MILL-WORK. Under this head we intend to treat of the parts and mechanical contrivances used in mills. Under the article MACHINERY, the reader will find observations of a similar nature to those of the present article, but applied to smaller and more delicate machines than those which are usually denominated mills.

The object of this article will therefore be, to give a general account of the most important pieces of mill-work, as cog-wheels, shafts, bearings, &c.; which parts being common to mills of all kinds, would, if minutely described under every head where they are employed, introduce a great many needless repetitions.

The different first movers of mills will be treated of, and described under their several heads of STEAM-ENGINE, WATER-WHEELS, and WIND-MILL; and the acting machines of several kinds of mills, as clay-mill, grinding-mill, under CUTLERY; fulling-mill, flour-mill, iron-mill, under MANUFACTURE OF IRON; oil-mill, cotton-mill, under MANUFACTURE OF COTTON; rolling-mill, spinning-mill, flax-mill, thrashing-mill, water-mill, sawing-mill, under MACHINERY for manufacturing SHIps' BLOCKS at Portsmouth; TILT MILL, &c. &c.

Cog-wheels are the most important and numerous parts of mill-work, few mills being without them, to modify the direction, and adapt the power of the first mover, which actuates the mill, to the working point, or the machine which performs the operations the mill is intended for. Most mills contain several different kinds of machines, or operative parts, all deriving their motions from the same source, or first mover. Thus, a flour-mill contains stones for grinding; dressing machines for fitting the flour; jack tackles, for drawing up the sacks, &c.; all which are moved by the same first mover as a water-wheel, wind-mill, steam-engine, or horse-wheel. But each of these machines requires to be moved with a different velocity to perform its work in the best manner; and it is the object of the mill-work to obtain these different velocities from the same first mover, chiefly by the means of wheels; which, therefore, from their importance, deserve the first notice. There are a variety of cog-wheels, as spur-wheels, (or gear in the technical phrase,) bevel-wheels, face-wheels or crown-wheels, pinions or nuts, trundles or lanterns; with a variety of other names which are local, but have the same signification with some of the above.

Spur-wheels are those in which the teeth project from the periphery of the wheel, in the direction of radials (see Plate 1. fig. 1. of MILL-WORK): they are so called, from the resemblance to the rowel of a spur. A spur-wheel is used to communicate motion by its teeth to another, situated in the same plane; consequently, the axes of the two are parallel to each other. The spur-wheel, at other times, works with a pinion, or nut (see fig. 2.), which is in fact a spur-wheel of smaller size; at other times with a trundle or lantern. This is a pinion of peculiar construction, consisting of two circular boards A, A, (fig. 3.) fixed, at some distance apart, upon its axis of motion or shaft B B, and united by a number of cylindrical pins a, a, called flaxes, or rounds, which are arranged in a circle, and fixed parallel to the axis of the trundle between the two boards of it. The teeth of the wheel act
MILL WORK.

act upon these rounds to give motion to the trundle; the rounds, therefore, must be the same pitch or distance apart as the cogs of the wheel. The number of the rounds of the trundle of course determines its diameter. Trundles have of late years fallen into disuse among millwrights, cast iron pinions being found much more preferable: they were sometimes used to work with spur-wheels, but more commonly with

Face-wheels, see fig. 4. In these, the teeth or cogs are fixed perpendicularly to the plane of the wheel, parallel, therefore, to its axis: they were used to work with another similar wheel, or with a trundle with a spur-wheel, or with a pinion, when the two axes were required to be perpendicular to each other, as shown in figs. 3 and 4.

The crown or face-wheel has of late years been almost wholly superseded by bevill-wheels, which, in all situations where a wheel is required to turn another in a direction perpendicular or inclined to itself, are found vastly superior.

Bevilled or Mitre-wheels, see fig. 5, of the plate, have their teeth formed upon a conical surface, the angle of the cone being the same as the angle the axes C, D, of the two wheels A, B, make with each other. The introduction of this class of wheels into machinery is a very essential improvement, which has been wholly made within these thirty years. Bevill-wheels are of course always used to work with others of the same kind.

The manner of setting out the teeth of cog-wheels, in such a form that they shall act in the most equable manner upon each other, and with the least friction, has been a subject of much investigation among mathematicians and theoretic mechanics; but the practice and observation of the millwrights have produced a method of forming cog-wheels, which answers nearly, if not fully as well in practice, as the geometrical curves which theory has pointed out to be the most proper. This they have effected by making the teeth of the modern wheels extremely small and numerous. In this case, the time of action in each pair of teeth is so small, that the form of them becomes comparatively of little importance; and the practical method of the millwrights (using arcs of circles for the curves) approximates so nearly to the truth, that the difference is of no consequence: and this method is the best, because it so easily gives the means of forming all the cogs exactly alike, and precisely the same distance asunder, which, by the application of any other curve than the circle, is not so easy. The method, which is extremely simple, is explained by fig. 1. The highest point of each tooth of the wheel being made, and the cogs fixed in much larger than they are intended to be, a circle, a, a, is described round the face of the rough cogs upon its pitch diameter, that is, the geometrical diameter, or acting line of the cogs; so that when the two wheels are at work together, the pitch circles, a, a, of the two are in contact.

Another circle, b, b, is described within the pitch circle for the bottom of the teeth, and a third, d, d, without it, for the extremities. After these preparations, the pitch circle is accurately divided into the number which the wheel is intended to have: a pair of compasses are then opened out to the extent of one and a quarter of these divisions, and with this radius arcs are struck on each side of every division, from the pitch line a to the outward circle d, d. Thus, the point of the compasses being fet in the division e, the curve f, f on one side of the cog, and n, n on one side of the other, are described; then the point of the compasses being fet on the additional point b, the curve m is described. This completes the curved portion of the cogs e, and this being done all round completes every tooth: the remaining portion of the cog within the pitch circle, a, is bounded by two straight lines drawn from the points g and m towards the centre; this being done to the cogs all round, the wheel is fet cut, and the cogs, being diversified or cut down to the lines, will be formed ready for work, every cog being of the same breadth, and the space between every one and its neighbour is exactly equal to the breadth, provided the compasses are opened to the extent of one division and a quarter, as first described.

Many different methods of forming teeth have been proposed, among them the following: Let the tooth a (fig. 6) be on the point b in the plane C; and draw the line F D E perpendicular to the touching surfaces in the plane C: draw A F, B E, perpendicular to F E, and let F E cut the line A B in D. It is plain from the common principles of mechanics, that if the line F E, drawn in the manner now described, always passes through the point D, whatever may be the situation of the acting teeth, the mutual action of the wheels will always be the same. It will be the same as if the arm A D acted on the arm B D. In the treatises on the constructions of mills, and other works of this kind, are many instructions for the formation of the teeth of wheels; and almost every noted millwright has his own nostrums. Most of them are egregiously faulty in respect to mechanical principle. Indeed, they are little else than instructions how to make teeth clear each other without sticking. Dr. Hooke was, we think, the first who investigated the form of teeth which procured this constant action between the wheels; and in a very ingenious dissertation, published among the Memoirs of the Academy of Sciences at Paris, 1665, this gentleman shews that this will be ensured by forming the teeth into epicycloids. Mr. Camus, of the same academy, has published an elaborate dissertation on the same subject, in which he propounds the principles of M. De la Hire, and applies it to all the varieties of cafes which can occur in practice. There is no doubt as to the goodnes of the principle, and it has another excellent property; that the mutual action of the teeth is absolutely without any friction. The one tooth only applies itself to the other, and rolls on it, but does not slide or rub in the slightest degree. This makes them last long, or rather does not allow them to wear in the least. But the construction is subject to a limitation which must not be neglected. The teeth must be so made, that the curved part of the tooth a, is acted upon by a flat part of the tooth a, till it comes to the line A B in the curve of its action; after which the curved part of a acts on a flat part of b, or the whole action of a on b is either completed, or only begins at the line A B, joining the centres of the wheels.

Another form of the teeth secures the perfect uniformity of action without this limitation, which requires very nice execution. Let the teeth of each wheel be formed by evolving its circumference; that is, let the acting face C G H of the tooth a have the form of a curve traced by the extremity of the thread F C, unrolled from the circumference. In like manner, let the acting face of the tooth b be formed by unrolling a thread from its circumference. It is evident that the line F E, which is drawn perpendicularly to the touching surfaces in the point C, is just the direction or position of the evolving threads by which the two acting faces are formed. This line must, therefore, be the common tangent to the two circles or circumferences of the wheels, and will, therefore, always cut the lines A B in the same plane C. This form allows the teeth to act on each other through the whole extent of the line F C, and admits of several teeth to be acting at the same time; (twice the number that can be admitted in Mr. De la Hire's method.) This, by dividing the pressure among several teeth, diminishes its quantity on any one of them, and, therefore, diminishes the dents or impressions which they unavoidably make.
MILL-WORK.

make on each other. It is not altogether free from sliding or friction, but the whole of it can hardly be said to be feasible. The whole side of a tooth three inches long, belonging to a wheel of ten feet diameter, acting on the tooth of a wheel of two feet diameter, does not amount to a third of an inch, a quantity altogether insignificant. Conical wheels, or bevelled gear, may be considered as consisting of two cones rolling on the surfaces of each other; let B and C, (fig. 7.) be the bases of two cones turning on their centres, having teeth cut on them diverging from the apex A to the bases B and C. These teeth will work freely into one another from the apex A to the bases B and C, when turned round; but the teeth near the point of the cone being small and of little use, may be cut off at G and H. These teeth may be made of any breadth, according to the files they are intended to bear; and this is of vital importance, because by this method they may be made to overcome a much greater resistance, and work smoother than a face-wheel and trundle of the common form. Besides, these kind of wheels are of figural use to communicate motion in any direction, or to any part of a building, with less trouble and friction than wheels of any other construction.

We shall now venture some remarks upon the manner of constructing wheel-work. Cog-wheels were formerly constructed in the mould, and became solid before the others; consequently, from their contraction, they are shorter than others which have retained their heat and fluidity longer. This circumstance happening to the arms of a wheel, will either warp the rim out of a true circle, or let the metal of one part upon a straight against another, so that the slightest blow or jar will cause them to tap in such parts. All this danger is avoided by making them in separate pieces, as in fig. 8; the end of each arm, as A B, has a flat expanded part, which lays against a proper socket within the rim C D, and is bolted to it. One-half of this wheel is delineated, with wooden cogs fitted in, at C D; and the other half, F F, shews the form of a rim, where the cogs and the arms C F are cast all in one piece. In the latter case the rim has a rib G within it for strength, in the same manner as all the arms have, and which is evidently shewn by the figure. In some situations it is necessary to fix wheels upon large shafts while they are in their places, and cannot conveniently be taken down; in this case such wheels may be made in two halves bolted together. Fig. 9. is drawn as if it were two halves of different kinds put together in this manner; the joint being up the middle of the arms L, L, and the connecting bolts are plainly shewn. By this method one wooden pattern, if very accurately made, will serve for casting both halves of the wheel. Cog-wheels are found to work with least friction, wear, or noise. When one has wooden, and the other iron cogs, dressed exceedingly smooth and true, the small wheel is usually made with the iron teeth, and the large one with the wooden ones. When such wheels are first set to work, the cogs are smeared with black lead mixed with tallow: this gives them a glossy surface, which greatly diminishes the friction. Hornbeam is found to be the best wood for the cogs, as it is not liable to split or splinter away by long wear. The cogs are held in by a pin driven through the tenon or tail, within the rim of the wheel. The wooden cogs are dressed by chisels to the marks set out, in the same manner as wooden wheels; but the iron cogs are first clipped with a cold chisel and hammer, and then filed true. The great labour of doing this induced Melfi, Boulton and Watt, some years ago, to erect machinery for dressing cogs. The wheel was provided with apparatus to hold it at the several divisions, and a stronglider, with a chisel fixed in it, was forced between the rough cogs by the revolution of a cam or heart, with

Vol. XXIII.
with a sufficient power to cut away a shaving, and form the
cog perfectly at twice repeating the operation. Some me-
dianes dispirit the propriety of dreaving iron cogs at all;
they say, that the exterior surface of the castings have
a kind of cale-hardening, which is removed by the dre-
ving, and a softer substance of metal exposed for the act-
ing surfaces. This is true, and the objection would have
its full force, if it were possible to make castings of
wheels perfectly true in the circle, and all the cogs pre-
cisely the same size: but as the present state of the
founder's art cannot infuse this, it is best to chip and
file the cogs; accuracy in the form of the teeth being a
superior considerarion to any quality of their substance.
The wheel being made in either of these methods, must next be
fixed, or hung, upon its shaft. Wheels are generally fixed
fast upon their shafts or axles before their teeth are set out;
or, if this is not convenient, they are fixed on a temporary
spindle to set them out. When the wheel is made of
wood, it is fixed upon the shaft, or a temporary axis, and
turned round upon its pivots, while a chisel is laid on some
fixed support to cut or turn its circumference to a true cir-
cle, or else to make a mark to which its rim may be re-
duced all round. The circumference is then divided, and mor-
ties cut out for every cog; and when these are fixed in
they are much larger than they are intended to be, that they
may be set out, as above directed, and reduced to their
true figure, without absolutely depending upon the accuracy
of the mortises which receive them. Iron wheels are, as
before-mentioned, treated in a different manner, being cast
in the impression of a truly circular pattern made of wood;
the cogs cast fold, with the rim or else mortises left all
round for the reception of the wooden cogs; in either case
the rim is a true circle, and must be fixed upon the shaft
exactly by its centre, instead of forming the circumference
to the centre, as in the wooden wheel. To do this, the centre
hole through the iron wheel is made much larger than the shaft
which is to go through it, and the space all round is
filled up by iron wedges driven in; so that by means of these
the wheel can be fixed exactly true in the centre (or in the
round), and also in the flat that is truly perpendicular
to the axis. The manner of arranging the wedges is shown
in fig. 8, where eight wedges are shown by a, a, a, a, &c.
round the shaft R. It is needless to explain how the wheel can,
by means of these, be set exactly true, when it is found by
turning round upon the pivots of its shaft that any one side
of the circumference is farther from the centre than another.
For the purpose of letting it square upon the shaft, each
wedge-hole is provided with two wedges, one driven in from
each side of the wheel, the two laying over each other in
the notch or hole in the manner shown at G. Thus, by gently
driving one in, and the other a little outwards, the wheel
may be very correctly rectified, if it has any deviation from
the perpendicular. This is the usual manner of hanging
wheels, and for large wheels it is the only applicable method.
Plate II. fig. 9 and 10, is a far superior plan for such iron wheels
as are not too large or heavy to be turned in a lathe upon a
chuck, so that the centre is exposed, and may be bored
through with a truly circular hole, and rather conical: of
course the wheel is fixed upon the chuck, so that its cir-
cumference runs truly; and at the same time the centre
is bored, the pitch circle is described upon the cogs, and some-
times the ends of the cogs are turned to reduce them to a
true circle, and also the lides, that they may be exactly flat:
for, as we have before observed, iron wheels, however true
their teeth may be, should always have their cogs rather
too large, and then be set out and dressed, by chiselling
and filing, to make them perfectly correct to the lines thus
described. But to return to fig. 9; the wheel being pre-
bared, and its centre bored out, the shaft is turned, as usual,
to form its pivots, and, at the same time, the part which is
to receive the wheel is turned conical, so that the hole through
the wheel being jambed therein will certainly be true at once:
and to prevent it from flipping round upon its axis various means are in use; sometimes a mortise is
formed through the shaft A, at the small part of the cone,
and a wedge r driven through, which is received in notches
at the sides of the hole through the central part of the wheel,
so that it holds the wheel from turning round on the shaft,
at the same time that it drives it hard, and fixes it upon
the conical fitting. Another method is to cut a channel
along the conical part of the shaft parallel to the axis of it,
and another similar one withinside of the hole through
the wheel; then a pin or feather of iron s, (fig. 10.) being
inferred into the two grooves, effectually prevents the wheel
from turning, unless the strain is so great as to cut the fea-
ther in two through its whole length, which is easily pre-
vented by making it of a proper thickness. Another method
of fixing a wheel is to have a flaunch, or flat shoulder, formed
upon the shaft, and the wheel is drawn up against this by
two, three, or four screw-bolts going through it, and also
through the central part of the wheel, parallel to its axis.
This plan is neither so neat, simple, nor strong as the former.
When a wheel is required to be sometimes difgaged from
its axis, the conical or cylindrical fitting is very conve-
nient. In this case, the wheel should be cut against a flat
shoulder, as at, in fig. 11, and at the opposite side should
be a collet, or ring b, to confine it, and kept up by a
key going through to the shaft R. In this way the wheel will
flip round freely upon its axis, and communicate no motion
thereto, though it is in constant motion itself; but when
they are required to be connected, a locking bayonet, or
clutch-box, is used. These pieces of mechanism are construc-
ted in different forms; one of them is shown in the figure.
Strong arms A, A, are fixed fast on the shaft R, just be-
fore the wheel either by a circular fitting with a fillet, by a
square, or they may be cast with it. Through the extre-
nities of these arms holes are drilled to receive the flanks f, f,
of the locking bayonet, which are fixed by nuts fast to an
arm D, very nearly similar to A A, but it slides on the
shaft, and has a central part g, with a circular groove
round it, in the manner of a pulley, and a fork embracing
the central piece in the groove gives the means of pulling
the bayonets f f, and D upon the shaft, so that the points
of its flanks intercept the arms of the wheel, so as to carry
it round with them and the shaft; but when the points of f f
are drawn back clear of the arms of the wheel, it slips round
freely upon the shaft. The clutch-box is rather different
from this; it is a piece fitted upon the shaft with a fillet, so
that it cannot flip round, but will slide endways upon it.
The end of the piece is formed with several notches, or in-
dentations across its face, which meet similar indentations
in the face of the central part of the wheel, and thus unites
the wheel and the shaft when the clutch is flid up to it; but
the wheel is difgaged when the clutch is drawn from it.
The construction of bearings for the support of pivots at
the ends of shafts or spindles, is a matter of great impor-
tance in mill-work. The old kind of bearing called brails is
shown in fig. 12. A lump of brails a, with a flicircular
notch in it, was let into the piece of timber A, which was to
support it; and two screw-bolts b, b, were fixed through the
 timber, being half received in notches formed in the sides
or ends of the brails; the upper brails d, was exactly similar
to the lower, and over it a plate of iron d, was placed, with
two holes through it to receive the two bolts b, b, and keep
them
MILL-WORK.

them together: the nuts \( z \), upon the tops of the bolts confined the upper brass down, and made all fast and tight. This kind of brass is not sufficiently strong or ready for all purposes; and, therefore, the bearing shown in fig. 12, has been moved to its place in this, as is a cast-iron plate, which is held by two or more bolts \( r, r \) down upon the timber or framing of the mill: this piece of cast-iron has two pieces \( b, b \) rising up from it, between which a piece of brass, \( b \), is bedded, and has a semicircular notch in it. Another similar piece of brass is fixed into the cast-iron cap-piece \( B \), which is fitted into the space between the two pieces \( b, b \), and is drawn down by nuts upon the two bolts \( e, e \). The braces are prevented from getting out sideway by small fillets projecting from the middle of them, which are received into proper notches in the cast-iron work. In the fame manner the cap \( B \) is fitted between the pieces \( b, b \), with a tongue or fillet, and groove, so that it cannot deviate sideway, and then the bolts have only to draw the braces down together. Sometimes a bearing of this kind is fitted up, so that it is adjustable in its position a little to adjust two wheels to work accurately with each other, or for other purposes where nicety is required. In this case, an iron plate \( D \), is bolted down to the framing, and the bearing, \( a, a \), places upon it, the frame bolts \( r, r \) going through both, and also through the framing beneath; but the holes through which they pass in the piece \( a, a \) are obliged to admit the whole bearing being adjusted sideways. This is done by two wedges \( o, o \), inserted at the ends of the piece \( a, a \), between the two ends of \( D \), which rise up for the purpose, as at \( n, n \). The bearing rests upon two wedges \( g, g \), and is drawn down upon them by the bolts \( r, r \). By these two wedges it can be raised up at pleasure, and by the other two, \( o, o \), at the ends, it can be adjusted endways to fit the bearing in the exact position required; and the bolts \( r, r \), when screwed fast, hold all tight. The best way to make the interior surface of the braces for a bearing exactly true, is to have them cast cold, that is, the two halves of the brass in one, with a notch which very nearly, but not quite separates them. In this state it can be chucked up in a chuck-lathe, and the inside bored or turned out true: then it may be fawn in two halves, and put into its place, to which it should have been previously fitted. Sometimes the bearing is all fitted together and screwed down in its place, and a borer is used to bore or broach out the hole for the braces, the same as is employed to bore pump barrels. Brass is found, by experience, to be the best substance to form bearings for a cast-iron gudgeon, having the least friction, and, consequently, leaf wear, of any other substance which can be used. To diminish this friction still farther, friction-wheels are sometimes used. The manner of constructing these, when merely required to support a gudgeon, leaving its own weight to keep it down in its place upon them, is shown in fig. 14. Here \( A A \) is an iron plate, which is to be bolted down upon the framing; it has holes through it to receive the friction-wheels \( B, B \), and supports bearings \( a, a \), for their pivots raised up to a proper height, and provided with sockets, for brasses, from which the pivots of the friction-wheels are to be inserted. The two friction-wheels \( B, B \), as is evident, lie by the side of each other, and the gudgeon \( D \), of the shaft they are to bear lies upon and between them, so that when it turns round it rolls upon them, or rather, their circumferences move with it, and, consequently, the pivots of the brake \( g, g \), are turned round, to diminish the friction very materially, the proportion depending on the relation between the diameters of the wheels \( B \) and the gudgeon \( D \). This is not the best kind of friction-wheels, though the simplest. Plate II.

fig. 15. of Mill-work, contains a view of another kind, called friction-rollers: here \( A A \) is an iron plate bolted down to the framing, and an iron ring, \( R \), rises up from it, all cast in one piece. The interior surface of this ring is turned in the lathe with the greatest accuracy, and the pivot or gudgeon \( C \), which is also turned true, rests in the centre thereof, being supported by fixed rollers \( a, a \), &c. arranged at equal distances round it, and of such a diameter as to exactly fill the space all round between the gudgeon and the ring. The rollers, it is evident, must be made of all one exact diameter, and extremely true, and they must fill up the space in which the gudgeon being turned round acts upon these rollers, and turns them round also at the same time by this motion. As they have no fixed centre, they also roll round within the ring \( B \) in the same direction as the motion of the gudgeon, but with a very slow motion, which will be in proportion to the relative diameters of the gudgeon \( C \) and the ring \( B \). By this means nearly all the friction is avoided, nothing like the sliding of a gudgeon round upon its bearing taking place here; it is all rolling of one surface upon another: and as the contact of two cylinders, supporting them hard, is but a line, the friction, or more properly adhesion, is exceedingly small; and at the same time that the gudgeon is as strongly supported as possible: but this depends upon the hardnness of the matter of the gudgeon, the rollers, and the ring \( B \). If the ring and gudgeon are made of hard cast iron, and the rollers of steel at a spring temper, it will act extremely well, through the strain or weight upon the rollers be very great. For light frames softer substances might be used, but not to so good an effect.

The manner of keeping all the rollers at their relative distances from each other, in the ring \( B \), that they may not run against each other, is yet to be explained. Each roller, as shown at \( z \), has a groove turned in it in the middle of its length, so as to reduce it to a small neck in the centre: then an iron ring, \( L \), is provided, which has five holes drilled in it, in the proper positions for the centres of the rollers, that is at equal distances round a circle, which is as much less than the ring \( E \) as the diameter of the rollers, or the same quantity larger than the diameter of the gudgeon \( C \). These holes are made to fit the small neck in the centre of the rollers, and to get them in, the holes are cut open from the outside of the ring, so as to reduce them to a small neck in the centre. Then an iron ring, \( L \), is provided, which has five holes drilled in it, in the proper positions for the centres of the rollers, that is at equal distances round a circle, which is as much less than the ring \( E \) as the diameter of the rollers, or the same quantity larger than the diameter of the gudgeon \( C \). These holes are made to fit the small neck in the centre of the rollers, and to get them in, the holes are cut open from the outside of the ring, so as to reduce them to a small neck in the centre.

The joints of these plates should be water tight, and then a quantity of oil being poured in, will remain in the bottom of the ring \( B \), and every roller, as it passes, will be kept oiled; though this would completely destroy the action of this ingenious mechanism, a circular iron plate is fitted into the ring \( B \), on each side, and both are fixed by small screws going through the ring. One of the plates \( N \) must of course have a hole through the middle, to admit the gudgeon. The joints of these plates should be water tight, and then a quantity of oil being poured in, will remain in the bottom of the ring \( B \), and every roller, as it passes, will be kept oiled; though this would completely destroy the action of this ingenious mechanism, a circular iron plate is fitted into the ring \( B \), on each side, and both are fixed by small screws going through the ring. One of the plates \( N \) must of course have a hole through the middle, to admit the gudgeon. The joints of these plates should be water tight, and then a quantity of oil being poured in, will remain in the bottom of the ring \( B \), and every roller, as it passes, will be kept oiled; though this would completely destroy the action of this ingenious mechanism, a circular iron plate is fitted into the ring \( B \), on each side, and both are fixed by small screws going through the ring.
centre rather than the outides; but they will never bear hard against the plate, having no drift that way.

A patent was taken out for these friction rollers many years ago, and a large manufactory was established for making them for various purposes, as carriage and wagon-wheels, the gudgeons of heavy water-wheels, &c.: they were found to possess great advantages, having scarcely any feeble friction when in motion, but were liable to get out of order exactly from the entrance of dust, which occasioned the rollers to wear out of the round more on one side than the others; and if once by this accident the rollers stood still for an instant, the gudgeon wore a flat place in the two rollers beneath it, and they would never run round again: a very little time would wear this flat side so deep as to stop the rollers, because of the very small surfaces in contact with the gudgeons. For delicate purposes, where hardened steel can be employed for all the rollers and the ring, they are a most admirable contrivance, and the above objections will then apply very slightly: but, as before mentioned, their perfection and durability will ultimately depend upon the hardness of the substances employed.

Fig. 16. represents a pair of friction rollers for supporting the weight of a heavy vertical shaft, as a hoist-wheel, a horizontal wind-mill, a capstan, &c. A is a plate f a plate supporting the weight of the shaft, and, at the same time, in contact with the pivot or gudgeon c at the bottom of the shaft R: upon this gudgeon a conical plate B is formed, exactly of the same shape and size as the conical part of the plate A, and between these two plates three or four rollers a, a, are situated, and bear the weight of the shaft R, or whatever presses upon the plate B. The rollers are kept at proper distances afar, by a ring, shown separate at L, with three arms, a, projecting from it, which being formed into spindles, pass through the centres of the rollers a, and have collets and crofs keys to keep them on. In this manner, as the gudgeon and plate B turn round, the plate rolls upon the rollers a, a, keeping always in the true centre, by the end of the gudgeon c fitting the hole in the centre of the plate A.; but the weight is supported by the rollers a, a, which, at the same time that the upper plate rolls upon them, roll upon the lower, and thus very considerably diminish the friction which any other kind of gudgeon would have in such a situation.

Shafts.—In almost all modern mills, the shafts or spindles for the conveyance of motion, and support of wheels, are made of iron, either wrought or cast. Square shafts are the most common, but sometimes octagonal and round ones are used; and if they are very large, they are call hollow, like pipes, and the gudgeons fixed in at the ends by wedges; but the pivots should always, if possible, be formed of the same piece of metal, as the slightest possible deviation from the straight line causes them to strain, and work very irregularly in their bearings. In wooden shafts this is impracticable, and it is one of the greatest objections to the use of them. The best method of fixing gudgeons into wooden shafts is shown in fig. 17. Here A is the gudgeon, made in cast iron, turned true; it has four leaves, a, b, c, d, forming a crofs, which is let into the end of the wooden shaft R: the front edge of each leaf is considerably thinner than the back, so that a pair of strong iron hoops r r being driven tight on the end of the shaft, cloes the wood round the crofs, and holds it fast, and the back of the leaves being wider than the front, it will not come out. As an additional security, firewheels are sometimes put in: these are put through holes in the arms of the crofs, which are then made flat, in the other way, and do not go so far into the wood. The firewheels go into the timber a considerable distance, where a mortise is cut into the wood, to meet the end of the bolts, and an iron nut is dropped in, to screw the bolt into, when it is turned round by a screw driver. By this contrivance a gudgeon may be fitted into a wooden shaft very fast, and will never come into competition with iron shafts, when the gudgeon is made all in one solid piece with the whole of the shaft. A judicious mechanic will never make more than two bearings upon any one shaft, if it can be avoided, because if the three, by any means, as the warping of the frame work, or other cause, get the smallest possible quantity out of the straight line, they can never work well afterwards, but will always strain and wear the bearings with great friction. In very extensive mills, such as woolen and cotton mills, breweries, &c. when the buildings are of great length, it becomes necessary to join several shafts together in length, to reach from one end to the other of a mill. The manner of making the joinings is of some consequence: it is necessary that every shaft should have a bearing at each end, and consequently that the connection of the ends of every one should be made by uniting the ends of the shafts which project beyond their bearings. This can be done in various ways: one is by having the ends of each of the shafts provided with circular heads (see A B Fig. 18.), which have teeth in one, and corresponding indentations in the other, to receive them, and thus one is made to turn the other. But there is danger that if any slight settlement of the building or other cause depresses one of the bearings, or raises another, so as to put the two shafts out of the perfect straight line they ought always to preserve; these joints will admit the slight flexure, and still communicate the motion of one shaft to the other.

As this accidental settlement in large buildings is almost unavoidable in some degree, care should be taken to make such joints as will admit of a trifling bending. Sometimes the ends of the shafts are made circular, and turned quite true in the lathe; then a metal tube or collar is fitted truly upon both to cover the joint, and connect them, a bolt being put through each end, which unites both shafts with the collar, and thus by means of it causes one to turn the other round. This method is sometimes used to save the great expense of having a bearing at each end of every length of shaft, one bearing to each length being then sufficient, the other end of the shaft being supported by this collar, connecting it with the end of the adjacent length just where it projects beyond its bearing. But this is not a good method, as the shafts are apt to bend and work with so much friction in the bearings, if they get the least out of the straight line, because the kind of joints will not admit any flexure of the shafts, or if they do, they will only bend on one side, whereas it is necessary for the joint to bend successively on all sides, when the bearings are not precisely in a straight line. Plate III. fig. 19. represents a coupling-box, used by Mr. Murray of Leeds, for connecting the lengths of a long line of shaft which are to carry a heavy strain: it is so made that it will communicate the motion in the manner of an universal joint, if they should be out of the line. Let A, B, be the two shafts to be united; C, D, their necks or collars which lay in the bearings: the ends projecting beyond these have boxes E, F, fixed on them, either by a square with wedges, or by a round part with a fillet: one of these boxes, E, has a piece projecting from the inside of it on each side, and extending into the other box, as is shown at a, a, (No. 2.), which is an inside view: the other box, F, has two similar pieces projecting from it at b, b, into the other box E: within the boxes an iron crofs c d d is situated; it has screws fixed into the ends of the crofs, and by the motion is communicated: thus, the pieces a, a, when the shaft A and box E are turned round in the direction of the arrow (No. 2.) act against the screws c, c, of the crofs, and turn it.
MILL-WORK.

It about: at the same time the other two screws d, d, at the other arms of the croms prees against the pieces b, b, which belong to the box F and shaft B, thus turning them round: the crom is placed quite detached in the box, and thus acts as an unsewer joint, to communicate the motion of one to the other: the screws c, c, d, d, at the ends of the croms are only put in that the acting points may be made of steel, and made smooth to have but little friction in these parts. Another method of uniting shafts by Mr. Murray is shown at fig. 20: it has the advantage of requiring only one bearing for every length of shaft, whereas the above method requires one for each end of every length. A, B, represent the two shafts; each has a pivot formed at the end: these pivots are fitted into a coupling piece C D E, which is bored out truly to fit them inside, and the outside turned true, with a neck D D, which is received and fitted into a bearing: the two shafts A, B, are connected with the coupling piece D, at C and E, by means of a croms key l m, put through each shaft, and the ends of them received in notches made withinide of the coupling piece at C and E, where it receives the ends of the shafts. It is to be observed that the shafts do not fit tight in those parts C and E, but only in the pivots a, b, within which means they have liberty of a little motion, and this without straining the bearing in which D runs, because it is only the short coupling piece which is received therein; and consequently, any trifling deviation from the straight line will not strain it, because of the play allowed in the fittings.

The universal joint, called also Hooke's joint, from its inventor Dr. Hooke, is a method of uniting shafts, which permits them to be rather inclined to each other. This is shown in fig. 21, where A, B, are the two shafts, with necks to be received in bearings: each shaft beyond is formed into a fork, as C and D; and these are united by a croms of iron E, or sometimes a ring, in which four pins are inserted, and pass through holes in the ends of the forks. On one or other of these pins the joint will bend in any direction, on the same principle as a compass hangs in its gimbals, and will communicate a rotary motion from one shaft to the other, when they are rather inclined; but this inclination should be small, or else the joint will not act well, or without great friction, and irregularity of motion. If an angle of more than 15 degrees from the straight line is required, a pair of flightly bevelled wheels are best.

The regulation of the velocity of a mill is a matter of considerable importance, to preserve an uniformity of motion, either when the force of the first mover is fluctuating, or when the resistance or work of the mill varies in its degree: either or both of these caues will occaion the mill to accelerate or diminish its velocity; and in many instances it will have a very injurious effect upon the operations of the mill. Thus, in a mill for spinning cotton, wool, flax, driven by a water-wheel, are a multiplicity of movements, many of which are occasionally disengaged, in different parts of the mill, for various purposes. This tends to diminish the resistance to the first mover, and the whole mill accelerates. Or, on the other hand, the head of water, which drives the wheel, may be liable to rise and fall suddenly, from the wheel, the water, which great and rapid rivers are subject to, and cause similar irregularities in the speed of the wheel. For such cases, judicious mechanics have adopted contrivances, or regulators, which counteract all these causes of irregularity; and a large mill, if regulated, will move like a clock, with regard to its regularity of velocity. These regulators are usally termed governors, and are made on different principles. Thoef most generally used are called flying-balls, operating by the centrifugal force of two heavy balls, which are connected and revolve with a vertical axis. Fig. 22 represnts the simplest form of this ingenious apparatus: A A is the vertical axis, which is constantly revolving by the machinery; at a and b are arms or pendulums, a, b, d, are jointed, and are elevated at every extremities a heavy metal ball each, as b b, from the pendulums two chains or iron rods, d, d, proceed, and suspend a collar e, which slides freely up and down the axis, and has a grove formed all round it, in which the end of a forged lever, D, is received; and thus the rifting and falling of the collar, e, produces a corresponding motion of the end of the lever D; but the collar is always at liberty to turn round with the axis freely within the fork, a, at the extremity of the lever. The operation of the governor is this: when the vertical axis is put in motion, the centrifugal force of the balls, b, b, caues them to recede from the centre; and as this is done both together, they caue the collar, e, and the end of the lever to rise up: the balls fly out to a certain height, and there they continue as long as the axis prefers the same velocity; as it is the property of a pendulous ball, like b, to make a greater effort to return to the perpendicular, in proportion as it is removed farther from it, in consequence of the suspending rod being more inclined, and bearing less of its weight. The weight of the balls to return to the axis may be considered as a constantly increasing quantity; while the quantity of the centrifugal force, cauing them to recede from the axis, depends exactly upon the velocity given them. But this velocity increases as they open out, (independently of any increased velocity of the axis), in consequence of their describing a larger circle. The combination of these oppositely acting forces caues the governor to be a most finible and delicate regulator. Thus: suppose the balls hanging perpendicular, put the axis in motion with a certain velocity, the centrifugal force will caue the balls to fly out; and this increaes their velocity, (by putting them farther from the centre, and cauing them to revolve in a larger circle,) gives them a greater centrifugal force, which would carry them still farther from the centre, but for the counteracting force, or the weight of the balls tending to return. This is, as before stated, an increasing quantity, and consequently these oppositie forces come to a point where they balance each other; that is, the balls fly out till their weight to return balances the centrifugal force. But if the flighted alteration takes place in the velocity of the axis, the equilibrium is destroyed by the increaes or diminution of the centrifugal force, and the balls alter their distance from the centre accordingly, and by elevating or deprefing the end of the lever, operates upon some part of the mill to rectify the cause of the irregularity. In a steam-engine, the lever acts upon a vane or door situated in the passage of the steam from the boiler to the cylinder; and if the mill looses in velocity, from an increas of resistance, the balls fall together a little; and the consequent fall of the lever opens the door or throttle valve a little wider, and gives a stronger supply of steam to restore the mill to its original velocity. On the other hand, if the mill accelerates, the balls open out and then close the vane, so as to moderate the supply of steam. See a more full description of this under STeam-Engine.

A water-wheel is not so easily regulated by the governor, because the flutter of a large wheel requires a much greater force to raise or lower it, when the water is prefling against it, than the lever, D, can at any time poole; it therefore becomes requisite to introduce some additional machinery, which has sufficient power to move the flutter, and this is thrown, in or out of action, by the flying balls. The simplest contrivance, and that which we believe was the regulator first used for a water-wheel, was erected at a cotton mill at Belper, in Derbyshire, belonging to Mr. Strutt.
MILL-WORK.

A square well, or large cistern, was situated close by the water-wheel; it had a pipe leading from the mill-dam into it, to admit water; and another pipe from it to the mill-tail, to take the water away; both were closed at pleasure by cocks or sluices. Within the well was a large floating chaff, very nearly filling up the space; it of coarse rose and fell with the water in the cistern, and had a communication by rack and wheel-work with the machinery for drawing the flutlile, so that the rise and fall of the floating chaff elevated and depressed the shuttle of the wheel. The lever of the governor was connected with the cocks in the two pipes, in such a manner that when the mill was going at its intended velocity, both of the cocks were shut; but if the water-wheel went too slowly, the falling of the balls of deceit of their lever, D, opened the cock in the pipe of supply, and, by letting water into the well, raised the float, and, with it, the shuttle, to let more water upon the wheel, till it acquired such a velocity that the balls began to open out again, and thus shut the cock; on the other hand, if the mill went too fast, the balls opened the pipe of exit from the well, and then the sinking of the float closed the shuttle till the true velocity was restored.

Since this first application of the regulator to the water-wheel, the manner of its operation has been greatly varied; and as the fame mechanism is applicable to any kind of mill-work, we shall give a sketch of it. Suppose A, fig. 23, an axis, receiving its motion from the mill by wheel-work; it is provided with a pair of governors, a b, a b, constructed like those before described; and at the lower part of the spindle is a bevelled wheel, R, turning two others, B and C, situated upon one spindle, D, which goes away, and communicates motion to the racks of the shuttle; the wheels, B and C, are neither of them fixed to the spindle D, but both flip round freely upon it, turning in contrary directions, as they receive motion from the opposite fides of the wheel R. A locking clutch, d, is fitted upon the spindle between these two wheels, B, C, and can, by moving it one way or the other, be made to lock either one of the wheels to the spindle D, at the same time that it leaves the other disengaged. The locking-box is moved by means of a lever, shown in fig. 24; the arm m, having a fork to embrace a groove in the box; the lever is fixed on a vertical axis n, which has at the upper end two other levers, o, p; these lay on each side of the vertical axis A, but at different heights, as is evident from the figure. The collar e, which is raised up when the balls fly out, is fitted upon a square part of the spindle A, and is formed like a snail or camm, which will act upon either of the levers, o or p, according to the height at which it hangs upon its spindle. Now when the mill is going at its true velocity, this camm, e, is at such a height that it is beneath one lever, o, and above the other, p, so as to interfere with neither; consequently the locking-box, d, remains detached; but on any alteration in the velocity of the mill and the axis A, the balls open or shut, as before explained, and the camm, e, either rises or falls, and then it presses against one of the levers, o or p, and by pushing it away from the axis, it moves the lever m, and the locking-box d, up to one of the wheels, B or C, which locks to the axis D, and turns it round in the direction of that wheel's motion, by which it either raises or depresses the water-wheel's shuttle, as is required. This apparatus may, it is plain, be applied to any other kind of mill-work.

Governors or flying-balls are very frequently used in the wind-mills employed for grinding flour; the variable force of this first mover renders some such regulator necessary, to increase the resistence, by allowing a greater feed of corn, when the mill moves too quickly, and thus in some degree counteracting the irregularity. If the mill moves too slowly, the balls tend to diminish the feed, and at the same time they raise the upper flume, to set them at a greater distance aunder, that they may require less power to drive them, and consequently suffer the mill, as nearly as it can, to retain its full velocity, though the motive force is greatly diminished. This application of the governor was, we believe, first made by the ingenious captain Hooper of Margate, who invented the horizontal wind-mill. (See Wind-Mill.) It is a very great advantage, and no wind-mill should be without them. Many wind-mills are provided with flying-balls, which, by very ingenious mechanism, clothe and unclotke the falls just in proportion to the strength of the wind.

In many mills it is of consequence to be able to detect small variations in the velocity, and to ascertain the quantity of them; for the governor only corrects the irregularities, without asswering any scale of them. In kales where this is required, it may be done by a very ingenious instrument, invented by Mr. Bryan Donkin of Fort-Place, Bermoudey. He received a gold medal from the Society of Arts, Manufacuters, and Commerce, in 1810, for this instrument, which he calls a tachometer.

A front view of this instrument is represented in fig. 25, and a side view in fig. 26, of Plate II. XYZ, fig. 25, is the vertical section of a wooden cup, made of box, which is drawn in elevation at X, fig. 26. The whiter parts of the section, in fig. 25, represent what is solid, and the dark parts what is hollow. This cup is filled with mercury up to the level LL, fig. 25. Into the mercury is immersed the lower part of the upright glass tube AB, which is filled with coloured spirits of wine, and open at both ends, so that some of the mercury in the cup enters at the lower orifice, and, when every thing is at rest, supports a long column of spirits, as represented in the figure. The bottom of the cup is fastened by a screw to a short vertical spindle D, so that when the spindle is whirled round, the cup (whose figure is a solid of revolution) revolves at the same time round its axis, which coincides with that of the spindle.

In consequence of this rotation, the mercury in the cup acquires a centrifugal force, by which its particles are thrown outwards, and that with greater intensity, according as they are more distant from the axis, and accordingly as the angular velocity is greater. Hence, on account of its fluidity, the mercury rises higher and higher as it recedes from the axis, and consequently sinks in the middle of the cup; this elevation of the fides and depression in the middle increasing always with the velocity of rotation. Now the mercury in the tube, though it does not revolve with the cup, cannot continue higher than the mercury immediately surrounding it, nor indeed so high, on account of the superincumbent column of spirits. Thus the mercury in the tube will sink, and consequently the spirits alio; but as that part of the tube which is within the cup is much wider than the part above it, the depression of the spirits will be much greater than that of the mercury, being in the fame proportion in which the square of the larger diameter exceeds the square of the smaller.

Let us now suppose, by means of a cord pulling round a small pulley F, and the wheel G or H, or in any other convenient way, the spindle, D, is connected with the machine whose velocity is to be ascertained. In forming this connection, we must be careful to arrange matters, so that when the machine is moving at its quickest rate, the angular velocity of the cup shall be at least as great as to depress the spirits below, C; into
MILL-WORK.

C, into the wider part of the tube. We are also, as in the figure, to have a scale of inches and tenths applied to A C, the upper and narrower part of the tube, the numeration being carried downwards from zero, which is to be placed at the point to which the column of spirits rises when the cup is at rest.

Then the instrument will be adjusted, if we mark on the scale the point to which the column of spirits is depressed when the machine is moving with the velocity required. But, as in many cases, and particularly in steam-engines, there is a continued oscillation of velocity; in those cases we have to note the two points between which the column oscillates during the most advantageous movement of the machine.

Here it is proper to observe, that the height of the column of spirits will vary with the temperature, when other circumstances are the same. On this account the scale ought to be movable, so that, by flipping it upwards or downwards, the zero may be placed at the point which the column reaches when the cup is at rest, and thus the instrument may be adjusted to the particular temperature with the utmost facility, and with sufficient precision. The essential parts of the tachometer have now been mentioned, as well as the method of adjustment; but certain circumstances remain to be stated.

The form of the cup is adapted to render a smaller quantity of mercury sufficient than what must have been employed either with a cylindrical or hemispherical vessel. In every case two precautions are necessary to be observed. First, that when the cup is revolving with its greatest velocity, the mercury in the middle shall not sink so low as to allow any of the spirits in the tube to escape from the lower orifice; and that the mercury, when most distant from the axis, should not be thrown out of the cup. Secondly, that when the cup is at rest, the mercury shall rise so high above the lower end of the tube that it may support a column of spirits of the proper length.

Now, in order that the quantity of mercury, sufficient with these conditions, may be reduced to its minimum, it is necessary, first, that if M M (Fig. 4) be the level of the mercury at the axis when the cup is revolving with the greatest velocity, the upper part M M X Y of the cup should be of such a form as to have the sides covered only with a thin film of the fluid; and secondly, that, for the purpose of raising the small quantity of mercury to the level L L, which may support a proper height of spirits when the cup is at rest, the cavity of the cup should be, in a great measure, occupied by the block K K, having a cylindrical perforation in the middle of it for the immersion of the tube, and leaving sufficient room within and around it for the mercury to move freely, both along the sides of the tube and of the vessel.

The block, K K, is preferred in its proper position in the cup or vessel X Y Z, by means of three narrow projecting slips or ribs, placed at equal distances around it, and is kept from riling or floating on the mercury by two or three small iron or steel pins inserted into the under-side of the cover, near the aperture through which the tube passes. It would be extremely difficult, nor is it by any means important, to give to the cup the exact form which would reduce the quantity of mercury to its minimum; but we shall have a sufficient approximation, which may be executed with great precision, if the part of the cup above, M M, is made a parabolic cone, the vertex of the generating parabola being at that point of the axis to which the mercury sinks at its lowest depression, and the dimensions of the parabola will be determined in the following manner. Let V G (Fig. 27.) represent the axis of the cup, and V the point to which the mercury sinks at its lowest depression; at any point, G, above V, draw G H perpendicular to V G; let n be the number of revolutions which the cup is to perform in 1, at its quickest motion; let v be the number of inches which a body would describe uniformly in 1, with the velocity acquired in falling from rest through a height = to G V, and make G H = $\frac{v}{314 n}$. Then the parabola to be determined is that which has v for its vertex, V G for its axis, and G H for its ordinate; at G the cup has a lid to prevent the mercury from being thrown out of it, an event which would take place with a very moderate velocity of rotation, unless the sides were raised to an inconvenient height; but the lid, by obstructing the elevation of the sides of the cup, will diminish the depression in the middle, and, consequently, the depression of spirits in the tube; on this account, a cavity is formed in the block immediately above the level L L, where the mercury stands when the cup is at rest, and thus a receptacle is given to the fluid which would otherwise disturb the centrifugal force, and impair the sensibility of the instrument.

It will be observed, that the lower orifice of the tube is turned upwards. By these means, after the tube has been filled with spirits, by friction, and its upper orifice stopped with the finger, it may easily be conveyed to the cup, and immersed in the quicksilver, without any danger of the spirits escaping, a circumstance which otherwise it would be extremely difficult to prevent, since no part of the tube can be made capillary, conveniently with that free passage to the fluids which is essentially necessary to the operation of the instrument.

We have now to attend to the method of putting the tachometer in motion, whenever we wish to examine the velocity of the machine. The pulley F, which is constantly whirling during the motion of the machine, has no connection whatever with the cup, so long as the lever, Q R, is left to itself. But when this lever is raised, the hollow cone T, which is attached to the pulley, and whirls along with it, is also raised, and, embracing a solid cone on the spindle of the cup, communicates the rotation by friction. When our observation is made, we have only to allow the lever to drop by its own weight, and the two cones will be disengaged, and the cup remain at rest.

The lever, Q R, is connected, by a vertical rod, to another lever S, having at the extremity, S, a valve, which, when the lever, Q R, is raised, and the tachometer is in motion, is lifted up from the top of the tube, so as to admit the external air upon the depression of the spirits. On the other hand, when the lever Q R falls, and the cup is at rest, the valve at S closes the tube, and prevents the spirits from being wafted by evaporation.

It is, lastly, to be remarked, that both the sensibility and the range of the instrument may be infinitely increased; for, on the one hand, by enlarging the proportion between the diameters of the wide and narrow parts of the tube, we enlarge, in a much higher proportion, the extent of scale corresponding to any given variation of velocity; and, on the other hand, by deepening the cup, to as to admit, when it is at rest, a greater height of mercury above the lower end of the tube, we lengthen the column of spirits which the mercury can support, and, consequently, enhance the velocity which, with any given sensibility of the instrument, is requisite to depress the spirits to the bottom of the scale. Hence the tachometer is capable of being employed in very delicate philosophical experiments, more especially as a scale might be applied to it indicating equal increments of velocity.
velocity. But, in the present account, it is merely intended to state how it may be adapted to detect, in machinery, every deviation from the most advantageous movement.