PATENT SPECIFICATION 704,150

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COMPLETE SPECIFICATION.

Improvements in and relating to Optical Systems for Galvanometers and the like.

We, THE BRITISH BROADCASTING CORPORATION, a British Body Corporate, of Broadcasting House, London, W.1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement :—

This invention relates to galvanometers and like instruments of the kind including a scale, an optical system and a reflecting member, the optical system being capable of producing on or approximately on the scale after reflection from said reflecting member a real image of an illuminated object, e.g. a narrow slit, the displacement of this image being representative of the rotary displacement of the reflecting member.

When a flat scale is used in such an instrument it is found that the image does not remain in focus over all the scale. The scale can be curved to fit the image plane of the optical system and the image will then remain in focus, but unless the optical path is inconveniently long or the angular displacement of the said member is small, a highly curved scale is required. Such a highly curved scale cannot be read conveniently and the apparent brightness of the image (i.e. the brightness as seen by a stationary observer) varies as the image is displaced over the scale.

The principal object of this invention is to provide an optical system with which one or both of the above-mentioned difficulties can be substantially overcome.

According to this invention, in an instrument of the kind specified, the optical system includes a cylindrical or spherical concave mirror disposed in the optical path between the reflecting member and the scale, the arrangement being such that the radius of the reflecting member in the absence of the concave mirror, the axis of the said circular locus of a real image produced by the optical system and the circular locus being coincident with the axis of rotation of the reflecting member, is less than the radius of curvature of the said concave mirror, which when in position is located between the scale and the said locus of the real image.

In such an instrument in which the concave mirror and the scale are cylindrical the geometrical axes of the concave mirror and the scale and the axis of rotation of the reflecting member are arranged to lie in the same plane and may be parallel to each other. Alternatively the axis of rotation of the reflecting member may be inclined relatively to the other two axes. The corresponding disposition of the concave mirror when this is spherical will be apparent to those skilled in the art. The optical system may include one or more further mirrors disposed in the optical path between the concave mirror and the reflecting member and/or between the concave mirror and the scale. When the optical system does not include such a further mirror, preferably the scale is so disposed that, as seen in plan, its plane is located between the planes of the concave mirror and the reflecting member. The scale may be viewed from a position located on the side of the scale remote from the concave mirror or alternatively the optical system may be so arranged that the scale may be viewed from a position located on the side of the scale near to the concave mirror. The scale may be arranged to form part of the front face of a container enclosing the instrument.

An embodiment of this invention will now be described, by way of example, with reference to the accompanying diagrammatic drawing showing an optical system for a mirror galvanometer, wherein :—

Fig. 1 is a plan view of the optical system, showing only the axial ray of the light pencil forming the observed image ;

Fig. 2 is a view in elevation of the system in Fig. 1, the vertical spacing of the members being exaggerated for the sake of clarity ; and

Fig. 3 is a view in elevation of a modification of the optical system shown in Figs. 1 and 2.

An image of a light source 1 is focussed on to a slit in a diaphragm 2 by a condenser lens system 3. A plane mirror 4, forming part of the reflecting member of the galvanometer, is rotatable about an axis 5 lying in the plane of the mirror. Light from the slit 2 is projected towards the galvanometer mirror 4 by a lens 6 and would form a first real image at I if a cylindrical mirror 8 were absent. Rotation of the galvanometer mirror 4 would cause this first real image to describe a circular locus 7 of radius Ra about an axis 5. The cylindrical mirror 8 is of radius Rb and is so disposed that its axis of curvature lies at 9 on the further side of the galvanometer mirror 4 with respect to the mirror 8, and spaced a distance Z from the axis 5, the two axes lying in the same plane.

A graduated scale 10 (in this example a cylinder of radius Rc) is located, as seen in plan in Figure 1, between the cylindrical and galvanometer mirrors 8 and 4 respectively : the axis of curvature of the scale 10 is disposed at 11 and lies in the same plane as the axes 5 and 9. The scale 10 lies substantially in the plane of the real image of the slot 2 formed at F by the lens 6 in combination with the cylindrical mirror 8. In this embodiment Ra is 10 cms., Rb is 17 cms. and Z is 9 cms.

It is found in this example that the value of Rc to give a scale which most nearly coincides with the image at F is 88 cm. The length of scale 10 which can be obtained is limited to about 16 cm. since it must be possible to reflect light from the mirror 4 under the scale 10 and on to the cylindrical mirror 8.

In this example the axes 5 and 9 and the axis of the scale are parallel to each other, but in some embodiments these axes, whilst lying in the same plane, may be inclined relatively to one another. In Figs. 1 and 2 if the axes are vertical then the scale, the galvanometer and the cylindrical mirrors and the lens 6 are disposed in different horizontal planes perpendicular to the axes, thus enabling the light rays to pass from one member to the other without obstruction. The scale 10 preferably is observed from a position on the side of the galvanometer mirror 4 remote from the cylindrical mirror 8, but if the scale is located above or below the cylindrical mirror 8 so that as seen by the observer the scale is clear of the cylindrical mirror, the scale may be viewed from a position on the side of the cylindrical mirror 8 remote from the galvanometer mirror 4.

In a modification (not shown) of the embodiment shown in Figs. 1 and 2 the light source 1, the slit 2, the lenses 3 and 6 and the galvanometer mirror 4 are disposed, as seen in plan, on the opposite side of the cylindrical mirror 8 to that shown in Figure 1, and a further mirror is disposed to reflect light from the galvanometer mirror on to the cylindrical mirror, thus turning part of the optical path through approximately 180° relatively to the remainder of the path and permitting a more compact construction of the instrument.

In known constructions of mirror galvanometers the displacement of the image on the scale is proportional to the tangent of twice the angle of rotation of the galvanometer mirror. It has been found that a displacement/rotation relationship which more closely follows a linear law can be obtained by tilting the axis 5 of the galvanometer mirror 4 relatively to the axes of the cylindrical mirror and the axis 9, and/or by arranging that the axis 5 does not lie in the plane of the reflecting surface of the galvanometer mirror 4. Thus, in the modification shown in Fig. 3 the axis 5 of the galvanometer mirror 4 is tilted, in the plane of the axes 5, 9 and 11, clockwise through about 10°. The scale 10 comprises part of the front face of a container 12 enclosing the galvanometer.

When designing a mirror system in which the observer is presented with an image on a viewing screen which is to be uniformly bright at all parts on the screen the following facts must be borne in mind.

Strict computation of the ray-paths in systems of the kind in accordance with the invention shows that there is no unique position for the observer but, in practice, there is such a position. The strict computation assumes that the observer must place his eye at the point at which the ray BB^1 reflected from the cylindrical mirror 8 cuts the axis AA^1, i.e. at D, and D is found to move further away from the axis 9 as the angle α is increased. In practice there are two factors which allow the observer's position to be fixed : firstly, the angle α will rarely exceed 45°, and secondly, the eye is not critical of changes in the distance D9 when α is small. If the mirror system is designed on the basis of the largest value of α which is to be used (and if this value does not exceed about 45°) the observer will at all points on the scale experience the desired illusion of viewing the light source 1 as immediately behind the illuminated patch of light on the scale 10. Moreover, since the scale is illuminated by rays which are nearly normal to it, an observer who fails to select the ideal viewing position will see the scale uniformly lighted, no matter what the deflection (within the limit of 45°). However, when the observer is in the correct position, the brightness is increased very greatly.

Simple trigonometrical analysis of Fig. 1 is possible if certain assumptions are made.

For example, it will be assumed that the maximum value of α is 45°, (i.e. the maximum angle subtended by the scale at the axis 5 is 90° and the maximum angular rotation of the mirror 4 is 45°). It will also be assumed that the viewing distance BD (hereafter called the distance Y) is also fixed at, say, 20 inches.

If, now, various values of the half-chord BE of the scale BB_1 are chosen the corresponding values of Z and Rb (the radius of the cylindrical mirror 8) can be calculated.

These calculations determine the conditions which so define the line of sight of the observer that, when he is in a fixed position, the line of sight directed towards the spot of light on the scale, when extrapolated, includes the source of light 1. In the following table D5 is the distance between the axis 5 and the point D, a is the distance between the points O and I, b the distance between the points E and O, and e the distance between the points E and F.

All measurements are in inches.

TABLE 1.

S = BE	Rc	D5	Rb	Z	a	b	e	$(b-e)$
1	13.09	1.414	2.465	1.253	0.202	0.212	0.038	0.174
2	16.10	2.828	4.663	2.218	0.379	0.450	0.124	0.326
4	18.05	5.656	8.534	3.439	0.650	1.007	0.443	0.564
6	18.64	8.484	11.572	3.896	0.810	1.656	0.996	0.690
8	18.69	11.310	14.200	3.732	0.846	2.468	1.712	0.756
10	18.46	14.142	16.472	3.032	0.748	3.395	2.709	0.686
12	17.95	16.971	18.315	1.836	0.492	4.478	4.012	0.466

It will be observed that $D5 = S\sqrt{2}$. This is firstly because α is taken as 45°, and secondly because at this point, being one extreme end of the scale, the image of the light source 1 is focussed onto the mirror surface. In practice, it is impossible to use the whole of the scale length, since a certain space is required between the scale 10 and the cylindrical mirror 8 for the reason given above. About 70% of the scale length quoted in Table 1 can be utilised.

When considering the shape of the scale it is ound that a practical compromise is again possible. Computation shows that if the second real image is formed at B when α is 45° and α is then reduced by rotating the mirror 4, the locus of the images formed is never a simple curve. For the cases which are being considered the locus closely approximates to an arc of a circle. The point F at which the second real image is formed when α is zero is readily computed. An arc which passes through B, F and B_1 fits very closely the locus of the images formed as α increases from zero to 45°. The relevant radii Rc have been computed and are shown in the table above.

It will be seen that the scale has a radius very nearly equal to Y (i.e. 20 ins.) and the observer views the scale from a point very near to its axis 11, for values of S between 3 and 12 inches. This is a great advantage since no part of the scale is forshortened.

In practice the exact location of the scale is not important and even a flat or slightly convex scale can be used without any obvious change in the sharpness of the image. In many cases it may be desirable to use a flat scale instead of the curved scale in order to provide an increased clearance between the cylindrical mirror 8 and the scale 10. Examination of Table 1 will show that the distance FO, which is equal to $(b-e)$, reaches a maximum of 0,760 inches when S is about 8.0 inches, and falls rapidly as S is increased beyond this point. By using a less curved or a flat scale and slightly defocussing the second real image obtained at the centre of the scale, the clearance $b-e$ can be made to approach the value b as closely as is desired. In this respect it will be observed that for a value of S of about 8 inches the distance D5 is of the order of about 11 inches. Therefore, small changes of the order of 1/2 inch in the position of the scale will have very little visible effect upon the sharpness of focus of the image on the scale.

For the same reason critical adjustment of any of the other parameters given in Table 1 is unnecessary and the optical system can be constructed using dimensions which are only approximations of the ideal values.

The final adjustment of the system to make Y of the correct value can then be made by adjusting the value of D5, i.e. by adjusting the position of the lens 6 along the optical axis. Experience shows that this adjustment of the lens 6 is very easily done.

It will be apparent that in the construction in Fig. 1 only about 80% of the maximum available rotation of the mirror 4 can be utilised (i.e. 35° instead of 45°). However, in optical systems in which it is not essential that the image on the scale is accurately in focus (e.g. in galvanometers and the like) values of α up to at least 45° may be utilised by moving the scale out of the ideal position to allow clearance for the reflection path. Displacement of the scale by an inch or more is found to be tolerable with a value of S of about 6 inches.

If it is desired particularly to arrange that the image on the scale is in focus over the whole scale, the feature of the equal-brightness of the image being of secondary importance, the values of D5, a and Rb can be calculated as follows. This arrangement has the advantage that a greater clearance can be provided between the cylindrical mirror 8 and the scale 10.

It is assumed that a clearance $b-e$ is required between the scale and the cylindrical mirror, and that b is approximately twice $(b-e)$.

Then if $\frac{Rb}{Rc} = 1-K$, where K is an arbitary integer, it can be shown that $b-e/b = 1-K$, from which relation the estimation of b can be checked and corrected if necessary.

The value of a can then be calculated from the relation $a = K.(b.Rb)/(Rb-2b.K)$ and the value of D5 from the relation $D5 = 1/2((S^2/a+b)+(a+b))$.

For the case when the scale is flat, Rc is regarded as being infinite in value and the integer K has the value 1. Moreover, e is zero so that the value of b is known accurately and the values of D5, a and Rb can be calculated immediately.

What we claim is:—

1. An instrument of the kind specified wherein the optical system includes a cylindrical or spherical concave mirror disposed in the optical path between the reflecting member and the scale, the arrangement being such that the radius of the circular locus of a real image produced by the optical system and the reflecting member in the absence of the concave mirror, the axis of the said circular locus being coincident with the axis of rotation of the reflecting member, is less than the radius of curvature of the said concave mirror, which when in position is located between the scale and the said locus of the real image.

2. An instrument as claimed in Claim 1, wherein the concave mirror and the scale are cylindrical and the geometrical axes of the concave mirror and the scale and the axis of rotation of the reflecting member are arranged to lie in the same plane and are parallel to each other.

3. An instrument as claimed in Claim 1, wherein the concave mirror is cylindrical and its geometrical axis and the axis of rotation of the reflecting member are arranged to lie in the same plane and are inclined relatively to one another.

4. An instrument as claimed in any of Claims 1 to 3, wherein the optical system includes one or more further mirrors disposed in the optical path between the concave mirror and the reflecting member and/or between the concave mirror and the scale.

5. An instrument as claimed in any of the preceding claims, wherein the scale forms part of the front face of a container enclosing the instrument.

6. An instrument substantially as hereinbefore described with reference to the accompanying drawing.

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PROVISIONAL SPECIFICATION.

Improvements in and relating to Optical Systems for Galvanometers and the like.

We, THE BRITISH BROADCASTING CORPORATION, a British Body Corporate, of Broadcasting House, London, W.1, do hereby declare this invention to be described in the following statement:—

This invention relates to galvanometers and like instruments of the kind including a scale, an optical system and a reflecting member, the optical system being capable of producing on or approximately on the scale after reflection from said reflecting member a real image of an illuminated object, e.g. a narrow slit, the displacement of this image being representative of the rotary displacement of the reflecting member.

When a flat scale is used in such an instrument it is found that the image does not remain in focus over all the scale. The scale can be curved to fit the image plane of the optical system and the image will then remain in focus, but unless the optical path is inconveniently long or the angular displacement of the said member is small, a highly curved scale is required. Such a highly curved scale cannot be read conveniently and the apparent brightness of the image (i.e. the brightness as seen by a stationary observer) varies as the image is displaced over the scale.

The principal object of this invention is to provide an optical system with which one or both of the above-mentioned difficulties can be substantially overcome.

According to this invention, in an instrument of the kind specified, the optical system includes a cylindrical or spherical concave mirror disposed in the optical path between the reflecting member and the scale, the arrangement being such that the virtual image produced by the concave mirror corresponding to the said real image is disposed at a distance behind the said mirror less than its radius or curvature.

In such an instrument in which the concave mirror and the scale are cylindrical the geometrical axes of the concave mirror and the scale and the axis of rotation of the reflecting member are arranged to lie in the same plane and may be parallel to each other. Alternatively the axis of the reflecting member may be inclined relatively to the other two axes. The corresponding disposition of the concave mirror when this is spherical will be apparent to those skilled in the art. The optical system may include one or more further mirrors disposed in the optical path between the concave mirror and the reflecting member and/or between the concave mirror and the scale. When the optical system does not include such a further mirror, preferably the scale is so disposed that its plane is located between the planes of the concave mirror and the reflecting member. The scale may be viewed from a position located on the side of the scale remote from the concave mirror or alternatively the optical system may be so arranged that the scale may be viewed from a position located on the side of the scale near to the concave mirror. The scale may be arranged to form part of the front face of a container enclosing the instrument.

An embodiment of this invention will now be described, by way of example, with reference to the accompanying drawing showing an optical system for a mirror galvanometer :—

An image of a light source 1 is focussed on to a slit 2 by a condenser lens system 3. A plane mirror 4, forming part of the reflecting member of the galvanometer, is rotatable about an axis 5 lying in the plane of the mirror. Light from the slit 2 is projected towards the galvanometer mirror 4 by a lens 6 and would form a first real image at I_1 if a cylindrical mirror 8 were absent. Rotation of the galvanometer mirror 4 would cause I_1 to describe a circular locus 7 of radius R*a* about an axis 5. The cylindrical mirror 8 is radius R*b* and is so disposed that its axis of curvature lies at 9 on the further side of the galvanometer mirror 4 with respect to the mirror 8 and spaced a distance C from the axis 5, the two axes lying in the same plane.

A graduated scale 10 (in this example a cylinder of radius R*d*) is located between the cylindrical and galvanometer mirrors 8 and 4 respectively: the axis of curvature of the scale 10 is not shown, but lies in the same plane as the axes 5 and 9. The scale 10 lies substantially in the plane of the real image I_2 of the slit 2 formed by the lens 6 in combination with the cylindrical mirror 8. In this embodiment R*a* is 10 cms., R*b* is 17 cms. and C is 9 cms.

It is found in this example that the value of R*d* to give a scale which most nearly coincides with the plane of the image I_2 is 88 cm. The length of scale 10 which can be obtained is limited to about 16 cm. owing to the position of the scale relatively to the cylindrical mirror 8.

In this example the axes 5 and 9 and the axis of the scale are parallel to each other, but in some embodiments these axes, whilst lying in the same plane, may be inclined relatively to one another. Assuming the axes to be vertical then, in general, the scale, the galvanometer and the cylindrical mirrors and the lens 6 will be disposed in known manner in different horizontal planes perpendicular to the axes to enable the light rays to pass from one member to the other without obstruction. The scale 10 may be observed from a position on the side of the galvanometer mirror 4 remote from the cylindrical mirror 8, but if the scale is disposed in a horizontal plane located above or below the horizontal plane in which the cylindrical mirror 8 is disposed, so that the scale is clear of the cylindrical mirror, the scale may be viewed from a position on the side of the cylindrical mirror 8 remote from the galvanometer mirror 4.

In a modification (not shown) of the embodiment described above the light source 1, the slit 2, the lenses 3 and 6 and the galvanometer mirror 4 are disposed on the opposite side of the cylindrical mirror 8 to that shown in the drawing, and a further mirror is disposed on the side of the scale remote from the cylindrical mirror, the further mirror is arranged to reflect light from the galvanometer mirror on to the cylindrical mirror, thus turning part of the optical path through approximately 180° relatively to the remainder of the path and permitting a more compact construction of the instrument.

The scale 10 can be made part of the front face of a container enclosing the galvanometer.

By suitable choice of the values of R*a*, R*b* and C other constructions embodying the invention can be obtained in which the scale is substantially flat, convex or concave to an observer as desired, the image obtained on the scale being approximately in focus over the whole of the scale.

In known constructions of mirror galvanometer the displacement of the image on the scale is proportional to the tangent of twice the angle of rotation of the galvanometer mirror. In some embodiments of this invention it can be arranged that the above-mentioned displacement/rotation relationship follows a law which is other than the said tangent law, e.g. the displacement of the image I_2 may be proportional to the tangent of an angle which is less than twice the angle of rotation of the mirror 4.

In addition, it has been found that a relationship which more closely follows a linear law can be obtained by tilting the axis 5 of the galvanometer mirror 4 relatively to the axes of the cylindrical mirror and the axis 9, and/or by arranging that the axis 5 does not lie in the plane of the reflecting surface of the galvanometer mirror 4.

It is found that, by suitable adjustments of the parameters Ra, Rb, and C the image I_2 will, for all angular positions of galvanometer mirror 4, appear, to an observer located at some point on the axis of symmetry I_2, 5, 9, to be uniformly brilliant. The distance at which the observer must be located to obtain this effect is variable within wide limits by altering the relative proportion of the three parameters, Ra, Rb and C. The value of Rd, which will bring I_2 into exact focus, is different in each case; but it is found in practice that a compromise can often be made, one value of Rd giving satisfactory focus for a variety of values of Ra, Rb and C.

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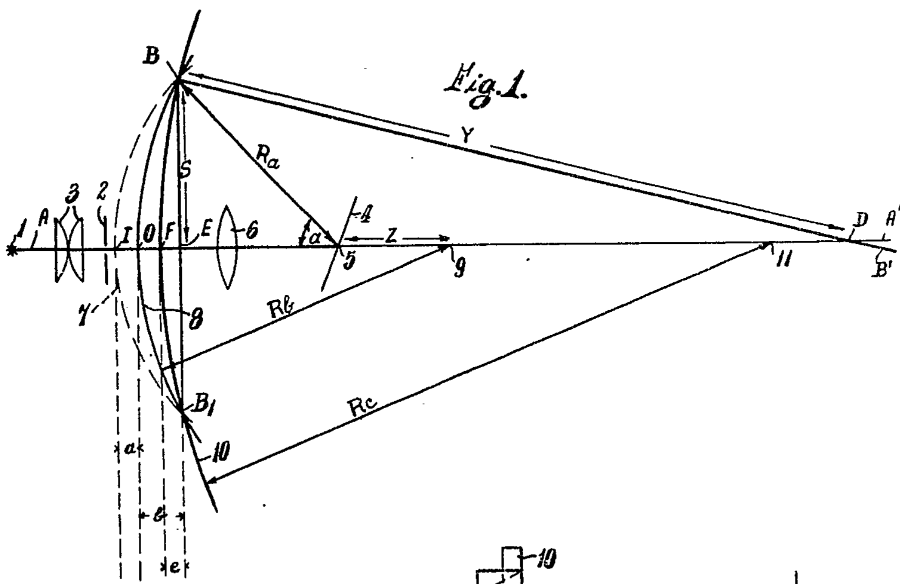

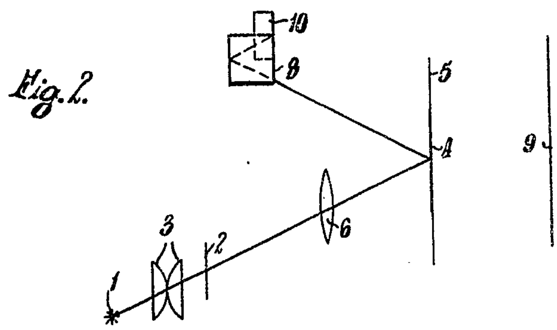

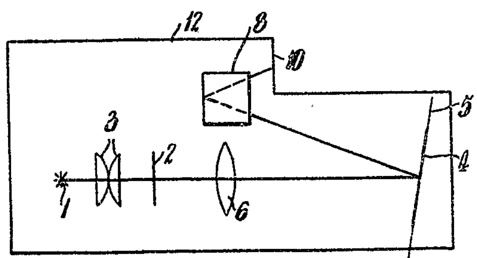

704,150 PROVISIONAL SPECIFICATION

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