June 27, 1944. D. R. LIGH 2,352,214

OPTICAL SYSTEM AND METHOD

Filed Feb. 25, 1941 4 Sheets-Sheet 1

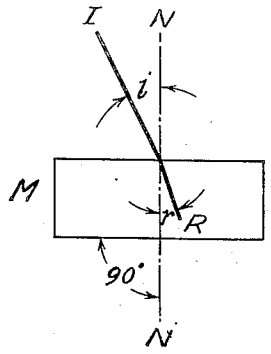


Fig.1.

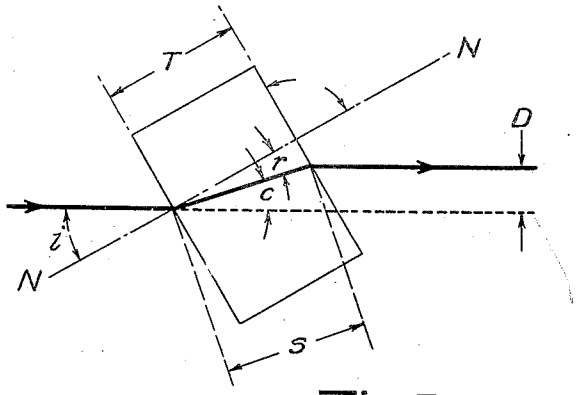


Fig.2.

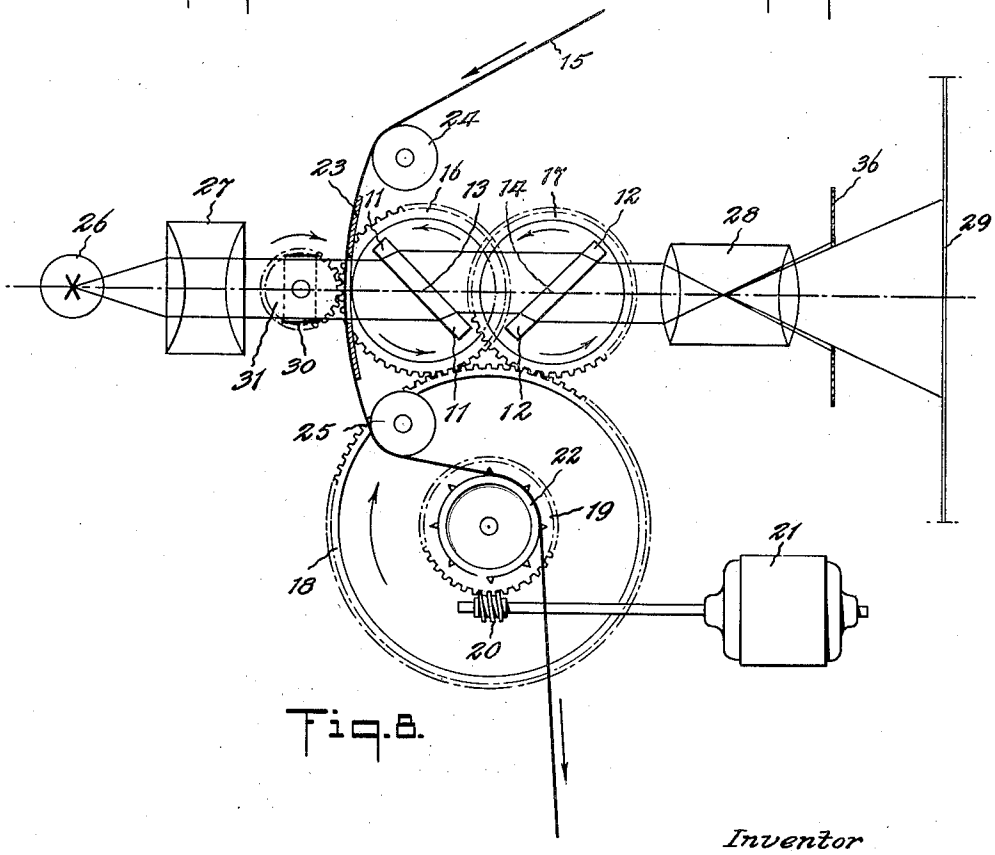


Fig.8.

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OPTICAL SYSTEM AND METHOD

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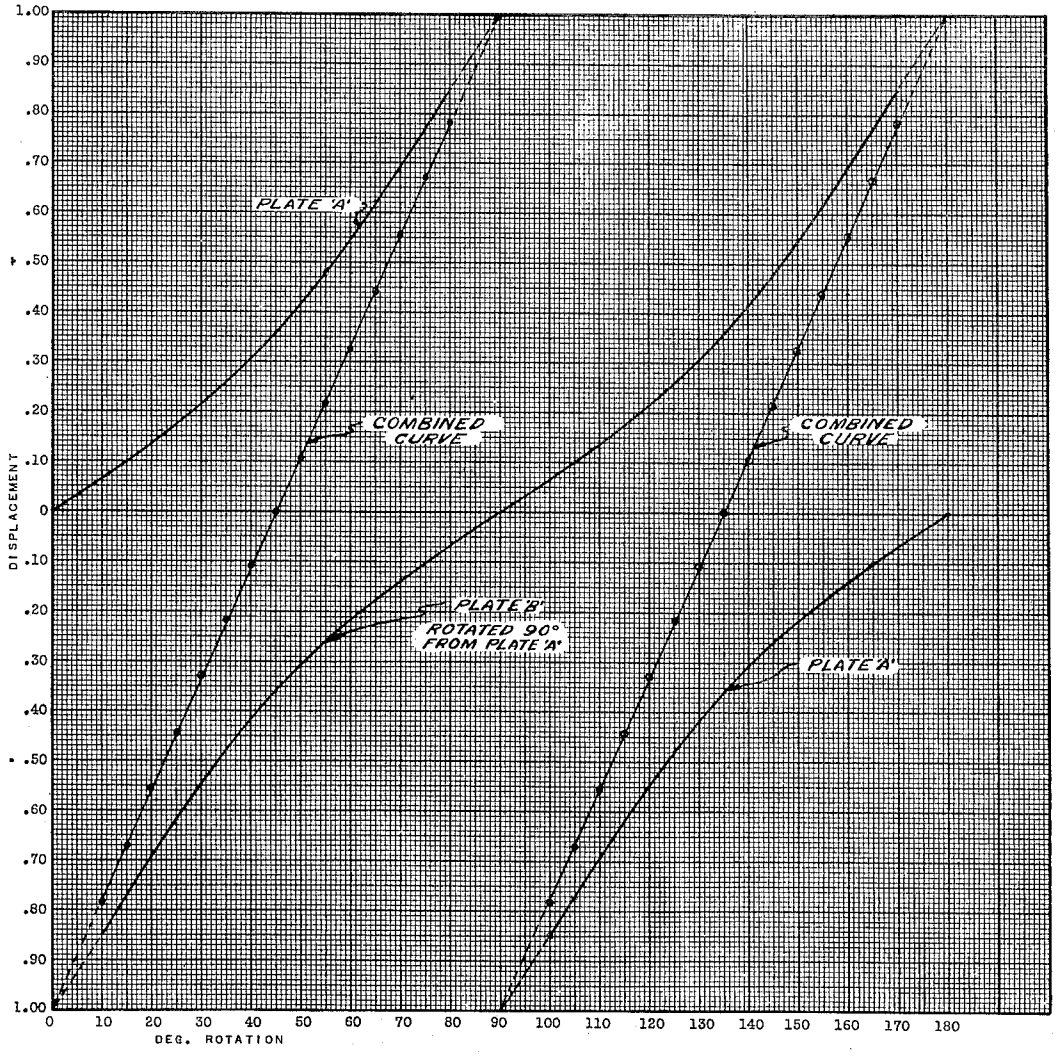


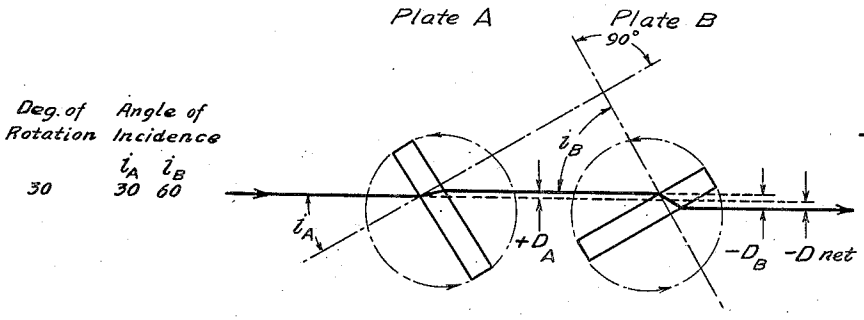
Fig. 3.

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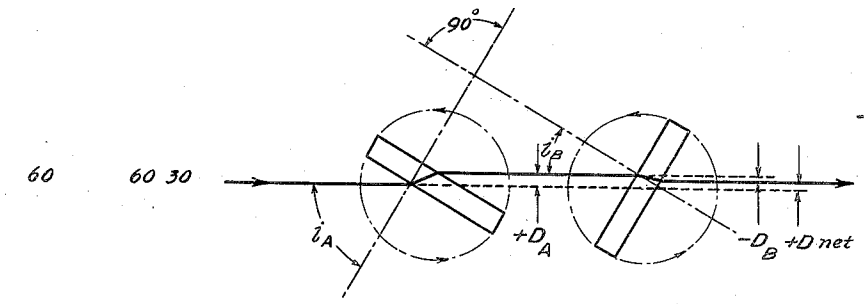
OPTICAL SYSTEM AND METHOD

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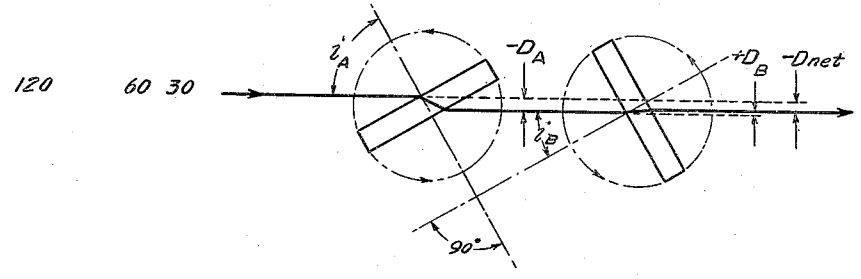
Deg. of Rotation	Angle of Incidence i_A	i_B
30	30	60

Fig. 4.



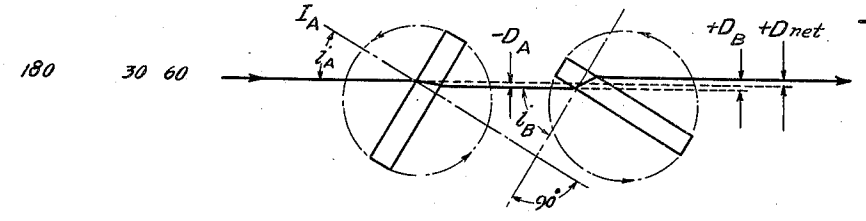
60	60	30

Fig. 5.



120	60	30

Fig. 6.



180	30	60

Fig. 7.

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OPTICAL SYSTEM AND METHOD

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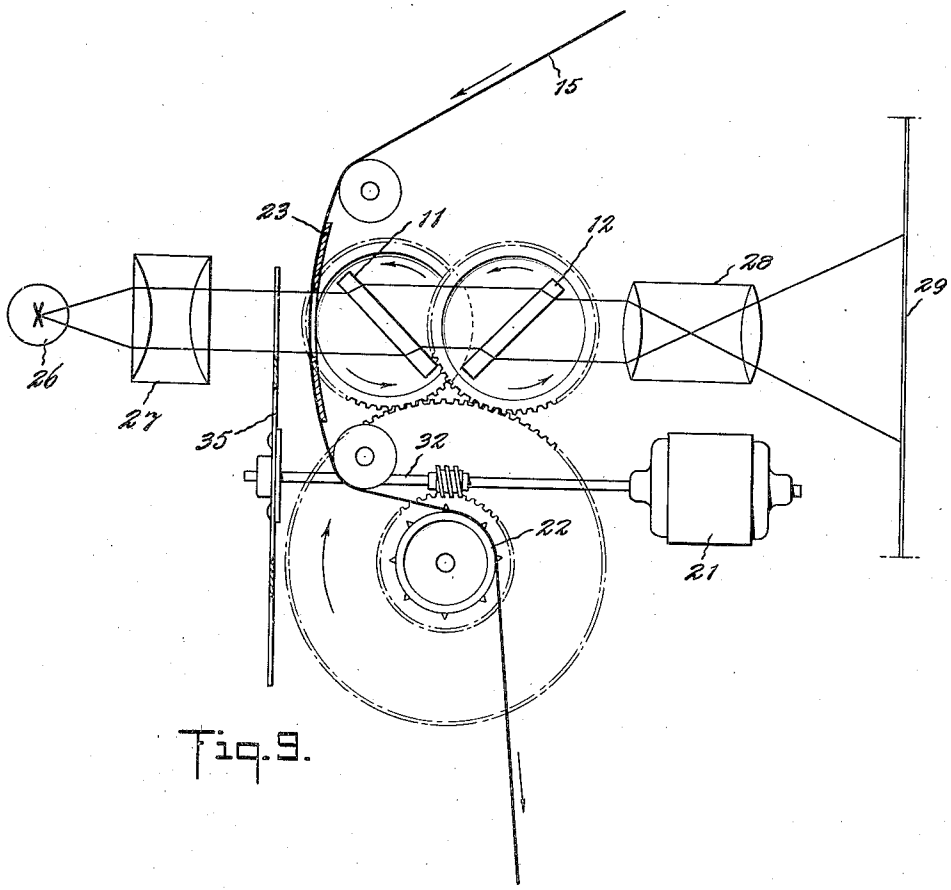


Fig. 9.

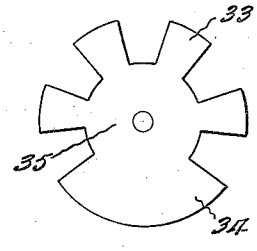


Fig. 10.

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UNITED STATES PATENT OFFICE

2,352,214

OPTICAL SYSTEM AND METHOD

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Application February 25, 1941, Serial No. 380,541

16 Claims. (Cl. 88—16.8)

This invention relates to an optical system and method for recording or portraying motion, in which either the object or the image projected therefrom is held in a stationary location while the conjugate is moving constantly; and more specifically the invention relates to motion picture projectors or cameras using a constantly moving film, or other apparatus embodying optical rectifiers. The object of the invention is to produce a practical method and means of diverting the light rays passing between an object and an image, the system being of the type employing planar refracting means to cause the rectification. It is characteristic of the invention that a plurality of planar refracting media are employed together so as to compensate for the sine ratio characteristics of the light displacement for each separate medium, giving a net displacement of the rays which is linear in relation to the rotation thereof and in synchronism with the uniform movement of the moving object or image.

In the drawings:

Fig. 1 is a geometric diagram of the refraction of a ray by a planar refracting medium such as can be used in the present invention;

Fig. 2 is a similar geometric diagram illustrating the parallel but displaced condition of the ray as it leaves the refracting medium;

Fig. 3 is a sheet of graphs illustrating the sine ratio character of the displacement of a light ray caused by rotation of a planar refracting medium, and the compensating effect produced by the present invention to make the rectification linear;

Figs. 4 to 7 are a series of diagrams showing the rotation of two planar refracting media operated in accordance with the present invention to illustrate the principle of compensated displacement of a ray as used in a motion picture machine; Fig. 4 showing the displacement at 30° of rotation from the vertical position of the first refracting medium; Fig. 5, the displacement at 60° of rotation; Fig. 6, the displacement at 120° of rotation; and Fig. 7, at 150° of rotation;

Fig. 8 is a diagrammatic view in side elevation of the essential parts of a motion picture projector made in accordance with this invention;

Fig. 9 is a view similar to Fig. 8, of a preferred form of motion picture projector made in accordance with the present invention; while

Fig. 10 is a front elevation of the shutter blade of the projector of Fig. 9.

It has heretofore been known to attempt projection of a motion picture film moving constantly, i. e., non-intermittently, and rectifying for this continuous movement of the film by using a plane parallel plate or refracting prisms to refract the light to give the necessary optical displacement to follow the film movement; but such efforts have revealed defects in the resulting screen images and methods of producing them which until the present invention have been incurable. According to the present invention, a plurality of such plates, "optical flats" or planar refracting media are employed in such a manner and location as to produce the necessary linear motion concurrently with the film movement by a compensating action which avoids the defects of the prior art.

Owing to the fact that the speed of light rays varies according to the medium through which they pass, when a light ray strikes the surface of another medium at an angle other than normal to that surface, it is refracted as shown in Fig. 1. In this figure the light ray I is shown entering a planar refracting medium M, namely, glass, at an angle i from the normal N, N, and the glass being denser than air, the ray is refracted or bent toward the normal so that its angle r from the normal is less than the angle of incidence i. The angles i and r are known as the angles of incidence and refraction, respectively, and the ratio of their sines is constant and is called the index of refraction. The ratio of the sines of air and any other medium gives the constant which is the index of refraction for that other medium. It is well known that in an "optical flat" or other glass having two parallel surfaces, the refracted ray R will be bent away from the normal on entering the glass and towards the normal on emerging, to amounts such that the emerging beam will be parallel to the incident beam I. However, while the emerging beam will be parallel to the original beam, there is a lateral displacement D, as shown in Fig. 2. Starting from this geometric premise, using glass with the preferred index of refraction of 1.60483 and the thickness T of the planar refracting medium as 1 inch, the displacement of the beam varies with

the incident angle i in accordance with the following table:

Incident angle	Displacement
0	0.0
10	.06646
15	.10097
20	.13704
25	.17521
30	.21605
35	.26011
40	.30764
45	.36004
50	.41688
55	.47870
60	.54553
65	.61710
70	.69264
75	.77087
80	.84984
90	1.00000

As can be seen in Fig. 3 of the drawings or demonstrated by geometry, the displacement D of each refracting medium will follow a complex curve so that with uniform angular turning of a planar refracting medium, the displacement of the emerging beam is not a uniform or constantly linear movement. Optical rectifiers using planar refracting media heretofore have sought to rely on the turning of the planar refracting medium to follow or synchronize with the linear movement of the object or image, according to whether the machine is a projector or a "stop motion" device, on the one hand, or a camera, on the other; but it has not proved practical to vary the rate of angular turning of the planar refracting medium in accordance with the displacement curve to keep the rate of rectification of the projected light rays constant.

As will now be described in an optical system according to the present invention, it has been found possible to compensate for the displacement curve variation in the rate of rectification of the light beams so as to produce a linear or constant rate of displacement of the light beams while rotating the planar refracting media at a uniform angular speed. Thus, although the displacement in the prior art is not a linear function of the degrees of rotation of the refracting medium and therefore the projected picture of a film frame moving at uniform rate has been "jumpy," it has been found possible by using the present invention to reach the ideal, wherein the refracting medium turning with uniform angular rotation operates in a concurrent or synchronous relation with the film moving at a constant speed across the aperture of the light of the projector. The principle employed will be described with particular reference to Figs. 4, 5, 6 and 7, which show the application of the principle to a motion picture camera. Thus these figures show a ray of an image being diverted for presentation to the moving film. By reversing the direction of the light ray, the figures would be applicable to a motion picture projector.

A multiplicity of planar refracting media are employed in such a way that they compensate and offset the non-linear portions of each other with the result that linear displacement, accurate well within practical limits, is obtained from uniform angular rotation of the refracting media. Basically it is necessary to have only two such media or plates, and the same have been identified in Figs. 4 to 7 incl. as plates A and B, respectively. Each plate rotates on its own individual axis which lies in a direction normal to the rays. Both plates rotate in the same direction, and in these figures it appears as counter-clockwise rotation. The angle of incidence i for each position of the plate is indicated beside each figure, identified as iA and iB for the plates A and B, respectively, and there is also indicated the degree of rotation from the position in which plate A was vertical. When plate A is vertical, plate B is horizontal, for plate B is always in a position 90° behind plate A, with the same angular 90° relation maintained at all times. While 90° is the most effective compensating angle, and the construction and calculations in the examples given are based on this angle, it should be understood that compensation can be obtained from angles which differ somewhat from 90°. In other words, lines normal to the planes of the two plates are always at right angles to each other, with the second plate through which the rays pass always lagging. It will be noted in Figs. 4 and 7 that the sum of the angles of incidence equals 90° and that this is true for all positions of applicant's device. In order that Figs. 4 to 7 may be properly considered with relation to the chart comprising Fig. 3, it is noted that plate A starts at 0° rotation at the midpoint on the left side of the sheet, which is the vertical position of that plate, and at that time plate B is 90° rotated from that position. As shown in Figs. 4 to 7, the light beam coming from the other elements in the optical system passes through first the left plate and then the right plate before going to the other main elements of the optical system. The result of this successive passing through these two planar refracting media in succession gives the desired compensatory effect. By compensation broadly is meant that the displacement D caused by one plate always is in the opposite direction from the displacement D caused by the other plate. It is the particular net displacement from my apparatus which is used to synchronize or cause concurrent movement of the film and the projector. To explain this in more detail, a table is given here showing by plus or minus signs whether the displacement of each plate is above or below the original or incident ray at the various angles of the two plates, as the rays, plates and displacements appear in Figs. 4 to 7.

Incident angle	Degrees rotation and algebraic displacement sign			
	Plate A	Displacement sign	Plate B	Displacement sign
0	0		90	
10	10	+	100	−
20	20	+	110	−
30	30	+	120	−
40	40	+	130	−
50	50	+	140	−
60	60	+	150	−
70	70	+	160	−
80	80	+	170	−
90	90		180	
80	100	−	10	+
70	110	−	20	+
60	120	−	30	+
50	130	−	40	+
40	140	−	50	+
30	150	−	60	+
20	160	−	70	+
10	170	−	80	+
0	180		90	

Actually it is found that the net displacement, taking cognizance of these algebraic plus and minus signs, approaches so closely to a straight line (as shown in Fig. 3) as to be well within the limits of tolerance of motion picture projection. (It might be noted that in passing through a cycle of 180° of rotation of the two plates, two

complete sweeps of displacement from top to bottom are made.) To illustrate with numerical figures the compensatory effect of this partial offsetting or combining of displacements, a table is given below showing the combined displacement at various angles of rotation, where the thickness of each planar refracting medium is one inch, the ideal linear displacement and the extremely small deviation from the ideal caused by this compensatory method.

Incident angle or angle of rotation	Combined displacement	Uniform linear displacement	Deviation from uniform linear displacement
0	−1.00000	1.00000	
15	−.66990	.66666	−.00324
20	−.55560	.55555	−.00005
25	−.44189	.44444	+.00255
30	−.32948	.33333	+.00385
35	−.21859	.22222	+.00363
40	−.10924	.11111	+.00187
45	0	0	0
50	+.10924	.11111	−.00187
55	+.21859	.22222	−.00363
60	+.32948	.33333	−.00385
65	+.44189	.44444	−.00255
70	+.55560	.55555	+.00005
75	+.66990	.66666	+.00324
90	+1.00000	1.00000	

In the above table it will be noted that for a complete cycle of 90° rotation the theoretical displacement D is two inches. It will be noted that the displacements vary from minus 1 to plus 1 or twice the thickness of one of the refracting media. This condition holds irrespective of the index of refraction of the media. For the purposes of mathematical calculation and scale of the charts, this is purposely made larger than is necessary in a practical machine. Obviously the amount of deviation from linear displacement will be proportionately reduced with any reduction of the displacement. For example, let us consider a 16 mm. projector in which the film is advanced one picture frame for each 90° rotation of the plates. In such a projector each picture frame is .30 inch high, and the displacement D will therefore be .30 inch for each cycle. In line 5 of the table given above, the deviation from true linear displacement by the use of the smaller plates will have as its maximum .00056 inch. Assuming that the picture is magnified sixty times on the screen, this would introduce a possible picture jump of about $\frac{1}{32}$ of an inch. This is well within the limits necessary for a steady picture.

With further reference to the refraction of the horizontal pencils of light by the plates as shown in Figs. 4 to 7, it should be noted that the effective angles through which the combined plates may be rotated are limited by several factors including (*a*) the aperture of the objective lens; (*b*) the size of the picture frame; and (*c*) the movement of the film. Furthermore the effective angle of rotation is limited by the size of the plates and the obvious fact that as the plane of a plate approaches the direction of the incident beam, its refractive effectiveness is limited as it changes over to receiving the rays on its other face. In this connection it should be noted that when the angles of the plates are plus or minus 45° from the vertical, i. e., 45° from normal to the rays, the net image displacement is 0. It has been found that in a practical design of 16 mm. projector under these various limitations, an angle of 38% out of each 90% is available for use, i. e., a light transmitting time efficiency of 42% can be obtained. A shutter can be used to stop the light when it is not desired and also to introduce a sufficient number of alternate periods of light and dark to reduce the apparent "flicker."

The embodiment of my invention in the motion picture projector shown in Fig. 8 will now be described. The central feature of the machine is the refracting or rectifying means, which in this case comprise two "optical flats" **11** and **12**. It should be understood that while I prefer to use planar refracting media, such as optical flats, any refracting media which by uniform rotation will provide displacement and compensate for each other so as to provide constant or true linear displacement, can be used. These refracting media will hereafter be referred to as "plates." I prefer to mount them in the machine without the intermediary of optical means such as converging or diverging lenses between them. Each plate rotates about its own axis **13**, **14**, which axis is normal to the direction of the rays, the axes themselves preferably lying at right angles to the direction of movement of the film. The plates have rotation relatively to each other, the rotation being maintained so that the plates or their planar normals are 90° apart at all times. The film **15** in Fig. 8 moves downwardly and the two refracting plates **11**, **12** therefore revolve in a counter-clockwise direction, as indicated by the small arrows. The plates are each mounted extending laterally from a gear wheel **16**, **17**, respectively, and are driven in synchronism with the movement of the film by means of a large gear wheel **18**, a small gear wheel **19**, a worm **20** and the film motor **21**. The film **15** is given continuous linear movement by a sprocket wheel **22** mounted on the same shaft with the gear wheels **18** and **19** and revolving in synchronism therewith, the film being led past the plates **11**, **12** on the side of an aperture plate **23** away from the plates and passing over the guide rollers **24**, **25** as it approaches and leaves the aperture plate. It will thus be seen that the speed of movement of the film **15** is accurately synchronized with the rotation of the refracting plates **11**, **12** and the parts are made of such dimensions and so arranged that in the case of a 16 mm. projector, as the film moves down the distance of one picture frame of .30 inch, the refracting plates **11**, **12** revolve 90° in a counter-clockwise direction. The thickness of those plates is such that for each 90° of rotation the total translation or displacement of the image corresponds to the movement of one picture frame, i. e., the opening in the aperture plate **23** is wide enough to follow the picture from a position half a picture above the middle position to one half a picture below.

A source of light **26** is indicated at the left of the figure, the diverging rays from this source of light passing through a converging or condenser lens **27** which efficiently transmits the light through the optical system. This lens brings the rays into a concentrated relation which is maintained preferably until after the rays have left the refracting plates **11**, **12**. After the rays have left the refracting plates **11**, **12**, they pass through the objective lens **28** which focuses the light on a screen **29**.

In the construction shown in this figure, there is a shutter located between the condenser lens **27** and the aperture plate **23** for the purpose of cutting off the light rays when either of the refracting plates is in a change-over position. In the construction shown it has been found that this results in having the light for about

42% of the time. The shutter comprises a pair of plates 30 projecting laterally from the side of a gear 31, the two plates being arranged parallel to each other a distance apart slightly greater than the opening of the aperture plate 23. The gear 31 is driven by the gear 16 of the adjacent refracting plate 11, and the widths of the plates 30 are such as to cover the aperture and cut off the light for the desired period of time.

From the description just given it will be obvious that in the projector of Fig. 8, as the plate 11 revolves from the vertical position the net displacement of the two plates will move down, synchronized with the movement of the film. For each 90° of rotation, the film advances one frame and the compensated net displacement rectifies the picture frame to a stationary image on the projection screen. An aperture plate 36 may also be provided between the objective lens 28 and screen 29, if desired, to cut off any rays outside the central picture.

A preferred form of shutter is shown in Figs. 9 and 10. In this construction there is a single shutter plate 35 lying in a plane perpendicular to the rays of light which originate at the lamp and are projected by the condenser lens. This shutter 35 can be mounted on a shaft 32 which is an extension of the shaft carrying the main drive worm gear 20 so that its rotation can be accurately synchronized with the rotation of the refracting plates. As can be seen in Fig. 10, the peripheral portion of the shutter, which is the portion lying in the path of the light, consists of spaced blades 33, 34, there being four small blades 33 spaced apart a distance equal to their width, and a very much wider blade 34 spaced from the four narrow blades a greater distance. In the construction shown in Fig. 9, I prefer to revolve this shutter 35 once for each movement of the picture frame. This means that the shutter revolves four times for each complete revolution of the refracting plates 11, 12. Since there are five blades 33, 34 altogether and a corresponding number of spaces between them, it follows that the light is interrupted with a frequency of five times per frame movement, so that if the film moves at the rate of 24 frames per second past a given point, these shutter blades interrupt the light 120 times a second. I find that this arrangement of blades produces the minimum amount of "flicker." It may be pointed out that the large blade 34 on the periphery of the shutter is interrupting the light while one or the other of the refracting plates is revolving through any non-operating position or change-over, while the four small blades 33 are merely to balance up or equalize the intensity of the light during the time that the image appears on the screen with relation to the dark period to minimize the "flicker."

If the invention is to be embodied in a camera for taking motion pictures, the object rays of light are displaced by means of the revolving refracting plates to conform with the moving film, and there is no necessity for balancing up the intensity of the light by the small blades 33. The shutter arranges for the exposure of the film in regular timed succession and in proper relation to the operative and non-operative positions of the refracting plates. The principle of image displacement by optical refraction utilizing the invention above described can, as above intimated, be used not only in motion picture projectors and motion picture cameras of standard or high speed construction, but also in film editing machines, or television projectors. It is applicable wherever persistence of vision is used to show the motion of a constantly moving object, whether such object be shown directly or through a series of images in a film, on the one hand, or on the other, in the case of the moving picture camera the projecting of the image on the moving film.

I claim:

1. In an optical system, means maintaining light rays in a concentrated relation, in combination with two effective rotating planar refracting media adapted successively to cause displacement of the rays from the projecting means, and means rotating the media at uniform angular speed but at 90° lag in angular relation to each other, whereby uniform linear displacement of the rays is obtained.

2. In an optical rectifier system, the combination of a plurality of refracting media each adapted to displace a ray of light in the same manner, said two media being adapted to rotate each about its own axis but at such relative angles that their displacements of the ray are in compensating phase, and obturating means synchronized to cut off the rays when either of the media is at an inoperative angle to the ray.

3. In an optical rectifier system transmitting a series of images of an object, or vice versa, where one is at a stationary location and the other at constantly changing location, the combination of two planar refracting media and means rotating them in the same direction with uniform angular speed, with the planes of one medium at a 90° angle to the other, whereby the displacement of light rays by one medium is compensated for by the other and uniform linear displacement results.

4. In an optical system for obtaining a stationary image from a moving one, or vice versa, the combination of two planar refracting media with means rotating them in the same direction and with uniform angular speed but with a 90° lag in the normals to their axes, whereby uniform linear displacement of the image received or projected is obtained.

5. In an optical system wherein uniform linear displacement of image is desired at one end of the system, the provision of two planar refracting media mounted in successive relation to the light path, in combination with means rotating them in the same direction about separate axes and with uniform angular speed but with a 90° lag in the normal axes of the media, and a shutter to obturate the light rays intermittently.

6. In a method of operating an optical refracting system, the rotation of two planar refracting media each about its own axis but in the same direction and with constant angular speed, holding their planar normals 90° apart, whereby the linear displacement of rays passing through the two media is made uniform.

7. In a method of operating an optical refracting system containing rotating planar refracting means, the steps of presenting rays to a planar refracting medium while rotating same with constant angular speed and subsequently presenting the refracted rays to a planar refracting medium at an angle 90° removed from the angle of the first incident ray, whereby the net linear displacement of the double passage of the rays is made uniform.

8. In a motion picture projector, means advancing a film in non-intermittent or constant speed manner and two planar refracting media located successively in the path of the image rays, in combination with means giving uniform angular rotation in the same direction to the media

with a 90° lag between the normal axes of the two media, whereby uniform linear displacement of image synchronized with the film movement is obtained.

9. In an optical rectifier system, the combination of two optical flats whose indices of refraction are in the order of 1.605 and which are located successively in the path of the light rays, and means rotating them at a uniform speed in the same angular direction but with their planar normals 90° apart, whereby the rays will be diverted from positions having uniform linear displacement to a stationary location, or vice versa.

10. In an optical rectifier system having a film and relying on persistence of vision, the combination of two optical flats located successively in the path of the light rays, and means to give the normals of said flats uniform angular rotation synchronized with the film movement, while maintaining the normals in 90° relation to each other, and a shutter to obturate the rays of light during change-over position.

11. In an optical rectifier system relying on persistence of vision, a lens adapted to maintain rays in concentrated relation, and two optical flats of about 1.605 indices of refraction arranged to receive the rays successively from the lens, in combination with means rotating the flats at uniform angular speed about their separate axes but with the planar normals maintained about 90° apart in compensating relation as to sine ratio displacement curves, whereby the linear displacement of the rays emerging from the second flat will be uniform.

12. In an optical rectifier system relying on persistence of vision, two optical flats of about 1.605 indices of refraction arranged to receive the rays successively from the lens, and means rotating the flats at uniform angular speed about their separate axes but with their planar normals maintained about 90° apart in compensating relation as to sine ratio curve characteristics of linear displacement of the rays, whereby the linear displacement of the rays emerging from the second flat will be uniform, in combination with a shutter obturating any rays passing when one of the flats is at an ineffective angle.

13. In an optical rectifier system relying on the persistence of vision, two refracting plates having similar light displacement qualities and whose total cycle displacement equals the sum of the thickness of the two plates, in combination with means rotating the plates on axes normal to the path of the light rays at uniform angular unidirectional rotation with a 90° lag in angular relation between the plates, whereby uniform linear displacement of the rays is obtained.

14. In an optical rectifier system, two refracting plates having similar light displacement qualities, in combination with means rotating the plates on axes normal to the path of the light ray and with the plates at such relative angles that the sums of the angles of incidence of the light rays at the two plates equals 90°, whereby the total cycle displacement of the light rays is independent of the index of refraction of the plates.

15. In an optical rectifier system, two refracting plates having similar light displacement qualities, in combination with means rotating the plates on axes normal to the path of the light rays and with the plates at such relative angles that the sums of the angles of incidence of the light rays at the two plates equals 90°, whereby the total cycle displacement of the light rays is dependent on the thickness of the plates and independent of the index of refraction of the plates.

16. In an optical rectifier system, two refracting plates having similar light displacement qualities and whose total cycle displacement equals the sum of the thickness of the two plates, and a photographic film, in combination with means rotating the plates on axes parallel to the plane of the film at uniform angular unidirectional speed, the relative angles of the two plates being such that the sums of the angles of incidence equal 90°, and the glass in the plates having an index of refraction of about 1.605, whereby the intra-cycle displacement caused by said plates is made uniformly linear and the cycle displacement of the rays is equal to the cyclic movement of the film.

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