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A HIGH SPEED SPECTROGRAPH SHUTTER

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THE INSTITUTE FOR FLUID DYNAMICS

and

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ABSTRACT

An event-triggered spectrograph shutter with a speed of 70 meters sec^{-1} has been constructed and used to study shock tube plasmas. The shutter can simultaneously serve two-high aperture spectrographs. Several sequential exposures of 8-150 μ sec can be obtained over a period of 300 μ sec. Jitter in opening and exposure times is 6-8%. Delayed times can be varied mechanically in a simple and predetermined way.

I. INTRODUCTION

This note describes an event-triggered shutter which provides exposure times in the range 8-150 μ sec. The open aperture of this device is large enough so that it should be useful for more general shuttering applications than the one for which it was specifically developed.

Gas-driven shock tubes are particularly difficult subjects for time resolved photographic spectroscopy.(1-2) Several plasmas, quite different from one another in thermodynamic conditions, appear in rapid succession as the incident, first reflected, and multiply reflected shocks sweep past the spectroscopic line of sight. Test times available for homogeneous, steady state regions vary between 10-200 μ sec.(3-8) The opening time of a high pressure diaphragm, which initiates events in the shock tube, cannot be predicted accurately. For this reason, high speed sectored disks cannot readily be employed as shutters. Revolving drum cameras offer the advantage of continuous recording,(3,4,8) but spectroscopic data is somewhat degraded by 1) a loss of resolution due to distortion and vibration of the film plane, and 2) the need to superimpose fiduciary spectra and the data intended for quantitative photometry. Relatively slow-moving shutters must employ narrow slits to achieve short sampling times. There is a tendancy for such shutters to stop-down the fast spectrographs needed for this type of work.

Use of exploding wires or foils to drive fast shutters has been reported previously.(9-12) However, the present shutter offers a combination of desirable features not incorporated into earlier designs. For instance, when employed with a stigmatic spectrograph, it can be operated in either a close-open-close mode, or to frame several events of 8-150 μ sec duration. It will not choke-off light in optical systems as fast as f/6.3 , and can provide time resolution for two spectrographs simultaneously, for example, a high resolution instrument for line broadening studies and a wide bandpass instrument for comphensive line intensity measurements. Time delays (above a minimum of 80 μ sec) and exposure times can be varied in a convenient way. The reproducibility of exposure and opening times is adequate for normal shock tube applications.

II. DESIGN

A cut-away diagram of the shutter is shown in Figure 1. The moving element is an aluminum slider, containing one or more slits, and terminated at one end by a circular cap. This cap fits closely to the walls of a cylindrical channel, acting as a gas seal. The slider behaves like a piston when driven from behind by an exploding wire.

a. Mechanical

The impulsive driving force for the slider is generated by the expanding products from an exploding wire, confined initially to a small volume. Because the mechanical stresses are quite formidable, the main shutter component (part No. 3 of Figure 1) is machined from a single 2" thick phenolic block. Two 3/4" diameter holes intersect within this block to form a tee. The horizontal 3/4" bore is used as a channel for the moving slider. The vertical bore houses a cylindrical phenolic plug, a sector of which has been removed to form a shallow expansion chamber for the exploding wire. A pair of aluminum electrodes Part No. 4 of Figure 1, containing taper pins for securing the exploding wire, form the ends of this plug. This assembly is extracted from the phenolic block after 10-12 firings, so that accumulated debris can be easily removed. Three 1/2" vents intersect the 3/4" horizontal bore 2" downstream from the exploding wire. These reduce the compressive work performed by the slider during its useful travel and, subsequently, allow the escape of the hot gasses trapped behind the slider disk. The slider bore gradually erodes, so that the phenolic block must be replaced after 300-400 runs.

A shell of tempered 1/8" aluminum plates surrounds the phenolic block on five sides. This shell provides mechanical reinforcement and serves as the outer conductor of a shorted coaxial cylinder, the inner member of which is the exploding wire. The coaxial arrangement optimizes the energy transfer to the exploding wire(13) and minimizes rf pickup in photomultipliers and oscilliscopes. Shrouds made of aluminum sheet (not shown in Figure 1) trap stray light and reduce noise from the discharge.

Sliders are made from 0.012" high strength alumium alloy (Alcad 2024-T3). The rectangular portion (42 x 19 mm) of the slider, the circular gas seal, and two small tabs which reinforce the junction between the slider and the seal, are die stamped and joined together with a spot-welder. The complete slider weighs 1.1 g. This mass helps maintain a nearly uniform coasting speed following the slider's initial acceleration. Various combinations of slits (widths 0.7 - 8.0 mm) can be die-stamped within the useful 15 x 30 mm portion of the slider. A slider can normally be used between two and four times.

The slider is arrested, after traveling the length of the horizontal bore, by a sturdy slab of aluminum (No. 6 in Figure 1). The rectangular portion of the slider passes through a slot in this cover, but the slider's gas seal rams into it. This heavy aluminum slab also serves as the point of attachment for static (1 x 10 mm) slits which aid in alignment of the shutter, and for a beam splitter, located behind No. 2 of figure 1, which permits the shutter to serve more than one spectrograph. The whole assembly can be quickly disconnected to allow changing or inspection of sliders. Preparatory to firing, a gauge block is used to accurately position the slider in its bore: the depth to which it is set back determines the time delay before the first exposure, i.e., before the first moving slit crosses the static slit.

b. Electrical

Figure 2 is a schematic diagram of the electrical circuit. Power for the exploding wire is supplied by two 7.5 μf capacitors [0.1 mh] in parallel with a 5.0 μf [20 nh] capacitor.
For the 26 gauge tinned copper exploding wire normally used, a charging voltage of 6.5 kV gave the best combination of repeatability and component life. Higher voltages tended to deform sliders, rather than giving them a greater acceleration, and to lessen reproducibility. Lower voltages did not impart sufficient speed to the sliders. A conventional thyratron-driven spark gap discharges the capacitor bank. The thyratron is triggered by a 200 volt pulse from an ionization gap located in the shock tube wall.

III. PERFORMANCE

Slider dynamics were tested using models having five equally spaced slits. As these passed across a well-colimated beam of white light, transmissions were measured with a photomultiplier and recorded on a CRO. After a period of acceleration lasting 80 μ sec, the sliders attain a speed of 70 m sec^{-1}, which remains essentially constant for 300 μ sec thereafter. Random variations in delay and exposure times are shown in Figure 3a, 3b, respectively. These data were obtained during a series of shock tube experiments in which wide (7 mm) slits were used to obtain the longest possible photographic exposures for weak lines in plasmas of 150-200 μ sec duration. Standard deviations in both histograms is 7 - 8% . Perhaps 10% of the scatter in time delays is due to jitter in the breakdown time of the shock tube ionization gaps which supply the initial triggering signal.

Figure 4 shows an 80 Å wide sample of the 1700 Å of spectroscopic shock tube data obtained with the shutter in a single experimental run. The spectrograph is a stigmatic, 1 meter grating instrument with a speed of f/9 . Such spectrograms provide data on both the strength and the Stark broadening and shifting spectral lines.[14,15] Plasmas behind first and multiply reflected shocks are quite different thermodynamically, so that spectroscopic data from both regions is desirable. The latter plasma is usually the brighter by 50 - 200% because of additional shock heating. Nevertheless, it is possible to obtain optimal photographic densities for both plasmas by suitably selecting the widths of the two slider slits. For the depicted data, slit widths of 2.5 mm and 1.5 mm are used to sequentially expose the first and multiply reflected regions, respectively. Both slits are 4.0 mm in height. There is a 1.3 mm high region where the two slits do not overlap vertically. This leaves a 1.3 mm portion of the film unexposed to the shock tube spectra. After firing the shock tube, this portion of the film receives an iron arc spectrum (a suitable mask prevents the arc spectrum from being superimposed on the shock tube data).

Because the gas-driven shock tube is not a highly reproducible spectroscopic light source, photographic sampling times should be directly correlated with the times at which plasma conditions are measured. For this purpose a small mirror near the focal plane of the photographic spectrograph is used to deflect light into a photomultiplier. The output is displayed on a multi-beam CRO on a common time base with photoelectric signals from various monochromators used for plasma thermometry.

IV. CONCLUSIONS

A high speed mechanical shutter has been developed and used routinely for quantitative shock tube spectroscopy. Delay and sampling times can be varied in a convenient way. The shutter can be used jointly by two spectrographs for enhanced efficiency in gathering data. It should prove useful for event-triggered sequential framing of transient (8 - 150 μ sec) plasmas, particularly where it is necessary to fully utilize available signal levels.

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REFERENCES

1. A. G. Gaydon and I. R. Hurle, The Shock Tube in High Temperature Chemical Physics, Chapman Hall, London (1963).
2. Y. B. Zel'dovich and Y. P. Raizer, Physics of Shock Waves and High Temperature Hydrodynamic Phenomena, Academic Press, New York (1966).
3. T. D. Wilkerson, D. W. Koopman, M. H. Miller, R. Bengtson and G. Charatis, Phys. Fluids Supp. 12, I-22 (1969).
4. R. D. Bengtson, M. H. Miller, D. W. Koopman and T. D. Wilkerson, Phys. Fluids, 13, 372 (1970).
5. M. H. Miller, University of Maryland Report Number BN-550, 1968 (unpublished).
6. R. D. Bengtson, University of Maryland Report Number BN-559, 1968 (unpublished).
7. O. Laporte and T. D. Wilkerson, J. Opt. Soc. Am. 50, 1293 (1960).
8. I. I. Glass and G. Hall, Shock Tubes, Sect. 18 of Handbook of Supersonic Aerodynamics, NAVORD Report 1438, 6 (1959).
9. J. C. Camm, Rev. Sci. Instrum. 31, 278 (1960).
10. J. O. Clayton, Rev. Sci. Instrum. 34, 1391 (1963).
11. W. Wurster, Rev. Sci. Instrum. 28 , 1093 (1957).
12. G. L. Grasdalen, M. Huber and G. H. Newsom, A Simple Closed-Open-Closed Spectrograph Shutter for Exposure Times in the Ten Microsecond Range, Harvard College Observatory Tech. Rep. 5 (1967).
13. W. L. Starr, Exploding Wires, ed. W. G. Grace and H. K. Moore, Plenum, New York (1959).
14. H. R. Griem, Plasma Spectroscopy, McGraw-Hill, New York (1964).
15. W. L. Wiese, Plasma Diagnostic Techniques, ed. R. H. Huddlestone and S. L. Leonard, Academic Press, New York (1965).

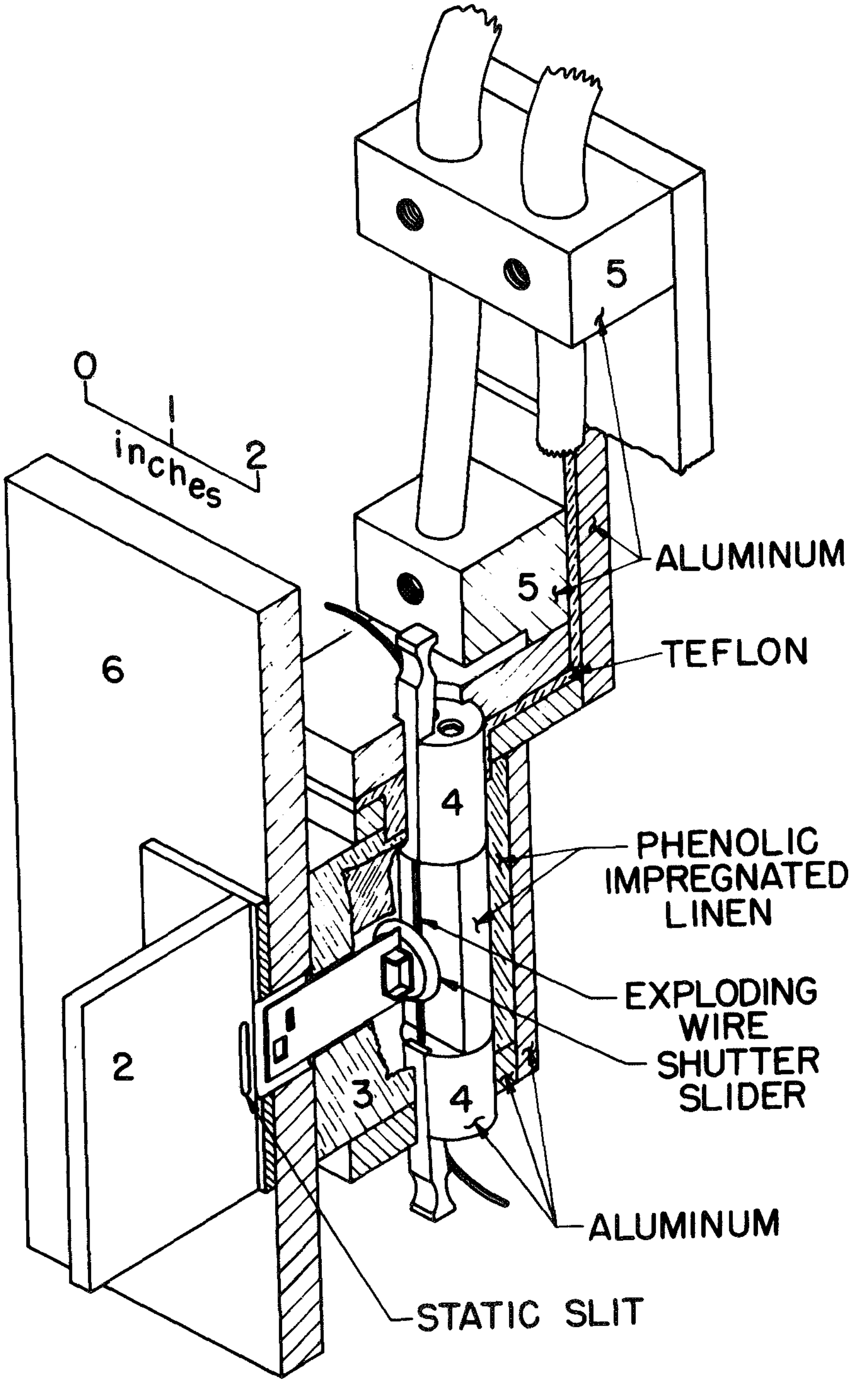

FIGURE 1. Cut-away view of shutter ready for firing: 2) static slit assembly, 3) breech, 4) electrodes for securing wire, 5) high voltage connections, 6) stop for shutter slider and the member used for mounting the shutter.

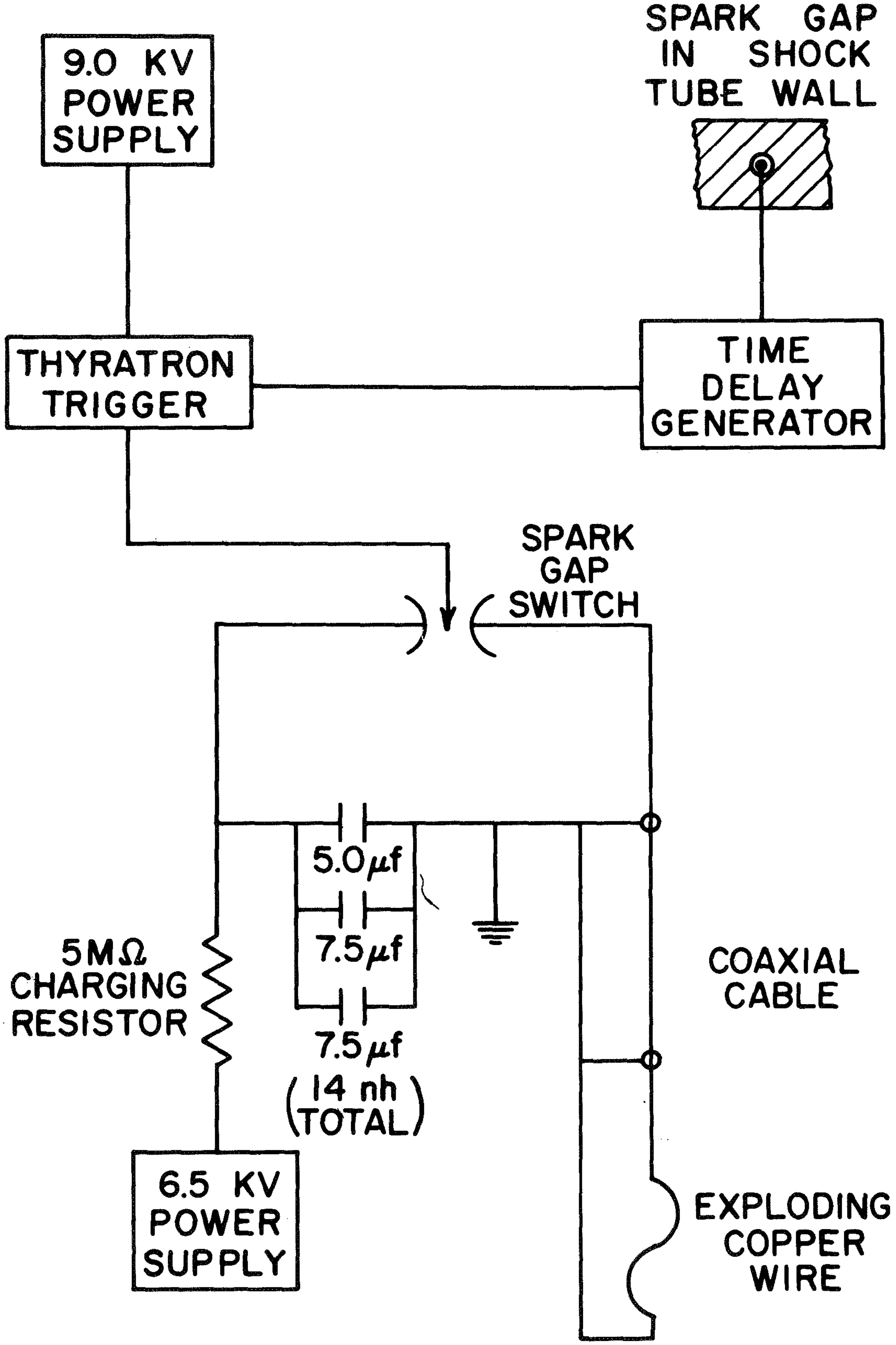

FIGURE 2. Schematic diagram of the electrical curcuit.

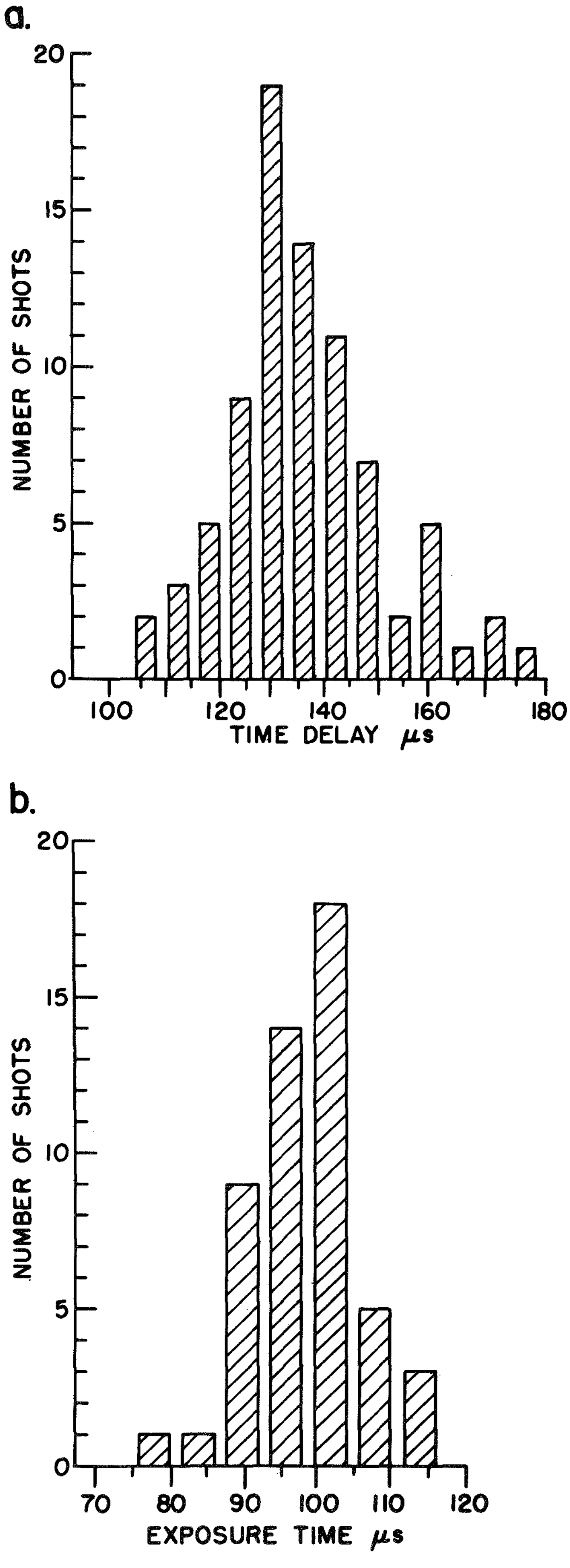

FIGURE 3. Histograms showing reproducability of a) delay times and b) exposure times.

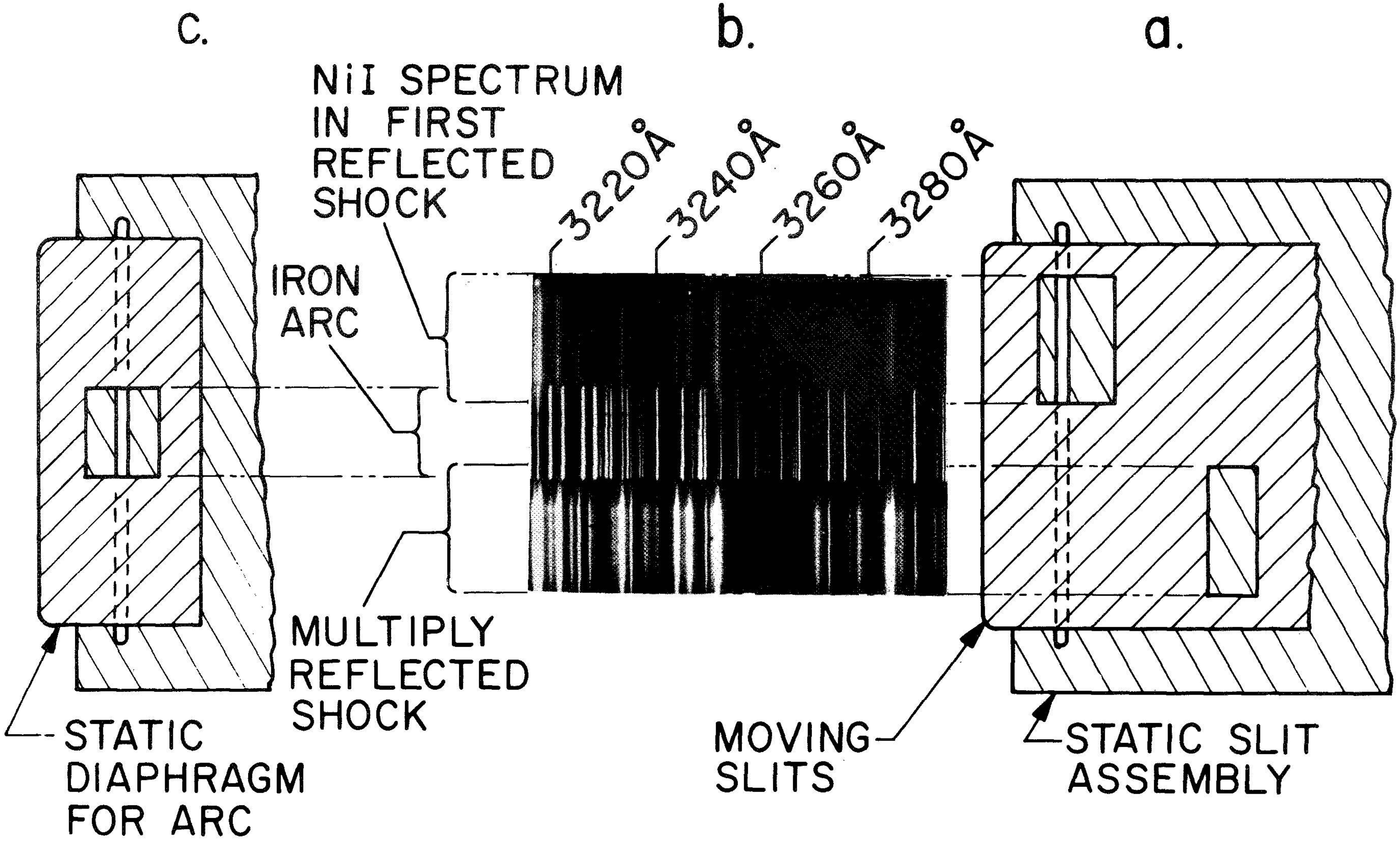

FIGURE 4. Typical data obtained by the shutter and a stigmatic (f/9) spectrograph: a) slider used to frame sequentially observed shock tube plasmas, b) spectrum of nickel in the plasma behind first-reflected and multiply-reflected shocks, c) mask used to expose the iron arc fiduciary spectrum.