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A High Resolution Camera for Bubble Chamber Photography*

J. D. Ferrie and R. C. Field

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

An account is given of the development of a camera system designed for the SLAC 1-m bubble chamber. The camera is used to photograph the decay vertices of charmed particles.

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A topic of substantial current physics interest is the production and decay of particles bearing the quantum numbers "charm" and "bottom". Several publications [1] have reported bubble chamber investigations where charmed particles were detected and measured by using high resolution optics and imaging the bubbles while they were as small as possible. One of these experiments was at the SLAC Hybrid Facility where a single 360 mm lens, set at f/11, was used. This produced an image of 80% of the 1m beam path on a 35 mm format. It gave a depth of field of about ± 6 mm and reconstructed bubble images equivalent to about 60 μm in space.

For a closer study of the physical processes, a new experiment proposed that the optics should be improved. This note describes the camera system which resulted and is presently in use.

Substantially improved resolution was desired, but some depth of field could be sacrificed. The experimental beam (of 20 GeV gammas) has a diameter of 3 mm. It was felt that a depth of field as small as 4 mm would support the analysis. This in turn would limit the resolution to $\sim$ 60% of that of the earlier experiment, assuming the Rayleigh criterion formulae. Of course, bubble visibility and contrast would fix the size of the reconstructed disc to ensure high scanning efficiency. It was considered that bubble images reconstructing to 40 or 45 μm in space would give a substantial improvement in the experiment.

Other improvements desired were: a reduction in the relative size of film grain with respect to the images; and the removal of the images of specular reflections of the flash tubes at the glass and retroreflector faces. These had caused a substantial loss of visible track length in the previous experiment. [2]

Some constraints imposed included the use of a single 35 mm film path (for compatibility with scanning machines), and the need to co-exist with the stereo triplet of lower resolution cameras which are used for 3 dimensional reconstruction and kinematic analysis. Since camera triggers were expected to be at random, with a mean interval of $\sim$5 seconds, a wind on time of 0.5 sec or less would be acceptable. Note that the bubble chamber itself pulses at 10 or 12 Hz.

A camera meeting these criteria has been built and has recorded over 6×10^5 pictures so far. It uses two lenses, each recording about half of the usable beam path, with a small overlap between the images. The two images are formed on a single 35 mm film, separated by about 40 cm of the film path. Aspects of the system are now described.

Physical Layout

The hydrogen bubble chamber, Fig. 1, is a cylinder with horizontal axis oriented north-south. Its diameter is 110 cm and liquid depth is 35 cm. A 28 cm thick optical window forms the south wall, opposite the retro-reflective piston which is the north wall. Photography is carried out via vacuum chamber viewports 169 cm from the optical window.

In order to mount the pair of lenses, it was necessary to install new viewports in the camera positioning plate, vacuum tank and radiation shield of the bubble chamber. Since the 20 GeV photon beam penetrates the chamber hydrogen close to diametrically, the new access was made 6.7 cm above the horizontal mid-plane, Fig. 2. In this way direct specular reflections of the flash tubes from the various glass surfaces and the piston surface were directed off the 35mm film. Similar interference with the low resolution views was kept away from the beam area of the film. Minor modifications to the 70 mm film path of the low resolution camera were necessary to allow this layout.

Lenses

The lenses could be mounted at 225 cm of optical path from the beam. Since the previous experiment had a space-to-film demagnification of 5.5, the desired improvement in the image size to grain size ratio was accomplished by making use of 610 mm lenses, giving a demagnification of 2.65. (The film in use is Kodak 2482. [3])

A pair of Nikon Apo-Nikkor 610 mm lenses was used. With an aperture setting of f/11, the Rayleigh criterion indicated a resolvable point separation of 30 μm in the beam plane for the field depth of 4 mm. Tests indicate that the lenses perform close to the diffraction limit.

During operation it was found difficult to maintain focus. The source of the shifts was found to be the sensitivity of the focal length, f, of the lenses to temperature variations. The fractional temperature coefficient, $df/fdT \simeq 1.6 \times 10^{-4}$ per degree C, is at least an order of magnitude larger than expected from typical expansion and refractive index coefficients of the materials involved. As a consequence, temperature stabilization to $\pm 1^oC$ was enforced by controlled heating of the purge air. (Because of hydrogen safety needs, the flash tube spaces around the lenses are constantly purged.)

Flash System

Photography of small bubbles required that the illumination occurred at about 175 μs after the start of bubble growth. Since the occluding disc grows as the square root of growth time, the image is not sharply defined unless the flash is of short duration. For this reason, short flash tubes were chosen, and the resistance and inductance of the charging and triggering circuit were minimized. The flash tube mounting is indicated in Fig. 3. The tubes [4] were fired with typically 1600 V from 16 μF condensers, using a helically wound trigger wire, and produced a pulse of $\sim$ 30 μs width, whose amplitude peaked about 30 μs after triggering was initiated.

Chromatic Aberration

The 28 cm thick optical window (BK7 glass) transmitted rays at up to 6^o on the way to the lenses. This produced a chromatic dispersion of the bubble images on the film, amounting to tripling of the apparent bubble length at the end of the frame, along a direction towards the intersection of the film plane with the camera axis. Colour filters placed near the lens have been shown to be of inadequate optical quality to be used against this problem.

Sharp cut glass filters in front of the flash tubes were introduced. These removed wavelengths below 560 nm [5] but made necessary the more efficient use of the light from the flash tubes. A pair of cylindrical condenser lenses mounted beyond the filter glass, Fig. 3., gave a factor of about 2.2 in intensity.

The harsh environment around the air-purged flash tube is known for the rapid destruction of many materials. The above system was introduced only after extended tests, and in the full knowledge that the filters would surface-darken noticeably within hours, but thereafter remain relatively stable for weeks. The filters protected the acrylic lenses from quick destruction. Replacement of the inexpensive filter-condenser system is anticipated every few weeks of operation.

With the filters in use, the bubble images throughout the chamber sharpened to the point where bubble sizes of close to 40 μm were being reconstructed, meeting the criteria for the experiment.

Shutter

The bubbles are illuminated twice, once at 175 μs, by the high resolution camera lamps, giving a recorded diameter of 40 μm. The second flash is from the low resolution camera lamps, at a bubble diameter of $\sim$ 400 μm. The growth time between the flashes is 3 msec. Unfortunately, specular reflection from the large bubbles – effectively dark field illumination – interferes with the bright field images recorded on the high resolution view just 3 msec earlier. Because of the inadequacy of filters, mentioned above, the preferred solution to this problem has been to use a synchronous shutter which closes the high resolution light path between the two flash times.[2]

The shutter used for the present system is similar to that of Ref. 2, but uses two shutter cylinders (one for each lens) on a single axle, driven by one motor. The extra inertia made it necessary to sample and correct the rotational speed at 720 Hz instead of 1440 Hz as in the referenced version. The somewhat looser shutter synchronism is still well within tolerance.

Film Platens

The film path is illustrated in Fig. 4. A pair of platens 19 cm long were spaced by 38 cm centre to centre. The correct spacing between the two views on film was set by a fixed loop between platens. The platens were machined from aluminum, drilled with a pattern of 108 holes of 0.6 mm diameter for vacuum clamping of the film, lapped to a flatness of about 10 wavelengths, and hard anodized. In use they were rigidly spaced from a front plate which had 16.8 cm long by 2.5 cm wide apertures for the images. The front plate could be positioned accurately with respect to the stereo triplet camera plate, and the relative positions remained stable because of the rigidity of the support structure, even though the supports of the two cameras were made independent to eliminate vibration coupling. This ensured stable positioning with respect to the bubble chamber, and in turn, the particle beam.

The film hold down vacuum was about 400 mm Hg. Its application was synchronized electronically with the wind-on mechanism.

On one of the two views were projected 4-digit roll and frame numbers, flash timing and hydrogen vapour pressure parameters. The corresponding second view was given only the frame number.

Film movement

The wind-on mechanism was based on a Giannini Corp. [6] Flight Research Camera. Essentially standard magazines, loaded with 1000-foot reels of film, fed into vacuum actuated reservoir loops on both the supply and takeup sides. These loops led to the box containing the drive mechanism, a sprocket arrangement which included a reciprocating arm to establish a film loop.

The initial load was too large for the original clutch, whose friction-spring broke at the anchoring pin. A graded stiffening of the spring spread the strain over a sufficient length to eliminate the problem.

Film wind-on required that the original mechanism was pulsed nine times. Including exposure time for the numerals and platen vacuum settling time, the minimum interval between exposures was about 450 msec.

Structure

The weight of the camera was supported from the floor, independently of the bubble chamber and its integral 70 mm camera, to eliminate vibration. For 70 mm camera maintenance and survey purposes, the high resolution camera could be removed by crane. Precise positioning and access to the lenses were provided by mounting the camera body as an integral unit on a lathe bed. This allowed easy retraction from the operating position.

The rigid support framework on the lathe way maintained the camera orientation and position with a four point support. This minimized flexure, while allowing precise positioning, together with ease of disassembly for maintenance. Specifically, the wind-on mechanism and the platens were contained in a subassembly (see Fig. 4) which could easily be removed and replaced by a spare unit, with no need for realignment of the platens or lenses.

The lens to platen distance was fixed by the rigid front section of the camera. At the outset, focussing was accomplished by shimming the distance between each lens and its platen. It could only be carried out by examining pictures of beam-induced tracks.

Operational Experience

More than 6 x 10^5 event-triggered pictures have been taken so far with the camera. Normal operation, including film changing, is simple and fast. A substantial "teething" period was needed, however, to identify and solve the problems associated with the clutch, the lens temperature sensitivity and the flash lamp filtering system.

The track images eventually obtained were of high quality and easily met the initial specifications. An example of an event is reproduced in Fig. 5. The camera maintenance interval is long and contributes negligibly to experimental inefficiency.

Acknowledgements

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2. J. D. Ferrie, R. C. Field and D. A. Talaska, Nucl. Instr. Meth. 203 (1982) 223

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4. EG & G Inc., Boston, Massachussetts, U.S.A.: FX51C.

5. Hoya Optics, Inc., Fremont, California, U.S.A.: Filter O-56

6. Giannini Scientific Corporation: Richmond, Virginia, U.S.A.: Flight Research Camera.

FIGURES

1. Vertical section along the bubble chamber cylindrical axis, shown in perspective. The arrows indicate, from left to right:- the drive shaft and piston; the liquid hydrogen volume; the optical window; the snout of the vacuum tank, containing the thin, cooled, thermal radiation shield; the camera positioning plate, penetrated by the view port window mounts.

2. Layout of bubble chamber vacuum tank view port window mounts. Flange reinforcements are indicated surrounding the optical windows. Numbers 1, 2 and 3 correspond to the low resolution stereo camera viewports, while V and P are used by operators to monitor hydrogen conditions visually and photographically. The two ports for the high resolution camera are shown as A and B. The central and bottom left viewports are no longer accessible.

3. Flash tube mounting fixture. The "π" shaped flash tubes, A, are mounted above and below the lens aperture. Supported in front of each tube is the filter, B, and condenser doublet, C.

4. Plan view of the Camera: A, lens body; B, shutter assembly (the cutaway shows a shutter closed); C, film gate and platen; D, Film advance mechanism; E, vacuum actuated film reservoir; F, film path; G, magazine. The scale represents 1 metre.

5. Enlarge image of a 20 GeV γp interaction. The bubble diameter is 40 μm.

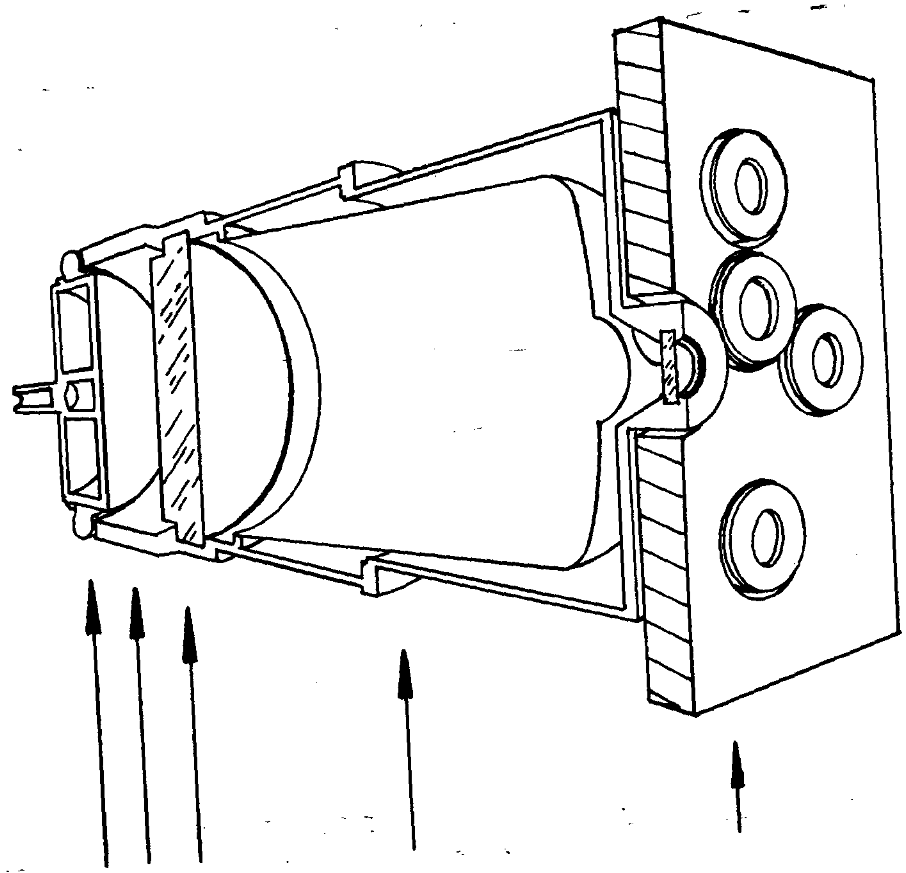

Fig. 1

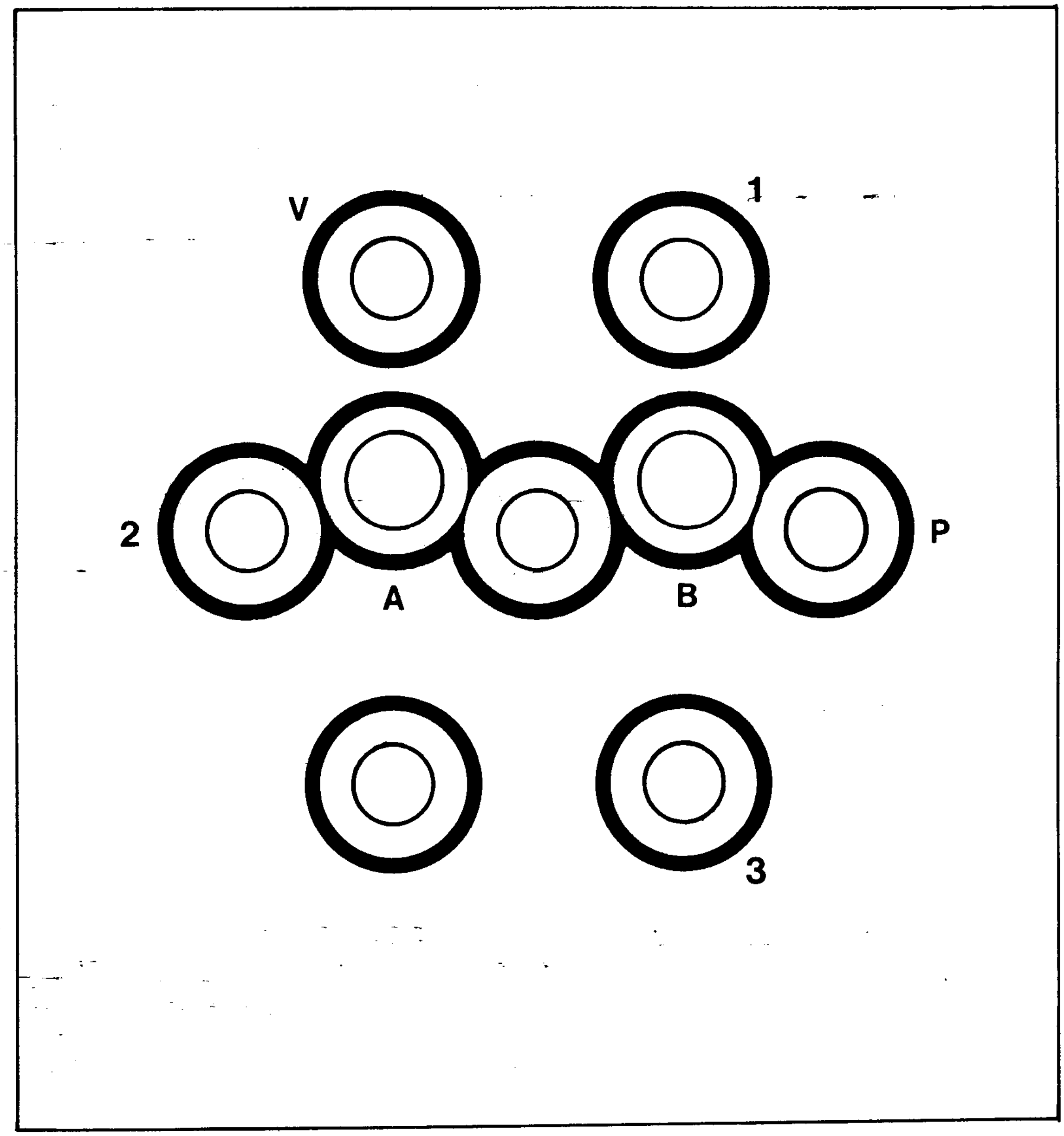

Fig. 2

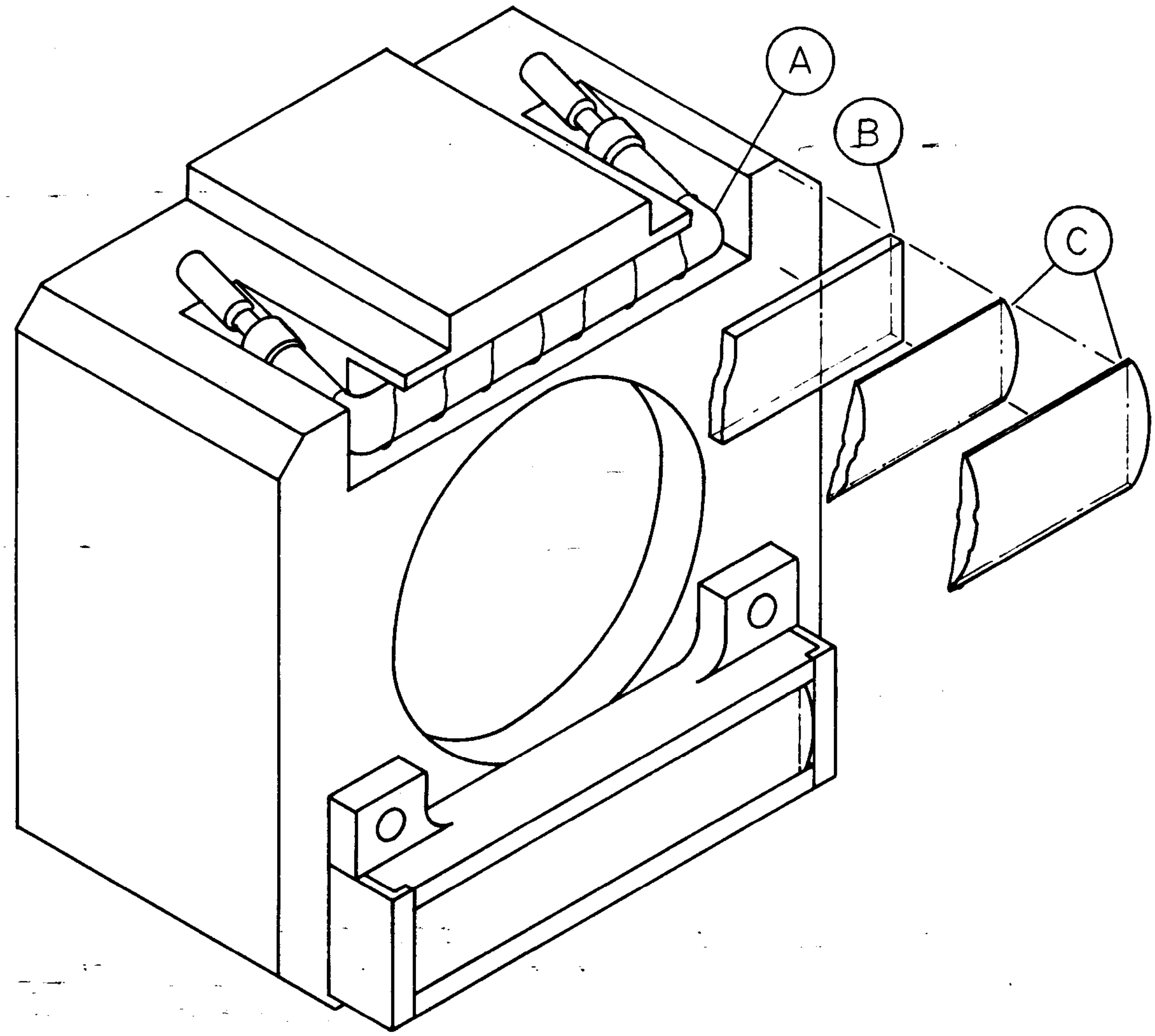

Fig. 3

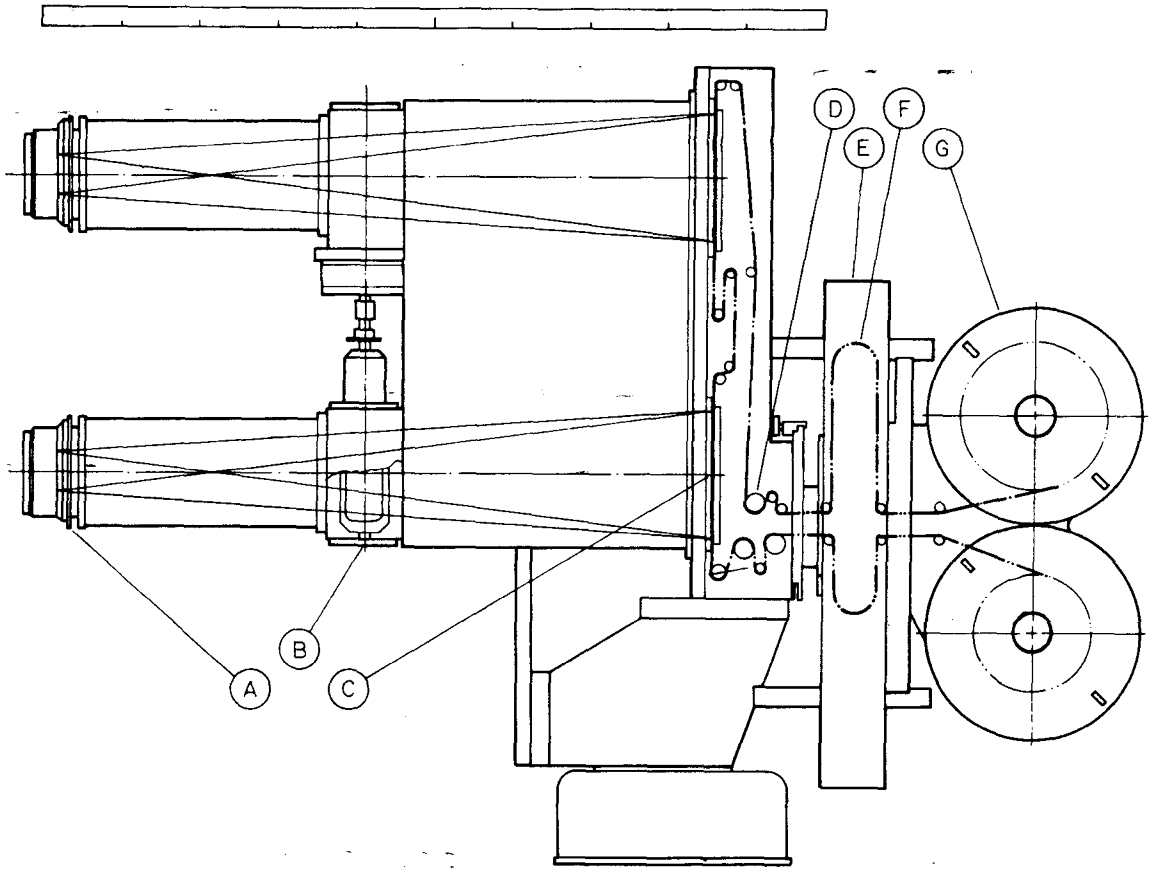

Fig. 4

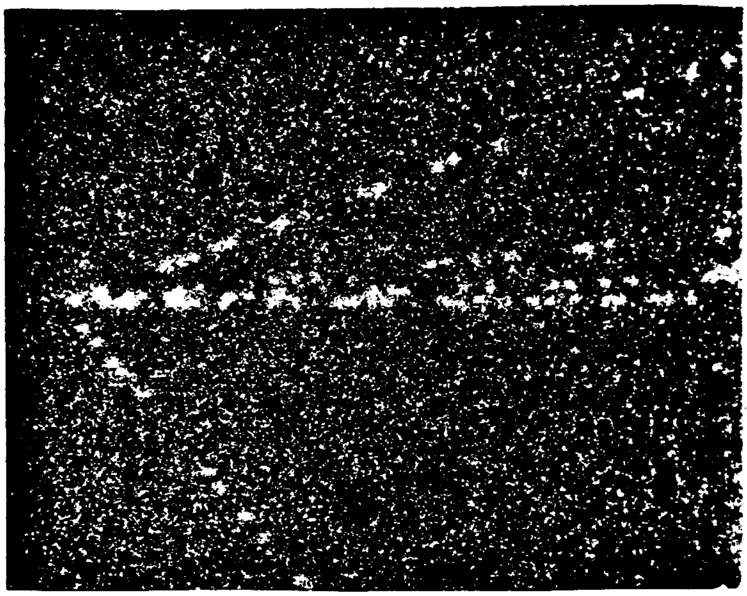

Fig. 5