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Edited by
G. Udny Yule

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TEXTILE MECHANICS

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BY

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"COTTON SPINNING," "COTTON SPINNING CALCULATIONS,"
"COTTON MACHINERY SKETCHES,"
"QUADRANT AND SHAPER OF THE S.A. MULE," ETC.
EXAMINER IN COTTON SPINNING TO THE CITY AND GUILDS
OF LONDON INSTITUTES: EXAMINER IN TEXTILE
MECHANICS, MATHEMATICS, DRAWING, AND
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PREFACE

THIS book is intended as a Preliminary Course of Mechanics for the students of Grade I. in the Textile Courses of the City and Guilds of London Institute. The usual Mechanics Course associated with these subjects is of a very general character, and the illustrations drawn form a wide variety of mechanical contrivances, but textile machinery is practically excluded.

It is desirable that in the course system of instruction all the cognate subjects should bear directly upon the main subject, so that students will realise that in studying these subjects they are acquiring an important part of the real subject. The advantages are twofold. In the first place, textile machinery embodies in its construction almost every class of mechanical contrivance and arrangement, so that they receive a thorough grounding in mechanical principles and their application; and secondly, the subject can be so taught that quite a large part of the textile teacher's work can be eliminated and relegated to the class in mechanics, thus enabling the main subject to be dealt with in a more thorough manner than is possible under present conditions.

It is essential that students should devote a considerable portion of their class time to practical work in the mechanics laboratory and even in the textile machinery room and no rule ought to be formulated or accepted until sufficient practical data has been obtained from which rules and formulæ can be deduced. Teachers are therefore strongly urged to teach in such a manner that no student need rely upon a teacher's statement or the authority of a text-book.

Sketching ought to be encouraged, and a diagram drawn to illustrate every problem wherever possible.

WM. SCOTT TAGGART.

BOLTON, 1915.

CONTENTS

TEXTILE MECHANICS

CHAPTER I

COMMUNICATION OF MOTION

Belt and Rope Driving.—In communicating motion from one shaft to another, pulleys are fixed on each shaft, and these pulleys are connected by a band of some flexible material, such as leather, ropes, woven or metal strips. The belt acts as the medium in transferring motion. In Fig. 1 two shafts are some

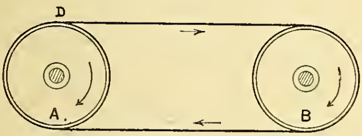


Fig. 1.

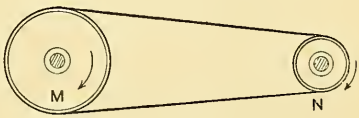


Fig. 2.

distance apart, and each shaft is provided with pulley fixed on them, as at A and B. The belt passes over both pulleys in the form of a continuous band and is made sufficiently tight to grip the surfaces of the pulleys. As pulley A revolves, say in the direction of the arrow, the portion of the belt that is gripping its surface will revolve also at the same speed, and in doing so will pull the part of the belt forward in the direction shown. The grip of the belt on pulley B will cause B to yield by turning, so that the belt is unwound from B at the same rate that it is drawn round by pulley A. The upper part of the belt on reaching the point D becomes free from the pulley, but the movement of B takes up the length unwound from A. The continuous revolution of A therefore gives a corresponding continuous revolution of B, and the belt throughout its length travels at the speed given to it by the surface of the driving pulley A. In Fig. 1 the two pulleys are the same diameters, so that their surface speeds are the same. In Fig. 2 the two pulleys M and N are of unequal diameters. The revolution of M will give to the belt a speed of movement equal to the surface speed of M, and as the whole belt will travel at this speed it will give to the pulley N the same surface speed as M. Surface speed is usually expressed in feet per minute.

Example.—A pulley is 12 in. dia. and runs at 325 revs. per min. What is its surface speed?

$$\text{Dia. of pulley} = 12 \text{ in.}$$

$$\text{Circumference } ,, = 12 \times \frac{22}{7} \text{ in.}$$

$$\text{Revs. } ,, = 325 \text{ revs. per min.}$$

$$\text{Surface speed } ,, = \frac{12 \times 22 \times 325}{12 \times 7} \text{ ft. per min.}$$

$$= 1021 \text{ ft. per min.}$$

A belt in contact with the pulley in above example would travel at the rate of 1021 ft. per min.

Example.—A 36-in. pulley runs at 126 revs. per min. and drives another pulley of 12 in. dia. Find the speed of the smaller pulley.

$$\text{Surface speed of 36-in. pulley} = \frac{36 \times 22 \times 126}{12 \times 7} = 1188 \text{ ft. per min.}$$

This means that 1188 ft. of belting passes over both pulleys in one minute. The speed of the 13-in. pulley must be such that its surface speed is equal to this 1188 ft. per min.

$$\text{Circumference of 13-in. pulley} = \frac{12 \times 22}{12 \times 7} \text{ ft. in one rev.}$$

$$\text{Revs. of 13-in. pulley} = 1188 \div \frac{12 \times 22}{12 \times 7}$$

$$= \frac{1188 \times 12 \times 7}{12 \times 22}$$

$$= 378 \text{ revs. per min.}$$

The above examples have been given to illustrate the equality of the surface speeds of the driving and the driven pulley. It will be seen that we have simply divided the circumference of the 36-in. driving pulley by that of the 13-in. driven pulley and multiplied the result by the revolutions per minute of the driving pulley—*i.e.*

$$\frac{36 \times 22 \times 126}{12 \times 7} \div \frac{12 \times 22}{12 \times 7} = \frac{36 \times 22 \times 126 \times 12 \times 7}{12 \times 7 \times 12 \times 7}$$

$$= \frac{36 \times 126}{12} = 3 \times 126 \text{ revs.} = 378 \text{ revs. per min.}$$

On examining this result it will be noted that everything else has cancelled out and simply left the two diameters and the revolutions of the driving pulley. The diameter of the driving pulley is divided by that of the driven pulley, and the number obtained (in this case three) represents the *velocity ratio* or ratio of the revolutions per minute (or per second) of the two pulleys. The 12-in. pulley thus runs three times faster than the 36-in. pulley, and as the 36-in. pulley makes 126 revs. per min., the 13-in. pulley will make $3 \times 126 = 378$ revs. per min.

Fig. 3 represents the usual method of altering speed by means of a counter-shaft. The line-shaft A has to drive the machine at D, but owing to practical difficulties, or to the high speed required at D, it is not possible to drive direct from A to D. In such cases a counter-shaft is arranged, which is driven from the line-shaft, and this counter-shaft then drives the machine. Openers, scutchers, and a variety of machines are driven in this way.

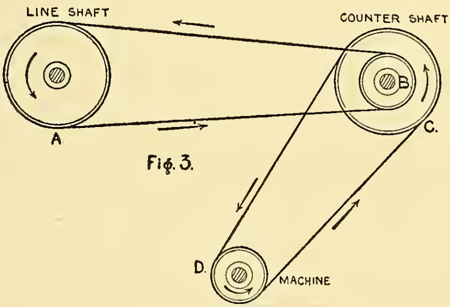


Fig. 3.

Example.—A pulley A (*see* Fig. 3) on line-shaft, 30 in. dia., drives pulley B, 12 in. dia., on counter-shaft; pulley C, 22 in. dia., on counter-shaft, drives pulley D, 10 in. dia., on the machine. What is the speed of the machine-shaft if the pulley on line-shaft makes 200 revs. per min.?

First, find the speed of B.

$$(a)\ \frac{\text{dia. of A} \times \text{revs. of A}}{\text{dia. of B}} = \text{revs. of B.} \quad \frac{30'' \times 200}{12''} = 500 \text{ revs. per min.}$$

The revs. of the counter-shaft being 500 revs. per min., the pulley C will revolve at this speed.

Second, find the speed of D driven from C.

$$(b)\ \frac{\text{dia. of C} \times \text{revs. of C}}{\text{dia. of D}} = \text{revs. of D.} \quad \frac{22 \times 500}{10} = 1100 \text{ revs. of D.}$$

Instead of making two calculations we can take advantage of the fact that the 1100 revs. have been obtained by multiplying (*a*) by (*b*), so the two may be expressed as one—

$$\frac{\text{dia. of A} \times \text{revs. of A} \times \text{dia. of C}}{\text{dia. of B} \times \text{dia. of D}} = \text{revs. of D.}$$

$$\frac{30'' \times 200 \times 22''}{12'' \times 10''} = 1100 \text{ revs. of D.}$$

The velocity ratio in this example is found as follows:—

$$\frac{A \times C}{B \times D} = \text{velocity ratio.}$$

$$\frac{30'' \times 22''}{12'' \times 10''} = 5{\cdot}5 \text{ velocity ratio.}$$

The velocity ratio multiplied by the speed of the first driver gives the speed of the last driven pulley.

$$5{\cdot}5 \times 200 = 1100 \text{ revs. per min. of D.}$$

It is often required to find suitable diameters of pulley to produce given speeds; for instance, in Fig. 4, A is 16 in. dia.

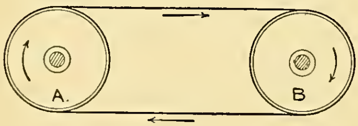


Fig. 4.

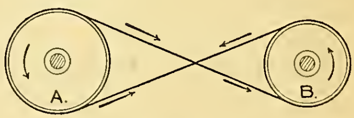


Fig. 5.

and runs at 140 revs. per min. Find diameter of B in order that B will revolve at 200 revs. per min.

The general formula will be—

$$\frac{\text{revs. of A} \times \text{dia. of A}}{\text{dia. of B}} = \text{revs. of B}$$

$$\text{so that dia. of B} = \frac{\text{revs. of A} \times \text{dia. of A}}{\text{revs. of B}}$$

$$\therefore \text{ dia. of B} = \frac{140 \times 16}{200} = 11\tfrac{1}{5} \text{ in.}$$

Fig. 5 shows the two shafts driven by a crossed belt. With an open belt both shafts run in the same direction; with a crossed belt they revolve in opposite directions.

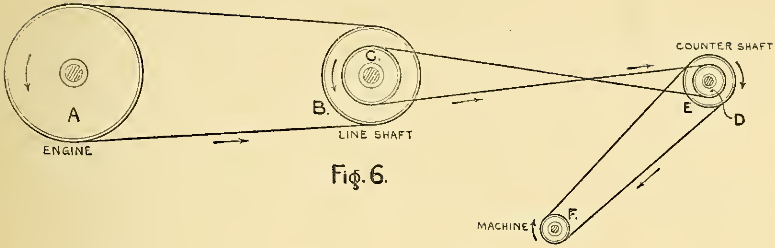


Fig. 6.

Example.—An engine drives a machine through a line-shaft and a counter-shaft, the following being the particulars:—

The engine runs at eighty revs. per min.

Engine pulley of 26 ft. dia. drives a pulley 5 ft. dia. on line-shaft.

A 2-ft. 6-in. pulley on line-shaft drives a 2-ft. pulley on counter-shaft.

An 18-in. pulley on counter-shaft drives a 14-in. pulley on machine.

Find speed of the machine.

First sketch the arrangement.

$$\text{revs. of A} \times \frac{A}{B} \times \frac{C}{D} \times \frac{E}{F} = \text{revs. of F.}$$

$$\frac{80 \times 312'' \times 30'' \times 18''}{60'' \times 24'' \times 14''} = 668{\cdot}5 \text{ revs. of F on machine.}$$

Example.—In the previous example assume the machine to run at 700 revs. per min. Find the dia. of pulley D, all the other factors remaining the same.

$$\frac{\text{revs. of A} \times A \times C \times E}{B \times D \times F} = \text{revs. of F.}$$

The diameter of D is unknown.

$$\therefore D = \frac{\text{revs. of A} \times A \times C \times E}{\text{revs. of F} \times B \times F}$$

$$D = \frac{80 \times 312'' \times 30'' \times 18''}{700 \times 60'' \times 14''}$$

$$\text{dia. of D} = 22\tfrac{7}{8} \text{ in.}$$

Example.—Fig. 7 is a sketch diagram of an engine driving the five rooms in a cotton spinning-mill. From the particulars given on the drawing find the diameter of the pulleys on the five line-shafts.

$$\frac{\text{revs. of A} \times \text{dia. of A}}{\text{dia. of B}} = \text{revs of B}$$

$$\text{dia. of B} = \frac{\text{revs. of A} \times \text{dia. of A}}{\text{revs. of B}}$$

$$\text{dia. of B} = \frac{70 \times 312''}{364} = 60 \text{ in.}$$

$$\text{revs. of C} = \frac{\text{revs. of A} \times \text{dia. of A}}{\text{dia. of C}}$$

$$\text{dia. of C} = \frac{\text{revs. of A} \times \text{A}}{\text{revs. of C}} = \frac{70 \times 312}{303} = 72 \text{ in.}$$

The pulleys on the line-shafts D, E, and F are the same as on B.

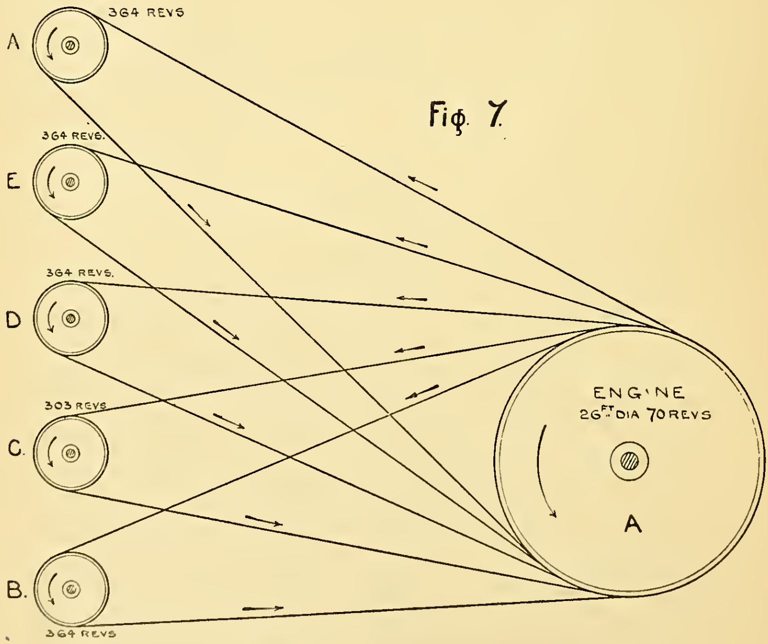


Fig. 7.

This is an example of rope driving as found in most modern cotton spinning-mills for communicating motion from the engine to the line-shafts in each room.

Slippage of Belts and Ropes.—So far it has been assumed that the belt has a perfect grip on the surface of the pulley, but since there is a considerable pull on the belt, this force may cause the belt to slip over the surface of the pulley, and in such cases the driving pulley does not communicate all its motion to the driver or following pulley. This slip is usually expressed as a percentage loss of the movement. It will vary according to the tightness of the belt, the condition of the surface of the belt and pulley, atmospheric conditions, relative sizes of pulleys, the power being transmitted, and the speed of the movement of the belt. Each case ought to be tested and the difference noted between the actual and calculated speeds. As a rule, 3 to 5 per cent. may be allowed for slippage.

A variety of methods of utilising belt and rope driving are to be found in our mills and workshops. Some of these are shown in the following sketches:—

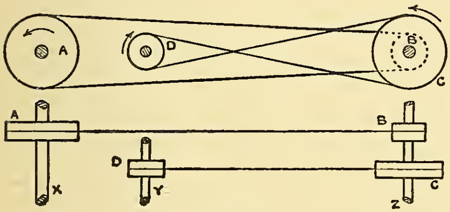


Fig. 8.

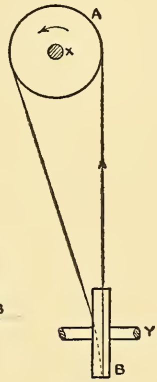


Fig. 9.

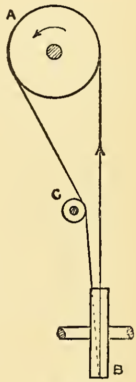


Fig. 10.

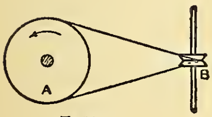


Fig. 11.

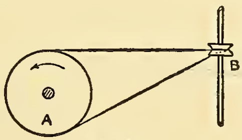


Fig. 12.

Fig. 8 represents the driving of two shafts X and Y near to and parallel to each other.

Fig. 9 is a half cross-drive where the two shafts X and Y are at right angles to each other. This is a very common drive in the card-rooms of spinning-mills.

Fig. 10 is similar to Fig. 9, but a guide pulley C is used. Such an arrangement is very seldom necessary.

Fig. 11 is the method now universal for driving spindles of the spinning machinery. The spindles are invariably vertical and at right angles to the tin roller A.

Fig. 12 is similar to Fig. 11, but since the spindles are vertical and are supported on a footstep, they are free to be raised, so the spindle driving band must tend to press the spindle downwards. For this reason the position of the small pulley or wharve on the spindle is set about the level of the upper surface of the tin drum.

Fig. 13 shows the method of driving the tin drum by rope; it will be noticed that it is a very complete example of combined drives by a single continuous rope.

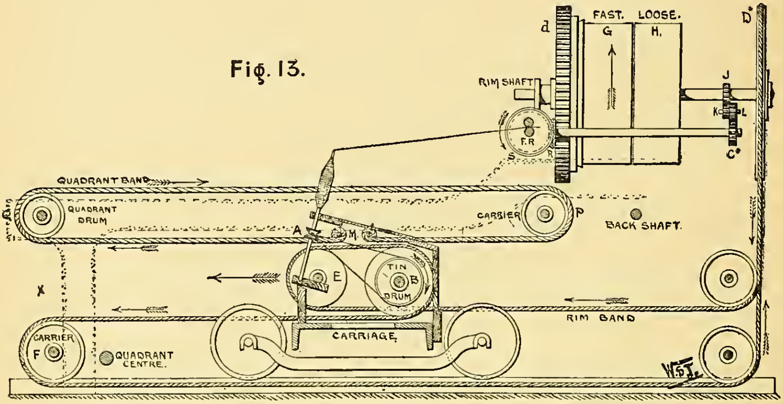


Fig. 13.

Gear-Wheels.—Fig. 14 illustrates a rough sketch of a pair of wheels in gear with each other. The number of teeth in each wheel, A and B, are equal, so that if A makes one revolution, the wheel B will revolve exactly the same amount.

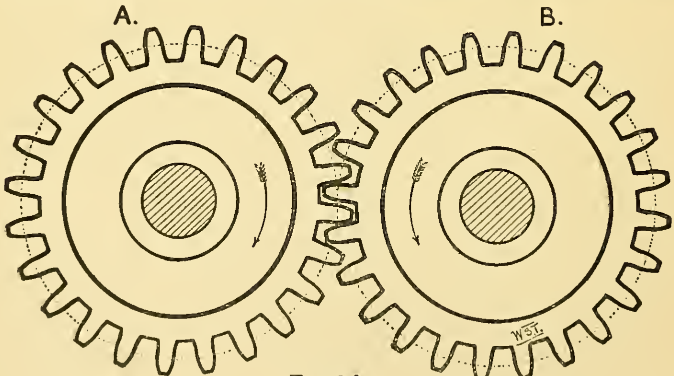


Fig. 14.

Two such wheels, as in Fig. 13, will revolve in opposite directions. The driving effect is a positive one and does not depend, as in pulley driving, on a belt or rope gripping a pulley. A tooth of one wheel simply forces a tooth of the other wheel out of the way, and as this is continuous, other teeth coming into action as the previous ones are moved away, we obtain a turning effect, and motion is transferred from one wheel to the other.

The circumference of the wheel is the chief factor in estimating speed, but as wheels are supplied already made and teeth are equally spaced in all wheels that are in gear with each other, it is simply necessary to use the number of teeth in a wheel to represent its circumference or its diameter.

Fig. 15 shows a case where the two wheels of Fig. 14 are not directly in gear but are put into gear by the introduction of an additional wheel C. As before, A and B have an equal number of teeth, whilst C may have any number of teeth consistent with design and purpose. The effect of separating A and B and gearing C with both of them is to alter the direction of the rotation of B. It has not altered the speed in any way, for one tooth of A drives one tooth of C and one tooth of C drives one tooth of B, therefore one tooth of A will drive one tooth of B, and we simply find that A will drive B at an equal speed to itself. The introduction of the extra wheel C does not enter into any calculation of speed, it merely alters direction of rotation: it is usually termed *a single carrier*.

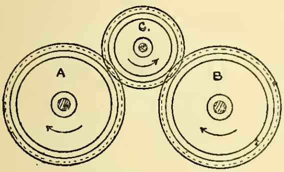


Fig. 15.

In Fig. 16 A and B are too far apart to gear them directly. One carrier between them would give a wrong direction to the rotation of B, so two single carriers, C and D, are introduced. As in the case of the single carrier-wheel in Fig. 15, these two single carrier-wheels of Fig. 16 have no influence on speeds, so they are ignored in gearing calculations.

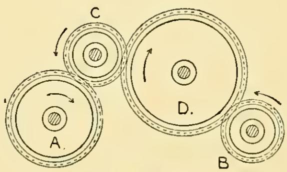


Fig. 16.

The next sketch (Fig. 17) shows an arrangement of four wheels in which the gap between A and B is filled with two wheels, both fastened together or keyed on the same shaft. The method is used extensively in textile machinery.

The arrows indicate the directions of rotation, and it will be seen that A and B revolve in the same direction as in the case of Fig. 15. In Fig. 17, however, there is something more than a mere change of rotation: A drives C, but quite another wheel drives B, and except when the two wheels C and D are equal in teeth, any difference in their sizes will make a difference in the speed of B. Whilst C and D are therefore carriers, they must be distinguished from single carriers, and this distinction is usually noted by referring to them as *compound carriers.*

Suppose that in Fig. 17 A has 24 teeth, C has 12 teeth, D has 24 teeth, and B has 12 teeth. It is quite clear if A makes one revolution that its 24 teeth must gear with 24 teeth

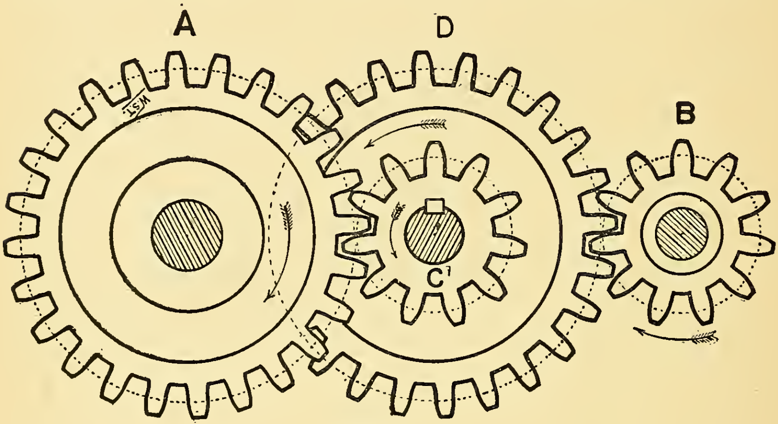


Fig. 17.

of C, but as C has only 12 teeth, this latter wheel must revolve twice whilst A revolves once. Since the two wheels C and D revolve together, D will also make two revolutions whilst A makes one. As D has 24 teeth, and it makes two revolutions, there will be $2 \times 24 = 48$ teeth of D to gear with the 12 teeth of B, so that B must revolve four times, whilst D revolves twice and A revolves once. This calculation, it will be seen, is similar to the method adopted for pulleys.

A's teeth divided by C's teeth = the revs. of C for one of A
D's teeth divided by B's teeth = the revs. of B for one of D or C.

If these two are multiplied together we have

$$\frac{A}{C} \times \frac{D}{B} = \frac{24}{12} \times \frac{24}{12} = \text{four revs. of B for one rev. of A}$$

so that $\frac{A}{C} \times \frac{D}{B} = \text{the velocity ratio} = 4.$

If A makes more than one revolution the speed of B must be multiplied by the revolutions of A in order to obtain the corresponding speed of B. In other words, B will always run four times faster than A. This four is termed the *velocity ratio* of the wheel arrangement, and simply means the proportionate speed of B as compared with A. In the form of a statement, velocity ratio is usually represented as follows :—

$$\frac{A}{C}=\text{velocity ratio between A and C}$$

$$\frac{D}{B}=\text{velocity ratio between D and B}$$

$$\frac{A \times D}{C \times B}=\text{velocity ratio between A and B.}$$

This applies just the same in regard to pulley driving and all other forms of moving mechanism, so that

$$\frac{\text{the terminal revs. per unit of time}}{\text{the initial revs. per unit of time}}=\text{velocity ratio of the system.}$$

A series of examples will now be given to illustrate the various types of driving already given and the calculations for them. As sketching any given arrangement is important, it will be advisable to suggest methods of illustrating the gearing and pulley driving.

One method is simply to draw circles for the wheels, lettering and numbering them and not showing any plan view. Fig. 16 will illustrate this method.

Another method is to draw a view of the driving by a plan only, and this may be done simply and quickly either by

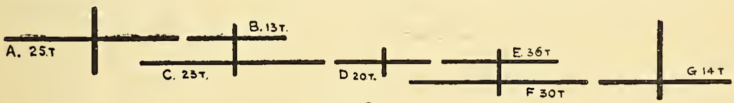


Fig. 18.

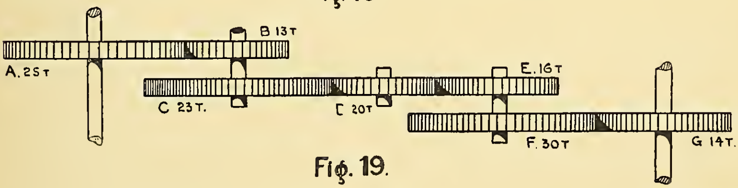


Fig. 19.

showing single lines, as in Fig. 18, or by indicating the width of the wheels and the teeth, as in Fig. 19. This latter method is perhaps the best method of sketching gearing, and gives a clear indication of the wheel arrangements.

Bevel Gearing.—Bevel wheels are used to drive shafts that are inclined to each other, the shafts being usually at right angles. Fig. 20 will illustrate the general method of driving.

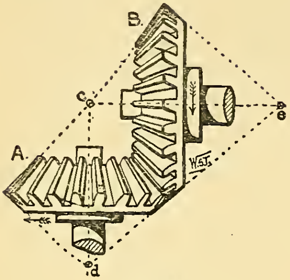


Fig. 20.

The direction of rotation and the calculations connected with bevel wheels are exactly as shown for the usual wheels. For instance, if A with twenty teeth is driving B with thirty teeth, then

$$\frac{A}{B} = \text{revs. of B}$$

$$\therefore \frac{20}{30} = \frac{2}{3} = \cdot 66 \text{ revs. of B.}$$

Worm and Worm - Wheel.—When a large reduction in speed is required, practical considerations prevent the use of a very small wheel driving a very large wheel, or the use of several compound carriers. In such cases a worm and worm-wheel are used. The worm A (*see* Figs. 21, 22, and 23) is

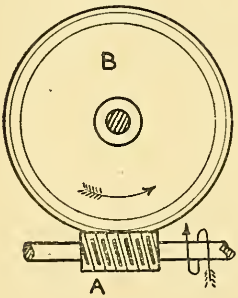


Fig. 22.

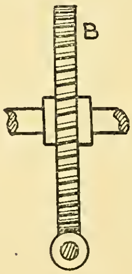


Fig. 21.

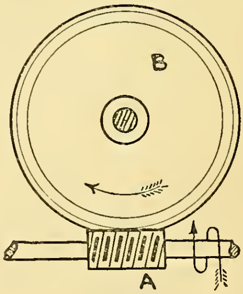


Fig. 23.

simply a portion of a screw of a suitable pitch, and into the spaces of which the teeth of a wheel B are geared. Fig. 23A shows the worm and a portion of the worm-wheel enlarged. The screw-thread is an inclined surface, so that as the worm revolves the helical thread will move the teeth of the worm-wheel aside, and other teeth will move into position, to be pushed aside in their turn. One revolution of the worm will move one tooth's distance of the wheel gearing into it if the worm has a single thread, as in Fig. 24, so that if the worm-wheel B in Fig. 21 has twenty teeth, it will require twenty revolutions of the worm A to give one complete revolution to B.

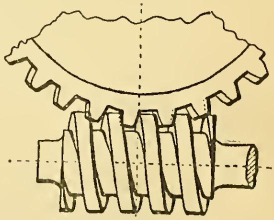


Fig. 23A.

When the worm A has two threads, cut on its surface as in Fig. 25, then one revolution of A will revolve the wheel to the extent of two teeth, so that A will require to make ten revolutions to produce one revolution of B. It will be seen that for practical purposes a single worm may be considered as a wheel with one tooth, a double worm as a wheel with two teeth, and so on.

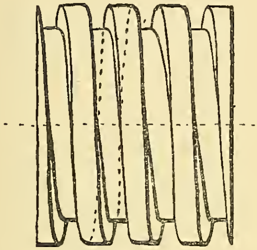


Fig. 24

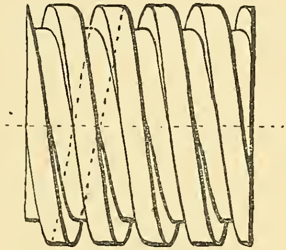


Fig. 25.

Rack and Pinion.—The rack and pinion is an important element in the gearing of textile machinery. A straight-toothed rack is used into which gears a wheel; the rack slides in guides and is attached to some part of the mechanism that requires to be moved in a straight line at a definite speed for a certain distance. Fig. 26 will illustrate the elementary

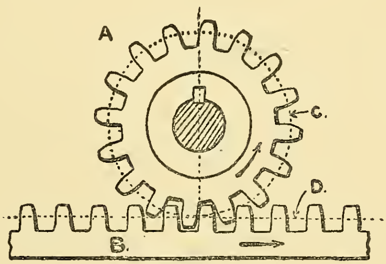


Fig. 26.

type. The wheel A revolves on a fixed centre in the direction of the arrow and by virtue of gearing with B it moves the rack forward as shown. If A has sixteen teeth, one revolution will move the rack a distance equal to sixteen teeth on the rack, so that to know the exact distance moved by the rack it is necessary to know the *pitch* of the teeth or else the space occupied by the whole of the teeth that are moved. If the pitch of the teeth in

Fig. 26 is half an inch, then three revolutions of A will move the rack $3 \times 16 = 48$ teeth and $48 \times \frac{1}{2}$ in. $= 24$ in., the distance moved by the rack.

Star-Wheel.—This arrangement sometimes forms part of the gearing of a machine, especially to produce an intermittent feed to the rollers whilst other parts of the gearing are running continuously. Fig. 27 gives its essential features. An arm,

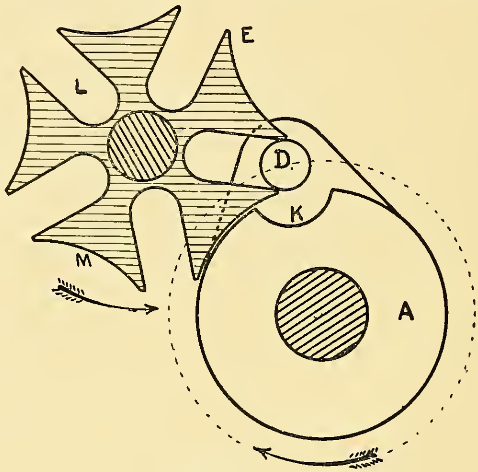


Fig. 27.

carrying a pin or stud D, is fixed to the shaft. This arm is also provided with a turned boss A having a recess cut out at K. On the shaft to be driven intermittently is keyed a specially formed wheel E, having slots L and the surface between the slots cut out to the same radius as the boss A. As the pin D revolves it passes into one of the slots L and carries the star-wheel E along with it until it emerges from the slot. The recess at K permits E to revolve by allowing room for the points of the star to describe a portion of a circle. On coming out of the slot of E the pin D will continue its motion for the greater part of a revolution without any effect on the star-wheel, which thus remains stationary, and E is only moved again when D enters the next slot. If E has five slots it will require five revolutions of A to produce one revolution of E. For purposes of calculation the pin D may be considered as a wheel of one tooth and the star-wheel E as a wheel of five teeth. The arrangement may be made for more than one pin D and varying slots to suit the characters of the intermittent motion required.

Fig. 27A shows its application to a combing machine. The object is to revolve the roller H intermittently so that a certain length of cotton will pass between the two rollers at definitely fixed times in the machine's cycle of actions. This effect is obtained by gearing H through G to the wheel F; on the same

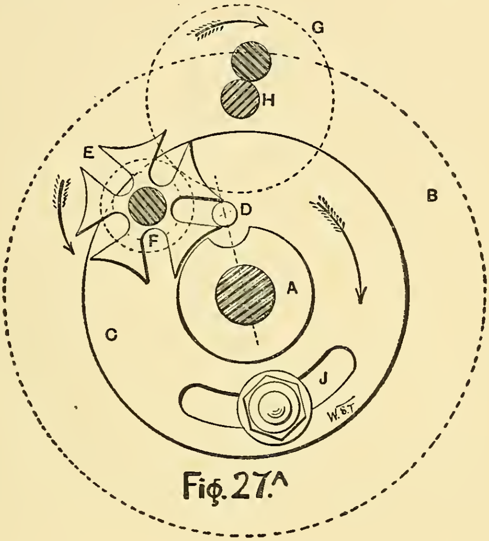


Fig. 27A

shaft as F is fixed the star-wheel E, and in this wheel is geared a pin D attached to a disc C. The disc C revolves continuously, but the star-wheel E will only move round a fifth of a revolution at that part of the revolution of C when the pin D gears with the slots in E. The rest of the movement of C will have no effect on E, so that the star-wheel is idle during this period.

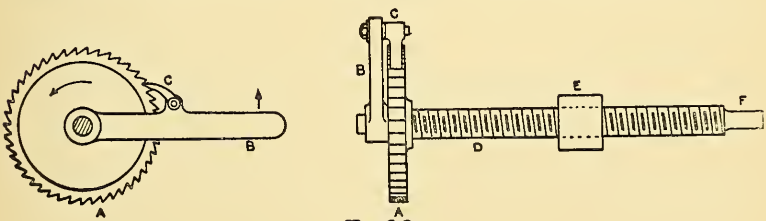


Fig. 28.

Ratchet-Wheel.—Another form of intermittent motion is obtained by a ratchet-wheel. Fig. 28 illustrates the general arrangement. A wheel A, with specially formed teeth, is fixed on a shaft or, as in the sketch, a screw D. If the ratchet-wheel A is turned, the nut E on the screw will move along the screw. The method of turning the ratchet-wheel is somewhat as follows:—An arm B is mounted loosely on the centre of the wheel A; this arm carries a *pawl* C which works freely on a stud. The end of the pawl fits between the teeth of the ratchet-wheel so that if the arm B is raised the pawl C, owing to the shape of the teeth of A, forces the wheel A round. The movement of B can be adjusted so that it rises just sufficiently to cause C to move the ratchet-wheel one tooth only or two or more teeth as desired. When B has moved the required distance it will fall back into its original position ready to be actuated again. In dropping back to this position the pawl C, being free on its centre, will slip over the teeth of A and so have no effect on them. If A has thirty teeth and the pawl takes one tooth at a time, it will require thirty movements of the arm B to cause the ratchet-wheel to make one complete revolution. If two teeth are taken, then the arm B will only require to make fifteen movements to effect one revolution of A. B will move ten times if the pawl takes three teeth of A.

$$\text{The revs. of A therefore} = \frac{\text{number of teeth in A}}{\text{number of teeth moved by C}}.$$

The movement of the nut E on the screw D is generally the chief object in view. The screw D is either square or vee-threaded, and of a suitable pitch for the purpose. If the pitch is $\frac{1}{4}$ in., then one revolution of A will move the nut E $\frac{1}{4}$ in. When one tooth only of the ratchet-wheel is taken, then the nut E will move

$$\frac{1}{30} \times \frac{1}{4} = \frac{1}{120} \text{ of an inch.}$$

The distance moved by a nut on a screw that is actuated by a ratchet-wheel will therefore be—

$$\frac{\text{teeth taken by pawl}}{\text{teeth in ratchet-wheel}} \times \text{pitch of screw in inches} = \text{travel of nut.}$$

Several examples of the ratchet-wheel and screw are to be found in textile machinery, the chief type being the shaper screw. A modified form of it is the arrangement for moving the nut along the screw of the quadrant.

The arrangement shown in Fig. 28 can be adjusted to take one, two three, etc., teeth at each stroke of the arm, but fractions of the teeth cannot be taken except by putting on ratchet-wheels with more or less teeth. This is done in the majority of cases, but sometimes this is not convenient, in which case two or more pawls are used as in Fig. 29, and by adjusting their distance apart along the tooth it is easy to obtain fractional movements of a tooth. The sketch shows the two pawls set so that half a tooth can be taken, and this is equal to putting on a ratchet-wheel with double the number of teeth.

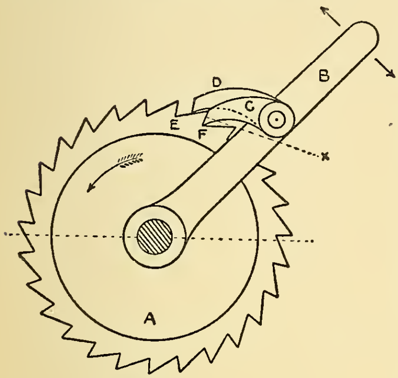


Fig. 29.

In order that the pawls shall not slip from the teeth when turning the wheel, the faces of the teeth are so cut that a line at right angles to their surface, such as F (Fig. 29), should always pass below the centre of the pawl pin. Springs are also used to keep the pawl on the teeth, and so prevent the pawls bouncing out on the return movement of the vibrating arm, which they are apt to do if a quick feed is being given.

Example.—A sketch is given in Fig. 30 as an exercise in calculating the velocity ratio or the value of a train of wheels. The combination of gearing does not represent any actual machine, but simply a general type of mixed driving elements.

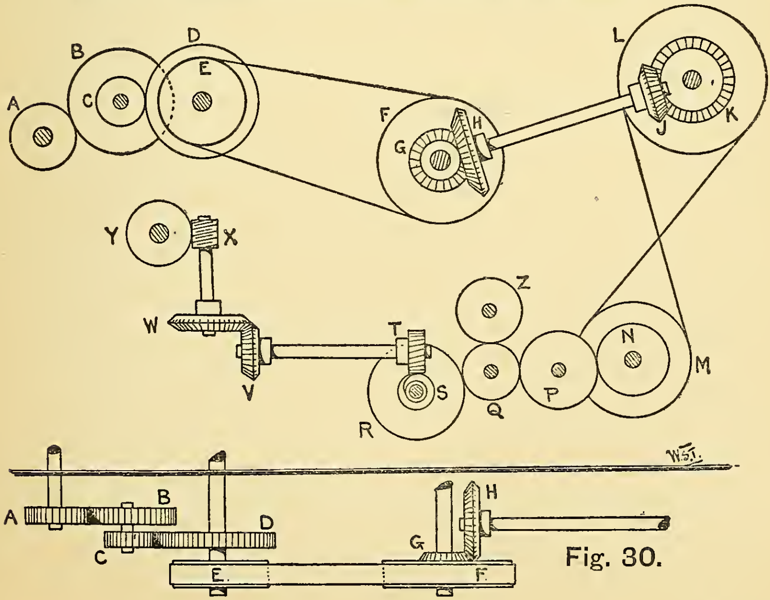


Fig. 30.

As an example the following particulars will be taken for purposes of calculation. A is the starting-point and its speed is 3000 revs. per min.

A	with	14 teeth	drives	B	with	28 teeth
C	,,	9 ,,	,,	D	,,	27 ,,
E	,,	10″ dia.	,,	F	,,	15″ dia.
G	,,	18 teeth	,,	H	,,	24 teeth
J	,,	12 ,,	,,	K	,,	18 ,,
L	,,	24″ dia.	,,	M	,,	16″ dia.
N	,,	36 teeth	,,	R	,,	16 teeth
S	,,	single worm	,,	T	,,	18 ,,
V	,,	12 teeth	,,	W	,,	14 ,,
X	,,	single worm	,,	Y	,,	27 ,,
Z	,,	18 teeth.				

The general statement of the driving in Fig. 30 would be—

$$\frac{A \times C \times E \times G \times J \times L \times N \times S \times V \times X}{B \times D \times F \times H \times K \times M \times R \times T \times W \times Y} = \text{revs. of Y for 1 rev. of A.}$$

This result is called the value of the train or the velocity ratio.

It will be noted that three wheels have been omitted in the above statement, viz. P, Q, and Z, the reason for which is that P and Q are simple carriers and have no influence on the value of the train of wheels; they simply fill up the space and connect the wheel N with the wheel R, and are also the means for transferring motion to the wheel Z, which is a terminal wheel. Simple carriers of the type of P and Q are always left out in calculations, but they may be of importance in altering the direction of motion.

As the velocity ratio of a driving system, or part of the system, is the revolutions of the last element, or finishing-point, when the first element of starting-point revolves once, we can represent the ratio either as a full formula or calculate it out to a definite result in figures. The speed of Y in Fig. 30, just given in the above formula, represents the velocity ratio of the combined driving, so that if this is multiplied by the revolutions of A the result will represent the speed of Y per minute. This will now be done by substituting the values of each wheel and pulley in the formula.

$$\frac{3000 \times 14 \times 9 \times 10'' \times 18 \times 12 \times 24'' \times 36 \times 1 \times 12 \times 1}{28 \times 27 \times 15'' \times 24 \times 18 \times 16'' \times 16 \times 18 \times 14 \times 27} = \cdot 99 \text{ revs. of Y}$$
say 1 rev. of Y.

To obtain the speed of the wheel Z a similar calculation is performed; for instance—

$$\frac{\text{revs. of } A \times A \times C \times E \times G \times J \times L \times N}{B \times D \times F \times H \times K \times M \times Z} = \text{revs. of Z.}$$

$$\frac{3000 \times 14 \times 9 \times 10'' \times 18 \times 12 \times 24'' \times 36}{28 \times 27 \times 15'' \times 24 \times 18 \times 16'' \times 18} = 500 \text{ revs. per min. of Z.}$$

In many cases the terminal speed is known or it is desired to run the last wheel at a certain speed. The calculation is then worked backwards by assuming that the last wheel is the driver. This can be done even though it is a practical impossibility actually to drive this train of wheels the reverse way. In Fig. 30 it will be seen that by starting at Y it will be impossible to drive the gearing, for a worm-wheel cannot drive a worm. This fact, however, does not prevent calculations being made the reverse way. If the wheel Y runs at one revolution per minute, what speed will the wheel A have?

$$\frac{Y \times W \times T \times R \times M \times K \times H \times F \times D \times B}{X \times V \times S \times N \times L \times J \times G \times E \times C \times A} = \text{revs. of A.}$$

$$\frac{27 \times 14 \times 18 \times 16 \times 16'' \times 18 \times 24 \times 15'' \times 27 \times 28}{1 \times 12 \times 1 \times 36 \times 24'' \times 12 \times 18 \times 10'' \times 9 \times 14} = 3024 \text{ revs. of A.}$$

By changing the number of teeth on the various wheels and the diameters of the pulleys, Fig. 30 can be used for a number of exercises.

It can readily be understood that innumerable combinations of wheel gearing and belt and rope driving are possible. Such

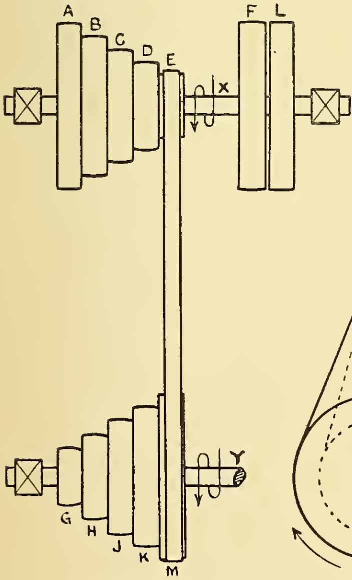


Fig. 31.

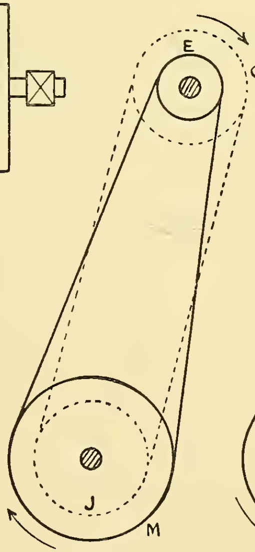


Fig. 32.

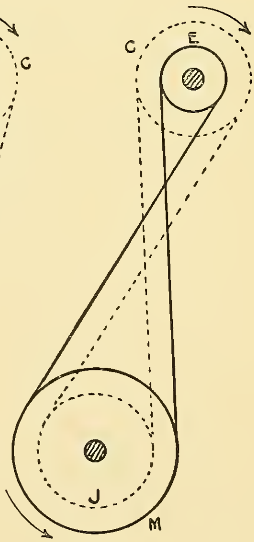


Fig. 33.

arrangements will be found distributed about most works and the machinery they contain.

Stepped Cone Pulleys.—Fig. 31 illustrates a very common form of belt drive where varying speeds are necessary, as in a lathe, to suit the different metals or sizes. Instead of single pulleys we have a series of pulleys side by side in the form of steps and all cast as one piece. This is keyed on the counter-shaft, which is driven from a line-shaft through the fast and loose pulleys FL. The stepped cone pulley ABCDE drives a similar pulley on the lathe, the sizes of these pulleys being such that the sum of the two opposite diameters are always practically equal. For instance—

$$A+G=B+H=C+J=D+K=E+M.$$

This is not mathematically correct but it is near enough for our purpose.

By moving the belt from one position to another a change of speed is easily obtained. Fig. 32 shows the strap moved from EM to CJ. If a reverse direction is required to the lathe spindle a crossed belt can be used, as shown in Fig. 33. When a crossed belt is employed, as in Fig. 33, the belt will fit exactly all the pulleys on a pair of stepped cone pulleys if the sum of the diameters of each pair of pulleys is the same.

Cone Drums.—For many purposes an arrangement for varying speed is necessary, which must be automatic and instantaneous in action. A stepped-cone arrangement is unsuitable

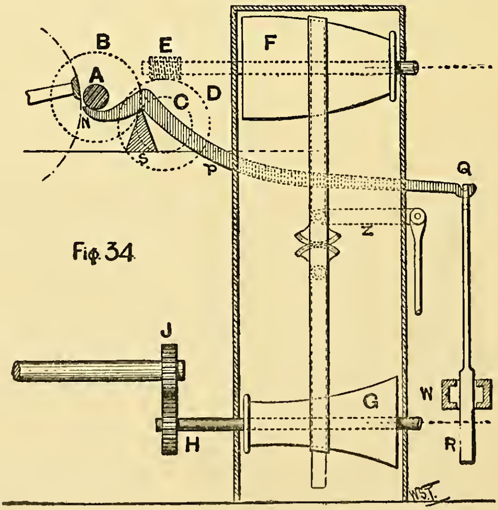


Fig. 34

for this, so, instead of sudden steps in the pulleys, lengthened pulleys of a conical form are employed. An example is given in Fig. 34.

In openers and scutchers these cone drums are used to

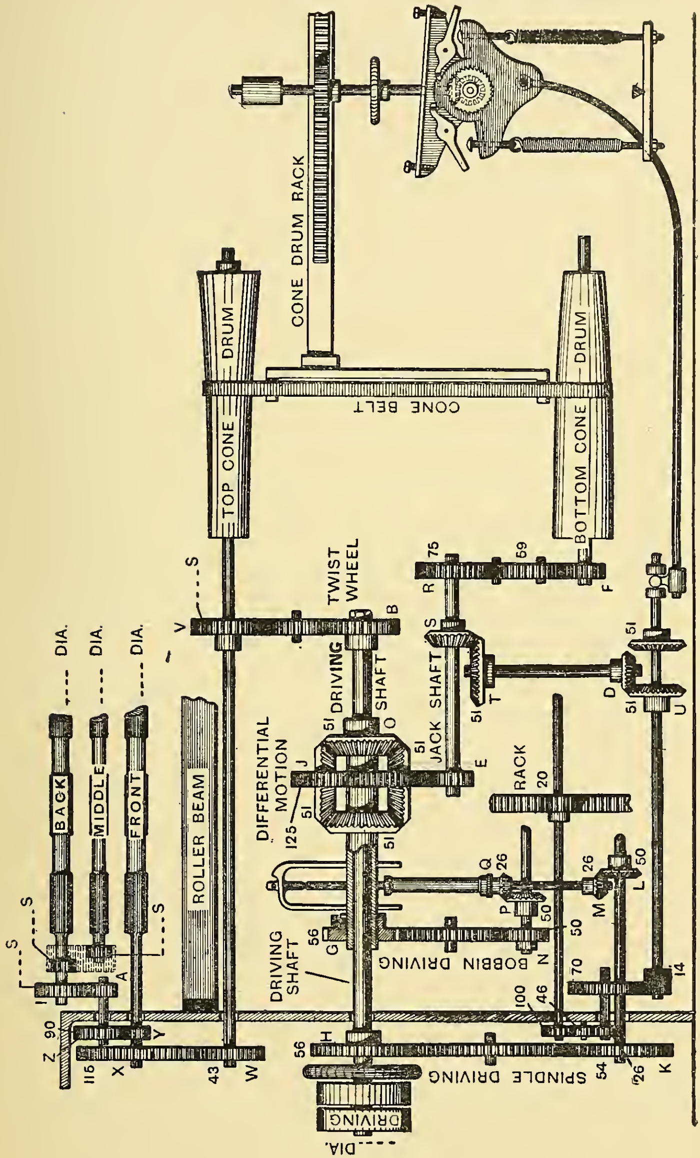

CONE DRUM RACK
TOP CONE
DRUM
CONE BELT
BOTTOM CONE
DRUM
TWIST WHEEL
DRIVING SHAFT
DIFFERENTIAL MOTION
JACK SHAFT
RACK
ROLLER BEAM
BACK
MIDDLE
FRONT
DIA.
DRIVING SHAFT
BOBBIN DRIVING
SPINDLE DRIVING
DRIVING
DIA.

Fig. 35.

regulate the amount of cotton being fed by the feed-roller. A further example is seen on all flyer frames. It is through cone drums that the speeds of the bobbins are regulated as the bobbins increase in diameter (*see* Fig. 35). In both these cases the cone drums require to be curved in outline, but they follow the rule that the sum of the opposite diameters is everywhere the same.

Reversing Motions.—A crank is a good type of reversing motion, for it gives to the cross-head a to-and-fro movement. Cranks are therefore commonly used for imparting a forward

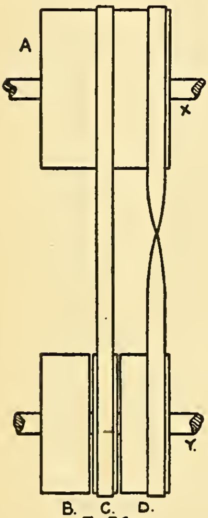


Fig. 36.

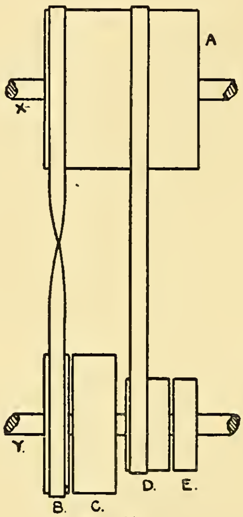


Fig. 37.

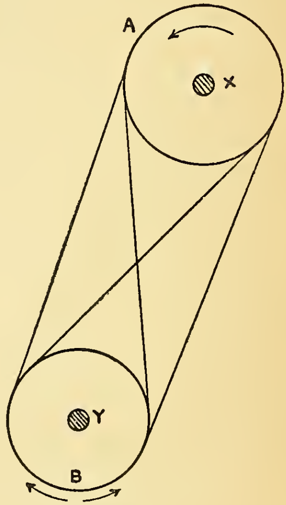


Fig. 38.

and backward motion to levers, etc., and they are equally useful in producing a certain speed forward and a faster or slower speed backwards. Other combinations are also made to reverse the direction of rotation, of which several examples are now given. Fig. 36 shows a large drum A on the shaft X. This drives by means of two belts, one open and one crossed, the shaft Y. On Y are keyed two fast pulleys B and D, and a loose pulley C is placed between them. The open and crossed belts are set apart by a strap fork, so that when the crossed belt is on the fast pulley D, the open belt is on the loose pulley, or when the open belt is on B, the crossed belt is on C. By moving the strap fork it is an easy matter to change the direction in which the shaft revolves. If a difference of speed is required as well as a change in rotation, the pulleys and belts are set as in Fig. 37. B and E are loose pulleys, whilst C and D are fast pulleys. In the sketch the open belt is driving the shaft Y through pulley D and the crossed belt is simply running idle on the loose pulley B. When the crossed belt is moved to pulley C the open belt will be transferred to the loose pulley E. We thus have a quicker speed when the open belt is driving than when the crossed belt drives.

Such arrangements are not uncommon and in cotton-mills are frequently met with as double-speed driving in self-acting mules. Students will note a very serious fault in both Fig. 36 and Fig. 37, and it is found in all such belt drives. As the belts move from C to B and from D to C there is a space of time when each belt is trying to drive the shaft Y in

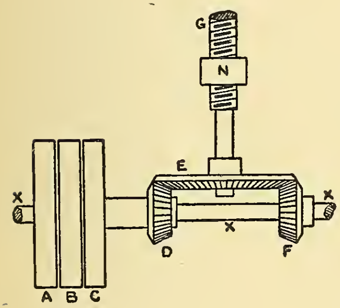


Fig. 39.

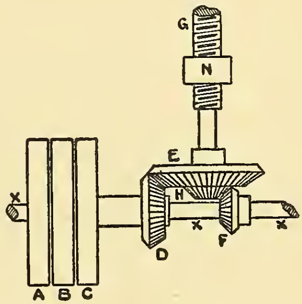


Fig. 40.

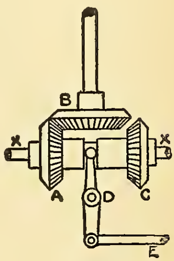


Fig. 41.

opposite directions, which results in a loss of speed, slippage of belts, and an increase in power exerted through A and the shaft X.

Fig. 39 exhibits a reversing motion by bevel wheels. A is a fast pulley on shaft X, B is a loose pulley, whilst C is also loose on the shaft but carries a bevel wheel D fixed on its extended boss ; the pulley C and the bevel D are therefore in one piece and revolve together. D gears into a bevel E, which in turn gears into a bevel F which is keyed on the shaft X. When the belt is on pulley A, the shaft X is driven and consequently the bevel F will drive the bevel E and turn the screw G, so that the nut N will travel in one direction. If the belt is now moved to pulley C, the bevel D drives the bevel E and revolves the screw, so that the nut N will move in the opposite direction. Of course, F and the pulley A will also revolve in an opposite direction to the pulley C, but this is of no consequence. In order to obtain a difference in the forward and backward movement of the nut N the bevels are arranged somewhat as sketched in Fig. 40.

In Fig. 41 we have a further example of a reversing motion. Two bevel wheels A and C are cast in one piece with a boss or connecting piece between them; they are mounted on a floating key so that they both revolve with the shaft X. By means of a lever and rod or any other suitable means the bevel A is moved into gear with the bevel B and drives it in one direction. If the lever centred at D is now actuated, the bevel A is moved away from B and the bevel C is put into gear with B, which at once reverses the direction of rotation of B. A well-known example of this method is to be found in the flyer frame, and is used to give the rise and fall to

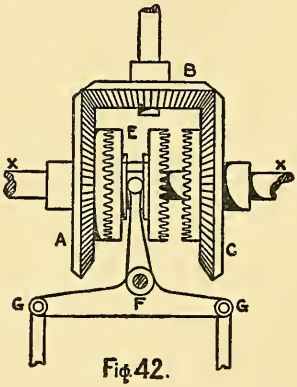


Fig. 42.

the bobbin rail. An adaptation of this method is seen in Fig. 42. Here the shaft X runs continuously in one direction. The bevels A and C are loose on the shaft; each of these bevels is provided with one half of a clutch. A double-faced clutch E is mounted on the shaft X on a floating key so that it revolves with the shaft but can be moved along it and thus engage with the clutch face of the bevels A or C, or can be set so that it engages neither. By operating the lever centred at F, the bevel B can be driven in either direction or kept stationary.

An interesting practical example of Fig. 42 is shown in Fig. 43, where it forms part of the gearing of a self-acting mule. The double clutch box or the reversing clutch box is indicated at W and X. A single clutch box is shown at Y, and at U is the cone clutch of the backing-off on the rim-shaft. It is not necessary at this point to explain this apparent complicated piece of wheel-work, it is sufficient to point out that by suitable means and at definite moments in the cycle of operations the various clutches are manipulated automatically

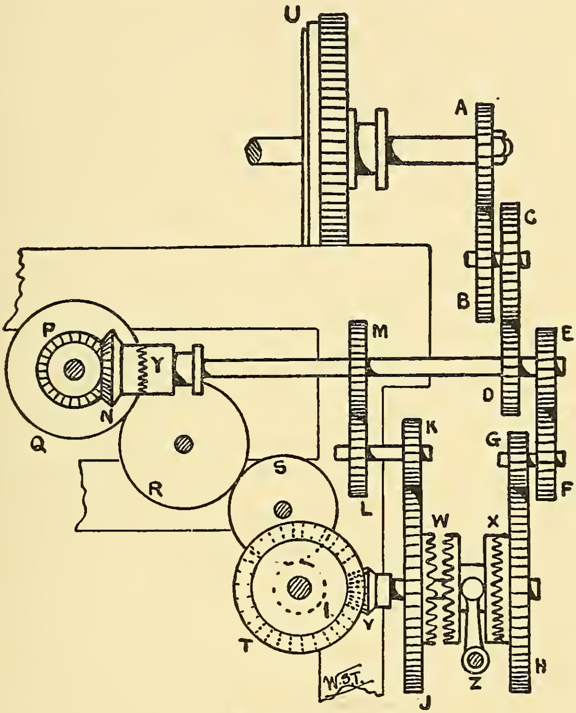


Fig. 43

so that we can obtain forward motion, backward motion, intermittent motion, or no motion at certain desired points. Students will find the example a good study in tracing out speeds and directions on the supposition of the clutches being in or out of action.

EXERCISES

1. A line-shaft runs at 320 revs. per min., a pulley 24 in. dia. on this shaft drives a pulley $13\frac{1}{2}$ in. dia. on a counter-shaft. At what revs. will the counter-shaft run per min.?

2. With a slippage of 3 per cent. in Question 1, at what speed will the counter-shaft run?

3. The pulley on a beater-shaft is 10 in. dia. The beater makes 1100 revs. per min. The counter-shaft which drives the beater makes 360 revs. per min. Find the diameter of the pulley on the counter-shaft to produce this speed.

4. At what surface speed will a belt travel in feet per minute which is driven by a 36-in. pulley running at 362 revs. per min.?

5. The velocity ratio of two shafts is $3\frac{1}{4}$. What sizes of pulleys, in full inches, are required if the smallest pulley is over 9 in. dia.?

6. An engine makes eighty revs. per min. The rope fly-wheel of 30 ft. dia. drives a line-shaft at 410 revs. per min. What diameter of pulley is required on the line-shaft?

7. A counter-shaft runs at 282 revs. per min. and carries a 27-in. pulley which must drive a machine shaft at 1260 revs. per min. What diameter of pulley is required on the machine if an allowance of $3\frac{1}{2}$ per cent. is made for slip?

8. Sketch the section through the rim of a rope-driven pulley and state the reason why an effective drive is obtained.

9. The centres of two shafts are 6 in. apart. Their velocity ratio is 3. What are the pitch diameters of the two wheels which gear the shafts?

10. A wheel of sixty-five teeth drives one of twenty-one teeth. On the same shaft as the twenty-one wheel is a double worm which gears with fifty-three's wheel. At what speed will the fifty-three wheel revolve if the first driver makes 496 revs. per min.?

11. What is the velocity ratio in Question 10?

12. Two shafts revolve in a clockwise direction and are geared together. Sketch the arrangement of the wheels (*a*) if the velocity ratio is low, and (*b*) if the velocity ratio is high.

13. Sketch the gearing in plan of the driving of the feed-roller or pedal-roller of a scutcher from the cone-drum shaft. Indicate clearly the direction of motion.

14. Sketch the gearing between the doffer-shaft and the feed-roller of a carding machine, showing clearly the direction of motion.

15. If it is desired to change the speed of the feed-roller of a carding machine, what wheel is changed, and how is it possible for this to be done?

16. A shaft is driven in a clockwise direction by belts, another shaft by a worm and worm-wheel, and a third shaft by bevel wheels. Show by sketches how each of the shafts could have the direction of rotation reversed.

17. A ratchet-wheel of forty-nine teeth is fitted on the end of a screw of $\frac{1}{2}$-in. pitch. The pawl is given a movement which takes two teeth of the ratchet-wheel every thirteen seconds. How long will it take a nut to traverse 6 in. of the screw? Sketch the arrangement as applied in some practical manner.

18. Sketch a toothed clutch box, and explain its action when applied to the feed-roller of a scutcher.

19. Sketch the gearing and rollers of a household mangle or wringing machine, and calculate the revolutions of the rollers if the handle is turned thirty times a minute.

20. Sketch and describe an intermittent taking-up motion of a loom, and give a calculation based on details taken from an actual loom.

21. Sketch and describe a continuous taking-up motion of a loom, and give a specimen calculation based on details taken from a loom at work.

CHAPTER II

SURFACE SPEEDS AND DRAFT

Surface Speed.—The surface speed of a pulley is the product of revolutions per minute and circumference.

$$\frac{\text{revs. per min.} \times \text{circumference in.}}{12} = \text{surface speed in ft. per min.}$$

When comparing surface speeds it is only necessary to use the diameters and not the circumference, as π cancels out.

This principle may now be applied to the finding of surface speeds of rollers. Such rollers are extensively used in the engineering industries for carrying material, and in textile work they are unusually important as a means of passing the fibrous substance from one point to another and also in obtaining "draft."

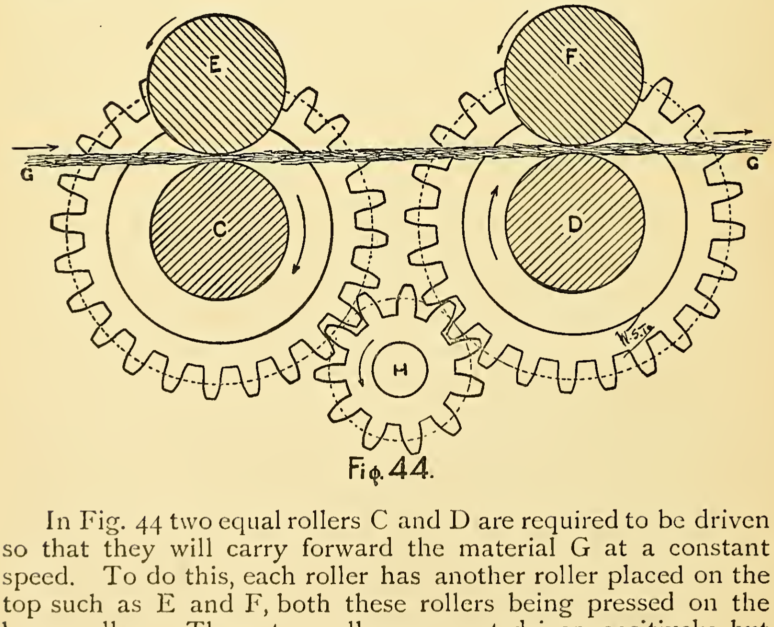


Fig. 44.

In Fig. 44 two equal rollers C and D are required to be driven so that they will carry forward the material G at a constant speed. To do this, each roller has another roller placed on the top such as E and F, both these rollers being pressed on the lower rollers. These top rollers are not driven positively, but are simply turned through their contact with the bottom rollers or their contact with the material passing between the two rollers. Two equal wheels A and B are used to gear up the rollers C and D, and a single carrier-wheel is placed between the wheels in order to revolve the rollers in the right direction. This arrangement indicates at sight that C and D will revolve at equal speeds. If C and D are each 2 in. in dia., and revolve at 150 revs. per min., the surface speed of each will be—

$$\frac{\text{revs. of C} \times 2'' \times \pi}{12''} = \frac{150 \times 2'' \times 22}{12'' \times 7} = 78{\cdot}5 \text{ ft. per min.}$$

Since C and D have each a surface speed of $78\frac{1}{2}$ ft. per min., the material G will be passed forward at the same speed by virtue of its contact with the surface of the rollers.

Fig. 45 illustrates the driving of two rollers where a compound carrier is placed between the wheels on the ends of

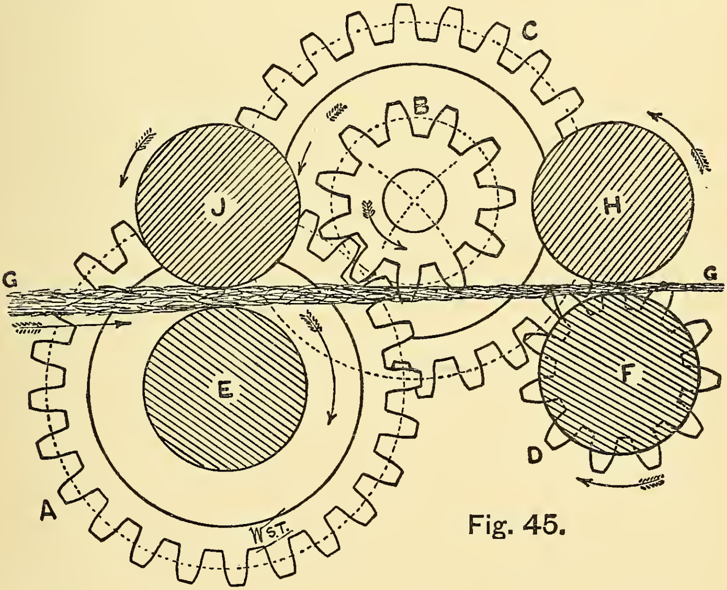


Fig. 45.

the rollers. Assuming the rollers E and F to be equal in diameter, a glance will show that the roller F will have a higher speed than E. A has twenty-four teeth, B has eleven teeth, C has twenty-four teeth, and D has eleven teeth. E and F are each $1\frac{1}{2}$ in. dia. Wheel A revolves at 296 revs. per min.

$$\text{The surface speed of E} = \frac{\text{revs. of A} \times 1\frac{1}{2}'' \times 22}{12'' \times 7} = \frac{296 \times 3 \times 22}{12'' \times 2 \times 7}$$
$$= 116{\cdot}28 \text{ ft. per min.}$$

To find the surface speed of the second roller F in Fig. 45 it will be necessary to know the number of its revolutions. This is found from the gearing between the two rollers, as follows :—

$$\frac{\text{revs. of A} \times \text{teeth in A} \times \text{teeth in C}}{\text{teeth in B} \times \text{teeth in D}} = \frac{296 \times 24 \times 24}{11 \times 11}$$
$$= 1409 \text{ revs. of F.}$$

Now

$$\text{the surface speed of F} = \frac{\text{revs. of F} \times 1\tfrac{1}{2}'' \times \pi}{12''}$$

$$\text{so that} \quad ,, \quad ,, \quad F = \frac{1409 \times 3 \times 22}{12'' \times 2 \times 7}$$

$$\therefore \quad ,, \quad ,, \quad F = 553{\cdot}5 \text{ ft. per min.}$$

Two separate calculations have been worked out in finding the surface speed of F, but this is not really necessary, the two can be combined by simply multiplying the two formulæ together and so obtaining one statement only; for instance—

$$\frac{\text{revs. of A} \times A \times C}{B \times D} \times \frac{\text{dia. of F} \times \pi}{12''} = \frac{\text{revs. of A} \times A \times C \times 1\tfrac{1}{2}'' \times \frac{22}{7}}{B \times D \times 12''}$$

Now substitute values and we get—

$$\frac{296 \times 24 \times 24 \times 3 \times 22}{12'' \times 11 \times 11 \times 2 \times 7} = 553{\cdot}5 \text{ ft. per min.}$$

This result is exactly the same as the previous one, simply because the same factors are used in both cases, but as only one calculation has been necessary instead of two, the latter method is the easiest and best to adopt in all cases where gearing and surface speeds are involved.

In reference to Fig. 45, we have now calculated the surface speeds of rollers E and F.

The surface speed of E = 116·28 ft. per min.
,, ,, F = 553·5 ,,

If the material G is fed to the roller E it will be taken forward at 116·28 ft. per min., but when it reaches the roller F it at once begins to travel at a speed of 553·5 ft. per min. Such an arrangement of speeds cannot therefore be used for rigid substances, but fibrous materials, in certain conditions, can be drawn down from a thick to a thinner state. If a sheet or strand of untwisted cotton fibres be fed to roller E, the faster surface speed of F will cause the fibres to slide over each other, and consequently the roller F will deliver the sheet or strand of cotton in a longer and thinner condition than it originally had. This effect is called the draft between the rollers.

Draft.—This draft is an all-important factor in textile spinning, as it is the chief method for reducing thick masses of fibres to a thinner condition. The amount of the draft is the ratio of the surface speed of the second rollers to that of the first rollers, through which the fibrous material passes. By dividing the faster surface speed by the slower surface speed we obtain the draft between the drawing rollers.

In Fig. 46 the plan view is shown of several rollers and the wheel-work used to drive them. If cotton, for instance, is passed through the rollers in the direction of the arrow, then the back

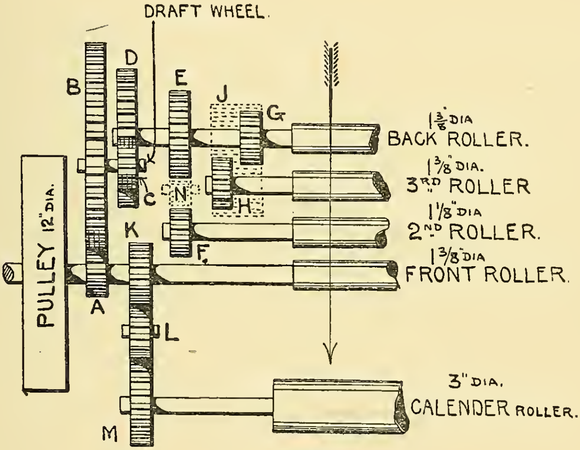


Fig. 46.

roller will have the slowest surface speed and the front roller the fastest surface speed of the four lines of rollers. The diameters of the rollers are shown on the sketch, whilst the teeth in the wheels are as follows:—

A	with	20 teeth	drives	B	with	100 teeth.
C	,,	40 to 70	,,	D	,,	70 ,,
E	,,	43	,,	F	,,	16 ,,
G	,,	22	,,	H	,,	18 ,,
K	,,	22	,,	M	,,	48 ,,

Wheels N and J are simple carriers, and therefore are not used in the calculations.

Since it is known that the back roller is the slowest, it is best to assume that it makes one revolution, and that we work from this as the starting-point.

The surface speed of back roller $= 1 \text{ rev.} \times 1\frac{3}{8} \times \frac{22}{7}$ in. per min.

The surface speed of third roller $= \dfrac{G \times 1\frac{3}{8} \times \frac{22}{7}}{H}$.

Now divide the surface speed of third roller by the surface speed of back roller.

$$\frac{G \times 1\frac{3}{8} \times \frac{22}{7}}{H} \div 1\frac{3}{8} \times \frac{22}{7} = \frac{G \times 1\frac{3}{8} \times \frac{22}{7}}{H \times 1\frac{3}{8} \times \frac{22}{7}} = \frac{22}{18} = 1\cdot222 \text{ draft.}$$

It is seen from this example that in calculating drafts between rollers it is not necessary to use $\frac{22}{7}$ or $3\cdot1416$; it is sufficient if the diameters only are used. A further point to observe is that if two rollers have the same diameter we can also leave the diameters out of the calculation; in other words, all questions of draft can be worked out by taking account of the gearing and the diameters of the rollers, the diameter of the fastest roller being divided by the diameter of the slowest roller. From this it will be seen that the gearing enables one to calculate the velocity ratio or the number of times one roller revolves faster than another, whilst the diameters of the rollers give the ratio of their circumferences. The product of the velocity ratio and the circumference ratio gives the surface speed ratio or the draft.

Draft between the third and second rollers.—To find this first trace out the gearing between the two rollers, starting at the slowest roller, which is the third. H drives G and E drives F. If H makes one revolution then—

the revs. of F will be $\dfrac{H \times E}{G \times F}$.

If the surface speed of the third roller is one, then the surface speed of the second roller will be—

$$\frac{\text{dia. of second roller}}{\text{dia. of third roller}} \text{ or } \frac{1\frac{1}{8}''}{1\frac{3}{8}''}$$

$$\therefore \text{ draft between third and second rollers} = \frac{H \times E}{G \times F} \times \frac{1\frac{1}{8}''}{1\frac{3}{8}''} = \frac{H \times E \times 1\frac{1}{8}''}{G \times F \times 1\frac{3}{8}''}$$

$$= \frac{18 \times 43 \times 9 \times 8}{22 \times 16 \times 8 \times 11} = 1\cdot8 \text{ draft.}$$

Draft between the second and front rollers.—Again follow the gearing, commencing at the second roller, as this is the slowest of the two. F drives E, D drives C, and B drives A. Now if F makes one revolution then—

$$\text{the revs. of A will be} = \frac{F \times D \times B}{E \times C \times A}.$$

If the surface speed of the second roller is one, then the surface speed of the front roller will be—

$$\frac{\text{dia. of front roller}}{\text{dia. of second roller}} = \frac{1\tfrac{3}{8}''}{1\tfrac{1}{8}''}$$

$$\therefore \text{ draft between second and front rollers} = \frac{F \times D \times B}{E \times C \times A} \times \frac{1\tfrac{3}{8}''}{1\tfrac{1}{8}''}$$

$$= \frac{F \times D \times B \times 1\tfrac{3}{8}''}{E \times C \times A \times 1\tfrac{1}{8}''}$$

$$= \frac{16 \times 70 \times 100 \times 11 \times 8}{43 \times 58 \times 20 \times 8 \times 9}$$

$$= 2{\cdot}744 \text{ draft.}$$

Draft between the back and front rollers.—To find this, first trace the gearing between these rollers, starting at the back roller as being the slowest. D drives C and B drives A. If D makes one revolution then—

$$\text{the revs. of A will be} = \frac{D \times B}{C \times A}.$$

If the surface speed of the back roller is one, then the surface speed of the front roller $= \dfrac{\text{dia. of front roller}}{\text{dia. of back roller}} = \dfrac{1\tfrac{3}{8}''}{1\tfrac{3}{8}''}$

$$\therefore \text{ draft between front and back rollers} = \frac{D \times B}{C \times A} \times \frac{1\tfrac{3}{8}''}{1\tfrac{3}{8}''}$$

$$= \frac{70 \times 100}{58 \times 20} = 6{\cdot}03 \textit{ draft.}$$

The results now obtained are—

Draft between	back	and	third	rollers	= 1·222.
,, ,,	third	,,	second	,,	= 1·8.
,, ,,	second	,,	front	,,	= 2·744.
,, ,,	back	,,	front	,,	= 6·03.

It will be seen that the first three of the above results must equal the last result, and as drafts are accumulative we can obtain the last or total draft by multiplying the intermediate drafts together—

$$1{\cdot}222 \times 1{\cdot}8 \times 2{\cdot}744 = 6{\cdot}03 \text{ total draft.}$$

The general formula for the total draft in Fig. 46 can be expressed as follows :—

$$\frac{D \times B \times \text{dia. of front roller}}{C \times A \times \text{dia. of back roller}} = \text{total draft.}$$

As exercises the student may calculate the surface speed of each roller; by dividing the quicker surface speed of one roller by the slower speed of another roller we obtain the draft between the two rollers.

Changing the Draft.—Altering the draft between rollers is frequently necessary in textile machinery. This is effected by altering the wheels, and most often this is done by so arranging the gearing that one of the wheels can be changed without interfering much with the other wheels in the train. In Fig. 46 the wheel C is the one that is usually changed, and on this account it is generally called the *change-wheel* or *draft-wheel.* In the calculations already made, C has been taken as having fifty-eight teeth. It will be clearly seen that any alteration of the draft-wheel will effect a change in the speed of the back roller, third roller, and second roller, but no alteration in the front roller speed, consequently the draft will be changed only between the second roller and front roller. A glance at the sketch Fig. 46 will show this. The student, however, is advised to calculate all the drafts as an exercise. It will be sufficient here to work out the total draft when a change-wheel with fifty teeth is used at C.

$$\frac{D \times B \times \text{dia. of front roller}}{C \times A \times \text{dia. of back roller}} = \frac{70 \times 100 \times 1\frac{3}{8}''}{50 \times 20 \times 1\frac{3}{8}''} = 7 \text{ total draft.}$$

A change of a wheel from fifty-eight teeth to fifty teeth has altered the draft from 6·03 to 7. By reducing the change-wheel the draft has been increased, and by increasing the change-wheel the draft will be decreased. The relation between the change-wheel and the draft may therefore be stated as follows for all cases where a similar arrangement of wheels is used :—

$$\frac{\text{present draft} \times \text{present draft-wheel}}{\text{required draft-wheel}} = \text{required draft}$$

$$\text{or } \frac{\text{present draft} \times \text{present draft-wheel}}{\text{required draft}} = \text{required draft-wheel.}$$

This statement affords a very convenient and simple test for changes made in draft. For instance, in Fig. 46 a draft of seven is produced when a fifty-teeth draft-wheel is used; then $7 \times 50 = 350$, and this number will be constant so long as no other wheels or rollers are changed. If 350 is divided by any draft required, the quotient will be the draft pinion for that draft; also if 350 is divided by the draft pinion the quotient will be the draft. This method of obtaining a *constant*, to save the trouble of always making perhaps a long calculation when changing draft, is the best and easiest to adopt. The usual method is to work out the gearing with the exception of the change-wheel; for example, in Fig. 46 the constant is obtained as follows:—

$$\frac{D \times B}{x \times A} = \frac{100 \times 70}{x \times 20} = 350 \text{ constant.}$$

The examples just given of draft are typical of the roller driving in many machines in a cotton-mill; the particular illustration in Fig. 46 is from a draw-frame, but the same type is used on other machines where either four or three rollers are used. Other machines are now given where calculations for draft are required. In Fig. 47 the completed gearing of a scutching machine is illustrated. The student must first trace out the gearing and write down a description of the various parts that are driven. The machine is driven from a counter-shaft by a belt to the pulley Q on one end of the beater-shaft. From this point all the driving of the various parts of the machine can be traced. The gearing is on each side of the machine, and to assist the student a plan view is given in Fig. 48. From this plan it will be noted that the pedal-roller or regulating roller is the real start for feeding the cotton, and the finishing-point is the lap-roller, where a lap is made ready for the carding machine. Between these two points there is a draft; three or four sheets of cotton enter the pedal-roller, and one sheet, much thinner, is rolled into lap on the lap-rollers. The driving arrangements between the start and finish can now be traced by using the letters on the drawings, the student to carefully follow the references on both drawings (Figs. 47, 48). As already explained, it is best to work out the draft on the supposition that the initial feed-roller is the first driver and that it makes one revolution.

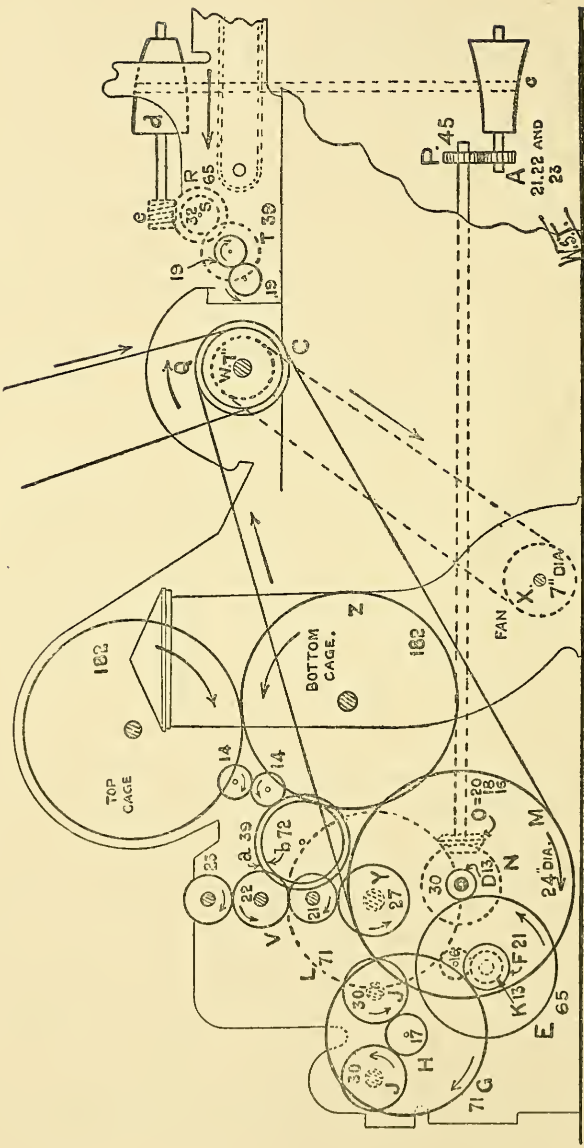


Fig. 47.

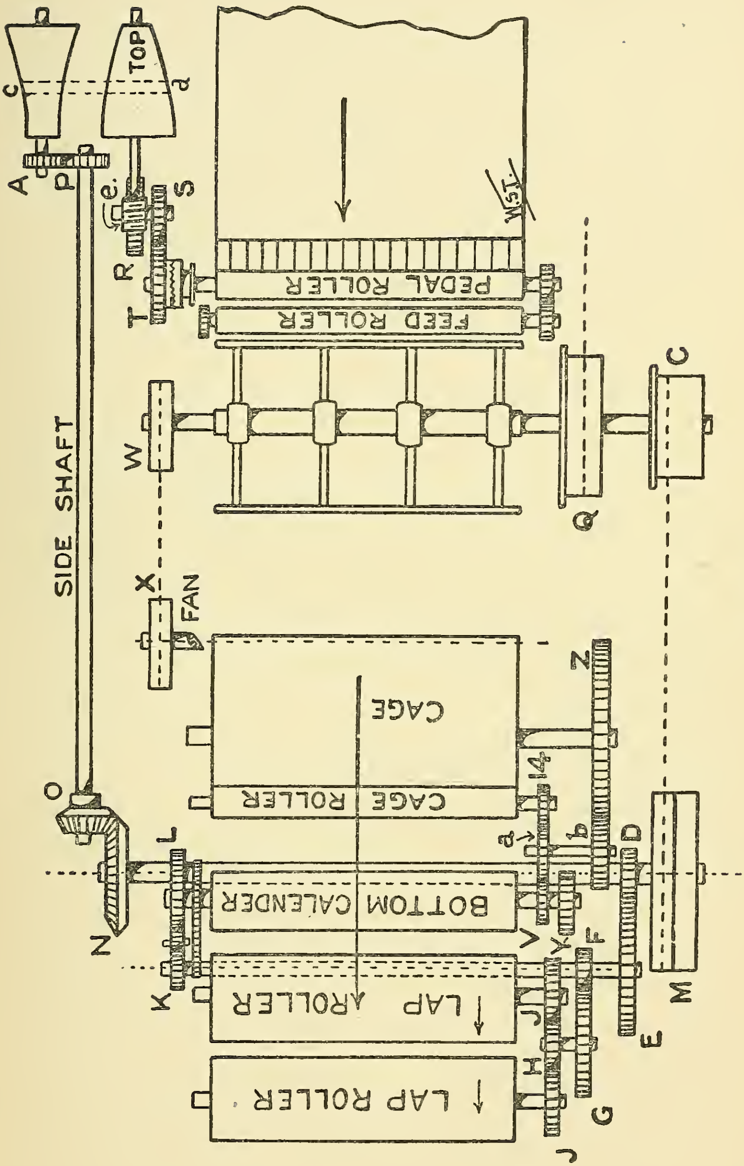

SIDE SHAFT
TOP
PEDAL ROLLER
FEED ROLLER
FAN
CAGE
CAGE ROLLER
BOTTOM CALENDER
LAP ROLLER
LAP ROLLER
A
P
c
d
e
S
R
T
W
X
Q
C
Z
O
L
N
K
D
M
E
F
G
H
J
V
Y
a
b
14

Fig. 48.

T with 39 teeth	drives	S with 32 teeth
R ,, 65 ,,	,,	*e*, single worm
d, top cone, $7\frac{1}{4}''$ dia.	,,	*c*, bottom cone, $5\frac{3}{4}''$ dia.
A with 22 teeth	,,	P with 45 teeth
O ,, 20 ,,	,,	N ,, 30 ,,
D ,, 13 ,,	,,	E ,, 65 ,,
F ,, 21 ,,	,,	G ,, 71 ,,
H ,, 17 ,,	,,	J ,, 30 ,,
Pedal-roller $2\frac{1}{4}''$ dia.		Lap-roller $8\frac{3}{4}''$ dia.

$$\therefore \frac{T \times R \times d \times A \times O \times D \times F \times H}{S \times e \times c \times P \times N \times E \times G \times J} = \text{revs. of lap- or shell-roller.}$$

If the surface speed of pedal-roller equals one, then the surface speed of lap-roller will be—

$$\frac{\text{dia. of lap-roller}}{\text{dia. of pedal-roller}}$$

$$\text{so that } \frac{T \times R \times d \times A \times O \times D \times F \times H \times \text{dia. of lap-roller}}{S \times e \times c \times P \times N \times E \times G \times J \times \text{dia. of pedal-roller}} = \text{draft}$$

$$\frac{39 \times 65 \times 7\frac{1}{4}'' \times 22 \times 20 \times 13 \times 21 \times 17 \times 8\frac{3}{4}''}{32 \times 1 \times 5\frac{3}{4}'' \times 45 \times 30 \times 65 \times 71 \times 30 \times 2\frac{1}{4}''} = \text{draft}$$

$$\frac{39 \times 65 \times 29 \times 4 \times 22 \times 20 \times 13 \times 21 \times 17 \times 33 \times 4}{32 \times 1 \times 4 \times 23 \times 45 \times 30 \times 65 \times 71 \times 30 \times 4 \times 9} = 4 \text{ total draft.}$$

Another example of a scutcher gearing is given in Figs. 49, 50, and 51. Fig. 49 is a plan view of the machine, whilst Figs. 50 and 51 represent elevations of each side of the same machine. The chief point of difference between this example and Fig. 47 is the arrangement of the cone drums.

The calculation for the total draft will proceed, as already shown, by commencing at the pedal feed-roller and continue as follows:—

T with 67 teeth	drives	S with 51 teeth
R ,, 90 ,,	,,	*e*, a double worm
c ,, $7''$ dia.	,,	*d* with $5\frac{1}{2}''$ dia.
A ,, 20 teeth	,,	P ,, 45 teeth
O ,, 20 ,,	,,	N ,, 60 ,,
H ,, 15 ,,	,,	G ,, 72 ,,
F ,, 14 ,,	,,	B ,, 26 ,,
Pedal-roller $3''$ dia.		Lap-roller $9''$ dia.

$$\frac{T \times R \times e \times A \times O \times H \times F \times \text{dia. of lap-roller}}{S \times e \times d \times P \times N \times G \times B \times \text{dia. of pedal-roller}} = \text{draft}$$

$$\frac{67 \times 90 \times 7'' \times 20 \times 20 \times 15 \times 14 \times 9''}{51 \times 2 \times 5\frac{1}{2}'' \times 45 \times 60 \times 72 \times 26 \times 3''} = 3{\cdot}75 \text{ draft.}$$

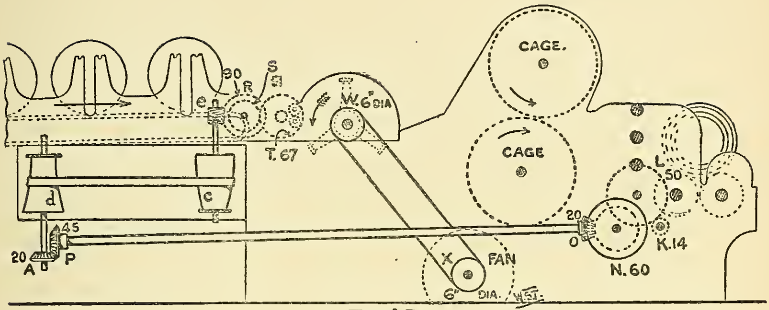


Fig. 49.

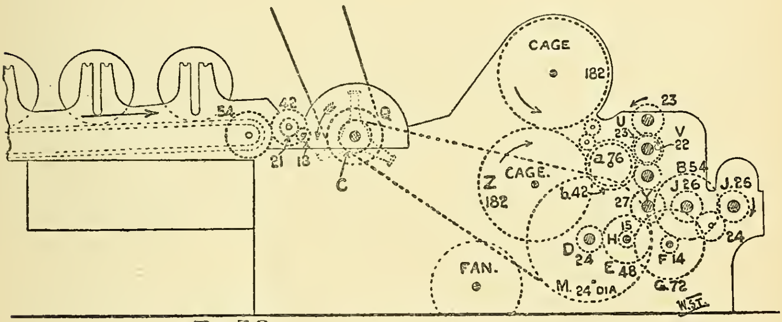


Fig. 50.

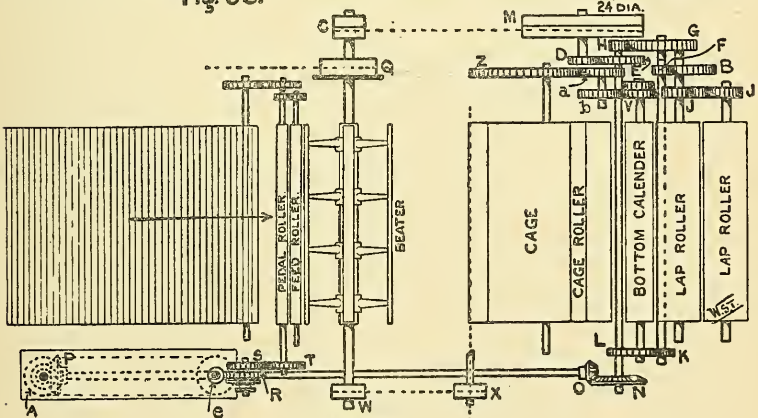


Fig. 51.

In addition to working out the total draft, a number of exercises can be found in calculating the draft between the feed-roller and cages and between the cages and the bottom calender-roller, etc.

The next example is that of a revolving flat card (Fig. 52), which may be taken as typical of the calculations associated with this class of machine. The machine is driven from a line-shaft through the driving pulley on the end of the cylinder-shaft. The other end of the cylinder-shaft, by means of pulley and belt, drives a pulley on the taker-in, and this organ, through the pulley C, drives through a pulley the gearing leading up to the doffer and calender-roller. The doffer, from the other end of its shaft, drives a side shaft, which by means of bevel wheels gives motion to the feed-roller, at which point the cotton enters the card in the form of a sheet. The finishing-point is the calender-roller, where the cotton is gathered up in the form of an untwisted strand. There has been a considerable amount of draft or attenuation of the cotton in its progress through the machine.

Taking the feed-roller as the starting-point, we trace out the driving as follows:—

N with	136	teeth drives	A	9-35	teeth
M ,,	32	,, ,,	L	27	,,
F ,,	180	,, ,,	J	23	,,

Feed-roller $2\frac{1}{4}''$ dia. Calender-roller $3\frac{1}{4}''$ dia.

This put in the form of a statement is—

$$\frac{N \times M \times F \times \text{dia. of calender-roller}}{A \times L \times J \times \text{dia. of feed-roller}} = \text{draft}$$

$$\frac{136 \times 32 \times 180 \times 3\frac{1}{4}''}{20 \times 27 \times 23 \times 2\frac{1}{4}''} = 91 \cdot 1 \text{ draft.}$$

The change-wheel for altering the draft is the small bevel A, and a fairly wide range of wheels is used. The peculiarity of this change should be noted, for under normal conditions a pair of bevel wheels are specially made as a pair to gear with each other; it has, however, been found practicable to drive the feed-roller of a card with one of a pair of bevels fixed and changing the other, the side shaft being supported in sliding bearings for the purpose. In the above formula A figures as a driven wheel, but in reality it is a driving wheel, for it clearly drives the feed-roller, therefore if a larger wheel is put on, no part of the machine will be altered except the speed of the feed-roller, and

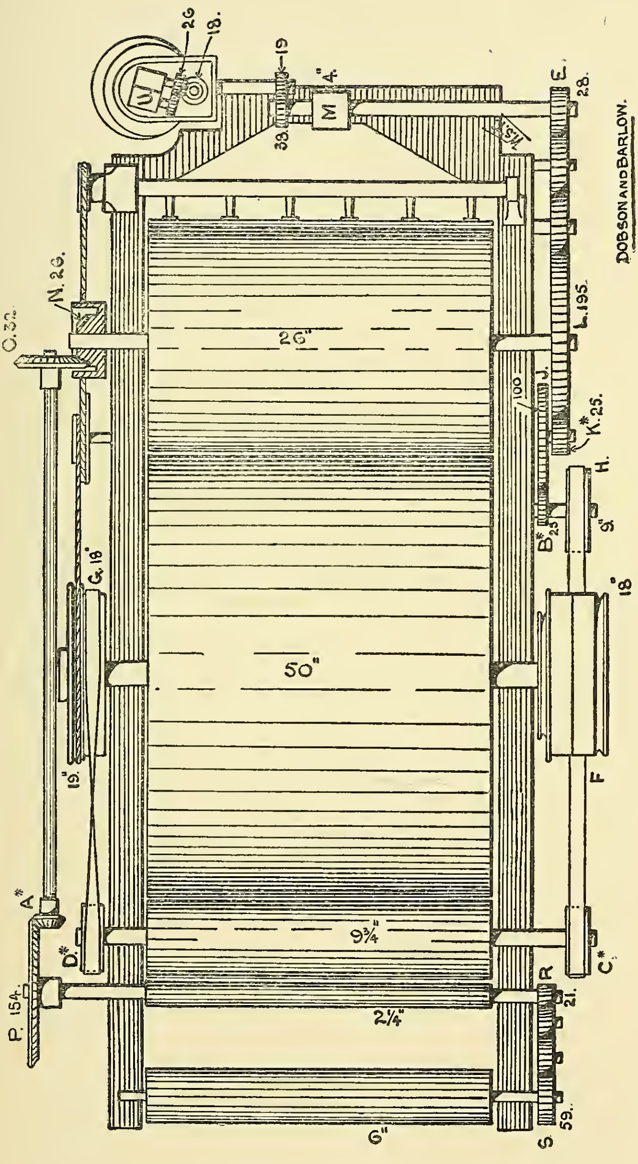

26
18.
19
4"
M
33.
E.
28.
DOBSON AND BARLOW.
O.32.
N.26.
26"
L.195.
J.
100
K*.25.
H.
B*
25
9"
G.18"
18"
50"
19"
F
A*
D*
9¾"
C*
R
P.154.
21.
2¼"
6"
S
59.

Fig. 52.

this will run faster. The draft will naturally be reduced. On the other hand, a smaller wheel A will drive the feed-roller slower and increase the draft, so that we have here a case of inverse proportion.

To save working out the full calculation for draft it is best to find the constant—

$$\text{present wheel} \times \text{present draft} = 20 \times 91 \cdot 1 = 1822 \text{ constant}$$

$$\text{so that } \frac{\text{constant}}{\text{required wheel}} = \text{required draft} = \frac{1822}{30} = 60 \cdot 74 \text{ draft}$$

$$\text{and } \frac{\text{constant}}{\text{required draft}} = \text{required wheel} = \frac{1822}{100} = 18 \cdot \text{ wheel.}$$

EXERCISES

1. In Fig. 44, p. 28, the roller D makes 113 revs. per min., its diameter is $1\frac{1}{4}$ in. How many yards will be delivered in ten hours?

2. A travelling lattice moves at the rate of 10 ft. per min. At what speed must the block-shaft revolve to give this speed?

3. An opener cylinder is 3 ft. in dia. and runs at 420 revs. per min. At what speed do the blades pass through the cotton that is fed to it?

4. The feed-roller of a scutcher is $2\frac{1}{4}$ in. dia. and runs at 9 revs. per min. The lap-roller is $8\frac{3}{4}$ in. dia. and runs at 9·3 revs. per min. What is the surface velocity ratio between the two rollers?

5. What is surface speed, and how is it calculated? Give an example to illustrate why the diameters alone can be used in calculations for draft.

6. Sketch an arrangement of gearing between two rollers so that the surface speed of one of the rollers can be readily altered.

7. The lattice of a scutcher travels at a rate of 5 yd. per min., and 3 per cent. of waste is taken out of the cotton as it passes through the machine. Find the revs. per min. of a 9-in. dia. lap-roller in order to obtain a draft of four.

8. Sketch a gearing plan view of a card and calculate the surface speeds of feed-roller, taker-in, cylinder, doffer, and calender-roller, and give the drafts of each of these organs relatively to the feed-roller.

9. What is a "constant number"? Give illustrations of its usefulness.

10. A machine has a draft of four, and a change-wheel with forty teeth produces this draft. What is the constant number for the machine?

11. Find the following drafts :—

Between the pedal-roller and the cages.
,, cages ,, cage-rollers.
,, cage-rollers ,, calender-roller.
,, cage-rollers ,, lap- or shell-rollers.

Particulars may be taken from the drawings in the book, or from an actual machine.

12. How is the vertical conical opener driven? Explain why a balanced rope-drive is used.

CHAPTER III

CRANKS, CAMS, AND SCROLLS

Cranks.—Wheels and pulleys give a continuous or intermittent circular motion. This circular motion can be transformed into a reciprocating motion by the mechanical appliance termed a crank. Fig 53 gives its essential features.

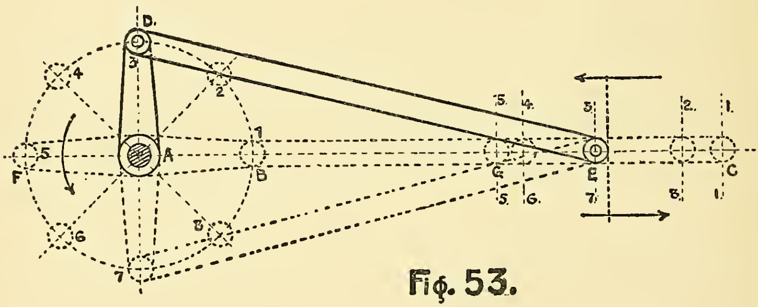


Fig. 53.

The crank AB is really a lever revolving round a centre A. A link or connecting rod BC swivels on the stud at B and the end C slides in guides and travels along a straight line as the crank AB revolves. When the crank has made half a revolution to F the end C has moved to G; during the next half of the revolution of AB the sliding end of the link will reverse its motion and travel back from G to C. It will thus be seen that the continuous circular motion of the crank AB has been transformed into a to-and-fro motion or reciprocating motion of the end C of a link or rod BC. If AB makes one quarter of a revolution to D, the end C will move to E. It will at once be noted that the point E is not half-way between G and C although D is half-way between B and F; in other words, the uniform circular motion of a crank does not produce a uniform movement at the end of a rod connected to the crank. All cranks, of whatever size, will produce the same character of motion as shown in Fig. 53, so that such a motion can only be used when it is desired to move the end C to G, and the intermediate parts of the traverse are not dependent on a uniform motion or are of little consequence. Typical forms of crank motions are seen in the steam-engine, planing machines, printing machines, eccentrics, and hosts of examples are to be found in general machinery.

Cams.—It frequently happens that some part or parts of a mechanism require to be moved in some well-defined manner that differs from the traverse produced by a crank motion. For instance, a common form of movement of a slide or the end of a lever is a uniform one, *i.e.* a movement over equal spaces in equal times. On the other hand, a very irregular traverse motion may be desired or an intermittent motion. Such movements are reversible, and variable motions may be required, such as a quick forward uniform motion and a slow return movement. Cams are the mechanical appliances used for producing movements of this kind.

Models are readily obtainable or easily made to illustrate the use of cams.

The illustrations in Figs. 54, 55, 56, and 57 will give a clear idea of their general character. Fig. 54 represents a flat piece

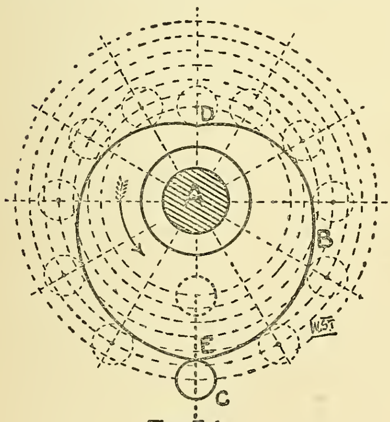


Fig. 54.

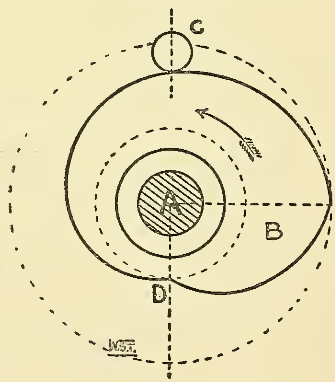


Fig. 55.

of metal B cut out in the form of a heart and fixed on a shaft A. A stud C is kept in contact with the periphery of the cam, so that as the cam revolves the pin C will rise and fall between the smallest and largest diameter of the cam. It will readily be seen that the shape of the cam can be made to give to C a straight line to-and-fro uniform motion and of equal extent in both directions. The actual construction of cams belongs to mechanical drawing, but Fig. 54 gives sufficient information to enable the method to be clearly understood. In Fig. 55 the pin C will have the same uniform traverse as in Fig. 54 and will make the to-and-fro motion in the same time, but the cam will make three-quarters of a revolution in moving C its full distance and only one-quarter of a revolution for C to return to its original position.

Fig. 56 again gives a uniform motion to the pin C, but one complete revolution is required to do this, and immediately the highest point E of the cam moves from under the pin, the pin will fall at once to D and commence again its upward motion. A further general example is given in Fig. 57. The

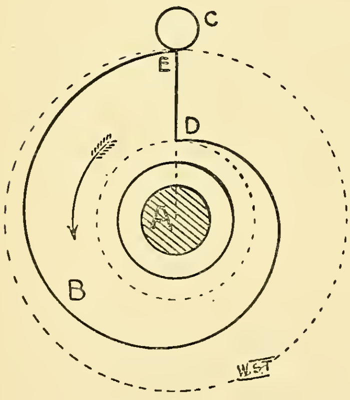


Fig. 56.

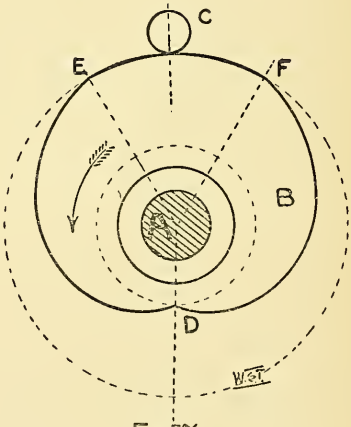
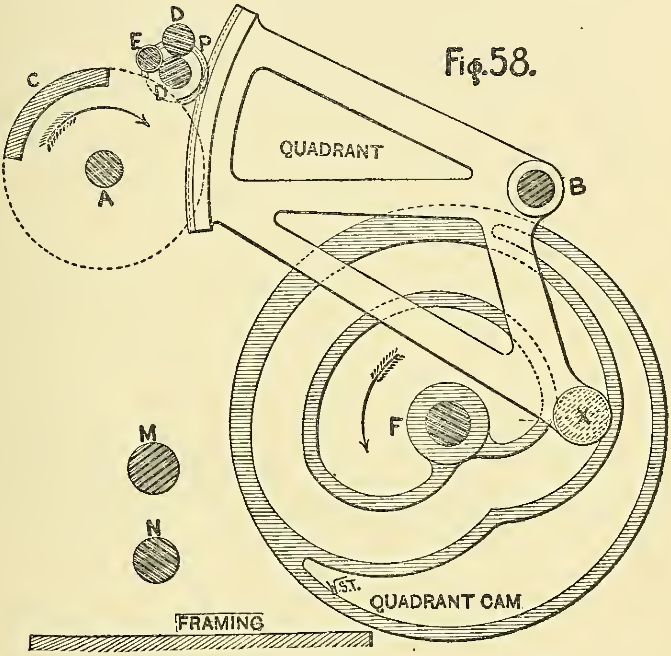


Fig. 57.

cam B is divided into three parts; the portion from D to E raises the pin E from the lowest to the highest point; then comes a portion of the cam, E to F, that is circular, so that during this portion of the revolution of the cam the pin C will not move. When this portion has passed, the remainder of the cam, from F to D, will permit the pin to return to its starting-point.

Whilst in some cases the pin C is kept in contact with the surface of the cam by pressure or weight, which ensures the pin rising and falling, it is sometimes necessary to make the cam in the form of a groove into which the pin has a sliding fit. Fig. 58 illustrates a cam of this type used on the combing machine. The inside cam is the essential portion; the bowl or pin X moves along an arc drawn from the centre stud B, and its motion produces a corresponding effect on

Fig. 58.



a portion of a wheel centred at B (termed a quadrant) which gears into a small wheel P on the roller D. This wheel D thus receives a forward motion, then a rest due to the circular portion of the cam, and then a reverse or backward motion.

Another form of cam is shown in Fig. 59. It consists essentially of a cylinder with a groove cut in it into which fits a pin or bowl. This pin fixed to a slide gives a uniform traverse to the bar, and is a frequent form for winding yarn in cheeses, etc., on quick-winding frames.

Scrolls.—When a long, heavy mass of material like the carriage of a self-acting mule has to travel 5 ft. outwards and 5 ft. back, and does this, say, four times per minute, ordinary cams or crank motions are impracticable, so an ingenious driving arrangement is adopted. Bands or ropes are attached to the square or centre piece of the carriage and to drums or pulleys; these latter are driven in one direction, and draw the carriage in, then reverse, and assist in drawing the carriage out. If the drums are one diameter throughout the carriage would

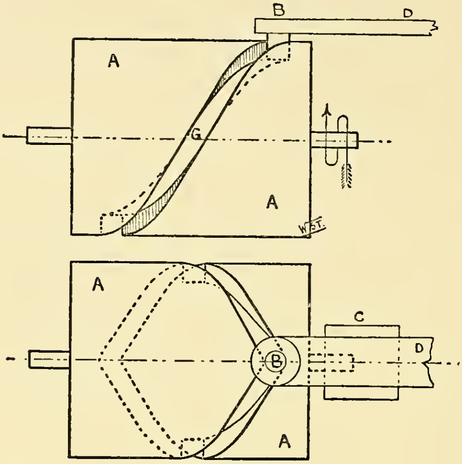


Fig. 59.

travel at an equal speed throughout its journeys, and it would start suddenly and finish abruptly, both effects being damaging to the machine and to the delicate yarn being spun. The

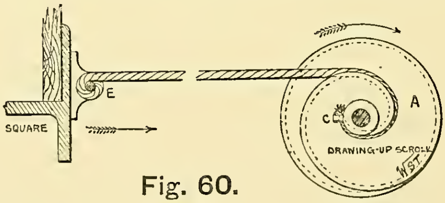


Fig. 60.

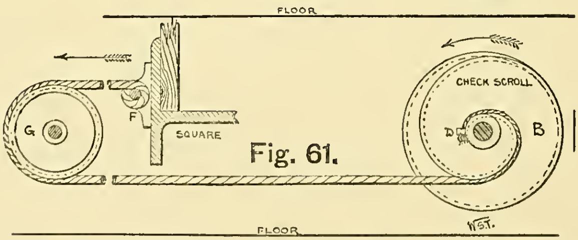


Fig. 61.

drums are therefore made so that the rope is wound on at the start and finish on small diameters, and the diameters gradually increased so that the highest speed of travel takes place when the carriage is about the middle of its traverse. Figs. 60 and 61 will illustrate the method. Variable winding drums of this type are termed scrolls.

A common form of cam for traverse guides in guiding the rovings to the back rollers of flyer frames, etc., is shown in Fig. 62.

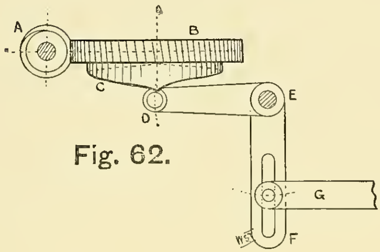


Fig. 62.

In Fig. 63 the cam H is used to slide the wheel P out of gear with the clutch at F.

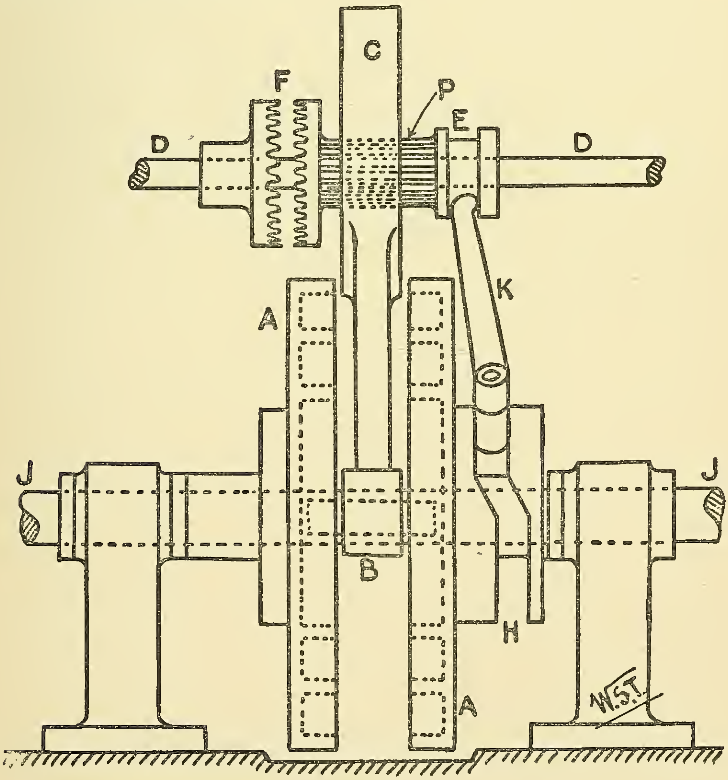


Fig. 63

EXERCISES

1. Sketch the crank arrangement for actuating the slay in a loom.
2. Sketch and describe a simple form of cam such as a tappet, giving reasons for the shape adopted.
3. Sketch and describe the action of any cam with which you are acquainted.
4. Describe an eccentric, and by means of sketches explain its action for some particular purpose.
5. What is the difference between a cam and a scroll?
6. Sketch and describe the comb box on a carding machine.
7. Sketch a picking cam arrangement of the loom, and explain its action.
8. Sketch and explain the picking motion known as the cone pick, with special reference to the tappet.

CHAPTER IV

FRICTION

A NUMBER of simple experiments may be made that illustrate friction, or what is more correctly termed the *Resistance of Friction.* A small ball on a smooth table only requires the slightest push to move it. A smooth flat weight on a smooth table is easily pushed or pulled along the table; a heavier weight under the same conditions may be found more difficult to move. Metal weights or wooden blocks with rough surfaces are not so easily moved, and still more force is necessary if the table is also rough. Tests of this kind give us general ideas of the resistance of friction under various conditions, but only systematised tests will give us information that can be applied to the design of machinery or enable us to explain effects that occur in such machinery.

The usual form of apparatus for friction tests is shown in Fig. 64. A table A made of timber fairly smooth on its

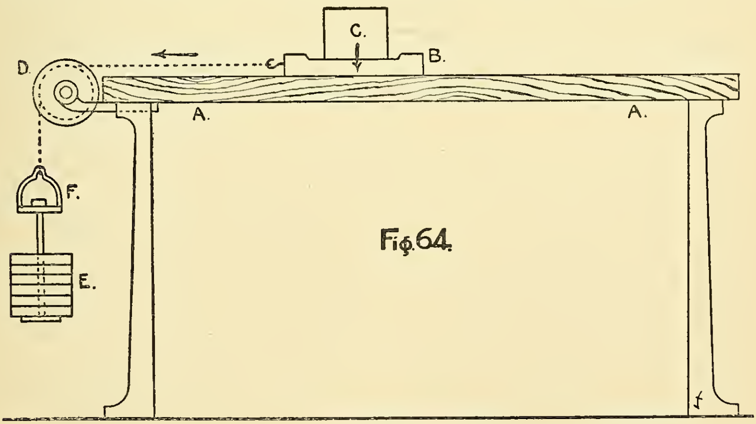


Fig. 64.

surface is supported at a convenient height by iron legs. On this surface is a loose block of timber B on which weights C can be placed. Attached to the loose block or slider B is a strong cord which passes over the pulley D, its free end carrying a weight hook or pillar E; a small pan F may be used for smaller weights. When making the tests it will be found that as weights are added at E the slider B will begin to move, and then quite suddenly rush along the table toward the pulley D. If, however, the slider is very slightly pushed on the table A, or tapped after each weight is added, the slider will ultimately move slowly and uniformly along the table. It will be found that it requires more weights to start the slider than to keep it moving slowly, so we can conclude that there is a friction of rest and a friction of motion. Friction of rest is called *Static Friction*, friction of motion *Sliding Friction*, and they must be carefully distinguished and experimented upon separately.

In making the tests, the weight of the slider B will be part of the weight causing friction between B and table A. Also the weight pillar E and pan F will be part of the load used to overcome the resistance of friction, so these must be added to their respective added weights.

Draw up the notes of observations as follows:—

EXPERIMENT ON SLIDING FRICTION.

Date.................... Observer....................

Kind of material . . . . . Oak
Weight of slider . . . . . 5 lb.
Weight of weight pillar . . . 0·8 lb.

Pressure between the surfaces causing friction = weight of C + B.	Resistance of friction = load + weight of pillar.
10 lb.	1·5 lb.
15 "	2·2 "
20 "	3·1 "
25 "	3·8 "
30 "	4·4 "
40 "	6·1 "
50 "	7·5 "
60 "	8·9 "
70 "	10·5 "
90 "	13·4 "
100 "	15·2 "
510 lb.	76·6 lb.

$$\text{Average results} = \frac{\text{resistance of friction}}{\text{pressure between the surfaces}} = \frac{76 \cdot 6}{510} = 0 \cdot 15$$

so that

$$\text{friction} = 0 \cdot 15 \times \text{pressure between the surfaces.}$$

The above results can now be plotted on squared paper as in Fig. 65. The horizontal lines will represent pressure and the vertical lines the resistance of friction as represented by the load on the weight pillar.

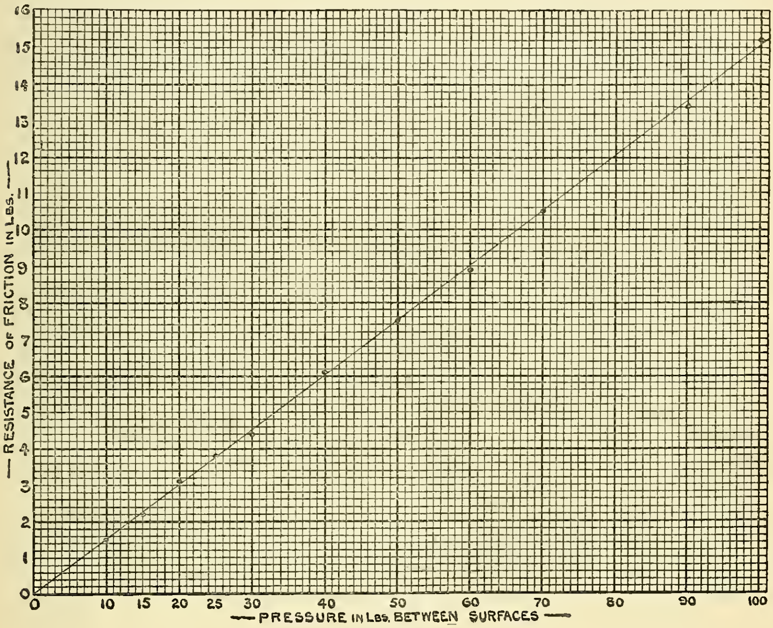


Fig. 65.

Fig. 65 is the diagram produced, and it is clearly seen that whilst some of the positions are not exactly in the path of a straight line, the variations from it are so slight that they can be considered small errors of observation, and that a straight line would represent the true results. From the diagram we therefore deduce the important conclusion that *friction is directly proportional to the pressure between two surfaces that remain in the same condition.*

The ratio

$$\frac{\text{resistance of friction}}{\text{pressure}}$$

is called the coefficient of friction.

Several tests, on different materials, must be made before the law of friction stated can be considered true. There must clearly be a limit to this law of friction, for if an excessive pressure is produced between the slider and the table in Fig. 64, the two surfaces will grip and quite another set of conditions will be set up. If it were possible for the student to cut away half the bearing surface of the slider B, so that it was certain only half the previous sliding surface would be sliding on A, then further tests would probably lead to the discovery that this alteration of surface or area of surfaces in contact had no influence on the resistance to friction, so a little further useful information would be obtained that could be expressed shortly as, *friction is independent of the areas of the surfaces in contact.* Much more difficult tests involving motion would also give a negative result, for they would probably lead to the conclusion that *friction is independent of velocity.*

It is practically impossible for anything to be done without friction playing a part to a greater or less extent, so that in all mechanical arrangements, from the most elementary to the most complicated, its resistance must be measured before we can get a clear idea of the actual usefulness of any given contrivance. The advantages and disadvantages of friction are relative terms, but in general we say that friction is an advantage if it assists in useful work being done, and a disadvantage if it neutralises or reduces the amount of useful work. Belts and ropes for transmitting motion depend on friction for their usefulness; nails, wedges, etc., rely upon friction to serve their purpose; a locomotive could not start or stop without friction, nor could we walk. A nut and bolt is a good example of the usefulness of friction. The binding effect is produced when the surfaces of the nut and bolt threads are forced into contact when the bolt meets with resistance to its further movement. This contact is so close that under normal conditions the nut will retain its grip. Vibrations will tend to loosen the nut, but this can be prevented by lock-nuts and special devices that stop the nut turning. The vice in its various forms depends on friction for its effectiveness. Any object held between the jaws of the vice is kept in place by the resistance of friction. The disadvantages are serious in the movement of one surface over another, for extra power is required to overcome friction, over and above the useful work that has to be done by a machine. This extra work also involves the wearing away of material.

A variety of means are adopted to reduce friction—by the use of lubricants, roller and ball bearings (*see* Fig. 66), anti-friction wheels (*see* Fig. 67), highly polished sliding surfaces, etc., and a choice of materials for the sliding surfaces that experiment teaches us have a low coefficient of friction.

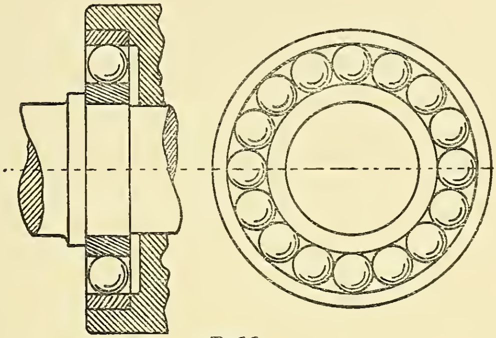


Fig. 66.

Example.—A wooden skip 30 lb. weight is filled with 200 lb. of yarn, the whole being pulled along the floor of a room. If the coefficient of friction is ·18, what is the force exerted to draw the skip along?

$$\text{Total load producing friction} = 30 + 200 = 230 \text{ lb.}$$

$$\text{Resistance of friction} = \text{coefficient} \times \text{load}$$

$$\therefore \text{pull} = \cdot 18 \times 230$$

$$= 41 \cdot 4 \text{ lb.}$$

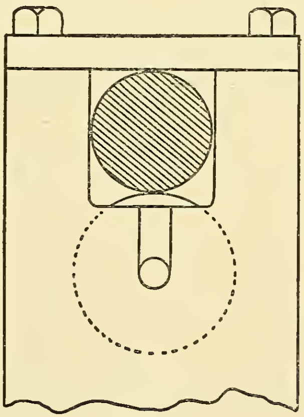


Fig. 67.

Example.—A block of dressed stone weighing 880 lb. has to be moved by sliding it a distance of 6 in. on brickwork. What force must be applied if the coefficient of friction between the surfaces is 44?

Total load producing friction = 880 lb.

Resistance of friction = coefficient × load

∴ force = 880 × ·44

= 38·72 lb.

Example.—A carriage weighing $2\frac{1}{2}$ tons is drawn along a road. The wheels are 5 ft. dia. and the axle is 4 in. dia. What pull must the horse exert if the coefficient of friction on the axle is ·16 and the road friction is ignored?

Total load producing friction = $2\frac{1}{2} \times 2240 = 5600$ lb.

Resistance of friction = coefficient × load.

If the coefficient at 4 in. is ·16 then the coefficient at 60 in. will be $\frac{4}{60} \times \cdot 16$,

so that the force $= \frac{4''}{60''} \times \cdot 16 \times 5600$

$= 59\cdot 73$ lb.

The most familiar form of the application of friction in machinery is in belt and rope driving. The power from the engine is exerted at the periphery of the fly-wheel, which is grooved for ropes. Fig. 68 illustrates the general type of

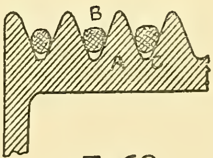


Fig. 68

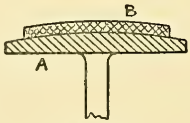


Fig. 69.

groove. The rope B, partly due to its own weight and partly to its tightness, becomes wedged in the groove C, so that the friction between the rope and the pulley A is sufficient to transfer the greater part of the motion to the rope itself, and consequently the rope becomes the power medium.

In the case of belt driving (Fig. 69) there is simply a flat surface of leather B that is tightened up into close contact with the metal surface of the pulley. The friction between these two surfaces A and B enables motion to be transferred from one pulley to another by pure friction. If the coefficient of friction between A and B is very small the belt will slip over the surface of the pulley, and so power and motion will be lost. The higher the coefficient of friction the better the grip, and to raise the coefficient the surface of either belt or pulley or both are specially prepared to increase the grip.

Innumerable examples are to be found in machines, that are illustrative of the advantageous use of friction. Several are

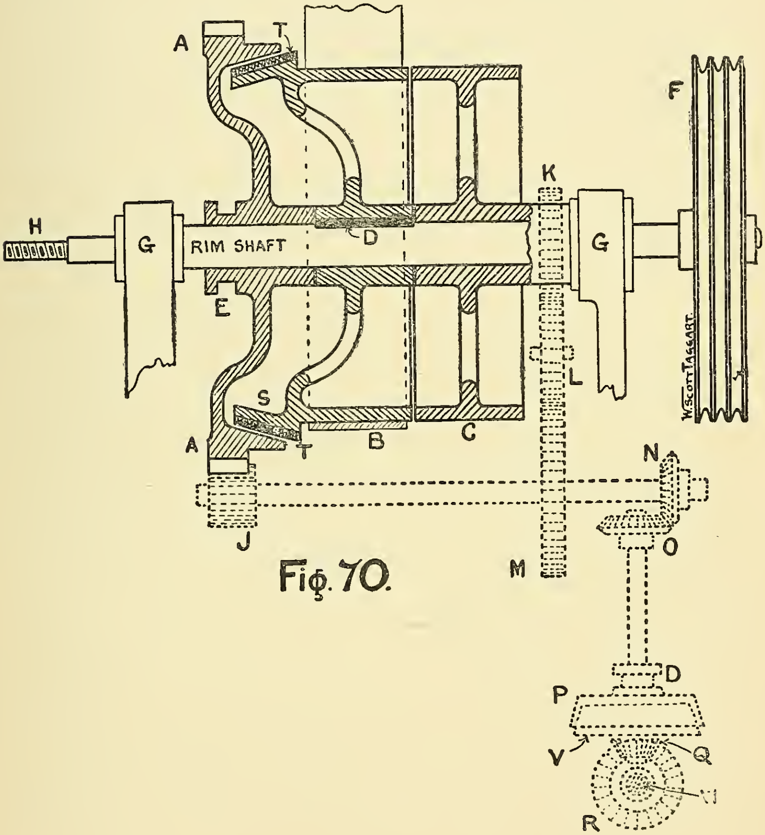


Fig. 70.

given in the accompanying drawings. Fig. 70 shows an example taken from the self-acting mule. The whole arrangement serves a very important purpose and affords an interesting exercise in tracing out mechanical operations involving the use of friction driving.

The rim-shaft is the main-shaft of the machine. It is provided with fast and loose pulleys B and C, through which the whole machine is driven from a counter-shaft. A large wheel A is loose on the rim-shaft. One face of this wheel is dished out in a conical form, and an extension S of the fast pulley B is also turned externally and covered with a leather belt so as to fit exactly the conical surface on A. The outside face of A has a groove E for the forked lever, which enables the coned wheel A to be moved to and fro along the shaft, and so forces the internal cone on A into contact with the external leather-covered cone on the fast pulley B. On the other hand, when the two conical surfaces are in contact the forked lever will separate them.

When the machine is being driven, the belt is on the fast pulley B and the wheel A is out of contact with it, but at a certain moment it is necessary to reverse the direction of the motion of the rim-shaft at a slow rate and for a second or two only. This is effected by moving the main belt on to the loose pulley C and at the same time forcing the wheel A backwards until the two conical surfaces grip each other. The wheel K, which is keyed on to the boss of the loose pulley C, will now drive the wheel A through L, M, and J in the opposite direction to its previous motion, and as A grips the fast pulley through the friction cones it will thus drive the rim-shaft in the reverse direction. A further example of friction driving is afforded by the extension of the gearing in the same figure, whereby motion can be imparted to the scroll-shaft W at desired intervals of time by putting the friction cones P and V into contact and driving through the bevel wheels Q and R. A forked lever is arranged to operate the cone clutch at the groove D.

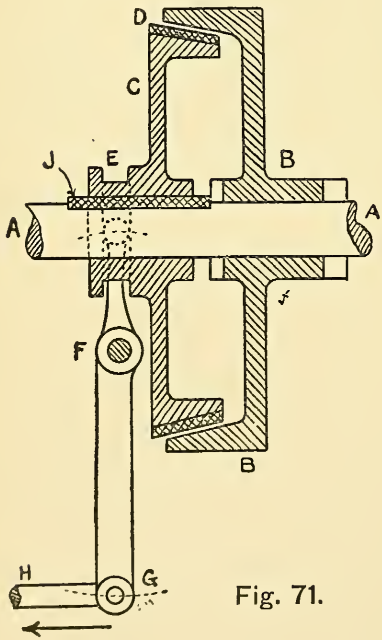


Fig. 71.

A simple type of friction clutch is shown in Fig. 71. A pulley B runs loose on the shaft A. This pulley may be driven by a belt or through gearing by cutting teeth on the face or keying a wheel on the boss. B is driven continuously, but this has no effect in moving the shaft. A conical dish form is turned on one side of B and a leather-covered conical surface plate or disc C of the same taper is mounted on the shaft A by means of a floating key; that is, the key J is fixed in the shaft, and C has a slot cut in its boss so that the disc can slide to and fro. As illustrated, the two conical surfaces are not in contact, so the shaft is not revolving, but pulley B is being driven. By pulling the rod H in the direction of the arrow, the lever centred at F will force the conical surface of C into contact with the corresponding conical surface of B, the two will grip, and the friction is sufficient for B to drive the shaft A through C. To stop the shaft all that is necessary is to push the rod H in the opposite direction to the arrow.

An example of a friction drive is sketched in Fig. 72. A is a flat disc which drives B by friction, A and B are kept in

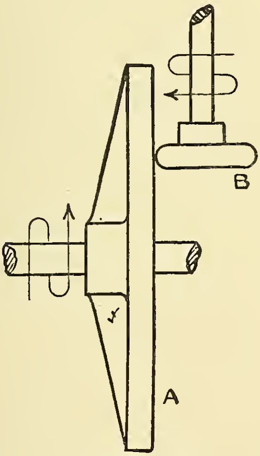


Fig. 72.

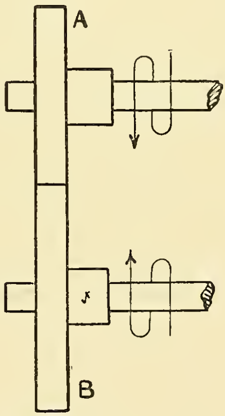


Fig. 73.

contact by pressure, and for light work an effective drive is obtained. Variable speeds of B can be obtained by sliding B nearer to or farther away from the centre of A. In Fig. 73 A and B are simple discs pressed into contact, and one drives the other by friction.

A silent feed motion is sketched in Fig. 74. The object of the arrangement is to give an intermittent motion to the shaft on which A is fixed. A loose ring, all in one piece, fits loosely over the wheel or disc A. One part of the ring is shaped as shown in the small detached sketch. A lever CEF is centred at X and actuated through a rod G. If G is pulled downwards the lever comes against a projection H on the ring B, so the lever and ring move freely together round the centre of A. If G is moved upwards the lever will turn round X as a centre. This movement is prevented by the portion C of the lever pressing against the wheel A. This pressure may be sufficient

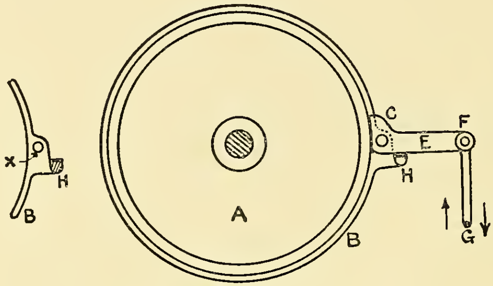


Fig. 74.

to cause the lever to grip A, and so the lever, ring, and wheel A will move round as one piece. The movement of G can be regulated to give a very small or large movement to A, the effect being that of a ratchet-wheel with an unlimited number of teeth in A.

Friction plays a very important rôle in textiles. Although the friction of one fibre when in contact with another is extremely small, the total friction among a large number of fibres is sufficient to maintain the fibres in a regularly ordered condition such as a lap, card web, and sliver. As the fibres are lessened in number it is found necessary to twist the reduced strand or roving slightly and so increase the friction among the fibres, the slightly rough surface of the fibres adding to this effect. Finally, the yarn is twisted fully and a maximum resistance to friction thus obtained; in fact, the total friction is so high that the yarn will break before the fibres will slide over each other. Interesting tests may be made on yarn testers with yarns twisted to various amounts of twist.

A further feature in textile machinery that is unusually important is the frictional driving of the top rollers in drawing-rollers of all kinds.

It has already been explained how fibrous material is drawn down from a thick to a thin condition by passing it between rollers running at different surface speeds (*see* p. 29).

In Fig. 75 the roller A is carried in fixed bearings; its surface is roughened by a series of smooth longitudinal flutes or grooves. Resting on A is another roller B made of iron and covered with a layer of flannel and an outside layer of thin leather. If A is revolved the friction between the rollers may be sufficient to cause B to revolve also; but this is never supposed to happen, for the thin leather covering on B would be quickly destroyed by contact with the fluted roller A. If cotton, say, is passed between the two rollers in the form of a strand as at C in Fig. 76, A and B will be separated. Their surfaces are no longer in contact with each other, so that the bottom fluted roller A will drive the top leather-covered roller

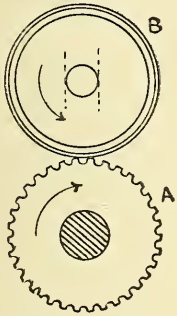


Fig. 75.

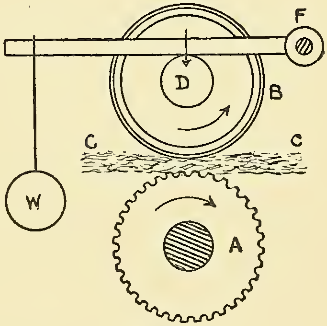


Fig. 76.

B by virtue of the resistance of friction of the fibres in contact with the surface of A, also by the resistance of friction among the fibres of the material passing between the rollers and also the resistance of friction between the fibres and the top roller B. In other words, the effort or power to drive the top roller in preparing and spinning machinery is transmitted through the fibrous material passing between rollers: it is a pure friction drive. In order to obtain a better grip on the material between the rollers and prevent a second pair of rollers pulling the fibres bodily away, the top roller is frequently pressed down by direct weights or by some form of lever weighting, in which case an additional strain is thrown on the fibres in causing B to revolve.

EXERCISES

1. A nail is driven into a piece of wood. Why cannot it be drawn out easily?

2. A belt on a pulley is found to be constantly slipping. Why is this?

3. Laps are placed in contact with the lattice of a scutcher; when the lattice moves forward the laps unwind. Explain this action.

4. Explain with sketches why a nut will come loose if the machine vibrates.

5. Describe some simple experiment to prove that friction is directly proportional to pressure.

6. If excessive friction is known to exist in a bearing, what means are adopted for reducing it?

7. Give a list of lubricants for various purposes, and state why each is used.

8. What are the usual signs that indicate excessive friction?

9. If a ladder is placed in position against a wall, what considerations limit the angle at which it is placed if there are no means of fixing it in position?

10. What is static friction and sliding friction? If a machine is alternately stopping and starting, what effect has this on the power required to drive it? Give reasons for the answer.

11. Describe a method of finding the friction absorbed in a worm and worm-wheel when used in raising a weight.

12. A piece of iron may possibly enter an opener along with the cotton. What will happen, and why, if the iron is struck by the rapidly revolving blades of the cylinder?

13. Explain clearly, with sketches, why the feed-rollers of a scutcher are fluted and the calender-rollers are smooth.

14. An arrangement is provided on a lap end to make the lap as compact as possible. Sketch the arrangement and explain fully how it effects its purpose.

15. Sketch and describe some simple form of clutch that depends on friction for its effectiveness.

16. State the various points in an opener or scutcher where friction is advantageous.

17. State where friction in a loom is an advantage and a disadvantage. (Bearings and gearing to be ignored.)

18. How is a strap moved from a fast to a loose pulley? Give full reasons for your answer.

19. Fibres of cotton can be pulled asunder quite freely when in a loose condition, but when twisted together some considerable force is required to draw the fibres apart, whilst in the case of yarn, breakage will occur before the fibres will separate. Explain this fully with sketches.

20. The web of cotton from the doffer to the calender-rollers is a fleece of loose fibres. Why do they not all fall apart during the passage?

21. How are the top rollers of textile machines driven? Explain fully, by enlarged sketches, the forces at work and the resistance to be overcome.

CHAPTER V

LINES REPRESENTING FORCES

ANY exertion, such as a push or a pull, is a force, and this force will have magnitude, and it will be exerted in some definite direction. The magnitude or amount of the force may be represented by a straight line drawn to scale (say 10 lb. = 1 in.), but any convenient scale can be used. Such lines are shown in Fig. 77. They represent by their lengths the forces marked;

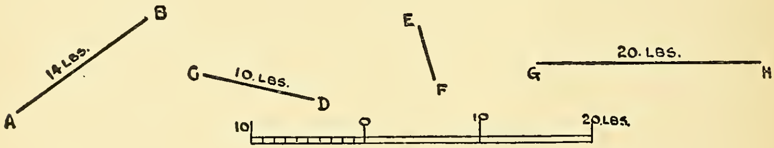


Fig. 77.

they also show by their position the directions of the force. But one important factor is missing: none of the lines tell us the *sense* of the direction of the force; that is, we do not know from Fig. 77 whether the force is from A to B or from B to A, and so on. To represent forces by lines we must represent amount, direction, and the sense of direction, this latter being indicated by an arrow-head somewhere on the line itself, as in Fig. 78.

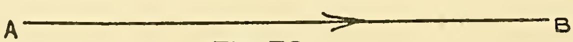


Fig. 78.

Since lines are sufficient to represent forces we can proceed to think in lines and to put our thoughts down graphically. For instance, suppose a man informs us that he wished to get to a certain spot, and to do this he walked 3 mls. due north, then 2 mls. north-east, then 4 mls. south-east, then $2\frac{1}{2}$ mls. south-west, which brought him to the place intended. Our first idea would be of direction, so we could jot down lines as in Fig. 79, showing the four directions he took. When this is

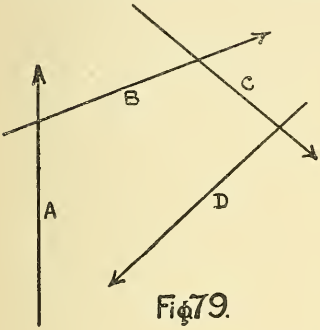


Fig. 79.

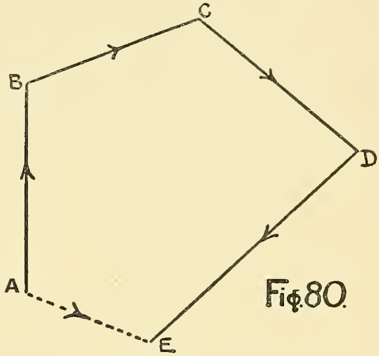


Fig. 80.

clear in our minds we can represent to scale the actual journey and find how far he was at the finish of his walk from his starting-point. This is done in Fig. 80. AB = 3 mls., BC = 2 mls., CD = 4 mls., and DE = $2\frac{1}{2}$ mls., the lines being drawn to scale in their order, parallel to the lines in Fig. 79. The result of his walk has been that he has only gone the distance AE from his starting-point, and if he simply went from A to E in the direction of the arrow it would be the resultant of all his efforts to reach it by the roundabout way he really took.

We can represent forces by lines just as simply as we have represented distances. If a number of forces act on a body and tend to move it in various directions, it will be equally simple to show the direction in which it will tend to move and the magnitude of the resultant force which is actually exerted in this direction.

Example.—A body is acted upon by several forces whose directions only are as shown in Fig. 81. A = 12 lb., B = 20 lb., C = 30 lb. and D = 7 lb. Find the resultant force.

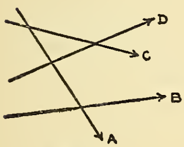


Fig. 81.

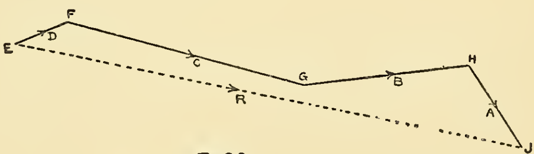


Fig. 82.

Take a scale, say 10 lb. = 1 in., and commence at a point E and draw a line parallel to *any* of the lines in Fig. 81. In Fig. 82 we have started by drawing EF parallel to D and in the same sense as shown by the arrow-head, and have made the length EF equal to 7 lb. on the scale. From F draw a line parallel to any of the lines in Fig. 81, with the exception of D, and again in the same sense we have chosen C, and so made FG parallel to C and equal to 30 lb. on the scale. From G draw a line parallel to B or A. We have chosen B and made GH parallel to B, noting the direction of the arrow-head again, and equal to 20 lb. on the scale. Now draw HJ parallel to the remaining line A and make its length equal to 12 lb. on the scale. By joining EJ we obtain a line which represents the resultant direction of the four forces acting on the body. When measured by the scale we get its amount; and, of course, the sense of direction must always be away from the starting-point, as shown by the arrow on EJ. If the length of EJ is measured on the scale it will be found to be $63\frac{1}{4}$ lb.

There was no obligation to start at any particular parallel; the force D was taken haphazardly. Any of the forces may be chosen as the starting-point; for instance, the next example takes the same diagram of the position of the forces as in Fig. 81, but A is chosen as the starting force. Note (1) that the arrow-heads of the *components* ABC, etc., must all run in the same direction; (2) that the arrow-head on the resultant runs in the opposite direction.

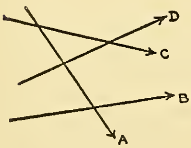


Fig. 83

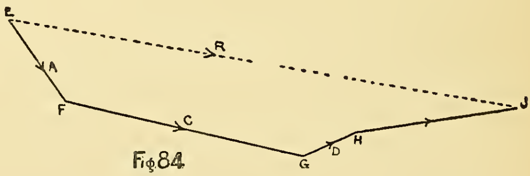


Fig. 84

Example.—Proceed by drawing EF parallel to A. Now draw FG parallel to C, then GH parallel to D, then HJ parallel to B. Join EJ and we obtain the resultant, and it will be found exactly equal the resultant of the same forces as in Fig. 82.

The forces in Figs. 81 and 83 have been drawn simply as showing the direction in which they are acting on any body, large or small. If the body is fixed or if there is great frictional resistance the body will not move, but the resultant is the force which tends to move the body.

Example.—We can easily take the diagram (Fig. 83), and arrange the forces so as to show them as acting on any small body. This is done by first drawing the position diagram (Fig. 85). Now draw a small circle to represent a body, and draw lines to its centre parallel to the force lines in Fig. 85. The same forces in Fig. 85 are now represented as acting on X in Fig. 86. These forces can now be treated as in the previous examples. Draw, for instance,

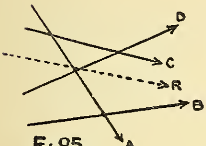


Fig. 85

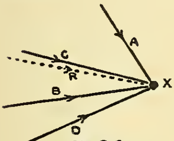


Fig. 86

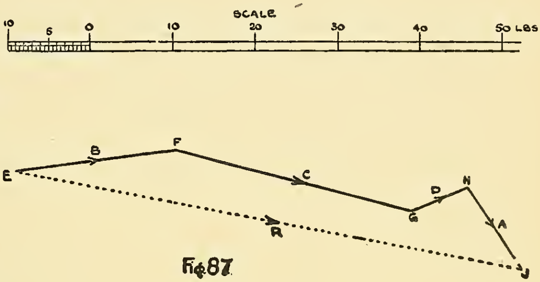


Fig. 87

EF parallel to and equal in magnitude to B on the scale chosen (Fig. 87), FG parallel to and equal in magnitude to C, GH parallel to and equal in magnitude to D, and HJ parallel to and equal in magnitude to A. Join EJ and this represents the resultant, its magnitude, its direction, and its sense of direction, for the small body would clearly have a resultant force acting upon it in the direction E to J. Although the force taken first and the order of the forces are different in the force diagram (Fig. 87), it will be found that the resultant EJ is still the same as in the previous examples, because the same position diagram has been used in all these examples. In all these diagrams it is advisable to use as large a scale as possible and to letter each step as it is taken so that confusion is avoided.

Resolution of Forces.—So far we have had to find the resultant when the full particulars of certain forces have been given us. We are also able to find some of the forces if we already know the resultant. If we know the resultant, all that is necessary is to draw lines in given directions and of such magnitude that the beginning and ending of the series of lines are at the beginning and ending of the resultant respectively.

Example.—A resultant force of 30 lb. is given in Fig. 88. Find two forces which produce this resultant.

First draw a line AB parallel to the resultant R and equal to 30 lb. by scale. Our question gives no information at all as to the two forces which produce this resultant, but we already know that by drawing a line from A, say AC, as in Fig 89, and from the end C of this line another line to the finishing-point B of the resultant, we shall represent a pair of forces in direction, sense, and magnitude that will give AB as their resultant. AC and CB are therefore two forces fulfilling the condition required, and their magnitude can be measured to scale.

Since we have no information as to the direction to draw AC in Fig. 89, we may draw it in any direction and also make it any magnitude; so a further diagram is given in Fig. 90, and the two forces AC and CB are shown, which also produce AB as the resultant. It is therefore clear that the example can be solved in innumerable ways, all of which may be correct. For instance, the four diagrams (Figs. 89, 90, 91, 92) are all correct

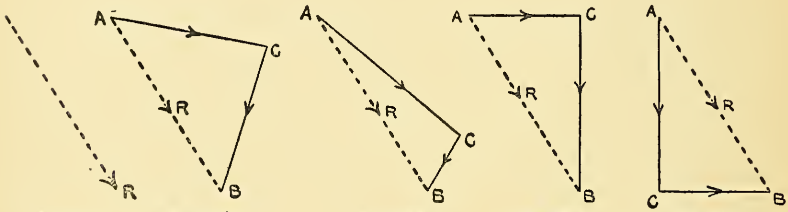


Fig. 88. Fig. 89. Fig. 90. Fig. 91. Fig. 92.

solutions to the problem. By measuring the lines AC and AB in each diagram by our scale we obtain the magnitude of each pair of forces, of which AB is the resultant.

The resolution of a resultant into two forces whose direction can be chosen to suit our purpose can thus always be effected. Very often we adopt such directions that one force is at right angles to the other, as shown in Figs. 91 and 92. The two forces are called *components*, the vertical force is the *vertical component* and the horizontal force is the *horizontal component*, and the whole process is termed resolving a resultant into its *rectangular components*.

Example.—Resolve the force SF of 30 lb. into its rectangular components (*see* Fig. 93). Draw SF to scale = 30 lb. From S draw a vertical line SA, and from F draw a horizontal line FA. The vertical and horizontal lines meet at A, so SA and FA are the components of SF. Measure SA and FA by the scale used for SF and it will be found that

SA, the vertical component, = lb.
FA ,, horizontal ,, = lb.

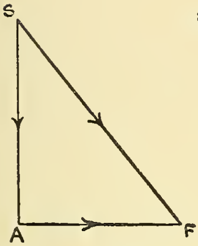


Fig. 93.

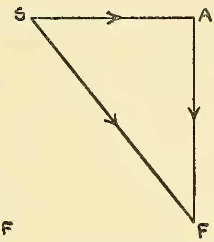


Fig. 94.

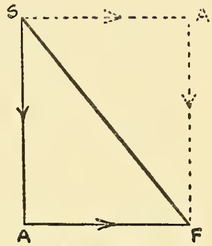


Fig. 95.

It is clear that there is no obligation to draw the vertical force from S; we can draw the horizontal force from S and the vertical one from F as is done in Fig. 94. The results, however, are exactly the same, simply because, as is shown in Fig. 95, the triangles shown are the two halves of a rectangular figure whose opposite sides are equal and parallel. A simple practical illustration will now make this clear.

Example.—A basket of yarn, as in Fig. 96, is pulled by a rope by someone who exerts a force of 60 lb. in the direction indicated by the arrow. What are the rectangular components of this force?

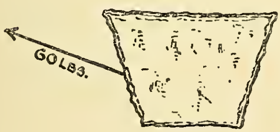


Fig. 96.

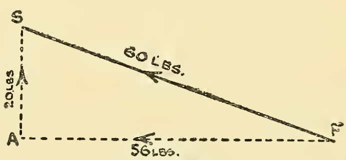


Fig. 97.

Draw a line SF, as in Fig. 97, parallel to the force of 60 lb. in Fig. 96 and to scale. From S and F draw vertical and horizontal lines respectively; then SA = 20 lb. the vertical component, and FA = 56 lb. the horizontal component. This means that the force has a lifting effect SA on the basket of 20 lb., and it also has a horizontal pulling or dragging effect AF of 56 lb.

EXERCISES

1. A load of 12 lb. hangs freely by a cord 8 ft. long from a support. A horizontal force keeps the weight 3 ft. from the vertical. Find the force.

2. Using a clock face as a guide for direction. A force of 10 lb. acts on a body from 1 to 7. Another force of 6 lb. from 4 to 10, a third force of 12 lb. from 9 to 3, a fourth force of 4 lb. from 12 to 6. Find the magnitude and direction of the resultant force.

3. Three forces act on a body. The first is a weight of 10 lb. acting in the direction 11 to 5. The second force of 16 lb. acts from 2 to 8, and the third force of 3 lb. acts from 3 to 9. What is the magnitude and direction of a single force that would represent the three forces? A clock face is used for direction.

4. Represent a force of 15 lb. acting in a direction N.E., one of 20 lb. acting S.E., one of 8 lb. acting due E. Find direction and magnitude of the resultant.

5. A force of 30 lb. acts in a N.E. direction. Resolve this force into its component parts graphically and also by calculation.

6. A bale of cotton weighing 500 lb. is hoisted to the mixing-room entrance. It is 3 ft. from the platform and suspended by a chain 40 ft. long. What pull must be exerted to draw the bale forward so that it may be lowered on to the platform?

7. A skip of cops weighing 300 lb. is drawn along the floor by a force of 56 lb. acting along a rope inclined at 60° to the floor. Another similar skip is drawn by a rope inclined at 30° to the floor. Find the component forces in each case.

8. A piece of cotton is thrown forward at an angle of 30° to the horizontal by a force of 6 lb. At the same time a current of air forces the cotton forward at an angle of 60° to the horizontal with a pressure of 2 lb. In what direction and under what resultant force will the cotton move?

CHAPTER VI

POLYGON OF FORCES—EQUILIBRIUM

THE last chapter dealt with forces and their resultant, and whilst polygons represented the force diagram they differ in an important feature from a polygon of forces. In Fig. 98 we have two forces AB, BC and their resultant AC. This line AC is not a separate force, it simply represents a single force, in magnitude, direction, and sense, that would produce the same

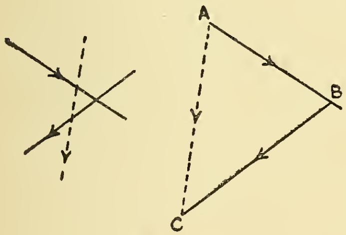


Fig. 98.

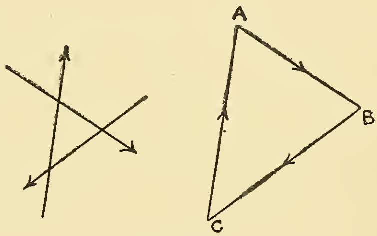


Fig. 99.

effect as the two forces AB and BC; the body that is being acted upon by the two forces can therefore be considered as acted upon by a force AC. Suppose the body acted upon can move, then the force AC will cause it to move in the direction AC; the most direct way to stop its movement would be to have an equal force pushing against the force AC; the body would then not move, it would be in a balanced condition or in a state of equilibrium. This is represented in Fig. 99. The three forces AB, BC, and AC act on a body, and it will be seen from the force diagram that there is no resultant; the three forces complete the triangle. The resultant is said to be zero. CA is therefore a separate force which neutralises the movement that would be produced by the forces AB and BC, and consequently equilibrium is established. A body is said to be in equilibrium when all the forces acting upon it have no resultant; that is, when the resultant is zero. An example of four forces will now be given. Fig. 100 represents four forces, two equal vertical and two equal horizontal forces. If these forces act upon a body P (suppose cords in Fig. 101 are attached to P), then forces A and C, being equal and acting in exactly opposite directions, will not move P; there is no

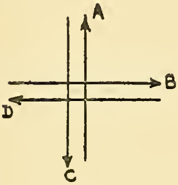


Fig. 100

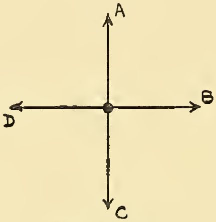


Fig. 101.

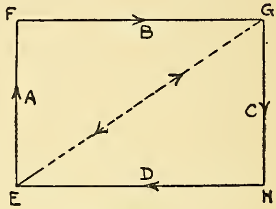


Fig. 102.

resultant, and P is therefore in equilibrium. In the same way, the two equal and opposite forces B and D will have no resultant. Consequently the body P is in equilibrium under all the forces acting upon it. Another way of presenting the case is as follows:—Draw EF (in Fig. 102) vertical and equal to A, from F draw FG horizontal and equal to B, then the resultant will be EG. Now draw from G the vertical GH equal to C, and from H draw the horizontal HE equal to D, then GE will be the resultant. These two resultants, EG and GE, are equal and act in opposite directions, so they neutralise each other; therefore the forces as shown in Fig. 102 represent the resultant as zero, and the body they act upon is in equilibrium.

It will be noted that the directions of all the forces in Fig. 102 follow each other round the four-sided figure just as they did in the triangular figure in Fig. 98. This is a general result for the polygon corresponding to any number of forces in equilibrium.

Example.—A very common example of forces acting on a mechanical structure is the jib crane in its various forms. The most simple type is shown in Fig. 103. It consists of a firm central pillar AB and two arms AC and BC. The arm BC is the jib and AC is the tie rod. A weight W is hung from C. It will be seen that the crane is in equilibrium; that is, it will remain just as it is without movement, provided AB is rigid enough and the two arms are of sufficient strength. Also each part of the crane is in equilibrium; for instance, the hinges at A, B, and C, for the same reason. Since equilibrium exists it is clear that there must be two or more forces at work, and yet Fig. 103 apparently only shows one, and this in the form of a pull exerted by the weight W. This weight is evidently trying to move the pin at C, but this is prevented by some force acting along the tie rod AC and some force acting along the jib BC. Three forces are therefore acting on the pin C, to keep it in equilibrium, at angles indicated by the vertical pull of the weight and the inclinations of the jib and tie rod. We now know the three directions of the forces acting on the pin C but only the magnitude and direction of one of them, but as the pin is in equilibrium it is an easy matter to find the magnitude of the other two.

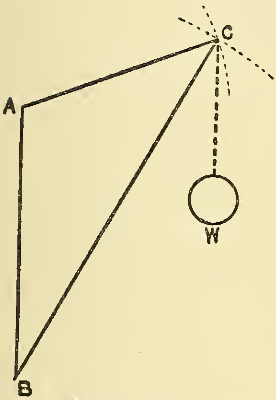


Fig. 103.

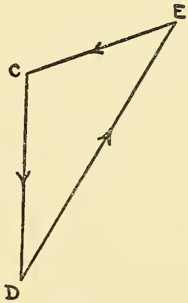


Fig. 104.

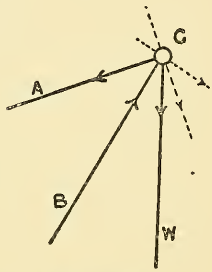


Fig. 105.

Draw a line CD (Fig. 104) parallel to the weight force, that is, vertical, and make it equal to the weight, on a suitable scale. From C draw CE parallel to AC, and from D draw DE parallel to BC, thus completing the triangle CDE. As the weight hangs downwards the sense of direction will be downwards; knowing this, all that is necessary is to follow round the triangle with the arrows in the same direction as on CD. The length of CE and DE on the same scale from which CD was drawn will give us the magnitude of the forces acting along BC and AC. The arrows tell us that the weight is pulling C vertically downwards, the force along BC is pushing C upwards and outwards, whilst the force along AC is pulling C downwards and inwards towards A.

It still remains to find out the effect these forces have on the jib and the tie rod. We know of no outside force acting along the jib from B to C, but since there is such a force the jib must be acting as if it were a compressed spring and, pushing C outwards and upwards, this is actually what happens; the jib BC is in compression and the weight W tends to crush it. This can readily be tested by making the jib in two parts and coupling them by a spring; this spring would be compressed. On the other hand, the weight has a tendency to pull the pin C along the circular path described by BC, but the tie rod prevents this movement, and so the weight whilst crushing BC is also trying to pull the tie rod AC asunder; in other words, AC is in tension, and if a spring were placed on AC it would be stretched and would indicate the magnitude of the pulling force on the pin C.

The foregoing explanation of the forces acting on a crane must be carefully tested by the student. An arrangement can easily be

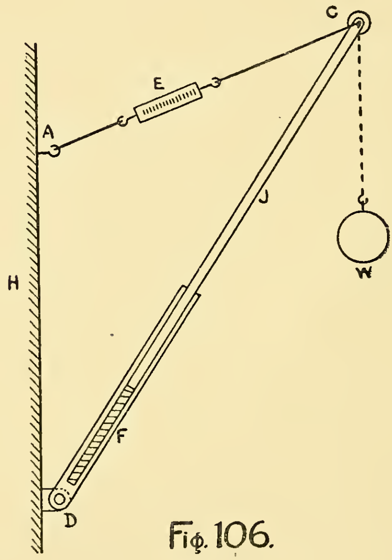


Fig. 106.

rigged up to illustrate this particular polygon of forces or, as it is generally called, the triangle of forces. Fig. 106 gives an idea of the apparatus. A spring E in AC will indicate tension in the tie, and a spring F in a tube, which can be compressed by the rod J, will indicate compression in the jib. Readings taken before the weight is applied and afterwards will enable the student to test the triangle of forces.

In practice, the chain carrying the weight W passes over a pulley at C and on to a winding drum so that the weight can be raised or lowered. In such cases the arrangement would be as shown in Fig. 107.

Take readings of the springs before and after the weight is added; the difference will represent the forces due to the weight. Draw the force polygon after the weight has been added. The weight chain ECW will represent two forces, each force equal to the weight. One of these is vertical due to the weight, and the other along CE due to the drum winding up or sustaining the weight; their directions will be as shown in Fig. 108. The forces acting along the tie and jib are to be found.

Draw FG vertical and equal by scale to the weight. From G draw GH parallel to the chain EC and equal by scale to the weight, and mark with arrows as shown, these being clearly the sense of direction of these forces. From H draw HJ parallel to

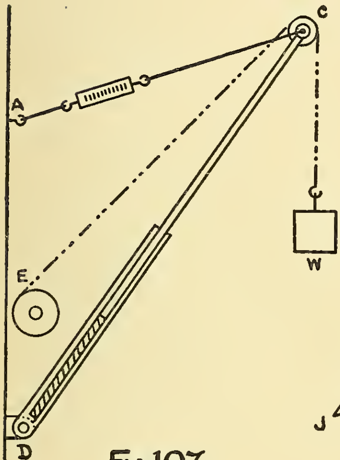


Fig. 107.

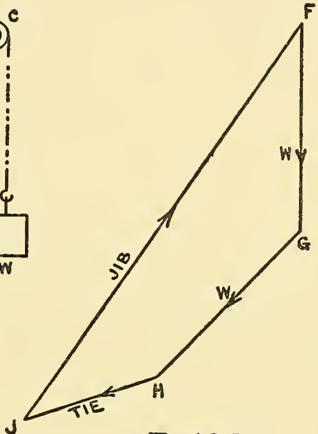


Fig. 108.

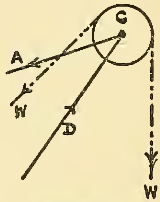


Fig. 109.

the tie AC; its length is not known. Draw from F a line FJ parallel to the jib CD; length also not known. Wherever FJ and HJ meet at J the lengths HJ and JF by scale will equal the forces acting along the tie and jib respectively. By placing arrows in the same order as on the forces due to the weight we obtain the sense of direction of the forces, and these show the jib in compression and the tie in tension. It will be noted that the jib is subject to the greatest force and the tie rod to the least force.

Information obtained by these polygons of forces enables the draughtsman to design his machine or structure with clear ideas as to the necessary strengths required in the various parts.

Example.—Three strings A, B, and C (Fig. 110) are attached to the small ring D, and each cord is pulled at the same time in the direction shown by the arrows. If cord C is pulled by a force equal to 20 lb., what forces are acting along A and B if the ring is stationary?

In Fig. 111 draw DE parallel to the known force C, and by scale make its length equal to 20 lb. From E draw EF parallel

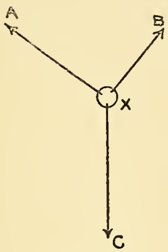


Fig. 110.

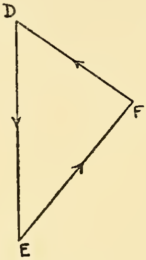


Fig. 111.

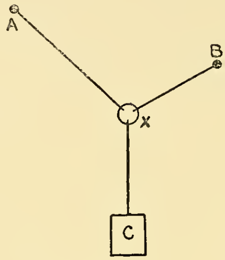


Fig. 112.

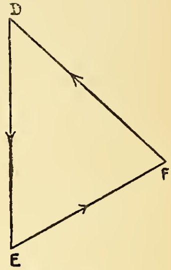


Fig. 113.

to the direction B, and from D draw a line parallel to the direction A. These two lines meet at F. Then EF+DF measured by scale will equal the magnitude of the forces A and B. The sense of direction of the forces round the triangle will follow those they represent in Fig. 111, and as shown they follow in order, and so the ring X will be in equilibrium.

Example.—Instead of the cords being pulled, the ends A and B (*see* Fig. 112) are fixed to pins, and a weight C, of 20 lb., is hung by a cord from the small ring X. What is the tension in the cords A and B respectively?

It will be noted that the ring X is in equilibrium without any weight C being hung from it. Any number of weights can be added at C, but the ring X will remain in its position and in equilibrium until one or the other of the cords breaks. The tension in the cords will therefore vary as the weight varies.

We draw DE, as in Fig. 113, vertical and parallel to C, and make DE = 20 lb. to scale. From E draw EF parallel to B, and from D draw DF parallel to A, thus completing the triangle DEF. As X is in equilibrium under the three cords the arrow on DE will indicate the direction of the other two forces along the sides of the triangle, and if these directions are transferred to Fig. 113 it will be seen that the forces in Fig. 113 are exactly as those in Fig. 111; in both cases the three cords are in tension.

The apparatus usually employed to illustrate the polygon of forces is shown in Fig. 114. It consists essentially of a vertical board AB, to which can be pinned a sheet of paper. Hooks or pins can also be screwed or fixed along the top and sides of the board, to which cords and springs can be attached or small pulleys mounted. When experimenting with the apparatus springs are hooked, say, at A and B, and to the springs are attached cords, whose other ends are tied to a ring C. A weight is hung from C. The springs indicate the respective forces acting along AC and BC, and the weight is the tension in CW, so that all the information required is known. Now mark a

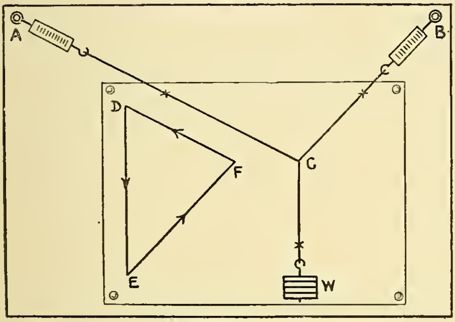


Fig. 114

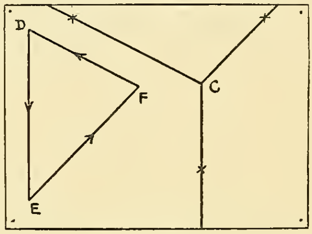


Fig. 115

point at C, on the paper beneath, where the three cords meet, and also a mark along each cord some little distance from C, and remove the paper. If lines are drawn through the marks that have been made a force position diagram is obtained, as in Fig. 115, and from this the triangle of forces DEF is readily drawn, using the weight W as the scale length of DE. Test if DF and EF scale to the indications of the springs.

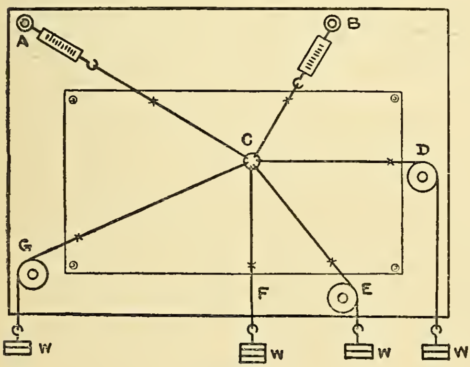


Fig. 116.

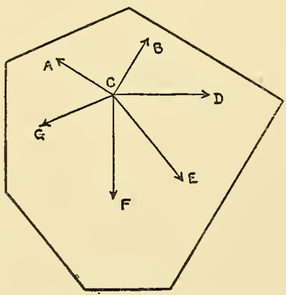


Fig. 117 & Fig. 118.

The same apparatus may be used for more than three forces. For instance, in Fig. 116 there are six cords attached to a small ring C. Two of the cords are attached to springs, whilst the other four cords are weighted, three of which pass over small guide pulleys D, E, G. Now make a mark on the paper through the centre of the ring, and also a mark as far from C as possible directly underneath each cord. Remove the paper and draw lines through each mark as is done in Fig. 117. All the magnitudes of these forces are known from the weights and springs, so proceed to draw the force diagram as in Fig. 118, when it will be found that a closed six-sided polygon results with the sense of direction in order round the polygon. A number of exercises may be worked by varying the weights and force diagrams may be drawn on the supposition that two of the

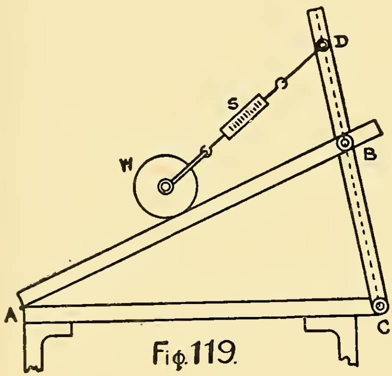


Fig. 119.

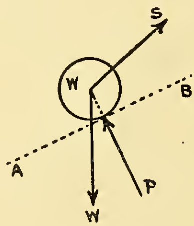


Fig. 120.

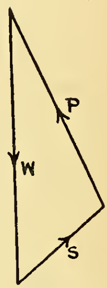


Fig. 121.

weights or the two spring indications are not known, in this way testing whether the diagram correctly represents all the forces in magnitude.

An interesting case of the "triangle of forces" may be seen in the apparatus sketched in Fig. 119.

A block of wood AC is fixed on supports. At A is hinged a board AB which can be fixed in any inclined position by clamping it at B to a support DC which is hinged at C. A weight W in the form of a roller is attached to a spring balance S, and the other end of the balance is clamped at D. The weight W is clearly in equilibrium, and it is kept in this state by three forces: (1) the weight of the roller acting vertically downwards; (2) the pull of the spring acting in the direction WS; and (3) the pressure of the roller perpendicular to the incline, for any body resting on any surface exerts a pressure at right angles to the surface, otherwise it would move. The three forces can therefore be represented in position as shown in Fig. 120. W is the weight acting vertically, P the pressure on the incline AB, and S the direction of the spring. From this diagram we can construct the triangle of forces as shown in Fig. 121. Suppose the pull of the spring alone is known. In such a case S in Fig. 121 is drawn parallel to S in Fig. 120 and made by scale equal to the reading on the spring. From the lower end of S draw a vertical line W, and from the upper end of S draw P parallel to P in Fig. 120. P and W will meet, and so complete the triangle of forces. Scale W and the weight of the roller will be given. This can be tested by weighing the roller. P is scaled off in a similar manner and its truth proved by lifting the roller by a spring balance in a direction at right angles to the incline.

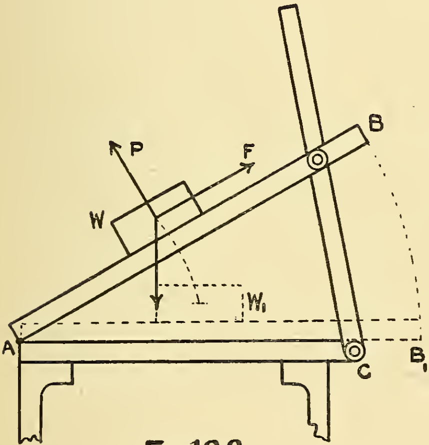


Fig. 122.

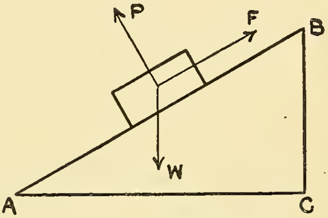


Fig. 123.

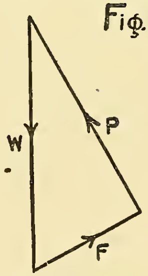


Fig. 124.

The apparatus in Fig. 122 can be used for a series of experiments to illustrate the *limiting angle of friction*.

A weight W rests on the board AB when it is closed and in a horizontal position. If AB is now gently raised it will at last occupy such an inclined position that the weight will begin to move down the incline. A moment before sliding commences the weight W is in equilibrium, and the forces that keep it so are its weight, the pressure between the surfaces, and the resistance to friction between the surfaces. These forces are shown in Fig. 123. The friction is indicated as opposite to the downward movement of W, because friction opposes motion, so it acts in an opposite direction to that in which motion takes place. The force diagram of these three forces is shown in Fig. 124, and, knowing the weight W, the magnitude of the other forces can be measured by scale. A variety of surfaces can be prepared on AB and the weight and tests made for the limiting angle of friction.

Incidentally, these experiments afford a means of obtaining the coefficient of friction. F in Fig. 124 is the force required to overcome the resistance to friction of the pressure P between the two surfaces, so that $\frac{P}{F}$ = the coefficient of friction. The triangle in Fig. 124 is similar to the triangle ABC in Fig. 123, so that $\frac{P}{F}$ corresponds to $\frac{BC}{AC}$; therefore the coefficient of friction between the weight and the surface of the incline is represented by $\frac{BC}{AC}$ in a right angle triangle in which the angle BAC is the limiting angle of friction. This ratio $\frac{BC}{AC}$ is termed the tangent of the angle A, or tan A. A ready way of finding the limiting angle of friction, but one not very exact, is to take a stick and try to move, say, a brick along the floor. If the stick is pressed vertically on the brick no movement takes place, but if the stick is gradually inclined a position will be reached when the brick just begins to move. The inclination of the stick to a vertical line at this moment will be the limiting angle of friction. The applications of wedges are usually based on this principle, the angle of the wedge being kept less than the limiting angle of friction for the surfaces in contact.

EXERCISES

1. Two forces of 12 and 18 lb. respectively act in directions which are inclined at 60° to each other. Find the resultant and also the force necessary to produce equilibrium. Explain fully the difference between the two results.

2. Give illustrations of a triangle of forces and a polygon of forces.

3. A rectangular gate formed of bars of wood is hinged on one side. Explain qualitatively the forces acting upon it, and how it may be strengthened.

4. The side of a rectangular tank usually has strengthening pieces connecting the opposite corners. Explain their purpose.

5. Four bars are hinged together forming a rectangle ABCD. If two opposite corners A and C are connected by an additional bar and forces are applied at A and C and at B and D, find the force, in each case, acting along the bar AC.

6. The central pillar of a jib crane is 15 ft. long. The tie rod is inclined at 30° and the jib 60° to the horizontal. A weight of 2 tons is supported by the crane. Find the forces acting along the various members of the crane and on the pin connecting the jib and tie rod.

7. A ladder 12 ft. long rests against a wall and is inclined at 60° to the floor. A man's weight of 160 lb. acts vertically 5 ft. from the top of the ladder. Find the pressure of the ladder against the floor and against the wall.

8. Describe an apparatus for illustrating the polygon of forces.

9. In Question 6 the chain supporting the weight passes over a pulley and on to the winding drum at an angle of 45°. Draw the polygon of forces.

10. A body weighing 20 lb. will move down an inclined plane having an angle of 60°. If it is held in position on the plane by a cord parallel to the plane, find the force to do this. Also find the force acting along the cord if it is horizontal.

11. Describe and sketch an apparatus that would illustrate the truth of your answer in Question 10.

12. A platform 8 ft. long is lowered until it occupies a horizontal position and is maintained in this position by two chains whose length, from their fastenings on the wall to the end of the platform, is 12 ft. A bale of cotton weighing 500 lb. is hoisted and placed on the platform, the centre of gravity of the bale being 6 ft. from the wall. Draw the force diagram and state the force acting on each chain.

CHAPTER VII

MOMENTS OF A FORCE—BEAMS, LEVERS

Moments of a Force.—A force acting on a body will tend to move the body about some given axis or point; the measure of this tendency is termed the moments of the force. If a rod is suspended on a board, and its lower end also pinned to the board, a force may be applied at any point in the rod without producing motion; but there is a tendency to produce motion, and this can readily be seen by removing the pin from the lower end of the rod, when the rod will swing in the direction in which the force is acting and will turn around the suspending pin as an axis. On the other hand, by removing the suspending pin and retaining the lower pin, the same force, applied at the same point in the rod and in the same direction, will move the rod round the lower pin as an axis. The moment of the force in each case will be the magnitude of the force into the length of the line drawn perpendicular to the direction of the force from the axis or point around which the rod would turn.

Several experiments may be made that will be helpful in obtaining a clear idea of what is meant by the moment of force.

Fix up an apparatus something similar to Fig. 125 and suspend a rod AB on spring balances L and R. As the rod AB has weight, the spring balances will show that they are supporting this weight. If a weight W is now hooked on to the rod at, say, C the two springs will indicate that they are now carrying or supporting this weight, and if the previous indications are subtracted from the new readings we shall obtain the actual effect the added weight has on the balances. These indications must be carefully noted. Their sum will always equal the weight W. Also a sketch should be made showing the distances of the springs and weight from each other.

Other rods may be bent into various shapes as shown in

Fig. 126, keeping the distance AB the same and the position of the weight hook the same distance from A. Note the effect of the rod on the springs before the load is applied, then add the weight W, and again take the indications of the springs. Subtract the readings of spring L without load from the readings when loaded, and do the same with the spring R. In all five experiments the spring balances will give the same pressures at each spring respectively. In other words, the various shapes of the rod have not affected the pressures on the springs. The fixed or unchanged factors in all five cases are

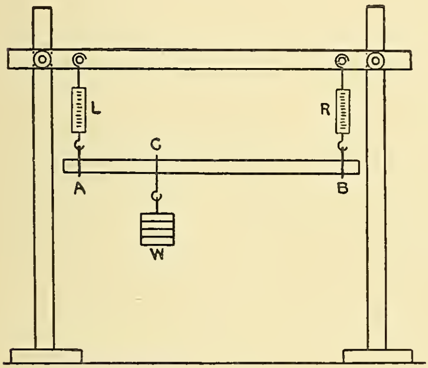


Fig. 125.

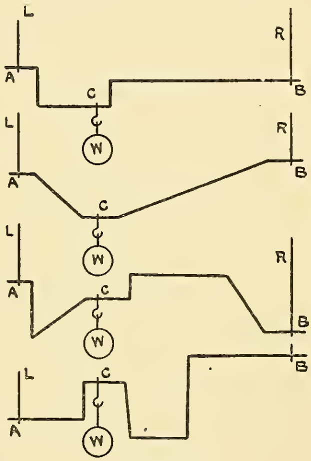


Fig. 126.

clearly the direction in which the force or weight is acting, and the perpendicular distance of the spring balance supports from this force.

Referring again to Fig. 125, we will assume the end A to be supported but the end B free. The adding of the weight W would cause the rod to turn in a clockwise direction round A as a centre. To prevent this movement we must apply a force at B acting in the opposite direction to the load, and this upward force would be that indicated by the spring R in Fig. 125. This is shown in Fig. 127. If the weight W were removed the upward force R at B would turn the rod anti-clockwise round A, and to prevent this movement the weight W is applied. No movement, therefore, takes place, but the tendency to movement is clearly there. The reason for actual movement not occurring is that the rod is balanced or in equilibrium, and if the weight W is multiplied by the distance x it will be found to be equal to the product of $R \times l$.

$\therefore$ $W \times x$ is the moment of force W rd. A in a clockwise direction,
and $R \times l$,, ,, R ,, A in an anti-clockwise direction,
or $W \times x = R \times l$.

When forces are acting on a body that is in equilibrium if the rotation they tend to cause is clockwise in direction, their

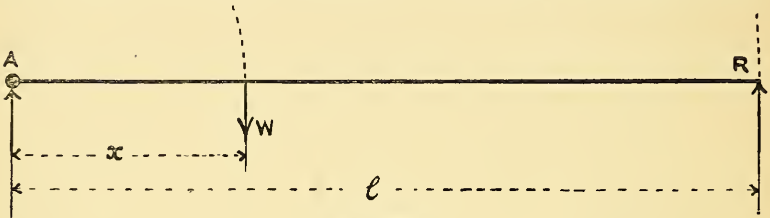


Fig. 127.

moments may be called positive (+), whilst if the tendency to rotation is anti-clockwise the moments may be called negative (−). As these two sets of moments are equal to each other we can formulate the statement that

clockwise moments = anti-clockwise moments.

We may now consider the rod as fixed for the time being at R as shown in Fig. 128. The force A will move the rod clockwise, and the moment is positive (+), whilst W will move it anti-clockwise, so the moment is negative (−).

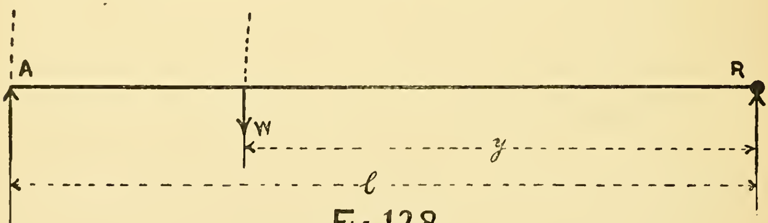


Fig. 128.

Then $A \times l = W \times y$.

The force acting at R has zero moment, just as the force acting at A in the previous example in Fig. 127 had zero moments. There is a pressure at R and consequently a reaction, but since there is no distance between the action of the force and the point around which the body is assumed to move, then there can be no moment for that force, and can be ignored so far as moments are concerned.

We can now make an experiment to illustrate the truth of the statement made above in a much more general case.

Take a piece—any shape—of strong cardboard or, better still, of thin hard wood, and attach springs and weights to convenient points in a somewhat similar manner as shown in Fig. 129. The wood will take up a definite position, to which it will always return if moved aside. Now mark a spot on the wood, say P, though any point will do as well. If the lines of the forces A, B, C, D, and E are continued and

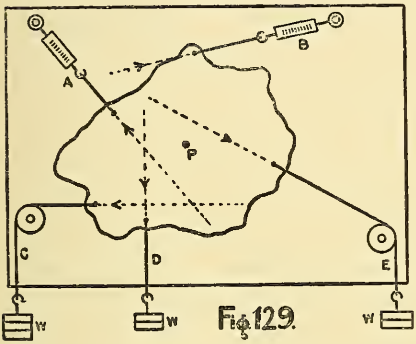


Fig. 129.

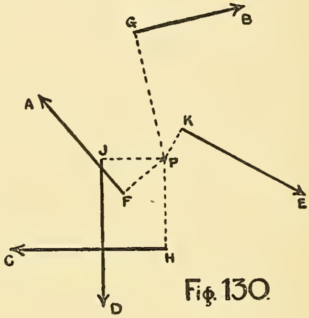


Fig. 130.

drawn on the wood, and the wood then removed after taking note of the weights and the spring indications, we can make a force diagram from it as in Fig. 130. Since the wood was in equilibrium the sum of the moments of each force round the point P must equal zero.

From P draw perpendiculars to each of the forces, then—

Force	A ×	the	perpendicular	distance	PF	is the	moment	of force	A
,,	B ×	,,	,,	,,	PG	,,	,,	,,	B
,,	C ×	,,	,,	,,	PH	,,	,,	,,	C
,,	D ×	,,	,,	,,	PJ	,,	,,	,,	D
,,	E ×	,,	,,	,,	PK	,,	,,	,,	E

Also it will be noted that—

Force	A	will	tend to	move body	clockwise	round	P,	so the	moment is	+
,,	B	,,	,,	,,	,,	,,	P	,,	,,	+
,,	C	,,	,,	,,	,,	,,	P	,,	,,	+
,,	D	,,	,,	,,	anti-clockwise	,,	P	,,	,,	—
,,	E	,,	,,	,,	clockwise	,,	P	,,	,,	+

$$\therefore \quad A \times PF + B \times PG + C \times PH + E \times PK = D \times PJ$$

$$\text{or } A \times PF + B \times PG + C \times PH + E \times PK - D \times PJ = 0.$$

On referring back to Figs. 127 and 128, that since the clockwise and anti-clockwise moments are equal in a balanced body, therefore their difference will be zero.

Several experiments ought to be made and calculations worked out by making careful observations of the weights and distances. Such experiments will prove the general law of moments, which may be expressed as follows :—

If a body is in equilibrium the sum of the moments of the forces acting upon it round any point is zero.

Now that the experiments have illustrated the general truth of the law, we are in a position to apply it to practical examples.

Example.—A beam (neglect its weight) is 12 ft. long and is supported at both ends. If a weight of 5 tons is placed 4 ft. from one end, what is the pressure on each support?

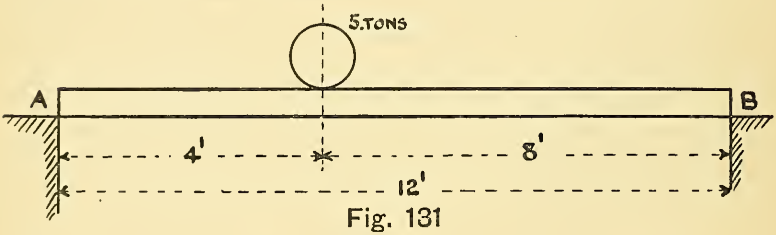


Fig. 131

(1) Find the pressure on the support A. Let x = this pressure (*see* Fig. 131).

Then $5 \times 8 - x \times 12 = 0$

$$x \times 12 = 5 \times 8$$

$$x = \frac{5 \times 8}{12} = \frac{40}{12} = 3\tfrac{1}{3} \text{ tons}$$

$\therefore$ pressure on A $= 3\frac{1}{3}$ tons.

Or (2) Find the pressure on B. Let x = this pressure.

Then $5 \times 4 - x \times 12 = 0$

$$x \times 12 = 5 \times 4$$

$$x = \frac{5 \times 4}{12} = 1\tfrac{2}{3} \text{ tons}$$

$\therefore$ pressure on B $= 1\frac{2}{3}$ tons.

The second calculations was unnecessary, for we have seen from the experiments on rods that the sum of the pressures on the two ends always equals the total force or weight on the rod. When we have found the pressure on A we subtract it from the 5 tons and so obtain the pressure on B.

Example.—A beam (neglect its weight) is 16 ft. long between its supports. Weights of 5, 3, and 7 tons are placed so that the 5 tons is 4 ft. from the left-hand support, the 3 tons is 6 ft. from the left support, and the 7 tons is 7 ft. from the right support. What is the pressure on each support?

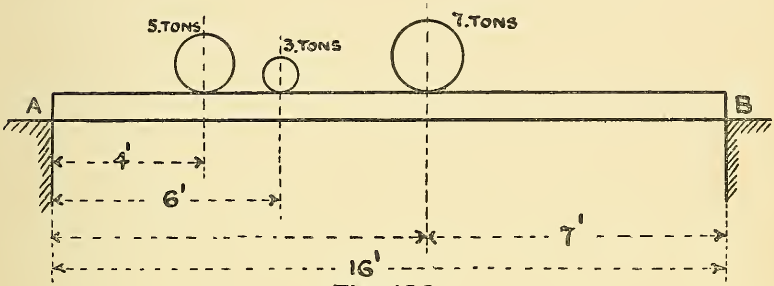


Fig. 132

First find the pressure on support A (*see* Fig. 132). Let x = this pressure. This means that we must find the moments of the forces round B. As the pressure on A acts upwards it will tend to turn the beam clockwise round B, so will be positive, or +. The three weights will all tend to turn the beam anticlockwise round B, so the moments will be negative, or −.

Moments of A will $= x \times 16$ ft. $= 16x$ ft. tons.
,, 5 tons ,, $= 5 \times 12$,, $= 60$ ft. tons.
,, 3 ,, ,, $= 3 \times 10$,, $= 30$,, ,,
,, 7 ,, ,, $= 7 \times 7$,, $= 49$,, ,,

$$\therefore \quad 16x - 60 - 30 - 49 = 0$$
$$16x = 139$$
$$x = 8\tfrac{11}{16} \text{ tons.}$$

So that the pressure on A $= 8\frac{11}{16}$ tons
and ,, ,, B $= 15 - 8\frac{11}{16} = 6\frac{5}{16}$ tons.

Example.—A beam 10 ft. long is supported at a point 3 ft. from one end. If a weight of 3 tons is placed on one end, what force must be applied at the other in order to obtain a balance? Neglect the weight of the beam.

Sketch the conditions of the problem as in Fig. 133. F is clearly the point round which the beam will turn if any move-

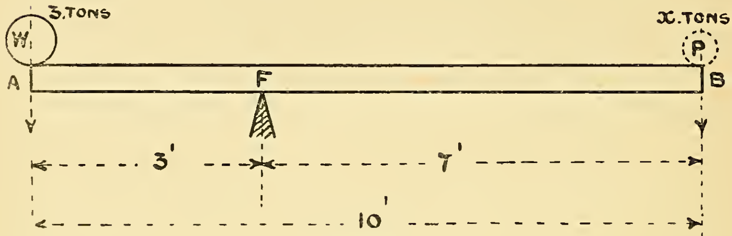


Fig. 133

ment take place. The 3 tons at A will turn it anti-clockwise, and the x tons at B will turn it clockwise, so that the moment of the 3 tons round F—the moment of x tons round F = 0.

$$\therefore \quad 3 \text{ tons} \times 3 \text{ ft.} - x \text{ tons} \times 7 \text{ ft.} = 0$$
$$3 \text{ tons} \times 3 \text{ ft.} = x \text{ tons} \times 7 \text{ ft.}$$
$$9 = 7x$$
$$x = 1\tfrac{2}{7} \text{ tons weight at P.}$$

The whole of the weight on the beam will be supported by F, so that F is carrying $3 + 1\frac{2}{7} = 4\frac{2}{7}$ tons.

Example.—A bent lever as in Fig. 134 is weighted at A by a freely hanging weight of 20 lb. What weight, hanging from B, will

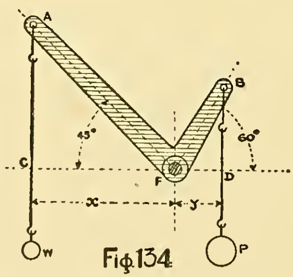


Fig. 134

balance the lever if AF is 12 in. and BF is 6 in. long? AF is inclined to the horizontal at 45° and BF at 60°.

First draw the lever to scale, as in Fig. 134, to the particulars given in the question. Both weights, W and P, will hang vertically. The distance they act from the fulcrum F will be measured on a line through F at right angles to the direction in which the weights are acting. This line is CFD. The moment of weight W round F will therefore be Wx, and the moment of weight P round F will be Py.

$$\text{Then } Py - Wx = 0$$
$$Py = Wx$$
$$P = \frac{Wx}{y}.$$

We know that W = 20 lb., and by scale we find that $x = 8\frac{3}{8}$ in. and $y = 3$ in. The weight P must be calculated.

$$P = \frac{20 \times 8\frac{3}{8}}{3} = \frac{20 \times 67}{3 \times 8}$$
$$\therefore \quad P = 55{\cdot}8 \text{ lb.}$$

The examples just given arise out of the general question of equilibrium and the moments of a force. Experiments were previously made to prove the laws of equilibrium, and the student may feel confident that the methods adopted in the examples are correct because they are based on these laws. It is, however, an easy matter to verify, by trial, answers to most

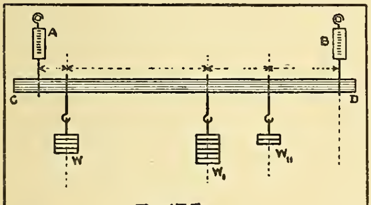


Fig. 135.

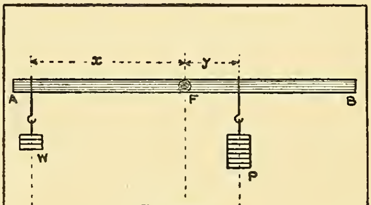


Fig. 136.

questions that may be asked, and students are strongly recommended to find an answer experimentally and then test the answer by the law.

A very simple arrangement can be fitted up for experiments on beams, rods, levers, etc. Fig. 135 will give the general idea. Careful measurements of distances and exact notes of the weights and readings of the spring balances are, of course, absolutely necessary in all these experiments.

Fig. 136 illustrates the arrangement for experiments on levers. A stud F is fixed in the upright board and a rod AB bored at the centre to fit the stud F loosely. If AB is made long enough it can be used for a variety of purposes.

Example.—A weight of 12 lb. is placed 13 in. from the centre F in Fig. 136. How far from F must a weight of 28 lb. be placed so that the rod AB is balanced?

First place the weight W of 12 lb. at 13 in. from F. Now slide a weight of 28 lb., P, until AB remains horizontal. Measure its distance from F and the problem is solved. Compare the result by calculating the position of P by the principle of moments.

As the lever is in a balanced condition it is in equilibrium.

$$\therefore \quad W \times x = P \times y$$
$$12 \times 13 = 28 \times y$$
$$y = \frac{12 \times 13}{28} = \frac{156}{28} = 5{\cdot}57 \text{ in.}$$

The weight P is therefore hung 5·57 in. from F.

During the experiment the student will observe that the lever AB will balance in any position, so naturally the moments round the centre F will always equalise each other.

Example.—A weight of 16 lb. is hung 15 in. from the fulcrum F (Fig. 137). What upward pressure must be exerted at a point 7 in. from F?

First find the result by experiment as shown in Fig. 137. Then check by calculation.

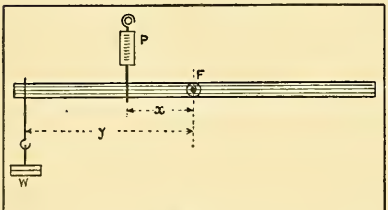


Fig. 137

$$W \times x = P \times y$$
$$16 \times 15 = P \times 7$$
$$P = \frac{16 \times 15}{7} = 34{\cdot}28 \text{ lb.}$$

Example.—A weight of 23 lb. is hung $6\frac{1}{2}$ in. from the fulcrum F in Fig. 138. What will be the indications on a spring P which supports the arm 15 in. from F?

As in the previous examples we have

$$W \times x = P \times y$$
$$23 \times 6\tfrac{1}{2} = P \times 15$$
$$P = \frac{23 \times 6\frac{1}{2}}{15} = 9{\cdot}96 \text{ lb.}$$

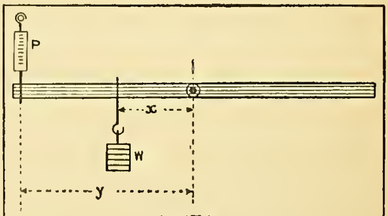


Fig. 138

In these examples of levers it will be noticed that the relative positions of the fulcrum, weight, and pressure are different.

This has led to the fanciful idea of there being three systems of levers, but the student will readily see that they are simply variations of one system, and all arrangements are covered by the simple rule. The weight × its distance to the fulcrum is equal to the pressure × its distance to the fulcrum.

Example.—A safety-valve is 3 in. dia. The centre of the valve is 5 in. from the fulcrum. What weight must be placed 20 in. from the fulcrum so that the valve will blow off when the steam pressure is 50 lb. per sq. in. in the boiler? (*see* Fig. 139).

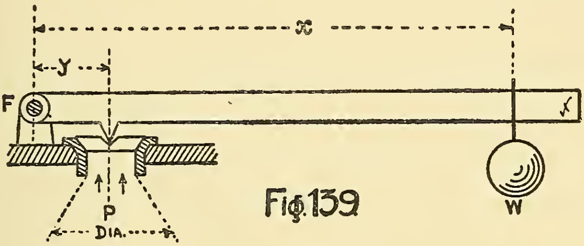


Fig. 139

$$\text{Area of valve} = \frac{3 \times 3 \times \pi}{4} = \frac{9 \times 3{\cdot}1416}{4} \text{ sq. in.}$$

$$\text{Total pressure on valve} = \frac{9 \times 3{\cdot}1416 \times 50 \text{ lb.}}{4} = 353{\cdot}43 \text{ lb.}$$

$$P = 353{\cdot}43 \text{ lb.}$$

$$P \times y = W \times x$$

$$\frac{P \times y}{x} = W$$

$$\frac{353{\cdot}43 \times 3''}{20''} = 53 \text{ lb.}$$

∴ weight to be hung at W = 53 lb.

Example.—Four calender-rollers of a lap end are weighted as shown in the sketch (Fig. 140). The top lever FW is 14 in. long, FP is 3 in. The bottom lever FW is 60 in. long, FP is 6 in. What pressure is exerted at P, and what is the pressure on the cotton as it passes between each pair of rollers if the top roller weighs 60 lb., the second roller 65 lb., and the third roller 72 lb.?

The weight on the bottom lever is 12 lb. Both sides of the machine are provided with levers and weights.

In the bottom lever the pressure P is found as follows :—

$$P \times y = W \times x$$

$$P = \frac{W \times x}{y} = \frac{12 \times 60}{6}$$

$$P = 120 \text{ lb.}$$

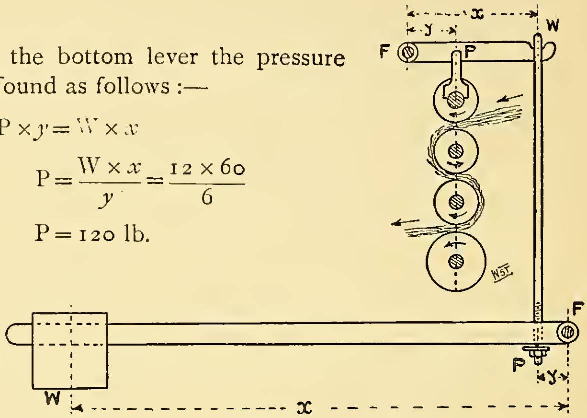


Fig. 140.

In the top lever the weight W is the same as the pressure P on the bottom lever, so that—

$$W \times x = P \times y$$

$$\frac{W \times x}{y} = P$$

$$\frac{120 \times 14}{3} = 560 \text{ lb.}$$

so that total pressure $= 560 \times 2 = 1120$ lb.

∴ the pressure on the top roller is 1120 lb.

„ between the top pair of rollers $= 1120 + 60 = 1180$ lb.

„ „ second „ $= 1180 + 65 = 1245$ „

„ „ bottom „ $= 1245 + 72 = 1317$ „

Example.—The calender-rollers of the lap end of an opener are weighted as shown in Fig. 141. The lever is 72 in. long and the pressure is applied 3 in. from the fulcrum. If a weight of 22 lb. is placed 66 in. from the fulcrum, what pressure is put on the cotton between each pair of rollers if the top roller weighs 70 lb., the second roller 78 lb., and the third roller 82 lb.? Separate levers act on each end of the top roller.

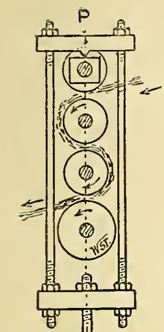
$x=66$ in. $y=3$ in. $W=22$ lb.

$$Wx=Py$$

$$\frac{Wx}{y}=P. \quad \frac{22\times 66}{3}=484 \text{ lb.}$$

$$\therefore \quad P=484 \text{ lb.}$$

$=484\times 2=968$ lb. total pressure on roller.



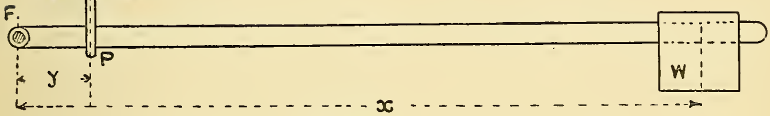


Fig. 141

The pressure between the top pair of rollers				$= 968+70=1038$ lb.
,,	,,	second	,,	$=1038+78=1116$,,
,,	,,	third	,,	$=1116+82=1198$,,

The levers shown in the last two examples are for the purpose of consolidating the opened and fluffy cotton, so that the sheet thus formed can be rolled up as a lap and readily unrolled without the surfaces of cotton adhering to each other.

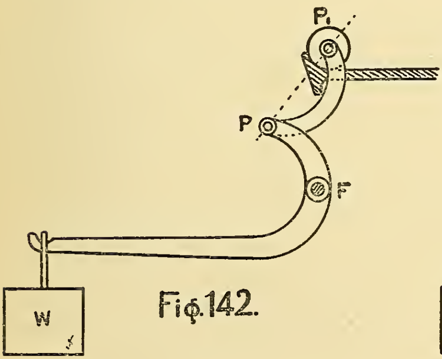


Fig. 142.

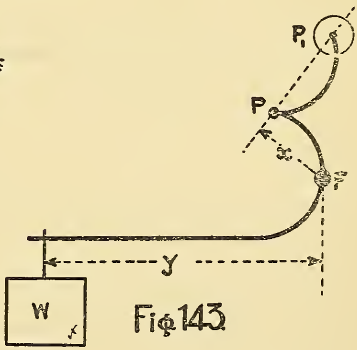


Fig. 143.

Example.—The dish feed-roller on the carding machine is weighted as shown in Figs. 142 and 143. The distance $x=12$ in. and the distance $y=2$ in. The weight $W=13$ lb. What pressure is exerted on the end of the feed-roller?

This is an interesting example of a bent lever. By joining P and P_1 we obtain the direction in which the pressure acts. The actual connection is made by a curved link. The distance x is the perpendicular distance to the fulcrum from the direction in which the weight acts. The distance y is the perpendicular distance of the fulcrum from the direction in which the pressure acts.

$$Wx = Py$$

$$\frac{Wx}{y} = P$$

$$\frac{13 \times 12}{2} = 78 \text{ lb.} \quad \therefore \quad P = 78 \text{ lb.}$$

Fig. 143 is a diagrammatic representation of the lever.

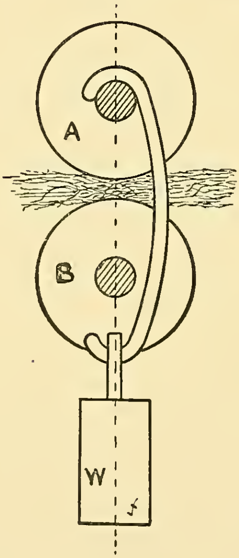


Fig. 144.

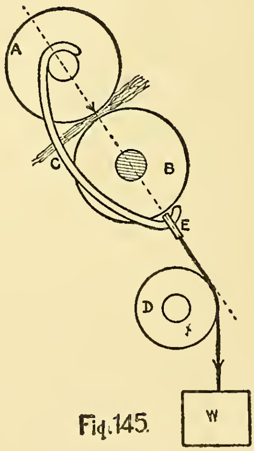


Fig. 145.

Fig. 144 illustrates what is termed a dead weight arrangement. Clearly the pressure on the cotton between A and B will be the weight of W.

On the other hand, the application of a dead weight in the way shown may not be practicable, and in such a case the weight may be arranged as in Fig. 145. The pressure on the material between A and B will be practically equal to the weight W, as the tension in the connecting chains from W to E is uniform.

Another type of direct weighting is sketched in Fig. 146.

The weight W acts vertically, but the pressure acts along the line joining the centres of A and B. The diagram in Fig. 147 will show how this pressure is found. Draw W to

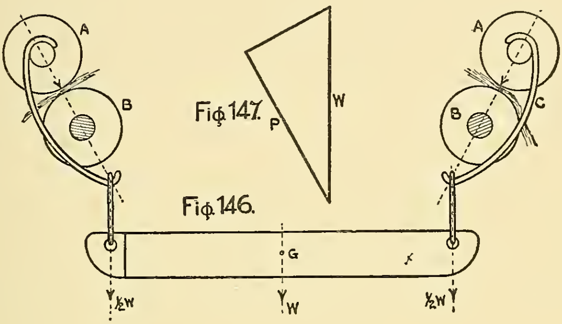


Fig. 147.

Fig. 146.

scale equal to half the weight of W in Fig. 146, and from one end draw P parallel to the pressure line. From the other end of W draw a line at right angles to P, then the line P will equal the pressure between the two rollers. This type of weighting is common in some textile machines.

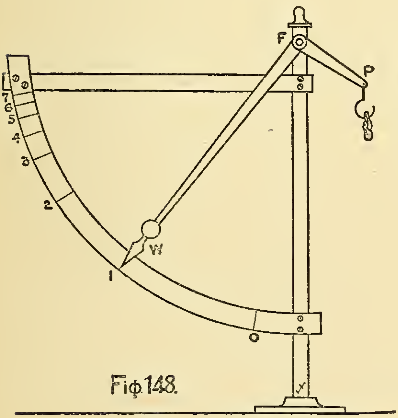


Fig. 148.

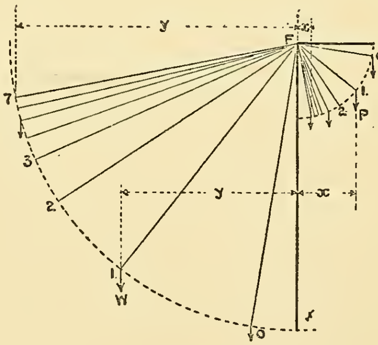


Fig. 149.

A form of lever, often used for textile purposes in the weighing of yarn, is shown in Fig. 148. It consists of a bent lever fulcrumed at F, one end or arm carrying a pivoted hook or pan on which the yarn is placed; the other arm is weighted and acts as a pointer on a circular scale. This scale is usually a quadrant of a circle, and is divided so that the weight of the yarn can be read off.

A diagram of this yarn balance is shown in Fig. 149. When the apparatus is in a state of equilibrium, the long arm pointer is at zero on the scale, this point being some little distance to the left of the stand. A weight, in the form of yarn, is placed on the hook; this depresses the arm FP and raises the pointer FW. The effect has been to alter the leverages or moments of

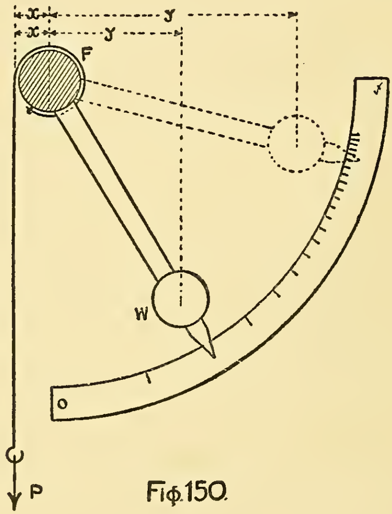


Fig. 150.

the arms; for when the arms come to rest, it is seen that the weight in P is nearer to the vertical line through F, whilst W is farther away. As P increases its moment decreases, whilst the moment of W increases. W itself is a constant quantity. The result of these changes in the moments of the arms is to cause the scale to have unequal divisions, the readings contracting as they ascend the scale. Such scales are graduated by trial, standard weights being used for this purpose.

The Lea Strength Tester is also an example of a bent lever of a special type. Fig. 150 gives a diagrammatic view of its features. A chain or cord is attached to a small drum. The other end of this carries a hook, to which the yarn is attached On the axle of the drum is fixed a weighted arm or pointer W

As the yarn is pulled at P, the drum F is turned, and the pointer rises along a quadrant scale which is graduated to indicate the force P in lbs. In this example, the pull of the yarn has a constant leverage or moment, but the weight W has a varying leverage as it moves upwards.

EXERCISES

1. What is the moment of a force and how is it measured?

2. A rod is suspended by a pin at its upper end. Show by means of sketches how the rod can be made to move clockwise and anti-clockwise by applying forces at various points.

3. A beam is supported at one end on metal and at the other end on clay. What will happen to the supports if a weight is hung from the centre of the beam?

4. A beam 20 ft. long is supported at each end, and a weight of 5 tons is being raised by pulley tackle hooked on it at a point 8 ft. from one end. Find the reactions on the supports.

5. A beam 18 ft. long supports a number of bales of cotton, each bale being 500 lb. One bale is 2 ft. from the end, another bale is 5 ft. from the end, a third bale is 10 ft. from the end, and a fourth bale is 13 ft. from the end, all the measurement being from the same end. Find the pressure on each support.

6. The effective pull in a belt is 35 lb. and it drives a machine whose pulley is 14 in. dia. What are the moments of force?

7. Sketch the lever-weighting arrangement for the calender-rollers in a lap end of a scutcher and calculate the pressure between the top and second roller if a weight of 75 lb. is placed 5 ft. from the fulcrum and the pressure is applied 3 in. from the fulcrum on the same side of the fulcrum as the weight. The weighting arrangement is on each side of the machine.

8. Sketch the brake motion used to consolidate the lap in the lap end and find the pressure on the surface of the pulley.

9. A bent lever AFB is pivoted at C; one arm is horizontal and carries a weight of 10 lb. placed 11 in. from C; the other arm is inclined to the first arm at an angle of 60° and is 4 in. long. Find the pressure exerted at B.

10. Two levers are pivoted on the same stud and each is 16 in. long. A cam or tappet with a 3-in. throw acts on one lever 13 in. from the stud and depresses it. What must be the throw of a second cam or tappet placed 9 in. from the stud in order that the second lever is depressed the same amount as the first lever?

11. Sketch and describe some form of lever weighting used for the feed-roller of a card.

12. The two pulleys of a Weston block are 7 and 6 in. respectively. The pull on the chain is 62 lb. Find the mechanical advantage by the principle of moments.

13. In a Lea strength tester the indicating finger on the dial can move through a complete circle whilst the weight arm moves through a quadrant of a circle. Sketch the arrangement that enables this to be done.

14. The ends of pedals in the regulating motion of openers and scutchers have link or lever combinations. Sketch one of these arrangements and analyse its action.

15. Sketch a yarn balance as used for short lengths of yarn. Point out clearly the difference between such a balance and a pair of yarn scales.

16. A safety-valve is 3 in. dia. The weight on the lever is 57 lb. The fulcrum is 4 in. from the centre of the valve. At what distance from the fulcrum must the weight be placed in order that 80 lb. per sq. in. pressure in the boiler will just lift the valve?

CHAPTER VIII

CENTRE OF GRAVITY

Centre of Gravity.—Every particle of a body is acted upon by the force of gravity, and the sum of these forces over the whole body gives it the quality of weight. Some parts of a body may be heavier than other parts, and such parts will be pulled downwards with greater force than the rest. The centre of gravity is therefore that point in a body where the resultant of the force of gravity acts. In other words, when a body is acted upon by gravity alone, the centre of gravity is the point upon which the body will balance; if supported at that point, the body will be in equilibrium.

Inspection alone in many cases is sufficient to inform us as to the position of the centre of gravity. A thin symmetrical plate of uniform material will have its centre of gravity in the centre as, for instance, a square plate, a circular or a uniform rod of any section will have its centre of gravity at its middle point.

In the case of irregular bodies or bodies that are not homogeneous in structure, the centre of gravity may be found by balancing the body on a knife-edge support or other test, and in many cases by calculation or graphics.

Pulleys and other revolving bodies, no matter how carefully they are made, may have their centre of gravity out of the centre of the pulley. They are said to be out of truth or out of balance and when running are liable to cause serious trouble. All such bodies are carefully balanced by adding to or removing portions of the material until they will be at rest in any position when supported on their geometrical centre.

If a uniform lever is supported on its centre, its weight will act directly over the support and will not affect the balance, but if such a lever is fulcrumed on one side of the centre of gravity, then the weight of the lever must be taken into account.

Example.—A uniform lever 18 in. long is pivoted at a point 3 in. from one end. From the short arm hangs 36 lb. How many pounds must be hung from the long arm to obtain equilibrium? The weight of the lever is 6 lb.

The centre of gravity is in the centre of the lever, so the weight of the lever will act 6 in. from the fulcrum.

The moment of W round F will be Wx
" " P " F " Py
" " G " F " Gd.

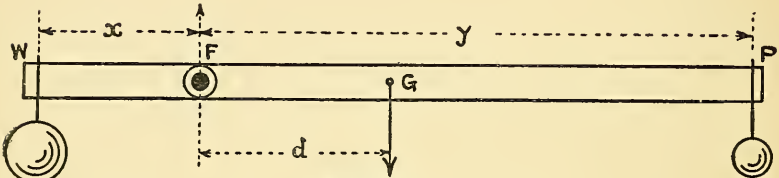


Fig. 151.

The moments on either side of the fulcrum must be equal.

$$\therefore \quad Py + Gd = Wx$$
$$P15 + 6 \times 6 = 36 + 3$$
$$P15 + 36 = 108$$
$$P15 = 108 - 36 = 72$$
$$P = \tfrac{72}{15}$$
$$P = 4{\cdot}8.$$

P must therefore be 4·8 lb. (*see* Fig. 151).

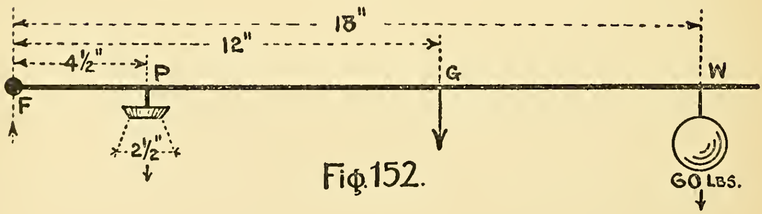


Fig. 152.

Example.—A safety-valve is 2½ in. dia. A lever 22 in. long is pivoted 4½ in. from the centre of the valve and a weight of 60 lb. is hung 18 in. from the fulcrum. What is the total pressure on the valve, and the pressure per sq. in.? The weight of the lever is 6 lb. and the centre of gravity acts at 12 in. from the fulcrum.

Make a diagram of the lever as in Fig. 152.

The pressure P is the unknown quantity.

$$\therefore \quad P \times FP = W \times WF + G \times GF$$

$$P \times 4\tfrac{1}{2} = 60 \times 18 + 6 \times 12$$

$$P \times 4\tfrac{1}{2} = 1080 + 72 = 1152$$

$$P = \frac{1152}{4\frac{1}{2}} = \frac{1152 \times 2}{9}$$

$P = 256$ *lb. total pressure on valve.*

$$\text{Area of valve} = \frac{2\frac{1}{2}^2 \times 22}{4 \times 7} = \frac{5 \times 5 \times 22}{4 \times 4 \times 7}$$

$$= 4{\cdot}9 \text{ sq. in.}$$

$$\text{Pressure per sq. in.} = \frac{\text{total pressure}}{\text{area}}$$

$$= \frac{256}{4{\cdot}9} = 52{\cdot}24 \textit{ lb. per sq. in.}$$

EXERCISES

1. What is the centre of gravity of a body?

2. A lever is 20 in. long and is pivoted at 3 in. from one end. A weight of 6 lb. hung from the short end balances the lever. At what point in the lever does the centre of gravity act, and what is the weight of the lever?

3. A uniform beam 11 ft. long weighs $3\frac{1}{2}$ cwt. Two tons are placed on the beam at a point 3 ft. from one support. What are the reactions on the supports?

4. The weight of a long, heavy, and irregularly shaped lever is required, and scales are not at hand to do this. If a standard weight, say 5 lb., is obtainable, how could the weight of the lever be ascertained?

5. A cone is balanced with difficulty on its apex but will stand on its base. Why is this?

6. Describe a simple method of finding the centre of gravity of a thin, irregularly shaped plate of material, such as cardboard, wood, or tin.

7. How would you find the centre of gravity of a lever?

8. A pendulum is forced to one side of the vertical line through its point of suspension. Why is force required?

9. If a pulley on a shaft is supported on straight edges or anti-friction rolls, and it always comes to rest in the same position, what does this indicate, and how can it be remedied?

10. If a card-cylinder is out of truth, what is meant by this condition? How would you proceed to find out if the statement were true?

CHAPTER IX

MECHANICAL ADVANTAGE

In a previous chapter the velocity ratio was defined by the relation

$$\frac{\text{the movement of the first driver}}{\text{the movement of the last driver}} = \text{the velocity ratio.}$$

This statement may assume a variety of forms all meaning the same thing; for instance—

$$\frac{\text{the first movement in a given time}}{\text{the last movement in the same time}} = \text{the velocity ratio}$$

$$\text{or} \quad \frac{\text{space moved over at driving end}}{\text{space moved over at finishing end}} = \text{the velocity ratio.}$$

It will be thus seen that in any given arrangement of driving mechanism it is a simple matter to find how much faster or how much slower the resulting speed or movement is than the starting speed

$$\text{or} \quad \frac{\text{starting movement}}{\text{resulting movement}} = \text{velocity ratio.}$$

Now this same method of comparing movements is applicable to practically all kinds of mechanism and is very often the basis of our methods for calculating any advantage we obtain by the use of mechanism. If by the use of some appliance a force of 10 lb. will enable a person to lift 50 lb., there is clearly a gain of five, which means that the appliance has enabled the person to move something against a resistance, to lift a load or to exert a force equal to five times the amount of the force applied. This five would be termed the *mechanical advantage* of the appliance

$$\text{or} \quad \frac{\text{force at the terminal end}}{\text{force at the starting end}} = \text{mechanical advantage}$$

$$\text{or} \quad \frac{\text{load lifted}}{\text{load applied}} = \text{mechanical advantage.}$$

This may be illustrated in the case of a simple lever, as in Fig. 153. If the load applied is 8 lb. and a weight of 32 lb. is required to balance it on the other arm in the position shown, then

$$\frac{\text{load lifted}}{\text{load applied}} = \frac{32}{8} = 4 \text{ mechanical advantage.}$$

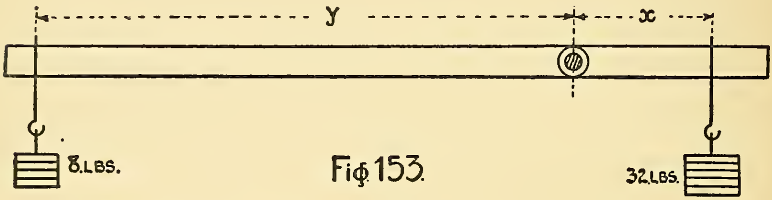


Fig. 153.

If instead of a weight being used we applied other forms of force, such as a driving effort, then there would be exerted also at the other end a resultant effort or load, so that the effect can be expressed in the form

$$\frac{\text{load}}{\text{driving effort}} = \frac{32}{8} = 4 \text{ mechanical advantage.}$$

We will now suppose that the lever moves round its fulcrum as in Fig. 154. When the lever has moved from position AB

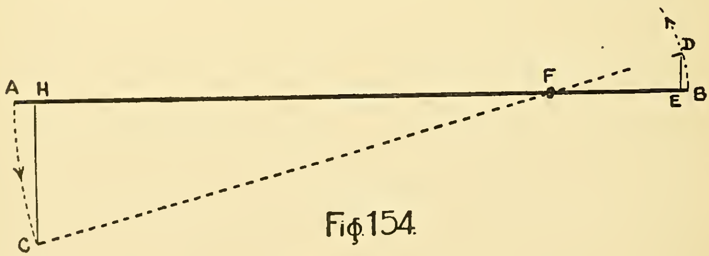


Fig. 154.

to CD the end A has traversed a portion of a circle AC and the end B has moved in the circular path BD, so that

$$\frac{\text{AC}}{\text{BD}} = \text{the velocity ratio.}$$

It is quite an easy matter to show that since AF is four times longer than FB, the arc AC is four times longer than the arc BD, and that therefore the velocity ratio is four, but the usual method is to prove it by drawing CH and DE at right angles to AB, and then from the similar triangles show that

$$\text{since} \quad \frac{HC}{CF}=\frac{DE}{DF}$$

$$\text{then} \quad \frac{HC}{DE}=\frac{CF}{DF}.$$

We already know that

$$\frac{CF}{DF}=\frac{4}{1}$$

$$\therefore \quad \frac{HC}{DE} \text{ also}=\frac{4}{1}, \text{ or } 4.$$

As HC and DE represent the respective arcs AC and BD we have

$$\frac{HC}{DE}=4, \text{ the velocity ratio.}$$

This shows us that the *mechanical advantage is equal to the velocity ratio,* and as a rule the mechanical advantage of most of the simple forms of mechanism is based on finding the velocity ratio of the mechanism. One factor, however, must not be overlooked, viz. friction, for it will be found, on making tests on various kinds of apparatus, that the friction destroys some of the advantage, so this factor must always be taken into account.

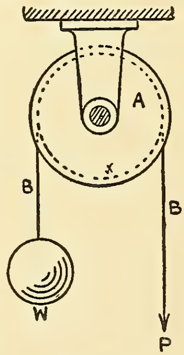


Fig. 155

Fig. 155 represents an ordinary simple pulley A, and over it passes a cord B, to one end of which is attached a weight W, that has to be raised by pulling at the other end P. If the force applied at P were equal to the weight W, there would be a balancing effect, for the weight will exert its force equally along the whole length of the cord B. To raise W we must apply at P a pressure in excess of W. In addition, an extra pressure must be added to P to overcome the friction on the axle or pin that carries the pulley A, and this extra pressure will vary according to the load that is being lifted. Under ordinary conditions, however, the student will do well to make himself clear as to the mechanical advantage of any given piece of mechanism and afterwards to find the efficiency.

In Fig. 155 it will be seen that the pulley offers no mechanical advantage, for the pressure is equal to the weight and the movements of each end of the cord are equal. The arrangement is simply a convenience, and as such is of great utility. Pulleys, however, can be arranged to afford great mechanical advantage and are extensively used for this purpose. For instance, in Fig. 156 a cord C is fastened to the framework and is passed under a movable pulley B and over a fixed pulley A. A pressure at P will raise the weight W which is attached to the movable pulley B.

The pressure P will be equal along the whole cord C, so that the pulley B is being supported by two cords, each transmitting a pressure P; the weight therefore will be equal to 2P and the mechanical advantage is two.

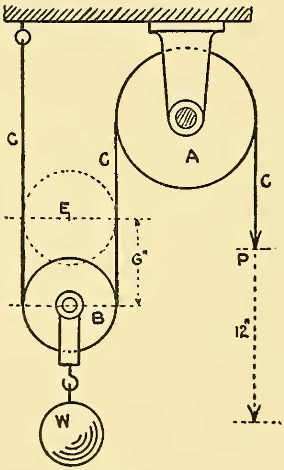


Fig 156

If we assume that the pressure P pulls the cord downwards a distance of 12 in., then the pulley B and weight would be raised 6 in., because it would require 6 in. of each supporting cord to obtain the 12 in. of P's movement. The space ratio or velocity ratio would therefore be two.

Fig. 157 shows an extended application of Fig. 156 by using more pulleys.

If P moves downwards 12″ then pulley B is raised 6″.

If pulley B rises 6″ then pulley C is raised 3″.

If ,, C ,, 3″ ,, D ,, $1\frac{1}{2}$″.

If ,, D ,, $1\frac{1}{2}$″ ,, E ,, $\frac{3}{4}$″.

For 12 in. movement of P we therefore obtain $\frac{3}{4}$ in. movement of the weight W, so that

$$\frac{12}{\frac{3}{4}} = \frac{12 \times 4}{3} = 16 \text{ velocity ratio and mechanical advantage.}$$

If the pull of P is 10 lb., then the tension of the whole of the cord round B = 10 lb., and B will support 2P = 20 lb.

The cord round C has a tension of 20 lb., then the pulley C will support 40 lb.

The cord round D has a tension of 40 lb., so the pulley D will support 80 lb.

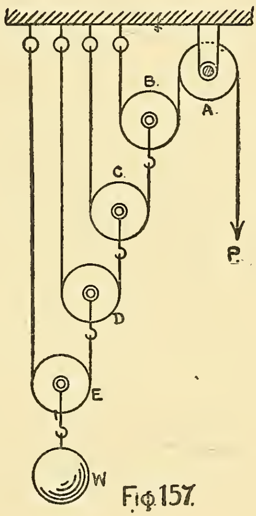


Fig. 157.

The cord round E has a tension of 80 lb., so the pulley E will support 160 lb.

A pull of 10 lb. at P will therefore support a weight of 160 lb. hanging from the pulley E, so that

$$\frac{160}{10} = 16 \text{ mechanical advantage.}$$

The beam will support the W + P, so the total load on the beam in the above example will be 160 + 10 = 170 lb.

Another arrangement of pulleys is shown in Fig. 158. A continuous cord is used which passes over all the pulleys.

The upper pulleys are fixed whilst the lower ones are movable. It will be at once seen that the weight is supported by five cords, and as the tension throughout the cord is equal to P, we conclude that P will support a weight equal to five times its own force, so the mechanical advantage equals five. If the force P moves 10 in. downwards, the five cords must each contribute an equal portion to make up the 10 in., so that the distance the weight will be raised equals $\frac{10}{5} = 2$ in., the velocity ratio, therefore $= \frac{10 \text{ in.}}{2 \text{ in.}} = 5$.

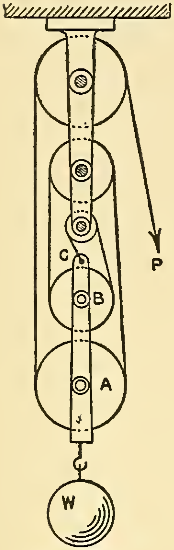


Fig. 158

It is clear that many combinations of pulleys are possible, but in practice the above arrangement is extensively used in a form, known as a "pulley block tackle," for raising weights. This is illustrated in Fig. 159, and on comparing it with Fig. 158 it will be noted that the upper fixed pulleys are placed side by side on a single axle and the lower pulleys are treated in the same way, all the pulleys being of the same size. When the cord is fixed to the upper block, the number of pulleys in each block will be the same, but if fixed to the lower block there will be one less pulley in the lower than in the upper block. The number of cords supporting the lower block in Fig. 159 is six, so the mechanical advantage and velocity ratio will be six.

One other arrangement of pulleys is given in Fig. 160. Here it is quite simple to trace the tensions in the various cords, and as each cord is attached to the weight, the total weight will equal the sum of the tensions in the cords.

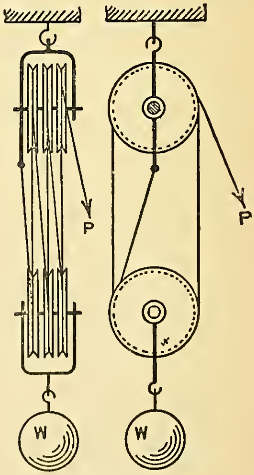


Fig. 159

The tension in each part of the first cord = P total weight = P
,, ,, second ,, = 2P ,, = 3P
,, ,, third ,, = 4P ,, = 7P.

If more pulleys were used we should continue—

The tension in each part of the fourth cord	= 8P	total weight	= 15P
„ „	fifth „	= 16P	„	= 31P
„ „	sixth „	= 32P	„	= 63P.

It will be seen that the total weight in each case is equal to two raised to the power of the number of the cords or pulleys minus 1 or $2^n - 1 = W$, where $n =$ number of cords or pulleys. In Fig. 160 the cords are three in number, so that $2^3 - 1 = 7$, the mechanical ratio and the velocity ratio.

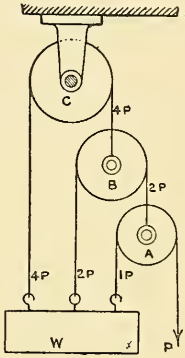


Fig. 160

Weston Pulley Block.—This is a pulley arrangement much used for hoisting purposes. Fig. 161 shows the arrangement in a diagrammatic form.

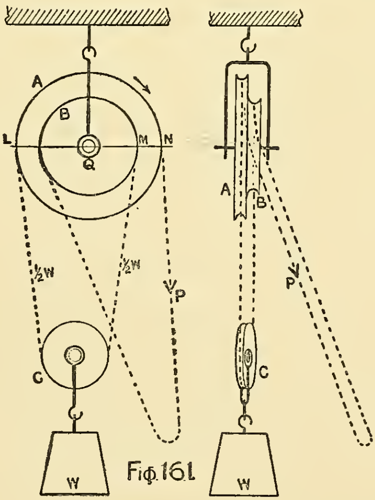


Fig. 161

Two pulleys or sheaves, A and B, of different diameters, are cast together so that both revolve as one on the axle, which is carried by a forked bearing hooked at its upper end. It can thus be attached to any convenient spot. The rims of the sheaves are provided with spaced projections to receive the links of a chain, so that no slippage of the chain can occur. The lower pulley C is single and carries the load to be raised.

An endless chain passes over the pulley A down and round the pulley C, then up and round the pulley B, and down again to the starting-point, where the ends are joined and hang freely. If the chain is pulled at P, the two pulleys A and B are revolved in a clockwise direction, the effect of which is that the larger pulley A raises the sheave C, whilst the chain from the smaller pulley B lowers the sheave C. The difference between these two movements is the amount the weight will be raised.

The velocity ratio may be found by assuming that the chain is pulled at P until A and B make one complete revolution in a clockwise direction.

Then A will wind up a length of chain $= \pi A$
and B ,, unwind ,, ,, $= \pi B$.

The sheave C will be raised half the difference between the two circumferences of the pulleys A and B, so that

$$\text{the weight is raised } \frac{\pi A - \pi B}{2} = \frac{\pi(A-B)}{2}.$$

Since P moves the chain a distance of πA the velocity ratio will be—

$$\frac{\text{first movement}}{\text{last movement}} \text{ or } \frac{\text{movement of pressure}}{\text{movement of weight}}.$$

$$\therefore \quad \frac{\pi A}{\frac{\pi(A-B)}{2}} = \frac{2\pi A}{\pi(A-B)} = \frac{2A}{A-B} \text{ the velocity ratio.}$$

This velocity ratio is numerically the same as the mechanical advantage.

The principle of moments may be used to find the mechanical advantage. Assume that there is no friction in the mechanism.

On reference to Fig. 161 it will be noted that there are three forces on a line drawn through the centre of the pulleys. These forces are—

P tending to turn the pulley clockwise acting at N
$\frac{1}{2}$W ,, ,, ,, ,, ,, M
$\frac{1}{2}$W ,, ,, anti-clockwise ,, L.

In order to obtain equilibrium or a balance, the clockwise moments = the anti-clockwise moments.

So that $P \times NQ + \frac{1}{2}W \times MQ = \frac{1}{2}W \times LQ$

since $NQ = \frac{1}{2}$ dia. of A and $MQ = \frac{1}{2}$ dia. of B and $LQ = \frac{1}{2}$ dia. of A.

$$\text{Then } \left(P \times \frac{A}{2}\right) + \left(\frac{W}{2} \times \frac{B}{2}\right) = \frac{W}{2} \times \frac{A}{2}$$

$$P \times \frac{A}{2} = \left(\frac{W}{2} \times \frac{A}{2}\right) - \left(\frac{W}{2} \times \frac{B}{2}\right)$$

$$P \times \frac{A}{2} = \frac{1}{2}W\left(\frac{A}{2} - \frac{B}{2}\right)$$

$$P = \frac{1}{2}W\left(\frac{\frac{A}{2} - \frac{B}{2}}{\frac{A}{2}}\right) = \frac{1}{2}W\left(\frac{A-B}{A}\right)$$

$$\therefore \quad \frac{W}{P} = \frac{2A}{A-B}.$$

The result is the same as the velocity ratio already found. It will be noted that the smaller the difference between the two pulleys A and B, the greater will be the mechanical advantage.

EXERCISES

1. What is the meaning of the term "mechanical advantage"? A definition is not required.

2. Compare the mechanical advantage and velocity ratio of a simple lever, a pair of unequal wheels in gear and pulleys coupled by a belt.

3. A double worm of $\frac{1}{2}$ in. pitch gears with a 50-teeth wheel. What is the mechanical advantage?

4. A single geared hoisting crab has a large wheel of 120 teeth and a small wheel of 18 teeth. The barrel is 6 in. dia. and the handle is 14 in. long. Find the mechanical advantage.

5. In a Weston pulley block the two pulleys are 8 in. and 7 in. respectively. What pull is required to raise 5 cwt. if friction is neglected?

6. In screwing up a nut, the fitter uses a screw-key 10 in. long, and applies a force of 50 lb. The pitch of the bolt thread is $\frac{3}{32}$ in. Find the mechanical advantage.

7. A screw-jack has a screw of $\frac{1}{2}$ in. pitch. A turning bar 14 in. long is used. What mechanical advantage is obtained, and what is the efficiency if 36 lb. pressure exerted at the handle raises a weight of 10 cwt.?

CHAPTER X

WORK

FORCES may act on bodies without causing any movement to the bodies. A weight resting on a table, the loads on a beam, a compressed spring, etc., are examples. Such bodies are at rest or in a state of equilibrium. When a force produces motion of a body, *work* is done. The amount of the work done will depend on the magnitude of the force and the distance through which the force acts or the body moves.

The unit of force is the pound weight, and the unit of distance or space is the foot. Work is estimated by the product of the magnitude of the force in pounds and the distance moved in ft. The unit of work is a force of 1 lb. × 1 ft. = 1 ft. lb. The foot pound (or ft. lb.) is the standard unit of work. A unit of work is frequently defined as the amount of work done in raising 1 lb. 1 ft. high. In this case the weight represents the force of gravity. Twenty units of work would be performed if 4 lb. were raised 5 ft., or 10 lb. raised 2 ft., or 2 lb. raised 10 ft.

Example.—A bale of cotton weighing 520 lb. is hoisted vertically 32 ft. How many units of work are expended in doing this?

Distance × weight = units of work

32 ft. × 520 lb. = 16,640 units of work.

Example.—How much work is done in raising 1000 gallons of water from a well 35 ft. deep? A gallon of water weighs 10 lb.

Weight raised = 1000 gal. × 10 = 10,000 lb.

Distance " = 35 ft.

Units of work = force × distance = 10,000 lb. × 35 ft. = 350,000 ft. lb.

Example.—A drum F (*see* Fig. 162) winds up a weight W. Motion is given to the drum, through the gearing shown, by a force of 30 lb. being exerted in turning the handle A. What weight will be raised, and how many units of work will be expended in turning the handle twelve complete revolutions? State the distance moved by the weight, friction to be neglected.

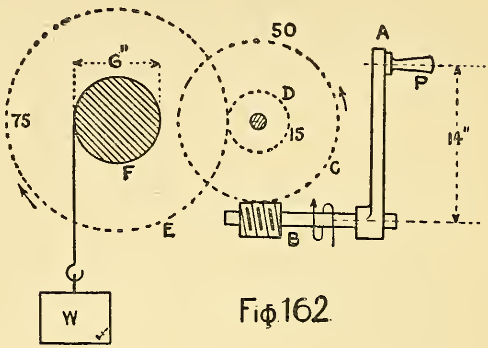


Fig. 162

Force acting on the handle = 30 lb.

Distance moved by handle in 12 revs. $= \frac{14'' \times 2 \times 22 \times 12}{12 \times 7} = 88$ ft.

Units of work exerted on handle in 12 revs. $= 30 \times 88 = 2640$ ft. lb.

To find the weight raised—

(*a*) $\frac{12 \text{ revs. of } B \times B \times D}{C \times E} =$ revs. of the drum F.

If the revs. of the drum F are multiplied by the circumference of F, we obtain the surface speed of F, and consequently the amount of movement given to the weight.

(*b*) $\frac{12 \text{ revs. of } B \times B \times D \times F \times 22}{12'' \times 7} =$ distance the weight is raised in ft.

$\therefore \quad \frac{12 \times 1 \times 15 \times 6'' \times 22}{50 \times 75 \times 12'' \times 7} = \cdot 0754$ ft.

(*c*) Since the initial movement at the handle is 88 ft., and the finishing movement is ·0754 ft., the mechanical advantage will be $\frac{88}{\cdot 0754} = 1167$. This means that 1 lb. pressure on the handle A will support 1167 lb. hanging from the drum F. With a force of 30 lb. on the handle, the weight lifted will be—

$30 \times 1167 = 35{,}010$ lb. (almost 17 tons).

We may take this example as a machine where there is an initial load, as at the handle, and a finishing load, as at the weight. Under perfect conditions, the units of work at the beginning would be equal to the units of work at the end, that is—

$$\text{the units of work on handle} = \text{units of work on weight}$$
$$30 \text{ lb.} \times 88 \text{ ft.} = 35{,}010 \text{ lb.} \times \cdot 0754 \text{ ft.}$$
$$2640 \text{ ft. lb.} = 2640 \text{ ft. lb.}$$

Examine the mechanism and note that there is no opportunity for any lost motion due to slippage, it is all positive drive. Three factors are therefore definite, viz.: the pressure on the handle, the distance moved by the handle, and the distance moved by the weight. In all such machines the weight raised is not equal to the calculated weight, owing to losses by friction; it will probably be only 15,000 lb. instead of 35,010 lb. We know that 2640 ft. lb. have been put into the machine, so that if the weight lifted is 15,000 lb., the output of the machine will be—

$$15{,}000 \text{ lb.} \times \cdot 0754 \text{ ft.} = 1131 \text{ ft. lb.}$$

that is $2640 \text{ ft. lb.} - 1131 \text{ ft. lb.} = 1509 \text{ ft. lb.}$ have been lost.

These 1509 ft. lb. are said to be lost or wasted because they have not done useful work in raising the weight. They have been used up in overcoming the resistance of friction.

The efficiency of the machine is low because of this large waste of the work put into it. The efficiency is expressed as a ratio—

$$\frac{\text{real load}}{\text{ideal load}} \text{ or } \frac{\text{work got out}}{\text{work put in}}.$$

In the example this would be—

$$\frac{1509 \text{ ft. lb.}}{2640 \text{ ft. lb.}} = \cdot 57 \text{ efficiency}$$

or expressed as a percentage

$$= 57\% \text{ efficiency.}$$

Experiments must be made on simple forms of mechanism to find the amount of lost work, and in this way obtain a clear idea of the efficiency of any given piece of mechanism.

Example.—A wagon containing 10 bales of cotton, each bale weighing 430 lb., is drawn a distance of 1 mile in an hour by a horse exerting a pulling force of 100 lb. How many units of work are performed?

In this example the student must ask himself, What is the force and for what distance does it act? These are the only factors that are necessary in order to find the units of work.

The force is clearly stated to be 100 lb.

The distance is ,, ,, 1 mile = 5280 ft.

∴ Units of work = 5280 × 100 = 528,000 *ft. lb.*

Example.—A belt exerts an effective pull of 56 lb. on the rim of an 18-in. pulley and drives it at the rate of 320 revs. per min. How many units of work are performed in 5 min.?

The force = 56 lb.

$$\text{distance moved by the belt} = \frac{18'' \times \frac{22}{7} \times 320 \text{ revs.} \times 5 \text{ min.}}{12''} \text{ ft.}$$

$$\therefore \text{ Units of work} = \frac{56 \times 18'' \times 22 \times 320 \times 5}{12'' \times 7} = 422{,}400 \textit{ ft. lb.}$$

EXERCISES

1. A wagon-load of cotton in the form of eleven bales, each 500 lb. weight, is raised 16 ft. by a hoist to the mixing room of a mill. How many units of work are performed in doing this?

2. An operative weighing 130 lb. carries an armful of bobbins, whose weight is 15 lb., up a flight of steps to the room above. If there are twenty-six steps, and each step is 6 in. high, what work has been performed?

3. Ten thousand gal. of water are in a tank on the roof of a mill. The mill is 90 ft. high. What work has been done to place the water in the tank?

4. A chain 100 ft. long and weighing 11 lb. per ft. hangs vertically and has half its length on the floor. What work is performed in winding up the whole of the chain?

5. A wall has been built to the following dimensions:—80 ft. high, 112 ft. long, and 2 ft. 3 in. in thickness. Find the ft. lb. of work done if a cubic foot of brickwork weighs 116 lb.

6. A ladder 26 ft. long is inclined at 60° to the ground. What work is done by a man of 13 stones in weight who goes up the ladder to within 3 ft. of its upper end?

7. A mill lodge is 20 ft. deep. Find the work done in emptying the lodge expressed in a unit area of 1 sq. ft.

8. Two thousand lb. of cotton are passed through a Bale Breaker per hour, and raised by lattices a vertical height of 14 ft. How

many units of work do the lattices perform during a week of fifty working hours?

9. How is work measured? (A definition not required.)

10. A man carries a heavy weight along a perfectly level but rough floor, and also the same weight along a very smooth floor. What difference would you expect in the amount of work done?

11. A cart-load of material weighing 3 tons requires a pull of 112 lb. to draw it along the road. How many units of work are performed by the horse in travelling 4 miles?

12. Why is the vertical height used in estimating ft. lb. of work? A belt has an effective tension of 64 lb. and drives a machine through a pulley 15 in. dia. at 320 revs. per min. Find the work done per min. when the belt is (*a*) vertical, and (*b*) when the belt is horizontal.

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