14 inches the ratio will be as 14 is to 10, or, dividing the lead by 10, the quotient 1·4 will be the ratio to 1.

If the required spiral has a lead of 36 inches the ratio will be as 36 is to 10, or dividing 36 by 10, we get the ratio of 3·6 to 1.

Examples of Change Gears

Example.—Find the necessary gears to cut a spiral having a lead of 27 inches.

The ratio is as 27 is to 10, and can be expressed as a fraction thus, $\frac{27}{10}$; this fraction can be broken into factors giving $\frac{3}{2} \times \frac{9}{5}$. Taking each fraction separately and multiplying the numerators and denominators by 16 and 8 respectively, we get $\frac{3}{2} \times \frac{16}{16} = \frac{48}{32}$ and $\frac{9}{5} \times \frac{8}{8} = \frac{72}{40}$.

Then 32 and 40 are driving gears, and 48 and 72 driven gears.

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

TANGENT OF ANGLE OF SPIRAL = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL / LEAD IN INCHES TO ONE TURN

C = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL
L = LEAD IN INCHES TO ONE TURN
T = TANGENT OF ANGLE OF SPIRAL

$T = \frac{C}{L}$ $L = \frac{C}{T}$

NOS. OF TEETH IN GEARS FURNISHED WITH MACHINE
24(2) 28 32 40 44 48 56 64 72 86 100

THE LEAD IN INCHES TO ONE TURN = 10 X GEAR ON WORM X 2ND GEAR ON STUD / GEAR ON SCREW X 1ST GEAR ON STUD

DIAMETER OF CUTTER, DRILL, OR MILL

Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches to One Turn	1/8"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"	4"	4¼"	4½"	4¾"	5"	5¼"	5½"	5¾"	6"
24	72	28	86	1.085	20	36	47¼																									
24	72	32	86	1.240	17½	32¼	43½	51¾																								
24	72	40	100	1.333	16½	30½	41½	49¾																								
24	48	28	100	1.400	15¾	29¼	40	48¼																								
24	64	40	100	1.500	14¾	27¾	38¼	46¼	52½																							
28	56	32	100	1.600	13¾	26¼	36¼	44½	50¾																							
24	72	44	86	1.706	13	24¾	34½	42½	49																							
24	64	48	100	1.800	12¼	23½	33¼	41	47½	52½																						
24	40	32	100	1.920	11½	22¼	31½	30¼	45¾	50¾																						
28	64	40	86	2.035	11	21	30	37¾	44	49¼																						
24	72	56	86	2.171	10½	20	28½	35¾	42	47¼	51¾																					
24	64	44	72	2.292	9¾	19	27¼	34½	40½	45¾	50¼																					
28	64	56	100	2.450	9	17¾	25¾	32¾	38¾	44	48¼	52																				
40	86	56	100	2.605	8½	16¾	24¼	31	37	42	46½	50¼																				
40	56	28	72	2.778	8	15¾	23	29½	35¼	40¼	44¾	48½																				
24	56	44	64	2.946	7½	15	21¾	28	33¾	38¾	43	46¾																				
24	86	72	64	3.140	7	14	20½	26½	32	37	41½	45	51¼																			
28	56	48	72	3.333	6¾	13¼	19½	25¼	30½	35½	39½	43¼	49¾																			
48	44	28	86	3.552	6¼	12½	18¼	23¾	29	33½	37¾	41½	47¾	53																		
44	56	48	100	3.771	6	11¾	17¼	22½	27½	32	36	39¾	46¼	51¼																		
72	100	48	86	4.019	5½	11	16¼	21¼	26	30½	34¼	38	44¼	49½																		
64	48	32	100	4.267	5¼	10½	15½	20¼	24¾	29	32¾	36¼	42½	47¾	52¼																	
56	48	28	72	4.537	5	9¾	14½	19	23½	27½	31¼	34¾	41	46	50½																	
56	64	40	72	4.861	4½	9¼	13½	18	22	25¾	29½	32¾	39	44	48½	52¼																

EXAMPLE ILLUSTRATING USE OF TABLE
DIAMETER OF CUTTER, DRILL, OR MILL.............. = 1½
LEAD IN INCHES TO ONE TURN....................... = 3.140
REQUIRED ANGLE TO NEAREST QUARTER DEGREE
TO SET SADDLE OF UNIVERSAL MILLING MACHINE = 51¼°

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

TANGENT OF ANGLE OF SPIRAL = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL / LEAD IN INCHES TO ONE TURN

C = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL
L = LEAD IN INCHES TO ONE TURN
T = TANGENT OF ANGLE OF SPIRAL

$T = \frac{C}{L}$ $L = \frac{C}{T}$

NOS. OF TEETH IN GEARS FURNISHED WITH MACHINE
24(2) 28 32 40 44 48 56 64 72 86 100

THE LEAD IN INCHES TO ONE TURN = 10 X GEAR ON WORM X 2ND GEAR ON STUD / GEAR ON SCREW X 1ST GEAR ON STUD

DIAMETER OF CUTTER, DRILL, OR MILL

Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches to One Turn	1/8"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"	4"	4¼"	4½"	4¾"	5"	5¼"	5½"	5¾"	6"
56	48	44	100	5.133	4¼	8¾	13	17	21	24¾	28¼	31½	37½	42½	47	50¾																
86	44	28	100	5.473	4	8½	12¼	16	19¾	23¼	26¾	29¾	35¾	40¾	45	49	52¼															
100	48	24	86	5.814	3¾	7¾	11½	15	18¾	22	25¼	28½	34	39	43½	47½	50½															
72	56	48	100	6.171	3¾	7½	10¾	14½	17¾	21	24	27	32½	37¼	41¾	45½	48¾	51¾														
72	56	44	86	6.578	3½	6¾	10½	13½	16½	19¾	22¾	25½	30¾	35½	40	43¾	47	50	52¾													
56	32	40	100	7.000	3¼	6½	9½	12¾	15¾	18½	21½	24¼	29¼	34	38½	42	45¼	48½	51													
56	28	32	86	7.442	3	6	9	12	14¾	17½	20¼	23	27¾	32¼	36½	40¼	43½	46½	49¼	51¾												
72	40	44	100	7.920	2¾	5¾	8½	11¼	14	16½	19¼	21¾	26¼	30¾	34¾	38½	41¾	44¾	47½	50	52¼											
56	32	48	100	8.400	2¾	5¼	8	10½	13¼	15¾	18	20½	25	29¼	33¼	36¾	40	43	45¾	48¼	50½	52½										
86	32	24	72	8.959	2½	5	7½	10	12¼	14¾	17	19¼	23¾	27¾	31½	35	38¼	41¼	44	46½	48¾	50¾	52¾									
64	48	40	56	9.524	2¼	4¾	7	9¼	11¾	14	16	18¼	22½	26¼	30	33½	36½	39½	42½	44¾	47	49	51	52¾								
100	44	32	72	10.101	2¼	4½	6¾	8¾	11	13	15¼	17½	21¼	25	28½	31¾	35	37¾	40½	43	45¼	47½	49½	51¼	53							
86	40	32	64	10.750	2	4¼	6¼	8¼	10¼	12¼	14¼	16¼	20	23¾	27	30¼	33¼	36¼	38¾	41¼	43½	45¾	47½	49½	51¼	52¾						
86	48	64	100	11.467	2	4	5¾	7¾	9¾	11½	13¼	15¼	19	22¼	25½	28¾	31¾	34½	37	39½	41¾	43¾	45¾	47½	49¼	51	52½					
72	44	64	86	12.178	1¾	3¾	5½	7½	9¼	11	12¾	14½	18	21¼	24½	27½	30½	32¾	35½	37¾	40	42	44	46	47¾	49½	50¾	52¼				
56	24	40	72	12.963	1¾	3½	5¼	7	8½	10¼	12	13½	16¾	20	23	25¾	28½	31¼	33¾	36	38¼	40¼	42¼	44	45¾	47½	49	50½	51½	51¾		
86	40	64	100	13.760	1¾	3¼	5	6½	8	9¾	11¼	12¾	16	19	21¾	24½	27¼	29¾	32	34½	36½	38½	40½	42½	44¼	45¾	47¼	48¾	50¼	51½	52¾	
86	44	48	64	14.659	1½	3	4½	6	7¾	9¼	10½	12	15	17¾	20½	23¼	25¾	28¼	30½	32¾	34¾	36¾	38¾	40½	42¼	44	45½	47	48½	49¾	51	52
64	32	56	72	15.556	1½	3	4¼	5¾	7¼	8½	10	11½	14¼	16¾	19½	22	24½	26¾	29	31¼	33¼	35¼	37½	39	40¾	42¼	43¾	45¼	46¾	48	49½	50½
72	40	44	48	16.500	1½	2¾	4	5½	6¾	8¼	9½	10¾	13½	16	18½	20¾	23¼	25½	27¾	29¾	31¾	33¾	35½	37½	39	40½	42	43½	45	46½	47½	48¾
100	44	56	72	17.677	1½	2½	3¾	5	6½	7½	8¾	10	12½	15	17½	19½	21¾	24	26	28	30	31¾	33¾	35½	37	38¾	40¼	41½	43	44¼	45½	46¾
86	28	44	72	18.770	1¼	2½	3½	4¾	6	7¼	8¼	9½	11¾	14	16¼	18½	20¾	22¾	24¾	26¾	28½	30¼	32	33¾	35½	37	38½	40	41½	42½	44	45
100	28	48	86	19.934	1¼	2¼	3½	4½	5½	6¾	7¾	9	11¼	13¼	15½	17½	19½	21½	23½	25¼	27	28¾	30½	32¼	33¾	35¼	36¾	38¼	39½	41	42¼	43½
86	32	44	56	21.12	1	2¼	3¼	4¼	5¼	6¼	7½	8½	10½	12½	14½	16½	18½	20½	22¼	24	25¾	27½	29¼	30¾	32¼	33¾	35¼	36¾	38	39¼	40½	41¾

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

TANGENT OF ANGLE OF SPIRAL = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL / LEAD IN INCHES TO ONE TURN

NOS. OF TEETH IN GEARS FURNISHED WITH MACHINE
24(2) 28 32 40 44 48 56 64 72 86 100

C = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL
L = LEAD IN INCHES TO ONE TURN
T = TANGENT OF ANGLE OF SPIRAL

$T = \frac{C}{L}$ $L = \frac{C}{T}$

THE LEAD IN INCHES TO ONE TURN = 10 X GEAR ON WORM X 2ND GEAR ON STUD / GEAR ON SCREW X 1ST GEAR ON STUD

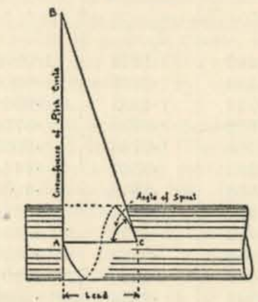
Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches to One Turn	Diameter of Cutter, Drill, or Mill: ⅛"	¼"	⅜"	½"	⅝"	¾"	⅞"	1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"	4"	4¼"	4½"	4¾"	5"	5¼"	5½"	5¾"	6"
72	28	56	64	22.50	1	2	3	4	5	6	7	8	10	11¾	13¾	15½	17½	19½	21	22¾	24½	26	27¾	29¼	30¾	32¼	33½	35	36¼	37½	38¾	40
64	40	72	48	24.00	1	2	2¾	3¾	4¾	5½	6½	7½	9¼	11	13	14¾	16½	18¼	19¾	21½	23	24½	26¼	27½	29	30½	31¾	33½	34½	35¾	37	38¼
100	64	72	44	25.57	1	1¾	2¾	3½	4½	5¼	6¼	7¼	8¾	10½	12¼	13¾	15½	17	18¾	20¼	21¾	23¼	24¾	26¼	27½	29	30¼	31½	32¾	34	35¼	36½
100	72	86	44	27.15		1¾	2½	3¼	4¼	5	5¾	6½	8¼	9¾	11½	13	14½	16¼	17¾	19¼	20½	22	23½	24¾	26¼	27½	28¾	30	31¼	32½	33¾	34¾
86	40	64	48	28.67		1½	2¼	3¼	4	4¾	5½	6¼	7¾	9¼	10¾	12¼	13¾	15¼	16¾	18¼	19½	21	22¼	23¾	25	26½	27½	28¾	30	31	32½	33¼
86	32	64	56	30.71		1½	2¼	3	3¾	4½	5	5¾	7¼	8¾	10¼	11½	13	14½	15¾	17	18½	19¾	21	22¼	23½	24¾	26	27	28½	29½	30½	31½
72	32	64	44	32.73		1¼	2	2¾	3½	4	4¾	5½	6¾	8¼	9½	10¾	12¼	13½	14¾	16	17¼	18½	19¾	21	22¼	23¼	24½	25¾	26¾	27¾	29	30
100	24	40	48	34.72		1¼	2	2½	3¼	4	4½	5¼	6½	7¾	9	10¼	11½	12¾	14	15¼	16½	17½	18¾	20	21	22¼	23¼	24¼	25½	26½	27½	28½
100	24	64	72	37.04		1¼	1¾	2½	3	3¾	4¼	4¾	6	7¼	8½	9¾	10¾	12	13¼	14¼	15½	16½	17¾	18¾	19¾	21	22	23	24	25	26	27
100	28	44	40	39.29		1¼	1¾	2¼	2¾	3½	4	4½	5¾	6¾	8	9	10½	11¼	12½	13½	14½	15¾	16¾	17¾	18¾	19¾	20¾	21¾	22¾	23¾	24¾	25½
86	24	56	48	41.81		1	1½	2¼	2¾	3¼	3¾	4¼	5¼	6½	7½	8½	9½	10¾	11¾	12¾	13¾	14¾	15¾	16¾	17¾	18¾	19¾	20½	21½	22½	23¼	24¼
100	28	40	32	44.64		1	1½	2	2½	3	3½	4	5	6	7	8	9	10	11	12	13	13¾	14¾	15¾	16¾	17½	18½	19½	20¼	21¼	22	23
100	28	64	48	47.62		1	1½	2	2¼	2¾	3¼	3¾	4¾	5¾	6½	7½	8½	9¼	10¼	11¼	12	13	14	14¾	15¾	16½	17½	18¼	19	20	20¾	21½
86	28	72	44	50.26		1	1¼	1¾	2¼	2¾	3¼	3½	4½	5¼	6¼	7¼	8	9	9¾	10½	11½	12¼	13¼	14	14¾	15¾	16½	17¼	18¼	19	19¾	20½
100	28	48	32	53.57			1¼	1¾	2	2½	3	3¼	4½	5	5¾	6¾	7	8½	9¼	10	10¾	11½	12½	13¼	14	14¾	15½	16¼	17	17¾	18¾	19½
100	28	64	40	57.14			1¼	1½	2	2¼	2¾	3¼	4	4¾	5½	6¼	7	7¾	8½	9¼	10¼	11	11¾	12½	13¼	14	14¾	15¼	16	16¾	17½	18¼
100	24	64	44	60.61			1	1½	1¾	2¼	2½	3	3¾	4½	5¼	6	6¾	7½	8	8¾	9½	10¼	11	11¾	12½	13	13¾	14½	15¼	16	16½	17¼
100	28	86	48	63.99				1½	1¾	2	2½	2¾	3½	4¼	5	5½	6¼	7	7¾	8½	9	9¾	10½	11	11¾	12½	13	13¾	14½	15	15¾	16½
72	24	64	28	68.57				1¼	1¾	2	2¼	2½	3¼	4	4½	5¼	6	6½	7¼	7¾	8½	9	9¾	10½	11	11¾	12¼	13	13½	14¼	14¾	15¼
86	24	64	32	71.67				1¼	1½	2	2¼	2½	3¼	3¾	4½	5	5¾	6¼	6¾	7½	8	8¾	9¼	10	10½	11¼	11¾	12¼	13	13½	14¼	14¾
100	24	72	40	75.00				1¼	1½	1¾	2	2½	3	3½	4¼	4¾	5½	6	6½	7¼	7¾	8¼	9	9½	10	10¾	11¼	11¾	12½	13	13½	14
100	24	64	32	83.33				1	1¼	1½	2	2¼	2¾	3¼	3¾	4¼	4¾	5½	6	6½	7	7½	8	8½	9	9½	10¼	10¾	11¼	11¾	12¼	12¾
100	24	86	40	89.59				1	1¼	1½	1¾	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
100	24	64	28	95.24					1¼	1½	1¾	2	2¼	2¾	3¼	3¾	4¼	4¾	5¼	5¾	6	6½	7	7½	8	8½	9	9¼	9¾	10¼	10¾	11¼

Table Angle for Cutting Spirals

After the necessary change wheels to cut the given spiral have been placed in position, it is necessary to find the correct angle the table must be set to in order that the cutter will be correctly in line with the helix.

The spiral angle depends upon the circumference of the work and the lead of the spiral. The greater the lead of the spiral of any given diameter, the smaller the angle; and the greater the diameter of the spiral with a given lead, the greater the spiral angle. It will be seen that if the circumference is increased or decreased and the lead remains the same, there will be a corresponding change in the angle, and for that reason the circumference is not always taken when calculating the spiral angle. The correct angle should be

FIG. 128.



found, not by the outside diameter of the work, but from the pitch diameter.

If the required angle cannot be found in the tables on pp. 142–4, then two methods are available.

The spiral angle can be found by first obtaining the natural tangent of the angle by dividing the circumference by the lead of the spiral, and when the tangent is known the corresponding angle in degrees can be found from a table of tangents. In formula this would be :—

Let C = circumference in inches.
,, L = lead in inches.
,, T = tangent.

$$\text{Then } T = \frac{C}{L} \text{ or } L = \frac{C}{T}$$

L

Example.—If the pitch diameter is 3¼ in. and the lead of the spiral 24 inches. Find the angle.

Then C = 3¼ × π = 10·21.
,, T = 10·21 ÷ 24 = ·425.

From a table of tangents ·425 gives an angle of 23 ft. 10 in.

The other method of determining the angle of the spiral is a graphical one. In Fig. 128 AB is equal to the pitch circumference and AC the lead, then BC is the required angle which can be taken by means of a protractor.

DIAMETRAL PITCH, CIRCULAR PITCH, AND ADDENDUM.

Diametral Pitch.	Circular Pitch.	Full Depth of Teeth.	Addendum.	Approximate or nearest Circular Pitch.
1	3·1416	2·1571	1·0000	3"
1¼	2·5133	1·7257	·8000	2½"
1½	2·0944	1·4381	·6666	2"
1¾	1·7952	1·2326	·5714	1¾"
2	1·5708	1·0785	·5000	1½"
2¼	1·3963	·9587	·4444	1⅜"
2½	1·2566	·8628	·4000	1¼"
3¾	1·1424	·7844	·3636	1⅛"
3	1·0472	·7190	·3333	1"
3½	·8976	·6163	·2857	⅞"
4	·7854	·5393	·2500	¾"
5	·6283	·4314	·2000	⅝"
6	·5236	·3595	·1666	½"
7	·4488	·3081	·1429	7/16"
8	·3927	·2698	·1250	⅜"

CHAPTER XV

PRECISION GRINDING

The very great improvements made in grinding machines and grinding wheels in recent years has led to the almost universal use of grinding as a means of producing precision work.

The grinding machine is not only used for finishing work to very fine limits, but it also, in many cases, shows to advantage in producing work from the rough.

It is due to the very accurate feeding arrangements, and the simple means by which work can be reduced to a predetermined size, that the grinding machine is particularly useful and economical on repetition work. The same features, however, which make the machine advantageous on repetition work can be applied to a single article, because, after taking a few trial cuts over the work, the amounts oversize can be removed with great exactness by means of the automatic feeding arrangements.

The development of grinding machines will be appreciated when it is mentioned that the Churchill Machine Tool Co., Manchester, are manufacturing machines having a swing of 50 inches, and admitting 25 feet between centres. This machine weighs 45 tons, and is provided with a grinding wheel of 50 inches diameter and 5 inch face. It is driven by means of two electric motors, a constant speed motor of 45 horse-power driving the grinding wheel and feeding gears, while a variable speed motor of 15 horse-power drives the work.

Erecting Grinding Machines

When grinding machines are being erected the instructions of the makers should be strictly carried out, and particular attention should be given to the question of speeds. Unless the speeds and feeds are correct, and the machine is rigid and level in all directions, successful and accurate work will not be possible.

ABRASIVE MATERIALS

Emery is an intimate mixture of corundum (oxide of alumina) and magentite (oxide of iron). It is found in Eastern Europe, Asia Minor, and North America. Corundum which gives the emery its hardness is found in two forms: sapphire, which is transparent, and commercial corundum, which is translucent but not transparent.

Emery contains a considerable percentage of impurities which have a tendency to burn instead of cut, and it is on that account the emery wheel is so inferior to the corundum wheel.

Artificial Abrasives

Many artificial abrasives are now used in place of emery, and are known under such names as aloxite, alundum, boro-carbon, carborundum, corundite, crystolon, electrite, etc.; these are produced either by fusing bauxite or some other material with a high alumina content; or by fusing sand, coke, sawdust, and salt in an electric furnace at a temperature of about 4,000° Fah.

Production of Grinding Wheels

Grinding wheels are produced by at least four distinct methods :—

(1) *Vitrified Wheels* are manufactured by mixing the particles of grits with a bonding clay of suitable consistency; after mixing the material is run into moulds and allowed to partly dry; the unfinished wheels are then shaped to size, and again dried. They are finally placed in a kiln and are subjected to a temperature at which the clay vitrifies; a process requiring from 5 to 20 days according to size.

(2) *Silicate Wheels* are produced by mixing the grits with a bond, of which silicate of soda is the principal ingredient; the temperature of the kiln for this process is lower than required with the vitrified process.

(3) *Elastic Wheels* have their grits moulded with shellac as the principal ingredient of the bond; they are baked at a temperature sufficient to set the shellac. Elastic wheels are sometimes produced with vulcanized rubber as the bond for the grits.

Grade and Grain

Grade.—The term grade is used when referring to the hardness or bond of the wheel, or the resistance of the grits to disintegrate when under cutting pressure. When the grit particles can be easily broken away from the bond, the wheel is termed soft, and when the wheel retains its particles longer it is termed hard.

The grades between very soft and extremely hard are obtained by varying the amount of bond, the harder the wheel the greater the amount of bond and the smaller the amount of grits.

An ideal wheel is one in which the grit particles break away from the wheel as soon as they become dull.

The various degrees of hardness are designated by means of the letters of the alphabet, A being extremely soft and Z extremely hard, M being medium. The wheels in general use vary from G to R, but J to M will be found to cover the greater part of the work met with in the engineering workshop.

Grain

The size of the abrasive grit particles used in the manufacture of the wheel indicates the degree of its fineness or coarseness, and is termed the *Grain.*

The abrasive material, after being crushed, is sifted and graded according to size. The numbers used for vitrified wheels are determined by the size of the mesh of the sieve. For example, grit number 30 indicates grits which have passed through a sieve with 30 meshes to the linear inch.

The degree of coarseness varies from about 8 to 200, but grit numbers 16 to 60 will cover most general engineering work.

The following table shows the method of indicating the hardness of the different types of wheels :—

Table Showing Degrees of Hardness of Grinding Wheels.

Degrees of Hardness.	Vitrified Process.	Silicate Process.	Elastic Process.
Soft . . .	E		
	F		
	G	G or ½	½ E
	H	H ,, ¾	¾ E
Medium Soft .	I	I ,, 1	1 E
	J	J ,, 1½	1½ E
	K	K ,, 2	2 E
	L	L ,, 2½	2½ E
Medium . .	M	M ,, 3	3 E
	N	N ,, 3½	3½ E
	O	O ,, 4	4 E
	P	P ,, 4½	4½ E
Medium Hard .	Q	Q ,, 5	5 E
	R	R ,, 6	6 E
	S	S ,, 7	7 E
	T		
Hard . .	U		

With the silicate wheel the degree of hardness is indicated by some manufacturers by letters and some by figures. When letters are used they correspond to the letters used in referring to the vitrified wheels.

Use of the Grinding Wheel

Before the grinding of a piece of metal is actually commenced, the following factors have to be considered: (1) The grade and grain of the grinding wheel. (2) Speed of the grinding wheel. (3) Speed of the work. (4) Feed of the work. (5) Depth of cut. (6) Water supply to the work.

Selection of Wheel

(1) Of the above factors the most difficult to determine is probably the first. Most manufacturers will furnish users of wheels with a list showing the most suitable grain and grade for various classes of grinding. This, together with some practical experience, will soon enable the user to select the correct class of wheel for most purposes. A list of grinding wheels showing the grade and grain for different materials is given on p. 152.

If on using a wheel it is found to glaze quickly a softer wheel should be tried. Should the work become overheated, and the wheel does not glaze, the overheating can often be reduced by increasing the work speed; should no improvement result a softer wheel should be tried.

When the wheel wears excessively, reduce the speed of the work; if the wheel still wears, try a harder grade wheel.

Increase of diameter of the work increases the arc of contact, and a wheel working satisfactorily and efficiently on a piece of work of small diameter may not be efficient on a similar material of larger diameter; in this case a grade softer wheel should be tried.

Speed of Grinding Wheel

(2) The peripheral speed of the grinding wheel is usually between 5,500 to 6,000 feet per minute. In all cases the speed given by the wheel manufacturers should be strictly adhered to.

Speed of Work

(3) Work speeds depend upon many factors and range between 25 and 60 feet per minute for external cylindrical work, and between 100 and 120 feet per minute for internal work. The low speed generally for work of large diameter and the higher speed for work of smaller diameter. Too low a speed has a tendency to cause local overheating, and too high a speed will often cause vibration. When the

wheel glazes quickly an increase of work speed can be tried, while if it wears rapidly a decrease in work speed may improve matters.

Feed of Work

(4) The width of the wheel to a great extent determines the amount of table travel. For roughing a transverse movement equal to two-thirds of the wheel width can be given per revolution of the work. For finishing the movement should be reduced to half the wheel width or less if necessary.

Depth of Cut

(5) When rough grinding work on which the turning marks are distinctly showing, a maximum cut of ·006 can be taken at each end of the table traverse. When the tool marks are ground out, the cut should be reduced to ·0015 to ·002, and when taking the last few cuts for finishing, the depth of cut should be reduced to ·00025 to ·0005.

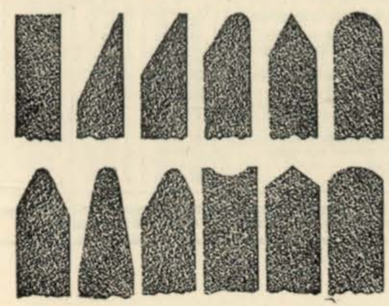
Water Supply

(6) The full available water supply should be used in all grinding operations. The water stream should be directed on to the position where the wheel makes contact with the work.

A very suitable grinding liquid is a solution of 2½ gallons of water, 3 lb. of soda, and ½ pint of soluble cutting oil, and is much better than plain water.

Shape of Wheel Faces

The following diagram shows some of the wheel faces in general use. The round and bevel faced wheels are chiefly used for sharpening saws.



Grade and Grain of Grinding Wheels for Different Materials*

(The Norton Co.)

Class of Work	Alundum		Crystolon	
	Grain	Grade	Grain	Grade
Aluminum castings	36 to 46	3 to 4 Elas.	20 to 24	P to R
Brass or bronze castings (large)	....	....	20 to 24	Q to R
Brass or bronze castings (small)	....	....	24 to 36	P to R
Car wheels, cast iron	....	....	16 to 24	P to R
Car wheels, chilled	20	Q	16 to 24	O to Q
Cast iron, cylindrical	24 comb.	J to K	30 to 46	J to L
Cast iron, surfacing	20 to 46	H to K	16 to 30	J to L
Cast-iron (small) castings	24 to 30	P to R	20 to 30	Q to S
Cast-iron (large) castings	16 to 20	Q to R	16 to 24	Q to S
Chilled iron castings	20 to 30	P to U	20 to 30	Q
Dies, chilled iron	....	....	20 to 30	O to Q
Dies, steel	36 to 60	J to L	....	....
Drop-forgings	20 to 30	P to R	....	....
Internal cylinder grinding	....	....	30 to 60	I to L
Internal grinding, hardened steel	46 to 60	J to M	....	....
Machine shop use, general	20 to 36	O to Q	....	....
Malleable iron castings (large)	14 to 20	P to U	16 to 20	R to S
Malleable iron castings (small)	20 to 30	P to R	20 to 30	Q to S
Milling cutters, machine grinding	46 to 60	H to M	....	....
Milling cutters, hand grinding	46 to 60	J to M	....	....
Nickel castings	20 to 24	P to Q	20 to 24	R
Pulleys, surfacing cast iron	....	....	30 to 36	K to L
Reamers, taps, etc., hand grinding	46 to 60	K to O	....	....
Reamers, taps, special machines	46 to 60	J to M	....	....
Rolls (cast iron), wet	24 to 36	J to M	24 to 36	J to M
Rolls (chilled iron), finishing	70	1½ to 2 Elas.	70 to 80	1½ to 2 Elas.
Rolls (chilled iron), roughing	....	....	30 to 46	2 to 3 Elas.
Rubber	30 to 50	J to K	30 to 50	K to M
Saws, gumming and sharpening	36 to 50	M to N	....	....
Saws, cold cutting-off	60	O to Q	....	....
Steel (soft), cylindrical grinding	24 comb.	L to N	....	....
	46 to 60	L to N	....	....
Steel (soft), surface grinding	24 to 36	H to K	....	....
Steel (hardened), cylindrical grinding	24 comb.	K	....	....
	46 to 60	J to L	....	....
Steel (hardened), surface grinding	36 to 46	H to K	....	....
Steel, large castings	12 to 20	Q to U	....	....
Steel, small castings	20 to 30	P to R	....	....
Steel (manganese), safe work	16 to 46	L to P	....	....
Structural steel	16 to 24	P to R	....	....
Twist drills, hand grinding	46 to 60	" M	....	....
Twist drills, special machines	36 to 60	K to M	....	....
Wrought iron	12 to 30	P to U	....	....
Woodworking tools	46 to 60	K to M	....	....

* The information contained in this table is general and only intended to give an approximate idea of the grade used under ordinary conditions.

Wheel Turning

An unglazed wheel should only require turning when a fine finish is required, and one turning of the wheel should keep it in good cutting condition for at least half an hour.

For turning wheels a diamond should be used, and this should be held in a special holder and fixed in a rigid position.

In turning the wheel a number of very light cuts (·0005) should be taken, using a fine traverse, and the maximum amount of water.

Chattering

An improperly fixed machine or lack of rigidity is a frequent cause of chattering. When the wheel is running out of truth or is badly balanced, or if the work is rotating too fast, there is a possibility that chatter marks will result.

Chatter marks on a long slender job can be overcome by the use of suitable steadies.

Travel of Work

When grinding internal or external cylindrical work, the traverse of the table should not allow the work to be carried completely away from the stone; not more than one-third the width of the stone should project beyond the ends of the work at each end of the stroke.

Grinding Allowance

The amount of metal to be left on the work for grinding depends to a large extent upon the size and power of the machine being used. Generally anything above $\frac{1}{32}$ inch is more economically removed in the lathe or other machine by turning.

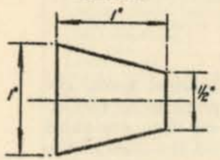
In all cases sufficient metal must be left to clean up all over, but time should not be wasted in turning metal to too fine a limit. On hardened steel cylindrical work about 0·02 will be found sufficient, while on unhardened work 0·01 to 0·015 will be satisfactory. For internal grinding the grinding allowances vary from about 0·008 to 0·015.

CHAPTER XVI

TAPERS AND TAPER TURNING

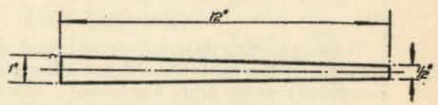
When the terms "taper per inch" or "taper per foot" are used, it means that in one inch or one foot there is a difference between the smaller diameter and the larger diameter of a given amount. In Fig. 129 the taper is ½ in. per inch, and in Fig. 130 the taper is ½ in. per foot.

FIG. 129.



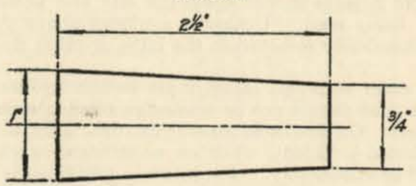
TAPER ½" PER INCH.

FIG. 130.



TAPER ½" PER FOOT.

FIG. 131.



TAPER ¼" IN 2½ INCHES.

In some cases the length of the taper is given in inches and fractions of an inch, as in Fig. 131; here the taper is ¼ in. in 2½ inches, which is equal to ¼ ÷ 2½ or $\frac{1}{10}$ in. per inch, or $\frac{1}{10} \times \frac{12}{1}$ equal 1⅕ in. per foot.

Problem 1

Given the diameter of both ends of a piece of work, and also the length. Find the taper per inch and per foot.

Example.—Diameters ⅞ in. and ⅝ in., length 3¼ inches, as in Fig. 132.

Then $\frac{\text{large diameter} - \text{small diameter}}{\text{length of work in inches}}$ = taper per inch.

Difference in diameter = $\frac{7}{8} - \frac{5}{8} = \frac{1}{4}$.

Taper in 3¼ inches = ¼.

" 1 inch $\frac{1}{4} \div 3\frac{1}{4} = \frac{1}{13}$ in.

" 1 foot $= \frac{1}{13} \times \frac{12}{1} = \frac{12}{13}$ = ·923 inch per foot.

In this problem the length of the taper will have no effect on the taper per inch or per foot. In Fig. 133 the length can be taken from B to C, or A to D, without altering the taper per inch or the taper per foot.

FIG. 132.

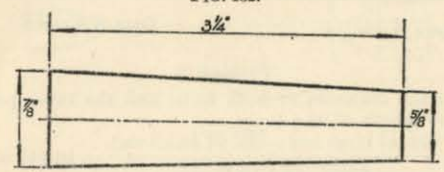
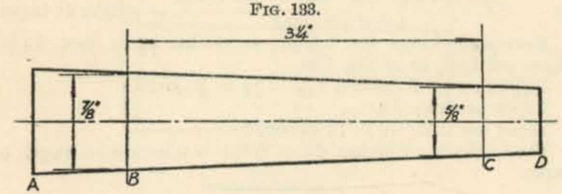


FIG. 133.



Problem 2

Given the diameter one end, the length, and the taper per foot. Find the diameter of the other end.

Example.—1⅛ inch large diameter, 4½ inches long, ½ inch per foot taper, as in Fig. 134.

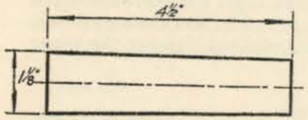
Then dia. large end $- \frac{\text{taper per foot}}{12} \times$ length of work) = dia. small end.

Taper per foot $\frac{1}{3}$ in., taper per inch $\frac{1}{3} \div 12 = \frac{1}{36}$ inch
$\frac{1}{36} \times 4\frac{1}{2} = \frac{1}{8}$ inch.
Dia. large end $1\frac{1}{8}$, then $1\frac{1}{8} - \frac{1}{8} =$ 1 inch dia. of small end.
When the diameter of the small end is given, as in Fig. 135.

Then dia. small end $+ \left(\frac{\text{taper per foot}}{12} \times \text{length of work}\right) =$ dia. large end.

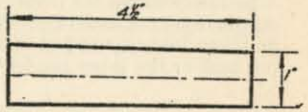
Taper per foot $\frac{1}{3}$ in., taper per inch $= \frac{1}{3} \div 12 = \frac{1}{36}$.
$\frac{1}{36} \times 4\frac{1}{2} = \frac{1}{8}$ in.
Dia. small end $+ \frac{1}{8} = 1\frac{1}{8}$ inch = dia. of large end.

Fig. 134.



TAPER 1/3" PER FOOT

Fig. 135.



TAPER 1/3" PER FOOT

Problem 3

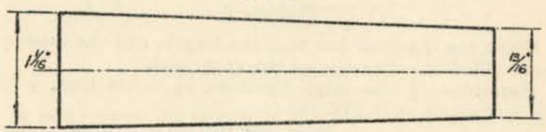
Given the diameter of both ends, and the taper per foot. Find the length of the taper.

Then $\frac{\text{dia. of large end} - \text{dia. of small end}}{\text{taper per foot} \div 12} =$ length of taper,

or $\frac{\text{dia. of large end} - \text{dia. of small end}}{\text{taper per inch}} =$ length of taper.

Example.—Large dia. $1\frac{1}{16}$ in., small dia. $\frac{13}{16}$ in., and ·75 in. taper per foot, as in Fig. 136.
Difference in diameters $1\frac{1}{16} - \frac{13}{16} = \frac{1}{4} = \cdot 25$.
Taper per foot ·75.
Taper per inch $\cdot 75 \div 12 = \cdot 0625$.
Then length in inches $\cdot 25 \div \cdot 0625 = 4$ inches = length of taper.

Fig. 136.



TAPER ·750" INS PER FOOT

Set-over of Tail-stock

A common method of turning tapers on lathes not fitted with special taper-turning attachments is to set the tail-stock centre out of line with the head-stock centre. If the tail-stock centre is set over a distance equal to A in Fig. 137, and the work is turned with the tool moving parallel to the bed, then the difference in the diameters of the taper will be equal to 2A.

To find the set-over of the tail-stock centre, use the following formula :—

$$\frac{\text{Length of work in inches} \times \text{taper per inch}}{2} = \text{set-over of tail-stock.}$$

Fig. 137.

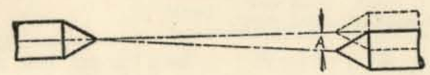
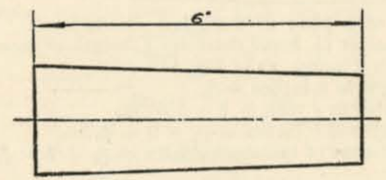


Fig. 138.



TAPER 3/8" PER FOOT.

Example.—Length of work 6 inches, taper per foot $\frac{3}{8}$ in., as in Fig. 138. Find amount of set-over.
Then taper per inch $= \frac{3}{8} \div 12 = \frac{1}{32}$.
Taper in 6 inches $= \frac{1}{32} \times 6 = \frac{3}{16}$.
Set-over of tail-stock $= \frac{3}{16} \div 2 = \frac{3}{32}$ in.
When both diameters are known, and work is turned its full length.
Then (large dia. − small dia.) $\times \frac{1}{2} =$ set-over.

Example.—Large diameter $1\frac{3}{16}$, small diameter $\frac{15}{16}$, as in Fig. 139. Find amount of set-over.

Large dia. $1\frac{3}{16}$ small dia. $\frac{15}{16}$.
$1\frac{3}{16} - \frac{15}{16} = \frac{1}{4}$.
$\frac{1}{4} \times \frac{1}{2} = \frac{1}{8}$ = set-over.

FIG. 139.

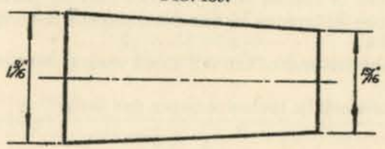
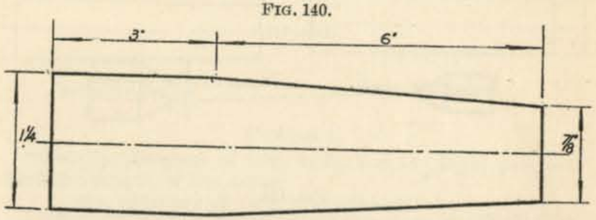


FIG. 140.



If part of a piece of work is to be tapered. Example: Large diameter $1\frac{1}{4}$, small diameter $\frac{7}{8}$, length of taper 6 inches, total length 9 inches, as in Fig. 140.

Then taper in 6 inches = $\frac{3}{8}$.
Taper in 1 inch = $\frac{3}{8} \div 6 = \frac{1}{16}$.
Taper in 9 inches = $\frac{1}{16} \times 9 = \frac{9}{16}$.
Set-over of tail-stock centre = $\frac{9}{16} \div 2 = \frac{9}{32}$.

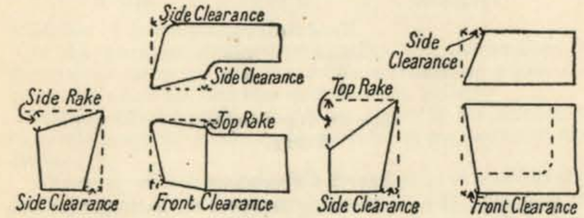
Tapers per foot with Corresponding Angles.

Taper per ft.	Included Angle.	Angle with Centre Line.	Taper per ft.	Included Angle.	Angle with Centre Line.
Ins.			Ins.		
$\frac{1}{8}$	0°—36′	0°—18′	1	4°—46′	2°—23′
$\frac{1}{4}$	1°—12′	0°—36′	$1\frac{1}{2}$	7°—09′	3°—35′
$\frac{5}{16}$	1°—30′	0°—45′	$1\frac{3}{4}$	8°—20′	4°—10′
$\frac{3}{8}$	1°—47′	0°—54′	2	9°—31′	4°—46′
$\frac{7}{16}$	2°—05′	1°—02′	$2\frac{1}{2}$	11°—54′	5°—57′
$\frac{1}{2}$	2°—23′	1°—12′	3	14°—15′	7°—08′
$\frac{3}{4}$	3°—35′	1°—47′	$3\frac{1}{2}$	16·—36′	8°—18′
$\frac{15}{16}$	4°—28′	2°—14′	4	18°—55′	9°—28′

APPENDIX

Useful Tables, Rules, and Notes

CAPSTAN AND TURRET LATHE TOOLS



	Metal	Top rake	Side rake	Front clearance	Side clearance
Turning and facing tools	Steel	12°	12°	12°	12°
,, ,,	Cast iron	8	8	12	12
,, ,,	Brass	0	0	12	12
Parting tools . . .	Steel	12	0	12	2
,,	Cast iron	1	0	12	2
,,	Brass	0	0	12	2
Knife tools . . .	Steel	0	35	8	7

Soldering

Fluxes used in Soldering

The flux prevents oxidization of the surface of the metal and facilitates the flowing of the solder.

NAME OF METAL.	FLUXES USED.
Brass . .	Resin, Sal Ammoniac, Chloride of Zinc.
Copper . .	,, ,, ,,
Zinc . .	Hydrochloric Acid dilute.
Iron . .	Chloride of Zinc, Sal Ammoniac.
Steel . .	Chloride of Ammonia.
Lead . .	Tallow, Resin.
Tin . . .	Resin.
Aluminium .	Stearin.

Soft Solders

	Composition.		Melting-point.
	Tin.	Lead.	Degrees.
Fine .	$1\frac{1}{2}$	1	334° F.
Tinmans .	1	1	370° F.
Plumbers .	1	2	440° F.

Hard Solders

	Copper.	Zinc.
Hard .	3	1
	1	1

Flux for Hard Solders

Borax.

Speed Calculation

A simple rule for calculating the speed of shafts and the size of pulleys to give a required speed neglecting slip and thickness of the belt.

Rule.—Multiply those two numbers together which belong to the same pulley, and divide by the third number, the result will be the answer required.

The number of revolutions made by connected pulleys are inversely as their diameters. In other words the diameter of the driving pulley multiplied by the number of revolutions it makes per minute, is equal to the driven pulley multiplied by the number of revolutions it makes per minute.

Therefore, to find the number of revolutions made by a driven pulley, if the diameter of the driver and driven pulley and also the number of revolutions per minute made by the driver are given.—

Multiply the diameter of the driver by the number of revolutions per minute, and divide by the diameter of the driven pulley.

Example.—Diameter of driving pulley, 12 in.; diameter of driven pulley, 6 in.; number of revolutions made by driver per minute, 120. Find speed of driven shaft. Then—

$$\frac{12 \times 120}{6} = 240.$$

Speed of driven shaft, 240 revs. per min.

If the diameter of the driver, and the number of revolutions made by the driver and driven pulleys are given. To find the diameter of the driven—

Multiply the diameter of the driver by the number of its revolutions per minute, and divide the result by the number of revolutions made by the driver.

8 *Example.*—Diameter of driving pulley, 18 in.; number of revolutions made by driver per minute, 160; number made by driven, 120. Find diameter of driven pulley. Then—

$$\frac{18 \times 160}{120} = 24.$$

Diameter of driven pulley, 24 in.

If the diameter of the driven pulley and the number of revolutions made by both the driven and driving pulley are given. To find the diameter of the driving pulley—

Multiply the diameter of the driven pulley by the number of its revolutions, and divide by the revolutions per minute of the driver.

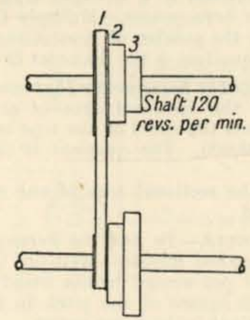
Example.—Number of revolutions per minute made by the driving pulley, 60; number made by driven, 120; diameter of driven pulley, 20 in. Find diameter of the driving pulley. Then—

$$\frac{20 \times 120}{60} = 40.$$

Diameter of driving pulley, 40 in.

Cone Pulleys

To find the speed given by cone pulleys as attached to a machine tool. The illustration shows a three-step cone pulley driven from a countershaft running at 120 revolutions per minute; the diameters are 8, 10, and 12 in.



To find the various speeds multiply the speed of the countershaft by the size of the pulley the belt is running on the countershaft and divide by the size of the corresponding pulley on the machine. The various speeds would be:

$$(1)\ \frac{120\times 12}{8}=180.$$

$$(2)\ \frac{120\times 10}{10}=120.$$

$$(3)\ \frac{120\times 8}{12}=80.$$

Transmission of Power

BELTING.—*To find the horse-power which can be transmitted by single leather belts.*—Multiply the breadth of belt in inches by 70, and by the speed of belt in feet per minute; and divide by 33,000. The quotient is the horse-power.

Double belts transmit 1½ times as much power as single belts.

To find the width of single belt for transmitting a given horse-power.—Multiply the horse-power by 33,000, and divide by 70 times the speed of the belt in feet per minute. The quotient is the width of belt in inches.

These rules are sufficiently approximate where there is no great degree of inequality in the diameters of the pulleys.

SHAFTING.—*To find the horse-power which can be transmitted by a wrought iron shaft.*—Multiply the cube of the diameter of the shaft in inches by the number of revolutions per minute, and divide by 80. The quotient is the horse-power.

To find the diameter of a wrought iron shaft required to transmit a given horse-power.—Multiply the horse-power by 80, and divide by the number of revolutions per minute. The cube root of the quotient is the diameter in inches.

ROPES.—*To find the horse-power that can be transmitted by ropes.*—Multiply the sectional area of one rope in square inches by 100 times the speed of the rope in feet per minute, and divide by 33,000. The quotient is the horse-power for one rope.

Or, multiply the sectional area of one rope by the speed, and divide by 330.

TOOTHED WHEELS.—*To find the horse-power that can be transmitted by toothed wheels.*—Multiply the velocity of the pitch-line in feet per second by the breadth of the teeth in inches, and by the square of the pitch in inches, and divide by 15. The quotient is the horse-power.

For bevel wheels, the mean diameter and mean pitch are to be taken.

ACME STANDARD SCREW THREAD

Formula:

$$P = \text{pitch} = \frac{1}{\text{No. thds. per inch.}}$$

$$D = \text{depth} = \tfrac{1}{2}\text{ p.} + \cdot 010.$$

$$F = \text{flat on top of thread} = \text{p.} \times \cdot 3707.$$

$$F^1 = \text{flat on bottom of thread} = \text{p.} \times \cdot 3707 - \cdot 0052$$

No. Thds. per Linear Inch.	Depth of Thread.	Width at Top of Thread.	Width at Bottom of Thread.	Space at Top of Thread.	Thickness at Root of Thread.
1	·5100	·3707	·3655	·6293	·6345
1⅓	·3850	·2780	·2728	·4720	·4772
2	·2600	·1853	·1801	·3147	·3199
3	·1767	·1235	·1183	·2098	·2150
4	·1350	·0927	·0875	·1573	·1625
5	·1100	·0741	·0689	·1259	·1311
6	·0933	·0618	·0566	·1049	·1101
7	·0814	·0529	·0478	·0899	·0951
8	·0725	·0463	·0411	·0787	·0839
9	·0655	·0413	·0361	·0699	·0751
10	·0600	·0371	·0319	·0629	·0681

British Standard Whitworth (B.S.W.)

Size.	Pitch.	Core Diameter.	Tapping Drill.
Ins.	t.p.i.	Ins.	
$\frac{1}{16}$	60	·0412	57
$\frac{3}{32}$	48	·0670	50
$\frac{1}{8}$	40	·0930	41
$\frac{5}{32}$	32	·1162	31
$\frac{3}{16}$	24	·1341	28
$\frac{7}{32}$	24	·1653	18
$\frac{1}{4}$	20	·1860	11
$\frac{5}{16}$	18	·2414	D
$\frac{3}{8}$	16	·2950	N
$\frac{7}{16}$	14	·3460	S
$\frac{1}{2}$	12	·3933	X
$\frac{9}{16}$	12	·4558	$\frac{15}{32}$
$\frac{5}{8}$	11	·5086	$\frac{33}{64}$
$\frac{11}{16}$	11	·5711	$\frac{37}{64}$
$\frac{3}{4}$	10	·6219	$\frac{5}{8}$
$\frac{13}{16}$	10	·6844	$\frac{11}{16}$
$\frac{7}{8}$	9	·7327	$\frac{47}{64}$
$\frac{15}{16}$	9	·7952	$\frac{51}{64}$
1	8	·8399	$\frac{27}{32}$
$1\frac{1}{16}$	8	·9024	$\frac{29}{32}$
$1\frac{1}{8}$	7	·9420	$\frac{61}{64}$
$1\frac{3}{16}$	7	1·0045	$1\frac{1}{64}$
$1\frac{1}{4}$	7	1·0670	$1\frac{5}{64}$
$1\frac{5}{16}$	7	1·1295	$1\frac{9}{64}$
$1\frac{3}{8}$	6	1·1616	$1\frac{11}{64}$
$1\frac{7}{16}$	6	1·2241	$1\frac{15}{64}$
$1\frac{1}{2}$	6	1·2866	$1\frac{19}{64}$
$1\frac{5}{8}$	5	1·3689	$1\frac{3}{8}$
$1\frac{3}{4}$	5	1·4939	$1\frac{1}{2}$
$1\frac{7}{8}$	4·5	1·5904	$1\frac{19}{32}$
2	4·5	1·7154	$1\frac{23}{32}$
$2\frac{1}{8}$	4·5	1·8404	$1\frac{27}{32}$
$2\frac{1}{4}$	4	1·9298	$1\frac{15}{16}$
$2\frac{3}{8}$	4	2·0548	$2\frac{1}{16}$
$2\frac{1}{2}$	4	2·1798	$2\frac{3}{16}$
$2\frac{5}{8}$	4	2·3048	$2\frac{15}{64}$
$2\frac{3}{4}$	3·5	2·3841	$2\frac{25}{64}$
$2\frac{7}{8}$	3·5	2·5091	$2\frac{33}{64}$
3	3·5	2·6341	$2\frac{41}{64}$

Système International (S.I.)

Size.	Pitch.	Core Diameter.	Tapping Drill.
mm.	mm.	mm.	
2·5	·45	1·87	49
3	·6	2·16	44
3·5	·6	2·66	36
4	·75	2·94	31
4·5	·75	3·44	28
5	·9	3·73	25
5·5	·9	4·23	18
6	1	4·59	$\frac{3}{16}$
7	1	5·59	I
8	1·25	6·24	E
9	1·25	7·24	L
10	1·5	7·89	O
11	1·5	8·89	T
12	1·75	9·54	W
14	2	11·19	Y
16	2	13·19	$\frac{17}{32}$
18	2·5	14·48	$\frac{37}{64}$
20	2·5	16·48	$\frac{21}{32}$
22	2·5	18·48	$\frac{47}{64}$
24	3	19·78	$\frac{51}{64}$
27	3	22·78	$\frac{29}{32}$
30	3·5	25·07	1
33	3·5	28·07	$1\frac{1}{8}$
36	4	30·37	$1\frac{7}{32}$
39	4	33·37	$1\frac{21}{64}$
42	4·5	35·75	$1\frac{27}{64}$
45	4·5	38·75	$1\frac{35}{64}$
48	5	41·05	$1\frac{41}{64}$
52	5	45·05	$1\frac{51}{64}$
56	5·5	48·36	$1\frac{59}{64}$
60	5·5	52·36	$2\frac{5}{64}$
64	6	55·66	$2\frac{13}{64}$

Cycle Engineers' Institute (C.E.I.)

Size.	Diameter.	Pitch.	Core Diameter.	Tapping Drill.
	Ins.	t.p.i.	Ins.	
17 I.W.G.	·056	62	·0388	No. 61
16 ,,	·064	62	·0468	,, 56
15 ,,	·072	62	·0548	,, 54
14 ,,	·08	62	·0628	1/16 in.
13 ,,	·092	56	·0730	No. 49
12 ,,	·104	44	·0798	2 mm.
1/8 in.	·125	40	·0984	2½ ,,
·154 ,,	·154	40	·1274	No. 30
·175 ,,	·175	32	·1417	,, 27
3/16 ,,	·1875	32	·1542	,, 23
1/4 ,,	·25	26	·2090	,, 4
·266 ,,	·266	26	·2250	,, 1
·281 ,,	·281	26	·2400	C
5/16 ,,	·3125	26	·2715	I
3/8 ,,	·375	26	·3340	8½ mm.
9/16 ,,	·5625	20	·5092	13 ,,
1 ,,	1	26	·9590	24½ ,,
*1·29 ,,	1·29	24	1·2456	1¼ in.
1·37 ,,	1·37	24	1·3256	1 21/64 ,,
*1 7/16 ,,	1·4375	24	1·3931	35½ mm.
1½ ,,	1·5	24	1·4556	37 ,,

* For right-hand threads only.

British Standard Fine (B.S.F.)

Size.	Pitch.	Core Diameter.	Tapping Drill.
Ins.	t.p.i.	Ins.	
7/32	28	·1731	16
1/4	26	·2007	6
9/32	26	·2320	B
5/16	22	·2543	F
3/8	20	·3110	O
7/16	18	·3664	U
1/2	16	·4200	27/64
9/16	16	·4825	31/64
5/8	14	·5335	35/64
11/16	14	·5960	39/64
3/4	12	·6433	21/32
13/16	12	·7058	23/32
7/8	11	·7586	49/64
1	10	·8719	7/8
1⅛	9	·9827	63/64
1¼	9	1·1077	1 7/64
1⅜	8	1·2149	1 7/32
1½	8	1·3399	1 11/32
1⅝	8	1·4649	1 15/32
1¾	7	1·5670	1 37/64
2	7	1·8170	1 53/64
2¼	6	2·0366	2 3/64
2½	6	2·2866	2 19/64
2¾	6	2·5366	2 35/64
3	5	2·7439	2¾

British Association (B.A.)

Size.	Pitch.	Core Diameter.	Tapping Drill.
No.	mm.	mm.	
0	1·00	4·80	11
1	·90	4·22	18
2	·81	3·73	25
3	·73	3·22	30
4	·66	2·81	33
5	·59	2·49	39
6	·53	2·16	44
7	·48	1·92	47
8	·43	1·68	51
9	·39	1·43	53
10	·35	1·28	55
11	·31	1·13	56
12	·28	·96	61
13	·25	·90	64
14	·23	·72	69
15	·21	·65	71
16	·19	·56	74
17	·17	·50	76
18	·15	·44	77
19	·14	·37	$\frac{1}{64}$
20	·12	·34	80

British Standard Pipe (B.S.P.)

Pipe Size.	Pitch.	Core Diameter.	Tapping Drill.
Ins.	t.p.i.	Ins.	
$\frac{1}{8}$	28	·337	$\frac{11}{32}$
$\frac{1}{4}$	19	·451	$\frac{29}{64}$
$\frac{3}{8}$	19	·589	$\frac{19}{32}$
$\frac{1}{2}$	14	·734	$\frac{3}{4}$
$\frac{5}{8}$	14	·811	$\frac{53}{64}$
$\frac{3}{4}$	14	·950	$\frac{31}{32}$
$\frac{7}{8}$	14	1·098	$1\frac{7}{64}$
1	11	1·193	$1\frac{13}{64}$
$1\frac{1}{4}$	11	1·534	$1\frac{35}{64}$
$1\frac{1}{2}$	11	1·766	$1\frac{25}{32}$
$1\frac{3}{4}$	11	2·000	$2\frac{1}{64}$
2	11	2·231	$2\frac{1}{4}$
$2\frac{1}{4}$	11	2·471	$2\frac{31}{64}$
$2\frac{1}{2}$	11	2·844	$2\frac{55}{64}$
$2\frac{3}{4}$	11	3·094	$3\frac{7}{64}$
3	11	3·344	$3\frac{23}{64}$

Temperatures of Lead Bath Alloys

Parts of Lead.	Parts of Tin.	Melting Temp. F°.
200	8	560
100	8	550
75	8	540
48	8	520
39	8	510
28	8	490
24	8	480
21	8	470
19	8	460
17	8	450

Horse-power of Shafting

Diameter of the Shaft.	Speed or Revolutions per Minute.											
	50	60	70	80	90	100	125	150	175	200	250	300
	Horse Power transmitted by the Shaft.											
Inches.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.
1	·40	·48	·56	·64	·72	·80	1·00	1·20	1·40	1·60	2·00	2·40
1¼	·78	·94	1·09	1·25	1·40	1·56	1·95	2·34	2·73	3·12	3·90	4·69
1½	1·35	1·62	1·89	2·16	2·43	2·70	2·87	4·05	4·72	5·40	6·75	8·10
1⅝	1·72	2·06	2·41	2·75	3·10	3·44	4·30	5·16	6·02	6·88	8·60	10·32
1¾	2·14	2·57	3·00	3·43	3·86	4·29	5·36	6·43	7·50	8·58	10·72	12·86
1⅞	2·64	3·17	3·70	4·23	4·76	5·27	6·59	7·91	9·23	10·55	13·19	15·82
2	3·20	3·84	4·48	5·12	5·76	6·40	8·00	9·60	11·20	12·80	16·00	19·20
2⅛	3·83	4·60	5·37	6·14	6·91	7·67	9·58	11·50	13·42	15·33	19·16	23·00
2¼	4·55	5·46	6·37	7·28	8·19	9·11	11·39	13·66	15·94	18·22	22·77	27·33
2⅜	5·36	6·43	7·50	8·57	9·64	10·72	13·40	16·08	18·76	21·44	26·80	32·16
2½	6·25	7·50	8·75	10·00	11·25	12·50	15·62	18·75	21·87	25·00	31·25	37·50
2¾	8·33	10·00	11·67	13·34	15·01	16·67	20·83	25·00	29·17	33·33	41·66	50·00
3	10·80	12·96	15·12	17·28	19·44	21·60	27·00	32·40	37·80	43·20	54·00	64·80
3¼	13·73	16·48	19·23	21·98	24·73	27·46	34·33	41·19	48·05	54·93	68·66	82·39
3½	17·15	20·58	24·01	27·44	30·87	34·30	42·88	51·45	60·03	68·60	85·75	102·90
3¾	21·09	25·31	29·53	33·75	37·97	42·17	52·71	63·25	73·79	84·33	105·42	126·50
4	25·60	30·72	35·84	40·96	46·08	51·20	64·00	76·80	89·60	102·40	128·00	153·60
4¼	30·71	36·85	42·99	49·13	55·27	61·41	76·76	92·12	107·47	122·82	153·53	184·23
4½	36·45	43·74	51·03	58·32	65·61	72·90	91·13	109·35	127·58	145·80	182·25	218·70
4¾	42·87	51·44	60·01	68·58	77·15	85·74	107·17	128·61	150·04	171·47	214·34	257·21
5	50·00	60·00	70·00	80·00	90·00	100·00	125·00	150·00	175·00	200·00	250·00	300·00
5¼	57·88	69·45	81·02	92·59	104·16	115·74	144·68	173·60	202·54	231·47	289·35	347·21
5½	66·55	79·86	93·17	106·48	119·79	133·12	166·39	199·68	233·96	266·24	332·77	399·36
5¾	76·04	91·25	106·46	121·67	136·88	152·08	190·10	228·12	266·14	304·16	380·20	456·24
6	86·40	103·68	120·96	138·24	155·52	172·80	216·00	259·20	302·40	345·60	432·00	518·40

Weights of Flat Bar Iron

Thickness.	Width in Inches.									
	2⅞	3	3¼	3½	3¾	4	4¼	4½	4¾	5
Inch.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
3/16	1·80	1·88	2·03	...	...	...	...	...	...	...
¼	2·40	2·50	2·71	2·92	3·13	3·33	3·54	3·75	3·96	4·17
5/16	3·00	3·13	3·39	3·65	3·91	4·17	4·43	4·69	4·95	5·21
⅜	3·59	3·75	4·06	4·38	4·69	5·00	5·31	5·63	5·94	6·25
7/16	4·19	4·38	4·74	5·10	5·47	5·83	6·20	6·56	6·93	7·29
½	4·79	5·00	5·42	5·83	6·25	6·67	7·08	7·50	7·92	8·33
9/16	5·39	5·63	6·09	6·56	7·03	7·50	7·97	8·44	8·91	9·38
⅝	6·00	6·25	6·77	7·29	7·81	8·33	8·85	9·38	9·90	10·4
11/16	6·59	6·88	7·45	8·02	8·59	9·17	9·74	10·3	10·9	11·5
¾	7·19	7·50	8·13	8·75	9·38	10·0	10·6	11·3	11·9	12·5
13/16	7·79	8·13	8·80	9·48	10·2	10·8	11·5	12·2	12·9	13·5
⅞	8·39	8·75	9·48	10·2	10·9	11·7	12·4	13·1	13·9	14·6
15/16	8·98	9·38	10·2	10·9	11·7	12·5	13·3	14·1	14·8	15·6
1	9·58	10·0	10·8	11·7	12·5	13·3	14·2	15·0	15·8	16·7

Thickness.	Width in Inches.								
	5½	6	6½	7	8	9	10	11	12
Inch.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
¼	4·58	5·00	5·42	5·83	6·67	7·50	8·33	9·17	10·0
5/16	5·73	6·25	6·77	7·29	8·33	9·38	10·4	11·5	12·5
⅜	6·88	7·50	8·13	8·75	10·0	11·3	12·5	13·8	15·0
7/16	8·02	8·75	9·47	10·2	11·7	13·1	14·6	16·0	17·5
½	9·17	10·0	10·8	11·7	13·3	15·0	16·7	18·3	20·0
9/16	10·3	11·3	12·2	13·1	15·0	16·9	18·8	20·6	22·5
⅝	11·5	12·5	13·5	14·6	16·7	18·8	20·8	22·9	25·0
11/16	12·6	13·8	14·9	16·0	18·3	20·6	22·9	25·2	27·5
¾	13·8	15·0	16·3	17·5	20·0	22·5	25·0	27·5	30·0
13/16	14·9	16·3	17·6	19·0	21·7	24·4	27·1	29·8	32·5
⅞	16·0	17·5	19·0	20·4	23·3	26·3	29·2	32·1	35·0
15/16	17·2	18·8	20·3	21·9	25·0	28·1	31·3	34·4	37·5
1	18·3	20·0	21·7	23·3	26·7	30·0	33·3	36·7	40·0

Driving Power of Leather Belts.

Diameter of Pulley.	Revolutions of the Pulley per Minute.											
	50	60	70	80	90	100	125	150	175	200	250	300
	Horse-Power Transmitted by each Inch Wide of Single Belt.											
Inches.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.
12	·20	·24	·28	·32	·35	·39	·49	·59	·69	·79	·98	1·18
14	·23	·28	·32	·37	·41	·46	·57	·69	·80	·92	1·14	1·38
16	·26	·32	·37	·42	·47	·53	·66	·79	·92	1·05	1·31	1·58
18	·30	·35	·41	·47	·53	·59	·74	·89	1·04	1·18	1·48	1·77
20	·33	·39	·46	·52	·59	·65	·82	·98	1·14	1·31	1·64	1·96
24	·39	·47	·55	·63	·71	·79	·98	1·18	1·38	1·58	1·97	2·36
28	·46	·55	·64	·73	·83	·92	1·15	1·38	1·61	1·84	2·29	2·75
32	·52	·63	·73	·84	·94	1·05	1·31	1·57	1·84	2·10	2·63	3·15
36	·59	·71	·83	·95	1·06	1·18	1·48	1·77	2·06	2·36	2·96	3·55
40	·65	·79	·92	1·04	1·18	1·31	1·64	1·96	2·29	2·62	3·27	3·94
44	·72	·87	1·01	1·15	1·30	1·45	1·80	2·16	2·53	2·89	3·60	4·34
48	·79	·94	1·10	1·26	1·42	1·57	1·96	2·36	2·75	3·15	3·93	4·72
54	·89	1·06	1·24	1·42	1·59	1·77	2·22	2·66	3·10	3·55	4·43	5·31
60	·98	1·18	1·38	1·57	1·77	1·96	2·46	2·95	3·44	3·93	4·91	5·90
66	1·08	1·30	1·52	1·73	1·95	2·17	2·71	3·25	3·79	4·33	5·41	6·50
72	1·18	1·42	1·65	1·89	2·13	2·36	2·95	3·54	4·13	4·72	5·90	7·10
78	1·28	1·53	1·79	2·04	2·30	2·56	3·20	3·84	4·48	5·11	6·40	7·68
84	1·38	1·65	1·93	2·21	2·48	2·75	3·44	4·13	4·81	5·51	6·89	8·28
90	1·48	1·77	2·06	2·36	2·66	2·96	3·68	4·43	5·18	5·90	7·38	8·85
96	1·57	1·89	2·21	2·53	2·84	3·15	3·95	4·73	5·51	6·31	7·89	9·45

Weights of Flat Bar Iron

Length, 1 foot

Thickness.	Width in Inches.								
	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
Inch.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1/8	·208	·260	·312	·365	·417	·469	·521	·573	·625
3/16	·312	·391	·469	·547	·625	·703	·781	·859	·937
1/4	·417	·521	·625	·729	·833	·938	1·04	1·15	1·25
5/16	·521	·651	·781	·911	1·04	1·17	1·30	1·43	1·56
3/8	·625	·781	·937	1·09	1·25	1·41	1·56	1·72	1·88
7/16	·729	·911	1·09	1·28	1·46	1·64	1·82	2·01	2·19
1/2	·833	1·04	1·25	1·46	1·67	1·88	2·08	2·29	2·50
9/16	·937	1·17	1·41	1·64	1·88	2·11	2·34	2·58	2·81
5/8	1·04	1·30	1·56	1·82	2·08	2·34	2·60	2·86	3·13
11/16	1·15	1·43	1·72	2·01	2·29	2·58	2·86	3·15	3·44
3/4	1·25	1·56	1·87	2·19	2·50	2·81	3·13	3·44	3·75
13/16	1·35	1·69	2·03	2·37	2·71	3·05	3·39	3·72	4·06
7/8	1·46	1·82	2·19	2·55	2·92	3·28	3·65	4·01	4·38
15/16	1·56	1·95	2·34	2·73	3·13	3·52	3·91	4·30	4·69
1	1·67	2·08	2·50	2·92	3·33	3·75	4·17	4·58	5·00

Thickness.	Width in Inches.									
	1 5/8	1 3/4	1 7/8.	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4
Inch.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1/8	·677	·729	·781	·833	...	...	...	...	...	...
3/16	1·02	1·09	1·17	1·25	1·33	1·41	1·48	1·56	1·64	1·72
1/4	1·35	1·46	1·56	1·67	1·77	1·88	1·98	2·08	2·19	2·29
5/16	1·69	1·82	1·95	2·08	2·21	2·34	2·47	2·60	2·73	2·86
3/8	2·03	2·19	2·34	2·50	2·66	2·81	2·97	3·13	3·28	3·44
7/16	2·37	2·55	2·73	2·92	3·10	3·28	3·46	3·65	3·83	4·01
1/2	2·71	2·92	3·13	3·33	3·54	3·75	3·96	4·17	4·38	4·58
9/16	3·05	3·28	3·52	3·75	3·98	4·22	4·45	4·69	4·92	5·16
5/8	3·39	3·65	3·91	4·17	4·43	4·69	4·95	5·21	5·47	5·73
11/16	3·72	4·01	4·30	4·58	4·87	5·16	5·44	5·73	6·02	6·30
3/4	4·06	4·38	4·69	5·00	5·31	5·63	5·94	6·25	6·56	6·88
13/16	4·40	4·74	5·08	5·42	5·76	6·09	6·43	6·77	7·11	7·45
7/8	4·74	5·10	5·47	5·83	6·20	6·56	6·93	7·29	7·66	8·02
15/16	5·08	5·47	5·86	6·25	6·64	7·03	7·42	7·81	8·20	8·59
1	5·42	5·83	6·25	6·67	7·08	7·50	7·92	8·33	8·75	9·17

Metals Weights for various Dimensions

Metal.	Specific Weight.	Weight of One Cubic Foot.	Weight of One Square Foot. 1 Inch Thick.	$\frac{1}{8}$th Inch Thick.	$\frac{1}{10}$th Inch Thick.	Weight of One Lineal Ft. 1 In. Sq.	Weight of One Cubic Inch.
	Wro'ght Iron=1.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
Aluminium, wrought	·348	167	13·92	1·74	1·39	1·160	·097
„ cast . .	·333	160	13·33	1·67	1·33	1·111	·092
Antimony . .	·879	418	34·83	4·35	3·48	2·902	·242
Bismuth . . .	1·285	617	51·42	6·42	5·14	4·283	·357
Brass, cast . .	1·052	505	42·08	5·26	4·21	3·507	·292
„ sheet . .	1·098	527	43·92	5·49	4·39	3·652	·304
„ yellow . .	1·079	518	43·17	5·40	4·32	3·597	·298
„ Muntz metal.	1·062	511	42·58	5·32	4·26	3·549	·296
„ wire . .	1·110	533	44·42	5·55	4·44	3·701	·308
Bronze, gun-metal .	1·106	531	44·25	5·54	4·43	3·688	·307
„ mill bearings .	1·133	544	45·33	5·66	4·53	3·780	·315
„ small bells .	1·004	482	40·17	5·04	4·02	3·347	·279
„ speculum metal	·969	465	38·75	4·84	3·88	3·299	·269
Copper, sheet . .	1·114	549	45·75	5·72	4·58	3·813	·318
„ hammered .	1·158	556	46·33	5·79	4·63	3·861	·322
„ wire . .	1·154	554	46·17	5·77	4·62	3·778	·315
Gold . . .	2·500	1200	100·00	12·50	10·00	8·333	·694
Iron, cast . . .	·937	450	37·50	4·69	3·75	3·125	·260
„ wrought . .	1·000	480	40·00	5·00	4·00	3·333	·278
Lead, sheet . .	1·483	712	59·33	7·41	5·93	4·944	·412
Manganese . .	1·040	499	41·58	5·20	4·16	3·465	·289
Mercury . . .	1·769	849	70·75	8·84	7·07	5·896	·491
Nickel, hammered .	1·127	541	45·08	5·64	4·51	3·757	·313
„ cast . .	1·075	516	43·00	5·37	4·30	3·583	·299
Platinum . .	2·796	1342	111·83	13·97	11·18	9·320	·777
Silver . . .	1·365	655	54·58	6·82	5·46	4·549	·379
Steel	1·020	490	40·83	5·12	4·10	3·403	·284
Tin	·962	462	38·50	4·81	3·85	3·208	·268
Zinc, sheet . .	·935	449	37·42	4·67	3·74	3·118	·260
„ cast . . .	·892	428	35·67	4·46	3·57	2·972	·248

Vulgar Fractions of a Lineal Inch in Decimal Fractions

Advancing by Thirty-seconds.

Thirty-seconds.	Fractions.	Decimals of an Inch.	Thirty-seconds.	Fractions.	Decimals of an Inch.
1	$\frac{1}{32}$	·03125	17	$\frac{17}{32}$	·53125
2	$\frac{1}{16}$	·0625	18	$\frac{9}{16}$	·5625
3	$\frac{3}{32}$	·09375	19	$\frac{19}{32}$	·59375
4	$\frac{1}{8}$	·125	20	$\frac{5}{8}$	·625
5	$\frac{5}{32}$	·15625	21	$\frac{21}{32}$	·65625
6	$\frac{3}{16}$	·1875	22	$\frac{11}{16}$	·6875
7	$\frac{7}{32}$	·21875	23	$\frac{23}{32}$	·71875
8	$\frac{1}{4}$	·25	24	$\frac{3}{4}$	·75
9	$\frac{9}{32}$	·28125	25	$\frac{25}{32}$	·78125
10	$\frac{5}{16}$	·3125	26	$\frac{13}{16}$	·8125
11	$\frac{11}{32}$	·34375	27	$\frac{27}{32}$	·84375
12	$\frac{3}{8}$	·375	28	$\frac{7}{8}$	·875
13	$\frac{13}{32}$	·40625	29	$\frac{29}{32}$	·90625
14	$\frac{7}{16}$	·4375	30	$\frac{15}{16}$	·9375
15	$\frac{15}{32}$	·46875	31	$\frac{31}{32}$	·96875
16	$\frac{1}{2}$	·5	32	1	1·0

Advancing by odd Sixty-fourths.

Sixty-fourths.		Decimals of an Inch.	Sixty-fourths.		Decimals of an Inch.
1		·015625	35		·546875
3		·046875	37		·578125
5		·078125	39		·609375
7		·109375	41		·640625
9		·140625	43		·671875
11		·171875	45		·703125
13		·203125	47		·734375
15		·234375	49		·765625
17		·265625	51		·796875
19		·296875	53		·828125
21		·328125	55		·859375
23		·359375	57		·890625
25		·390625	59		·921875
27		·421875	61		·953125
29		·453125	63		·984375
31		·484375	64		1·0
33		·515625			

Lineal Inches in Decimal Fractions of a Lineal Foot

Lineal Inches.	Lineal Foot.	Lineal Inches.	Lineal Foot.	Lineal Inches.	Lineal Foot.
1/64	·001302083̇	1⅞	·15625	6½	·5416̇
1/32	·00260416̇	2	·1666̇	6¾	·5625
1/16	·0052083̇	2⅛	·177083̇	7	·5833̇
⅛	·010416̇	2¼	·1875	7¼	·60416̇
3/16	·015625	2⅜	·197916̇	7½	·625
¼	·02083̇	2½	·2083̇	7¾	·64583̇
5/16	·0260416̇	2⅝	·21875	8	·6666̇
⅜	·03125	2¾	·22916̇	8¼	·6875
7/16	·0364583̇	2⅞	·239583̇	8½	·7083̇
½	·0416̇	3	·25	8¾	·72916̇
9/16	·046875	3¼	·27083̇	9	·75
⅝	·052083̇	3½	·2916̇	9¼	·77083̇
11/16	·0572916̇	3¾	·3125	9½	·7916̇
¾	·0625	4	·3333̇	9¾	·8125
13/16	·0677083̇	4¼	·35416̇	10	·8333̇
⅞	·072916̇	4½	·375	10¼	·85416̇
15/16	·078125	4¾	·39583̇	10½	·875
1	·0833̇	5	·4166̇	10¾	·89583̇
1⅛	·09375	5¼	·4375	11	·9166̇
1¼	·10416̇	5½	·4583̇	11¼	·9375
1⅜	·114583̇	5¾	·47916̇	11½	·9583̇
1½	·125	6	·5	11¾	·97916̇
1⅝	·135416̇	6¼	·52083̇	12	1·0000
1¾	·14583̇				

Tangents and Cotangents of Angles from 0° to 90°

(Radius = 1.)

Tangents of Angles.	Cotangents of Angles.	Values.	Tangents of Angles.	Cotangents of Angles.	Values.
°	°		°	°	
0	90	·00000	18·5	71·5	·33459
0·5	89·5	·00873	19	71	·34433
1	89	·01745	19·5	70·5	·35412
1·5	88·5	·02619	20	70	·36397
2	88	·03492	20·5	69·5	·37388
2·5	87·5	·04366	21	69	·38386
3	87	·05241	21·5	68·5	·39391
3·5	86·5	·06116	22	68	·40403
4	86	·06993	22·5	67·5	·41421
4·5	85·5	·07870	23	67	·42447
5	85	·08749	23·5	66·5	·43481
5·5	84·5	·09629	24	66	·44523
6	84	·10510	24·5	65·5	·45573
6·5	83·5	·11394	25	65	·46631
7	83	·12278	25·5	64·5	·47698
7·5	82·5	·13165	26	64	·48773
8	82	·14054	26·5	63·5	·49858
8·5	81·5	·14945	27	63	·50952
9	81	·15838	27·5	62·5	·52057
9·5	80·5	·16734	28	62	·53171
10	80	·17633	28·5	61·5	·54296
10·5	79·5	·18534	29	61	·55431
11	79	·19438	29·5	60·5	·56577
11·5	78·5	·20345	30	60	·57735
12	78	·21256	30·5	59·5	·58904
12·5	77·5	·22169	31	59	·60086
13	77	·23087	31·5	58·5	·61280
13·5	76·5	·24008	32	58	·62487
14	76	·24933	32·5	57·5	·63708
14·5	75·5	·25862	33	57	·64941
15	75	·26795	33·5	56·5	·66189
15·5	74·5	·27732	34	56	·67451
16	74	·28674	34·5	55·5	·68728
16·5	73·5	·29621	35	55	·70021
17	73	·30573	35·5	54·5	·71329
17·5	72·5	·31530	36	54	·72654
18	72	·32492	36·5	53·5	·73996

Tangents of Angles.	Cotangents of Angles.	Values.	Tangents of Angles.	Cotangents of Angles.	Values.
°	°		°	°	
37	53	·75355	57·5	32·5	1·56969
37·5	52·5	·76763	58	32	1·60033
38	52	·78129	58·5	31·5	1·63185
38·5	51·5	·79544	59	31	1·66428
39	51	·80978	59·5	30·5	1·69766
39·5	50·5	·82434	60	30	1·73205
40	50	·83910	60·5	29·5	1·76749
40·5	49·5	·85408	61	29	1·80405
41	49	·86929	61·5	28·5	1·84174
41·5	48·5	·88472	62	28	1·88073
42	48	·90040	62·5	27·5	1·92098
42·5	47·5	·91633	63	27	1·96261
43	47	·93251	63·5	26·5	2·00569
43·5	46·5	·94896	64	26	2·05030
44	46	·96569	64·5	25·5	2·09654
44·5	45·5	·98270	65	25	2·14451
45	45	1·00000	65·5	24·5	2·19430
45·5	44·5	1·01761	66	24	2·24604
46	44	1·03553	66·5	23·5	2·29984
46·5	43·5	1·05378	67	23	2·35585
47	43	1·07237	67·5	22·5	2·41421
47·5	42·5	1·09131	68	22	2·47509
48	42	1·11061	68·5	21·5	2·53865
48·5	41·5	1·13029	69	21	2·60509
49	41	1·15037	69·5	20·5	2·67462
49·5	40·5	1·17085	70	20	2·74748
50	40	1·19175	70·5	19·5	2·82391
50·5	39·5	1·21310	71	19	2·90421
51	39	1·23490	71·5	18·5	2·98868
51·5	38·5	1·25717	72	18	3·07768
52	38	1·27994	72·5	17·5	3·17159
52·5	37·5	1·30323	73	17	3·27085
53	37	1·32704	73·5	16·5	3·37594
53·5	36·5	1·35142	74	16	3·48741
54	36	1·37638	74·5	15·5	3·60588
54·5	35·5	1·40195	75	15	3·73205
55	35	1·42815	75·5	14·5	3·86671
55·5	34·5	1·45501	76	14	4·01078
56	34	1·48256	76·5	13·5	4·16530
56·5	33·5	1·51084	77	13	4·33148
57	33	1·53986	77·5	12·5	4·51071

Tangents and Cotangents of Angles

Tangents of Angles.	Cotangents of Angles.	Values.	Tangents of Angles.	Cotangents of Angles.	Values.
°	°		°	°	
78	12	4·70463	84·5	5·5	10·38540
78·5	11·5	4·91516	85	5	11·43005
79	11	5·14455	85·5	4·5	12·70620
79·5	10·5	5·39552	86	4	14·30067
80	10	5·67128	86·5	3·5	16·34985
80·5	9·5	5·97576	87	3	19·08114
81	9	6·31375	87·5	2·5	22·90377
81·5	8·5	6·69116	88	2	28·63625
82	8	7·11537	88·5	1·5	38·18846
82·5	7·5	7·59575	89	1	57·28996
83	7	8·14435	89·5	0·5	114·58865
83·5	6·5	8·77689	90	0	infinite.
84	6	9·51436			

Lengths of Circular Arcs from 1° to 76° (Radius = 1)

Deg.	Length.	Deg.	Length.	Deg.	Length.	Deg.	Length.
1	·0175	**20**	·3491	**39**	·6807	**58**	1·0123
2	·0349	**21**	·3665	**40**	·6981	**59**	1·0297
3	·0524	**22**	·3840	**41**	·7156	**60**	1·0472
4	·0698	**23**	·4014	**42**	·7330	**61**	1·0647
5	·0873	**24**	·4189	**43**	·7505	**62**	1·0821
6	·1047	**25**	·4363	**44**	·7679	**63**	1·0996
7	·1222	**26**	·4538	**45**	·7854	**64**	1·1170
8	·1396	**27**	·4712	**46**	·8029	**65**	1·1345
9	·1571	**28**	·4887	**47**	·8203	**66**	1·1519
10	·1745	**29**	·5061	**48**	·8378	**67**	1·1694
11	·1920	**30**	·5236	**49**	·8552	**68**	1·1868
12	·2094	**31**	·5411	**50**	·8727	**69**	1·2043
13	·2269	**32**	·5585	**51**	·8901	**70**	1·2217
14	·2443	**33**	·5760	**52**	·9076	**71**	1·2392
15	·2618	**34**	·5934	**53**	·9250	**72**	1·2566
16	·2793	**35**	·6109	**54**	·9425	**73**	1·2741
17	·2967	**36**	·6283	**55**	·9599	**74**	1·2915
18	·3142	**37**	·6458	**56**	·9774	**75**	1·3090
19	·3316	**38**	·6632	**57**	·9948	**76**	1·3265

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