CHAPTER IV.

ELEMENTARY COMBINATIONS.

CLASS A. { DIRECTIONAL RELATION CONSTANT.
VELOCITY RATIO CONSTANT.

DIVISION C. COMMUNICATION OF MOTION BY WRAPPING CONNECTORS.

177. ANY two curves revolving in the same plane whose wrapping connector (Art. 37) cuts the line of centers in a constant point, will preserve a constant angular velocity ratio. In practice, however, circles or rather cylinders only are employed, which revolve round their centers, and manifestly possess the required property. To enable the rotation to proceed in the same direction indefinitely, the band which serves as a wrapping connector has its two ends joined so as to form an *endless band*, which embraces a portion of the circumference of each circle or *pully*, and is stretched sufficiently tight to enable it to adhere to and communicate its motion to the edge.

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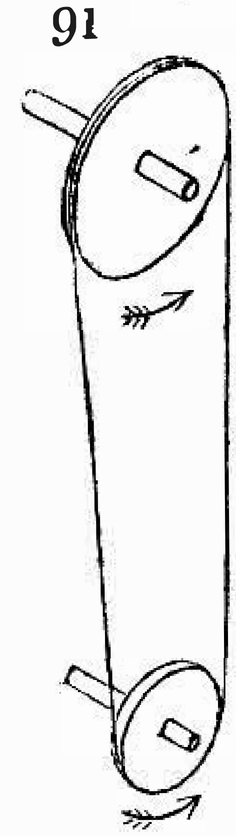
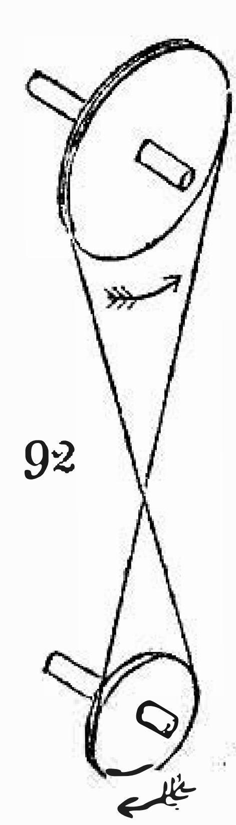


The band may be *direct*, that is, with parallel sides, as in fig. 91. or it may be *crossed*, as in fig. 92. In the first case the axes or pullies will both revolve in the same direction, in the latter case in opposite directions.



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178. Motion communicated in this manner is remarkably smooth, and free from noise and vibration, and on this account, as well as from the extreme

simplicity of the method, it is always preferred to every other, unless the motion require to be conveyed in an exact ratio.

As the communication of motion between the wheels and band is entirely maintained by the frictional adhesion between them, it may happen that this may occasionally fail, and the band will slip over the pully. This, if not excessive, is an advantageous property of the contrivance, because it enables the machinery to give way when unusual obstructions or resistances are opposed to it, and so prevents breakage and accident. For example, if the pully to which the motion is communicated were to be suddenly stopped, the driving pully, instead of receiving the shock and transmitting it to the whole of the machinery in connexion with it, would slip round until the friction of the band upon the two pullies had gradually destroyed its motion.

But if motion is to be transmitted in an exact ratio, such, for example, as is required in clock-work, where the hour-hand must perform one exact revolution while the minute-hand revolves exactly twelve times, bands are inapplicable; for, supposing it practicable to make the pullies in so precise a manner that their diameter should bear the exact proportion required, which it is not; this liability to slip would be fatal.

But in all that large class of machinery in which an exact ratio is not required to be maintained in the communication of rotation, endless bands are always employed, and are capable of transmitting very great forces.

179. Bands may be either *round* or *flat*, and the *materials* of which they are formed are various. The best but most expensive is *catgut;* but its durability and elasticity ought to recommend it in every case where it can be obtained of sufficient strength. It acquires by use a hard polished

surface, and it may be procured of any size, from half an inch diameter to the thickness of a sewing needle.

The ends of a catgut band may either be united by splicing or by a peculiar kind of hook and eye which is made for that purpose. Both hook and eye have a screwed socket into which the ends of the gut are forced by twisting, having been previously dipped into a little rosin. The hook and eye may be warmed to keep the rosin fluid while the band is being forced in, and the ends of the band that come out through the socket may, for further security, be seared with a hot wire.

Hempen ropes are only used in coarse machinery, but in the cotton factories a kind of cord is prepared, of the cotton-waste, for endless bands, which is tolerably elastic and soft, and is peculiarly adapted for driving a great quantity of spindles. Also the soft plaited rope, termed patent sash-line, answers very well for these purposes. All these bands must have their ends neatly spliced together, so as to avoid as much as possible the increased diameter at the place of junction, because the periodic passage over the pullies of the lump or knot so formed gives rise to a series of jerks, that interfere with the smooth action of the mechanism *.

Common *iron chains* are also used, but only in very rough and slow-moving mechanism.

Flat leather belts appear to unite cheapness with utility in the highest degree, and are at any rate by far the most universally employed of all the kinds. This they owe partly to the superior convenience of the form of pully which they require, over that which is employed for round bands and chains. Belts vary in width from less than one inch up to fifteen inches, and their extremities may be united by

* Vide Transactions of Society of Arts, Vol. XLIX. Part I. p. 99, for some practical directions.

buckles, but are best joined by simply overlapping the ends and stitching them together with strips of leather passed through a range of holes prepared for the purpose, or they may be glued or cemented at the ends; in which case, by carefully paring and adjusting the parts that overlap, they will be perfectly uniform in thickness throughout; but they thus lose the power of being adjusted in length, and must therefore be provided with stretching pullies.

Belts, on account of their silent and quiet action, are very much employed for machinery in London, to avoid nuisance to neighbours. It appears also from a recent work*, that the use of belts is greatly extended in the American factories. In Great Britain the motion is conveyed from the first moving power, to the different buildings and apartments of a factory, by means of long shafts and toothed wheels; but in America, by large belts moving rapidly, of the breadth of 9, 12, or 15 inches, according to the force they have to exert.

Of late, both flat belts and round bands have been manufactured of *caoutchouc* interwoven with fibrous substances, in various ways; and under peculiar management may be made to answer very well. But changes of temperature occasion great variations of length and elasticity in this material; nevertheless in this latter quality it is greatly superior to catgut, and, like that substance, it requires no stretching pullies, which must always be employed for rope-bands. Belts are also made of *woollen felt*, and round bands are cut out of thick *leather*. In small machinery an endless band may even be cut out, in one piece, of a skin of leather, so as to avoid the necessity of joining the ends, and thus the jerks occasioned by the passage of the knot over the pully are entirely avoided.

* Cotton Manufacture of America, by J. Montgomery, 1840, p. 19.

180. *The form of the pully* upon which an endless band is to act is of importance, as the adhesion of the band

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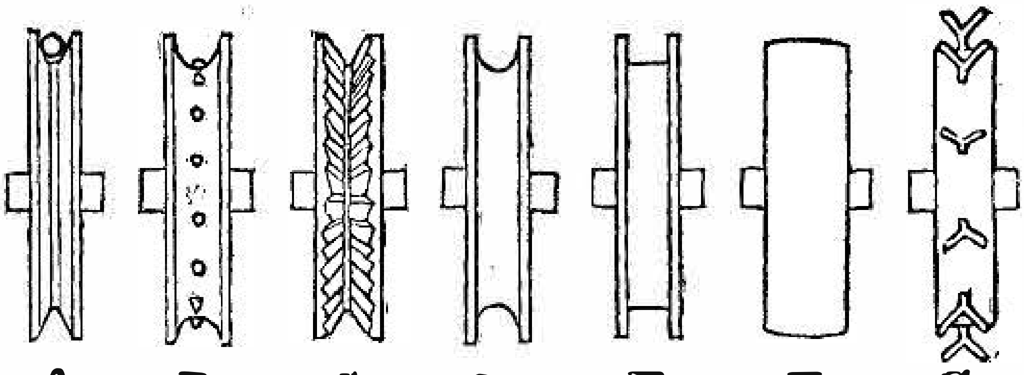

A *B* *C* *D* *E* *F* *G*

is greatly influenced thereby. Fig. 93 exhibits the principal forms. Round bands of catgut, rope, or other material, or even chains, require an angular groove (as *A*), into which their own tension wedges them, and thereby enables them to grasp more firmly the edge of the pully.

But when ropes or soft bands are used, the bottom of the groove is sometimes furnished with short sharp spikes, (as *B*), or else its sides are cut into angular teeth, (as *C*), which help to prevent the band from slipping, but at the same time are apt gradually to wear it out.

A pully for chains is sometimes formed by fixing Y formed irons at equal distances in the circumference of a cylindrical disk, as at *G*.

When the pully over which the band passes is used merely as a guide-pully (Art. 186), there is no need to provide against slipping, and the groove or *gorge* is made simply of a semicircular section, as *D*, to keep the band in its place.

181. If a tight flat belt run on a revolving cone, it will advance gradually towards the base of the cone, instead of sliding towards its point, as might be expected at first sight.

The reason of this is, that the edge of the belt nearest the base of the cone is tighter, and advances more rapidly than the other, because it is in contact with a portion of the cone of a larger diameter, and consequently moving with a proportionably greater velocity*. Thus the belt is bent into the form *Bb*, shewn in the figure, by which the part which is advancing to the cone is thrown still nearer and nearer to its base. In this manner the belt will gradually make its way from the smaller end of the cone to the larger, where it will remain. Advantage is taken of this curious property in forming the pullies for straps, which are made of the form represented at *F*, fig. 93, a little swelled in the middle. This slight convexity is more effective in retaining the belt than if the pully had been furnished with edges as at *E*; and the form, besides its greater simplicity, enables the belt to be shifted easily off the pully. In fact, when a pully of the latter form *E* is employed, the belt will generally make its way to the top of one of the lateral disks, and remain there, or else be huddled up against one or other of them, but will never remain flat in the center of the rim, if there be the slightest difference of diameter between the two extremities of the cylinder.

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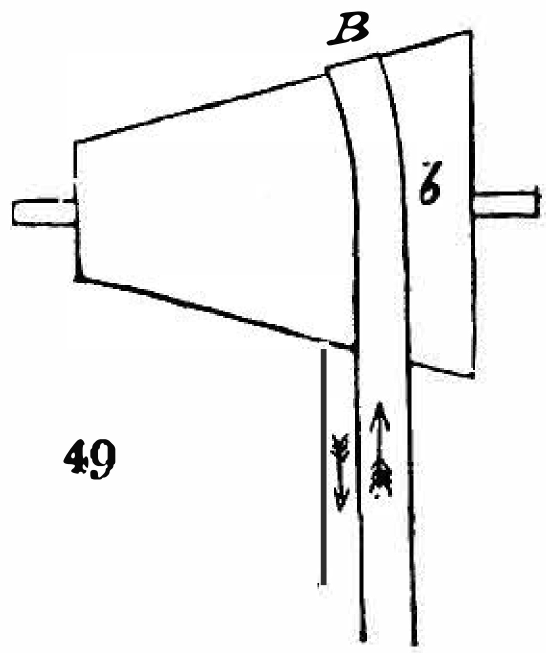
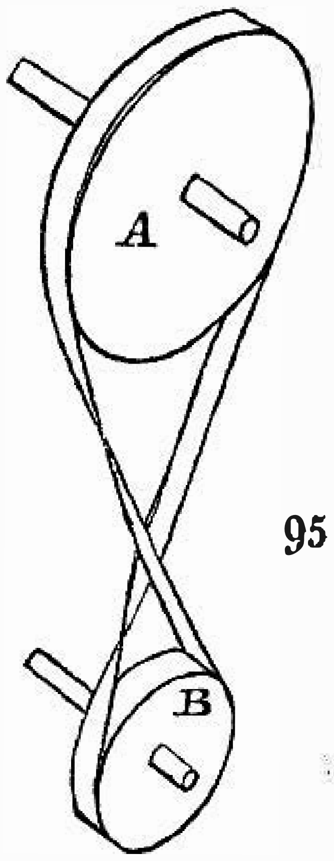


182. In order to bring the belt into contact with as much as possible of the circumference of the pully, it is better to cross it (Art. 177) whenever the nature of the machinery will admit of so doing.

When a strap or other flat belt is crossed, it must be put on to the pullies in the manner represented in fig. 95. Every leather belt has a smooth face and a rough face. Let the rough face be placed in contact with both pullies, by which each straight side of the belt will be twisted half

* Young's Nat. Phil. vol. II. p. 183.

round in the transit from one pully to the other, as shewn in the figure. Now the effect of this is, that at the point where the two sides cross, the belts lie flat against each other; for since the belt at each extremity where it joins the pully is perpendicular to the plane of rotation, and it is twisted half round in its passage, it must be parallel to the plane of rotation half way between the pullies, when the two sides of the belt cross. Hence they pass with very little friction, whereas if this half twist were not employed, the two halves of the belt would pass edgewise, which (in a broad belt especially) would occasion so much friction and displacement as to make the arrangement impracticable.



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183. The band moves with the same velocity as the circumference of the pully with which it is in contact, and consequently the circumferences of the two pullies which it connects move with equal velocities;

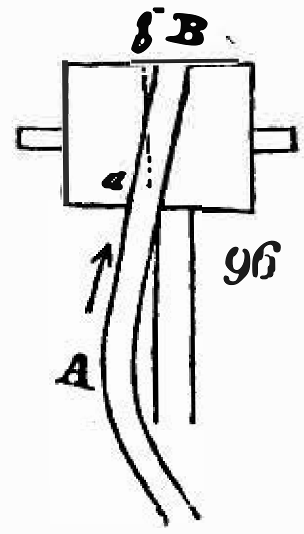
$$\therefore \frac{A}{a} = \frac{r}{R},$$

where A, a are the angular velocities, R, r the radii.

But when a thick belt is wrapped over a pully its inside surface is compressed and its outside surface extended, and the center, or nearly so, of the belt alone remains in the same state of tension as its straight sides, and therefore moves with the velocity of the sides Hence the radius of the circle to whose circumference the velocity of the belt is imparted, virtually extends to the center of the belt, and half the thickness of the belt must be added to the radius of the pully, in computing the angular velocities.

Similarly, to find the acting radius of a pully with an angular groove, as at *A*, fig. 93, the distance of the center of the section ofethe band from the axis of the pully must be taken, and this in a given pully will be greater the thicker the band employed.

184. An endless band of any kind is easily shifted during the motion to a new position on a cylindrical drum or pully, if the band be pressed in the required direction on its *advancing side*, that is, on the side which is travelling towards the pully; but the same pressure on the retiring side of the belt will produce no effect on its position.



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For example, if the belt *AB* has been running over the drum in the position *B*, and this belt be drawn a little aside, as at *A*, those portions of the belt which now come successively into contact with the drum, as at *a*, will begin to touch it at a point to the left of the original position, and in one semi-revolution the whole of the belt in contact with the drum will thus have been laid on to it, point by point, in a new position *ab*, to the left of the original one *B*; but if the direction of the motion were from *B* to *A*, the portions of belt drawn aside are those which are quitting the drum, and therefore produce no effect on its position thereon.

Therefore, to maintain a belt in any required position on a cylindrical drum, it is only *necessary* that the advancing half of the belt should lie in the plane of rotation of that section of the drum upon which it is required to remain, but the retiring side of the belt may be diverted from the plane, if convenient, without affecting its position.

If the machinery be at rest it is very difficult to shift the position of a belt of this kind, on account of the adhesion of its surface; but by attending to the simple principle just explained it becomes very easy to shift the belt by merely turning the drum round, and pressing the advancing side of the belt at the same time. The same principle applies to round bands running on grooved pullies; if it be required to slip them out of the groove, the advancing side of the band must be pressed to one side, so as to make it lay itself over the ridge of the pully, when half a revolution will throw it completely off.

185. Let AM, BN be two shafts, neither parallel nor meeting in a point, and let it be required to connect them by a pair of pullies and an endless band. Recollecting that the advancing side of the band must remain in the plane of rotation of each pully, find the line MN, which is the common perpendicular to the shafts. Fix the pullies upon the respective shafts, so that a line mn parallel to MN* shall be a common tangent to them, which is done by making the distance AM of the upper pully from the point M equal to the radius Bn of the lower pully, and *vice versâ*,

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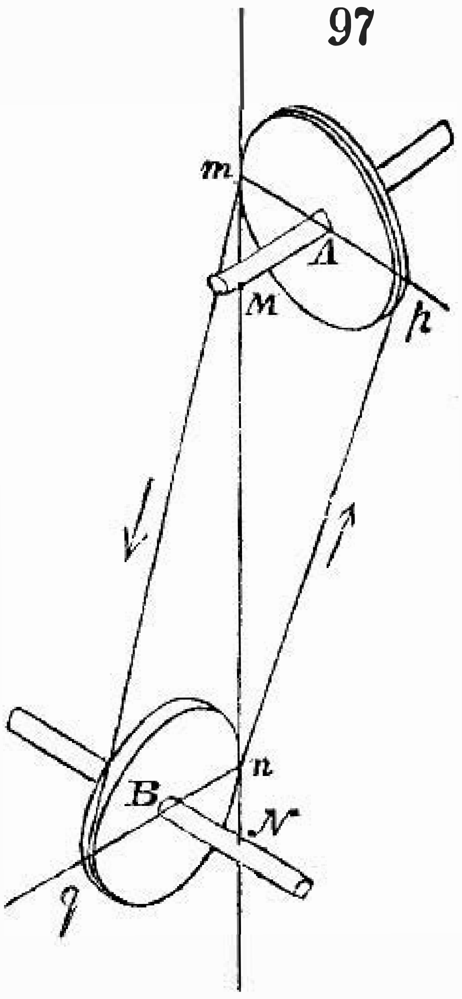

$$BN = mA.$$

Arrange the belt in the manner shewn in the figure, the arrows indicating the direction of motion; then the portion np which is advancing to the upper pully is plainly in the plane of rotation of that pully, and will therefore retain its position thereon, and similarly, the portion mq which is advancing to the lower pully, is also in the plane of rotation of the latter.

If, however, the motion be reversed the belt will immediately fall off the pullies, for in that case the portion pn

* The lines MN, mn are confounded into one in the figure, but it will be easily seen that mn lies considerably behind MN.

will advance towards the lower pully in a plane pn, making an angle with that of the pully. The belt will therefore begin to shift itself towards N, and, by so doing, will be thrown off the pully, and a similar action will take place between the belt qm and the upper pully.

The appearance of this arrangement in practice is very curious; for the retiring belts being twisted at a very considerable angle from the planes of the pullies, at the moment of quitting them appear as if they were slipping off at every instant, which however they never do. The only fault is, that this violent twist at m and n is apt to wear out the leather, especially if the shafts are pretty close together. For which reason it may be better to employ guide pullies to conduct the belt from one wheel to the other, as in Art. 187.

If it be required to cross the belts, the arrangement for so doing will be found by drawing a figure similar to 97, but in which qm shall be the intersection of the planes of rotation, mn the descending belt, and a common tangent from p towards q the ascending belt.

186. Pullies are sometimes employed for the purpose of altering the course or path of a band, in which case they are termed *guide pullies*. Their position and number may be determined in the following manner:

A band moving in the line Ab is required to have its path diverted into the direction bB by guide pullies.

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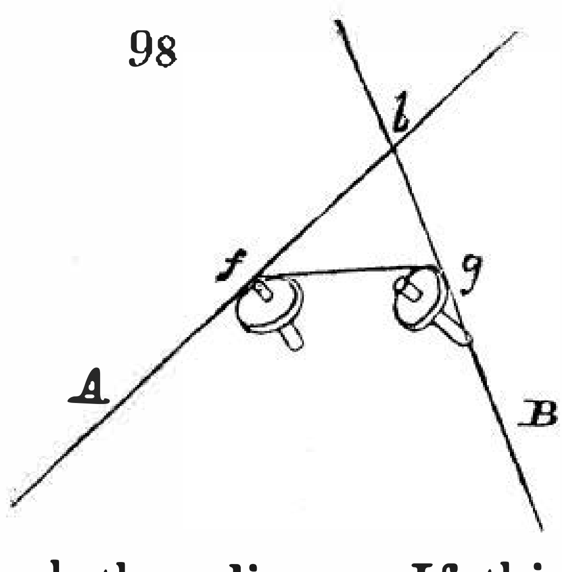

If these lines meet in the point b, one pully is sufficient; the axis of which must be placed perpendicularly to the plane which contains the two lines Ab, bB, and its mean diameter adjusted so that it may touch these lines. If this diameter be too great for convenience, or the point of intersection *b* too remote, or if the lines do not meet in a point, then two pullies are required, whose positions are thus determined.

Draw a third line *fg*, meeting the two former lines in any convenient points *f* and *g* respectively, and let this line be the path of the band in its passage from one line of direction to the other. Place, as before, one guide pully at the intersection *f*, and the other at the intersection *g*, the axes of these pullies being respectively perpendicular to the plane that contains the two directions of the band*.

187. Let *A*, *B* be two pullies whose axes are neither parallel nor meeting in direction, as in Art. 185, and let the line *cd* be the intersection of the two planes of these pullies.

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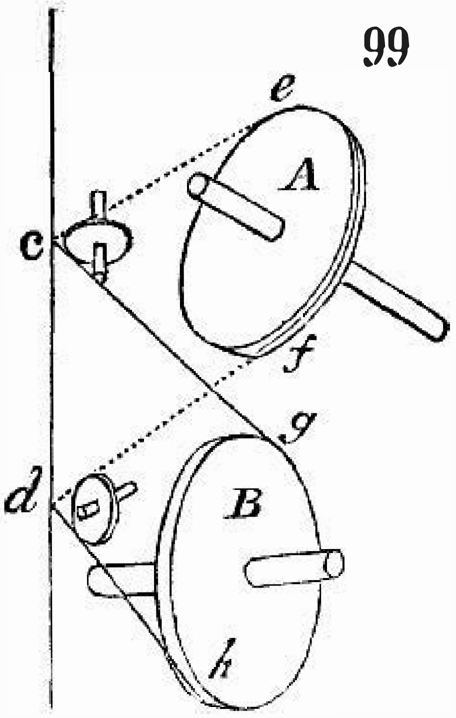


In this line assume any two convenient points *c* and *d*; and in the plane of *A* draw *ce*, *df*, tangents to the opposite sides of this pully; also in the plane of *B* draw *cg*, *dh*, similarly tangents to the pully *B*.

This process gives the path of an endless band *ecghdf*, in which it may be retained by a guide pully at *c* in the plane *ecg*, and another at *d* in the plane *fdh*. In this band both the retiring and advancing sides lie in the planes of each pully. The pullies will therefore turn in either direction at pleasure, and the band is not liable to the twisting wear already deprecated in the arrangement of fig. 97.

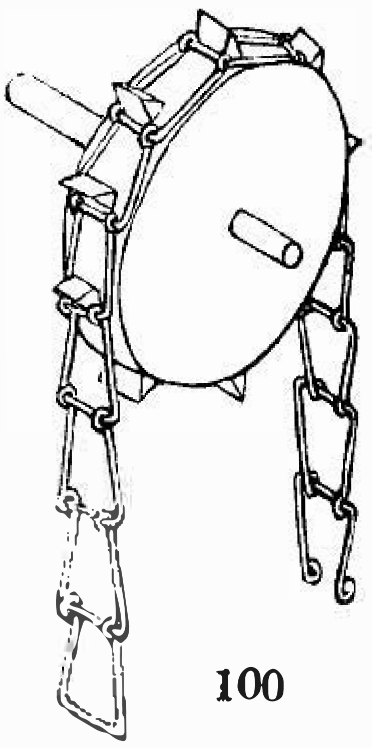
In other cases that may present themselves, the position and least number of the requisite guide pullies may be determined by similar methods.

* Poncelet, Mec. Ind. Part III. Art. 24.

188. If the bands are not made of elastic substances they require *stretching pullies*; that is, pullies resembling guide pullies, whose axes can be shifted in position, so as to increase the tension of the band as required; or else their axes are mounted in frames so that a weight or spring may act upon them, to retain the band in the proper state of tension; but as the operation of these contrivances involve considerations of force, they do not fall under the plan of this portion of the present work. Neither do certain arrangements by which the quantity of circumference embraced by the bands are increased or multiplied, for the purpose of improving the adhesion.

189. We have seen that a common iron-chain with oval links may be employed as an endless band; using the form of groove *A*, fig. 93. If the chain be formed with care, and the wheels between which it works be provided with teeth, the spaces between which are accurately adapted to receive the successive links, then the chain will take a secure hold of the circumference of each wheel; and its action upon these teeth will resemble that of one toothed wheel upon another, or rather of a rack upon a toothed wheel, the successive links falling upon and quitting the teeth without shocks or vibration, so that the motion of one toothed circumference will be conveyed to the other without loss from slipping. A chain of this kind is termed a *geering chain*, and various forms have been given to its links to ensure smoothness of action. But these chains are expensive and troublesome, and are not much in use, as, generally speaking, the communication of motion to a distance can be as completely effected by a long shaft with bevil-wheels at each end; and the geering chain, in all its forms, is liable to stretch, by which the spacing or pitch of its links is increased, so that they no longer fit the teeth of the wheels.

Fig. 100 shews the geering chain which was proposed by the celebrated Vaucanson, about 1750. The links of the chain are made of iron-wire, and adapted to lay hold of the teeth of a wheel in the manner shewn by the figure*.



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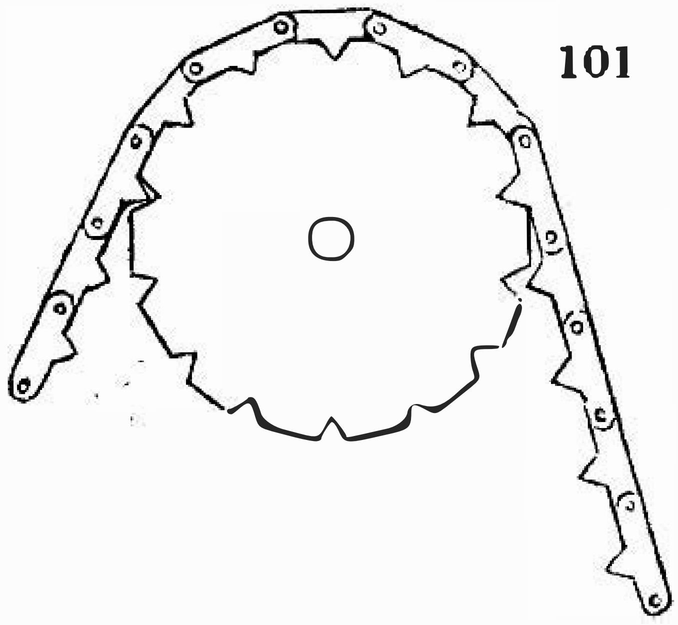
Geering chains had been, however, employed long before this period, as for example, by Ramelli in 1588†; and the very chain of Vaucanson is represented by Agricola, in 1546, as an endless chain, to carry buckets in a machine for raising water from a mine.

Fig. 101 is another form, from Hachette, in which the



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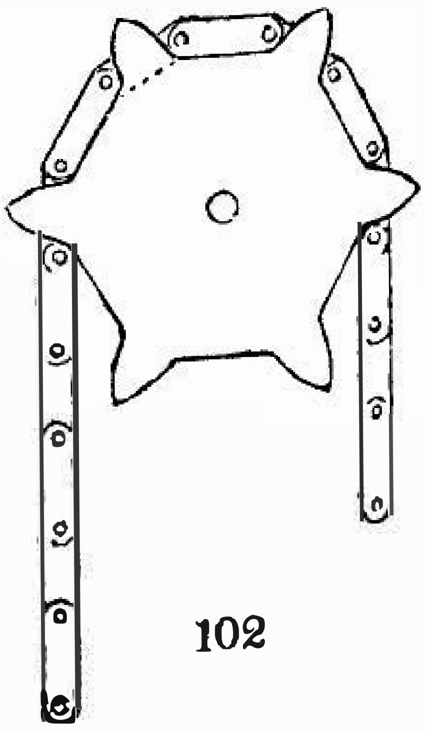
links are made of plates rivetted together, somewhat after the manner of a watch-chain; and 102 is a third modification‡, in which a plate-chain is also employed; but the teeth of the wheel are much better disposed for grasping the successive links. Nevertheless, in all these cases, when the rivets enlarge the holes by wearing, the pitch of the chain is increased, and each link enters its receptacle on the wheel with a jerk, producing vibration and accelerated deterioration.



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* Vide Encyc. Method. Manufactures, tom. II. p. 132.

† Figs. XXXIX. and XCIII. ‡ Used in Morton's patent slip.

190. If the axes be required to make only a limited number of rotations in each direction, the slipping of the band may be entirely prevented by fixing each end of it to one of the pullies or rollers, and allowing it to coil over them as many times as may be required; as in fig. 103, where rotation is conveyed from one roller *A* to the other *B* by the cord *a*, one end of which is fastened to the surface of *A*, and the other end to that of *B*. To enable the motion to be conveyed in both directions a similar cord *b* may be coiled in the opposite direction round each roller, so that while *b* coils itself round *A*, *a* will uncoil itself, and *vice versa*.

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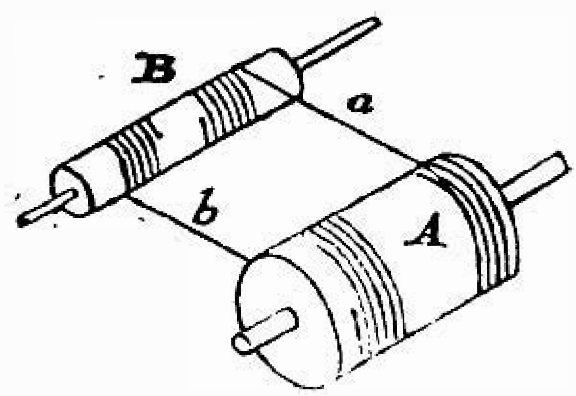

The carriage *B*, fig. 104, runs back and forwards upon the rollers *f*, *e*, and derives its motion from the roller or barrel *A*, which is mounted on an axis above it. A cord *c* is tied to one end of *B*, and another cord *d* to the other end; these cords are passed as many times round the roller as is necessary, in opposite directions, and their ends fastened to its surface. When the roller revolves the carriage will travel along its path, preserving a constant velocity ratio, provided the circumference of the roller nearly touch the line *dc*. Otherwise the variation of the angle *Acd*, during the motion of the carriage, will cause the velocity ratio to change*. If, however, pullies be fixed to the frame of the machine beyond *d* and *c*, and the cords be carried from the barrel over these pullies and then brought back again to *d* and *c*, the axis *A* may be fixed at any required height above *B*. Either piece may be the driver.

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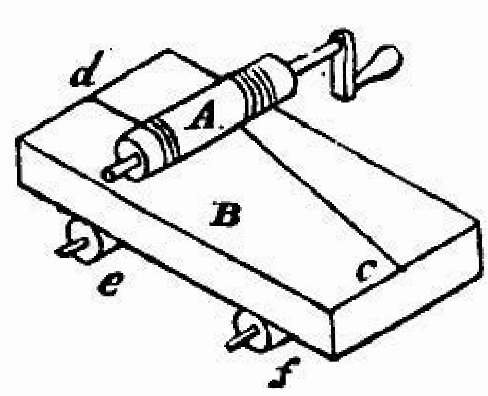
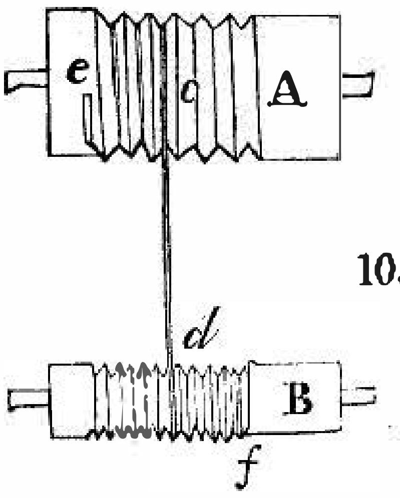


* For the line *Ac* acts as a link jointed at *c*, and therefore;

vel. of *Ac* : vel. of *B* :: cos *Acd* : 1. (Art. 32. Cor. 3.)

Sometimes a single line is employed, which being fastened at d is coiled three or four times round the roller, and then carried on to c; the coiling is sufficient to enable the cord to lay hold of the roller in most cases, as for example, in the common drill and bow.

191. But the constancy of the ratio is interfered with in both these contrivances, by the varying obliquity of the straight parts of the cords which connect the pieces, as well as by the tendency to heap up the successive coils in layers upon each other, thereby increasing the effective diameter of the rollers. This is remedied by cutting a screw upon the surface of each roller, which guides the cord in equidistant coils as it rolls itself upon the cylinder.



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Thus, fig. 105, let A give motion to B by a cord cd, in the manner already shown in fig. 103, but let screws be cut upon the surface of the rollers; then during the motion of A the extremity c of the straight portion of the cord will be gradually carried to the right as it is wound up, and *vice versa*; and this motion will be constantly proportional to the rotation, and at the rate of one pitch of the screw to each complete turn of the cylinder.

To cause the straight portion cd to move parallel to itself, the screw cut upon B must be of such a pitch that the endlong motion of d may be the same as that of c. Now since the velocity of the surfaces of the two cylinders are equal, and every revolution of either screw carries the cord endlong through the space of one pitch, let $m \times$ circumferences of $A = n \times$ circumferences of B, and let C, c be the respective pitches of their screws; R, r their radii, then we must have $mC = nc$,

$$\text{or } \frac{C}{c} = \frac{R}{r}.$$

192. In the combination of fig. 104, the screw roller will prevent the irregular heaping up of the cord on the band, but will not correct the varying obliquity of the cord. This may be got rid of thus.

Let *B*, fig. 106, be the sliding carriage, *CD*, *HK* the

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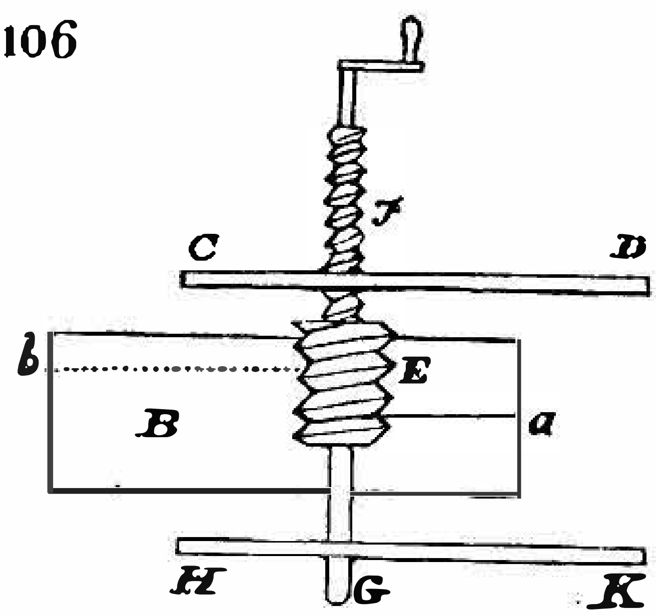


sides of the frame which supports the roller, *E* the roller formed into a screw. This roller has a screw *F* cut on its axis, of the same pitch as that of *E*, and passing through a nut in the frame *CD*; the other extremity of the roller is supported by a long plain axis *G*, passing through a hole in the frame *HK*; the cord being tied at *b* to the carriage, and at the other end to the screw-barrel *E*; it follows, that when the latter is turned round, it will travel at the same time endlong by means of the screw and nut *F*, exactly at the same rate, but in the opposite direction, as the end of the cord is carried along the barrel by its coilinge, consequently the one motion exactly corrects the other, and the cord *b* will always remain parallel to the path of the slide *B**.

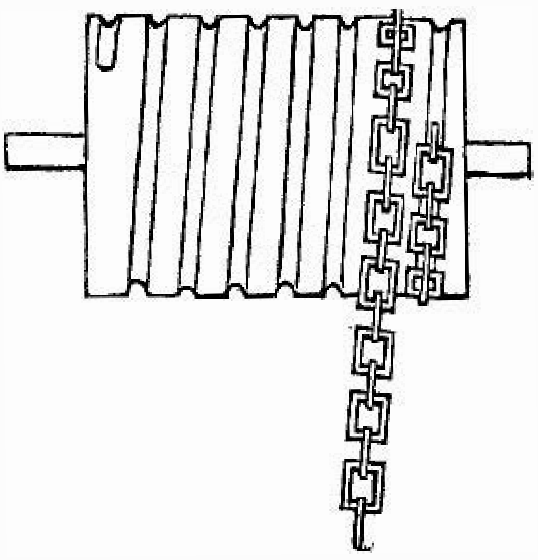
A similar and contrary cord being employed to connect the other end of the slide with the band, will enable the roller to move the slide in either direction.

193. A well made chain of the common form, with oval links, will coil itself with great regularity upon a re-

* From a machine by Mr. Holtzapfel.

volving barrel, if a spiral groove be formed upon the surface, of a width just sufficient to receive the thickness of the links. As shewn in fig. 107, the links will alternately place themselves edgewise in the groove and flat upon the surface of the barrel.

107.



194. When the revolving piece is required to move only through a fraction of a revolution, the combination is made more simple.

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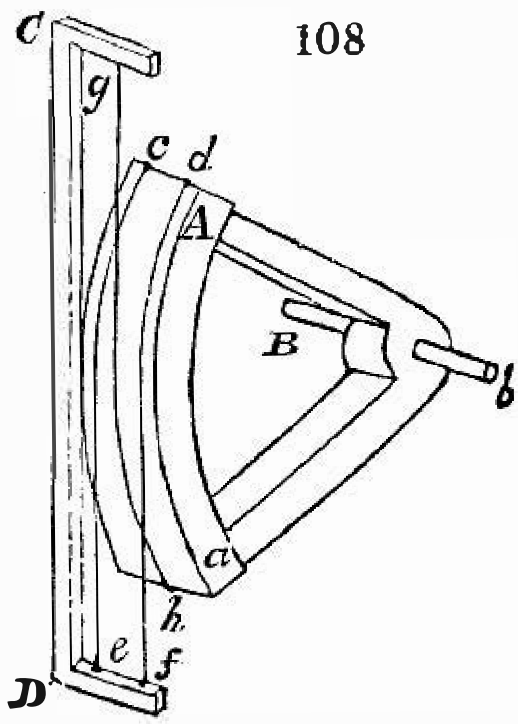

Thus let A represent a revolving piece or quadrant, whose axis is B, b, and whose edge is made concentric to it, and let CD be the sliding piece represented as an open frame for clearness only, but supposed to be guided so as to move in either direction along the line CD produced. If cords or chains be attached at c, d, to the quadrant and at e, f, to the sliding frame; and a third cord be attached contrariwise to the quadrant at h and the frame at g, then either motion of the quadrant or the frame will communicate motion to the other in a constant ratio, and in either direction at pleasure.