The CORE Camera: Continuous Receptivity — One Rotating Element

PAPER H—7

By J. N. WHYTE

The advantages of a streak camera having continuous receptivity and employing only one rotating element are discussed. The essential element of such a camera is a prism-mirror combination which is rotated at high speed. Various arrangements of this combination are possible, and have been investigated with a view to compensating for the aberrational and "splitting" effects. The theory of image formation through the combination is reviewed and alternative schemes are discussed.

THE ADVANTAGES of a film drum camera in which the film drum remains stationary and a mirror is rotated at high speed in order to sweep the image around the film drum, have been treated exhaustively in the literature. The alternative method of forming the image on to a rotating film drum has also been used.

In the former case, the event has to be synchronized with the mirror position. In the latter case, one has to contend with the greater mass of moving parts and the consequent reduction in writing speed, although such a camera does give continuous receptivity. On the other hand, the film drum camera with moving optical parts has the advantages of potentially higher writing speed in the chronograph role and higher frame rates in the cine role (i.e., the recording of discrete pictures of the event).

Various attempts have been made to produce a stationary film drum camera using moving optical parts and having continuous receptivity. It is considered that these have not been entirely satisfactory. Those systems which give continuous receptivity require an image rotation compensation device which must also be rotated at high speed and, in general, at a different speed from that of the main sweep mirror. Those which do not require image rotation do not give continuous receptivity without sacrifice of illumination (e.g., beam-splitting) and considerable optical complexity.

A camera, either streak or cine, containing the best of both systems can be specified as follows:

(i) continuous receptivity,
(ii) one rotating optical system,
(iii) "in-line" film recording for ease of analysis, and
(iv) no unnatural reduction of the illumination available.

Such a camera can be achieved by the use of the optical system to be described, and the description is confined to a streak camera.

Presented on October 20, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by J. N. Whyte, Armament Research & Development Establishment, Sevenoaks, Kent, England.

Prismor System

A prism-mirror combination, which has been named "prismor," has been investigated and manufactured in a variety of forms at Fort Halstead with encouraging results. These have been found to have many applications.*

The arrangement consists of an optical glass block comprising two isosceles prisms cemented together at their base, the interface being silvered. Figure 1 shows three possible arrangements, each having the property of sweeping the incident beam through 360° in the plane of the paper. The choice of shape depends upon the particular application. The best compromise for application to a streak camera is the right-angled block shown in Fig. 1(c).

When the prismor is inserted in a parallel beam the path of the rays for an axial beam is shown in Fig. 2, the parallel beam being undeviated. It will be noted that the optical axis is split by a distance D. It can also be shown that the separation of the split optical axis is given by

$$D = 2H \left\{ 2 \sin^2 \frac{\alpha}{2} - \tan \left(\sin^{-1} \left[\frac{\sin \frac{\alpha}{2}}{n} \right] \right) \sin \alpha \right\}$$

where n = refractive index of the material
α = apex angle of the prism, and
H = height of a single prism.

For example, for a 90° prism, assuming $n = 1.5$

$$D = 0.93H.$$

Application to Streak Camera

The general arrangement of the optical components in a streak camera is well known. Briefly, the event to be studied is focused by means of a lens on to a narrow slit, this slit being projected via a rotating reflecting element on to the film wrapped round the inside of a drum. The rotating reflecting element is generally a double-sided

* *Instrument Practice, Vol. 14*, No. 1, Jan., 1960.

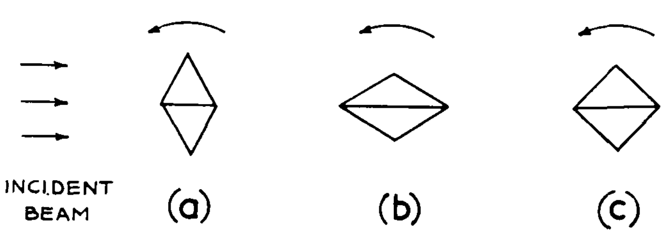

Fig. 1. Prismor shapes.

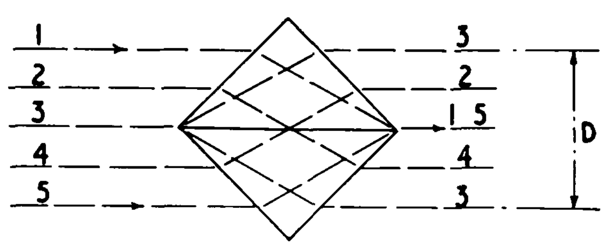

Fig. 2. Path of rays.

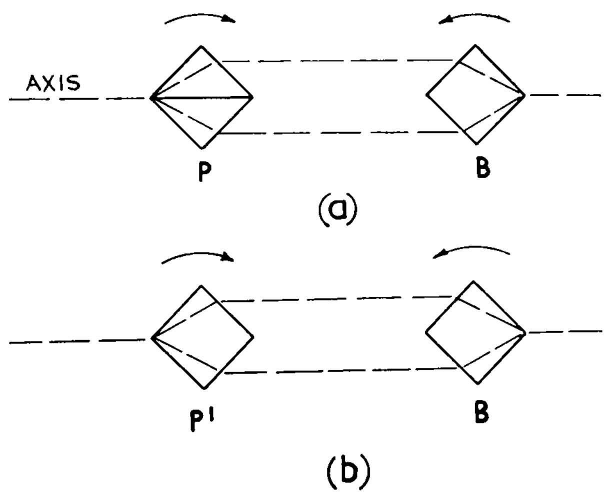

Fig. 3. Compensation for image splitting.

mirror or a multi-sided reflecting block. It is these particular rotating elements which it is proposed to replace by the prismor arrangement.

In this arrangement the prismor would be placed in a converging beam, therefore it is necessary to consider the effects of both aberrations and image splitting. Since it was felt that the image splitting effect might be the more pernicious, this is considered first.

Prismor Arrangement in Conjugate Beam

In Fig. 3(a), P is the prismor and B is a plane glass block of the same material and equal shape.

The refracting equivalent of the reflecting prismor is P'. To analyze the effect and compensation of splitting, Fig. 3(b) shows that the optical axis which is split by the prismor is brought into coincidence by the contra-rotating block. This condition is maintained throughout rotation.

This arrangement, as it stands, does not, of course, meet our original specification of one rotating element. Thus the arrangement illustrated schematically in Fig. 4 is adopted.

The object O is focused by lens L on to the slit S. The slit is projected via the plane right-angle block P_2 and stationary mirror M, through the prismor P_1, on to the stationary film track. P_2 and P_1 are cemented together, in line, and rotate on a common spindle. The slit image is swept continuously around the circular stationary film track.

A model camera was constructed to confirm the theory and is shown in Fig. 5. In this camera no attempt was made to compensate for the aberration effect of two rotating, refracting elements placed in the converging path. The definition was consequently inferior.

It will be noted that the system operates off-axis. This is to ensure that the image lies in the plane of the film. This off-axis angle α can be determined from the relationship

$$\alpha > \tan^{-1}\frac{H}{4x}$$

where H is the height of the plane block or the prismor, and x is the distance from the plane of the prismor face to the plane of the stationary mirror when these two planes are parallel.

Effect of Optical Path in Glass

As a result of the path in glass, the aberration contributions are of two types: one is constant, and the other cyclically variable. The constant aberration contributions can be reduced by redesign of the elements in the optical train. The cyclically varying aberrations, however, cannot be so easily reduced. Distortion, coma, and axial chromatic aberration are matched by virtue of the contra-rotation of the blocks; but the cyclic contribution of astigmatism is additive. Means of compensating for this defect are currently being investigated.

Collimated Beam CORE Camera

Further investigation has shown that an alternative arrangement is possible whereby there is no aberration contribution due to the path in glass, no cyclic variation of aberration, and no splitting effect. Such a camera is shown schematically in Fig. 6.

Light from the slit S is collimated by lens L, passed through the prismor P, and focused by means of the annular mirror M on to the stationary film drum F. The radius of the annular mirror M is equal to its perpendicular distance from the axis of rotation of the prismor. To keep the prismor as small as possible, the entrance pupil to the mirror M is arranged to fall on the axis of rotation.

In order to ensure that the film drum does not obscure any of the light from the annular mirror, it is necessary for the system to work off-axis.

In Fig. 7, H represents the semiaperture of the system which is approximately equal to the length of the prismor along the rotational axis of the prisms. The principal ray passes through the center of this pupil making an angle α with the horizontal. On reflection from the mirror M, it forms the center of the image of semi-height h on the film drum. The upper ray makes an angle $(\alpha + \Delta)$ with

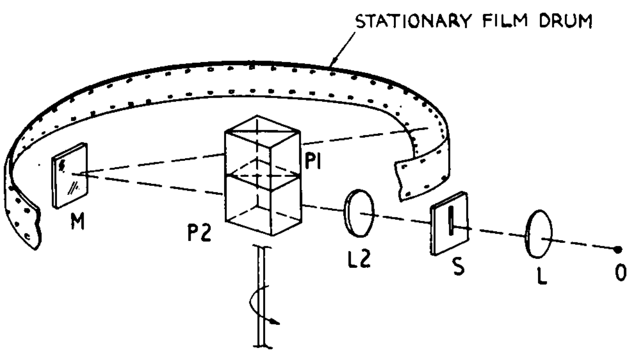

Fig. 4. Schematic representation of camera.

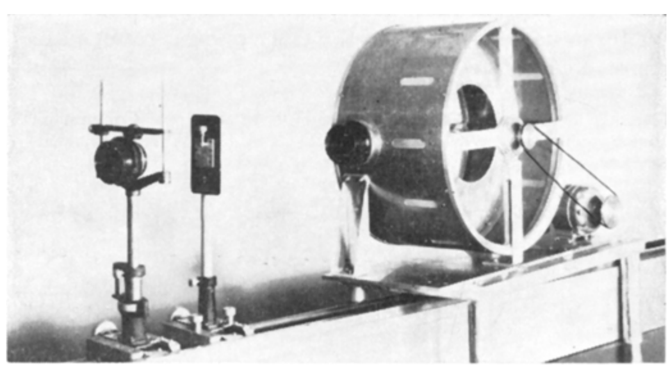

Fig. 5. Model camera. (Crown copyright reserved. Published with permission of the Controller of Her Britannic Majesty's Stationery Office.)

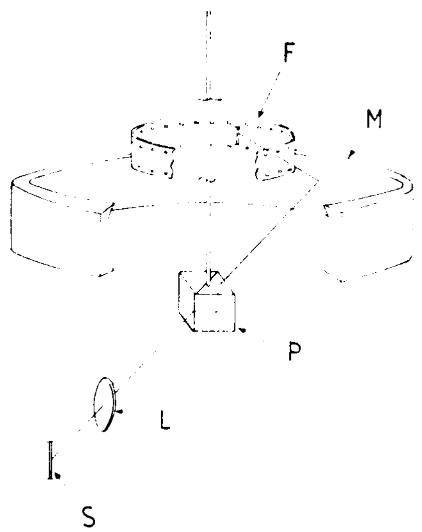

Fig. 6. Collimated beam core camera.

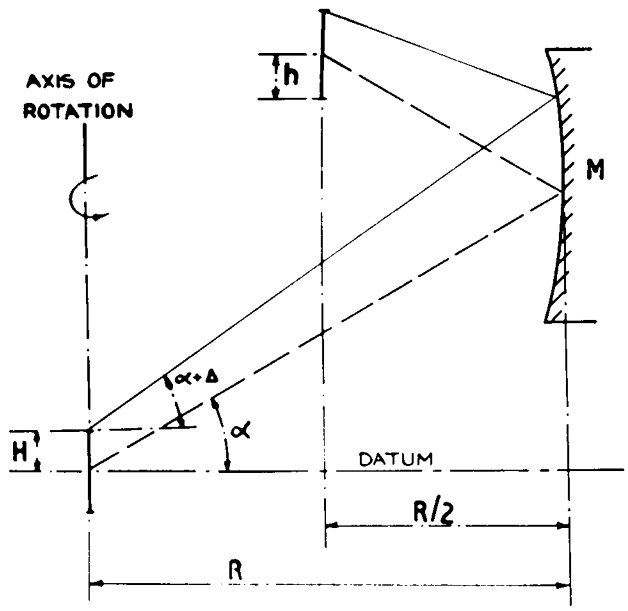

Fig. 7. Ray diagram.

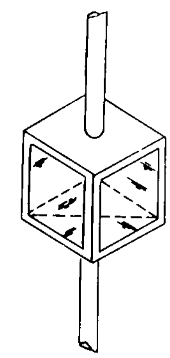
Fig. 8. Caged prismor.

the horizontal. The mirror M has radius R and focal length $R/2$. Then the incident height of the principal ray on film drum from the datum line

$$= \frac{3R\alpha}{2}$$

Height from datum to bottom of image $= \frac{3R\alpha - h}{2}$

$$= \frac{3R\alpha - R\Delta}{2}$$

Incident height of upper ray in plane of film drum

$$= \frac{R}{2}(\alpha + \Delta) + H$$

$$\therefore \frac{3R\alpha - R\Delta}{2} \geq \frac{R}{2}(\alpha + \Delta) + H$$

Rearranging the terms

$$\alpha \geq \Delta + \frac{H}{R}$$

Since the entrance pupil to the mirror has a diameter $2H$ and focal length $= R/2$, the f-number of the camera

$$= \frac{R}{4H}.$$

$$\therefore \alpha \geq \Delta + 1/4\ (f\text{-number})$$

For ease in manufacture and assembly the mirror is segmented. The number of segments is at least 24, irrespective of the size of the mirror. This is to ensure that the segments are cut with an aperture ratio not higher than $f/2$.

Dynamic Considerations

The usefulness of both cameras is, to a great extent, dependent upon the speed with which either the single or compensated prismor can be rotated. This is the subject of a current design study contract. The dynamic performance of the prismor combination is being studied with a view to determining the factors which limit the upper speed of rotation.

It seems likely at this stage of development that the adhesion of the two halves of the prismor (or the cohesion of the aluminized film to the base) may be a limiting factor. There may be some merit in leaving a small size gap between the two aluminized surfaces. Alternatively, the tensile strength of the glass may be a limiting factor, resulting in either deformation or fracture at very high speeds. The effect of strengthening the prismor by surrounding it in a metal cage, as shown in Fig. 8, is being investigated.