

[54] CATOPTRIC LENS ARRANGEMENT
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240/41.1, 240/46.45
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[58] Field of Search 240/4.1, 46.45; 350/288,
350/293, 294, 299, 296

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[57] **ABSTRACT**
Improved catoptric lens arrangements to form a beam from an extended source of wave propagated energy are shown. In the preferred embodiment a substantially cylindrical source, as an incandescent filament, is disposed so that its longitudinal axis is coincident with the axis of symmetry of at least one paraboloidal mirror, such axis being perpendicular to the principal axis of the parabola generating such mirror and being spatially separated from the focal point of such parabola. A light baffle is provided so that the rays from the source impinging on the at least one paraboloidal mirror are limited to those rays which cross the principal axis on one or the other side of the focal point of the generating parabola.

2 Claims, 3 Drawing Figures

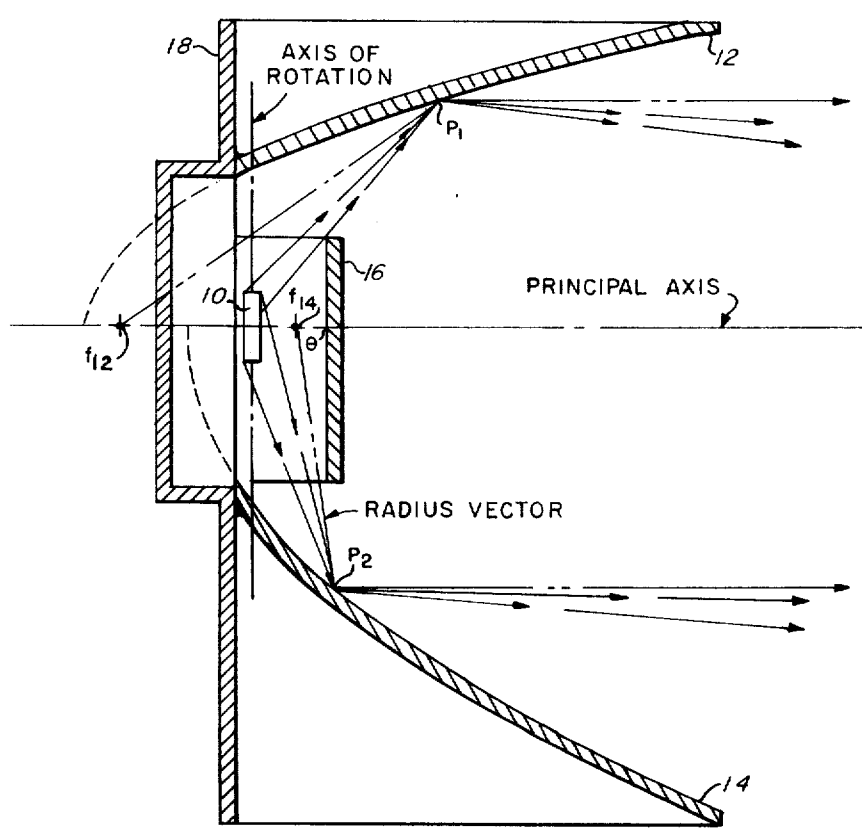
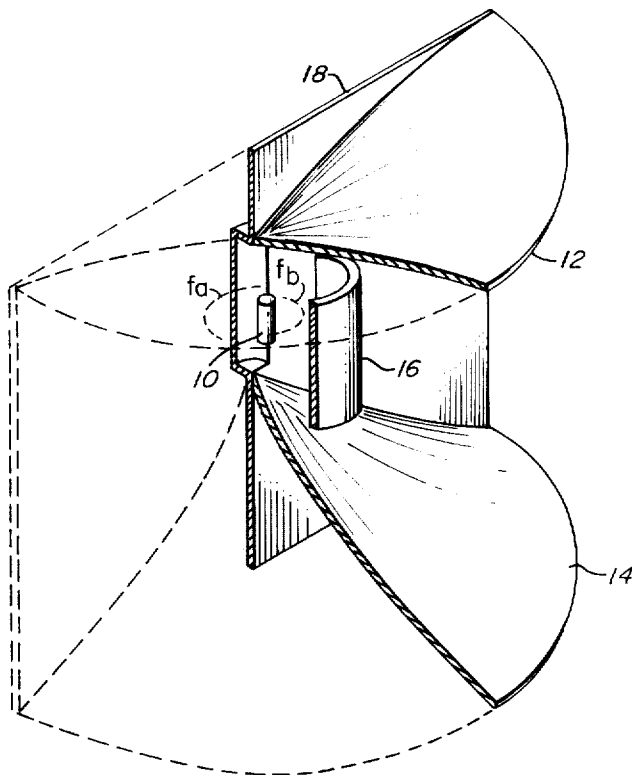


FIG. 1



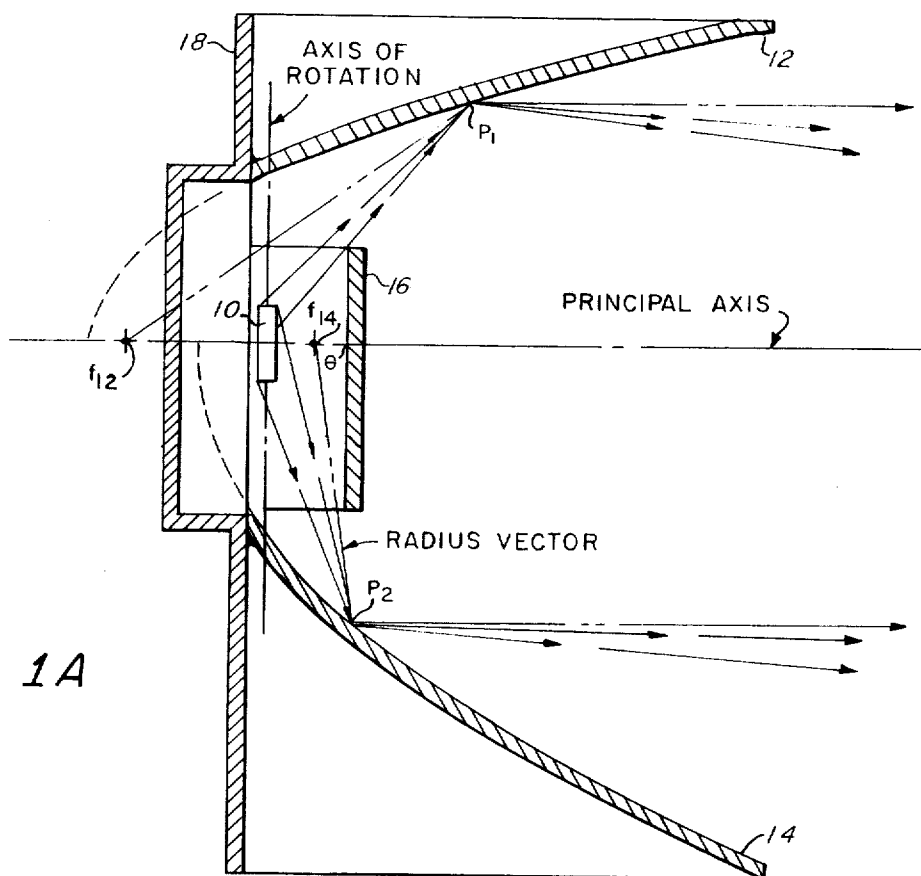


FIG. 1A

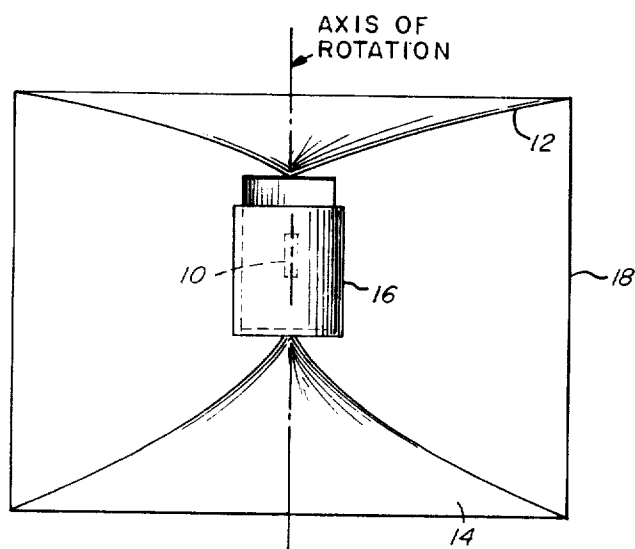


FIG. 1B

CATOPTRIC LENS ARRANGEMENT

BACKGROUND OF THE INVENTION

This invention pertains generally to catoptric lens arrangements and particularly to arrangements of such sort used to direct wave-propagated energy.

For convenience, the following definitions will be used in connection with the catoptric lens arrangements referred to hereinafter.

- a. focal curve — the locus of the focal point of a generatrix of a reflecting surface when such generatrix is moved relative to a reference line; if the generatrix is rotated, or nutated, about an axis of symmetry not passing through the focal point, the focal curve may be referred to as a focal circle or focal arc; if the generatrix is translated with respect to its axis of symmetry, the focal circle may be referred to as a focal line;
- b. meridional plane — any cross-sectional plane passed through nonparallel reflecting surfaces having a common axis of symmetry in a manner that such common axis and the normal to the reflecting surfaces at any point on the lines of intersection between the cross-sectional plane and nonparallel reflecting surfaces lie in the cross-sectional plane; if the reflecting surfaces themselves are divergent planes, any cross-sectional plane orthogonal to both reflecting surfaces and to the intersection between such surfaces is a meridional plane;
- c. nonmeridional plane — any cross-sectional plane passed through nonparallel reflecting surfaces having a common axis of symmetry to intersect such axis at a point, all of the normals to the reflecting surfaces along the lines of intersection between such cross-sectional plane and such nonparallel reflecting surfaces not lying in such plane;
- d. reflection plane — any plane defined by a ray incident on a reflecting surface and the normal to such surface at the point of incidence; if any particular reflection plane is coincident with a meridional plane, all rays in that reflection plane may be referred to as meridional rays and if any particular reflection plane is coincident with a nonmeridional plane, all rays in that reflection plane may be referred to as nonmeridional rays;
- e. ideal ray — any ray that actually or apparently originates at, or is (after reflection) directed toward, a focal point or a focal curve of a reflecting surface; if the generatrix of the reflecting surface is a parabola, such a curve is hereinafter deemed to have an imaginary focal point, or focal curve, at infinity;
- f. meridional plane aberration — the angular difference, if any meridional plane, between an ideal ray reflected from a point on a reflecting surface and any meridional ray reflected from the same point;
- g. nonmeridional plane aberration — the angular difference, measured in any reflection plane coincident with a nonmeridional plane, between an ideal ray reflected from a point on a reflecting surface and any nonmeridional ray in that reflection plane and reflected from the same point;
- h. Rambauske mirrors — at least a pair of mirrors wherein the generatrices of the reflecting surfaces are sections of curves having a focal point moved relative to a reference line to cause the locus of each one of the focal points to be a focal curve as

defined hereinbefore; in a catoptric lens arrangement, two, or more, Rambauske mirrors may be positioned so that their focal curves are coincident, i.e., confocal, or spaced one from another in a predetermined manner.

It is known in the art that a catoptric lens arrangement may be utilized to direct substantially coherent wave-propagated energy, as light in a beam from a laser, in any desired manner (within limits imposed by the effects of diffraction arising out of the finite dimensions of the exit aperture of such an arrangement). Thus, as described in detail in the copending U.S. application of Werner R. Rambauske, entitled "Catoptric Lens Arrangement," Ser. No. 244,393, filed Apr. 17, 1972, (which application is assigned to the same assignee as this application) various diffraction-limited catoptric lens arrangements are shown. The just-cited application shows that a catoptric lens arrangement incorporating at least two confocal Rambauske mirrors may direct a laser beam, or a beam of any type of wave-propagated energy. In particular, the cited application shows that the Rambauske confocal mirrors may have reflecting surfaces whose generatrices are portions of any quadratic conic sections (excepting the circle) rotated or nutated about axes of symmetry not containing both focal points of the selected curve. (As noted hereinbefore in the definition of an ideal ray, if the generatrix is a portion of a parabola, a virtual focal point at infinity may be deemed to be the second focal point). All rays in a beam from an ideal source of coherent wave-propagated energy positioned at one focal point of the entrance mirror in such an arrangement are, therefore, ideal rays which are directed without aberration by such an arrangement.

As noted, the catoptric lens arrangement shown in the cited application is used to direct the rays in a beam from a laser. While such a device may ordinarily be considered to be a completely coherent source, i.e. a point source producing a narrow beam, it is self-evident that a completely coherent source is a physical impossibility. That is, some of the rays from even a laser are not ideal rays. Further, it is obvious that the positioning of a laser so that its beam apparently originates at a focal point of any catoptric lens arrangement may be difficult to achieve. Mispositioning of the laser adds to the deviation of the rays in the beam from ideal.

Fortunately, when a laser is used as a source of coherent light, even the aberrations (if such are significant) caused by the just-mentioned anomalies may be substantially reduced by adjustment of any catoptric lens arrangement using Rambauske mirrors. That is, as described in the cited application, the relative positions of the Rambauske mirrors may be adjusted so that their focal curves are not coincident, but rather are spaced apart along the line between the coherent source and such mirrors. With proper spacing between such mirrors, at least "narrow field" aberrations, i.e., spherical aberration and coma, may be significantly reduced to attain diffraction-limited operation. This is so even though the source may be not perfectly coherent or positioned.

While the just-mentioned method of compensating for narrow field aberrations is effective when light from an almost completely coherent source, as a laser, is passed through any known catoptric lens arrangement using Rambauske mirrors, a different situation obtains when light from an extended source, as an incandes-

cent or a fluorescent lamp, is to be formed into a beam. That is, because the rays from each different point in an extended source are spatially different, the compensation technique used for eliminating (for all practical purposes) aberration resulting from inherent characteristics or positioning of any known coherent source may not lead to totally successful results when light from an extended source is to be corrected for aberrations.

When light from an extended source, as a luminescent filament in an incandescent lamp, is to be directed in a beam of any desired shape, it is well known to combine reflective and refractive lens elements to form such a beam. Thus, for example, conventional headlamps for automobiles usually incorporate the combination of a concave paraboloidal mirror and a refractive lens disposed over the exit aperture of such a mirror. An incandescent light is disposed as near the focal point of the concave paraboloidal mirror as possible. Light reflected from such mirror then is directed through the refractive lens, along with unreflected light from the incandescent light. Obviously, because the light finally passing through the refractive lens apparently originates at many different points, a simple refractive lens cannot properly direct all of such light. The refractive lens in a conventional headlamp, therefore, is made up of a number of lenslets, each covering a relatively small portion of the exit aperture of the concave paraboloidal mirror. With such design, each lenslet may be shaped and oriented so that the finally emergent light is directed generally in a desired direction.

Although an acceptable beam may be formed by a conventional automobile headlamp, many difficulties and shortcomings are experienced. For example, light falling on the junction between adjacent lenslets cannot be properly directed. Such light, if permitted to pass without change, contributed to glare in the eye of an observer; on the other hand, if redirected, such light contributes little, if any, illumination in the desired field. Further, because of the curvature of each lenslet, some of the light falling on the surface may be reflected back onto the paraboloidal mirror and, after further reflection, either contribute to glare or be lost. Finally, and probably most important from the point of view of the optical designer, the necessity of using many lenslets, each having its own axis of symmetry but required to redirect rays apparently originating at points on or off such axis, makes it manifest that the optimum design of each one of such lenslets may be, at best, a compromise design. That is, optimum design involves balancing the effects of incorrectible deficiencies, rather than increasing efficiency or providing a better beam.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide an improved catoptric lens arrangement for forming a beam from the light emitted by a source of finite dimensions; and

another object of this invention is to provide an improved catoptric lens arrangement for controlling the sense of the aberration in the emergent beam.

These and other objects of this invention are attained by providing a pair of nonconfocal Rambauske mirrors formed by rotating portions of two concave parabolas about an axis of rotation orthogonal to a line joining the focal points of such parabolas and intersecting such

line intermediate such focal points. A substantially cylindrical source of light is disposed so that its longitudinal axis is coincident the axis of rotation and baffles are provided so that the emergent beam is made up entirely of rays reflected from either one of the Rambauske mirrors.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this invention, reference is now made to the following description of the accompanying drawings, wherein:

FIG. 1 is an isometric view, partially cut away, of a preferred embodiment of this invention;

FIG. 1A is a cross-sectional view showing the manner in which meridional rays are reflected in the embodiment shown in FIG. 1; and

FIG. 1B is a front view of the embodiment shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the Figures, it may be seen that a beam forming arrangement according to this invention includes a substantially cylindrical source of light, as the filament in an incandescent lamp 10, mounted between the focal circles f_{12} , f_{14} of a pair of Rambauske mirrors 12, 14. As shown most clearly in FIG. 1A, the generatrices of the Rambauske mirrors 12, 14 here are sections of parabolas having coincident principal axes. The filament of the incandescent lamp 10 is oriented as indicated so that its longitudinal axis corresponds with the axis of rotation, or symmetry, of the Rambauske mirrors 12, 14 and is disposed between such focal points. The axis of rotation of the generatrices preferably is orthogonal to the principal axis. To complete the illustrated assembly, a semicylindrical baffle 16 and backplate are provided as shown. The latter two elements here are non-reflective, the length of the semicylindrical baffle 16 being such that no rays from the incandescent source 10 may pass directly through the exit aperture (not numbered) between the Rambauske mirrors 12, 14. It is deemed evident that the various illustrated elements may be secured together in any conventional manner. Further, it is deemed evident that the incandescent lamp 10 may be energized in any convenient manner.

It will be seen in FIG. 1A that there are rays emanating from the incandescent lamp 10 which directly impinge on the Rambauske mirror 12. Upon reflection from that mirror, such rays are directed through the exit aperture. The magnitude of the aberration suffered by any one of such reflected rays, as illustrated by the exemplary rays incident at the point marked P_1 , is a function of the angular difference between each ray and an ideal ray incident at the same point. The sense of such aberration is such that the exemplary ray and all reflected rays are directed either parallel to, or toward, the principal axis.

Rays emanating from the incandescent lamp 10 and impinging on the Rambauske mirror 14 are reflected as indicated by the exemplary rays incident at P_2 . It will be noted here that the sense of the aberration suffered by the rays reflected from the Rambauske mirror 14 is such that all rays are directed either parallel to, or away from the principal axis.

Referring now to FIGS. 1 and 1B it may be seen that, because of the finite radius of the incandescent lamp

10, all reflection planes do not coincide with meridional planes. It follows then that there are rays emanating from the incandescent source 10 which suffer nonmeridional plane aberration. The magnitude of such aberration, being a function of the radius of the incandescent lamp 10, is constant when the distance from the incandescent lamp 10 to a line of reflection points on the Rambausk mirrors is constant. It follows, then, that the rays passing through the exit aperture which suffer nonmeridional plane aberrations lie in planes which deviate to some degree from meridional planes.

It may be shown that, at any assumed reflection point on either Rambausk mirror 12, 14, the greatest meridional plane aberration may be determined by: (a) applying the law of cosines to determine the length of the third side of a triangle having one side equal to the radius vector of the assumed reflection point, a second side equal to the greatest distance along the principal axis between the focal point and any point on the incandescent lamp and an angle included between such sides being equal to the supplement of θ ; and (b) applying the law of sines to the triangle solved in (a) to calculate the angular deviation between the radius vector and the ray corresponding to the third side of the triangle. It may also be shown that the greatest nonmeridional plane aberration at any reflection point is, to a first approximation, the angle whose tangent is the ratio between the radius of the incandescent lamp 10 and the radius vector. It will be noted that the greatest nonmeridional plane aberration is suffered by a ray impinging on either Rambausk mirror at the intersection of the axis of rotation with either mirror. The nonmeridional plane aberration, then in degrees, equals the angle whose tangent equals the ratio between the radius of the filament in the incandescent lamp 10 and the minimum distance from the nearer end of such filament to the reflection point. It is evident, then, that the nonmeridional plane aberration is always far less than the meridional plane aberration.

It will be observed that the illustrated arrangement produces light throughout a 180° sector. If it be desired to produce light throughout a full circle then the reflecting surfaces could be rotated throughout a complete circle about the longitudinal axis of the incandescent lamp 10 with the light baffle being similarly extended. Further, it will be evident to one of skill in the art that the illustrated source could be used in conjunction with a conventional ring mirror if it be desired to provide a beam substantially aligned with the axis of rotation.

Although the illustrated embodiment of this invention uses Rambausk mirrors whose generatrices are sections of parabolas, the principles of this invention are not limited to Rambausk mirrors of such shape. For example, the generatrices of the Rambausk mirrors could be sections of concave hyperbolas. In an arrangement using mirrors of such shape the rays emerging through the exit aperture would apparently have originated near the conjugate focal curve of the generating hyperbola. Aberrations in such an arrangement would be generally the same as those described in connection with the illustrated parabolic generatrices. The semicylindrical light baffle and the back plate may be at least reflective in part. That is, because a basic concept of this invention is to arrange a cylindrical source and a pair of Rambausk mirrors in such a manner as to have all meridional rays from the source and impinging on the Rambausk mirrors, such baffle and plate may be arranged to reflect light from the source to either one of the Rambausk mirrors, provided only that the so reflected ray (or their projections) cross the principal axis on the same side of the focal circle as the rays falling directly on the Rambausk mirrors. It is felt, therefore, that this invention should not be restricted to its disclosed embodiment but rather should be limited only by the spirit and scope of the appended claims.

What is claimed is:

1. In a catoptric arrangement for forming from light radiated by a light source having a substantially cylindrical incandescent filament, a fan-shaped beam wherein substantially all aberrant rays are directed toward one of the broader sides of such beams, the improvement comprising:

- a. a first and a second opposing mirror, each one being concave and having a reflecting surface corresponding to the surface generated by rotating a segment of a different quadratic conic section about a line, such line passing between the adjacent focal points of the two quadratic conic sections;
- b. means for mounting a substantially cylindrical incandescent filament with its longitudinal axis collinear to the line; and
- c. baffle means disposed to intercept all rays from such filament which are initially directed to pass between the first and the second mirror without reflection.

2. The improvement as in claim 1 wherein each segment of the different quadratic conic sections is a segment of a parabola.

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