X. *On Polishing the Specula of Reflecting Telescopes.*

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During my sojourn in Malta (1861 to 1864) I made many experiments in repolishing my four-foot mirrors, with a view to the obtaining, if possible, further excellence in figure and polish. To obtain perfection in both these qualities, or so near an approach to it that no fault is discoverable in a four-foot surface, is not easy, at least I have not found it so.

Errors of figure may be of various kinds. A surface may be so near to the true parabolic curve that the central and circumferential rays may come to the same focus; but the intermediate rays, those halfway between the centre and circumference, may have a different focus. If this error be considerable, and the telescope be turned to an object requiring fine definition, the effect is most annoying. A first glimpse may lead you to expect you are coming to a very sharp image; but just as the image ought to be formed in perfection, the outstanding intermediate rays introduce confusion, and after several vain attempts to improve the focus you retire in disgust. This irregularity of curve I consider to be the most vexatious fault a mirror can have. A deviation from the parabola at the circumference of the mirror, whether the deviation be within or beyond the parabola, is far more tolerable, if it be in a regular progress from the centre to the circumference. Indeed a figure which deviates sensibly, but moderately, towards the edge, whether within or beyond the parabola, may give very tolerable vision, if the curve deviate from the parabola only in regular proportion from the centre outwards. There is another error which is of less consequence, but still desirable to be got rid of, as it practically reduces the available aperture of the mirror, and consequently the size of the telescope. The *figure* may be sensibly parabolic up to near the margin of the mirror, where it rapidly falls off and becomes grossly hyperbolic. Probably this may arise from some different action of the polisher upon those parts of the speculum which in the process of working are alternately covered and exposed, or from the injudicious application of the rouge and water *only* near the edge. With a view to obviate this defect of figure, I have found it advantageous to increase the sweep or stroke of the polisher, or, in other words (referring to the description of my polishing-machine in the eighteenth volume of 'Memoirs of the Royal Astronomical Society'), to increase the throw of the quick-moving crank. While attempting to do this at Malta, using the same machine which had been originally constructed for the two-foot speculum, and had given repeated indications of its being too weak for the work, it broke down hopelessly, and

I was obliged then to use some other arrangement or modification. I was not able to alter my machine and carry out my experiments fully before my return home, and it is only of late that I have had leisure again to return to the subject. But I have succeeded so perfectly and completely, even beyond my hopes, and by processes so simple, so certain, and so pleasurable, that I am desirous to place on record and before the world the means by which this has been accomplished.

In the machine I am about to describe, those familiar with the subject will probably recognize little that is *new*, for I have not hesitated to adopt parts of other machines that have been contrived, and rearrange or simplify them as I thought best for the required result. In describing, however, this new machine, I am desirous not to say any thing in disparagement of that which I invented many years ago (above referred to); for with that machine, especially since I applied to it the elegant improvement of a train of wheels for producing uniform axial motion of the polisher (a condition I had indeed attempted to secure by less efficient means) invented by Mr. De La Rue, I have produced many surfaces, on various specula up to 12 inches diameter, which I have never been able to surpass, and which are indeed so perfect that I cannot discover in them any error whatever. Still I have found it difficult, though not impossible, to use Mr. De La Rue's train for specula as large as 24 inches diameter, the strain on the wheels (being levers of the third kind) endangering the teeth. It was in applying this arrangement to polishing the four-foot that, although I had purposely had the wheel and pinion on which is the greatest strain made of cast steel, the machine broke down, and I was obliged to give up its use.

Description of the more recently constructed Machine.

Throughout the several figures the same letters generally indicate the same parts of the machine. Those figures which represent that part of the machinery supporting the speculum are on a scale of $1\frac{1}{2}$ inch to the foot, or one eighth the full size.

Plate 50. fig. 1 represents a firm support of wood or masonry for the cast-iron frame B of fig. 2, to which all this part of the machinery is fixed; and it will be seen that there is provision made for attaching it to a wall; but that method is not so convenient as placing it on a firm and independent base. The form of the plate and bracket B will be understood from the several views of it in figures 1 to 4. On its upper surface are two V-shaped planed grooves shown at B^1. On this travels a cast-iron plate, C, with V-shaped ribs fitting the grooves of the frame B, and, depending from its centre, is cast a hollow tube accurately bored inside (C^2, figs. 1 & 2). There is also a boss cast on its under surface (C^3, fig. 2) to afford a firmer support to the axis of the pinion (or wheel) of 26 teeth working through it. In the upper and lower plates of frame B are two wide recesses or grooves shown in plan at B^2, fig. 4. These allow the downward projecting tube of plate C to pass backward and forward within certain limits, as the plate C travels along the V-shaped grooves. Fig. 5 shows a turned shaft fitting the bored tube of plate C with two toothed wheels keyed upon it, the upper wheel having

77 teeth and the lower wheel 60 teeth. These are shown in position in figs. 1 & 2. Frame D, shown in the several figures, carries a tangent-screw (figs. 3 & 4) working into the upper wheel of the shaft (fig. 5), the shaft of the tangent-screw having three speed-pulleys, the largest of which is 9 inches diameter, keyed on to it at its end, distant about 20 inches from the middle of the tangent-screw. The lower wheel of the shaft (fig. 5) engages with a smaller wheel or pinion of 26 teeth, in the lower end of the shaft of which is cut a slightly dove-tailed slot (G, fig. 1). Through this slot passes the adjustable crank-arm (E, fig. 2), with a turned pin and shoulder at its end. The stout bracket F is bolted to the underside of B, and contains a planed groove, vertically cut, which is fitted by a brass step bored to the size of the crank-pin, and travelling truly and smoothly in the slot or groove cut in the bracket. The extreme throw of this crank is, radially, 2·2 inches; therefore the entire journey of the plate C, with all that it carries, along the V-grooves in B is thus insured to the extent of 4·4 inches extreme thrust to and fro. Cast on to the upperside of the tangent-wheel H are a central and three circumferential bosses, seen in plan in fig. 4, and in elevation in figs. 1 & 2. The projecting pin of the central boss enters a hole of similar size in the centre of the back-plate of the speculum, on which, on its disks and levers, it reposes. This central boss thus secures the centrality of the speculum whenever it is placed upon the machine. The steadiness and horizontality of the back-plate is secured by three adjusting-screws affixed to the other three bosses (of which one is seen in fig. 1), having pins entering corresponding holes in the back-plate. By a band from a suitable-sized pulley on the main driving-shaft of the steam-engine, motion is given to the pulley on the tangent-screw shaft (I, fig. 1). This being engaged with the wheel of 77 teeth, causes the speculum to revolve on its axis, and at the same time, by means of the wheel of 60 teeth working into the pinion of 26 teeth, carries the speculum transversely or laterally along the V-shaped grooves, according to the setting of the adjustable crank-arm E, fig. 2. The object of this transverse motion (not always used or even necessary) is to wipe out (so to speak) any ring-like character which might possibly appear in the process of polishing.

Thus far is a description of the apparatus by which the two motions of the speculum are obtained. I proceed now to describe the method by which the required motions of the polisher or grinder are secured.

Description of the Apparatus for driving the polisher or grinder of a two-foot Speculum.

Fig. 7 of Plate 51 is a plan, and fig. 8 an elevation, of this part of the machine. A represents the speculum as placed in position on the bosses of the tangent-wheel H, figs. 1 & 2. B is the principal spindle, with its adjustable crank for driving the long shaft C, which, seen in its two positions (figs. 7 & 8), needs but little description. D is the main driving-pulley, which, in connexion with a shaft running along the ceiling, also driving the speed-pulley I (fig. 1), gives motion to the whole. E is another vertical spindle attached to the wall of the laboratory, furnished also with a crank of nearly similar range to that on the spindle B, and connected also, by a radial bar, with the

long shaft or lever C, as shown in fig. 7. On the spindle E is keyed a pulley 8·3 inches diameter, connected by a crossed band with another pulley of 9 inches diameter, keyed on to the main spindle or shaft B. These pulleys, differing but little in diameter, are intended to be prime to each other, to avoid a repetition of the same strokes in the crank-arms.

Attached to the long shaft C is an apparatus for securing a regular slow motion of the polisher on a vertical axis. On the back of the polisher is a circular rack of 128 teeth, driven by a pinion of 15 teeth, the shaft of which works in a little frame attached to the long shaft, as shown at F. On this small shaft are two pulleys, either of which, by means of two direction-pulleys (G) and a round band, may be driven by any of the pulleys which are keyed on the upper portion of the driving-pin of the crank-arm H. The axis of the direction-pulleys G is secured to a separate piece of wood, which can be fastened to the long shaft, or raised somewhat from it by means of two wooden screws, as shown in the drawing; thus the band can be kept at a proper degree of tension. If the direction-pulleys were to be brought into immediate connexion with any of those on the shaft H, the speed would be too great, and therefore two supplementary systems of speed- or cone-pulleys are introduced between G and H. These afford abundant scope for alteration of speed; and by crossing any one of the bands the motion of the polisher on its axis may be either in the direction of that of the sun or the reverse. At J is a hook, attached by a cord going over a large pulley in the ceiling to a counterpoise-weight, by which the whole or any portion of the weight of the long shaft C may be supported. The teeth of the circular rack and of the pinion are made as long as can be, consistently with their working well together; and the counterpoise is so regulated that they remain engaged without the apices of any of the teeth coming into contact with the opposite bases. Therefore the weight of the polisher, which is of course a constant quantity, or very nearly so, is the only weight pressing on the surface of the speculum. The axial motion of the polisher is usually in the opposite direction to that of the speculum, and its speed is slower. These constitute the ordinary motions of both the speculum and polisher.

The polisher, equal in diameter to the speculum, is made of two strata of white deal, such as is generally used for the inside carpentry of dwelling-houses, the grain of the wood being placed at right angles in the two disks, which are about $1\frac{1}{4}$ inch thick, cut out of adjacent parts of the same well-seasoned board. One surface of each board is planed as flat as possible, and then they are united together with the best glue under strong and equal pressure. While the pressure is still applied and the glue warm, the disks are further secured in contact by about two dozen countersunk screws, equally distributed. Calling the disks A and B, half the screws are entered on the side A, and half on the side B, each disk having been previously bored and countersunk for its own screws (for expedition's sake), so that only what boring may be necessary in the other disk is done after gluing. The two external surfaces of the polisher are now to be wrought or planed, for symmetry's sake, to fit approximately the concave gauge of cur-

vature of the speculum. The polisher is then to be painted with the best thin oil-paint, the process being continued or renewed until all the pores of the wood are perfectly saturated with the oil. When perfectly dry it is to be well varnished, and then will be ready to receive the pitch. For covering the polisher symmetrically with squares of pitch with due interstices (a most essential condition), I have used a peculiar apparatus, which really converts this troublesome and very unmanageable process into one not at all irksome and also cleanly, speedy, and efficient. This, which may be called a pitch-mould, is represented in Plate 52. fig. 9, half the real size. *a b* is a square prism of white deal, on the upper part of every side of which is hinged a piece of deal fitting closely to the prism, and extending about four tenths of an inch beyond the upper end of the prism. The outsides of the upper ends of these pieces are a little tapered, so that, when their sides or surfaces are in contact with the prism, as in the figure, a light zinc hoop (*e*) may be dropped over them to hold them in position. A cell or mould is thus made on the top of the prism about $1\frac{1}{4}$ inch square and four tenths of an inch deep. The lower part of the prism (*c d*) is encompassed by a hoop of sheet lead, sufficient to make it sink in water and keep upright. To have five or six of these moulds saves time in the process of casting the pitch. Previous to being used, the moulds should be immersed for days, or *at least* 24 hours, in order that the pores of the wood may be so saturated with water that the melted pitch will not attach itself to any part of it. And to bear this treatment well, the *pins*, as well as the leaves of the hinges, should be brass, and the attaching screws also brass. Fig. 10 represents a cylindrical vessel of thin copper, about 11 inches in diameter and 11 inches deep, with a short copper tube hard-soldered in its side near the bottom, six tenths of an inch wide. This tube is to be fitted with a very long and slowly tapering mahogany plug, so as to give plenty of latitude for regulating the flow of pitch. I use black pitch, made from Swedish or Russian tar, and have obtained it of very good quality from TOLHURST and SONS, 60 Tooley Street, in small kegs. Formerly I used to strain the pitch through muslin (a most disagreeable operation), but for many years I have forborne to do so, deeming it quite unnecessary; and some other niceties, such as polishing the speculum in water of the same temperature as the laboratory, also I have laid aside. The general tendency of my experience has been to approximate to the utmost simplicity consistent with accuracy of workmanship. The best way of opening a barrel of pitch is to saw the staves through in the middle all round, when by a smart blow or two it will generally break in the middle into two portions. By inverting one of them over a large sheet of brown paper and slightly tapping the loosened staves, any required quantity may be readily detached. The pitch is generally so hard that it will bear this treatment even in hot weather. The pitch-vessel may be conveniently placed on a low iron tripod, and the pitch melted by a BUNSEN burner mounted at the end of a gas-bracket. The pitch is adjusted to the proper temperament by adding tar if it be too hard, and resin if too soft. If the latter has to be added, it should be melted in another vessel and poured in while fluid. The due attempering of the pitch may be secured by

a trial-and-error process as follows:—Take a small sample of the melted pitch, and pour it on a thin copper plate. Immerse it in a vessel of water of the probable temperature of the apartment in which the polishing-process is to be conducted. When the pitch has acquired this temperature, place it on a table, and subject it to the weight of a new sovereign placed on edge for sixty seconds. If it receives three clear impressions of the milling-strokes in that space of time, it will be about right. It should not receive less than $2\frac{1}{2}$ nor more than $3\frac{1}{2}$ strokes. A simple frame should be made to hold the sovereign vertically, without influencing its weight. When of right consistence, the burner should be so regulated that the pitch should not flow too rapidly when the plug is partially or wholly withdrawn: indeed, the cooler the pitch, without endangering its regular flow, the better; it will be less liable to adhere to any of the moulds when poured into them. The moulds should have been placed, as before directed, in cold water, the surface of the water being an inch or two above the tops of the moulds. One of the moulds is to be withdrawn from the water, quickly emptied by inversion, placed under the side tube of the pitch-vessel, and filled level full of pitch by partially withdrawing the plug. The filled mould is then to be sunk just under the surface of the water of another vessel and allowed to remain a few minutes. This time may be occupied by filling about half a dozen other moulds, when the first will be ready to be taken out of the water. On lifting off the zinc hoop and letting down the hinged sides, the symmetrical casting of pitch will have become hard enough to drop off instantly into the water, leaving the mould quite clean, which should, however, be returned to the water before being used again. But little experience will, I think, be required to secure this process being carried on easily and successfully. Should a single particle of pitch stick to any of the moulds it must be *perfectly* removed before being used again; and if any of the moulds should give any trouble in this respect, a *slight* touch of rouge on the wood will probably defend it from the pitch; but if the moulds have been long enough in the water this ought not to be required. The squares of pitch must not remain *long* in contact, even under water, as they are apt to adhere. They are best placed, soon after being formed, on a level deal board, the squares just covered with water, when they will take no harm for a considerable time.

I use the following mode of attaching the squares of pitch symmetrically and firmly to the base of the polisher. Fig. 11, Plate 52, represents a piece of stout sheet iron $3\frac{1}{2}$ inches broad and about 13 inches long, bent into the form *a a*, to which is riveted another piece (*b*). The lower part of the upper portion of *a* is curved into a channel, and a sheet-iron cup (*c*) receives any waste pitch which may overflow. The upper part of *a* is heated by a BUNSEN burner being placed below it. Three prisms of deal, four tenths of an inch square, two of them 12 inches long, the other 24 inches, are to be prepared and well soaked in water: these are to be lightly tacked to the base, as shown in fig. 12 (Plate 50). A fourth prism, some 8 or 9 inches long, is also required, and these serve to aid in placing the squares correctly and to mark out the interstices between them. The fourth prism is unattached, and kept in the hand to mark the separation as each

square is applied. I begin at the centre, as in the figure; and after laying down two rows along the two radii of the first quadrant, I then proceed to the opposite quadrant, and similarly with the remaining quadrants, with a view of producing uniformity as much as possible over the whole surface. The squares are now to be successively taken up by the fingers, drawn rapidly across the heated plate (*a*, fig. 11), which completely melts the under surface of the square without penetrating beyond a mere film, and prepares it to adhere firmly to the base by a pretty hard but quickly withdrawn pressure. The 24- and 12-inch rods should be removed as soon as they have answered their purpose, lest any of the squares should adhere to them. If not used immediately, the polisher should be kept in a strictly horizontal position, either face up with a cover on, or inverted and suspended by hooks embracing three pins of stout wire, inserted equidistantly in the circumference of the polisher, as in figure 13.

Before describing the actual process of polishing, I may say a word or two on the rough-grinding and preparing the speculum for reception of the polisher. The rough-grinding proper is a very easy process, and may be accomplished in various ways, the chief requisite being *patience*. A very good grinder may be constructed exactly as is the base of the polisher, and then covered with 2-inch or $2\frac{1}{4}$-inch square leaden castings, four or five tenths of an inch thick, each screwed to the base by a couple of stout joiner's screws. A convenient mould for the castings may be very easily constructed of sheet iron, with pins inserted to leave holes for the screws. The metal is improved if a little tin be added to the lead. Of course, the process of grinding must be watched, and the gauge of curvature applied occasionally, correcting any error by lengthening or shortening the strokes of the machine as the case may require. In this way, by gradually increasing the fineness of the emery, the surface of the speculum *may* be brought up to a condition fit for the polisher; but, finding the process very tedious towards the last, and having been frequently much annoyed by the sudden appearance of a scratch or two, I have resorted to a *bed of hones*, as an intermediate tool between the grinder and polisher.

The base of this is a circular disk of Bangor slate, 24 inches in diameter, and about eight tenths of an inch thick, planed flat on both sides. This is covered with pieces of German hone (Bohemian blue stone); they are to be obtained from F. ALEXANDER, 103 Leadenhall Street. The hones are about 7 inches long, and about eight tenths of an inch square. They are cemented on to the base with hard pitch, their under surfaces having been previously ground flat on a facing-plate, as it is necessary that their contact with the base should be intimate and accurate. The upper surface of the bed of hones must of course be made to fit the gauge of curvature, which is accomplished, without much difficulty, with a coarse file or rasp, correcting it as the coincidence approaches accuracy by a few strokes upon the speculum itself. Fig. 14 represents generally the form of the bed, and the direction in which the hones are placed, attention being paid to balancing, so to speak, the opposite sides of the tool by having the grain

of the hones in the same direction*. When the coincidence has been rendered nearly perfect, the tool may be wrought upon the speculum with a little fine-sifted emery, water being freely applied as the mud forms, and finishing with finely powdered hone-dust. This process will produce a very fine surface on the speculum, quite fit for the application of the polisher and for examination of the figure by the image of a bright star. This tool is very convenient in case of having, in polishing, produced a hyperbolic figure, as it may be reverted to and a spherical figure obtained in an hour's working. On the back of the bed of hones, as also on the back of the polisher, is screwed a cast-iron socket, loosely fitted by a stout pin, about half an inch in diameter, depending from the lever or long arm (C, fig. 8). This pin should be firmly attached, as it has to bear all the strain of the machine, both in grinding and polishing. The weight of the bed of hones is about 61 lb., and of the polisher about 35 lb.

Presuming the speculum to have now a sufficiently fine and approximately spherical surface from the hone-tool, it will be ready for the polisher. The temperament of the latter should be of course in due relation to the existing temperature of the laboratory. The surface of the pitch must retain its originally pure texture, or it will not polish quickly and well; and it must be slightly warmed and placed upon the clean wetted face of the speculum before any powder is applied, to insure a nearly even and uniform contact between the polisher and speculum.

The surface of pitch is conveniently and uniformly warmed by the apparatus represented in fig. 13. Two pulleys revolve on axles driven horizontally into a beam, a stout cord (sash-line) running over both. One end of the cord is attached to a counterpoise-weight, and the other by a swivel and three cords to the polisher, which is thus suspended face downwards. The three cords terminate in three hooks, respectively receiving the ends of the three equidistant pins inserted in the circumference of the polisher. At *a* is a piece of wood and tightening-screw, which can be made to clip the cord to the beam, and prevent its motion when the equilibrium is about to be destroyed by removal of the polisher. When *in æquilibrio* the polisher can be raised or lowered at pleasure, the screw being withdrawn during the process of warming. On the floor, under the polisher, is placed a small chauffer or furnace (Plate 52. fig. 12), made of four fire-bricks or tiles 9 inches long, $4\frac{1}{2}$ broad, and $2\frac{1}{2}$ inches thick. These are put together so as to enclose a space about $5\frac{1}{4}$ inches square and $4\frac{1}{2}$ inches deep, which forms the receptacle for the charcoal. The base on which the bricks stand contains a grating of bars $\frac{1}{4}$ inch square, with equal spaces between. Supported on the bricks, and a few inches above them, is a piece of sheet iron rather larger than the area of the furnace, to prevent the direct heat of the ignited charcoal from acting on the pitch. The heated air ascends all round the plate, and by revolution of the polisher with a little swinging motion, its surface is uniformly warmed. By means of the counterpoise, the polisher can be raised or lowered at pleasure according to the heat required. Some judgment is necessary in warming the pitch.

* The hones are put on entire in their whole length; but their upper surfaces are slightly grooved, so as to give the tool the aspect of a system of squares.

The heat must not penetrate far into it, nor must the heat be so suddenly or powerfully applied as to *melt* the surface; it must be merely softened. The surface of the speculum having been freely wetted by a large sponge and clean cold water, the pitch-surface as softened must be quickly laid upon the speculum and gently and slowly moved to facilitate contact. It is well not to err on the side of too much warming, as if necessary the process can be repeated until the contact is complete. On removal of the polisher it will be instantly seen to what extent the surfaces coincide; and it is desirable that the contact should be very uniform, and that some part at least of every square should touch the speculum; if that is not the case, another warming should be resorted to. For polishing I use the *finest* plate-powder, or jeweller's rouge, which may be obtained of excellent quality from MEDWAY and Co., Owen's Court, Goswell Road. This requires no further sifting. A quantity of it is put into a flat-bottomed jar and well stirred about with water equal to seven or eight times its bulk. It is then left to subside until almost all the water can be poured off *quite clear*. Of course the finest particles of the powder will be now upon its upper surface; and I have ever found these to be capable of producing as fine a lustre as the speculum is capable of receiving. Without disturbing much more than the surface of the powder, the speculum is now, by means of a flat camel's-hair pencil, to be covered with the rouge and water of the consistence of cream. The polisher may be again very slightly warmed, placed upon the speculum and the machine set to work.

The motive power I have used and found quite adequate is a steam-engine of $4\frac{1}{2}$ inches diameter of cylinder and 8 inches stroke, making 120 revolutions per minute, with pulleys on the horizontal shaft of such size as to drive the crank H either thirteen or seven revolutions per minute.

The mode I have employed for converting the spherical curve into a parabolic one has been by flattening or wearing down the exterior parts of the mirror, not by deepening the central ones; and this has been accomplished generally by altering the throw of the crank H and its rate of motion. In this I have been guided by the following consideration. If the polisher, at a proper temperament, be placed out of the centre upon the speculum with one part of its edge hanging over the speculum some 3 or 4 inches, and be allowed to remain a few minutes in that position, it will require a strong effort to bring it back to a central position over the speculum, the unsupported pitch-surface having in that interval fallen down slightly by the force of gravity. In forcing the pitch back to its normal figure, it must necessarily exert an undue pressure upon the exterior part of the speculum over which it travels, and, if charged with powder, would certainly abrade that part more than other parts nearer the centre, and, so far as its operation reached, would tend therefore to produce a parabolic curve. Now if the throw of the crank H be lengthened, the polisher at each stroke will be carried more over the edge, and therefore this tendency would be increased; and if at the same time the speed be diminished, the duration of the overhanging of the polisher at each stroke would be longer, and the parabolic effect proportionally increased. The result is still

further augmented by the slight increase of temperature acquired by the pitch in the act of polishing.

Acting on this principle, which has been supported by pretty extensive practice, I usually set the crank H, for polishing a twenty-four-inch speculum with a focus of ten diameters, to a radius of 3·0 inches, and the crank E to a radius of 2·75 inches, with a speed of motion of H producing about seven revolutions per minute. The pulley on the main shaft, in connexion with the largest speed-pulley I, of fig. 1, Plate 50, is about 4·1 inches diameter, causing the speculum to revolve once in about 3^{m} 45^{s} against the sun; and the speed-pulleys on the long arm C of fig. 8 have their bands so arranged as to cause the polisher to revolve on its axis once with the sun in about 5^{m} 8^{s}, none of these bands being crossed. The band on the pulley on the vertical shaft H, connecting it with that on the vertical shaft E, is necessarily crossed to increase its friction. A slight addition to the counterpoising weight of the long arm C lifts its end about 2 inches above its ordinary working position, so that there is now room to place the polisher upon the speculum already charged with rouge. By restoring the counterpoise the pin may be introduced into its socket on the back of the polisher and the engine started. Pretty frequent supervision of the operator will now be necessary through the whole process, which may last three or four hours; and perhaps the lustre may not be brought up to its maximum even in that time. I generally allow the machine to proceed uncontrolled until the powder begins to disappear from the intermittently exposed margin of the speculum. By this time the powder, as it works slightly over the edge of the speculum or adheres to it, ought, if it has been working well, to have become considerably darker in hue, so as to tend to a purplish colour, from the admixture of minute metallic particles. Nothing like *dryness* of the edge must be permitted to supervene. The engine should now be stopped and the polisher withdrawn by *sliding* it off the speculum. Probably the incipient polish may be somewhat more advanced towards the exterior of the speculum, which is what is desired; but it should not be very strikingly so, and the advance should be regular, not sudden. It is not well to add powder while the machine is going; it cannot then be added uniformly over the whole surface, and it tends therefore to irregularity of action. The aspect of the polisher should be examined. Some part at least of every square ought to have been obviously in contact, and an oblique view should reveal no apparent inequality of texture. As rapidly as convenient, and before the squares can dry, the powder which may have lodged in the grooves should be distributed evenly over the whole surface; and after the speculum has had another pretty free dose of powder, the polisher should be placed upon the speculum and the process be carried on. When the powder has apparently been again used up and has nearly disappeared from the speculum, the polisher may again be removed. And now the lustre ought to be very considerably advanced, and the little powder adhering to the edge of the speculum be of at least a deep purple colour. The powder may be lightly and quickly removed from the grooves in the pitch with the camel's-hair brush, and distributed over the

surface as before. A very slight application of only the finest particles of fresh powder is now to be applied to the speculum and the process renewed. Before this powder becomes used up, the lustre ought to be sufficient, as may be ascertained by inspecting the circumferential parts of the speculum as they become successively exposed. The tendency to dry at the edge is now much increased, and must be prevented by touching the edge from time to time with the camel's-hair pencil charged with scarcely coloured water. This may be continued for some time, the lustre advancing very rapidly, and the colour of the powder becoming really black. What I have described, if all has gone on well, may occupy perhaps three hours, speaking roughly; for the perfect success of the process depends upon some niceties—such as the exact adjustment of the temperament of the pitch to the heat of the apartment, and the steadiness of its heat during the time of working. I may remark that nothing abnormal in the process, such as any irregularity in the motion of the polisher on its axis, must be permitted to occur without at once stopping the engine and correcting the error; perfect smoothness and evenness of motion must exist throughout, and also perfect uniformity of aspect of the polisher in its several removals must be apparent, or a good result cannot be hoped for. But in this machine the motions of the polisher are so perfectly, and yet, so to speak, so gently controlled, that irregularity is not to be expected; and if it should occur, a moment's reflection will most likely reveal the cause. It is probable that this first polishing may not have brought the speculum quite up to the parabola, but I think it desirable to clean it off and prepare it for examination. This is best done with a large and very soft sponge and plenty of pure water. This cleansing must be continued until not a vestige of powder remains, nor any trace of smear or impurity whatever. The sponge having removed all superfluous water, the *drying* is to be effected with a couple of old soft linen cloths, good absorbents. The wiping must be light and quick, and continued until every particle of moisture has disappeared from the speculum. It is then best left without a cover for half a day, that it may uniformly acquire the exact temperature of the apartment. The cover may then be put on, and afterwards the less the surface of the speculum is touched the better. *If there be occasion for it,* however, I never hesitate to wash and wipe it in the same soft and careful manner; nor indeed, if at any time there appear any grease-stains or spots, to first pour upon the surface a very little soft water in which a bit of soda has been dissolved, lightly distributing it over the whole surface with the finger, and immediately afterwards applying the large sponge and pure water.

The *polisher* also requires immediate attention, as if no great change in the temperature of the air occurs, it may be used for repeated polishings. But the *surface* charged with rouge and metallic particles must be completely removed or it will never polish well. This is best done by first well washing, to remove all that a painter's brush will remove, and then tearing up the extreme film of the surface with a piece of "steel-card," such as is used in cotton-mills for carding cotton. As this film is extremely hard and rapidly destroys the edge of any cutting-tool, it was a relief to me to find that this

instrument answers the end perfectly, exposing the pure under surface of the pitch without sensibly diminishing its thickness. The polisher should be placed in an inclined position and plenty of cold water used. If not immediately required, the polisher may be kept for an almost indefinite time in a perfectly fit state for use, and amidst considerable changes of temperature, by keeping it suspended horizontally, and occasionally examining its surface to see if it requires to be kept face downward or the reverse.

For examination of the figure of the speculum I have always chosen to remove it from the machine, place it in the tube and turn it on a bright star, which is doubtless a severe and even crucial test. And in addition to thus examining the image and penumbræ of a star with the full aperture, I am accustomed to expose successively different portions of the mirror to the stellar rays, noticing whether or not any different setting of focus is required.

For this purpose I have a set of six diaphragms, exposing respectively a central disk and five concentric rings, all of equal area; and I do not pronounce any mirror perfect in which the eye is not satisfied with the same focus for all these. I do not say that the same precision of image is to be expected from the extreme external annulus when all the rest of the mirror is blocked out; but if the focus be set upon it, it ought to be the same as that required for the central portion. This I consider a severe test; and beside revealing the character of the general curve, it affords a means of determining its *regularity*, by examination of the images formed by the intermediate annuli. A strict measure of any differences of foci which may be manifested will point out where the error lies. In the surface in question there may probably be a slight spherical error, which may be removed by another hour's polishing with the same settings of the machine and a very moderate dose of the finest rouge. If, on the contrary, the figure should be hyperbolic, I should revert to the hone-tool, and repeat the process of polishing.

From this description I think it will be seen that there is little that is irksome, tedious, or even uncertain in polishing by this process and with this machine a two-foot mirror. With a little experience and some mechanical aptitude, the operation is easy, and becomes very interesting; for though to obtain the highest perfection of figure repeated trials may be necessary, the process is by no means disappointing—the figure, if reasonable care be taken, being always useful and to a considerable extent satisfactory. The principal part of the work can be done single-handed, though occasionally an assistant is required, chiefly in removing the speculum to and from the observatory. The speculum (weight about four hundred pounds) is lifted from the machine with a small pair of three-sheave blocks, placed upon a low carriage, taken to the observatory, hoisted with the same blocks on to a platform nearly level with the lower end of the tube when placed vertically, and finally lifted into its place by an elevating-screw placed centrally under the back-plate. The time consumed by this operation, including fixing the levers of horizontal support and final adjustment, extends to about two hours.

A well-fitting, but not tight, tin cover, which may be removed and replaced when the speculum is in the tube through a slit in its side, is all the protection the mirror requires; but it is desirable that there should be a light wooden cover hinged so as to fall over this opening when the telescope is in use, to prevent any drop of moisture falling from the roof from reaching the speculum. This is all the protection I give my mirrors, and I have never found them tarnish. I have tried quicklime, but found it to be quite unnecessary, and, besides, an intolerable nuisance.

I may add, finally, that I shall rejoice if I have succeeded in my endeavour to describe this interesting process so that any person of ordinary intelligence, and not quite unacquainted with mechanics, may succeed in producing, without difficulty, surfaces of at least a very high degree of perfection.

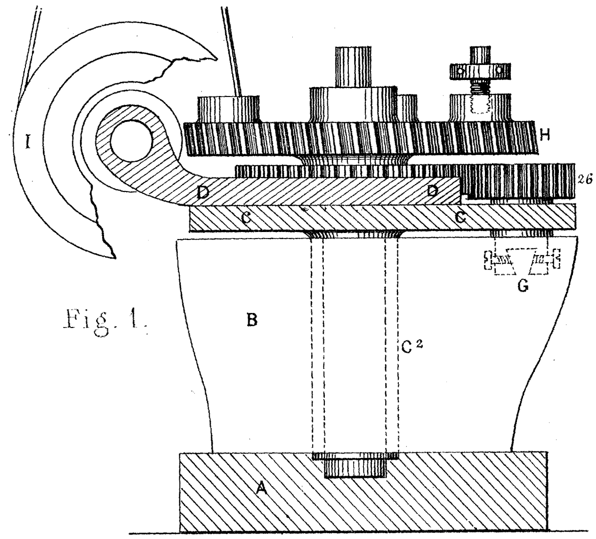


Fig. 1.

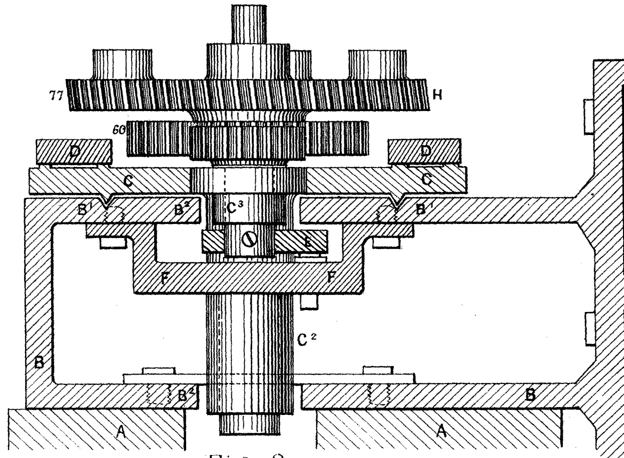


Fig. 2.

Speed-pulley on Shaft, 20 ins. from middle of tangent screw.

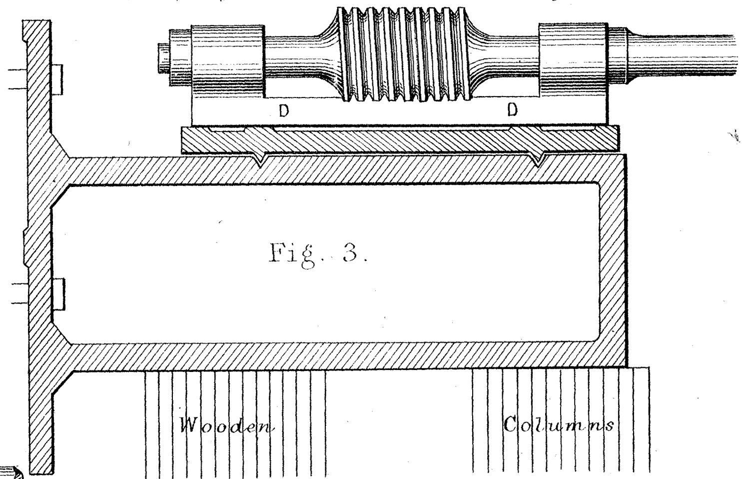


Fig. 3.

Fig. 4.

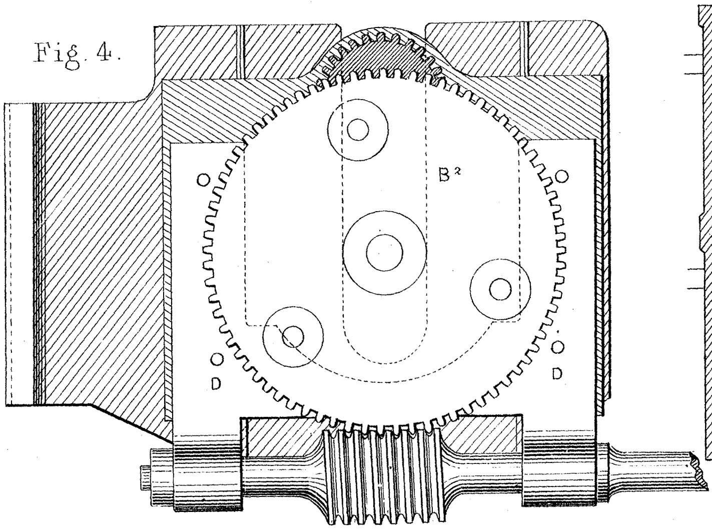


Fig. 12.

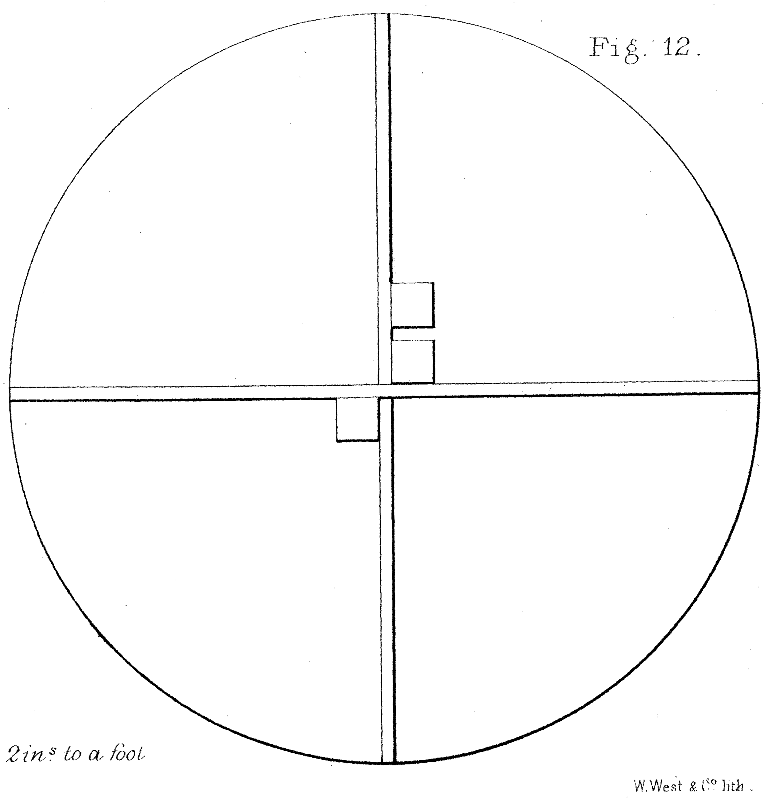
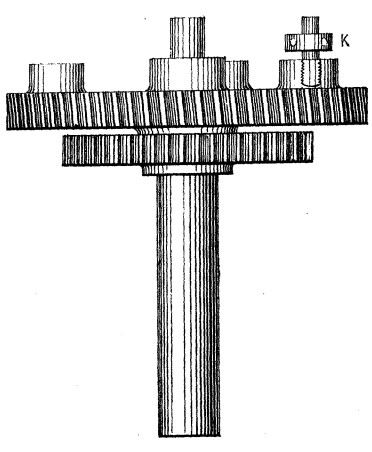


Fig. 5.



Scale 1½ inch to a foot, except Fig. 12 which is 2 ins. to a foot

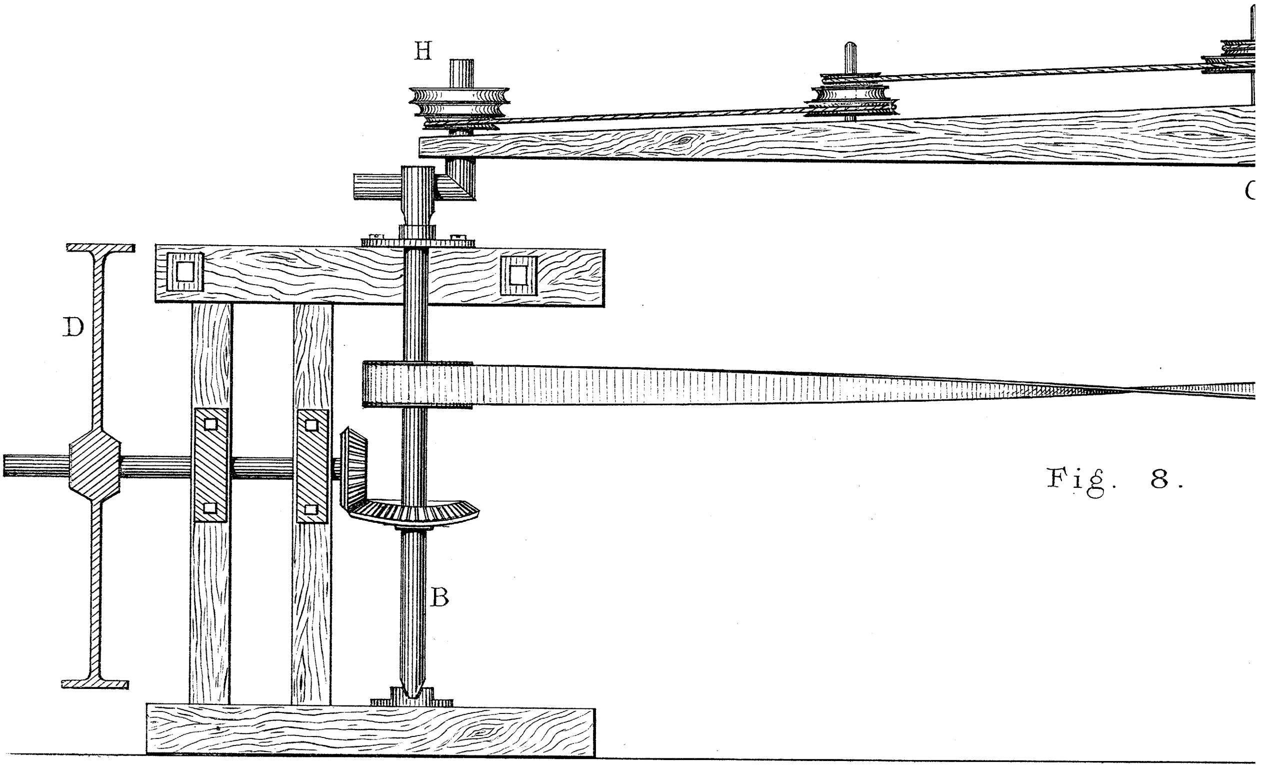


Fig. 8.

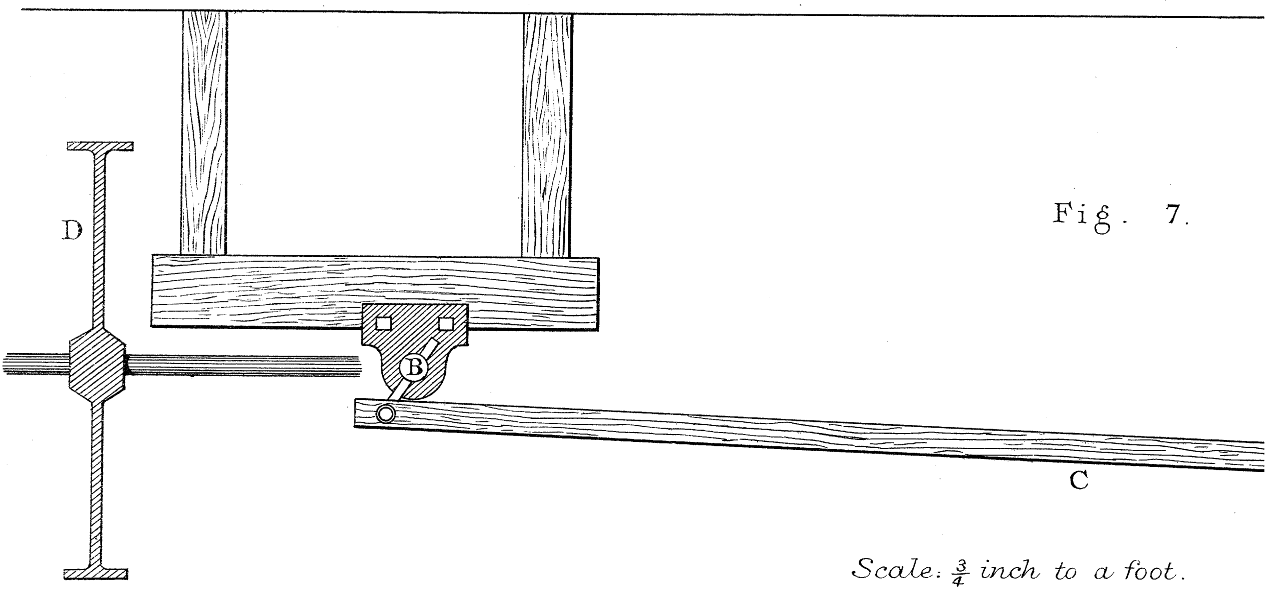
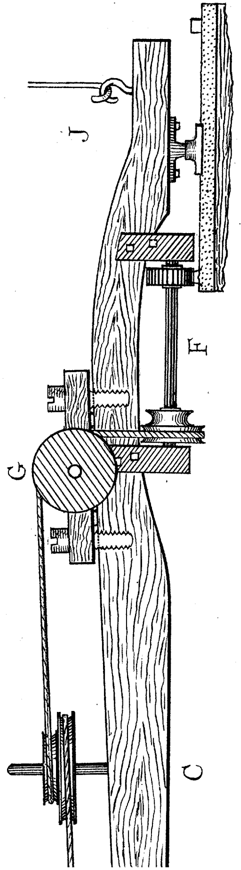


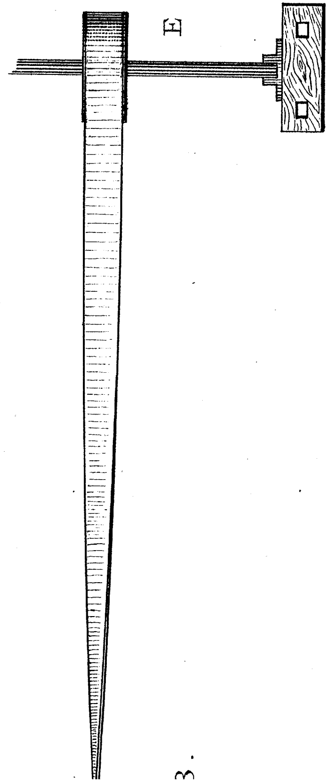
Fig. 7.

Scale: $\frac{3}{4}$ inch to a foot.

Lassell.

Phil. Trans. 1875. Plate 51.





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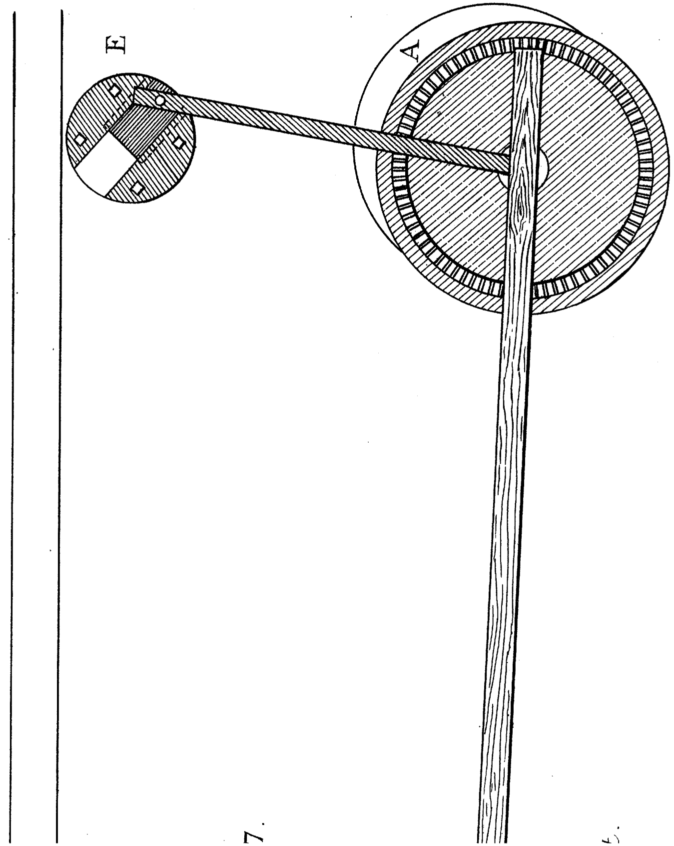


7.

5.

Fig. 9.

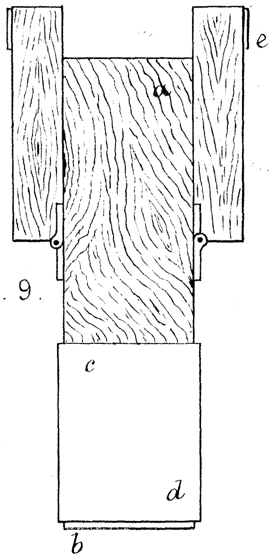


Fig. 13.

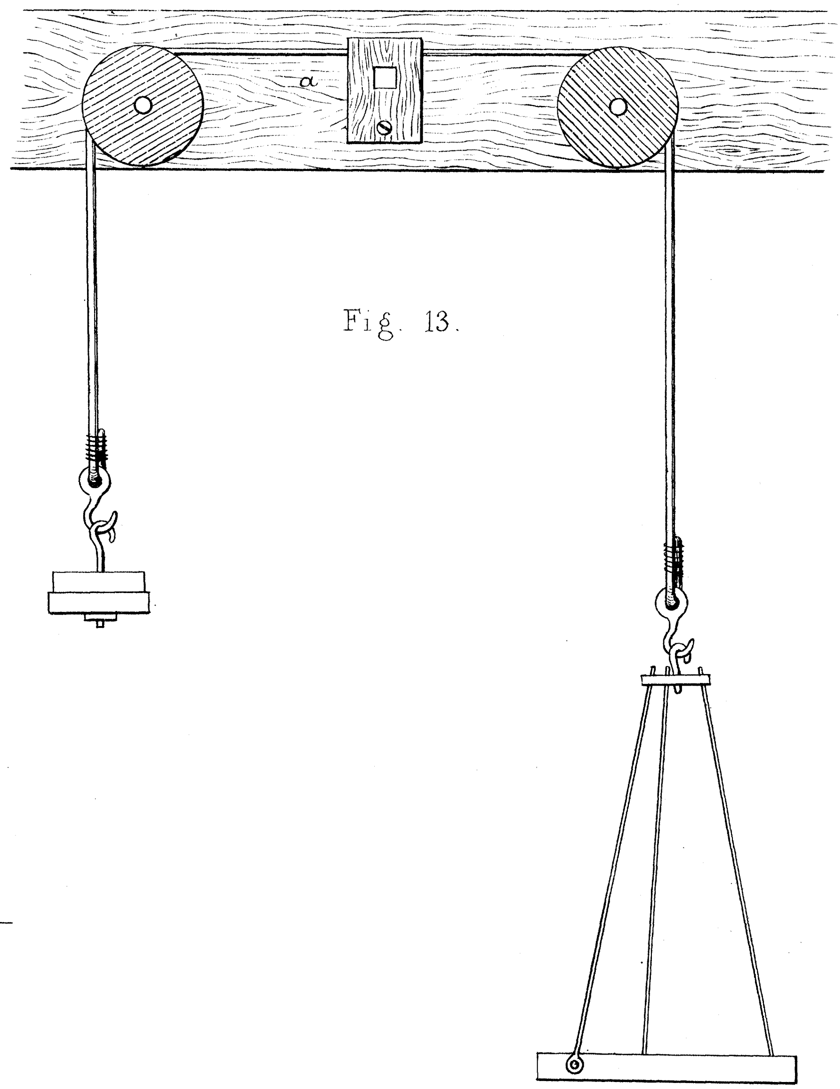


Fig. 11.

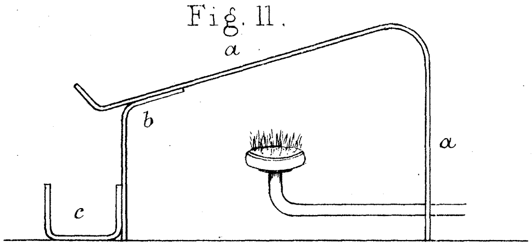


Fig. 14.

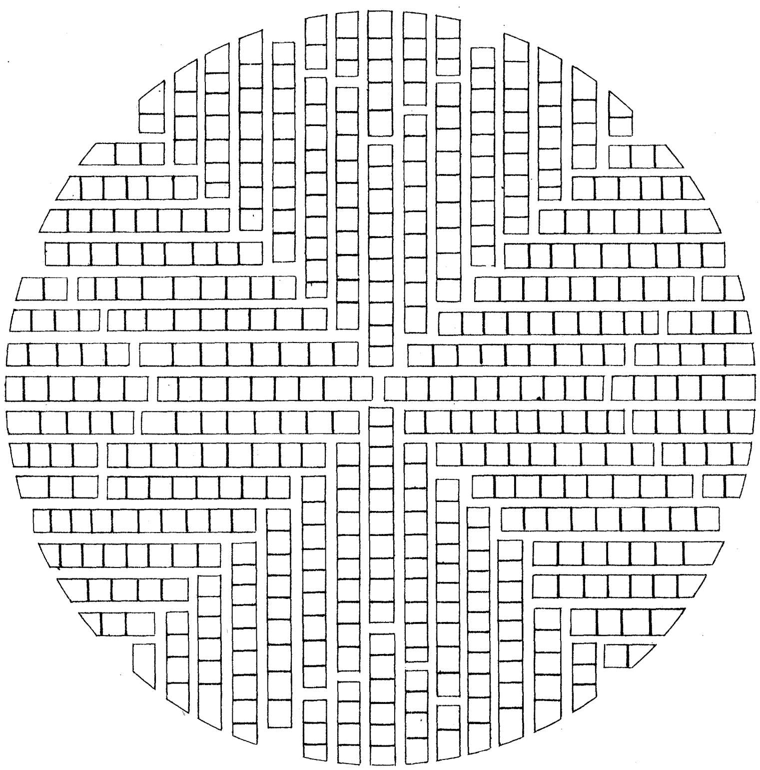


Fig. 12.

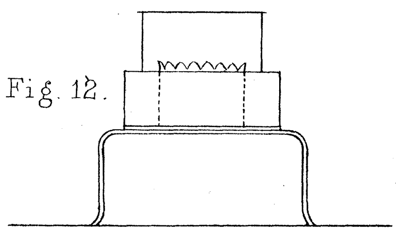
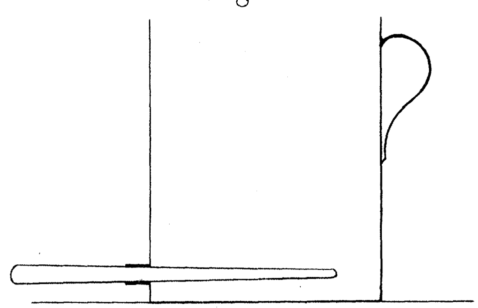


Fig. 10.



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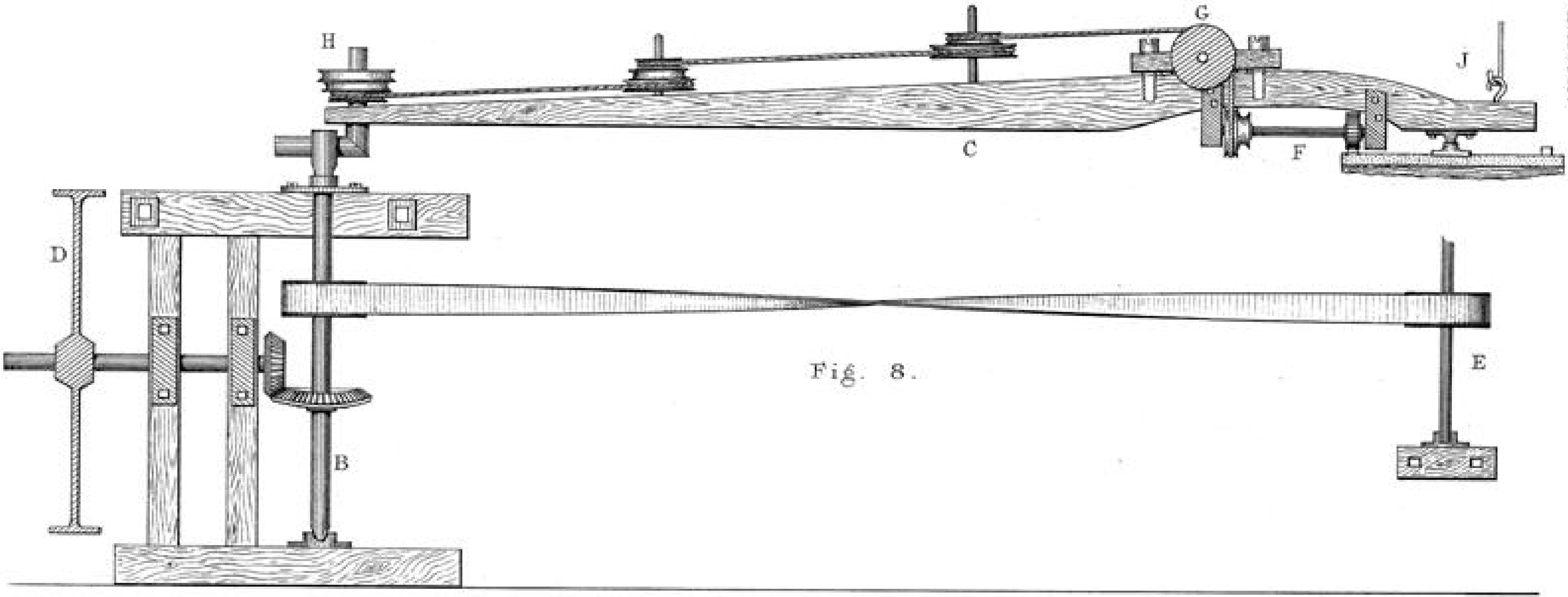

Fig. 8.

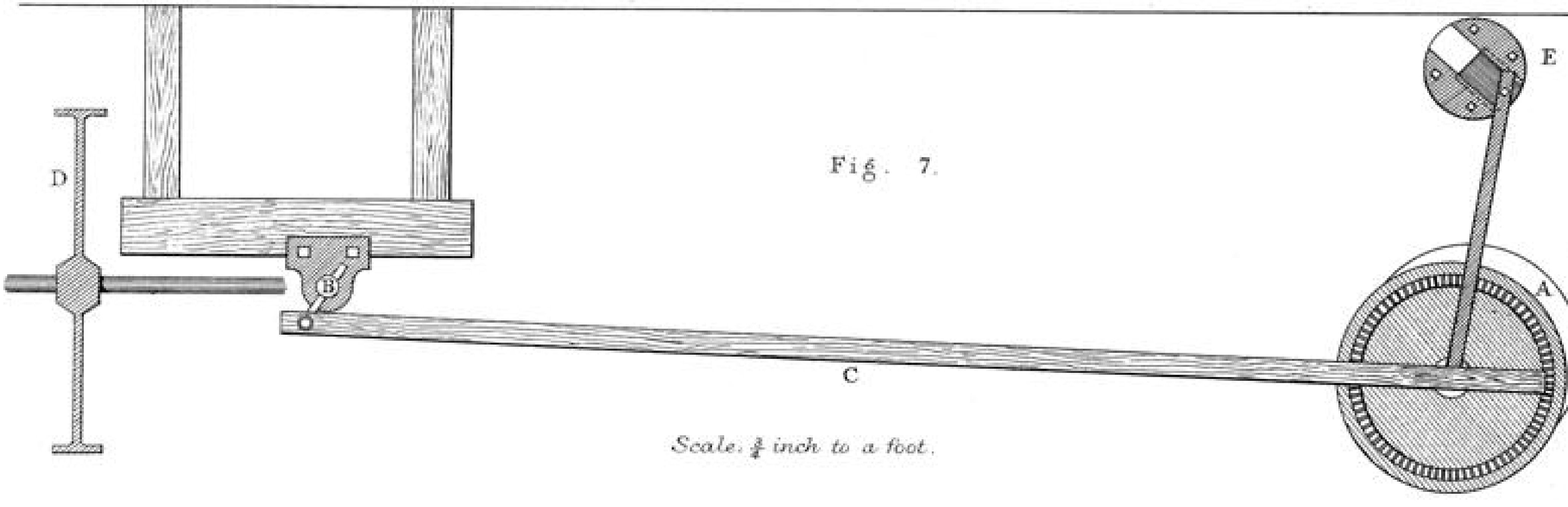

Fig. 7.

Scale. ¾ inch to a foot.

W. West & Co. imp.