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A High Speed Rotating Mirror Frame Camera

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Summary -- A high speed framing camera of some general utility has been developed at the Los Alamos Scientific Laboratory and operated up to 3,500,000 frames per second. Use is made of a rotating mirror and 170 framing lenses working at f/26 to produce frame pictures 1.2 x 1.4 centimeters in size. Another model operating at 100,000 frames per second has been made with 90 circular frames 2 centimeters in size.

Introduction

The continuous writing high speed frame camera herein described was made for the detailed study of explosive phenomena and is primarily useful for the photography of high speed events that are self-luminous or illuminated by very intense explosive light sources using an argon atmosphere.¹ Frame cameras operating up to 500,000 frames per second have been made,^{2,3} but the systems used probably cannot be increased in speed to any great extent because of the limitations of the strength of the rotating mirrors used. The camera to be described was designed for operation up to 3,400,000 frames per second and makes use of a small mirror so that much higher rotational speeds can be obtained.

Optical System

The principle of operation of the camera is the same as has been used in highest speed cameras previously made in that an object to be photographed is imaged on the surface of a rotating mirror and then relayed to successive positions on the film by a series of relay lenses. The novel feature of this camera is the use of a small, thin, two-faced rotating mirror and the division of the optical system into two sections so that appreciable blind time is avoided.

Figure 1 shows a schematic isometric view of the optical system. The objective lens L_1 forms an image I_1 in the field lens L_2 . The beam splitting mirror M_1 divides the light from I_1 into two paths A and B. Consider path A first. The combined relay and field lens L_{3A} relays the first image I_1 to the position I_{2A} near the surface of the rotating mirror RM, using the mirrors M_{2A} and M_{3A} to properly direct the light path. The mirror M_{3A} is so placed that the rays forming the image I_{2A} are reflected from the surface of the rotating mirror RM into the final relay lens L_{4A} to form the image I_{3A} in the film plane F_A . A series of lenses identical to L_{4A} are placed in the 180° arc shown to form a series of pictures on the film F_A . This lens and film arc records pictures for the rotating mirror in the range of 45° from the position shown. For positions of the rotating mirror beyond that range it is necessary to follow the optical path B which is seen to be at 90° around the Z axis from path A. The combined field and relay lens L_{3B} then relays the image I_1 to the position I_{2B} . The image forming rays are so directed that they pass into the relay lens L_{4B} to form the image I_{3B} in the film plane F_B . It is thus seen that pictures are obtained for another 90° range of the rotating mirror adjacent

FIG. 1

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Fig. 1 -- Optical diagram of High Speed Frame Camera.

to the previous 90° range or a total of 180° . Since both faces of the rotating mirror are polished, pictures can be obtained for the entire 360° , with the exception of the region obscured by the mirrors M_{3A} and M_{3B} which amounts to less than 3 per cent of the cycle in a practical case. There are always two images on the rotating mirror face but the displacement of the relay lens arcs away from the X-Y plane insures that light from only one reaches a relay lens at any one time. Achromatic doublet lenses are used throughout since these give excellent resolution over the small angular field required. The axes of the final relay lenses are coincident with the central optical path and hence the film plane is a conic rather than a cylindric section as shown. The various lenses of the system are assigned focal lengths such that the pupils are located at the objective lens, the beam splitter, and the final relay lenses. This insures even illumination for all the points of the final image and the minimum exposure time for each picture. To obtain a rate of 3,400,000 frames per second, a series of 85 framing lenses were used for each of the 180° arcs and the rotating mirror operates at 10,000 revolutions per second.

The loss of light entailed by the use of a beam splitting mirror may be objectionable to some users even though a factor of 2 or 3 in exposure usually makes only a minor change in the final print quality. In that case the use of a roof mirror in place of the partial reflecting mirror is advisable. The use of a roof mirror also introduces the need for the objective lens to be of twice the aperture and may result in appreciable distortion in the final image. The objective lens axis is then placed midway between the A and B optical paths.

The shutter for the camera is located between the field lens L_2 and the

beam splitter since this part of the system has a small aperture. The shutter must be closed within $1/20,000$ second after the start of exposure or recycling and multiple exposure will occur. Since a mechanical shutter cannot operate in such a short time it was necessary to devise a much faster mechanism. A small block of glass can be rendered sufficiently opaque within a few microseconds by shattering it with a shock wave from a high explosive detonator. Such an arrangement has been found practical if the glass is enclosed in a suitable steel case.

Camera Construction

The exterior of the camera is shown in Figure 2. The tube at the top is the focusing mount for the 2 1/4 inch objective lens used. The electrical controls for operation of the camera are mounted on the circular end plate. The rectangular projection on the plate is the high speed explosive shutter mentioned above. It is easily removed for loading a glass block and the explosive detonator. The viewfinder is located just above the shutter. The adjustable time-delay and detonator firing circuits are housed within the camera body. The two semicircular relay lens rings and film holders are seen at the rear of the camera. Standard 35 mm camera cassettes are used to hold the film.

The disassembled explosive shutter is shown in Figure 3. It is made of steel and withstands the detonator explosion without any noticeable deformation of the piece. The one-half inch round optical aperture is near the center of the shutter. Circular pieces of transparent plastic are fitted in these holes to prevent glass fragments from entering the camera. The block of one-half inch plate glass fits in the long groove. The electric detonator (not shown) is

Fig. 2 -- Exterior view of High Speed Frame Camera.

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Fig. 3 -- High speed shutter used with frame camera.

pressed against the end of the glass block by means of the hollow screw which fits in the shutter cap. A chamber is formed around the detonator so that the explosive gas pressure will not be too high before exhausting to the outside through the ports in the cap. The detonator is loaded after the shutter has been assembled and fitted to the camera.

The 10,000 revolutions per second rotating mirror and air turbine drive⁴ is shown in Figure 4. The mirror has faces $15\frac{1}{2} \times 17\frac{1}{2}$ mm and is 8 mm thick. The air and oil lines for driving and lubricating the unit are at the left. The compact construction was achieved by combining the mirror and turbine into a unit. There is a turbine and sleeve bearing at each end of the mirror. Dural bucket wheels are press fitted on the mirror shaft. Ordinary #10 grade lubricating oil at 100 pounds per square inch in a circulating system is used for lubricating and cooling of the bearings. The bucket wheel manifolds are so arranged that the exhaust air sweeps the bearing oil leakage out the exhaust pipe so that it will not deposit on the mirror and optics inside the camera. A $19 \times 17\frac{1}{2}$ mm drive has also been constructed so that image cutoff is avoided when the mirror is at 45° to the optic axis. This larger size mirror operates with very little strength safety factor at 10,000 revolutions per second, and its use is avoided when the highest speed of operation is required.

The camera has an effective aperture of f/26 and the final image size is 12×14 mm. Dynamic resolution tests with Shell Burst Panchromatic film give 30 lines per mm over the entire picture area. Diamond shaped stops⁵ are used for the lenses as it has been found that there is no practical loss of resolution relative to a circular or rectangular stop of the same linear dimensions. The diamond stop has the advantage that the effective time of exposure is about

Fig. 4 — 10,000 revolution per second turbine with rotating mirror.

Fig. 5 -- Photograph of the surface of an explosive driven metal plate.

two-thirds of that obtained by a rectangular stop.

The design of the camera is such that it is adaptable for a wide range of operating speeds. Another model almost identical in appearance to the one illustrated was made for operation at 100,000 frames per second to give ninety 20mm diameter images. It uses an electric motor drive to give a mirror speed of 550 revolutions per second.

Sample Photographs.

The photographs in Figure 5 are a few of the frames from a series showing the surface of an explosive driven metal plate⁶ by reflected light. An explosive flash with an argon atmosphere was used to illuminate the plate and the camera was operating at about 3,500,000 frames per second. The first frame shows the surface of the plate just before it was struck by a shock from behind. The dark lines are from the reticle in the optical system of the camera. The fine triple line reticle is painted on the plate. The second frame shows the plate within 0.3 microseconds after being struck by the shock. There is a considerable increase in the contrast of the reticle lines and trivial imperfections of the plate surface show up strongly. A velocity of 3,000 meters per second is attained almost immediately and the movement is easily detected on the succeeding frames by examination of the relative positions of the two reticles.

Figure 6 shows a contact print of the sequence of negatives obtained when exploding primacord was photographed in silhouette at 1,700,000 frames per second. A scale has been placed adjacent to the primacord to facilitate measurement, and an explosive light source was used. The early frames show the light source as it brightens up and shortly thereafter the shock wave from the primacord can be seen to progress across the illuminated area. The shock wave was found to be traveling at 6.2 mm per microsecond along the primacord.

Fig. 6 -- Contact prints of film showing
exploding primacord.

Fig. 7 -- 10X enlargement of photograph
showing exploding primacord.

Figure 7 shows a 10X enlargement of one of the frames from Figure 6.

Conclusion

The continuous writing frame camera described is the fastest practical camera so far produced. Its use is probably largely limited to the study of high explosive phenomena where the destruction of the object being examined is of no importance. Somewhat slower models of the camera (with even better space resolution) can undoubtedly be used to obtain reflected light photographs of objects illuminated by the high intensity gas discharge lamps. The camera is rugged in construction and can be readily moved about. It has been found that the sequence of 50 to 100 frames obtained is quite adequate for the studies so far encountered.

Bibliography and Notes

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- (3) J. S. Stanton and M. D. Blatt, "Bowen 76-Lens Camera," NAVORD Report 1033; 1948.
- (4) The perfection of this rotating mirror drive is largely due to the efforts of W. E. Buck, Los Alamos Scientific Laboratory of the University of California, Los Alamos, New Mexico, with considerable assistance by Prof. J. W. Beams, University of Virginia, during the initial development stage.
- (5) The use of diamond stops was suggested by T. E. Holland, Los Alamos

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