THE CULGOORA MAGNETOGRAPH

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Abstract. The magnetograph is based on a high-resolution filter which serves in place of a spectrograph, except that a reasonably large field of view (one-quarter of the Sun's diameter) can be observed at the one instant. Observations are made by obtaining filtergrams of opposite circular polarizations simultaneously in the wing of a magnetically sensitive line. Exposure times are about 0.3 s, the angular resolution of the magnetic field is about 2 arc s, closest frame repetition rates about 8 s. The filtergrams are processed subsequently by photographic or television subtraction. Semi-automatic photographic and/or TV subtractions yield magnetograms suitable for cinematographic projection though the subtractions are not yet as perfect as those obtained by individual subtraction.

1. Introduction

This instrument has been developed with the intention of producing magnetograms of spatial resolution approaching or surpassing 1 arc s with a fast repetition rate. The spatial resolution achieved at present is about 2 arc s, and observations may be obtained over a circular field of one-quarter the solar diameter every 8 s.

The magnetograph consists of a telescope with which filtergrams are obtained simultaneously in opposite circular polarizations in the wing of a magnetically sensitive line, and a subtractor which displays the image differences due to the longitudinal magnetic field. Subtractions can be obtained semi-automatically, yielding cinefilms with which rapid changes in field may be studied.

2. The Telescope

Most photoelectric magnetographs suffer from the disadvantage that light may be recorded at only one resolved image point at a time. Spectroheliograph methods of observing magnetic fields allow observations to be made at all points along the length of the spectrograph slit simultaneously, but considerable time is still taken in scanning to yield an adequate field of view. To overcome this disadvantage, the Culgoora magnetograph incorporates a narrow-band filter (Ramsay *et al.*, 1970), consisting of a series of Fabry-Perot interferometers and a prefilter to isolate light from the wing of a suitable spectral line, the filter replacing the more conventional spectrograph.

The filter has a clear diameter of 50 mm and may be adjusted to any spectral line in the range 4000–6600 Å by coarse tuning provided there is a suitable interference prefilter of about 20 Å pass band available to isolate the required spectral region. Fast, smooth fine-tuning is available over a range of about 5 Å. The pass band varies irregularly in width throughout the spectrum, being about 0.05 Å at 6100 Å and nowhere exceeding 0.1 Å. As in any interferometer, the peak wavelength is shifted to the blue for rays incident at increasing angles θ to the axis, the variation being proportional to θ^2; at 6100 Å it amounts to 0.05 Å for $\theta = 15$ arc min. We regard 0.05 Å as the

Howard (ed.), Solar Magnetic Fields, 24–29.

tolerable limit of variation across the field, so the field diameter 2θ is about 30 arc min.

Interreflections between the three interferometers are quite strong. They preclude the filter from being used near a focal plane, for multiple reflections would then overlap the main image. To overcome this disadvantage the filter is used in a collimated beam, the individual interferometers being tilted relative to each other so that the multiple images produced by the final imaging lens (*c*, Figure 1) fall outside the useful field. Tilting the interferometers makes the transmission slightly asymmetric around the centre of the field, but this is generally negligible or tolerable.

The Airy disk of a lens of diameter 50 mm has a radius of about 3.1 arc s at 6100 Å, and it might have been hoped that the above filter-telescope lens combination would have an angular resolution of this order. In practice wave-front deformations on passing through the filter reduce the angular resolution to about 5 arc s. In the

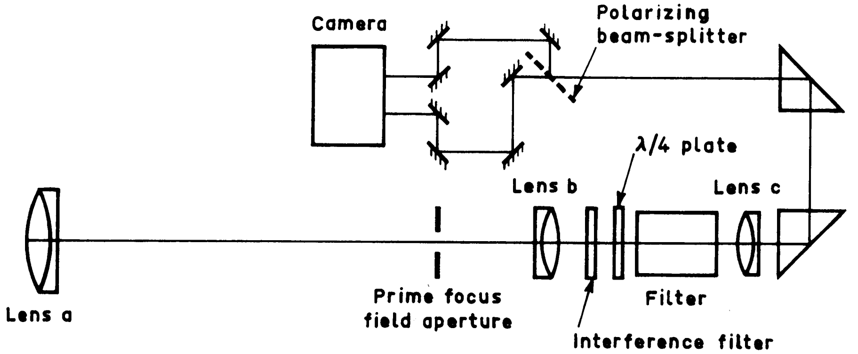

Fig. 1. Schematic diagram of the magnetograph optical system.

present magnetograph we use a telescopic magnifying system (lenses *a* and *b*, Figure 1) before the filter, sacrificing angular field of view for improved spatial resolution on the Sun.

To decide on optimum focal lengths, we note that f_C should be short in order to keep exposure times short, however subject to the condition that the film does not limit the resolution. For f_C we have selected 180 cm, in the focal plane of which 5 arc s represents $\frac{1}{24}$ mm. This is to be compared with the resolution data for the most suitable film we have found, Kodalith Pan; manufacturers' data indicate that this has a one-dimensional transfer function of 0.8 for 30 line-pairs per mm. For the telescopic magnifier we have chosen a $\times 4$ system, the prime objective lens *a*, made by Grubb Parsons, having a diameter of 20 cm and, for compactness, a focal length of 170 cm. Lens *b* has focal length one-quarter of this and a clear diameter rather larger than the minimum required. A chrome-plated stop at the focus of lens *a* restricts the angular field on the Sun to 7.5 arc min to match that of the filter. This stop is perforated, the air heated by the stop being sucked away through the perforations to avoid internal seeing degradation.

The telescope is mounted on an equatorial spar 305 cm long. To contain the total length of the optical system it has been necessary to fold the beam using two 90°–45° prisms as shown in Figure 1.

Pointing at the required solar region is achieved by fine adjustments incorporated in a separate photoelectric guider mounted on the spar.

The polarizing system consists of a $\lambda/4$ mica plate cemented between cover glasses and mounted before the filter, together with a polarizing beam splitter (Steel *et al.*, 1961) immediately before a 35 mm cine camera. The gate of the camera has been opened out to accommodate two frames, and a pair of rhomboidal prisms transfers the two images from the beam splitter to the camera. The axis of the beam splitter must be such as to sort out components polarized in and at right angles to the plane containing the incident and reflected rays in the two 90°–45° prisms, since the states of polarization of these rays are unaffected by the 45° reflections. This decides the orientations of the $\lambda/4$ plate axes, which must be at 45° to the face of the spar.

The solar image may be checked visually for alignment and focus via a reflex mirror immediately preceding the beam splitter. A second reflex mirror may direct light onto a photomultiplier for monitoring telescope transmission and thus establishing the wavelength.

In operation, a pair of photographs in opposite circularly polarized components may be obtained simultaneously in any desired position in a spectral line, a second pair being obtained 8 s later in the same position or, by automatic tuning, in any other wavelength out to ± 0.5 Å from the first. This sequence may be repeated automatically at intervals of approximately 16, 32, 64, 128 or 256 s. By making the wavelengths symmetrical about the line centre we may obtain Doppler records as well as magnetograms in opposite wings, though the Doppler pairs are not obtained simultaneously and so suffer from seeing differences.

Initial observations have been concentrated on the 6102.7 Å line of Ca I. Exposure times for a density of 1.00 (about the bottom of the straight-line portion of the Kodalith Pan film characteristic curve when processed in Kodak D19 developer for 5 min at 20 °C) are about 0.1–0.2 s in the neighbouring continuum and 0.3 s in the wings where magnetograms are normally obtained. There is a slight variation in density across the field which depends on the location in the line and is due to the variation of filter peak wavelength with field angle. This has not been found disadvantageous in obtaining magnetograms, and can be turned to advantage in the ready identification of the part of the line being recorded. However Doppler subtractions show a variation of background density across the field.

The angular resolution of the magnetograph could be improved by replacing lens *a* by one of larger diameter but of identical *f*/ratio, though this implies a corresponding reduction in angular field, and by improvement in the spacing uniformity of the interferometers by the use of different high-reflectance coatings. These improvements are currently being undertaken.

3. Subtraction

To obtain magnetograms three different methods of subtraction have been used. The first, the well-known technique of photographic subtraction (Leighton, 1959) yields the best results, though this method is too slow for processing large numbers of pairs of frames (500 upwards) obtainable in a day. The emulsion used for printing is Kodak Gravure positive film, and is developed in Ilford PQU developer, diluted 40 cc to a litre, at 25°C for approximately 4 min, the precise time being selected by trial and error to give $\gamma = 1 \pm 0.02$.

For fast subtraction, a semi-automatic photographic or a TV subtraction system is used. The photographic process has been developed in collaboration with Supreme Sound Studios, who carry out subtractions for us. A 35 mm positive print with $\gamma = 1$ is made on Eastman fine-grain positive film in an automatic optical printer at unit magnification. This positive is then used as a focal plane filter in the optical printer. The positive is placed in contact with unexposed film and is transported at the same rate through the printer as the unexposed film. The negative, displaced one frame with respect to the positive, is imaged on to the positive/unexposed film combination and an exposure taken, thus providing a magnetogram. Once the original alignment between the image of the negative and the positive has been established, the remainder of the process is automatic since the separation between each pair of frames to be subtracted is fixed by the beam splitter. Since a subtraction of the correct sense is obtained on only every second frame, every alternate frame must be removed in a subsequent stage of editing.

The biggest disadvantage of this method is difficulty of controlling the value of γ which, while very uniform along the film, is not as good as under laboratory conditions. Thus there is usually background 'noise' across the subtraction.

An alternative method for fast subtraction uses a modified TV subtractor developed by Amalgamated Wireless (Aust.) Ltd. This consists of two 'Vidicon' television cameras, one viewing the filtergram obtained in one circular polarization while the other views the oppositely polarized filtergram. The output of the two cameras is fed into a differential amplifier, the difference being displayed on a monitor screen which is photographed by a 35-mm cine camera. The filtergrams are presented to the Vidicons by means of two nominally identical optical systems. We are currently using diffuse illumination from fluorescent lamps to illuminate the filtergrams, and have found no disadvantage due to flicker. Provision has been incorporated in the subtractor for independent adjustment of image magnification, position and rotation in the two cameras, in order to achieve optimum superposition, while adjustable sawtooth and parabolic 'shading' is available in x and y coordinates to compensate in part for systematic density variations across the filtergrams. The film transport mechanism is operated manually. There is some drift in the system, particularly in the maintenance of image coincidence, so that occasional slight adjustments are required. However, a time of about 5 to 10 s is usually adequate for each magnetogram, so that a day's observations can be subtracted in about the same time.

Figure 2 shows two original filtergrams together with magnetograms obtained by photographic subtraction of the two frames, by the semi-automatic photographic method, and by TV subtraction. The TV subtraction is inferior in part to the photo-

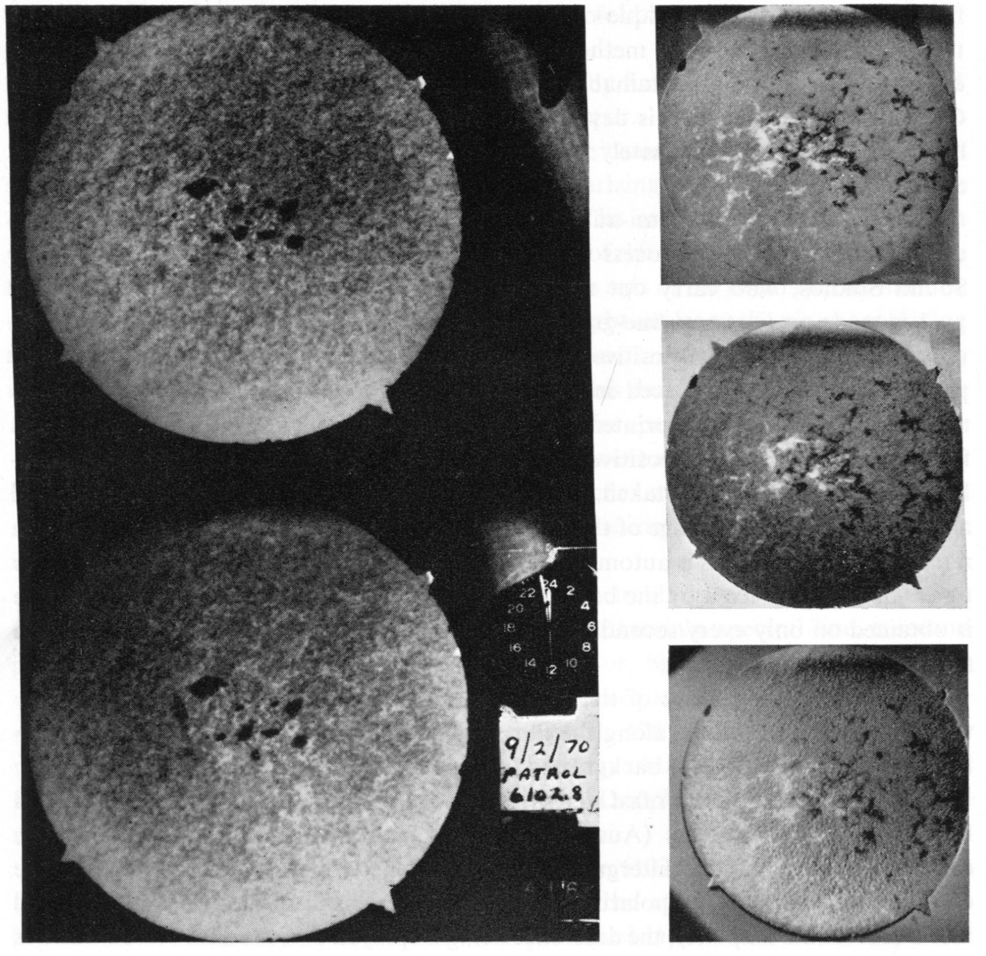

Fig. 2. The two frames on the left hand side are simultaneous filtergrams in opposite circular polarizations in the blue wing of the Ca I absorption line at 6102.7 Å. The resulting subtractions of the two filtergrams are shown on the right hand side; the upper is by individual photographic process, the middle by a semi-automatic photographic procedure and the lower by a TV subtraction technique.

graphic methods because the Vidicons and the yokes used at present are not matched, each camera having its individual time base synchronized to the mains frequency, and the superposition is perfect over only part of the frame. Plans are in hand to improve on these drawbacks.

In the meantime, the semi-automatic photographic method and the TV technique provide acceptable solutions to the problem of producing cine films showing changes in magnetic fields, whilst the usual slower photographic subtraction of individual pairs of frames is used for more critical studies.

Acknowledgements

Many people have been involved in this project, amongst whom are A. F. Young, R. Riches, and D. Neill. We thank T. Nurse of Supreme Sound Studies for his cooperation in the development of the semi-automatic photographic methods. This work has been supported in part by the National Aeronautics and Space Administration under Contract NASr-208.

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