SWEEPNIK II, AN IMPROVED TRACK MEASURING MACHINE

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1. Principle and Brief History

Sweepnik is a semi-automatic machine for measuring track photographs, developed at the Cavendish Laboratory, Cambridge, U.K. We have a tradition for building these machines: our first TARA (similar to IEP) was built in 1957, and four similar machines were built here, three of which are still in use. A more ambitious machine named RHODA (inspired by the SMP) was completed in 1965 but never put into use; instead we decided to put all our effort into a new idea.

This was to build a fast track follower, the track being followed by a beam of light, steered by digitally controlled mirrors. As usual one would need a small area scan, to see where the track was. For this the beam was to form a small line image on the film (just as e.g. in PEPR) which would sweep round in a circle, like the hand of a clock. Thus all track directions would be covered in each scan. The operator would put the sweep centre approximately on the track to be followed. Each time the line image sweeps across the track the light would be dimmed for an instant, and the precise time when that happens would indicate the direction in which the sweep centre has to be moved so as to follow the track.

At first we could not get enough light; with a motor car head lamp the signal-noise ratio was marginal. Then we tried a 1 mW He-Ne laser and our intensity troubles were over; the brightness per steradian of such a laser is over 100 times that of the sun! Also we no longer needed achromatic lenses. After that (Jan 1966) the project was pushed hard, and money was found to buy a PDP 7 computer. Graham Street developed much of the hardware, electronics in particular, and Julian Davies most of the software. Tracks were followed in May 1967, but much was still to be done. In September 1968 Sweepnik was described at Versailles, and soon afterwards we measured events which showed good agreement with previous measurements, and better accuracy. Since then, Sweepnik has been in use, and Dr. Street will tell you about the operating experience.

2. Sweepnik II

Already in October 1967 we started on the design of a second machine. Apart from the pedestrian virtues of being more solid and easier to adjust, we aimed at more basic improvements. The first model had steering mirrors of 5 cm diameter, with an optical lever of about 1 m. That meant an aperture of 1:28, (45° incidence!) and hence a diffraction-limited image of $1.22 \times 28\lambda =$ 22 μm width (containing 80% of the light). Because of imperfections the image was really more like 50 μm wide. Sweepnik II has mirrors of 7.5 cm diameter, and a slightly shorter optical lever. Moreover, the cylindrical lens that is used to create the line image is arranged (Fig. 1) so that only a (rotating) strip along a diameter of the main lens is illuminated; that gets rid of the Airy factor of 1.22. The calculated width then becomes about 12 μm, and the measured width is not significantly larger.

For measuring end points etc., it is arranged that the computer can flip the cylindrical lens out of the beam, giving a point image; but programs for using this "point mode" have yet to be written.

To make the line image sweep around we are again using a Dove prism, but we have replaced the motor that spun it by a small air turbine, with air bearings. This runs with much less vibration and eliminates the small erratic precession we got with ball bearings, and the hum from the motor; also the speed can be adjusted and raised to any value we may dream of using. Originally we used about 24 rps, that is 48 sweeps per second; now we use about 75 sweeps per second and can probably go higher still; our present electronics is not fast enough.

The bigger aperture and the narrower image means that the defocussing as the image travels over the film is no longer negligible, as it was with the first model. To deal with that problem we have mounted the lens L_2 on a kind of loudspeaker coil; the current through the coil is controlled by the computer so that the image is kept focussed. The mounting of the coil keeps sideways movements within the needed limits of 1 μm.

The new steering mirrors are merely an enlarged and improved version of the old ones, again suspended on crossed springs, moved by somewhat larger loudspeaker coils, with stronger magnets, and their movement digitized by a Michelson interferometer much as before. Despite the heavier mirror the movement is faster than previously. (See Figure 3)

A new film carriage has been designed for quick film transport and view change, both under computer control. The general layout is indicated in Figure 2.

3. Software and displays

The software was mostly written by Julian Davies but is still being developed. Basically the computer is told the angular position of the line image when it falls on the track; it then computes the amounts by which the two steering mirrors have to be tilted to move the probe along the track by one millimetre, and puts those two numbers into two scalers; a piece of logical circuitry then moves the mirrors so that the scaler content is made zero again. To pick up a track one presses the TRACK button and places the probe close to the required track; Sweepnik then assumes control.

As soon as three points of the track have been measured the computer can extrapolate from known curvature; it will disregard signals from crossing tracks, and if a grazing track causes a sudden broadening of the signal the computer will ignore it and go on at constant curvature, like a driver clenching the steering wheel in a patch of fog. This works very well with tracks in hydrogen and normal optics.

Fiducials are measured automatically with the same hardware: the direction and length of the arms is checked, the coordinates of the intersection are computed and stored and then the probe travels at high speed to the next fiducial. Only when work is started on a new format of film does the operator have to set the probe on the fiducials manually; after that, the computer knows. Similarly, after tracks have been measured on one view the computer knows enough to measure them automatically on the other two views; the operator merely watches that all goes well.

The displays include the usual projection screen, on which is also seen a bright red dot, indicating the instantaneous position of the sweep centre. It is formed by the pointer beam, a laser beam that is also reflected by the steering mirrors but does not pass through the film and is therefore always clearly seen, even if the probe crosses a dark area. The pointer is accurate to about 0.2 mm on the film. Higher accuracy (to a few μm) is obtained by a closed-circuit TV which looks backward at the film via the steering mirrors at a small area (enlarged 65 times on the monitor) around the sweep centre, whose position is indicated by a mark that shows on the monitor. In that way one can accurately measure identifiable points by hand.

The film carriage has been completely redesigned; it allows rapid view change and film advance, both under computer control.

We hope that Sweepnik II will be a useful machine owing to its high accuracy and resolution, good signal-noise ratio and fair speed, and to its simple design, which largely avoids expensive fine-tolerance machining. Arrangements for commercial manufacture have been made.

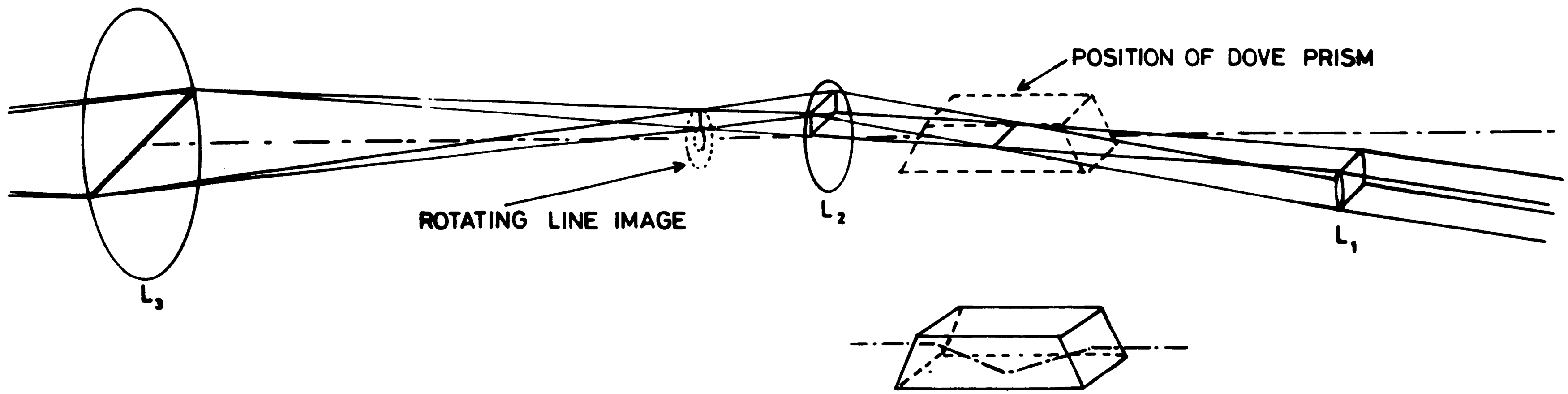

Fig. 1 The Laser beam, coming from the right, is made astigmatic by the cylindrical lens L_1. A first line image is formed inside the Dove prism; a second line image is formed by L_2 and then imaged onto the film by L_3. The image rotates at twice the speed at which the Dove prism rotates about the optical axis (—•—•—•—•—). The first line image is imaged by L_2 on L_3. The inset shows the passage of the beam through the Dove prism.

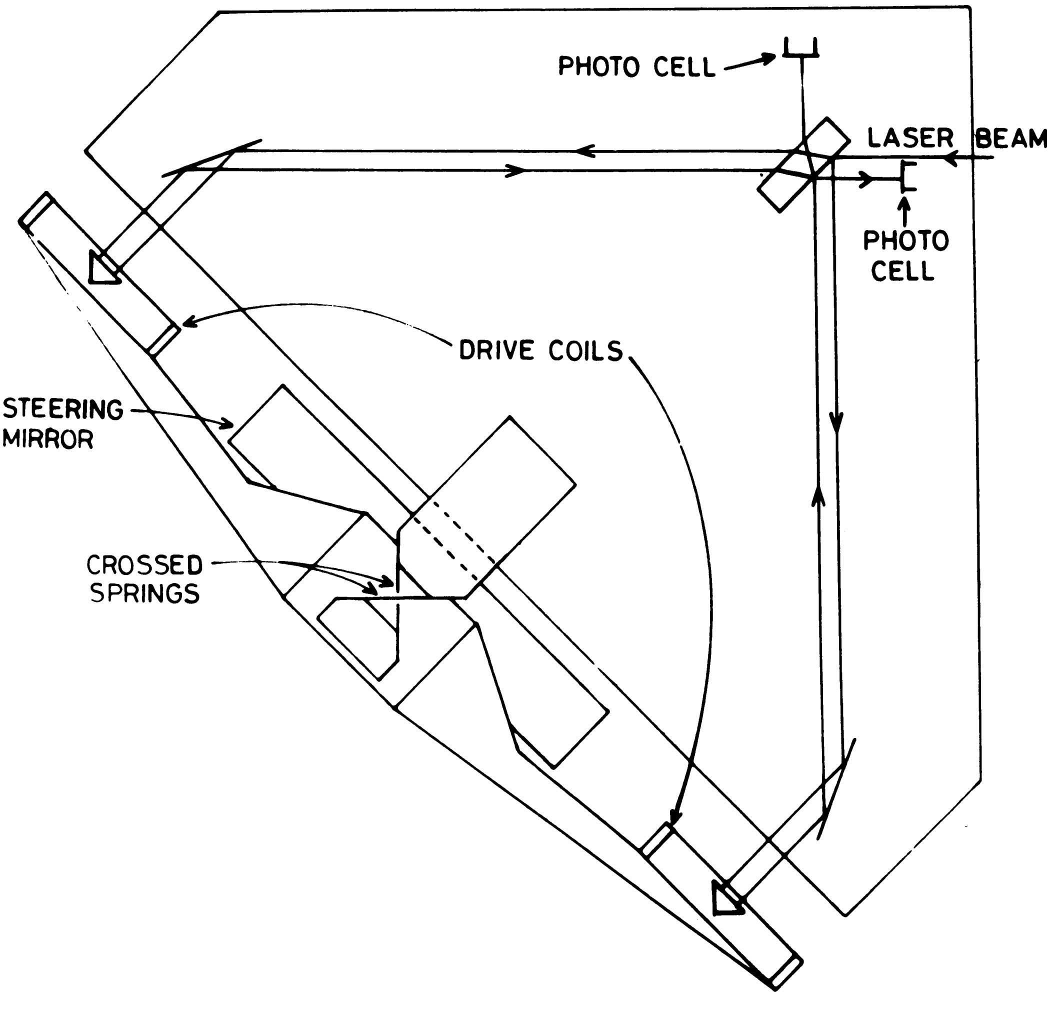

Fig. 2 The steering mirror is suspended by two pairs of crossed springs, free to swing about an axis defined by their respective intersections; it is moved by passing a current through the two drive coils which move in the fields of two magnets (not shown), like loudspeaker coils. The two prisms (one attached to the centre of each coil) together with the three mirrors form a Michelson interferometer; if the mirror turns the currents in the two photocells vary sinusoidally, about 90° out of phase, so that the movement of the mirror can be digitized (as with a Moiré fringe counter).

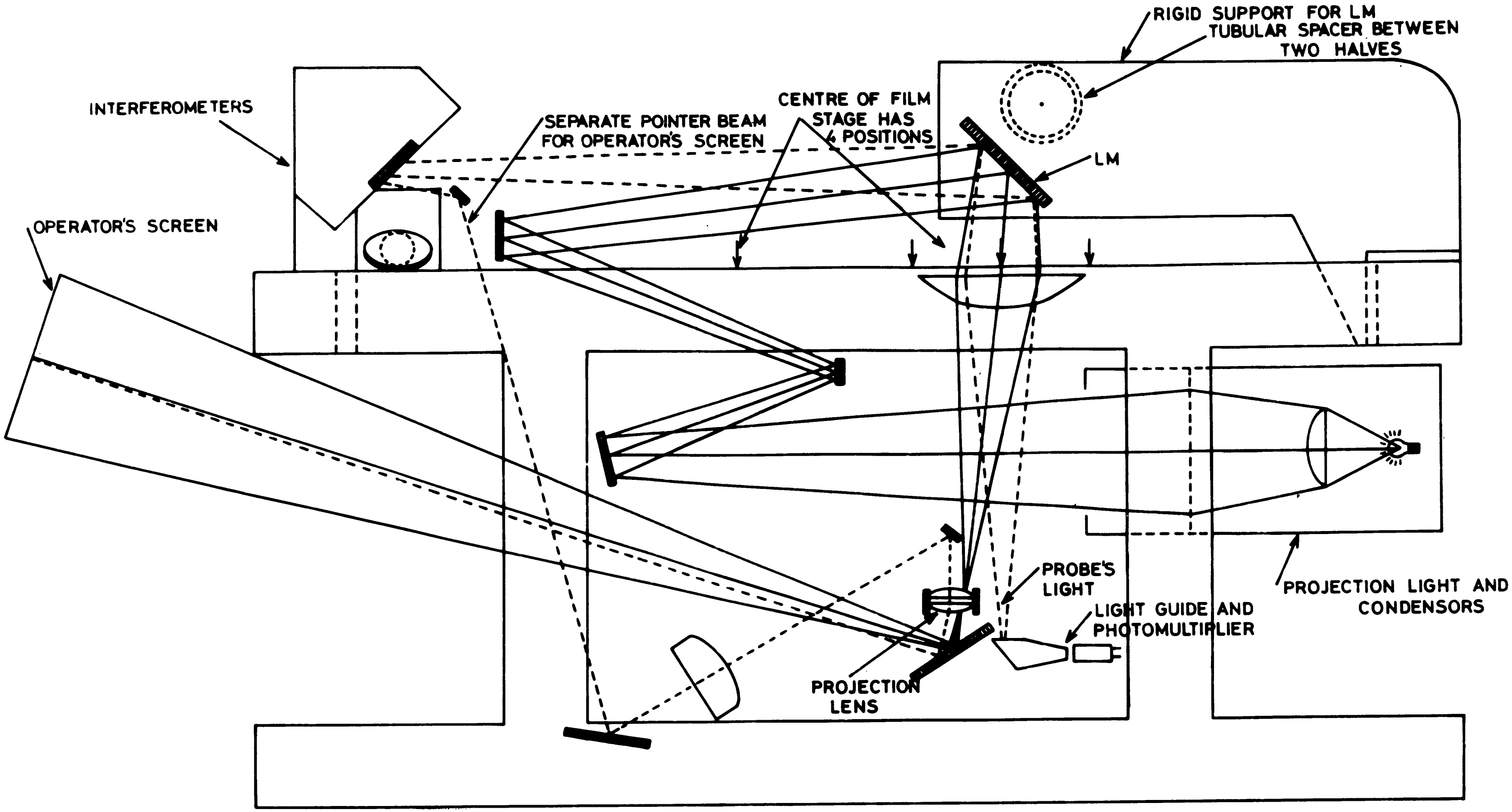

Fig. 3 Side elevation of the machine; schematic but approximately to scale (length without screen is about 1.5 m)