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Among the more unusual high speed cameras is the Beckman and Whitley, or now the Cordin, Dynafax rotating drum framing camera. The original Beckman and Whitley camera is capable of up to 25,000 pictures per second (the Cordin version goes up to 35,000 pps) making 224 16mm frame size photographs on a 3 foot length of 35 mm film placed around the inside flange of a rotating drum.

This drum rotates and at the same time drives an 8-sided counter rotating reflecting glass block at its center. The glass block rotates 14 times faster than the lager, film carrying, drum. Each facet of the mirrored block "prints" 112 images on one side of the film and another 112 on the other side of the film to make up the 224 total frames.

It does this by reflecting the image from the central 8 sided glass block mirror to a pair of deflecting mirror assemblies located 22.5 degrees apart along the inside of the camera. Thus after "printing" one image of the subject on one side of the film through one set of deflecting mirrors it prints the next one after turning 11.25 degrees further (and reflecting the light from the objective lens 22.5 degrees) through the second set of deflecting mirrors. Each facet of the rotating mirror block thus prints 2 frames. This is 16 frames per revolution for a total 224 with 112 along one side and another 112 along the other side of the film strip.

The Dynafax overcomes some of the physical limitations that put a ceiling on the rate at which film can be transported through a high speed motion picture camera. To reach higher framing rates than those reached by rotating prism cameras, cameras based on a different image motion compensation scheme were devised. The Dynafax is a prime example and can reach speeds to 35,000 pps although it compromises on image sharpness due to small amounts of motion between the film and the image during exposure.

In the Dynafax the image forming rays are deflected by a rotating multifaceted mirror driven by a rotating drum that also holds the film during exposure. The mirror turns at a rate set by the camera design parameters so that the image moves at the same rate as the film located along the inside periphery of the rotating drum. The motion-inducing rotating mirror also deflects the image of a "stop", through which the image forming rays pass. As it moves across a physical replica of the stop and because the stop's image is moved more rapidly than the subject's image, the shuttering of such a camera is quite remarkable in terms of duration.

The optical complexity of the camera, use of several relay lenses and the shutter stops determine the operating or effective aperture of the optical system as well as the shutter factor. The camera can be equipped with a shutter stop (often called a diamond stop due to its shape) that limits the effective aperture to f/11. f/16 or f/22 even though the primary objective (a "C" mount lens of 75mm focal length) is usually used wide open at an aperture of f/2.8. At the same time, the shutter factor is 10, 20 and 40 respectively.

To put these factors in perspective when the camera is fitted with the smallest shutter stop and running at the highest speed the effective aperture is f/22 and the exposure time is 1/25,000x40 or 1 microsecond!

As shown in the diagram below in operation the image formed by the objective lens is brought to a focus at an image plane. Beyond this image there is a field lens whose function is to collect all the light rays formed in the image plane and send them on to the entrance realy lens placed 2 focal lengths away from the image plane. The light rays pass through an opening, called a "diamond stop" which is used for shutterinmg the system, and located 1 focal length of the field lens away from it. The light rays then are deflected towards the center of the camera by a first surface mirror placed at 45 degrees to the incoming beam. This relay lens then brings the image plane to a focus just beyond the surface of the central rotating 8 sided mirror. The relay lems, being 1 focal length from the diamond stop projects an image of the diamond stop, filled with light, as an unfocused beam of essentially parallel light.

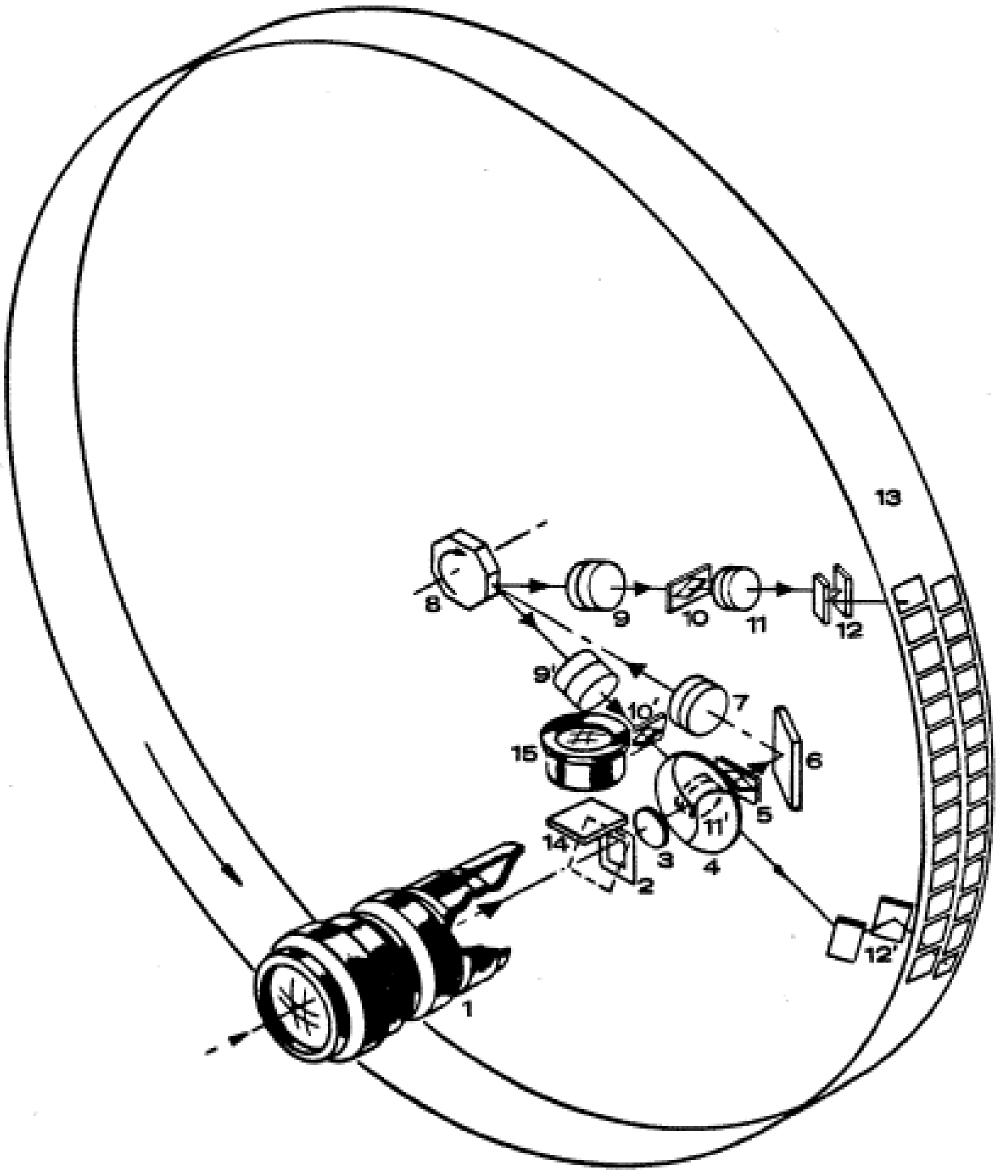
The fact that the image of the image formed by the primary objective is brought to a focus just beyond the surfave of the rotating glass block menas that as the block rotates it also moves the image along with it. The beam of light that is associated with the diamond stop, however, is swept towards edge of the drum at a very fast rate. Much faster than the image of the image plane is moving.

Beyond the central rotating glass block the image forming light rays encounter a collimating relay lens located 1 focal length from the moving image near the surface of the glass block. From here the image forming rays leave this lens as a parallel bundle and proceed through the diamond stop until they encounter a lens which brings these rays to a focus at the film plane located 1 focal length away. Because the image just beyond the rotating mirror is moving the final image is also moving. It moves in the opposite direction that the image located near the mirror does because the optics reverse the direction of motion of the image forming rays.

On the way to this last lens the light beam associated with the first diamond stop is brought to a focus by the relay collimating lens, located 1 focal length of the lens away from the 2nd diamond stop, at the location of the 2nd diamond stop. Here an image of the first stop moves across the physical obstruction intoduced by the 2nd diamond stop. The image moves relatively quickly and this gives rise to the possibility of shuttering the system very effectively. The system transmits the maximum amount of light when the image of the first diamond stop exactly matches the opening of the 2nd one. Any mismatch and the light level drops. Since the image of the first stop moves very rapidly the camera has the capability of reaching very short exposure times.

Shapes other than diamonds can be used for shuttering but the diamond shape provides the shortest exposure times when these are measured from 1/2 peak transmission to 1/2 peak transmission of the system.

The principle of operation of image motion compensation and shuttering in cameras such as the Dynafax is referred to, after its inventor David Miller, as the Miller Principle.



Diagrammatic layout of the Cordin 350 Dynafax rotating mirror and drum high speed camera. 1 Objective lens, 2 Mask, 3 Field lens, 4 Capping shutter, 5 Entrance stop, 6 Entrance relay mirror, 7 Entrance relay lens, 8 Rotating hexagonal mirror, 9 and 9' Collimating relay lenses, 10 and 10' Exit stops, 11 and 11' Imaging relay lenses,12 and 12' Exit relay mirrors,13 Film

To go further then, as stated above the Dynafax only holds enough film for 224 separate full-frame 16mm pictures but can achieve recording rates of up to about 35,000 pictures per second at exposure times for each frame of less than a microsecond. Such a relationship obviously means that the camera is out of film in less than 1/100 second when running at full speed but the framing rate is uniform along the film and generally no timing lights are needed. One simply needs to make a record of the framing rate the camera was running at during the recording. This is displayed by a simple tachometer readout.

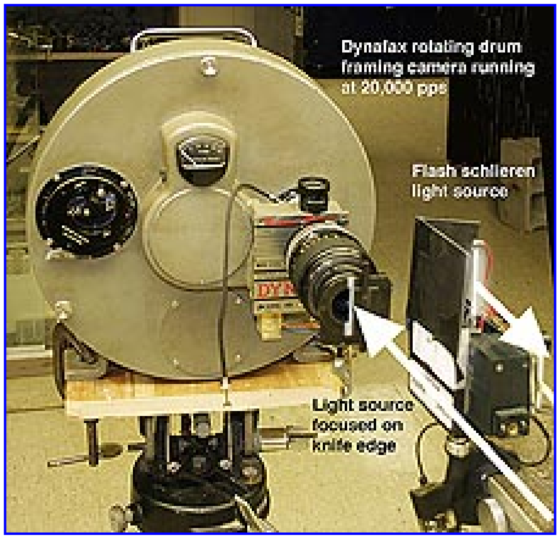
Unlike most other cameras, drum-type cameras generally do not need any sort of synchronization scheme between the camera and the event as long as the event is self-luminous. It is said that they are "always alert". This is a result of the camera running the same film past the image gate over and over at the desired framing rate. The drum is simply brought up to the desired speed and when an event happens it turns on a bright light and the event gets recorded by the film. One only needs to close a shutter (or use a light that lasts less than one revolution of the drum) before the drum has made a complete turn to prevent multiple exposures. If the built-in shutter (called a "capping shutter") is used it needs to be set to a time shorter than one revolution of the drum and in this case the camera needs to be synchronized to the event somehow.

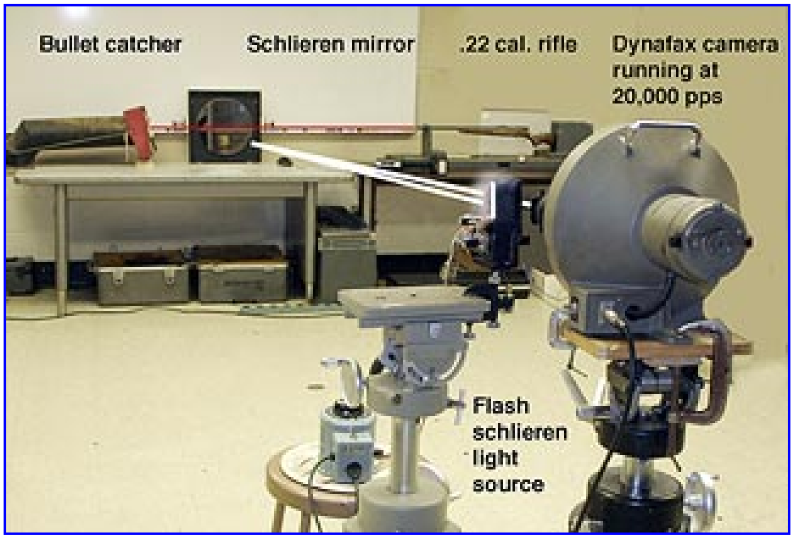
The camera's framing rate, and thus time magnification capability, is high but the images captured by the cameras can generally not be conveniently viewed with a projector. They are, instead, viewed as a series of still images or are "animated" by duplication onto standard motion picture stock. The Dynafax is manufactured by the Cordin Corporation, (Salt Lake City, UT).

Determining the velocity of a .22 caliber bullet

In this application the Dynafax camera is used to determine the velocity of a .22 caliber high speed long rifle bullet. For this application the camera is fitted with a 20x shutter or diamond stop and to make data reduction calculation convenient the framing rate chosen is 20,000 pictures per second. This makes the time between frames on the final record 1/20,000 second.

Because the camera provides an aperture of f/10 with an exposure time of 1/20,000 x 20 or 1/400,000 second per frame a transillumination lighting scheme is used. In this case this is a single mirror schlieren optical system. The mirror provides a convenient scale as it is 12 inches in diameter. Lacking this, some other scale would have to be included in the photograph in the plane of the bullet's flight path so that eventual data reduction becomes possible.





Click on each picture to see an enlarged copy.

The general layout of the experiment is shown in the two figures above. To prevent rewrite or multiple exposure of the film in case the drum turns more than once during the event a flash light source is used that lasts lest than one revolution of the drum. This light lasts only about 1/500 of a second and since at 20,000 pps the drum takes 1/90 second to make one revolution that ensures that there will be no multiple exposures of the film to the light of the flash.

The drawback to using a flash as a light source if the fact the light level will vary considerably from the beginning of the exposure to the end but this is acceptable for this application. In fact, the resulting images should also give an idea as to what the duration and performance of the output of the flash.

In practice the flash is synchronized with the passage of the bullet in front of the mirror by the use of a sound synchronizer placed a foot or so on the side of the schlieren mirror towards the gun. This causes the flash to turn on just before the bullet arrives at the edge of the mirror and since the light lasts for about 1/500 second this should be ample time for the bullet to traverse the mirror while the light is "on".

This is the product of the project. As shown at the left the Dynafax camera makes two rows of images along the length of the film (here reduced to a length shorter than the whole length that was loaded in the camera). The two rows are offset by 14 frames which is due to the fact that the rotating multifaceted mirror imprints each row in an alternating basis and when the mirror has turned 11.25 degrees causing an image beam displacement of 22.5 degrees.

On the right there is an enlarged section of the resulting film. The sequence has been shortened to the time during which the bullet passed in front of the mirror. The images have been adjusted for a uniform look.

The sequences have also been brought so they are displayed side by side and only offset by 1/2 frame so they can be read, time wise, as 1,2,3,4 when alternating from left row to right.

Data analysis for this event then starts by identifying the first image that will serve as the zero or "base" time marker. We assume that this is the 2nd image on the right. That one almost has the bullet visible. The next image in the series would be the 2nd one on the left and it was recorded 1/20,000 second after the one we assumed to be time=0.

Now we count images where the bullet clearly can be seen moving from right to left until we reach the mirror where the bullet seems to have reached the same position as it had int the frame we called "0" and that would be the second one from the bottom on the left row, the total number of images involved there fore is 14. Since the first image is our reference image it does not count and therefore we deduce that the bullet traveled a distance of 1 foot (the diameter of the mirror) in 13/20,000 second. Velocity being determined from the relationship of change in distance divided by the change in time, the velocity of the bullet is 1 foot in 13/20,000 second or 1,540 feet per second.

If we had estimated that the traverse duration was off by just a single image, so 15 instead of 14, then the determination of the bullet's velocity would have yielded a result of 1428 feet per second.

Another approach would be to divide the width of the mirror in 12 parts. This would provide the distance across the mirror for 1 inch. Then we measure the distance that the bullet moved between two consecutive images based on the known dimension for 1 inch. That distance divided by 20,000 is the velocity of the bullet in inches per second and this divided by 12 the velocity in feet per second.

In this case the image of the mirror was made to be 2 inches on an enlarged print from the negative making 1 inch equal .1643 inches. This scaled inch can then be used to make measurements directly on the print.

Between the top two consecutive images on the print the bullet moved from a point located .861inches from the left edge of the first print to .722 inches away from it. Thus it moved .139 inches on the print. But 1 real inch equals .164 inches on the print so that makes the displacemnt .139 divided by .164 or ..847 real inches. So, ,847 in 1/20,000 second is 16951 inches per second or 1412 feet per second.

The discrepancy between the two approaches can be due to errors in judgement as to where the image of the bullet actually is in the sequence or to slight errors in measurement between locations of the bullet in consecutive pictures.

It may be more accurate to measure the distance traveled over several mirrors instead of just two. So let us pick 8 of them. In the first mirror where the bullet is clearly seen it is 1.861 inches from the left edge of the mirror. In the 8th image it is .813 inches from the same edge so it traveled 1.048 inches. But 1 inch is .164 scaled inches so it went 1.048 / .164 or 6.39 real inches over 8 mirrors. 8 mirrors minus 1 (the reference mirror) is 7/20,000 seconds and that is 1/2857 seconds. The velocity then is 6 inches divided by 1/2857 second or 17142 inches per second or 1428 feet per second.

All this goes to show that small errors in locating the position of an image in a photographs for measurement purposes can lead to errors or discrepancies in results depending on various factors.

By assuming that the location of the bullet is exactly the width of the mirror in the when counting whole frames errors can creep in if the assumption is not valid. In the case of measuring velocity from frame to frame small errors in identifying the position of the bullet in consecutive frames also leads to possibly erroneous results. It is best to measure over a larger distance then over a small one.

As mentioned above, sequences of images made by the Dynafax do not lend themselves readily for projection and analysis in with a motion picture projector but selected frames can be rephotographed and assembled into an animated sequence. This is shown in the example that you can see by clicking on **ANIMATION** where a supersonic bullet flies across a schlieren field mirror.

Hopefully you found this project report of interest. The Dyanfax is truly an image engineering marvel. Especially of high framing rate and good action stopping ability are important. Its drawbacks are poor light transmission capability and some loss of resolution. Although not of major importance it is cheap to operate and it provides a consistent recording rate throughout its run eliminating the need for timing lights to keep track of recording rate.

If you'd like to write to me about this camera or related matters contact me through my email address.
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