Supplement to the Photographic Journal.
The Cyclograph by A. H. Smith.
(*See p.* 253).

Vase. Taken with the Cyclograph.

Vase. Taken in Ordinary Camera.

S. B. Bolas & Co., Collotype Printers, 11, Ludgate Hill, E.C.

THE CYCLOGRAPH.

By A. H. SMITH.

This instrument is principally designed for the purpose of photographing, without distortion, a larger part of the surface of a cylinder than can be seen at one view.

The general method employed is that of rolling the object along a smooth surface in front of the lens while at the same time a narrow vertical slit is caused to travel at a suitable pace, so that at each moment that point of the circumference is exposed which is for the instant at rest. In this way it is possible to maintain continuous motion without confusing the photograph. As the object travels along, at the same time that it revolves, we are able to use an ordinary camera and dark slide, with a fixed plate. [253/254]

I shall have occasion to use certain mathematical terms which it may be convenient to explain.

A cycloid is the curve generated by a point on the circumference of a circle rolling along a straight line in a plane. The points where the curve touches the straight line are the cusps of the cycloid. Near the cusps the lateral movement of a point is very small for a given angular rotation.

An epicycloid is the curve generated, in a similar manner, by a point on the circumference of a circle, which rolls along the circumference of another circle, instead of along a straight line.

A trochoid is the curve produced by a point on the radius of a circle rolling along a straight line. The form of the curve obviously varies according to the position of the point on the radius from a cycloid to a straight line.

An epitrochoid is the curve produced by a point on the radius of a circle rolling on along another circle. The diagram shows the cycloid and trochoids described by points on the radius, and radius produced of a circle, when it rolls along a straight line.

The instrument is shown in Figs. 1, 2, 3 and 4. Its foundation consists of a substantial bed (CC) to which two spurs are attached at right angles (M). This is

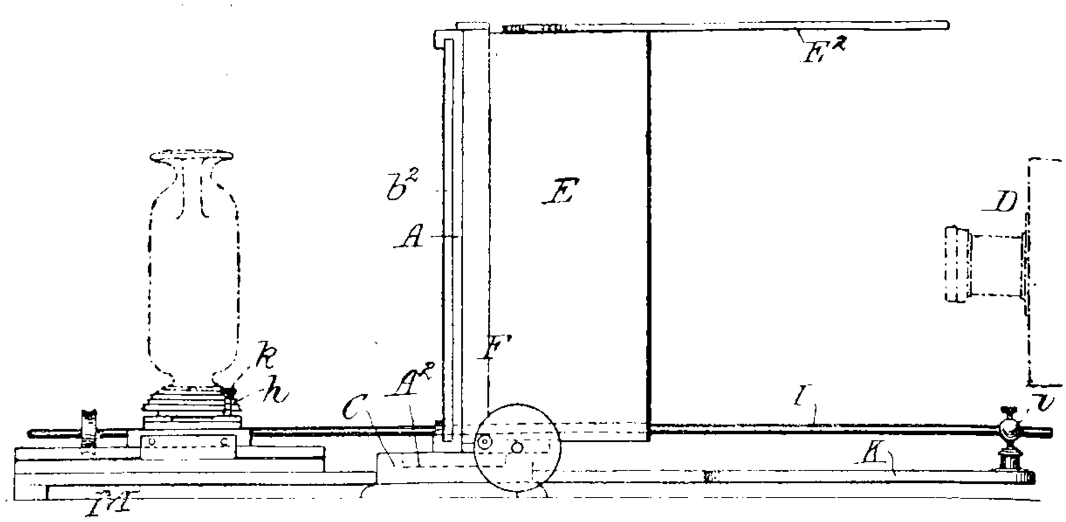

FIG. 1.

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clamped to a steady table. On the spurs is a plane table, adjustab1e in respect of its distance from the bed, and on it is a sheet of plate glass to reduce friction. A pivot

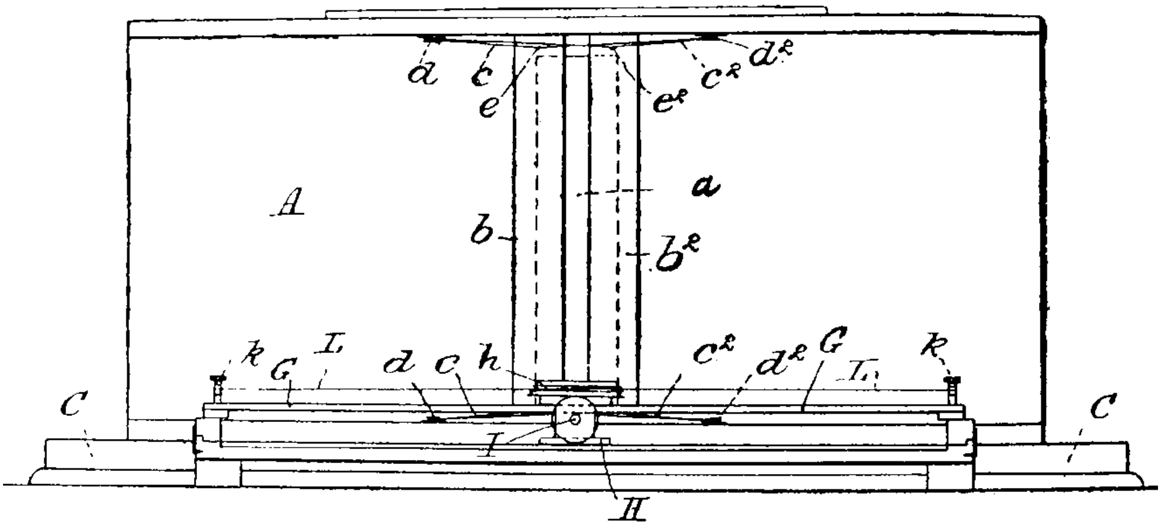


FIG. 2.

FIG. 2

ram (K) passes through the middle of the bed at right angles to it. In a groove of the bed is a dark screen (A) attached to a base (A^2) having a lateral movement [254/255] imparted to it by a long screw of fine pitch (B) and having in its centre a vertical slit *(a)* of adjustable width between the shutters *b, b2.* I will now suppose that the instrument is prepared for the cycloidal movement. Two parallel guides (G) are slipped on to their grooves at the ends of the plane table. Between these guides we insert an accurately turned brass turntable (H) which slides on the plate-glass, but is confined by the parallel guides to a path parallel to the screen. A long steel rod (I) is inserted through the bearing *(i)* at the end of the pivot arm, through a bearing in the middle of the screen, and through the turntable.

A small bearing wheel is slipped over the end of the steel rod, and rests on the glass plate. A pulley *(h)* is next chosen of the size of the object to be photographed,

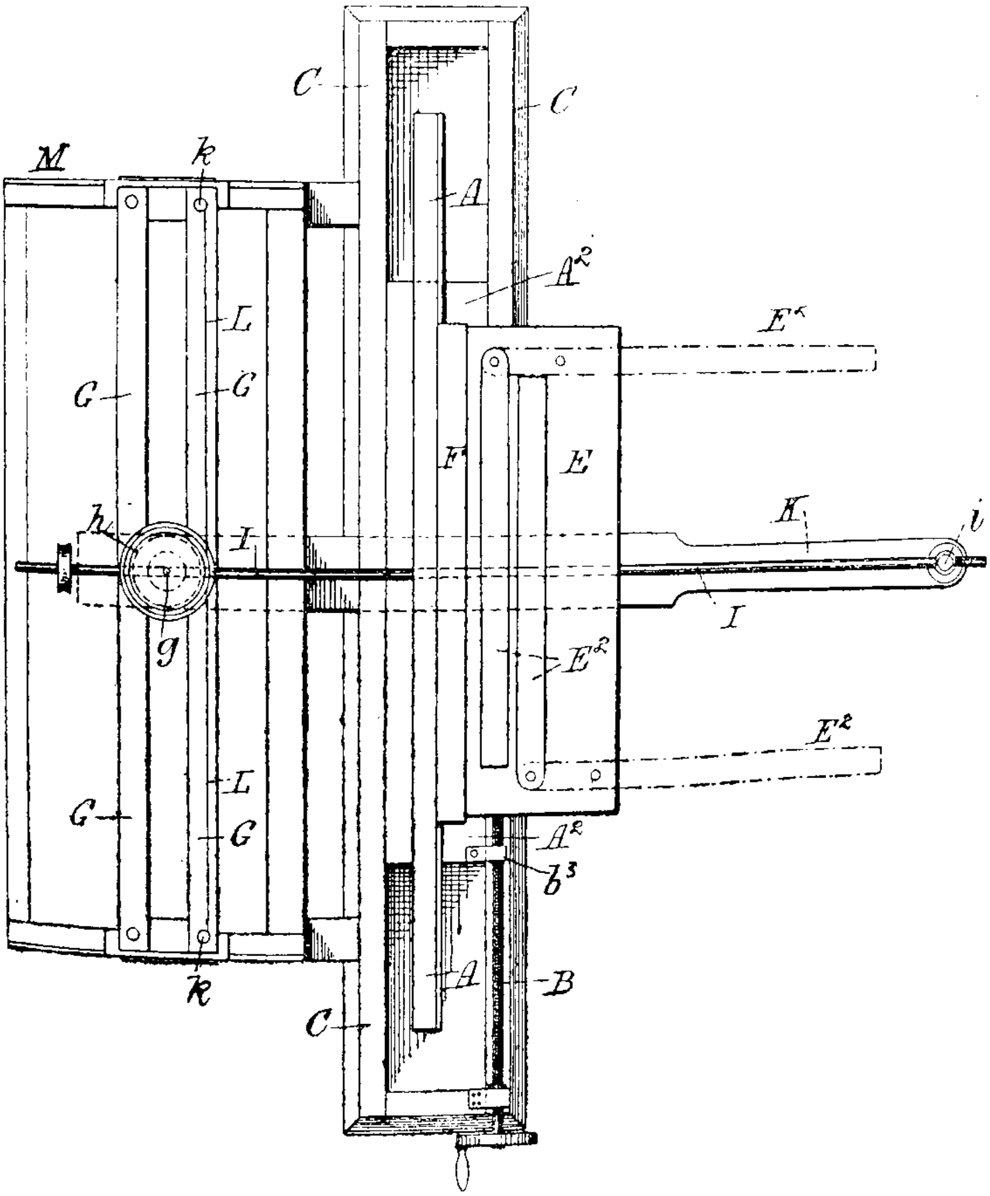


FIG. 3.

FIG. 3

and placed on the turntable. A catgut string (L) is passed from string clamp at one end of the guides (*k*) round the pulley groove and so to the string clamp at the opposite side (*k*). We place the object to be photographed on the pulley. A small piece of modelling wax will prevent accidental movements. We open the vertical slit in the screen by means of an arrangements of cords c, c^2, d, d^2, e, e^2, and erect the camera, so that the diaphragm of the lens is nearly over the pivot (*i*) and so that its axis is at right angles to the bed, and clamp the plate attached to the long screw in its place on the base of the screen. [255/256]

It will now be found, on turning the handle attached to the long screw, that the vertical slit in the dark screen travels across the field of the camera. Meanwhile, the turntable is caused by the steel rod to travel at a pace which, as compared with that of the slit, is proportionate to their respective distances from the pivot. The wooden pulley on the turntable, being confined by the coiled string, receives a movement of cycloidal rotation. If the ground glass of the camera is watched during the movement, the circumference of the object will seem as a plane surface seen through a narrow slit travelling from side to side of the plate.

The instrument is now ready for the more delicate adjustments. The distance

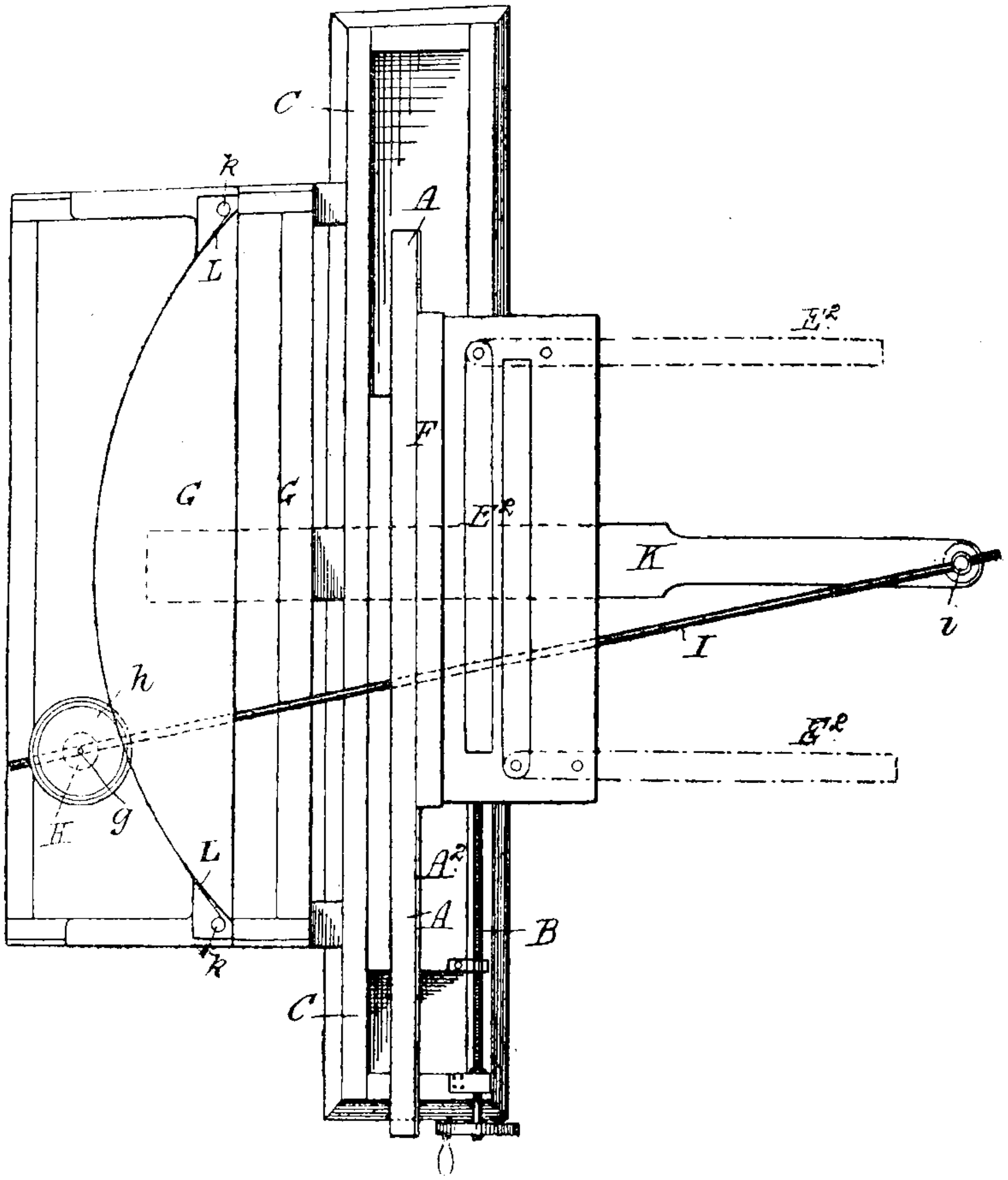
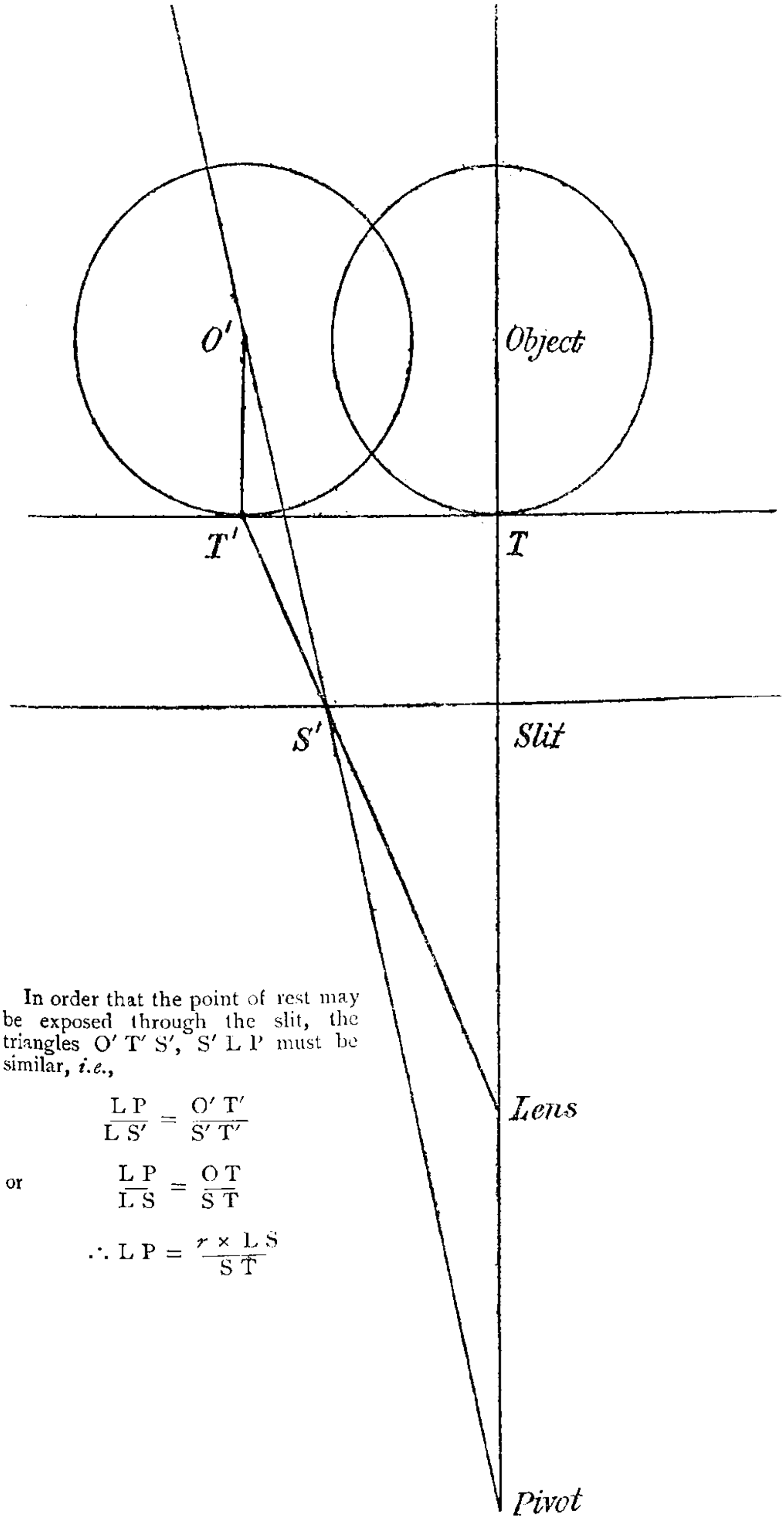


FIG. 4.

FIG. 4.

of the lens from the object is determined in the usual way, in order to make a photograph of the desired scale, or to include the desired portion of the circumference in the limits of the plate. The distance of the screen from the object must be sufficient for the object to be well lighted at the front. (This is assisted by white paper or other reflectors, pinned to the back of the screen.) The distance should not be much larger than is necessary for the lighting, because as the distance increases, the rod becomes less rigid and the movement less steady. On the other hand, however, the edges of the slit lose their sharpness, and any accidental [256/257]



In order that the point of rest may be exposed through the slit, the triangles O′ T′ S′, S′ L P must be similar, *i.e.*,

$$\frac{\text{L P}}{\text{L S}'} = \frac{\text{O}'\text{ T}'}{\text{S}'\text{ T}'}$$

or

$$\frac{\text{L P}}{\text{L S}} = \frac{\text{O T}}{\text{S T}}$$

$$\therefore \text{L P} = \frac{r \times \text{L S}}{\text{S T}}$$

irregularity is less conspicuous. In practice about 6 to 9 inches will usually be sufficient.

The position of the screen being fixed, the board and parallel guides are arranged in such position that the object is well lighted, and the lens is then erected at the proper distance from the object, in front of the screen. The position of the pivot should be nearly but not exactly under the optical centre of the lens. If the pivot is placed exactly under the optical centre of the lens the part of the object exposed to the lens would be that which is on the straight line joining the pivot with the centre of the object. It is desirable, however, to expose that portion of the circumference to which the string is tangential, since the movement of a point during exposure, is thus reduced to a minimum.

In order that this may be a constant condition the pivot should be placed behind the centre of the lens, at a distance equal to the expression

$$(\text{radius of object} \times \text{lens to slit}) / (\text{slit to object}).$$

Suppose we are photographing an object 3 inches in diameter, and that the slit is 6 inches from the object, and 12 inches from the lens, the pivot should be $(3 \times 12) / 6 = 6$ inches behind the centre of the lens. A less amount, however, is usually enough, if the shape of the camera makes it more convenient.

The width of the slit must next be determined. If the object is a true cylinder it will be found that the slit may be of any width up to about

$$(\text{radius} / 4) \times (\text{lens to object} / \text{lens to slit}).$$

It is advisable, however, not to make the slit narrower than necessary to obtain sharp definition, because a small slit involves a long exposure, and accidental irregularities in the light or the rate of movement have more effect.

[The above rule is based on the following considerations. The width of the slit must be such that a point on the circumference, while visible to the lens, shall not have a photographically noticeable movement. Suppose the width of the slit to be such that the lens sees an arc $r\,\theta$. In that case a given point on the circumference will be visible while the generating circle rotates through an angle whose circular measure is θ. The lateral movement of the point during exposure may be shown to be

$$r \{ \theta - 2 \sin (\theta / 2) \},$$

while its movement of approach and retreat is

$$r \text{ vers } (\theta / 2)$$

If the value of θ is small, these expressions are infinitesimal. For example, if $\theta = 1°$, the lateral movement is .0000003 r, and its movement of approach is .00004 r. If

$$\theta = 15°,\ r\,\theta = (\text{radius} / 4)\ (\text{nearly}).$$

The lateral movement = .0008 radius, and movement of approach and retreat .0085 radius, and it is found by experiment that this approaches the limit of what is photographically negligible. In order to expose through the slit a required arc, the arc and the width of the slit must be (nearly) proportional to their respective distances from the lens.

(slit / lens to slit) = (arc / lens to object) (nearly).

slit = arc × (lens to slit / lens to object) (nearly).

If θ = 15°, slit = (radius / 4) × (lens to slit / lens to object) (nearly).

For the final adjustments the lens is connected with the dark box, by means of dark cloths thrown over the movable arms (E^2) on the top of the dark box (E) and the subject is placed on the turntable, so that what is desired to be in the centre of the picture is exposed when the rod is in its middle position. After final focussing, and adjustment of the width of the slit, the screen and rod are drawn to one side, so that the left hand side of the subject is exposed at the right of the ground glass. The lens [258/259] is covered, and the plate placed in position as usual. To calculate the exposure, the operator must determine in the usual way the length of exposure required, considering the light, lens, stop, plate and subject, and must turn the handle at such a pace that the slit will travel its own width in the required number of seconds. We will suppose that the slit is *m* inches wide, and that an exposure is required of *n* seconds. The slit must travel *m* inches in *n* seconds.

1/28 of an inch (*i.e.*, one turn of the screw) in *n*/28*m* secs.

If, as often happens, the top or the bottom requires a longer exposure, the sides of the slit can be made to diverge. The exposure can also be lengthened if desired, for any part of the circumference of the object.

The exposure. All being thus prepared, the cap is taken off the lens, and the operator begins turning the handle as steadily as he can, at the required pace. If necessary, the exposure may be stopped for a time at any stage, if the lens is covered while the screw is at rest. It is advisable to begin and end the exposure slightly outside the parts required in the picture.

The epicycloidal method. The method of procedure is somewhat different in the case of the epicycloid, *i.e.*, in the case where the object rolls along the arc of a circle whose centre is the optical centre of the lens. Instead of the parallel guides, the curved guide (*cf.* fig. 4) is placed on the board, and the turntable is clamped to the rod so that it describes a part of a circle about the pivot. The rod is clamped at the pivot. The string is fastened to one of the clamping screws, led round the curved arc, round the pulley, again round the curved arc, to the second clamping screw. The arc is curved with a radius of 20 inches but it is not necessary that the pivot should be exactly at this distance. If it is at a less distance, the turntable will be a short distance from the guide, at the middle position, and if it is at a greater distance at the end positions. These discrepancies, if small, are negligible. It is necessary, however, that the string should be led round the arc of a circle. Otherwise, we have an error in the rate of angular rotation of the object.

[The rate of rotation is determined by the amount of string taken up by the pulley. When the arc is used the rolling circle generates an epicycloid. If, however, the string is stretched from the two pins to the pulley, the amount wound up, between two positions of the rod, is not equal to an arc of the circle about which the epicycloid is generated but to the difference of the chords drawn from one of the string-clamps to the tangent points in the two positions. If the two positions of the rod include an angle at the pivot of θ, and if the second position of the rod and the line joining the pivot with the string-clamp towards which the circle is rolling contain an angle of Φ, the error if the string is not led round the arc of a circle is

$r\ (\theta - 2 \sin\{(\theta + \varphi) / 2\} + 2 \sin\{(\varphi / 2\}).]$

The advantages of the epicycloid are—
(1) A gain in the sharpness of the focus.
(2) The placing of the pivot is simplified, as it should be exactly under the optical centre of the lens.

The disadvantage is that, as the rod diverges from the central position, there is an error of scale, each successive degree of the circumference of the object being spread out over a greater width on the plate. This, however, only becomes material when the rod has diverged about 6° from the central position.

[A series of equal arcs $r\ \theta$ of the circle of the described by a point on the rod are represented on the sensitive plate as a series of lines $r \tan \theta$, $r (\tan 2\ \theta - \tan \theta)$ &c. The 5th degree from the central line is elongated .63 per cent., the 10th degree 2.8 per cent., the 15th degree 7.7 per cent., and so on at a rapidly increasing rate.] [259/260]

NON-CYLINDRICAL FORMS.

Hitherto we have been proceeding on the assumption that the forms to be photographed are cylindrical. If the form varies from the cylinder, and forms a portion, say, of a cone or of a sphere, new considerations are involved. Suppose we are dealing with a part of a cone which may be represented in plan as a series of concentric circles.

The circumference which is equal to that of the pulley will be accurately rendered. The larger and smaller circumferences are liable to a double error. (1) Points on the circumferences other than that of the pulley have trochoidal not cycloidal paths. The further removed the point is from the principal circumference, the more obtuse are the cusps of its curve, and the less is the amount of angular rotation admissible without causing confusion in the photographic image. (2) As the object rotates, the larger circumferences are compressed and the smaller circumferences are spread out, thus distorting the total widths.

For the first error, it is useful to make the slit as narrow as possible, and thereby to make the angular rotation during the exposure of any point as small as possible. When only a part, less than a half of the circumference is required, the method of *Tilting the cone* is employed. In this case the cone is tilted on the pulley, and wedged up with wax or otherwise in such way that the important part of its surface may be made to coincide as nearly as possible with an imaginary cylinder erected on the pulley.

When the whole circumference is required, it is useless to tilt the cone. It is useful, however, to choose a pulley only slightly larger than the smallest circumference to be photographed, as points outside the principal circumference suffer less confusion than those within it. From the diagram of curves it is obvious that they move backwards and forwards during exposure and not in one direction alone. It is impossible, however, to state a definite rule, as the exact position will be determined by the comparative importance of the different parts of the subject.

When the smaller radius differs from the larger by more than about 15 per cent., if tilting is impossible, as in the case of a spheroid, we reach the limit of what is practicable without excessive distortion due to the spreading out of the smaller circles.

For some purposes, however, we obtain a useful and interesting correction, by placing the pivot behind the screen, opposite to the lens. The result of this arrangement is that the smaller arcs are spread over smaller spaces (see Fig. 3A), and by this method we can obtain a sharp photograph of a considerable portion of an almost spherical surface.

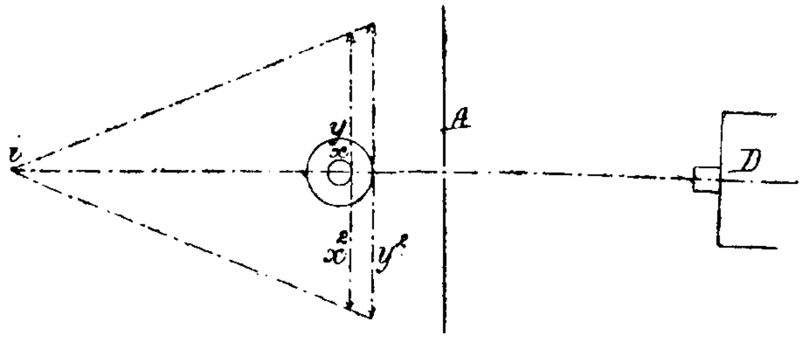


FIG. 3A.

FIG. 3A.

In this case the relations of the different parts become singularly complex, and I have tried without success to get light thrown on them by skilled mathematicians. I exhibit however a print of a photograph of three-quarters of the circumference of a strongly spheroidal vase. It will be seen that the result, though not free from distortion, gives a sharp image of quite small circumferences, and serves to give a [260/261] fair idea of the general decorations and subject on the vase, in a way that no other method could accomplish.

In this case it is obvious, on consideration that the slit and the object no longer cross the field at rates proportional to their distance from the lens. The slit starts behind the object, gradually catches it up, is opposite to the middle of it in the middle position, and then passes it. The result of all this is that we obtain a vase of a new and imaginary form in which the belts approximate in width to the circumferences of the object. The imperfection of the result is due to the fact that we cannot correct the foreshortening due to the vertical curvature.

The complexity of this arrangement is such that I have not been able to formulate any methodical way of working. The best result is obtained by making the distance of the lens from the object the maximum that is convenient; by bringing the object as near to the screen as the lighting permits, and the pivot near to the object. It may then be found by repeated trials how far the pivot must be withdrawn in order to show the important part of the subject, with a good margin on each side.

The PRESIDENT said he had had the pleasure of seeing an earlier and much rougher specimen of Mr. Smith’s apparatus, and the work done with even that imperfect model was sufficient to show that the instrument had a very useful practical application. The problem in itself was not a very complicated one although there was some difficulty in carrying it out mechanically. It was necessary to roll the cylinder round so that it exposed every point of its circumference in succession as it turned to the eye or to the lens, and as it rotated on its own vertical axis to cause it also to travel along such a path that each point of its circumference might occupy successively a different point in space. Then the lens must be made to follow that movement, and between the lens and the object there must be placed a screen through which might pass the rays from the narrow vertical bar in focus, and to carry all this out was a very difficult matter. Mr. Smith approached the problem from its mathematical side, and having first formulated the mathematical conditions of what was to be done he devised means to carry them into effect. There was no doubt about the practical value2 of the instrument, although its utility was confined almost entirely to work with things such as simple cylinders and which were capable of being mounted and revolved in front of the camera.

Mr. T. BOLAS said M. Damoiseau's cyclograph, and other instruments, photographed the inside of a cylinder or all round the horizon, but Mr Smith's device was very interesting as being the first to photograph the outside of a cylinder, the slot screen being necessarily close to the object. One of the earliest pantascopic cameras was introduced by Martens of Paris in the early Daguerreotype days (1845), the lens rotating on its so-called optical axis or between the gauss points. He thought Fox Talbot was the first to use a flexible band of sensitive material and to photograph all round a circle: at any rate Fox Talbot's patent specification, 12,906 of the year 1849, refers to the pantascopic principle.

Mr. J. TRAILL TAYLOR had seen and admired the early model of Mr. Smith's apparatus, and agreed as to the excellence of the completed specimen.

The PRESIDENT expressed the hope that he would continue his work and at some future time report to the Society as to his further progress.

A vote of thanks was passed to Mr. Smith.

[A. H. Smith, "The Cyclograph," *Photographic Journal*, vol. 19 (30 May 1895), pp. 253-261. The equations have been slightly altered in order to transcribe them in single line form. Numbers in square brackets separated by a slash (e.g. [253/254]) indicate the original page numbers.

Arthur Hamilton Smith (1860-1941) worked as a curator for the British Museum from 1886 to 1925; he was appointed Keeper of Greek and Roman Antiquities in 1909. Some of his cyclographs appear in A. S. Murray and A. H. Smith's *White Athenian Vases in the British Museum* (1896). According to the *Dictionary of National Biography*, Smith received a gold medal at the 1896 Berlin photographic exhibition for the cyclograph.

The reference by Thomas Bolas in the discussion to Talbot and Thomas Malone's patent 12,906 of 19 December 1849 (see abridgement at http://archive.org/stream/patentsforinven47offigoog#page/n38/mode/2up), relates to its 3rd part, which mentions sensitized transparent paper for "photographic pictures giving panoramic views of scenery, which are produced upon a curved surface by a movement of the object glass of the camera." However Talbot requested a disclaimer for this part of the patent (among others), and he may not have experimented with the concept.]