Chapter XXXI.—PULLEYS.

PULLEYS for the transmission of power by belt may be divided into two principal classes, the solid and the split pulley. The former is either cast in one entire piece, or the hub and arms are in one casting, and the rim a wrought-iron band riveted on. The latter is cast in two halves so that they may be the more readily placed upon or removed from the shaft.

On account of the shrinkage strains in large pulley castings rendering them liable to break, it is usual to cast pulleys of more than about 6 feet in halves or parts which are bolted together to form the full pulley. On account of these same shrinkage strains it was formerly considered necessary to cast even small pulleys with curved arms, so that the strains might be accommodated or expended in bending or straightening the curves of the respective arms. It is found, however, that by properly proportioning the amount of metal in the hub, arms, and rim of the pulley, straight arm pulleys may be cast to be as strong as those with curved arms, and being lighter they are preferable, as causing less friction on the shafting journals, and, therefore, being easier to drive.

It is obvious that a pulley for a double belt requires to be stronger than is necessary for a single one, but the difference is not sufficiently great to give any practical advantage by making separate pulleys for single and double belts; hence all pulleys are made strong enough for double belts.

Pulleys are weaker in proportion to their duty as the speed at which they rotate is increased, because the centrifugal force generated by the rotation acts in a direction to burst the pulley asunder, so that if the speed of rotation be continuously increased a point will ultimately be reached at which the centrifugal force generated will be sufficient to cause the wheel to burst asunder. But the

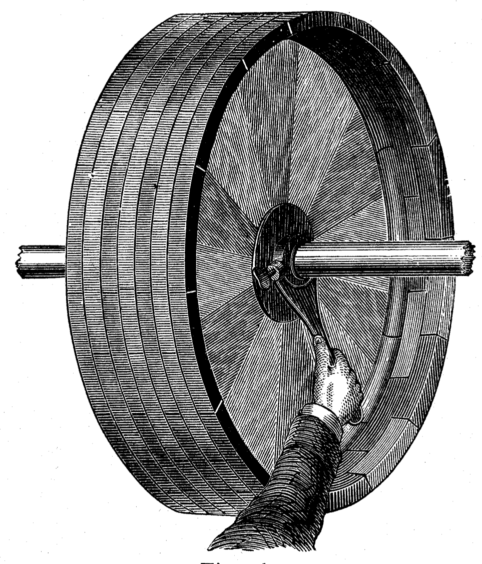

Fig. 2640.

speed at which pulleys are usually run is so far within the limits of the pulley's strength, that the element of centrifugal force is of no practical importance except in the case of very large pulleys, and even then may be disregarded provided that the pulleys be made in a sufficient number of pieces to avoid undue shrinkage strains in the castings, but if solid pulleys are rotated at high velocities the internal strains due to unequal cooling in the mould has been known to cause the wheels to fly asunder when under high speeds.

Fig. 2635 represents a solid pulley, the tapered arms meeting the rim in a slightly rounded corner or fillet, and the rim being thickened at and towards its centre. When the width of rim is excessive in proportion to one set of arms a double set is employed as in Fig. 2636.

In some forms of pulley the arms and hub are cast in one piece and the rim is formed of a band of wrought iron riveted to the arms. By this means shrinkage strains are eliminated and a strong and light pulley is obtained.

Fig. 2637 represents a split pulley in which the two halves are bolted together after being placed on the shaft.

Variable motion may be transmitted by means of an oval driving pulley, as in Fig. 2638, it being obvious that the belt velocity will vary

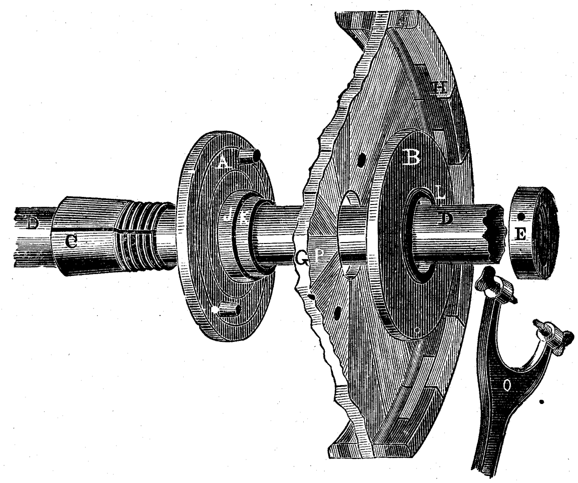

Fig. 2641.

according to the position of the major axis of the oval. Arrangements of this kind, however, are rarely met with in practice.

In Fig. 2639 is shown an expanding pulley largely employed on the drying cylinders of paper machinery, and in other similar situations where frequent small changes of revolution speed is required. Each arm of the wheel carries a segment of the rim, and is moved radially to increase or diminish the rim diameter by sliding in slots provided in the hub of the wheel, a radial screw operated by bevel gears receiving motion from the hand wheel and gear-wheels shown in the engraving. It is obvious that in this case the driving belt must be made long enough to embrace the pulley when expanded to its maximum diameter, the slack of the belt due to reduction of diameter being taken up by a belt tightener.

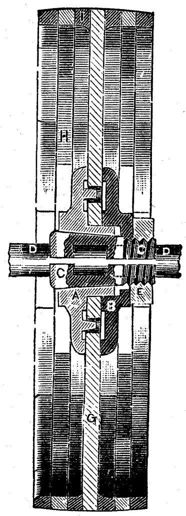

Fig. 2642.

In Fig. 2640 is shown a wooden pulley having a continuous web or disk instead of arms. It is built up of segments, the web being secured to the shaft as follows. In Figs. 2641 and 2642 A,B are clamping plates, and C a split sleeve fitting easily to the shaft and passing through A,B, while receiving the nut E on the other side. The web of the pulley fits on the shoulder J, and the flange B fits on the shoulder K, so as to keep these parts true or concentric to A. The bore of A is taper to fit the taper of C; hence the nut E in drawing C through A, causes C to close upon and grip the shaft, while the flanges A,B grip the pulley and hold it to C.

In Figs. 2643 and 2644 are represented the Otis self-oiling loose pulley, designed to automatically oil itself upon its starting or stopping.

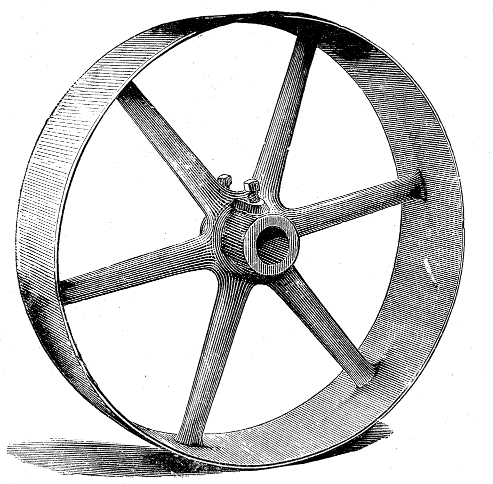

Fig. 2635.

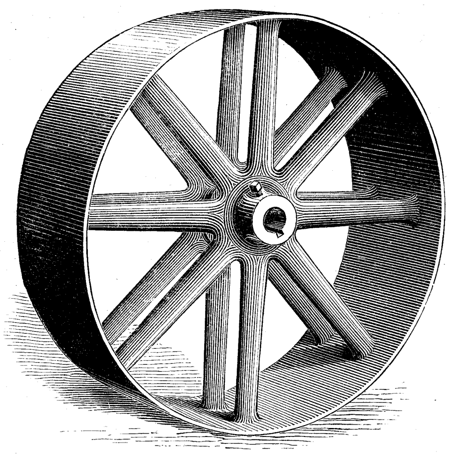

Fig. 2636.

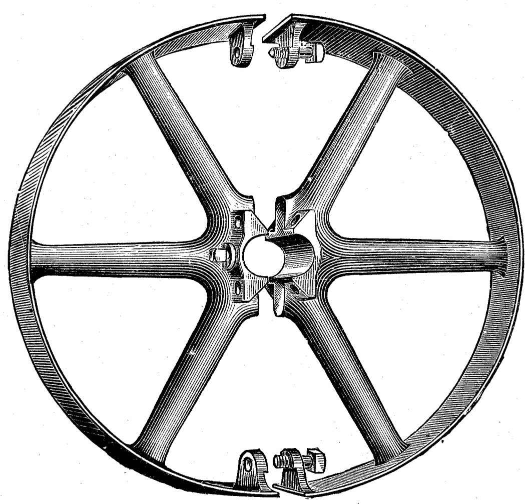

Fig. 2637.

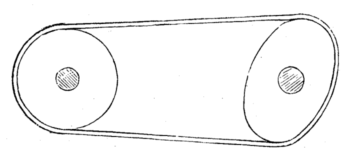

Fig. 2638.

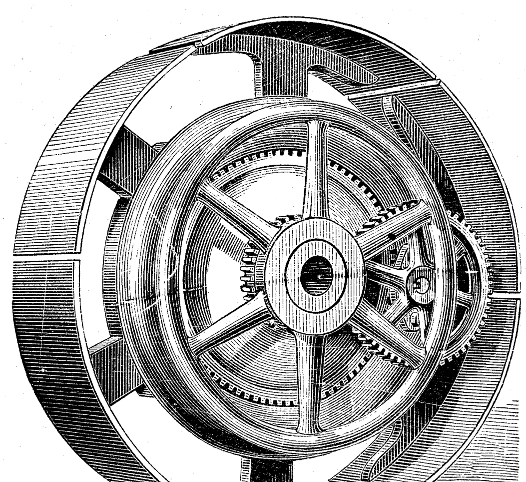

Fig. 2639.

The hub D is cored out in such manner as to form within it an annular chamber or cavity B B, entirely surrounding the bore, and serving as a reservoir to contain oil or other lubricating liquid.

This chamber or reservoir has no direct communication with the bore of the hub, but a communication is formed between it and the bore through one or more chambers C C, which are termed supply chambers, and which are partitioned off within the bore from the reservoir B, by coring the hub in a suitable manner.

These supply chambers have openings N N in their sides or ends communicating with the reservoir B, and also openings C C communicating with the bore of the pulley. These supply chambers supplying, at such times, of a small quantity of oil to the bearings of the loose pulleys, the makers claim that a perfect and reliable means is obtained for guarding against any needless waste of the lubricant.

A crowning or crowned pulley is of largest diameter in the middle of its width or face, the object being to cause the belt to run on the middle of the pulley width. It would appear that this crowning would give to the belt a greater degree of tension at its centre than at its edges, but it is shown by experiment that if a piece of belt be clamped square across its width at each end and stretched, the centre as section *b*, in Fig. 2645, will stretch the most, and that if the piece be divided along its centre lengthwise, and

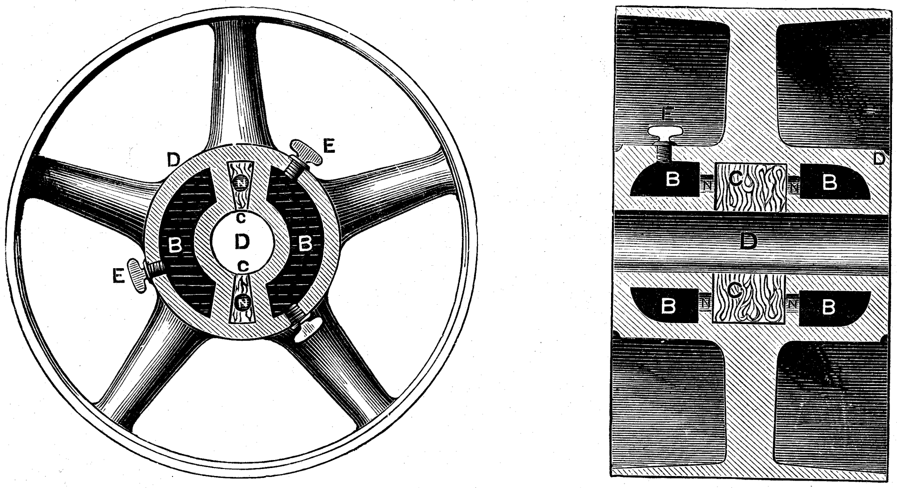

Fig. 2643.

are filled with wick or other fibrous or capillary material, which is also inserted into the openings N N, to draw the oil from the reservoir by capillary attraction and supply it in moderate quantities between the bore of the pulley and the shaft on which it runs. Three or more openings are provided in the outer shell of the hub for the introduction of oil into the reservoir B, which openings are closed by thumb-screws, plugs, or other stoppers E E. There being three of these openings, one will always be at or near the top when the pulley is at rest, and through this the oil may be introduced without difficulty. It is not intended that the reservoir

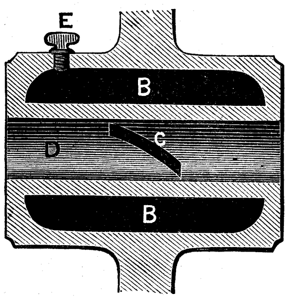

Fig. 2644.

should at any time contain more than one-third its capacity of oil, so that whenever the pulley is at rest the surface of the oil will be below the lowest point of the bore, thus preventing any waste of oil at such times.

When the pulley is in motion, the centrifugal force imparted to the oil in the reservoir throws it outwardly, causing it to be distributed in an even layer against the inner surface of the shell which encloses and forms the reservoir, thus preventing any possible waste when the pulley is in motion.

But when the pulley is either stopped or started, the oil is caused to change its position, and in so doing is brought into contact with the wicks protruding from the small openings N N, by which it is conveyed into the supply chamber, and thence to the shaft. By thus taking advantage of what is a necessity in all business establishments in which machinery is employed—to wit, the stopping and starting of the machinery at regular intervals—to insure the

both halves again stretched, they will again do so the most in the middle of their widths.

From this it appears that the crowning serves to produce a tension equal across the pulley width, because it will stretch the belt the most in the middle of its width, where it has the greatest capacity to stretch.

The amount of crowning employed in practice varies from about $\frac{3}{16}$ to $\frac{3}{8}$ inch per foot of width of pulley face, the minimum being employed where the belt requires to be moved or slipped laterally from one pulley to another of equal diameter, as from a fast to a loose pulley and *vice versâ.* To relieve the belt of strain when on a loose pulley the loose pulley is sometimes made of smallest diameter, and has a coned step up which the belt moves when pressed against it. During this passage of the belt, however, one edge is stretched more than the other, while in passing from the large to the smaller pulley the same edge is under tension, while the other is released from tension ; hence, with the belt passing either to or from the large pulley there is a tendency to unduly stretch one of its edges. On the other hand, however, in cases where the belt requires to run for long periods on the loose pulley relieving it from tension is a great advantage.

In fixing pulleys so that they shall run true upon their shafts several difficulties are met with. First, it is difficult to turn the

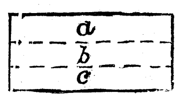

Fig. 2645.

shafts quite parallel and to exact standard gauge diameter. Second, the bore of the pulley must be made a sufficiently easy fit to enable their being moved by hand along the shaft to the required location. As a result the set-screw pressure throws the pulley out of true, unless the mandrel on which the pulley is turned in the lathe be the same diameter as the pulley shaft, and the pulley be held upon the mandrel by the set-screw pressure, and not by driving the mandrel into the pulley bore. In this case two set-screws must be used one on each end of the pulley hub, so as to steady the pulley on the mandrel. A pulley thus trued will still run out of true when on its shaft unless the shaft be of the same diameter as the mandrel.

One means of obviating this difficulty is to reduce the diameter of the shaft between the pulley seats sufficiently to allow the pulley to pass easily, and to make the pulley bores a driving fit to their seats. This, however, is only practicable in cases where the locations of the pulleys are permanently fixed, and no occasion arises for the addition of new pulleys.

To obviate this difficulty what is termed an internal clamp pulley has been constructed. This pulley is shown in Fig. 2646. The bore is made sufficiently smaller than the shaft diameter

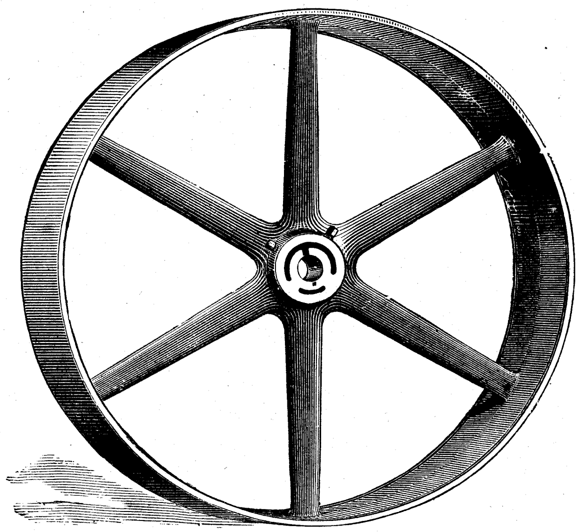

Fig. 2646.

to be a forcing fit. A slot in the form of an arc of a circle is formed in the hub as shown, and a split runs from this arc into the bore. As a result a wedge driven between the walls of the split will spring open the bore and permit its easy passage along the shaft to its required location, when the removal of the wedge will permit the bore to close upon the shaft. To secure the pulley to the shaft four set-screws are employed, two of them being shown in the cut, and the other two being similarly located on the other side of the pulley.

By this means there will be less difference between the diameters of the pulley bore and of the shaft should the latter be slightly less than its standard diameter, and as a result the pulley will run more true.

Split pulleys are bored a tight fit to the shaft when the two halves are bolted firmly together. They may, however, be made

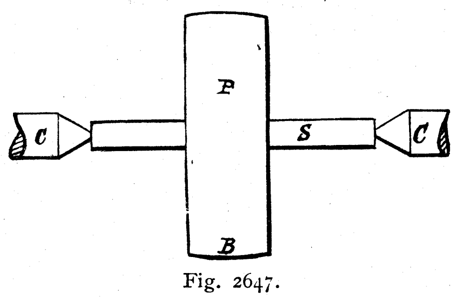

Fig. 2647.

to grip the shaft in two ways; first, if bored when bolted together the edges of the bore will meet the shaft and clip it so firmly as to require each half bore to spring open to permit it to pass on the shaft, but by inserting between the two halves of the hub two thicknesses of writing paper, and boring out the hole the thicknesses of the paper too large (which may be done by placing two pieces of the same paper beneath the calipers or gauge) the bore will be slightly oval when the paper is removed, and will grip the shaft at the crown of each half bore, but the grip thus obtained will not be so firm.

Pulleys of small diameter, as three feet or less in diameter, are usually held to their shafts by set-screws, the consideration of their shapes and position having been already treated of when referring to the applications of keys and set-screws. Pulleys of large diameters, and those which act as fly-wheels as well as pulleys, are usually held by keys.

Balancing Pulleys.—A pulley (more especially those running at high speed) should be balanced or in balance when rotating at the greatest speed at which it is intended to run. This is necessary, because if the centrifugal force generated by the pulley's rotation be greater on one side than on another of the pulley, it will cause the pulley shaft to vibrate and shake whenever the amount of unbalanced centrifugal force becomes, on account of the speed of rotation, sufficient to bend the shaft or deflect the framing holding the shaft.

The balancing of a pulley will not be correct unless the centrifugal force is equal at all points on the perimeter in the same plane, as will appear presently. In practice two methods of testing the balance of a pulley are employed: first, the standing; and second,

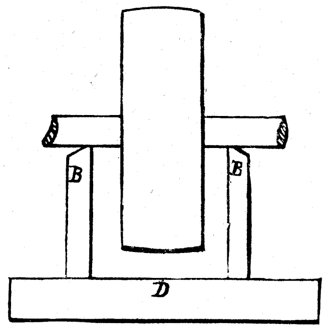

Fig. 2648.

the running balance. A standing balance does not in any sense balance a pulley, but merely corrects the want of balance to a limited degree. A running balance correctly balances a pulley when running up to the speed at which the balance was made, but does not balance for greater speeds.

A standing balance is effected when the shaft being supported horizontally and with as little friction as possible, the pulley will remain at rest in any position in which it can be placed. Thus, in Fig. 2647 let C C represent the two centres of a lathe adjusted in their distance apart so as to sustain the shaft S with just sufficient force to prevent end movement or play of the shaft, and if the pulley P remains motionless when arrested at any point of rotation it is in standing balance. A common method of balancing is to set the pulley in slow rotation several times in succession, and if the same part of the pulley's circumference comes to rest

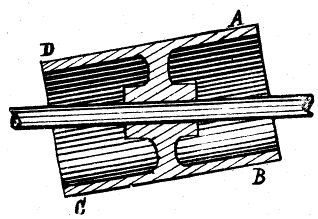

Fig. 2649.

in each case at the bottom as at B then it is heaviest and its weight must be reduced, or weight must be added on the diametrically opposite side of the pulley. Another method is to rest the shaft horizontally on a pair of metallic strips as B B in Fig. 2648, the strips resting on a flat horizontal surface D, the testing being applied as before. Sometimes, however, cylindrical pieces are used in place of the strips or pieces B B.

A pulley that is in balance thus tested, may not, however, be in balance when rotated, or, as already stated, a standing balance may not be a running balance, for the following reasons: In Fig 2649 is a pulley that if turned true inside and out would be of correct standing balance, because the weight is equal on each side of the shaft; thus the point A, though farther from the axis than B, would be counterbalanced by C, while B would be counterbalanced by D, but as soon as the pulley was put in rotation there would be more centrifugal force generated at A than at B, and more at C than at D, because, though the weights would be equal, the velocities of A and C would be greatest.

Now, suppose that instead of a continuous wide pulley several pulleys were used, being out of true so as to be practically equal in shape to Fig. 2649, and it is apparent that the fact of pulley A B being out of balance is not removed by pulley C D being out in an opposite direction, and that each pulley will tend to bend the shaft in the direction of its excessive centrifugal force.

The effect of this inequality of centrifugal force will depend, in each case, upon the strength of the shaft in comparison with the amount of unbalanced centrifugal force. Suppose, for example, that the centrifugal force at a point A in Fig. 2650 were 10 lbs. greater than at B at a given velocity, and that the strength of the shaft be such that it will bend $\frac{1}{32}$ inch under a weight of 10 lbs.,

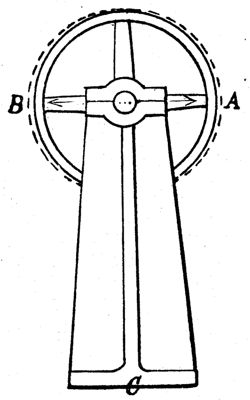

Fig. 2650.

then the effort of the point A will be to swing in a circle $\frac{1}{16}$ inch larger than that due to its diameter. Suppose, then, the stand be so firmly fixed at C as to be motionless in a vertical direction under this effort, then the point A will swing in an oval, as denoted by the dotted lines, the shaft vibrating as denoted by the arrows.

Thus vibrations of the shaft, bearing, &c., occur whenever the excess of centrifugal motion on one side of a pulley is sufficient to spring the shaft, bearings, standard or foundation, as the case may be, and will occur most in the direction in which those parts will most easily succumb. From this it is evident that a pulley practically in balance, so far as being free from vibration at a certain speed, may be considerably out of balance at an increased speed. Thus, suppose a pulley P, in Fig. 2651, has a rim of equal thickness, but the distance of A from the axis of rotation is

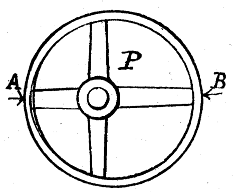

Fig. 2651.

6 inches, while the distance of B is 8 inches; then the centrifugal force at B will, at any speed of rotation, be one-quarter more than that at A, because the distance is one-quarter greater. Suppose, then, that its shaft, bearings, and foundation be capable of resisting 100 lbs. without sensible flexure, but that sensible flexure of those parts will occur under any pressure over 100 lbs.

The centrifugal force of 1 lb. at A and at B, respectively, may be calculated by the following rule :—

Rule.—Multiply the square of the number of revolutions per minute by the diameter of the circle of rotation in feet, and divide the product by 5,870. The quotient is the centrifugal force in terms of the weight of the body.

In the case of A the pulley making, say, 200 revolutions per minute, we have by the rule :

$$\frac{200^2 \times 1}{5{,}870} = 6{\cdot}81 = \text{the centrifugal force.}$$

Likewise, centrifugal force at B $= \frac{200^2 \times 1{\cdot}25}{5{,}870} = 8{\cdot}51 =$ the centrifugal force, 1 and 1·25 being diameters of circle of rotation of A and B in feet.

Now, suppose the revolutions to be 2,000 per minute, we have in the case of A 2,000 × 2,000 × 1 (= 4,000,000) ÷ 5,870 = 681 lbs. centrifugal force. Add one-quarter more, or 170 lbs., to obtain the centrifugal force at B = 851 lbs.; the unbalanced centrifugal force = 170 lbs.; and this being 70 lbs. more than the shaft, bearings, &c., are capable of resisting without flexure, a corresponding vibration will occur, whereas at 200 revolutions the unbalanced centrifugal force was: Centrifugal force at B = 8·51 lbs. less that at A = 6·81 = 1·70 lbs. unbalanced centrifugal force, and it becomes apparent that while at 200 revolutions the pulley would rotate without sensible vibration, at 2,000 revolutions (in the same time), sensible vibration would occur; hence, the sensible vibration of a pulley is in the proportion as the unbalanced centrifugal motion is to the resistance of the shaft, bearings, &c., to flexure, and further, as the unbalanced centrifugal motion increases

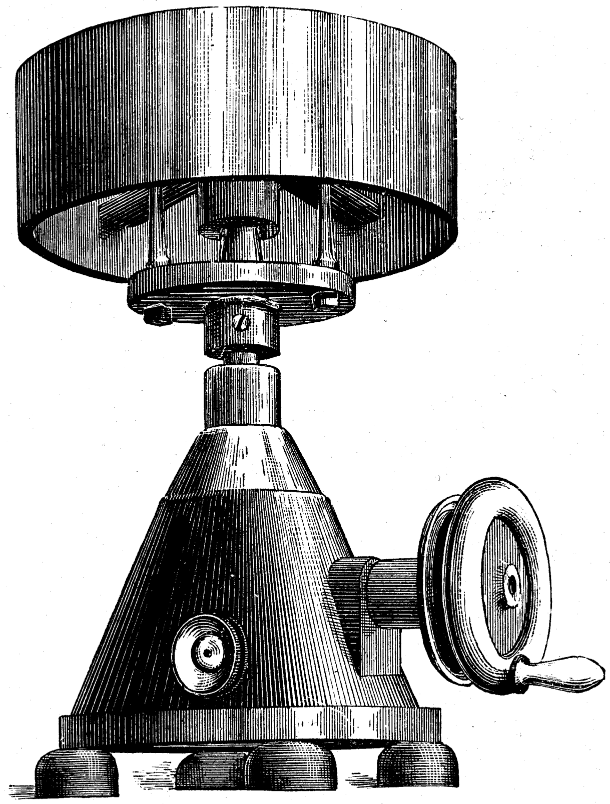

Fig. 2652.

with the velocity, so also does the sensible vibration increase with the velocity.

But there are two ways of increasing the velocity of a pulley: 1st, by increasing the revolutions of a given pulley; 2nd, by employing a pulley of a larger diameter, but making the same number of revolutions. In our example we increased the speed tenfold (from 200 revolutions to 2,000) but the centrifugal force was increased one hundredfold, according with the law that the centrifugal force increases with the square of the revolutins, and 10 × 10 = 100. But if the velocity had been increased by augmenting the diameter of the pulley, the centrifugal force would have increased in the same ratio as the pulley diameter was increased; hence it appears that under equal velocities larger pulleys generate less centrifugal force per unit of unbalanced weight than do smaller ones.

A device for testing the balance of pulleys is shown in Fig. 2652; it consists of a frame carrying a vertical spindle, which may be rotated by suitable bevel-wheels, and the hand wheel shown. In this case it would be preferable to balance the pulley at the greatest speed at which it would be convenient to run it by hand with the wheel shown, because a pulley balanced at any given speed will be balanced at any lesser speed, although not at a greater one. But the pulley should not be driven by the arms, because the pressure against the same will affect the balance. It would be better therefore to let the spindle of the machine be small enough in diameter to fit the smallest bore of pulley to be balanced, to employ sleeves fitting the spindle and the bores of all larger bored pulleys, and to obtain the most correct results the pulley should be fastened to the sleeve by its set-screws, or keys of the pulley, as the case might be, so that whatever error there might be induced by tightening the same will be accounted for in the balancing. It is obvious also that the pulley bore should fit the sleeve with the same degree of tightness as it will fit the shaft to which it is to be fixed. The heaviest side of the pulley will rotate through a circle of larger diameter, and may be marked by a point, as a tool point moved up to it by a slide rest, or roughly by a piece of chalk steadily moved up to it by hand until it just touches the high side of the pulley.

The methods of correcting the balance are as follows: The heavy side of the pulley having been found, a weight is attached to

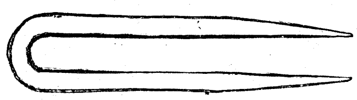

Fig. 2653.

the diametrically opposite side of the pulley; a convenient form of light weight for this purpose is shown in Fig. 2653; it consists of what may be termed a spring clamp, since it holds to the edge of the pulley rim, on which it is forced by hand, by reason of the spring of the jaws. There are numerous clamps of this form, each having a definite weight, as 2 ozs., 3 ozs., 4 ozs., &c.; but for weights above about $1\frac{1}{2}$ lb. a clamp with a set-screw is employed. For a running balance a set-screw is indispensable. It is obvious that pulleys will be more easily and correctly balanced when the inner side of their rim is turned up, as far as the arms will permit, in the lathe; but on account of the expense this is not usually done, except in the case of large pulleys.

In the best practice, however, the pulley is set in the lathe, so that the inside of the rim runs as true as possible. Remarks on this subject are given under the head of chucking pulleys.

When the balance is to be effected by adding weight to the pulley mushroom-shaped pieces of metal are made for the purpose, their weights varying by ounces; the stems are driven through holes drilled through the rim to receive them, and riveted on the face side. The stems are of wrought iron, while the heads may be of cast iron, but are better of lead, because in that case they may be set with a hammer to fit the inner surface of the pulley rim.

In some practice, protuberances, or a web in the middle of the pulley, are cast on the pulley, and the balance is effected by cutting this away to reduce the weight on the heavy side.

When pulleys are to revolve at very high speeds, as in the case of those for emery-wheel spindles, the shafts themselves require to be balanced, especially if of cast iron, because that part of the shaft uppermost in the mould will be of less density and weight than that at the bottom of the mould. The pulley should be balanced separately, and the whole again balanced after being put together, because the weight of the key or set-screw will be sufficient to destroy the balance under a sufficiently high speed of rotation.

The edges of pulley rims should be trued up in the lathe when the rim is turned so that the pulleys to receive a belt may be set in line by pressing a straight-edge, or setting a line to have contact with (as near as possible) diametrically opposite points of the edge of one pulley, and setting the other to have its corresponding edge in line.

Pulleys should run true so that the strain or tension of the belt shall be equal at all parts of the revolution, and the transmitting power shall be equal. The smoother and more polished the surface of the pulley the greater its driving power.

The transmitting power of a pulley may be increased by covering the pulley face with leather or rubber bands, but the thickness of these should be equal both across the width and all around the circumference so as to run true.

The amount of increase of driving power due to this covering is variously stated, but may be taken at about 20 to 30 per cent. A cement for fastening such pulley coverings may be made as follows: Take one ounce of caoutchouc (pure or native rubber) and cut it into thin slices, place it in a tinned sheet-iron vessel with six or seven ounces of sulphide of carbon; the vessel is then to be placed in a water tank previously heated to about 86° Fahr. To prevent the solution from becoming thick and unmanageable, mix with a solution consisting of spirits of turpentine, in which half an ounce of caoutchouc in shreds has been dissolved over a slow fire, and then a quarter of an ounce of powdered resin; from an ounce and a half to two ounces of turpentine being afterwards stirred in, to be added in small quantities. This cement must be kept in a large-mouthed bottle well corked, and in using clean the parts to be united thoroughly with benzine; apply two coats of cement, allowing each to dry before applying the next; when applying the last coat allow the cement to dry so as to become very sticky, then press the surfaces firmly together and allow to thoroughly dry. This is waterproof.

A pulley that imparts motion to the belt enveloping or partly enveloping it is termed a driving pulley or driver. A driven pulley is one that receives motion from, or is driven by, the belt; hence in every pair of pulleys connected by belt, one is termed the driver and the other the driven. The revolutions of two pulleys connected by belt will vary in the same proportion as their diameters, although their rim velocity will be equal.

Suppose, for example, that a pulley of 7 in. diameter drives one of 14 in. diameter, then if there is no slip on either pulley both pulleys will run at the same velocity as the belt, and this velocity must be equal to the velocity of the driver, because the belt is moved by the driver. Now, suppose the driver which is of 7 in. diameter makes one revolution in a minute, and as it is only one-half the diameter of the driven wheel, its circumference will also be half that of the driven, so that it must make two revolutions to carry around length of belt enough to pass once around the driven pulley. The revolutions of the two are, therefore, in the same proportions as are their diameters, which in this case is two to one. As the driven pulley is the largest diameter, it will make one revolution in the same time that the driver makes two. But suppose the driving pulley was 14 and the driven was 7 inches in diameter, then the proportion would still be two to one, and the driven would make two revolutions to every revolution of the driver.

If we are given the number of revolutions a driving pulley makes and the diameter or circumference of both pulleys, and require to find the number of revolutions the driven pulley will make to one or

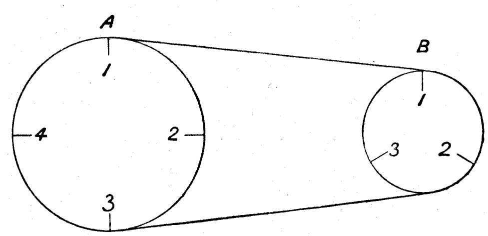

Fig. 2654.

to any given number of the driver, we may consider as follows: Suppose the circumference of the driver to be 24 inches and that of the driven to be 18 inches, then in Fig. 2654 let circle A represent the driver, and circle B the driven pulley. If we divide the circumference of A into four equal divisions, as at 1, 2, 3, and 4, each of these divisions will equal 6 inches, because the whole circumference being 24 inches, one quarter of it will be 6. If we divide the circumference of B into six-inch divisions there will be but three of them as marked, because one-third of 18 (its circumference) is 6. Now three of the divisions at A will move A a full revolution, and the remaining division on A will move B through another one-third of a revolution, hence, each revolution of A equals $1\frac{1}{3}$ revolutions on B. The proportions of the circumference are, therefore, as $1\frac{1}{3}$ to 1, or as 133 is to 100, taking A as the driver, and, therefore, as the basis of the proportion. But suppose we take B as the basis of the proportion, and one revolution of B will cause A to make three quarters of a revolution, or during 100 revolutions of B, A will make

75. But nevertheless during the period that A is making 100 revolutions B will have made one-third more, or $133\frac{1}{3}$, because B makes $1\frac{1}{3}$ revolutions to cause A to make one revolution. From this it will be seen that the proportion is as the greater is to the lesser, and not as the lesser is to the greater, or, in other words, it is in this case as 24 is to 18, which is one and one-third times, for one-third of 18 is 6, and $18+6=24$.

Suppose, now, we take the four divisions on A and the three on B to consider their proportions, and we may say 4 is $1\frac{1}{3}$ times 3, or we may with equal propriety say 3 is $\frac{3}{4}$ of 4, hence 4 is not in the same proportion to 3 that 3 is to 4. Let it now be supposed that a driven pulley B is 18 inches in diameter, and requires to be driven one quarter faster than the driver, what then must be the diameter of that driver? As the revolutions require to be increased one-fourth the pulley diameter must be increased one-fourth. Thus one quarter of $18=4\frac{1}{2}$, and this added to 18 is $22\frac{1}{2}$, which is therefore the diameter of the driving pulley, as may be proved as follows: Suppose the circumferences instead of the pulley diameters to be $22\frac{1}{2}$ and 18 respectively, and that the largest pulley makes 100 revolutions, then it will pass 2,250 ($22\frac{1}{2} \times 100 = 2{,}250$) inches of belt over its circumference, and every 18 inches of this belt will cause the small pulley to make one revolution; hence we divide 2,250 by 18, which gives us 125 as the revolutions made by the small pulley, while the large one makes 100. Thus it appears that we obtain the same result whether we take the circumferences or the diameters of the pulleys, because it is their relative proportions or relative revolutions that we are considering, and their actual diameters do not affect their proportions one to the other. Thus, if a 10-inch pulley drives a 30-inch one, the proportions being three to one, the revolutions will be three to one, and the driven being three times the largest, will make one revolution to every three of the driver. If the driver was 3 inches in diameter and the driven 9, the revolutions would be precisely the same as before, but with equal revolutions the velocities would be different, because in each revolution of the driver it will move a length of belt equal to its circumference; hence, the greater the circumference the greater length of belt it will move per revolution. To take the velocity into account, we must take into consideration the number of revolutions made in a given time by the driver. Suppose, for example, that the driver being 3 inches in diameter makes one revolution in a minute, then it will move in that minute a length of belt equal to its circumference, so that the circumference of the driver, multiplied by the number of its revolutions per minute, gives its velocity per minute. Thus, if a pulley has a circumference of 50 inches, and makes 120 revolutions per minute, then its velocity will be 6,000 inches per minute, because $50 \times 120 = 6{,}000$. The velocity of the belt, and therefore that of the driven wheel, will also be 6,000 inches per minute, as has already been shown. From this train of reasoning the following rules will be obvious:—

To find the diameter of the driving pulley when the diameter of the driven pulley and the revolutions per minute of each are given:

Rule.—Multiply the diameter of the driven by the number of its revolutions, and divide the product by the number of revolutions of the driver, and the quotient will be the diameter of the driver.

The diameter and revolutions of the driver in a given time being known, to find the diameter of a driven wheel that shall make a given number of revolutions in the same time:

Rule.—Multiply the diameter of the driver by its number of revolutions, and divide the product by the number of revolutions of the driven. The quotient will be the diameter of the driven.

To find the number of revolutions of a driven pulley in a given time, its diameter and the diameter and revolutions of the driver being given:

Rule.—Multiply the diameter of the driver by the number of its revolutions in the given time, and divide by the diameter of the driven, and the quotient will be the number of revolutions of the driven in the given time.

Suppose, however, that the speed of the shaft only is given, and we require to find the diameter of both pulleys, as, for example, suppose a shaft makes 150 revolutions per minute, and we require to drive the pulley on a machine 600 revolutions per minute. Here we have two considerations: first, the relative diameters of the two pulleys, and secondly, the diameter of pulley and width of belt necessary to transmit the amount of power necessary to drive the machine at the speed required. Leaving the second to be discussed hereafter in connection with the driving power of belts, we may proceed to determine the first as follows: The pulley on the machine must be as much smaller than that on the main shaft, as the speed of the pulley on the machine requires to run faster than does the main shaft, hence we divide the 600 by 150 and get four, which is the number of times smaller than the driver that the driven pulley must be. Suppose then the driver is made a 24-inch pulley, then the driven must be a 6-inch one, because $24 \div 4 = 6$; or we may make the driver 36, and the driven 9, because $36 \div 4 = 9$; or the driver being 48 inches in diameter, the driven must be 12, because $48 \div 4 = 12$. To reverse the case, suppose the shaft to make 200 revolutions per minute, and the machine pulley to make 50, then since $200 \div 50 = 4$, the driven (or machine pulley) must have a diameter four times that of the driver, and any two pulleys of which one is four times the diameter of the other may be used, as say: Pulley on line shaft 10 inches in diameter, pulley on machine 40 inches in diameter; or, pulley on line shaft 20 inches in diameter, pulley on machine 80 inches in diameter.

Now, in nearly all cases that are met with in practice, it would be inconvenient to have so large a pulley as 80 inches in diameter to drive a machine, and again in most cases a driving pulley of 10 inches in diameter would be too small. So likewise in cases where the machine pulley requires to run faster than the line shaft, a single pair of pulleys will be found to give, where great changes of revolution are required, too great a disproportion in the diameter of the pulleys; thus in the case of a shaft making 150, and the machine requiring to make 600, we may use the following pairs of pulleys:—

	On Main Shaft.	On Machine Shaft.
First . . .	32 inch diameter	8 inch diameter.
Second . . .	40 ,, ,,	10 ,, ,,
Third . . .	48 ,, ,,	12 ,, ,,
Fourth . . .	60 ,, ,,	15 ,, ,,

But the machine may require so much power to drive it, that with the width of belt it is desired to employ, a pulley larger than either of these is necessary, as, say, one 20 inches in diameter. Now, with a 20-inch driven pulley, the driver would require to be 80 inches in diameter, because $20 \times 4 = 80$. But there may not be room between the shaft and the ceiling for a pulley of so large a diameter, or such a large pulley may be too heavy to place on the shaft, or it may be too costly, and to avoid these evils, countershafts are used.

By the employment of a countershaft we simply obtain—with two pairs of pulleys and by means of small pulleys—that which could be obtained in a single pair, providing the great difference in their diameters (necessary to obtain great changes of rotation), were not objectionable; all that is necessary, therefore, is to accomplish part of the required change of rotation in one pair, and the remainder in the other. In doing this, however, while the velocity of each driver and driven will be equal (as was explained with reference to a single pair), notwithstanding the difference in their diameters, yet the velocity of one pair will necessarily differ from that of the other, so that the pulley on the machine will vary in its velocity as well as in its rotation from that of the first driver. The first driver is that on the main or driving shaft, and the pulley it drives is the first driven. The second driver is the second pulley on the countershaft, and the second driven is the one it drives or that on the machine. Suppose, then, a driving shaft makes 100 revolutions per minute, and the machine requires to make 600, then the speed of rotation requires to be increased six times. Now we may effect this change of six times in several ways; thus: Suppose we increase the rotations three times in the first pair, then the second pulley will make 300 rotations, or three times those of the main shaft, and all we have to do is to make the second driven one-half the diameter of the second driver, and its rotations will be double those of the second driver, which will give the required speed of 600 revolutions. Suppose, however, we change the speed four times in the first pair, and the 100 of the shaft becomes 400 on the countershaft, and to increase this to 600 on the second driven, all that is required is to make its diameter one-half less than that of the second driver, because 600 is one-half more than 400. From this it will be perceived that the number of changes or amount of increase or decrease of speed being given, the proportion of diameters for both pairs of pulleys will be represented by any two numbers which, multiplied together, will give a sum equal to the number of increased revolutions required. Having found the proportions for each pair, it remains to determine their actual diameters, and they will be found to vary under different conditions.

Suppose, for example, we have the following conditions: Main shaft runs 100; machine must run 600. The pulley on the line shaft is 36 inches in diameter; required, the diameters for the other three pulleys.

To make three changes in the first pair, the first driven must be $\frac{1}{3}$ the diameter of the first driver, which is 12 inches. Now the second pair we may make any diameters that are two to one; and since the second driver is to be the smallest, we may select as small a pulley as will answer for the machine, and make its driver twice its diameter.

But suppose it is the diameter of the pulley on the machine that is fixed, and the diameter of the other three require to be found. Let the diameter of the second driven be 12; then its driver on

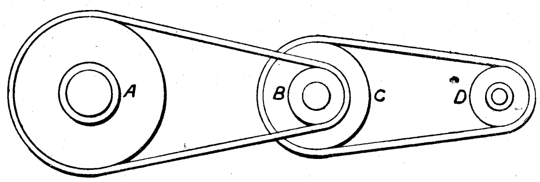

Fig. 2655.

the countershaft must be 24. The other two must have diameters 3 to 1 as before, any suitable wheels being selected.

Yet another condition may occur. Thus, suppose the countershaft is on hand, and that it has on it two pulleys, as a 12 and a 24-inch; then a 36 on the inner shaft will be three times as large as the 12, and a 12-inch on the machine will be twice as small; or, what is the same, one half as large as the 24.

When the principle is clearly understood the calculations can be performed mentally with ease so far as the required diameters to attain the necessary speed is concerned, but there are other considerations that claim attention.

Thus, for example, to multiply the rotations 6 times we may proportion the first pair as follows: Driver 48, driven 16; second pair, driver 30, driven 15 inches in diameter.

Or we may proportion them as follows: First pair: driver 36, driven 12; second pair: driver 28, driven 14 inches in diameter.

In the second arrangement of diameters the drivers are each 2 inches, and the driven each 1 inch less in diameter than in the first; hence their cost would be diminished, as would also be the wear of the journals, on account of the reduced weight of the pulleys; hence, if the driving capacity of each pulley is equal to the requirements the second arrangement would be preferable.

In considering this part of the subject, first let it be shown that although the horse-power transmitted by the two belts is equal whatever be the proportions of the pulleys (provided, of course, that the belts do not slip), yet the strain or wear and tear of the belts varies, and the requirements for one belt are therefore different from those for the other.

In Fig. 2655 let A represent a 36-inch pulley on the driving shaft, B a 12-inch, and C a 24-inch pulley on a countershaft, and D a 12-inch pulley on a machine shaft. Let the main shaft make 100 revolutions per minute, and the machine requires a force to move it equal to 50 pounds applied to the perimeter of D. Now the rotations of D will, with these pulleys, be six to one of the main shaft or A, which gives D 600 revolutions per minute, thus: 100 × 6 = 600. The circumference of D is about 37·69 inches, which, multiplied by 600 (the number of its revolutions), gives 22,614 inches, or 1,884·5 feet as its speed per minute. This multiplied by the 50 pounds it takes to move the machine at the perimeter of D, gives 94,225 as the foot pounds per minute required to drive the machine 600 revolutions per minute, and this, therefore, is the amount of power transmitted by each belt. On the second belt this is shown to be composed of 50 pounds moving 1,884½ feet per minute, hence we may now find how it is composed on the first belt, as follows:—

The diameter of the first driver is 36 inches, and its circumference 113·09 inches, or 9·42 feet; this, multiplied by its revolutions per minute, will give its speed, thus: 9·42 × 100 = 942 feet per minute. To obtain the necessary amount of pull for this first belt, we must divide this speed into the number of foot pounds it takes to drive the machine, thus: 94,225 ÷ 942 = 100·02. The duties of the two belts are therefore as follows:—

First belt, weight of pull	100·02
,, speed per minute	942 feet.
Second belt, weight of pull	50·00
,, speed per minute	1884·5 feet.

The duty in foot pounds being equal, as may be shown by multiplying the feet per minute by the force or weight of the pull, leaving out the fractions, thus:—

$$942 \times 100 = 94{,}200.$$
$$1884 \times 50 = 94{,}200.$$

The difference in the requirements is, then, that the first belt must have as much more weight or force of pull than the second as its speed is less than that of the second.

It is obvious that in determining the proportions of the pulleys this difference in the requirements should be considered, and the manner in which this should be done depends entirely upon the conditions.

Thus, in the case we have considered, the speed was increased, but the object of the countershaft may be to decrease the speed, and in that case the conditions would be reversed, inasmuch as though the foot pounds transmitted by both belts would still be equal, yet the speed would be greatest and the strain or pull the most on the second belt instead of on the first.

It is obvious, then, that the proportions of the pulleys being determined the actual diameters must be large enough to transmit the required amount of power without unduly straining the belt.