

# Tripod-Mounted High-Speed Framing Camera

PAPER H-6

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*A portable, rotating-mirror framing camera weighing 35 lb has been built and operated. Standard 35mm film cassettes are used. Each 5-ft load is good for 5 exposures comprising 12 information frames per exposure. All loading and film advance is done in full daylight. The camera has an interframe time of 1  $\mu$ sec and its variable-aperture stops range from f/10 to f/64. Incorporated within the camera body is a "foolproof" optical synchronizing "gate." The range of focus is from 5 ft to infinity with typical resolution of 30 timewise by 60 spacewise information lines per millimeter on Panatomic-X film.*

*Some of the synchronizing electronics are in the camera and some in a remote portable chassis. Within the camera housing is a transistorized synchronizer preamplifier. Remote electronics include power supply, camera operating chassis, high-voltage pulse and pulse-delay circuits, camera synchronizing circuitry, rotor driving pressure, rotor frequency and lubrication pressure monitors, all with the capability of programmed, manual or remote operation. These chassis are mounted in a standard "Bud" rack 24 in. wide and 36 in. high.*

THE rotating-mirror framing camera has become standard equipment for the study of hydrodynamics at typical high-explosive temperatures and energies. Several models with framing rates in the "one per microsecond" class are commercially available in this country, and several others have been designed and put into local use by individual laboratories.

Almost all these instruments were designed for stationary use in heavily armored bunkers with shielded periscope-like vision of their targets. Design from this point of view has resulted in bulky units, poorly suited for use in the normally crowded laboratory environment. This factor, coupled with the high prices of the commercial equipment, has inhibited the introduction of rotating-mirror framing cameras into some of the fields that clearly would benefit most from their use. The camera to be described here is an outgrowth of our feeling that this design trend needs to be reversed.

Presented on October 20, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by Richard J. Krumhansl, Lawrence Radiation Laboratory, University of California, Livermore, Calif.

## Design Features

It is an f/10, 12-frame, "one per microsecond" rotating-mirror framing camera that weighs 35 lb including the rotor. Physical dimensions are 13 in. long by 11 in. high and 4 in. wide. The camera is designed for use on a commercial camera tripod base of the type used by Fastax and other medium-speed framing cameras.

Figure 1 illustrates the camera layout. The objective lens images the object directly onto the rotor mirror. Owing to the rotation of the mirror, the light from the image is consecutively swept over a number of relay-lens pairs which individually reform the images at the film plane. The objective lens also serves to image the entrance pupil with unit magnification onto a set of similar stops located between the relay lenses.

Since the entrance stop and the relay-lens stops are symmetrically located about the objective lens, motion of the objective, to accomplish imaging at the rotor only varies the entrance-stop image size; it does not disturb the focus. In order to compensate for this relative magnification, as well as to provide a variable-aperture camera,

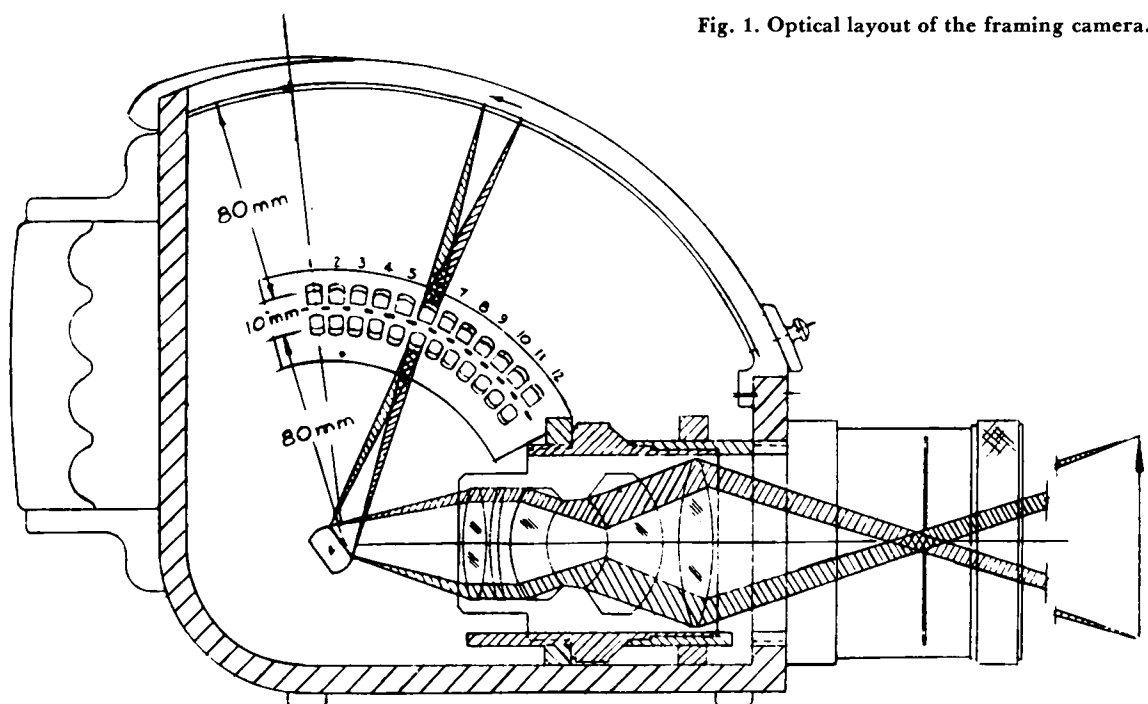


Fig. 1. Optical layout of the framing camera.

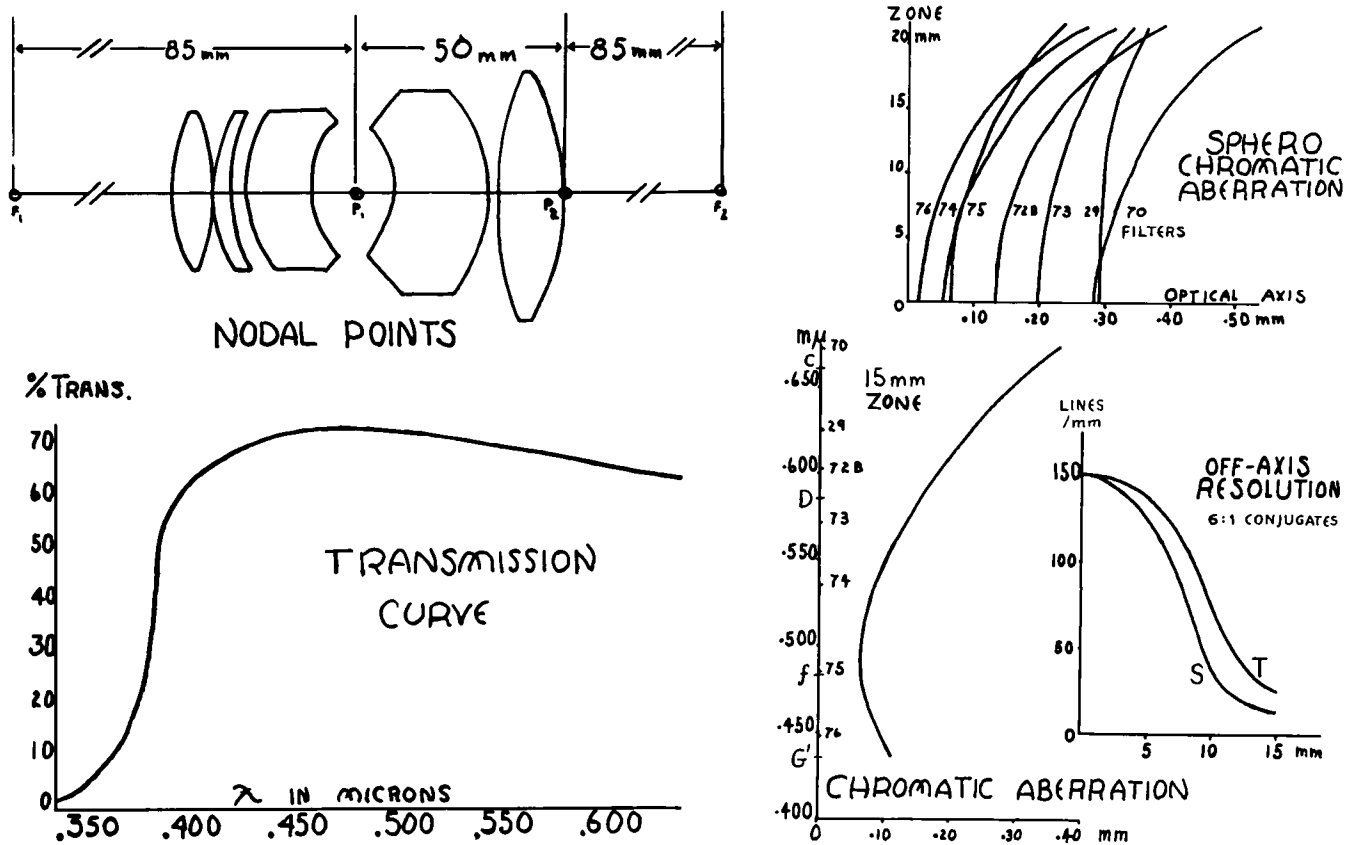


Fig. 2. Performance data secured by bench tests of objective lens (Carl Meyer Speed Lens 85mm,  $f/1.4$ , Serial No. RT 270): (a) (left) nodal points; transmission curve (b) (right) sphero-chromatic and chromatic aberration; field angle resolution.

both the front stop and the relay-lens stops can be varied continuously from a full 4 by 11-mm rectangular shape to a slit essentially 0 by 11-mm in size. Since the exposure time for each frame is directly related to the narrow stop dimension, this gives the operator direct control of the so-called "Q factor," i.e., the ratio of interframe time to exposure time.

The objective has a range of focus of from 5 ft to infinity. The objective is mounted on four tracks and is moved by a cam against spring action to accomplish focusing. A locking knob is provided to secure the focus.

#### Objective Lens Performance Data

The objective lens is the Carl Meyer Speed Lens, which is an  $f/1.4$  and is 85 mm in focal length. Figures 2a and 2b show the results of the bench tests on this lens. Note the  $D-G'$  achromatism which is advantageous for photography of high-energy events. Also notice that the lens is overcorrected spherically. Field curvature and distortion over a 1-in. field were negligible, so they are not presented.

Since there is no field lens in the optical system, the rays that form the outer part of the image field at the film plane are those which have traversed a corresponding outer zone of the objective lens. There is a 1:1 correspondence between image-field points and the objective-lens region that formed the images at those points. Therefore, we find the spherical overcorrection of the objective providing us with an image which has negative field curvature. This helps to eliminate some of the curvature introduced by the relay-lens pair. The final film-plane-image sag is about 1 mm across a 1-in. field. An optical sophistication of this camera is planned which will flatten the field and reduce the astigmatism.

A modified Compur C.R. shutter is located between the objective lens and the entrance stop, close enough to the stop to be essentially in focus at the relay-lens stop location. The shutter has the customary exposures of 1 sec to 1/200 sec. A mechanical lock is used to stop the shutter action in open position for viewing. A 24-v solenoid was built up to operate the shutter trip. It must be hand-cocked before each exposure.

The objective lens is so situated as to place the optical axis 0.072 in. above rotor center. This position was chosen as a best compromise to minimize the transcendental film-plane curve correction and to optimize the field coverage. Further, the image is formed at such a position that when the normal to the rotor is inclined at an angle of  $40^\circ$  to the optical axis, the center of the image is in focus at the surface of the rotor. This minimizes "drag," or image motion during exposure.

The rotor is a 10,000-rps tool-steel mirror driven by a miniature gas turbine on each end of the shaft. It is similar to the Model 6 rotor developed at the Los Alamos Laboratory several years ago. The size of the mirror face is roughly 15 by 17 mm. Since the relay lenses operate at 1:1 conjugates, this is also the maximum frame size.

#### Relay Lenses

The relay-lens bank is made up of 12 pairs of 80-mm focal length government surplus achromats mounted face to face. These lenses have been trimmed so as to fit into rectangular slots milled into an aluminum lens mounting quadrant. The slots are milled as radii from a common center at the middle of the rotor face when its normal is inclined at  $40^\circ$  to the objective optical axis. The amount of metal left between slots is only thick

enough to provide a firm, yet slightly flexible support for the lenses, which are held by a friction fit in the slots.

Focus and magnification are adjusted by use of a Teflon prying tool to push the lenses back and forth in their tracks. Once all the lenses have been located correctly, they are locked permanently into place by a single cover plate which presses each lens tightly against the bottom of its track.

**Film Plane**

The film plane is made up with 2-mm-diameter stainless-steel rollers located between each picture. The film is pulled tight over the rollers, which are adjusted so as to present a film surface perpendicular to the relay-lens optical axis for each frame. A thin sheet of stainless steel is spring-loaded to the underside of the dark cover and presses the film against the rollers to ensure register.

At each end of the film are film cartridge wells to hold either standard 35mm 36-exposure cassettes or the Zeiss 35mm cassettes. For use of the latter equipment, the film cover locking mechanism was coupled to a cassette opening-and-closing contact to eliminate the possibility of the Zeiss cassette being removed from the camera while open and so ruining the film. The Zeiss cassettes reduce film scratching due to transport.

**Synchronization and Control**

Since the camera is not of a continuous-writing design, a synchronizing signal is provided so that the shot may be timed to occur during the camera recording cycle. A second aperture in the front stop plate is illuminated by a G.E. 328 instrument bulb and miniature condenser lens. This hole is located outboard of the optical system stop so that the shutter must uncover the optical aperture before uncovering the illuminated hole. The objective lens images this light source at the relay-lens circle, but displaced to one side. A 2N 469-A phototransistor is located on this arc some 10° before the first frame.

Output from the phototransistor goes directly to a transistor pulse amplifier and emitter-follower circuit mounted inside the camera housing. The synchronizer pulses are amplified at this point to 5 v and are routed via 50-ohm coaxial cable to the electronics control rack. See Fig. 3 for the control and monitor block diagram.

Since several pulses will be received from the synchronizer circuit during the time required for the shutter blades to completely uncover the synchronizing light source aperture, and the pulse voltage will vary with the uncovering process, a pulse height discriminator is needed to ensure consistent triggering in the external circuits. A blocking oscillator located in the camera control rack is used for this purpose. The output signal from this circuit is +150 v.

The camera control chassis is a modified version of the one in standard use at the Lawrence Radiation Laboratory for field operations. The desirable functions of manual, remote and programmed operation, in addition to rotor frequency preamplifier, pulse-delay network and detonator circuitry, have been retained while the capability of synchronizing external circuits with a discontinuous-writing camera has been added. A single 12-conductor cable, including two coaxial line pairs, connects the camera housing to the camera control chassis.

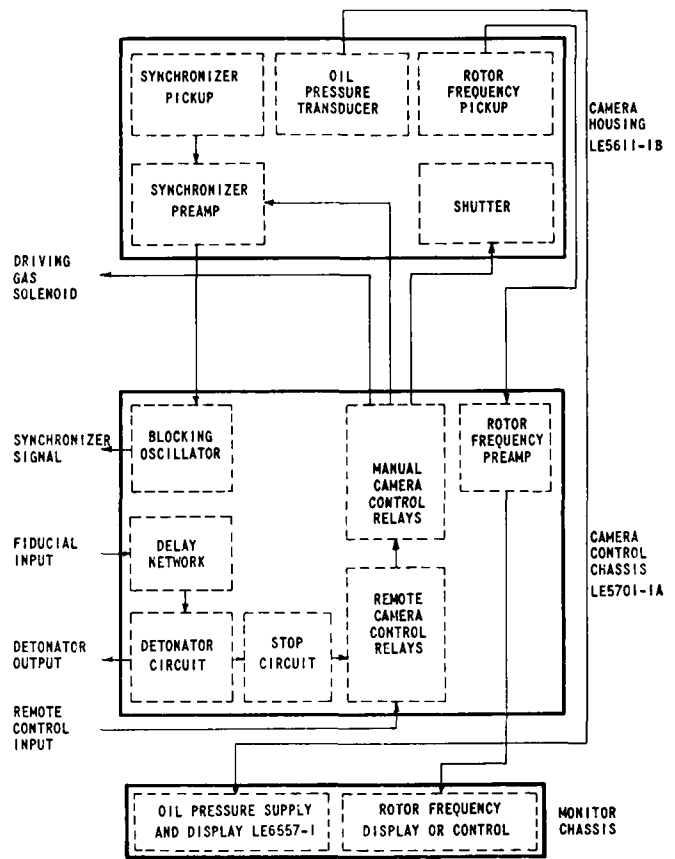


Fig. 3. Control and monitor block circuit diagram.

The oil-pressure transducer is a bridge-type CEC 4-312-A and is mounted on the rotor block to monitor lubricating pressure delivered to the rotor bearings. A direct-reading meter is located at the monitor chassis.

The rotor frequency display or control panel in the monitor chassis is at the choice of the local user. Frequency meters, pulse counters and Lissajous pattern displays offer a wide range of presentation accuracies. As an alternative, automatic rotor speed control units can be used if so desired.

**Camera Operation**

Operation of the camera is very direct. A "run" switch on the camera control chassis provides power to the synchronizer circuitry, the synchronizer light and the

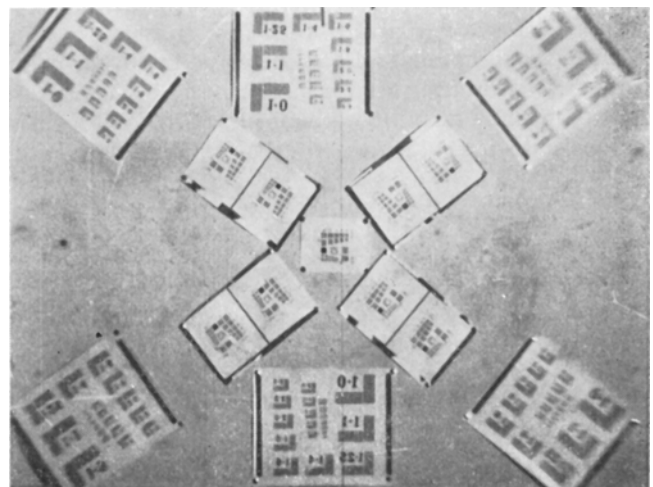
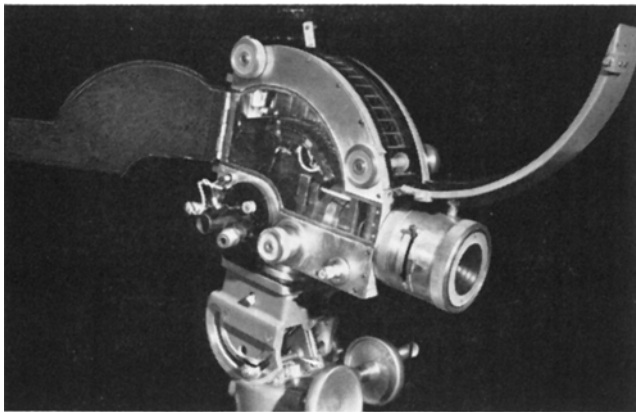


Fig. 4. Dynamic exposure of a resolution target.



**Fig. 5. Completed unit mounted on tripod.**

driving gas solenoid. When the correct rotor speed has been reached, the "shutter" button is pushed, tripping the camera shutter. The synchronizer signal is excited during the time the shutter is open and the event is fired. When the "run" switch is not on, the "shutter" button operates the shutter to achieve the usual "bulb" and timed exposures for visual inspection and static exposures.

Normally the delay-network and detonator circuits are used, either to fire an optical blast shutter or to delay the synchronizing pulse. In this case, a stop circuit de-energizes the synchronizer, the synchronizer light, the driving gas solenoid and the detonator high-voltage circuits. A "reset" button reactivates all these circuits.

Rotor frequencies are controlled manually with a spring diaphragm gas-pressure regulator when the automatic rotor speed control is not desired.

Figure 4 shows a resolution target photographed with the camera on Panatomic-X film. This is a dynamic picture with the stops set to a static  $f/10$ . Resolution is typically 30 lines/mm timewise and 60 lines/mm space-wise in the center of the frame. Resolution fall-off near the edge of the frame is almost entirely a result of astigmatism and field curvature due to the doublet relay pairs.

Figure 5 is a picture of the completed unit.

*Acknowledgments:* The optical layout was originated by W. C. Goss, and the electronic coordination and design of the control components were carried out by George Oja, both of the Lawrence Radiation Laboratory.