

# High-Speed Photographic Recording of Dual Data at High Magnification

By B. H. AMSTEAD

*This paper describes a technique whereby two or more physically contrasting types of data may be recorded simultaneously and in concord on a single strip of film at camera speeds in excess of 4000 frames/sec. The physical image of the photographed subject is recorded on film in the conventional manner employed in high-speed motion-picture techniques, but in addition to this image, a second physical characteristic of the system may be recorded as a moving spot of light on the film. This spot of light moves according to instructions it receives from an amplified electronic signal originating from a strain gage, piezoelectric crystal or similar-type high-response-rate detection device. As a result of this technique at least two types of discrete data may be recorded at speeds of over 4000 times/sec. over a short time interval.*

THE DETAILS OF the technique used in high-speed photographic recording of dual data at high magnification may be understood by reference to Figs. 1 and 2. Since the device was initially developed to study the dynamic characteristics of chip formation during metal cutting, the method as discussed in this paper applies to that problem. In this case the physical image of chip formation was photographed at high magnification, and the tool forces were simultaneously recorded on the film.

The machine tool used was a 20-in. Model No. 20620 Step-toe Shaper manufactured by the Western Machine

Presented on October 19, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by B. H. Amstead, College of Engineering, The University of Texas, Austin 12, Tex.

Tool Works of Holland, Mich. In order to focus the camera on a stationary tool, the action of the shaper was inverted; a special fixture was built to hold the workpiece on the ram and the toolholder was mounted in the vice on the shaper bed. The camera was fixed to a table rigidly mounted to the shaper bed in order to keep relative movement between the camera and machine to a minimum.

The  $\frac{7}{8}$ -in.-square cutting tool was made of Rex AAA high-speed steel manufactured by the Crucible Steel Corp. of America. The cutting edge of the tool was 1 in. from the holder. The tool was set to cut orthogonally with an  $8^\circ$  relief angle and a  $20^\circ$  back-rake angle. The

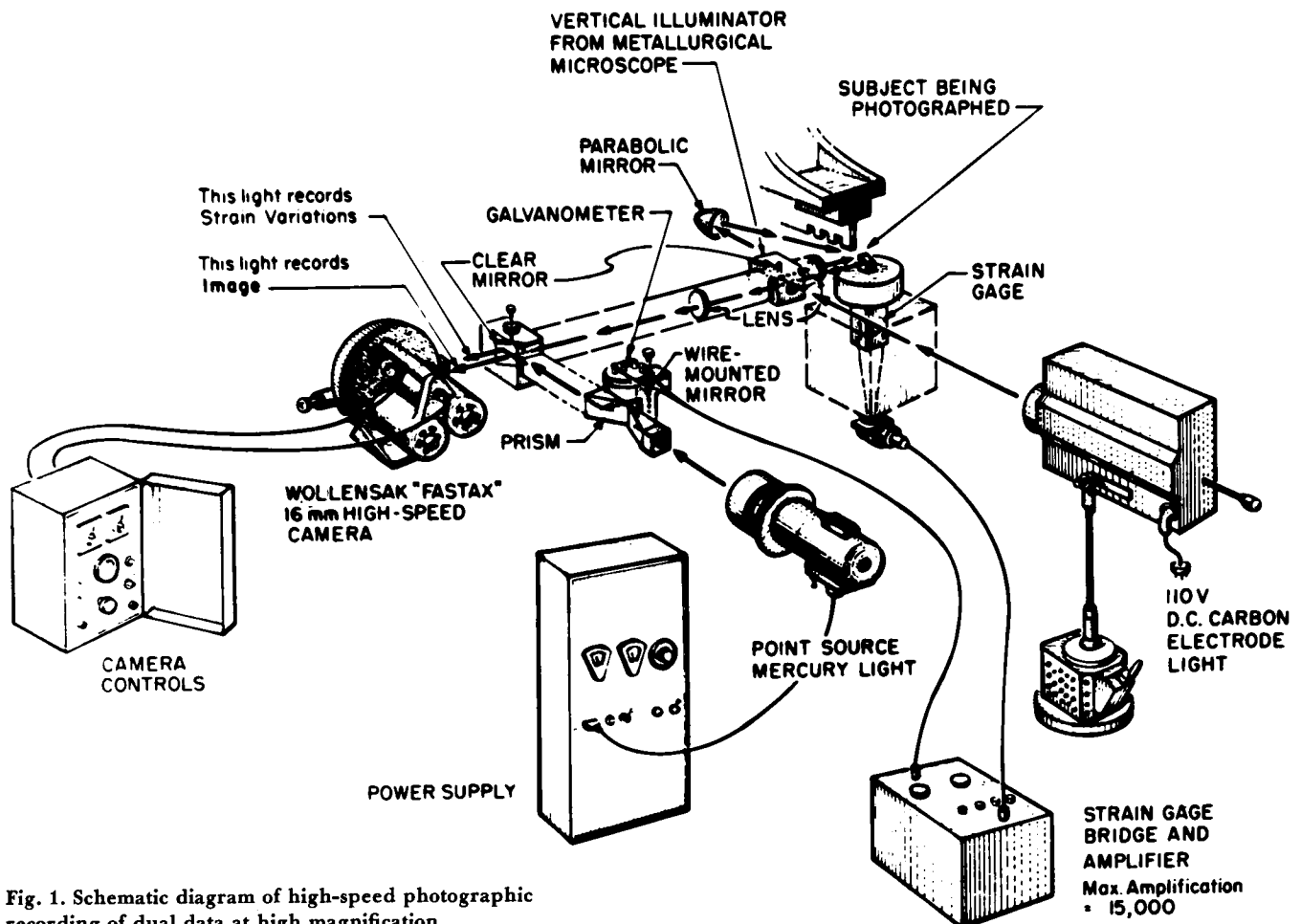


Fig. 1. Schematic diagram of high-speed photographic recording of dual data at high magnification.

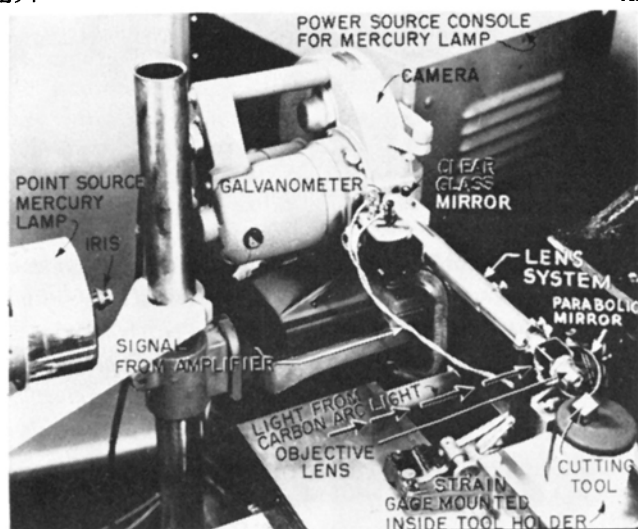


Fig. 2. Arrangement of apparatus.

workpiece was a  $\frac{1}{8}$  by 6-in. strip of C1018 steel with a tensile strength of 74,000 psi.

The Wollensak Fastax 16mm high-speed camera was equipped with a lens section designed to give a magnification of 5X, a relatively large magnification at which to photograph a nonluminous subject because of the difficulty normally encountered in lighting. The subject was illuminated with a 110-v d-c carbon-electrode arc light which was directed on the spot to be photographed by means of a vertical illuminator from a metallurgical microscope as well as by a parabolic mirror. A clear image was recorded on film using this more or less conventional system.

Although the camera was equipped with the customary "Goose" timer which had settings for "Event" and "Camera," in order to start the shaper ram and the timer under the proper timing conditions, a remote microswitch was attached to the clutch lever of the shaper.

The toolholder was equipped with a strain gage designed to indicate the vibratory response of the tool and the absolute magnitude of the force at any instant. The strain response was amplified in a strain-gage bridge and amplifier. The amplifier had a maximum amplification of approximately 15,000. The amplified signal was made the input to a galvanometer from a Westinghouse type PA four-element oscilloscope. The response rate of the galvanometer was tested to 7000 c/sec with a signal generator. The mirror in the galvanometer reflected the light pip in accordance with the strain on the tool. The light pip, thus reflected, shone on a nearly transparent mirror which in turn directed the light to the film. Pencil-type galvanometers may be used in the place of that described, but their response is limited to about 3500 c/sec, and care must be taken to match the impedance of the galvanometer to that of the amplifier, as was necessary in this case.

The light source for the pip was a small PEK-109 high-pressure point source mercury-arc lamp manufactured and distributed by the PEK Labs, Inc. The lamp is rated at 140,000 candles/sq cm and the arc size is 0.015 by 0.015 in., giving it the highest brightness of any commercially available light source. A 50-v d-c, 100-w power supply designed to provide a 10-kv starting

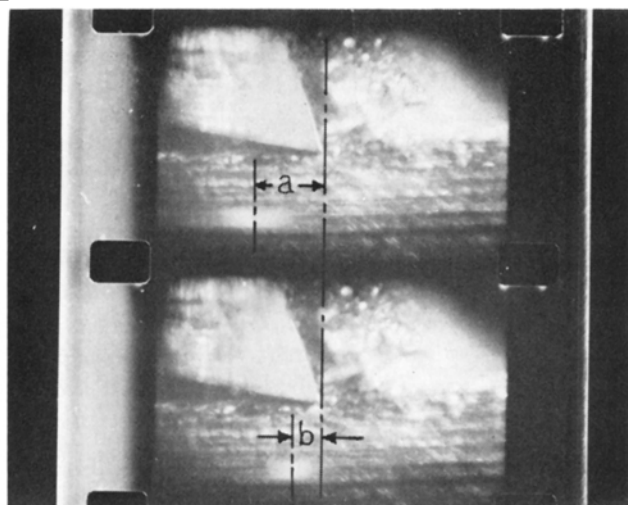


Fig. 3. Frames from a strip of film, showing cutting tool, metal fracture and light "pip"; overall magnification, 20X.

impulse was built. The value of the inductance necessary to generate such a starting pulse for the PEK-109 is 200 mh. Once the arc had stabilized, the proper operating characteristics were obtained at approximately 20 v and 4.5 amp. No forced-air cooling was required; the internal pressure in the lamp during operation is 75 atm. This high-intensity light was directed through an iris to give a small point of light.

In order to calibrate the magnitude of force as traced by the pip on the film, it was only necessary to find the tool force needed to give a given light deflection as viewed through the reflex telescopic viewfinder of the camera. This calibration was accomplished with a spring scale and an adapter attached to the tool.

Figure 3 is a photograph made from a strip of data recorded at 3000 frames/sec while mild steel was being cut at a depth of 0.010 in. and 92 surface ft/min. The photograph is at 20X and clearly shows the cutting tool and light pip which, in approximately 1/3000 sec, has moved a distance indicated by (a-b). In the case shown (a-b) represented a 200-lb change in tool force.

Kodak Tri-X Negative type film with an American Standard Exposure Index of 320 for daylight and 250 for tungsten was used. Depending upon the light from the subject, it was developed at ASA speeds up to 1000 and positive prints were made from the negative originals.

This technique for recording two categories of data simultaneously on a film at high speed can be adapted to record at least three parameters. The development may be utilized to study not only metal-cutting processes, but also can be used to make basic studies of stresses and strains, and to solve fundamental vibration theory problems. It also has applications to fluid mechanics, where stream movement can be recorded, along with fluctuating pressure and temperature data. Piezoelectric crystals with response rates up to 50,000 c/sec will provide a signal in the case of pressure changes.

The paper, as presented at the International Congress, included a two-minute motion picture showing the results of a film made at 4000 frames/sec. The screen magnification was approximately 400X and metal fracture could be seen on this film simultaneously with the "dancing pip" indicating tool forces and vibrations.