CHAPTER IV.

ON THE APPLICATIONS OF THE SYSTEM.

(40.) The purposes to which I have found my system applicable may be classed under four heads: (1,) the formation of models of the Elementary Combinations described in my work entitled 'Principles of Mechanism,' and other similar ones; (2,) the construction of such machines as I select as examples, either of the principles of mechanism or of the processes employed in manufactures; (3,) the construction and arrangement of apparatus for Experimental Philosophy in general; (4,) the trial of new combinations and original research.

(41.) I will now endeavour to explain more at length, and in order, these several applications of the system; and first, the *Elementary Combinations*, nearly the whole of which I am thus enabled to exhibit; whereas, if each were constructed, as usual in such cases, as a separate model complete on its own foot or stand, the expense and bulk of such a collection would render it impossible.

Many of these combinations consist of pieces of peculiar forms which admit of being made of wood, and in which the axis of motion does not even require a stud-socket. For example, large models to illustrate the forms and action of the teeth of wheels may be cut out of mahogany, with the teeth on a large proportional scale, as in the diagrams given in my work, and such wheels will turn very well upon strong ordinary joiners' screws. In this case I generally mount the two pieces of which such combinations usually consist upon a bar of wood, and fix this bar, when wanted for exhibition, by means of a bolt to one of the posts (Art. 18) or to an iron rectangle (fig. 19), which serves to hold it up or enable it to stand on the table during the explanation.

In other cases a little more building is required; thus, if the action of ratchets, clicks, and detents is to be shown, a cast-iron ratchet-wheel is mounted on a stud-socket, the stud of which is fixed in a hole in a board, on which board is also properly mounted an arm for the clicks, a detent, &c., and the board bolted to the front of an iron rectangle or bracket. Here the rectangle, the ratchet-wheel, and the stud-socket and stud, are general pieces removed after the lecture, to serve for other purposes: the board with its clicks is *peculiar*, and reserved for this purpose alone.

Elementary trains of spur-wheels, of bevels, and mitres, are mounted wholly by means of the general system of parts. Thus, according to the nature of the combination we desire to represent, we must either employ a peculiar construction, frame or pieces, or build it up entirely of the general forms; or, finally, employ such a mixture of the two methods as may suit our convenience.

(42.) Fig. 42 may serve as a specimen of an elementary combination. This is known as Roëmer's wheels, ('Principles of Mechanism,' p. 257,) and was invented by him to effect the varying motion of planetary machines, but will also serve in any case where a rotation of varying velocity is required to be produced from a uniformly revolving shaft. In the figure, the shaft, to which a handle F is attached, is the uniformly revolving shaft, and upon it is fixed a cone A, fluted into sixteen regular and equidistant teeth, like those of an ordinary bevel-wheel, but occupying the surface of a much thicker frustum of the cone than usual. Opposite to this cone is placed, upon a parallel axis, a smooth frustum of another cone B, of the same angle, but set with its smaller end in the reverse direction to the first cone, so that its surface lies parallel to the teeth of the latter, and so close as just to escape contact. Upon the surface of B are planted a series of pins (of brass wire driven into it), and so arranged as to fall in succession between the teeth of A, when the latter is made to revolve. As this series is so placed as to be in some parts at the small end, and at others in the middle or at the large end, the velocity which B receives from A continually varies; for A and B are about the same diameter at the remote ends, and at the other ends the diameter of B is considerably greater than that of A. Thus, when the pins that are engaged in the teeth of A happen to lie opposite its small end, as in the figure, B revolves much more slowly than A. When the pins are opposite the large end, the velocities of the two are nearly equal, and between these two extremes the passage from one velocity to the other may be made gradual or abrupt, according to the path upon which the pins are placed. To mount this apparatus, a *slit table* (fig. 16) is employed for the base. The cone A, made of hardwood, is bored with a $\frac{1}{2}$-inch hole, and is fixed on a $\frac{1}{2}$-inch shaft by pinned rings (fig. 30). The shaft is carried by tube-fittings upon No. 2 brackets (C, D), and the endlong motion of it prevented by the handle F at one end, and by a shaftring at the other end. The frustum B is also made of wood, and bored with an inch hole, so as to be mounted on a long stud-socket which is carried by a No. 2 bracket, E.

In this model the only *peculiar parts* are the two cones, every thing else being derived from the general system. I have already described two other specimens of this class; namely, the link-work, fig. 40 (Art. 34), and Ferguson's Paradox, fig. 41 (Art. 37).

(43.) The second purpose to which this system is applied is the construction of models of such machines as I select as exemplifications either of the principles of mechanism or of the processes employed in preparing and working raw material.

A model of a machine is generally constructed for one or other of the following purposes,—to explain the use and contrivance of the machine, or its actual form and construction. If the latter be the object, the model must necessarily resemble the original as nearly as possible, and differ from it only in material or magnitude; as, for example, when a large model is made of a small machine, as a clock scapement, to make its various minute parts more clear; or *vice versâ*, when a small model is made of a large steam engine. When the purpose is to explain and teach the arrangement (or '*packing*') of the different parts, and the form and mode of putting together the frame-work, no deviation from the original, or simplification of it, can be permitted, with this exception, that as the model is not subjected to the strains which the work of the original throws upon its various parts, wood may be used instead of brass or iron.

The case is very different, however, when the object of the model is to explain the motions and mechanism of the original.

Real machines consist of a number of parts of various sizes, packed together in a *cubical form* in a frame-work contrived so as to support the pieces in the best manner, and to reduce the machine to the smallest possible compass consistent with the proper access to the parts for oiling, cleaning, &c. In such machines it is difficult even for an experienced observer to see all the parts, without looking on all sides, or even removing some of them, because they are placed without any reference to the display of their motions, which are often hidden by the frame-work and by other portions of the mechanism.

In preparing a representation of the action of such a machine for the Lecture Room, it is necessary to alter its arrangement by displaying the parts as much as possible on a *plane* system, instead of a *cubical one*, so that one piece may not conceal another. Instead of ingenious *packing* of the parts, we must have them *unpacked* and laid out, as it were, for inspection, without interfering with their connexion and action. Moreover, the frame-work must be kept out of the way as much as possible. Again, the small parts must be made larger in proportion, to render them visible at a distance, and the larger parts may often be reduced in scale. All this may, by judicious care, be effected without disturbing the connexion of the trains of mechanism, or destroying the individual character of the machine. When a machine contains a repetition of working parts, as in spinning, weaving, &c., a few such parts will do better for our purpose. Two or three *real spindles* set in a frame, with their proper drawing rollers above, may be set in motion by a combination built up of the general pieces above described, and will enable a clearer and better idea to be given of the action of these machines than if the Lecturer was provided with a complete throstle-frame. Many subsidiary contrivances also, which are necessary for adjustments or other secondary objects, and not essential to the primary work of a machine, may be dispensed with in an explanatory model, or explained subsequently by a model made on purpose.

(44.) As an example of the manner in which the parts of a machine may be arranged for Lecture-Room exhibition and explanation, I will take the striking part of a clock on the repeating principle (fig. 43). This model contains so many peculiar parts, and is so complex, that a peculiar frame is provided for it.[1] (The drawing is made to scale.) The frame consists of a base-board with two feet (A, B), and two upright pillars (C and D) of inch deal are attached to the base, as shown in the figure. The left-hand pillar (C) is 8 inches broad and 2 feet 7 inches high, and serves to carry the studs upon which the train of wheel-work is mounted, and also the hammer F, and bell E. The right-hand pillar D, 5½ inches broad and 2 inches higher than the other, carries the snail N, the rack M, and the detent L. This pillar stands 2 inches in advance of the other, and the pieces which it carries are all made of wood and mounted on strong screws, which are quite sufficient for the motion required by these parts, although they would not answer for the wheels, &c. on the other pillar. The snail and the rack have bosses behind, which set them at the proper distances from the pillar; for from the nature of the machine the detent lies behind the rack, and the rack behind the snail. The rack has a projecting knob at the lower extremity, which rests upon the step of the snail when it falls. The detent here is of the simplest construction, consisting merely of an arm turning freely on the screw at the upper end, and having a projecting pin at the lower end, which lies in the teeth of the rack. It is unnecessary to introduce a *lifting-piece* or any other contrivance for the *warning*, because this device is fully explained by a similar large model which I have, of the count-wheel striking train, which it is convenient to exhibit pre-

[1] See Art. 8.

viously to the present one. Also the snail (N) is so mounted as to turn on its axis by stiff friction, and can therefore be set by hand to the proper positions required for the different hours. The rack (M) turns freely on its centre, and therefore, when the train is discharged by raising the detent (L), it falls on the snail by its own weight.[1]

The train is mounted on three stud-sockets, and is furnished with cast-iron wheels and pinions of the *twelve-pitch* size.[2] The lowest stud-socket carries a wheel of 120 teeth, and a barrel of hardwood, 6 inches in diameter and an inch thick, to the front of which is screwed an annular plate of iron (G), provided with six pins for the hammer-tail.

The hammer (F) turns on a stud which is fixed to a block of sufficient projection to bring the hammer-tail in front of the plate: to the same block are fixed the hammer-springs (not shown in the drawing); the bell (E) is also mounted on a block; a slender cord (P) is coiled round the barrel, to give motion to the train, and passes through a notch in the base-board. The machine, when in use, is set upon a stool or other open-legged frame that will allow the string to hang down, and motion may be given to the machine during the explanation of its action by pulling the string by hand. After the action of the parts has been demonstrated, a weight may be hung to the string, for the purpose of still better showing the effect, by allowing the machine its proper self-action.

It is unnecessary to employ a ratchet for winding up; for by drawing the hammer-tail sideways, so as to clear the plate G, the string may be wound upon the barrel.

The wheel of 120, behind G, gears with a pinion of 20 fixed to the next stud-socket, H. This socket carries in front of the pinion a wheel of 108, and also the gathering pallet and its hook.

It is required that this gathering pallet stand visibly at the end of the socket, and for this purpose it is better to employ a stud-socket of the form fig. 11 or fig. 13, Plate I. (Arts. 6, 7), or to make a stud-socket expressly for the machine in question, in which the pallet and hook are permanently attached to the front of the socket, but from which the wheel and pinion can be removed for other purposes, when the machine is not in use.

The fly K is carried by a third stud at the top of the pillar C, the peculiar

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[1] In this description I assume that my reader is already acquainted with the mechanism of the contrivance, the description of which may be found in any treatise on clock-work. My object is only to show the actual construction of the Lecture-Room model.

[2] For simplicity sake, the *teeth* of the wheels are not introduced into the figure.

arrangement of which is shown in fig. 44, which is a view of the fly, &c. seen from above: *a b* is the pillar; *c*, a block screwed to it, to which is also fixed a long stud (5 inches long). The stud carries two separate sockets; the first, which lies next to the block, is a short socket of the common form, ¾ inch in diameter, upon which a pinion (*d*) of 12 is fixed, and gears with the wheel of 108.

In front of this is placed a socket with two branches, to which the fly *h* (of sheet iron) is riveted. This fly, 10 inches wide and 4½ broad, projects so far as to enable it to revolve clear of the other mechanism. It has a semi-circular opening, which allows the end of the stud to project and receive a pin which keeps the sockets in their place. The socket has two springs (*e* and *f*) riveted to it, which are bent backwards, as shown, so as to press upon the shoulder of the pinion socket, which may be notched. Thus, when the pinion turns, the pressure of the springs enables it to carry the fly along with it; but when the train is checked by the tail of the gathering pallet striking the pin of the rack, the fly can proceed alone in the usual manner.

By the peculiar disposition of the parts of this model, every motion is visible during the action of the machine. I have also constructed large models of the same kind, representing the going part of a clock and the count-wheel striking part.

The above machine is an example of the first method of frame-work, which I have explained in Art. 8. Every model thus constructed has an analogy with a section of the machine made by a draughtsman, or rather with a machine in which, by the common artifice of representation, the front plate or some other part is supposed to be removed, to show the machinery. Fig. 43 may be considered as a drawing of a clock, in which the frame consists as usual of two plates connected by pillars. In such a clock the wheel-work on the left-hand deal post (c) would be contained between the plates, and the detent, rack, and snail would be attached to the outside of the front plate. The draughts-man would describe this drawing as made under the supposition that a part of the left-hand portion of the front plate was removed to show the machinery. In the model, the employment of stud-sockets enables this part of the plate to be dispensed with, without disturbing the arrangement or action of the machine or destroying its identity.

A great number of machines, therefore, in which the framing consists of two parallel and similar frames, connected by transverse pillars or braces, and supporting shafts or other axes, may be modelled under this system without materially altering their general appearance, by making one only of these frames of the same shape as in the original engine, and substituting studs for the axes. The employment of the general system of framing with beds, stools, brackets, &c. necessarily alters the appearance of the machine, and is therefore not to be employed when the actual form and construction of the real machine does not allow of much modification, or is part of the object of the Lecture.

(45.) Fig. 45 is a machine to describe the curves that belong to parallel motions under various proportions of the radius rods and link, and different positions of the describing point upon the latter. I select this as an example of the employment of the stool (fig. 24), the brackets, &c. to the fitting up of a lighter class of mechanism than the cast-iron machinery hitherto described.

A drawing-board inclined forwards, to make it more visible to the audience, is fixed to the stool, as shown. The back edge rests on the frame (fig. 23), which is bolted behind the stool, and it is kept in its place by looped squares (like B, fig. 20), bolted to the front legs,[1] and by a hook-bolt not visible in the figure, which is passed through the slit of the back frame, these fixing pieces being lodged in notches cut in the drawing-board.

The instrument which it is the object of the frame to support requires to be suspended, as it were, over the board, so that its arms may be perfectly free to revolve, and that their action may be as little concealed as possible. A parallel motion (see 'Principles of Mechanism,' page 399, &c.) consists of two radius rods connected by a link: a pencil is attached to this link, and when the rods are made to turn about their fixed centres of motion, the pencil describes a curve, which, under certain proportions between the lengths of the rods, link, &c., possesses the property that a part of its length is so nearly rectilinear, that in practice it may be employed as if it were a true right line. The radius rods of the machine we are considering are made of sheet iron or brass, with a slit towards one end and a rivet-joint at the other, by which they are united to the link: *a b*, *c d* are the radius rods, and *c b e* the link to which they are jointed at *b* and *c*: *e* is the place of the describing point or pencil.

The axis of motion of each rod is provided by taking the tube-fitting of a $\frac{1}{2}$-inch shaft (fig. 29), and turning a piece of hardwood with a shoulder at one end, and of such a length as will just project beyond the tube when it is placed within it. The diameter must just allow it to turn freely and steadily in the tube. It is bored to receive a small bolt with a fly-nut. Let the bolt

[1] One of these is shown in its place at a, but is omitted on the opposite side at c, in order to show the notch in the drawing-board.

be now passed through the slit of the radius rod, and then through the wooden axis just described, placed so that the shoulder may be downwards and in contact with the radius rod. The wooden axis must now be inserted into the tube, and a washer put on the upper end of the bolt, and the whole secured by the fly-nut. The nut will, of course, bind the radius rod fast to its wooden axis, and the length of the rod can be adjusted before the last turn is given, by means of its slit. But as the axis is a little longer than the tube, the washer of the bolt is not pressed upon the tube, and thus the axis is free to turn within the tube, and the radius rod becomes capable of a steady rotation.

A bed 3 feet long is fixed as a bridge over the drawing-board, in the manner shown in the figure. By combining at each end a No. 1 bracket (D) with a No. 3 bracket (E), and bolting the latter to the bed, we obtain the means of inclining this bed so that its lower surface becomes parallel with that of the inclined board. To the lower side of the bed are bolted two No. 3 brackets (F, G), which carry the tube-fittings. Thus the axes of the radius rods are firmly supported, and yet the frame is kept so high and so far backwards as not to conceal the action of the rods and pencil.

I have not thought it worth while to enter into the minutiæ of the construction of the link and pencil carriage, which are so contrived as to allow of ready changes of length and of the position of the pencil. In the positions shown in the figure, the curve, which is usually a distorted figure of eight, has two isolated branches, *m n p* and *q r s*, of which the portions *m n* and *q r* are nearly rectilinear. By gradually altering the proportions of the machine, the curves respectively drawn in each adjustment are seen gradually to approach each other, and finally to unite into the single figure of eight.

Other varieties of the curve, corresponding to different combinations of the parallel motion, are obtained by fixing the pencil to a transverse bar which can be clamped fast to the link, so that the pencil is no longer situated in the right line which passes through the joints of the link. Thus we get curves that belong to such arrangements as that given at page 411 of my 'Principles of Mechanism.'

In this apparatus, the only peculiar parts are the radius rods and link, with the wooden axes that turn in the tube-fittings: the whole of the frame is built from the parts of the general system.

In a similar manner may be mounted the machine termed a 'geometrical pen,' or 'Suardi's pen,' which I have constructed with *sixteen-pitch wheels*, for showing to an audience the mechanical description of epicycloids and hypocycloids on a large scale.

(46.) Fig. 47 represents an arrangement for the exhibition or trial of various regulators for mechanism moved by weight.

The regulator, which is shown in operation, is of the class usually employed for the clock-work which is attached to equatorial telescopes, and is similar in its mode of action to that description of these regulators which was first introduced by Mr. Sheepshanks,[1] but differs in the manner of carrying out the principle, which I have endeavoured to simplify as much as possible.

As my purpose in giving these examples is not so much to describe peculiar contrivances as to illustrate the method of building up frame-work and machinery out of the parts of my general system, I shall very briefly describe this revolving regulator, which is, in the present example, the only *peculiar part* required.

A vertical spindle A is supported below by a centre-point screwed to a No. 6 bracket (B); the upper end of the spindle is guided in its revolutions by a *tube-fitting* carried by a bar of wood C D, which is bolted to a pillar formed of two *rectangles*: the bracket and the lower rectangle are bolted to the *stool* as shown in the drawing.

The spindle has a small bar *m* pinned to it near its upper end, and a longer bar of wood *p q*, pinned to it below. The upper bar serves to suspend the pendulum rod *k q*, which, as the figure shows, terminates upwards in a fork which embraces the bar, and is pierced so as to swing on a steel wire fixed to the bar. The lower end of the rod carries a heavy ball, and rests, when the machine stands still, against one end of the lower bar at *q*: the other end (*p*) of this bar carries a similar ball to counterpoise that of the pendulum rod. The details of the upper part of the spindle are best seen in fig. 50, where they are exhibited on a larger scale.

Between the upper short bar *f*, fig. 50, and the tube-fitting *c d*, there is a metal collar *e*, upon the spindle, which can travel freely upon it vertically, but is compelled to revolve with it by its connexion with a lever *f g*, the fulcrum of which is carried by the end of the bar at *f*. This lever expands into a loop which presses against the collar at two opposite points, and beyond it terminates in a single arm *e g*, which rests upon a short branch *h*, projecting from the pendulum rod just below its fork.

When the spindle revolves, and its speed is accelerated, the ball and rod are carried outwards by the centrifugal force, and the branch (*h*) thus raising the long arm (*g*) of the lever, the collar (*e*) is pressed upwards against the lower surface of the tube *c*: thus a friction is produced which retards the spindle, and prevents its velocity from increasing.

To the lower part of the spindle, beneath the long bar *p q*, fig. 47, is screwed an *adapter*, which carries a small wooden pulley, and a larger cast-iron one, E; the former to receive the band which sets the spindle in motion, the latter to act as a

[1] See a Paper on these Regulators by the Astronomer Royal, Mem. Astron. Soc. vol. xi. p. 251.

fly-wheel. The spindle, with its bars, balls, pendulum rod, lever, &c. are *peculiar parts*, and are therefore not taken to pieces; the *adapter*, &c. are *general parts*, applied for the occasion only.

To keep this spindle in motion, and thus to exhibit its action, the following mechanism is built up. A *two-feet bed* (F) is bolted to the opposite side of the stool to that which supports the pendulum frame; upon it two No. 1 brackets (O, H), with tube-fittings, carry a ⅞-shaft (T) 18 inches long: upon this shaft will be perceived a drum Q (of wood), a ratchet-wheel, and a large iron band-wheel, 14 inches diameter. The wooden drum is fixed fast to the shaft by an adapter; the ratchet and wheel are mounted on a second adapter, which is left loose on the shaft; but a click is fixed to the side of the drum, which engages the teeth of the ratchet.

A high post (10 or 12 feet high) is secured to the stool by a bolt, the head of which is seen below at K, and by a *hook-bolt* (shown separate at fig. 48),[1] which engages the lower side of the upper rail of the stool (behind L). To the upper end of this post is fixed a No. 3 bracket (M), carrying a *guide-pulley* N, and a loop O (like B, fig. 22), to which the end of a cord is tied: this cord passes (as shown in the figure) downwards and over a pulley P, to which a weight is suspended, then upwards and over the guide-pulley N, thence downwards to the drum Q. As the drum is fixed to the shaft, a handle (fig. 34), applied to either free extremity of it, will wind up the weight, which in its descent gives motion to the revolving pendulum by means of an endless band from the large wheel. This band passes over a guide-pulley R, similar to fig. 38, Plate II.

To receive this pulley and other mechanism, a 3-feet bed (S) is bolted against the front legs of the stool.

It may be required to exhibit the action of other regulators,—flys, for example, like fig. 44, or with longer arms and surfaces capable of being set at different angles.

For this purpose a No. 6 bracket may be bolted at the back of the bed S, into which bracket the stud of the fly may be screwed, which will thus project horizontally forward. A pulley must be used instead of the pinion *d* (of fig. 44), and a band provided of proper length to suit the great wheel.

The fly may be taken off its stud and laid by, so as not to interfere with the action of the pendulum, and the bracket must be fixed in such a position that its

[1] The upright branch of the hook-bolt is placed in the slit of the top rail of the stool, and the tapped end passed through the post, and the nut secured. Thus the post is firmly fixed against the inside of the top rail. The crooked form of the shank is adopted to give a firm central bearing to the upright branch; but in some relative positions of the post and stool (as, for example, when the post is to be bolted against the outside of the leg AB, fig. 24, the hook being inserted in the vertical slit of the leg), this bent form is inadmissible, and the straight hook, fig. 49, must be used.

stud may not interfere with the band of the pendulum. When the latter has been exhibited and explained, the fly can be readily put into gear. I mention these details by way of showing the advantage of the stud-socket system in readily allowing the parts of machinery to be dismounted or replaced before an audience, by which the explanations and arrangements of a Lecture are greatly facilitated.

If it be desired to prolong the motion of the machine, an additional axis may be introduced into the train by bolting a No. 6 bracket with a stud-socket at the back of S. A toothed-wheel must be placed upon the adapter which carries the ratchet, instead of the band-wheel, and the band-wheel must be transferred to the stud-socket, which must also carry a pinion to gear with the toothed-wheel. The bracket may be either fixed between H and B, or on the prolongation of the bed S, at its left-hand extremity beyond H; and if more room is wanted, a 4-feet bed must be substituted for the 3-feet bed S.

(47.) Fig. 46 is a machine to elucidate the laws of friction.

The frame of this machine is built up of four beds, bolted to each other as already explained above (Art. 16). A ⅞-shaft, 18 inches long, having a handle (K) screwed to one end of it, is mounted in a pair of tube-fittings carried by No. 3 brackets, one of which only is seen in the drawing. To this shaft a cylinder of hardwood (A) is fixed, in the manner already explained (Art. 29), by means of pinned shaft-rings. The cylinder is 6 inches in diameter and in length, and is turned very true and smooth.

Above this cylinder is seen a smaller one, B (4 inches diameter and 4½ long); this revolves upon the points of a pair of steel centre-screws, inserted into the ends of an iron frame, which itself swings upon another pair of steel centre-screws inserted in the heads of the two No. 1 brackets (C, D), which are bolted at the remote ends of the wooden frame: a transverse board is fixed to the iron frame, upon which a 7 ℔. weight is resting in the drawing.

A bar of wood (E) is placed between the two cylinders: this bar, 2 feet long and 3 inches broad, is made flat on its lower surface, but the edges of the upper surface are chamfered off so as to leave only a narrow fillet. The bar rests upon the lower cylinder, and is pressed into contact with it by the weight of the iron frame and upper cylinder, assisted by the 7 ℔. weight. The upper cylinder being, as before stated, mounted in a swing-frame, is at liberty to press upon the bar. The far end of the bar rests upon a roller F, the stud of which is carried by a No. 3 bracket, bolted to the bed between those which carry the centre of the swing-frame and the tube-fitting of the shaft of the great cylinder. The bracket in question is, however, raised to the requisite height by a *sole-block* (Art. 13).

One of the beds of the frame is longer than the other, to enable it to support a Marriott's Spring Dynamometer (G): the latter is furnished with a larger dial-plate than usual (1 foot in diameter), and will indicate pressures up to 25 lbs. This dynamometer has a bolt at the back, by which it can be attached to any frame (it being a very useful piece of apparatus for various purposes). In the present machine the bolt attaches it to a No. 2 bracket, bolted to the projecting end of the long bed: the sole of this bracket is just visible in the drawing behind the dial; the bar of wood is linked to the dynamometer.

The action of the machine is as follows: the pressure exerted by the upper cylinder and swingframe on the bar, without the 7 lb. weight, but estimated at the point where the centre of that weight is to be placed, is 7 lbs.; consequently the addition of one or more 7 lb. weights enables us to double or triple the pressure.[1]

If the handle be turned, the bar E is drawn between the cylinders, extending the dynamometer spring as it goes until the resistance of this spring becomes so great as to balance the friction of the bar upon the lower cylinder. At this point the bar stops, and the cylinder may be turned, without otherwise disturbing the index than by the slight variations of friction at one part or other of the circumference of the cylinder. The weight indicated by the index is plainly the measure of the friction of the materials of which the lower cylinder and bar are made, under the pressure exerted by the swing-frame and upper cylinder. Accordingly, when no additional weight is put on, the index stands at about $1\frac{1}{2}$ lb. The addition of 7 lbs., as in the drawing, raises the index to 3 lbs.; of 14 lbs. to $4\frac{1}{2}$, and so on; thus exemplifying the law of friction which declares it to be proportional to the pressure.

But it will be found, under any of these pressures, that the index remains stationary at its proper point, whether the cylinder be turned slowly or rapidly; that is, that the amount of friction is unaffected by the velocity with which the rubbing surfaces move in contact. Thus another law of friction is shown, which it is impossible to exhibit to an audience in the usual manner in which experiments have been made to examine it.[2]

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[1] This pressure can be easily and conveniently measured, and shown to an audience by attaching the hook of a portable spring dynamometer to the swing-frame, and raising the latter thereby.

[2] The law is usually experimented on by observing the motion of a sledge along a long horizontal bar, for the purpose of ascertaining whether or no its motion be uniformly accelerated,—a result which can only be accurately attained by a strictly level bar, and an apparatus constructed in a solid and exact manner wholly incompatible with the arrangements of a Lecture-Room, to say nothing of the care required in observing the law of motion of the sledge.

In accurately determining the pressures of the above apparatus, the friction of the upper cylinder

Lastly, if the bar be reversed so as to place the narrow fillet in contact with the lower cylinder instead of the broad lower surface, the friction under each pressure will be found to remain the same as before. Thus the remaining law of friction is exemplified, namely, that it is independent of the quantity of surface in contact.

By this apparatus, therefore, the three principal laws may be rapidly exemplified.

(48.) Many machines occur so peculiar in forms and arrangements as not to admit of or require the employment of the stud-sockets, frames, or other parts of the general system, but in which the general principles above explained may still be brought into play; namely, of so modifying the frames and relative scale of the parts, simplifying their forms, and separating them, as to make every part and action of the machine, as far as possible, visible at once. The sectional models of steam engines which are now so generally employed may be quoted as examples; but I have applied the same principles to the construction of many other machines, of which I will mention only two or three in illustration of the manner in which I conceive Lectures on Mechanism should be illustrated.

(49.) *A loom* with four treadles and corresponding parts is built upon a single light frame (4 feet long and 5 feet 6 inches high): the rollers, or *beams*, as they are termed, are of mahogany (9 inches long and 3 inches diameter), and turn on stout studs fixed 2 feet 9 inches from the ground: the warp (5 inches broad) is formed of 40 threads of stout white round bobbin, so as to be visible at a distance; the *heddles* are formed of *brass wire*, with a hole drilled in the middle of each wire, and the *treadles* with their levers and apparatus mounted on a cross frame, so arranged as to interfere in the least possible manner with the view of their action. The *lay* consists of a single bar swinging on a stud at the top, and having a rail projecting at right angles at the bottom, to carry the *reed*, &c. In lieu of a shuttle I employ a wooden needle, like that used for netting. This machine enables me to exhibit the first principles of weaving, tweeling, diapering, &c. None of its parts are applicable to general

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on its pivots, and its rolling friction on the bar, must be taken into account; but these are so small as not to affect the result sensibly.

The rubbing friction shown by this engine is not that of two plane surfaces, but that of a plane rubbing tangentially upon a cylinder, the contact taking place along a *line* instead of a *plane*. But these frictions follow the same law, as is indeed evident, seeing that the amount of rubbing friction is unaffected by the extent of surface in contact under a given pressure, and is therefore the same whether it be a plane or a line. Plane surfaces might be exhibited in frictional contact by means of a revolving horizontal disk of wood, upon which a small plane surface, loaded with weights and supported by a radial bar, swinging round the vertical axis of the disk, might rest, the surface being linked to a dynamometer.

purposes, and it therefore remains undisturbed from one Course of Lectures to another. It may be considered as an example of the kind of models described at the end of Art. 44, in which the general appearance of the original is not materially interfered with. I have constructed a large similar model of the Jacquard loom, the whole mounted upon the stud principle, and the parts of the Jacquard apparatus on a highly magnified scale, with a group of few wires, so as to make the action of the successive cards perfectly visible.[1] To this also belongs a model of the machine used for piercing the cards, and several others.

(50.) For rope-making I have also made models of the registering machine and laying machine, in which the frame-work is constructed in skeleton, and the machinery mounted, as far as practicable, on the stud system, so as to make the entire action of these complex and beautiful contrivances visible.[2] These models, although constructed with the same kind of cast-iron wheels that are employed in the general system, are so complicated and peculiar that it would be absurd to take out the wheels for other purposes. The strands are formed of soft worsted, and each of a different colour, to make their progress through the mechanism more visible, while the material opposes little resistance to the skeleton frame-work. The result, therefore, resembles a bell-rope about half an inch in diameter. The actual machines must be seen for themselves, and will be easily intelligible after a sight of the dissected models, the object of which is to exhibit the principles and action of the mechanism.

(51.) Lastly, I may mention a large sectional model of a complete organ, with three rows of keys, pedals, and all the usual stops,[3] together with the whole of the usual couplings and combination pedal-work. The system upon which this is contrived is the following: The model includes two keys and two pedals, and may be supposed to be a slice taken out of the heart of the machine by two parallel planes, the distance of which is sufficient to include the two keys and all that belongs to them. It is true that it seldom happens that all the appendages in question really lie in the same vertical plane, but they may be brought into that relative position, and in the present case are supposed to be, exactly as they would be in a section of the instrument made by a mechanical draughtsman. In

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[1] This model is 8 feet 9 inches high from the ground: the prism of the Jacquard apparatus is 5 inches square and 8 inches projection, and each face has four rows only of large holes, six in a row. Four in a row would be sufficient.

[2] The whole of the machinery for rope-making is described, with many plates, in the 'Professional Papers of the Royal Engineers,' vol. v.

[3] Including eleven stops for the great organ, and seven each for choir and swell; the latter having a proper swell-box with shutters.

fact, the model is an acting section on the full scale: but of these two keys, &c., the front one of each key-board has its pipes made of wood painted and represented in section; the wind-channels, pallets, and all other matters also in section where required, and thus serving to show how the depression of the central key draws down the pallet of the great organ wind-chest,—how the wind-passage, thus opened, may be made to communicate with the pipes of one stop or other, by drawing the stop-sliders,—how the other key-boards and pallets are connected, and how they may all be linked and combined at pleasure by the couplings, levers, &c., all of which are mounted on studs; and lastly, how the draw-stops may be grouped by the combination pedals.

But the back key of each key-board acts upon a real pallet, in a proper wind-channel supplied by real bellows, and the pipes of this hinder system are the actual pipes that would be employed in such an organ, including a complete set of one of each stop of Great, Choir, and Swell organ for middle c, together with a great pedal-pipe. The wind-channels and pallets of this real system lie exactly behind their sectional representations, and their levers, couplings, &c. are of course mounted on the same studs and standards as those of the front keys.

Thus the front keys show the visible action of the machine,—the hind keys, the audible action; the front pipes exhibit the interior form and sections of the different stops,—the hinder pipes produce their real sounds.

To separate more distinctly the interwoven mechanism of the three key-boards and the pedals, different colours are employed.[1] The cut parts and connecting links of the great organ are painted bluei; of the choir, yellow; of the swell, red; and of the pedal, green.

By this machine, which is, when mounted for exhibition, very large (13 feet long and 8 feet 6 inches high), I am enabled to explain this most curious instrument mechanically and acoustically; to show the qualities of the different stops, their harmonic relations, their combinations, and the use and arrangement of every part of the instrument.

A single-key system might be used, in which the wind-channels might be faced with glass, to show the motion of the pallets; but this is not so perfect a representation of their action and of the distribution of the condensed air as by the double system I have adopted. In all models of the kind above described, the acting parts should be, where practicable, made exactly as if for

[1] This plan is useful in many cases; for example, in a large sectional steam engine I have painted all that belongs to the steam, grey; to the condenser, yellow; to the warm water, blue; and to the cold water, green.

real use. Thus the set of pipes were made for me by Gray, and my audience are thereby assured that their forms and voicing are genuine. So also real shuttles, spindles, reeds, &c. should be obtained from the proper makers, in illustration of the processes to which they belong, as well as specimens of the products in various stages of preparation and of the raw materials.

(52.) The third application of the system is to the construction and arrangement of apparatus for elucidating the principles of Statics, Dynamics, or other branches of Natural and Experimental Philosophy. For this subject a great quantity of apparatus exists ready-made in the shops of the mathematical instrument makers, the accumulation of many centuries' work of contriving philosophers. But by the application of the system described above, I am enabled greatly to reduce the stowage space required for such apparatus, principally by dispensing with the frame-work, which, in the common forms, is usually made expressly for each machine. On the contrary, by building up frames for this purpose, I am enabled to display such combinations on a much larger scale than usual, and of course in greater number and variety. In apparatus of this class, however, the peculiar moving parts require to be made light, and with as little friction as possible; and the framework often requires posts and gallows-frames, as for suspending pulley systems, collision balls, strings with weights, often led over pulleys in different directions, and so on. The guide-pulleys which I use for machinery are too coarse for this purpose, and I therefore employ pulleys of the form represented in fig. 31. This pulley, of brass (made under my directions by Watkins and Hill), is $2\frac{1}{2}$ inches diameter, $\frac{1}{4}$ inch thick, as light as possible, and running with very little friction on a small steel pivot-screw, and is mounted in a brass frame provided at the back with a clamp-screw, the opening of which is sufficient to enable it to grasp a piece of frame-work a full inch thick. The posts and beds already described being too clumsy for this class of apparatus, lighter supports for the pulleys and strings are provided, one of which is shown in fig. 28, which consists of a bar of wood 1 inch thick and 2 inches wide, attached to a block similar in form and dimensions to the sole of the cast-iron brackets. Supposing this sole to be horizontal, the flat sides of the bar are vertical; but it is inclined slightly, as shown in the figure, so that when a weight is suspended from one of the pulleys, which may be clamped to any part of it, this weight may hang freely downwards.[1]

[1] The weights used with this class of apparatus for statical experiments are usually cylindrical, and rarely greater than 24 oz., which are nearly 2 inches in diameter. A silk line passed over the pulley in the drawing stands only half an inch from the surface of the post to which the clamp is fixed, and therefore, without inclining the post in the manner shown, the large weights would not hang free. The clamp might be crooked so as to throw the pulley at a greater distance from the post, but its form is then more clumsy. I have several pulleys of this kind, in which, instead of the clamp behind, a

This machine I term a *pulley-post,* and I have some inclined to the right, and some to the left, and others perfectly vertical. They are employed by being bolted to the beds, rectangles, or stools of the usual frame-work, which, as it will easily be seen, enables frames to be mounted so as to convey strings, weights, &c. in any of the varied directions required for apparatus to elucidate the laws of statics, the mechanical powers, &c. For the latter purpose they merely require the addition of an inclined plane, a wedge, &c., which being bolted to the same frames, the pulley-posts must be adjusted upon these frames so as to place the pulleys in proper relative positions.

Fig. 27 is an example of a frame convenient for suspending various pieces of light apparatus. This consists of two *iron rectangles*, connected and kept at the proper distance asunder by a *bed* 4 feet long, or more, if necessary. The uprights and transverse piece are made lighter; they each consist of two bars of wood (see Art. 32), screwed together with two blocks between in the form of a light *bed,* so as to leave a slit for a small bolt with a fly-nut. Such bolts are sufficiently strong for this class of apparatus, and are employed to connect the horizontal and vertical bars of the frame, and also to connect the latter with the rectangles below. Many other combinations will, of course, readily suggest themselves to any experienced Lecturer.

(53.) In contriving apparatus, I have had frequent occasion to employ paste-board where lightness and stiffness are required, and especially where it is necessary to combine diagrams, coloured figures, and letters of reference, or any kind of drawing or writing, with the moving parts of the mechanism. The paste-board should be of the stout kind which is termed sixteen-sheet paste-board (a full $\frac{1}{16}''$ in thickness and 24″ × 19″ surface), and is covered on each face with a white, or rather light grey, smooth paper which will take ink and even water-colour, so as to admit of diagrams being drawn upon it, or letters of reference.[1] The thickness makes it unmanageable with scissors or knives, but it can be readily cut with a small pair of tinman's shears, mounted in the manner described in the next Article, and mortises or apertures can be cut through it easily with joiners' chisels or gouges and a mallet, or with gun-punches. Its thickness enables it to be used for small tablets upon which to fix light specimens of seeds or other small objects of natural history, or impressions of seals, &c. in the drawers of a cabinet. When used in combination

stem is fixed, which is tapped with a strong screw, and has a nut. Thus the pulley-frame can be fixed in a bracket-head, or carried by one of the loops, fig. 22. But the clamp-pulley will also grasp the bracket-heads and loops, and will answer the same purpose.

[1] I have always procured this material of Messrs. Wilson, Richard, and Co., 26, St. Martin's Court, Leicester Square. For finer work, the thickest Bristol-board may be substituted, as its colour and surface enable any kind of graduations or colours to be applied to it.

with the other mechanism described in the foregoing pages, as for dial-plates, scales, or diagrams, the pieces of paste-board may be fixed to the frames by small bolts or clamps uniting them to the iron loops (fig. 22), or to the pulley-posts (fig. 28), or in any similar manner, as the case in question may require; and if the pieces of paste-board are to revolve, they may be mounted upon the smaller stud-sockets, adapters, or other contrivances.

But paste-boards may be combined in the form of various solids, exceedingly convenient for the illustration of many subjects, and the parts of these solids so connected that the component pieces may be separated and laid flat, thus allowing them to be kept in portfolios. Thus models may be built up, representing complex architectural structures in section and elevation, combined with the plan; also, solids bounded by vertical planes, and showing the relations of strata for geological purposes, the dispositions of mines, the arrangement of complex frame-work, and a variety of other cases in which drawing can be combined with solid representation. If much drawing and bright colours are required, I usually employ stout Bristol-board in combination with the paste-board, and my general method is to draw the plan of the structure in question, be it a building, a section of ground, or a frame, upon one or more sheets of the paste-board, which are then united together, and at the same time raised an inch and a half above the table by being secured to a pair of wooden bars[1] by small bolts with thumb-nuts. Usually a part only of the object to be shown is given in solid, and the rest in plan; as, for example, when a building is explained by making a transverse section and supposing one half to be removed. The half-plan that is exposed is carefully delineated; the solid part of the building constructed of vertical sheets of Bristol-board, with proper pieces for the roof, as the case may be; long narrow mortises are cut through the base-board, and the vertical pieces are provided with corresponding tenons, which are passed through and secured each with a pin beneath.[2] The edges of these pieces are either connected in the same way, or, if possible, merely hinged in the common manner by cutting the

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[1] The bolts are $\frac{1}{16}$ inch diameter, and have thin square heads, $\frac{5}{8}$ inch square. The bars are an inch and a half high and an inch and a quarter broad, and have a flat shallow groove sunk along their lower surface, $\frac{5}{8}$ inch wide, which receives the heads of the bolts and prevents them from twisting. Holes are bored through the bars at regular intervals of 4 inches, and of these bars there are provided several pairs of five different lengths, from 2 feet to 5 feet. Two bars serve for each paste-board plan, and they may be set at the distance required by the nature of each model, and the holes for the bolts punched through the paste-boards accordingly. Some models require no such foundation, as they may be hinged to a flat base, and turned up like a box, or be supported in other ways that will readily occur.

[2] The base-boards are raised above the table, to allow of these tenons being passed through the mortises.

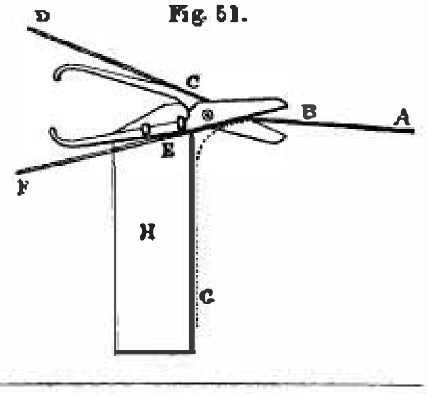
Bristol-board half through, or by pasting cloth slips along the joints, so as to allow the model to be unfolded and laid flat when out of use. A solid being thus built up in the form of the block of the building, the details of the sectional sides and of the elevations can be supplied by drawing; and thus we obtain a model which shows the relation of the several parts of the structure to each other and to the plan. Shifting pieces may be employed to show varieties, or to assist in the dissection of the structure.

A simple parallelopipedon put together in this manner[1] may be supposed to represent a block cut out of the ground by four vertical planes, its upper surface being the surface of the ground (and therefore inclined, if necessary). By proper painting of the four sides we convert it into a geological model to show the intricacies of strata, or into the model of a mine to illustrate the shafts and galleries, in which case the raised part of the model should be combined with a portion of the plan, as in the manner described above for a building.

The paste-boards may be sometimes united by means of little hook-bolts made of brass wire with nuts, instead of the mortises and pins. The nuts may be made like those used by piano-forte makers and organ builders. These are of thick sole-leather, cut out by a centre-bit, of which the chisel part has been filed away. With such a bit, the little roundels may be cut out of a sheet of leather with great rapidity. The centre-pin of the bit must be a little reduced and sharpened, and the hole which it makes serves for the wire. The wire must be tapped with a coarse sharp thread, and will cut its own way into the nut. These hooks save the trouble of cutting the mortises and tenons, as each hook requires only a hole in each of the two pieces which it serves to join. Many other modes of connexion will occur, which I will not weary my reader by detailing.

(54.) The shears will be much more manageable if mounted in the way represented in fig. 51. This shows a pair of hand-shears, as they are termed, one foot long: such shears are usually fixed in a vice when wanted. Now, from the nature of this implement, any thin material, as A B, submitted to its action, is, as fast as it is cut, slightly diverted from its course. The half which is on the remote side of the figure is turned upwards in the direction C D, and the

Fig. 51.



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[1] Many of my readers may recollect the models of this kind which served for the illustration of my Lectures on Ecclesiastical Architecture, at the Royal Institution, Albemarle Street, in 1846 and 1847.

nearest half downwards in the direction E F. If the shears are fixed in a vice, this lower half encounters the upright side of the vice, and is turned abruptly downwards into the course indicated by the dotted line B G. This bruises the paste-board, and soils it so as to make it useless, so that card-makers usually employ shears the blades of which are long enough to extend completely over the sheet. But this effect may be got rid of by fixing the shears as shown in the figure. A wooden bar (H) is provided, about 1 foot long, 4 inches wide, and 1 inch thick, which may be fixed in a vice, or to the side of a table, or even held between the knees. The fixed leg of the shears is clamped against the upper part of the bar by two hook-bolts, the nuts of which are on the remote side, and a shallow groove is sunk in the face of the bar, to receive the leg and keep it steady. Thus the shears can be readily removed when their edges require grinding. As by this disposition the face (H) of the bar lies a little behind the vertical plane which passes through the edges of the shears, it is plain that the lower half (E F) of the separated material no longer encounters any obstacle, and is at liberty to travel onwards in the direction E P, which it receives from the shears. The upper half glides over the hand of the operator.[1] With this arrangement a pair of shears the blade of which is but 3 inches long will readily cut a sheet of paste-board or mill-board 2 feet or more in length.

(55.) Fourthly and lastly, I have often applied the parts of my system to the construction or trial of new mechanical combinations, or of apparatus required for original research. It will easily be seen that the revolving contrivances described above are only necessary in such cases as may require machinery; whereas the system of frame-work is very generally applicable to philosophical apparatus in which mechanism often forms no part, and in which the principal portions must be of peculiar forms, but require solid frame-work to keep them in their relative positions.

Every experimental philosopher must have experienced the vexation of delays in his researches occasioned by the difficulty of getting apparatus made for trials, and of altering it when trial has suggested change and improvements. To obviate this impediment to research, apparatus should be designed in the most general manner possible; the parts that require peculiar forms be brought within the narrowest limits; the connexions and frame-work made by pieces that will serve for various purposes, and which may therefore be provided be-

[1] If used for tin plate, it would probably cut the hand instead of gliding. This may be obviated by fixing a transverse handle to the shears, either horizontally or vertically.

fore-hand, and kept ready for use. Those parts that require good workmanship should be carefully distinguished from those that do not, and may therefore be constructed by an inferior and less expensive class of workmen; and although in this manner the resulting machine will often turn out somewhat clumsy, at least this advantage is secured,—that if it prove successful, small changes may be made and tried, and finally a complete and especial frame may be, if necessary, designed with confidence after experience has shown what is really required. On the other hand, if unsuccessful, the parts will mostly be ready to be employed again for other purposes.

The system which I have endeavoured to explain in the preceding pages offers many examples of such constructions and of universal methods of uniting and generalizing the forms of framing, and of various parts of apparatus. It would occupy too much space were I to pursue the subject by describing at length other machines which I have from time to time constructed, in which the same general principles have been kept in view.

In the present work I have confined myself to those details which I have found of the most universal application; and I trust that it will be of service by furnishing suggestions for the improvement of Mechanical Apparatus, and thus facilitating the important researches that depend thereon, and contributing to further the great work of Education by supplying new implements of instruction.

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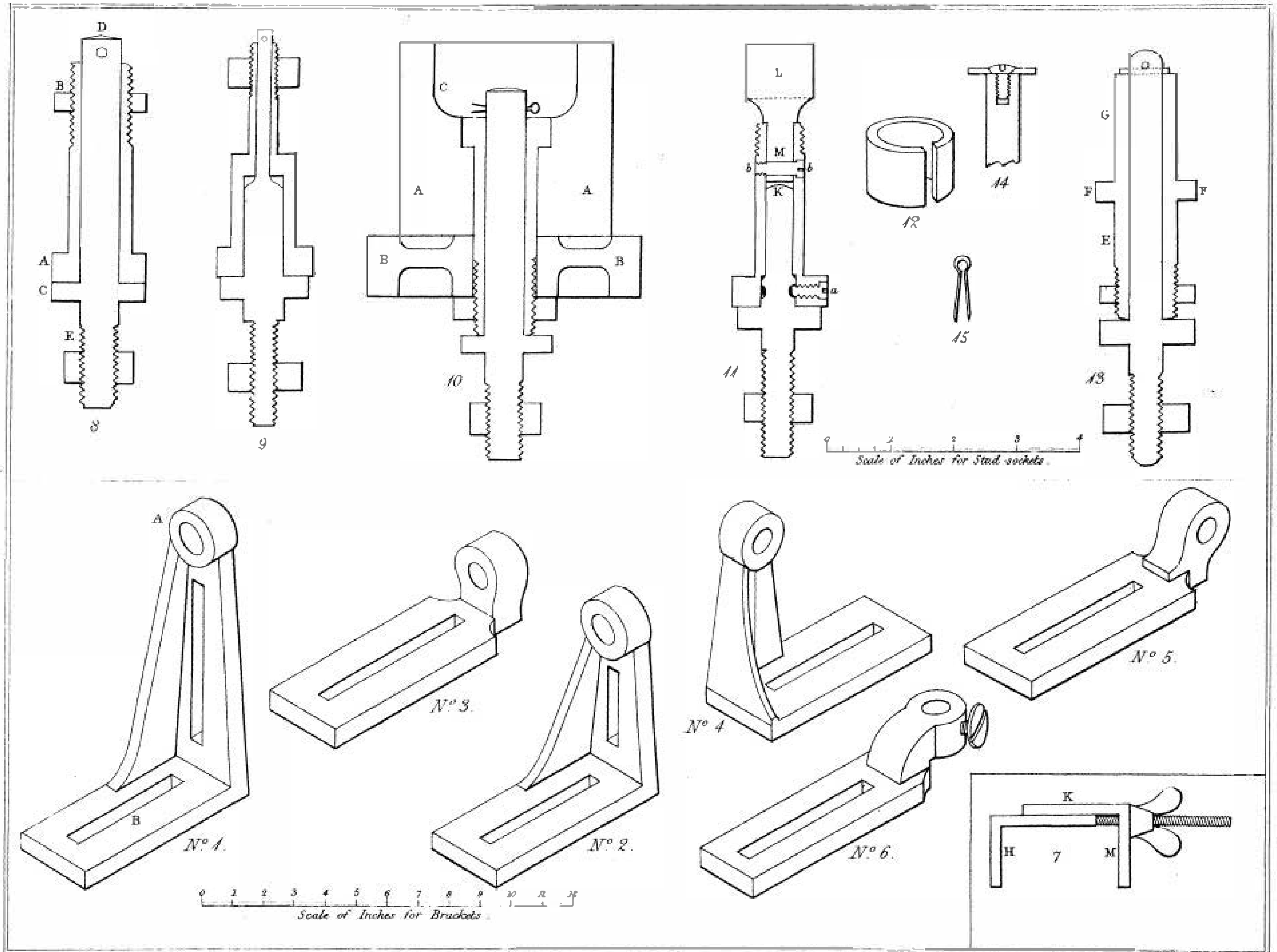

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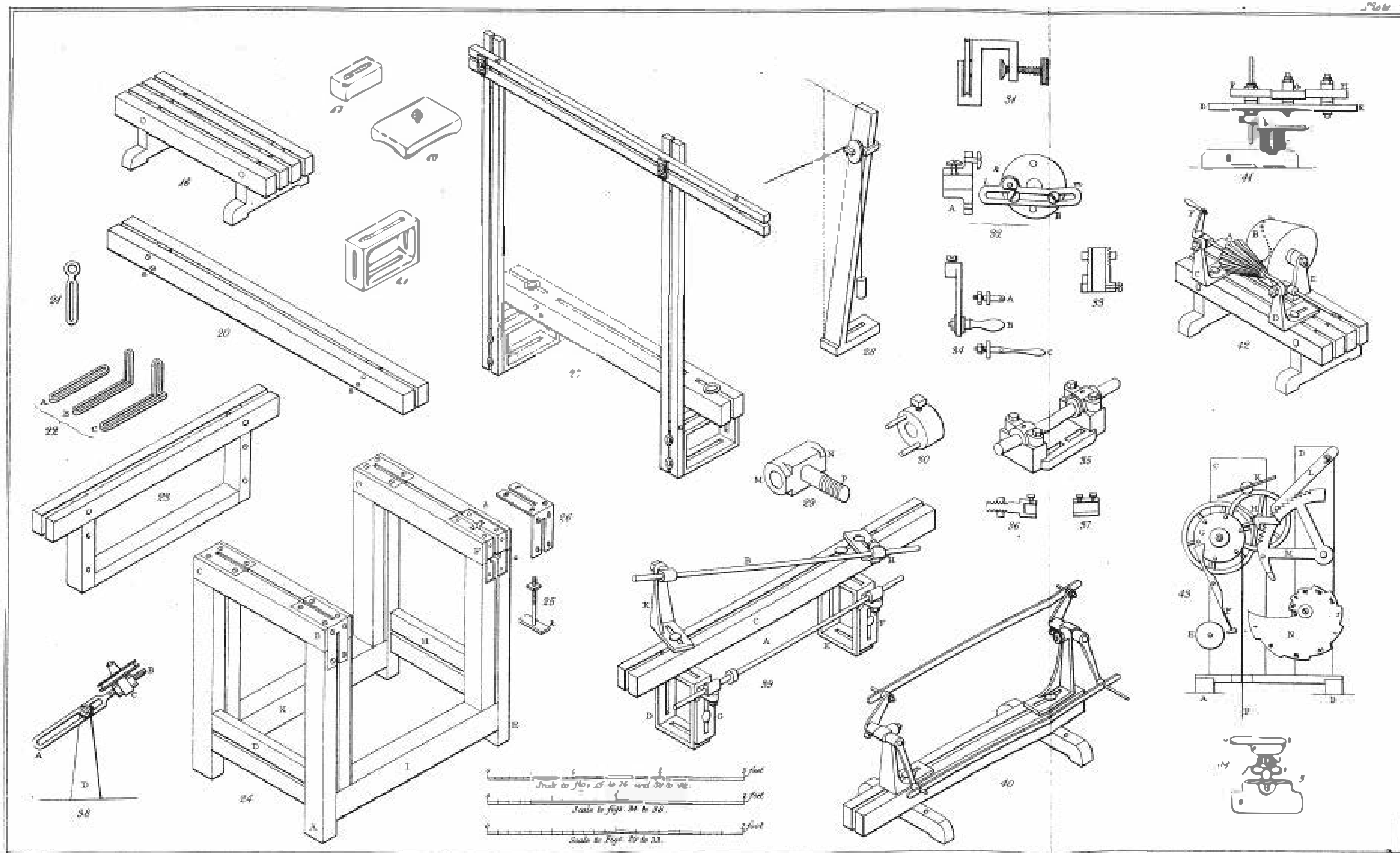
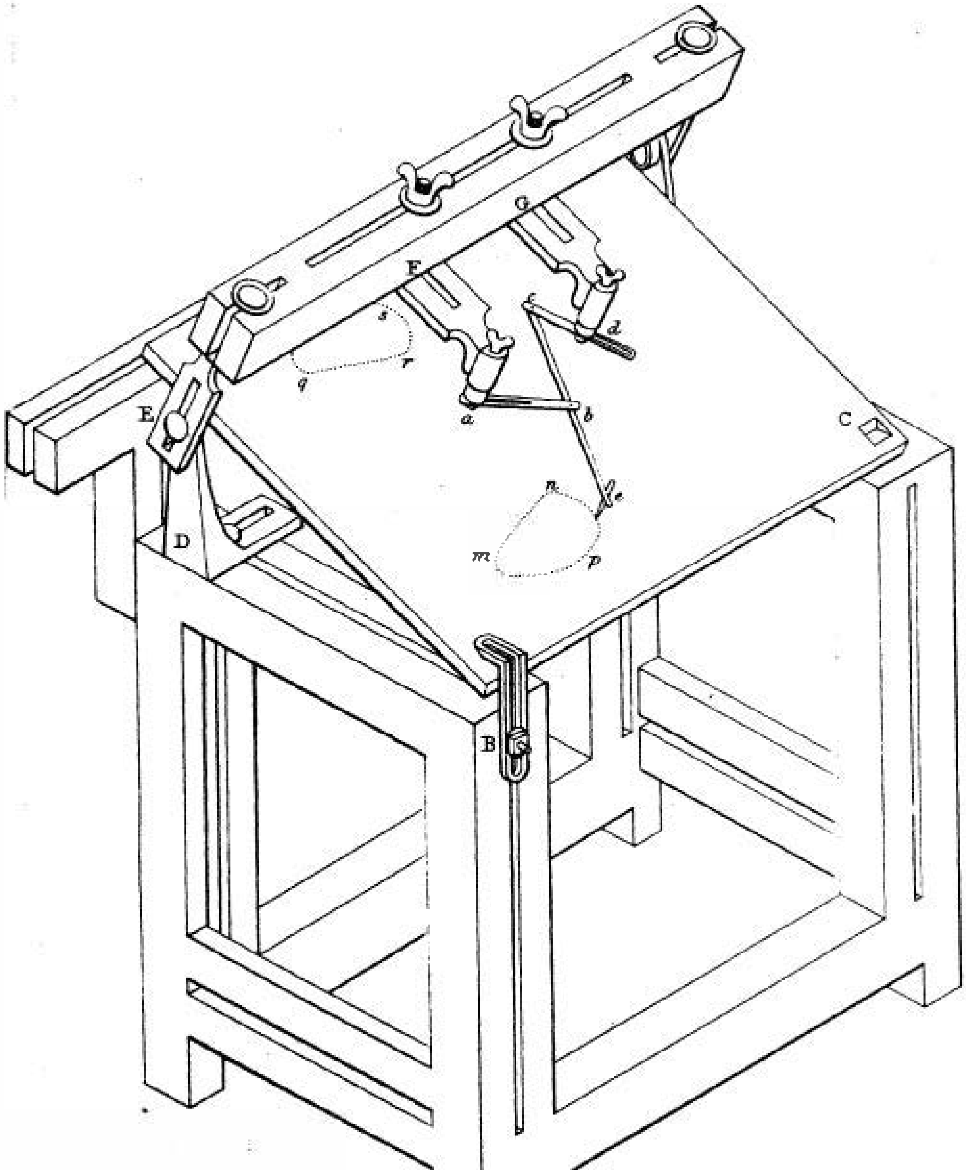


Scale to figs. 34 to 38.
Scale to Figs. 29 to 33.



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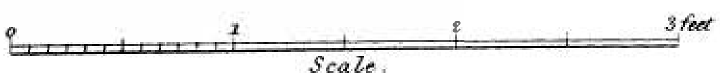

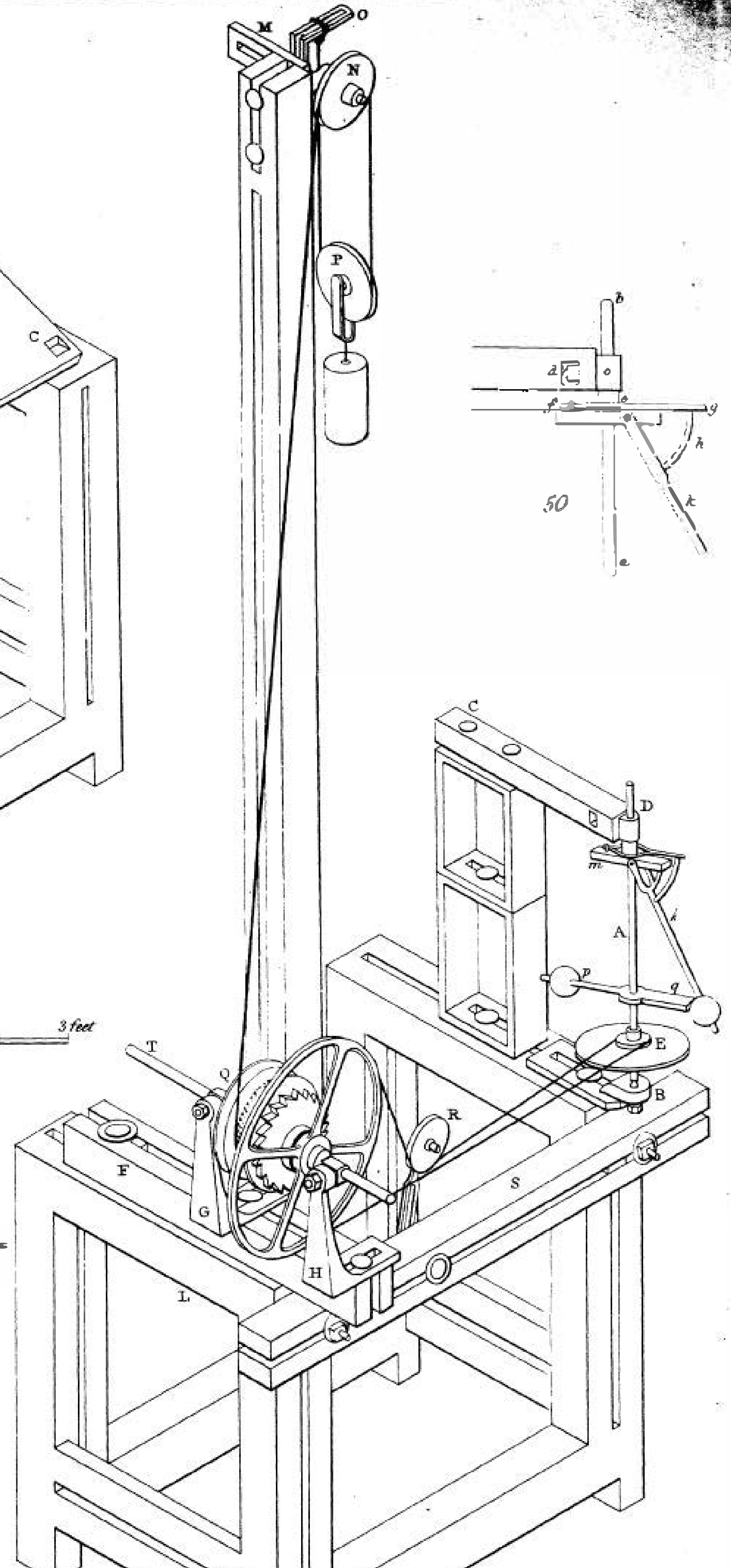

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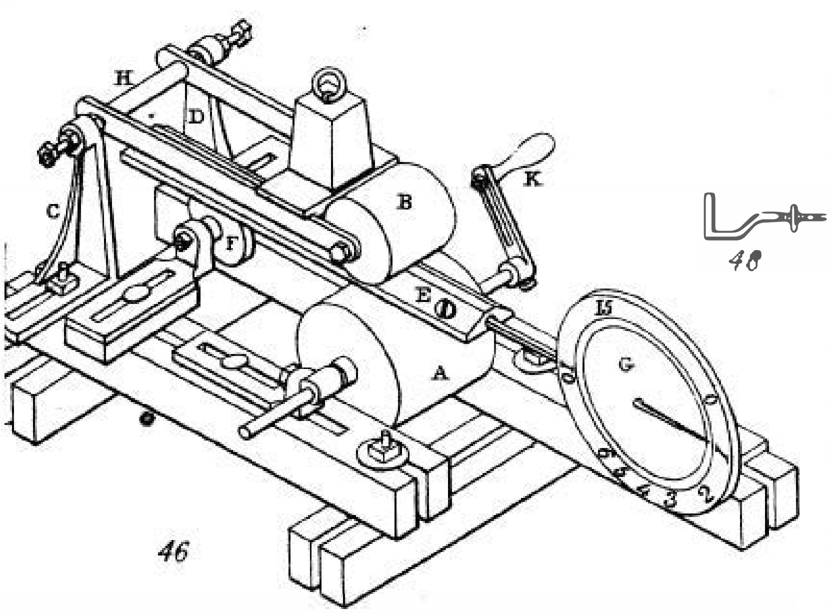

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