Mill-*Work*. Under this head we intend to treat of the parts and mechanical contrivances ufed in mills. Under the article Machinery, the reader will find obfervations of a fimilar nature to thofe of the prefent article, but applied to fmaller and more delicate machines than thofe which are ufually denominated mills.

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

The different firft movers of mills will be treated of, and defcribed under their feveral heads of Steam-*Engine*, Water-*Wheels*, and Wind-*Mill;* and the acting machines of feveral 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, fpinning-mill, filk-mill, thrafhing-mill, water-mill, fawing-mill, under Machinery *for manufacturing Ships' Blocks at Portfmouth*; Tilt *Mill*, &c. &c.

Cog-wheels are the moft important and numerous parts of mill-work, few mills being without them, to modify the direction, and adapt the power of the firft mover, which actuates the mill, to the working point, or the machine which performs the operations the mill is intended for. Moft mills contain feveral different kinds of machines, or operative parts, all deriving their motions from the fame fource, or firft mover. Thus, a flour-mill contains ftones for grinding; dreffing machines for fifting the flour; fack tackle, for drawing up the facks, &c.; all which are moved by the fame firft mover as a water-wheel, wind-mill, fteam-engine, or horfe-wheel. But each of thefe machines requires to be moved with a different velocity to perform its work in the beft manner; and it is the object of the mill-work to obtain thefe different velocities from the fame firft mover, chiefly by the means of wheels; which, therefore, from their importance, deferve the firft notice. There are a variety of cog-wheels, as fpur-wheels, (or *gear* in the technical phrafe,) bevil-wheels, face-wheels or crown-wheels, pinions or nuts, trundles or lanterns; with a variety of other names which are local, but have the fame fignification with fome of the above.

Spur-wheels are thofe in which the teeth project from the periphery of the wheel, in the direction of radials (fee *Plate* I. *fig*. 1. *of Mill-work*): they are fo called, from the refemblance to the rowel of a fpur. A fpur-wheel is ufed to communicate motion by its teeth to another, fituated in the fame plane; confequently, the axes of the two are parallel to each other. The fpur-wheel, at other times, works with *a pinion*, or nut (fee *fig*. 2.), which is in fact a fpur-wheel of fmall fize: at other times with a *trundle* or *lantern*. This is a pinion of peculiar conftruction, confifting of two circular boards A, A, (*fig*. 3.) fixed, at fome diftance apart, upon its axis of motion or fhaft B B, and united by a number of cylindrical pins *a, a*, called ftaves, 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

act upon these rounds to give motion to the trundle; the rounds, therefore, must be the same pitch or distance asunder as the cogs of the wheel. The number of the rounds of the trundle of course determine its diameter. Trundles have of late years fallen into disuse among mill-wrights, 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 shewn in *figs*. 3 and 4.

The crown or face-wheel has of late years been almost wholly superseded by bevil-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. Bevil-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 mill-wrights 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 slight importance; and the practical method of the mill-wrights (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 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 set in the division *e*, the curve *f g* on one side of the cog, and *n o* on one side of the other, are described; then the point of the compasses being set on the adjacent division *k*, the curve *l 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 set out, and the cogs, being dressed 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.) press on the tooth *b* in the point C; and draw the line F C D E perpendicular to the touching surfaces in the point 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 pass through the same 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 mill-wright 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, 1668, 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 prosecutes the principles of M. De la Hire, and applies it to all the varieties of cases which can occur in practice. There is no doubt as to the goodness 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 *b*, is acted on by a flat part of the tooth *a*, till it comes to the line A B in the course 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 G C H of the tooth *a* have the form of a curve traced by the extremity of the thread F C, unlapped from the circumference. In like manner, let the acting face of the tooth *b* be formed by unlapping a thread from its circumference. It is evident that the line F C 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 line A B in the same point D. This form allows the teeth to act on each other through the whole extent of the line F C E, and, therefore, will admit 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

make on each other. It is not altogether free from ſliding or friction, but the whole of it can hardly be ſaid to be ſenſible. 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 $\frac{1}{70}$th of an inch, a quantity altogether inſignificant. Conical wheels, or bevilled 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 ſtreſs they are intended to bear; and this is of vaſt 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 ſingular 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 made of wood, and ſome are ſtill conſtructed of that material; but of late years caſt-iron wheels have been ſubſtituted, and found much ſuperior in ſtrength, accuracy, and durability. Wooden wheels are framed together in ſegments uſually of three thickneſſes, to break the joints upon each other. (See *fig.* 1.) The middle thickneſs is made in ſix or eight pieces, and left on the inſide with ſtraight ſides, *x*, *x*, into which the arms are fitted, and bolted againſt it. On each ſide this middle thickneſs, another is (X X, *fig.* 1.) placed with break joints, and all the three are bolted together to make a ſolid rim, in which the cogs are to be fixed by mortiſes, the tenons or tails of the cog being held in their places by a pin driven through each. The arms of wooden wheels are made in different ways; ſometimes they are mortiſed through the ſhaft, and the ends are notched in the middle of the ſides of the octagonal pieces *x*, *x*, and laying againſt the face of them behind, are bolted to them to make all faſt. This manner of uniting the arms with the rim is ſhewn at *l* (*fig.* 4.); but this method is not the beſt, becauſe the mortiſes weaken the ſhaft very materially, and it is difficult to get ſuch a wheel off if ever it is required, on a failure of the ſhaft, &c. On this account, the method called claſp arms is much preferable; it is ſhewn in *fig.* 1. Four arms E E, F F, are uſed, which are halved into each other, and form a frame as in the figure, leaving a ſquare opening in the centre, and holding the rim of the wheel by their ends, which are bolted to the middle thickneſs of the rim, as ſhewn in *fig.* 4. To fit on ſuch a wheel as this, the ſhaft is made up to a ſquare, by fixing pieces of wood upon its ſides; and the wheel being hung upon this, is made faſt by wooden wedges driven in all round, the ſquare formed between the arms being rather larger than the ſhaft, by which means the wheel can be adjuſted to come quite true by the wedging. Face-wheels, like *fig.* 4, have ſometimes ſtays or braces proceeding from the back of the rim to ſome diſtance along the ſhaft, where they are received in mortiſes, as ſhewn by the dotted lines: theſe make the wheel exceedingly ſtrong, and keep it very ſtiff in the ſquare upon its axis, which is very neceſſary, as the action of the teeth of a face-wheel meeting a trundle, is to throw the wheel back upon its ſhaft, which tendency theſe ſtays effectually counteract. At other times, two ſets of claſp arms are uſed for the ſame end, one bolted on each ſide of the middle thickneſs of the wheel, by the ſame bolts which paſs through both, as well as the wheel, and unite the two ſets like one, but of conſiderable depth, ſo that the wedging will have a greater effect to keep the wheel in the ſquare. Small wheels are frequently made of plank, ſolid, without any arms. In this caſe the middle thickneſs is made of four pieces, leaving a ſquare hole between them, and they are kept together by a circular ring of ſegments, bolted on at each ſide all round, and the joints overlapped. The conſtruction of trundles (*fig.* 4.) has been ſufficiently explained, except that they uſually have an iron hoop fitted round the circular boards to prevent them from ſplitting: indeed many large face-wheels have the ſame. Small pinions are made out of one block of wood, and the cogs are fitted into it much in the ſame manner as the ſpokes are let into the nave of a coach-wheel. Iron-wheels either have the cogs caſt in the ſame ſolid piece with the rim, or mortiſes are left in the caſtings for the reception of wooden cogs, as theſe are found to work much better. The wheel and its arms are ſometimes caſt in one piece, but for large wheels the rim and its arms are formed in two ſeparate pieces and ſcrewed together. The reaſon of this is, that in caſting a large and extended piece of iron, it frequently happens that ſome parts will cool in the mould, and become ſolid before the others: conſequently, from their contraction, theſe parts will be 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 ſet the metal of one part upon a ſtrain againſt another, ſo that the ſlighteſt blow or jar will cauſe them to ſnap 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 withinſide of 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 *e f* are caſt all in one piece. In the latter caſe the rim has a rib *g* withinſide 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 long 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, withinſide the rim of the wheel. The wooden cogs are dreſſed by chiſſels to the marks ſet out, in the ſame manner as wooden wheels; but the iron cogs are firſt chipped with a cold chiſſel and hammer, and then filed true. The great labour of doing this induced Meſſrs. Boulton and Watts, ſome years ago, to erect machinery for dreſſing cogs. The wheel was provided with apparatus to hold it faſt at the ſeveral diviſions, and a ſtrong ſlider, with a chiſſel fixed in it, was forced between the rough cogs by the revolution of a camm or heart, with

with a fufficient power to cut away a fhaving, and form the cog perfectly at twice repeating the operation. Some mechanics difpute the propriety of dreffing iron cogs at all; they fay, that the exterior furface of the caftings have a kind of cafe-hardening, which is removed by the dreffing, and a fofter fubftance of metal expofed for the acting furfaces. This is true, and the objection would have its full force, if it were poffible to make caftings of wheels perfectly true in the circle, and all the cogs precifely the fame fize: but as the prefent ftate of the founder's art cannot infure this, it is beft to chip and file the cogs; accuracy in the form of the teeth being a fuperior confideration to any quality of their fubftance. The wheel being made in either of thefe methods, muft next be fixed, or *hung*, upon its fhaft. Wheels are generally fixed faft upon their fhafts or axles before their teeth are fet out; or, if this is not convenient, they are fixed on a temporary fpindle to fet them out. When the wheel is made of wood, it is fixed upon the fhaft, or a temporary axis, and turned round upon its pivots, while a chiffel is laid on fome fixed fupport to cut or turn its circumference to a true circle, or elfe to make a mark to which its rim may be reduced all round. The circumference is then divided, and mortifes cut out for every cog; and when thefe are fixed in they are much larger than they are intended to be, that they may be fet out, as above directed, and reduced to their true figure, without abfolutely depending upon the accuracy of the mortifes which receive them. Iron wheels are, as before-mentioned, treated in a different manner, being caft in the impreffion of a truly circular pattern made of wood; the cogs caft folid, with the rim or elfe mortifes left all round for the reception of the wooden cogs: in either cafe the rim is a true circle, and muft be fixed upon the fhaft exactly by its centre, inftead 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 fhaft which is to go through it, and the fpace all round is filled up by iron wedges driven in; fo that by means of thefe the wheel can be fixed exactly true in the centre (or in the round), and alfo in the flat that is truly perpendicular to the axis. The manner of arranging the wedges is fhewn in *fig.* 8, where eight wedges are fhewn by *a*, *a*, *a*, *a*, &c. round the fhaft R. It is needlefs to explain how the wheel can, by means of thefe, be fet exactly true, when it is found by turning round upon the pivots of its fhaft that any one fide of the circumference is farther from the centre than another. For the purpofe of fetting it fquare upon the fhaft, each wedge-hole is provided with two wedges, one driven in from each fide of the wheel, the two laying over each other in the notch or hole in the manner fhewn 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 ufual manner of hanging wheels, and for large wheels it is the only applicable method. *Plate* II. *figs.* 9 and 10, is a far fuperior plan for fuch iron wheels as are not too large or heavy to be turned in a lathe upon a chuck, fo that the centre is expofed, and may be bored through with a truly circular hole, and rather conical: of courfe the wheel is fixed upon the chuck, fo that its circumference runs truly; and at the fame time the centre is bored, the pitch circle is defcribed upon the cogs, and fometimes the ends of the cogs are turned to reduce them to a true circle, and alfo the fides, that they may be exactly flat: for, as we have before obferved, iron wheels, however true their teeth may be caft, fhould always have their cogs rather too large, and then be fet out and dreffed, by chiffeling and filing, to make them perfectly correct to the lines thus defcribed. But to return to *fig.* 9; the wheel being prepared, and its centre bored out, the fhaft is turned, as ufual, to form its pivots, and, at the fame time, the part which is to receive the wheel is turned conical, to fit the hole through the wheel, which being jambed thereon will certainly be true at once: and to prevent it from flipping round upon its axis various means are in ufe; fometimes a mortife is formed through the fhaft A, at the fmall part of the cone, and a wedge *r* driven through, which is received in notches at the fides of the hole through the central part of the wheel, fo that it holds the wheel from turning round on the fhaft, at the fame 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 fhaft parallel to the axis of it, and another fimilar one withinfide of the hole through the wheel; then a fillet or feather of iron *s*, (*fig.* 10.) being inferted into the two grooves, effectually prevents the wheel from turning, unlefs the ftrain is fo great as to cut the feather in two through its whole length, which is eafily prevented by making it of a proper thicknefs. Another method of fixing a wheel is to have a flaunch, or flat fhoulder, formed upon the fhaft, and the wheel is drawn up againft this by two, three, or four fcrew-bolts going through it, and alfo through the central part of the wheel, parallel to its axis. This plan is neither fo neat, fimple, nor ftrong as the former. When a wheel is required to be fometimes difengaged from its axis, the conical or cylindrical fitting is very convenient. In this cafe, the wheel fhould fit up againft a flat fhoulder, as *a*, in *fig.* 11, and at the oppofite fide fhould have a collet, or ring *b*, to confine it, and kept up by a key going through to the fhaft R. In this way the wheel will flip round freely upon its axis, and communicate no motion thereto, though it is in conftant motion itfelf: but when they are required to be connected, a locking bayonet, or clutch-box, is ufed. Thefe pieces of mechanifm are conftructed in different forms; one of them is fhewn in the figure. Strong arms A, A, are fixed faft on the fhaft R, juft before the wheel either by a circular fitting with a fillet, by a fquare, or they may be caft with it. Through the extremities of thefe arms holes are drilled to receive the fhanks *f*, *f*, of the locking bayonet, which are fixed by nuts faft to an arm D, very nearly fimilar to A A, but it flides on the fhaft, 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 this groove gives the means of fliding the bayonets *f f*, and D, upon the fhaft, fo that the points of its fhanks intercept the arms of the wheel, fo as to carry it round with them and the fhaft; but when the points of *f f* are drawn back clear of the arms of the wheel, it flips round freely upon the fhaft. The clutch-box is rather different from this; it is a piece fitted upon the fhaft with a fillet, fo that it cannot flip round, but will flide endways upon it. The end of the piece is formed with feveral notches, or indentations acrofs its face, which meet fimilar indentations in the face of the central part of the wheel, and thus unites the wheel and the fhaft when the clutch is flid up to it; but the wheel is difengaged when the clutch is drawn from it. The conftruction of *bearings* for the fupport of pivots at the ends of fhafts or fpindles, is a matter of great importance in mill-work. The old kind of bearing called braffes is fhewn in *fig.* 12. A lump of brafs *a*, with a femicircular notch in it, was let into the piece of timber A, which was to fupport it; and two fcrew-bolts *b*, *b*, were fixed through the timber, being half received in notches formed in the fides or ends of the brafs *a*: the upper brafs, *b*, was exactly fimilar 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

them together: the nuts *c, c,* upon the tops of the bolts confined the upper brafs down, and made all faft and tight. This kind of brafs is not fufficiently ftrong or fteady for all purpofes, and, therefore, the bearing fhewn in *fig.* 13. has taken its place: in this, *aa* is a caft-iron plate, which is held by two or more bolts *r, r,* down upon the timber or framing of the mill: this piece of caft-iron has two pieces *b, b.* rifing up from it, between which a piece of brafs, *l,* is bedded, and has a femicircular notch in it. Another fimilar piece of brafs is fixed into the caft-iron cap-piece B, which is fitted into the fpace between the two pieces *b, b,* and is drawn down by nuts upon the two bolts *c, c.* The braffes are prevented from getting out fideways by fmall fillets projecting from the middle of them, which are received into proper notches in the caft-iron work. In the fame manner the cap B is fitted between the pieces *b, b,* with a tongue or fillet, and groove, fo that it cannot deviate fideways, and then the bolts have only to draw the braffes down together. Sometimes a bearing of this kind is fitted up, fo that it is adjuftable in its pofition a little to adjuft two wheels to work accurately with each other, or for other purpofes where nicety is required. In this cafe, an iron plate, D, is bolted down to the framing, and the bearing, *a a,* lays upon it, the fame bolts *r, r,* going through both, and alfo through the framing beneath; but the holes through which they pafs in the piece *a a* are oblong, to admit the whole bearing being adjufted fideways. This is done by two wedges *o, o,* inferted at the ends of the piece *a a,* between the two ends of D, which rife up for the purpofe, as at *n n.* The bearing refts upon two wedges at *g, g,* and is drawn down upon them by the bolts *r, r.* By thefe two wedges it can be raifed up at pleafure, and by the other two, *o, o,* at the ends, it can be adjufted endways to fet the bearing in the exact pofition required; and the bolts *r, r,* when fcrewed faft, hold all tight. The beft way to make the interior furface of the braffes for a bearing exactly true, is to have them caft folid, that is, the two halves of the brafs in one, with a notch which very nearly, but not quite feparates them. In this ftate it can be chucked in a chuck-lathe, and the infide bored or turned out true: then it may be fawn in two halves, and put into its place, to which it fhould have been previoufly fitted. Sometimes the bearing is all fitted together and fcrewed down in its place, and a borer is ufed to bore or broach out the hole for the braffes, the fame as is employed to bore pump barrels. Brafs is found, by experience, to be the beft fubftance to form bearings for a caft-iron gudgeon, having the leaft friction, and, confequently, leaft wear, of any other fubftance which can be ufed. To diminifh this friction ftill farther, friction-wheels are fometimes ufed. The manner of conftructing thefe, when merely required to fupport a gudgeon, leaving its own weight to keep it down in its place upon them, is fhewn 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 fupports bearings *a, a,* for their pivots raifed up to a proper height, and provided with fockets for braffes, in which the pivots of the friction-wheels are to lie. The two friction-wheels B, B, as is evident, lie by the fide of each other, and the gudgeon, D, of the fhaft they are to bear lies upon and between them, fo that when it turns round it rolls upon them, or rather, their circumferences move with it, and, confequently, the pivots of the friction-wheels move fo flowly, as to diminifh 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 beft kind of friction-wheels, though the fimpleft. *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, B, rifes up from it, all caft in one piece. The interior furface of this ring is turned in the lathe with the greateft accuracy, and the pivot or gudgeon C, which is alfo turned true, refts in the centre thereof, being fupported by fix rollers *a, a,* &c. arranged at equal diftances round it, and of fuch a diameter as to exactly fill up the fpace all round between the gudgeon and the ring. The rollers, it is evident, muft be made all of one exact diameter, and extremely true, and they muft fill up the fpace: then the gudgeon being turned round acts upon thefe rollers, and turns them round alfo at the fame time by this motion. As they have no fixed centre, they alfo roll round within the ring B, in the fame direction as the motion of the gudgeon, but with a very flow 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 fliding of a gudgeon round upon its bearing taking place here; it is all rolling of one furface upon another: and as the contact of two cylinders, fuppofing them hard, is but a line, the friction, or more properly adhefion, is exceedingly fmall; and at the fame time that the gudgeon is as ftrongly fupported as poffible: but this depends upon the hardnefs of the matter of the gudgeon, the rollers, and the ring B. If the ring and gudgeon are made of hard caft iron, and the rollers of fteel at a fpring temper, it will act extremely well, though the ftrain or weight upon the rollers be very great. For light ftrains fofter fubftances might be ufed, but not to fo good an effect.

The manner of keeping all the rollers at their relative diftances from each other, in the ring B, that they may not run againft each other, is yet to be explained. Each roller, as fhewn at *z,* has a groove turned in it in the middle of its length, fo as to reduce it to a fmall neck in the centre: then an iron ring, L, is provided, which has fix holes drilled in it, in the proper pofitions for the centres of the rollers, that is at equal diftances round a circle, which is as much lefs than the ring E as the diameter of the rollers, or the fame quantity larger than the diameter of the gudgeon C. Thefe holes are made to fit the fmall neck in the centre of the rollers, and to get them in, the holes are cut open from the outfide of the ring, fo as to become notches; then the rollers being put into them, are all in one clufter, and in this ftate are introduced into the ring E. They will now be kept at their proper diftances afunder, and when the gudgeon C is introduced between them, they will all take their proper places, and lie truly parallel. It is to be obferved that the holes or notches in the ring L, do not exactly fit the necks of the rollers, which have therefore confiderable play, and but very little friction, for it is not effential to keeping the rollers at their relative diftances that this ring fhould be ufed, but it will prevent the danger of their getting wrong by accident. To prevent any duft or dirt getting in, which would completely deftroy the action of this ingenious mechanifm, a circular iron plate is fitted into the ring B, on each fide, and both are fixed by fmall fcrews going through the ring. One of the plates N muft of courfe have a hole through the middle, to admit the gudgeon. The joints of thefe plates fhould 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 paffes, will be kept oiled; though this is no ways neceffary to their action. The end plate, which is not perforated, will make a ftop to prevent the gudgeon moving endways, and the two plates will keep the rollers from fhifting their pofition on end; but to prevent friction, if ever they come in contact, the ends of the roller fhould be rather convex, as fhewn at *z,* that they may touch in the centre

centre rather than the outfides; but they will never bear hard againft the plate, having no drift that way.

A patent was taken out for thefe friction rollers many years ago, and a large manufactory was eftablifhed for making them for various purpofes, as carriage and waggon-wheels, the gudgeons of heavy water-wheels, &c.: they were found to poffefs great advantages, having fcarcely any fenfible friction when in motion, but were liable to get out of order chiefly from the entrance of duft, which occafioned the rollers to wear out of the round more on one fide than the others; and if once by this accident the rollers ftood ftill for an inftant, 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 fide fo deep as to ftop the rollers, becaufe of the very fmall furfaces in contact with the gudgeons. For delicate purpofes, where hardened fteel can be employed for all the rollers and the ring, they are a moft admirable contrivance, and the above objections will then apply very flightly; but, as before mentioned, their perfection and durability will ultimately depend upon the hardnefs of the fubftances employed.

Fig. 16. reprefents a fuit of friction rollers for fupporting the weight of a heavy vertical fhaft, as a horfe-wheel, a horizontal wind-mill, a capftan fugar-mill, &c. A A is a plate fupporting the weight of the fhaft; it has a conical eminence upon it, and a hole in the centre of this, which exactly fits the pivot or gudgeon *c*, at the bottom of the fhaft R: upon this gudgeon a conical plate B is formed, exactly of the fame fhape and fize as the conical part of the plate A, and between thefe two plates three or four rollers *a*, *a*, are fituated, and bear the weight of the fhaft R, or whatever preffes upon the plate B. The rollers are kept at proper diftances afunder by a ring, fhewn feparate at L, with three arms, *n*, projecting from it, which being formed into fpindles, pafs 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 A; but the weight is fupported by the rollers *a*, *a*, which, at the fame time that the upper plate rolls upon them, they roll upon the lower, and thus very confiderably diminifh the friction which any other kind of gudgeon would have in fuch a fituation.

Shafts.—In almoft all modern mills, the fhafts or fpindles for the conveyance of motion, and fupport of wheels, are made of iron, either wrought or caft. Square fhafts are the moft common, but fometimes octagon and round ones are ufed; and if they are very large, they are caft hollow, like pipes, and the gudgeons fixed in at the ends by wedges; but the pivots fhould always, if poffible, be formed of the fame piece of metal, as the flighteft poffible deviation from the ftraight line caufes them to ftrain, and work very irregularly in their bearings. In wooden fhafts this is impracticable, and it is one of the greateft objections to the ufe of them. The beft method of fixing gudgeons into wooden fhafts is fhewn in *fig.* 17. Here A is the gudgeon, made in caft iron, turned true; it has four leaves, *a*, *b*, *c*, *d*, forming a crofs, which is let into the end of the wooden fhaft R: the front edge of each leaf is confiderably thinner than the back, fo that a pair of ftrong iron hoops *r r* being driven tight on the end of the fhaft, clofes the wood round the crofs, and holds it faft, and the back of the leaves being wider than the front, it will not come out. As an additional fecurity, fcrews are fometimes put in: thefe are put through holes in the arms of the crofs, which are then made flat the other way, and do not go fo far into the wood. The fcrews go into the timber a confiderable diftance, where a mortife is cut into the wood, to meet the end of the bolt, and an iron nut is dropped in, to fcrew the bolt into, when it is turned round by a fcrew driver. By this contrivance a gudgeon may be fitted into a wooden fhaft very faft, but ftill it will never come into competition with iron fhafts, when the gudgeon is made all in one folid piece with the whole of the fhaft. A judicious mechanic will never make more than two bearings upon any one fhaft, if it can be avoided, becaufe if the three, by any means, as the warping of the frame work, or other caufe, get the fmalleft poffible quantity out of the ftraight line, they can never work well afterwards, but will always ftrain and wear the bearings with great friction. In very extenfive mills, fuch as woollen and cotton mills, breweries, &c. when the buildings are of great length, it becomes neceffary to join feveral fhafts together in length, to reach from one end to the other of a mill. The manner of making the joinings is of fome confequence: it is neceffary that every fhaft fhould have a bearing at each end, and confequently that the connection of the ends of every one fhould be made by uniting the ends of the fhafts which project beyond their bearings. This can be done in various ways: one is by having the ends of each of the fhafts provided with circular heads (fee A B *fig.* 18.), which have teeth in one, and correfponding indentations in the other, to receive them, and thus one is made to turn the other about, at the fame time that if any flight fettlement of the building or other caufe depreffes one of the bearings, or raifes another, fo as to put the two fhafts out of the perfect ftraight line they ought always to preferve; thefe joints will admit the flight flexure, and ftill communicate the motion of one fhaft to the other.

As this accidental fettlement in large buildings is almoft unavoidable in fome degree, care fhould be taken to make fuch joints as will admit of a trifling bending. Sometimes the ends of the fhaft 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 fhafts with the collar, and thus by means of it caufes one to turn the other round. This method is fometimes ufed to fave the great expence of having a bearing at each end of every length of fhaft, one bearing to each length being then fufficient, the other end of the fhaft being fupported by this collar, connecting it with the end of the adjacent length juft where it projects beyond its bearing. But this is not a good method, as the fhafts are apt to bend and work with fo much friction in the bearings, if they get the leaft out of the ftraight line, becaufe thefe kind of joints will not admit any flexure of the fhaft, or if they do, they will only bend on one fide, whereas it is neceffary for the joint to bend fucceffively on all fides, when the bearings are not precifely in a ftraight line. *Plate* III. *fig.* 19. reprefents a coupling-box, ufed by Mr. Murray of Leeds, for connecting the lengths of a long line of fhaft which are to carry a heavy ftrain: it is fo made that it will communicate the motion in the manner of an univerfal joint, if they fhould be out of the line. Let A, B, be the two fhafts to be united; C, D, their necks or collars which lay in the bearings: the ends projecting beyond thefe have boxes E, F, fixed on them, either by a fquare with wedges, or by a round part with a fillet: one of thefe boxes, E, has a piece projecting from the infide of it on each fide, and extending into the other box, as is fhewn at *a a*, (No. 2.), which is an infide view: the other box, F, has two fimilar pieces projecting from it at *b b* into the other box E: within the boxes an iron crofs *c c d d* is fituated; it has fcrews fixed into the ends of the crofs, and by thefe the motion is communicated: thus, the pieces *a*, *a*, when the fhaft A and box E are turned round in the direction of the arrow (No. 2.) act againft the fcrews *c*, *c*, of the crofs, and turn

it

it about: at the ſame time the other two ſcrews *d, d*, at the other arms of the croſs preſs againſt the pieces *b, b*, which belong to the box F and ſhaft B, thus turning them round: the croſs is placed quite detached in the boxes, and thus acts as an univerſal joint, to communicate the motion of one to the other: the ſcrews *c c, d d*, at the ends of the croſs 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 ſhewn 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 croſs key *l m*, put through each ſhaft, and the ends of them received in notches made withinſide 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 theſe parts E and C, but only in the pivots *a, b*, within, by 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 ſhewn in *fig.* 21, where A, B, are the two ſhafts, with necks to be received in bearings: each ſhaft beyond this is formed into a fork, as G and D; and theſe are united by a croſs 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 gombals, and will communicate a rotative 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 ſlightly bevilled 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 cauſes will occaſion 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, &c. 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 many cauſes, 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, ſo regulated, will move like a clock, with regard to its regularity of velocity. Theſe regulators are uſually termed *governors*, and are made on different principles. Thoſe 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 repreſents the ſimpleſt form of this ingenious apparatus: A A is the vertical axis, which is conſtantly revolving by the machinery; at *a a* two arms or pendulums, *a b, a b*, are jointed, and carry at their 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 groove formed all round it, in which the end of a forked lever, D, is received; and thus the riſing 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, 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*, cauſes them to recede from the centre; and as this is done both together, they cauſe 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 preſerves 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, cauſing 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 cauſes the governor to be a moſt ſenſible and delicate regulator. Thus: ſuppoſe the balls hanging perpendicular, put the axis in motion with a certain velocity, the centrifugal force will cauſe the balls to fly out; and this increaſing their velocity, (by putting them farther from the centre, and cauſing 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, *viz.* the weight of the balls tending to return. This is, as before ſtated, an increaſing quantity, and conſequently theſe oppoſite 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 ſlighteſt alteration takes place in the velocity of the axis, the equilibrium is deſtroyed by the increaſe or diminution of the centrifugal force, and the balls alter their diſtance from the centre accordingly, and by elevating or depreſſing 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 loſes in velocity, from an increaſe 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 ſhuttle of a large wheel requires a much greater force to raiſe or lower it, when the water is preſſing againſt it, than the lever, D, can at any time poſſeſs; it therefore becomes requiſite to introduce ſome additional machinery, which has ſufficient power to move the ſhuttle, 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.

A ſquare

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 cheſt, very nearly filling up the ſpace: it of courſe roſe and fell with the water in the ciſtern, and had a communication by rack and wheel-work with the machinery for drawing the ſhuttle, ſo that the riſe and fall of the floating cheſt 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 and deſcent 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 ſame mechaniſm is applicable to any kind of mill-work, we ſhall give a ſlight 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 bevilled 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 ſlip round freely upon it, turning in contrary directions, as they receive motion from the oppoſite ſides 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, ſhewn 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 one 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 with 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 it 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 reſiſtance, 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 ſtone, to ſet them at a greater diſtance aſunder, 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 unclothe the ſails 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 ſhewing any ſcale of them. In caſes where this is required, it may be done by a very ingenious inſtrument, invented by Mr. Bryan Donkin of Fort-Place, Bermondſey. He received a gold medal from the Society of Arts, Manufactures, 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. X Y Z, *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 L L, *fig.* 25. Into the mercury is immerſed the lower part of the upright glaſs tube A B, 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 according 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 ſides 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 alſo; 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 ſame proportion in which the ſquare of the larger diameter exceeds the ſquare of the ſmaller.

Let us now ſuppoſe, by means of a cord paſſing 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 not be ſo great as to depreſs the ſpirits below,

C, into

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 ſpirit 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 moveable, ſo that, by ſlipping 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, conſiſtent with theſe conditions, may be reduced to its minimum, it is neceſſary, firſt, that if M M (*fig.* 1.) is 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 preſerved 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 riſing or floating on the mercury by two or three ſmall iron or ſteel pins inſerted into the underſide 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 conoid, 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 $GH = \frac{v}{314\,n}$. 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 twined upwards. By theſe means, after the tube has been filled with ſpirits, by ſuction, 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, conſiſtently with that free paſſage to the fluids which is eſſentially neceſſary to the operation of the inſtrument.

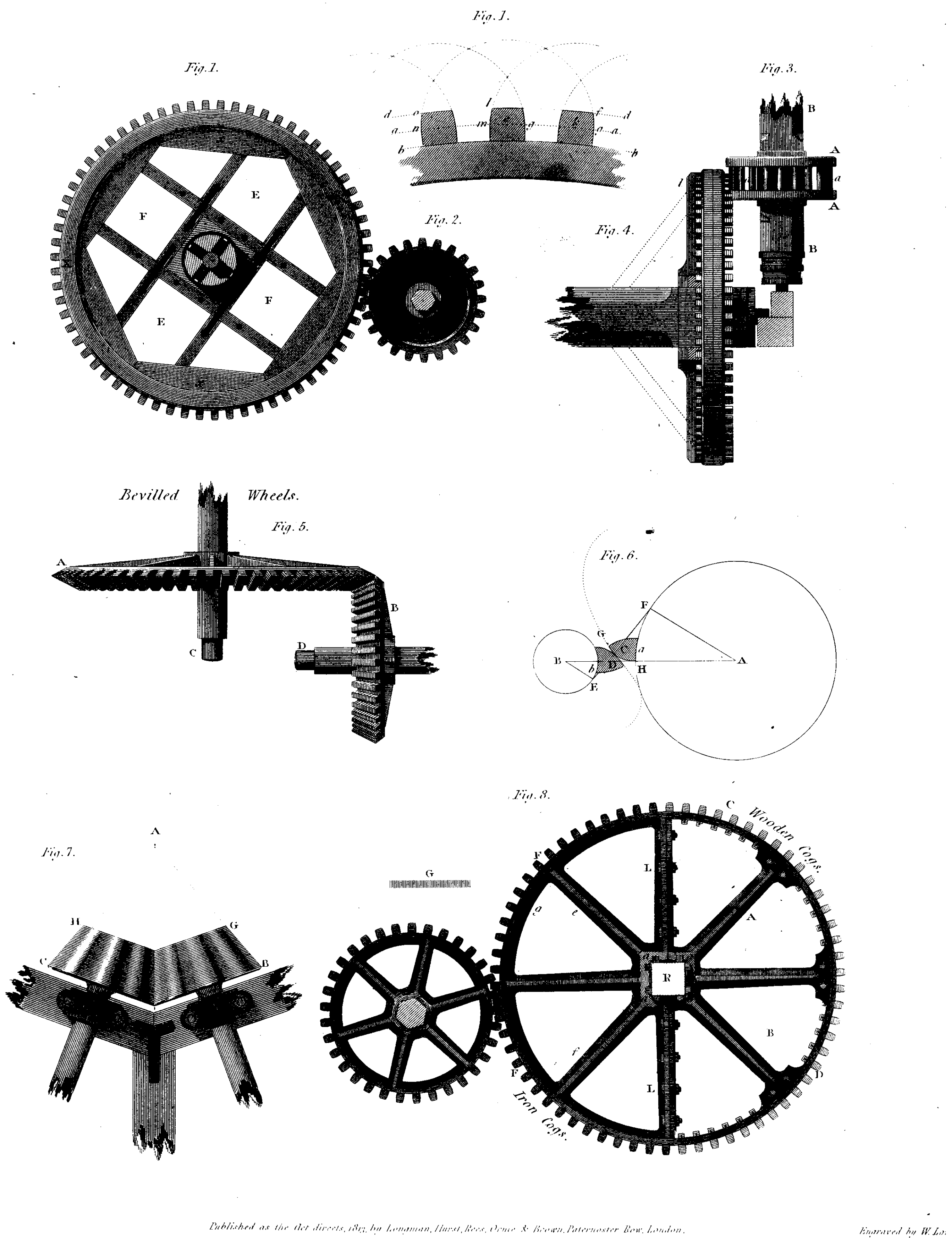
We have next to attend to the method of putting the tachometer in motion, whenever we wiſh to examine the velocity of the machine. The pulley F, which is conſtantly whirling during the motion of the machine, has no connection whatever with the cup, ſo long as the lever, Q R, is left to itſelf. But when 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 waſted 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, ſo 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, enlarge 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.

MILL-WORK.



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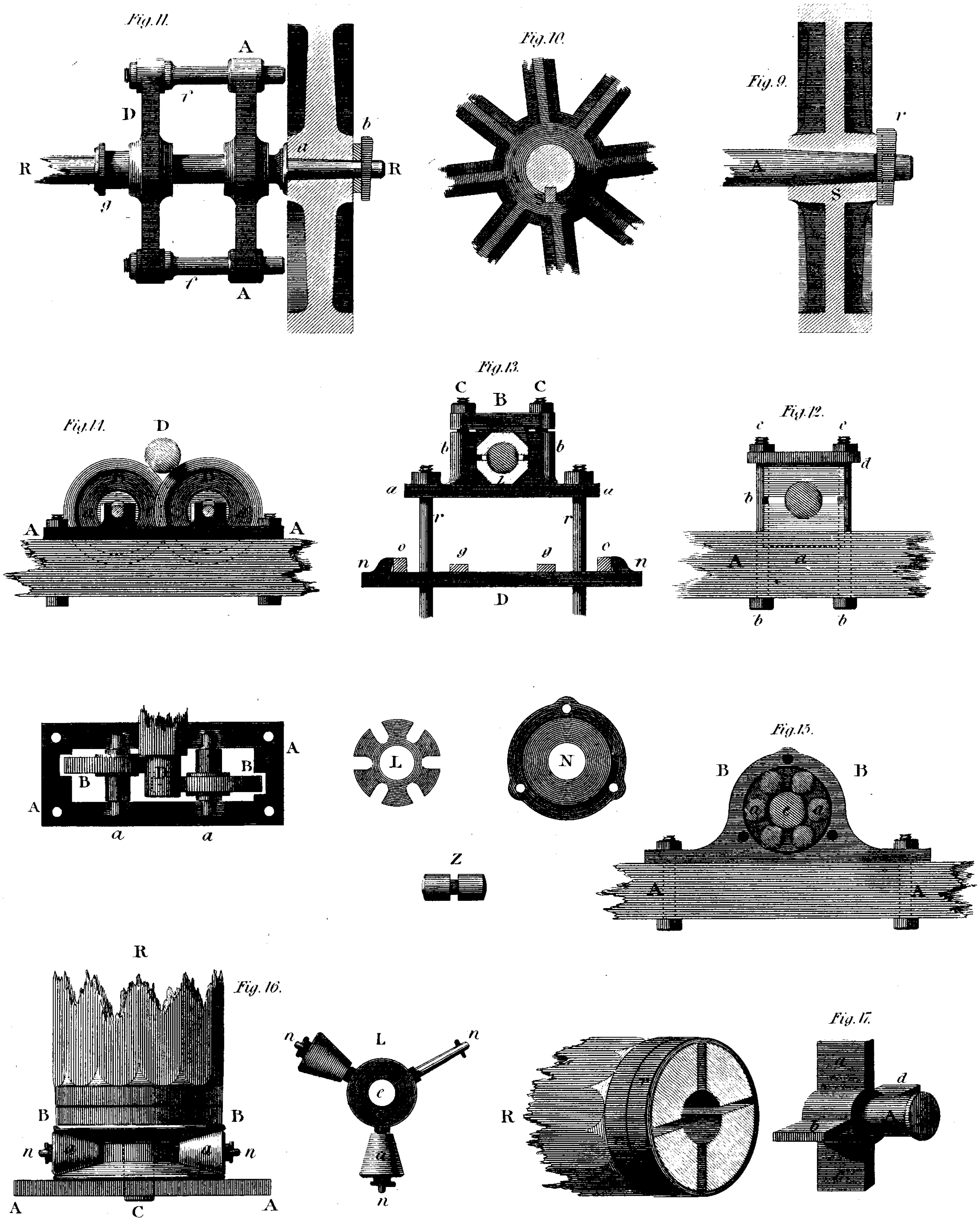

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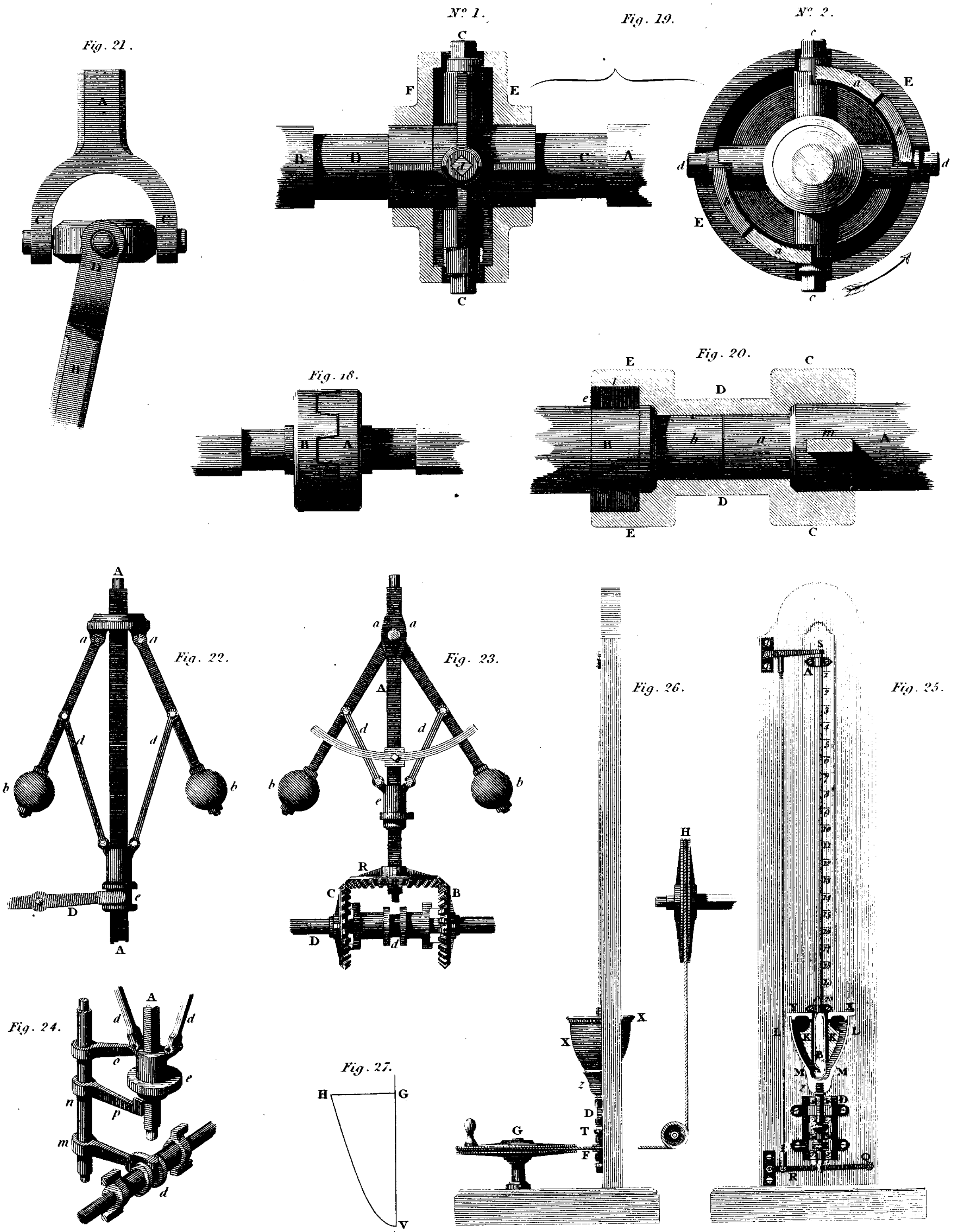

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