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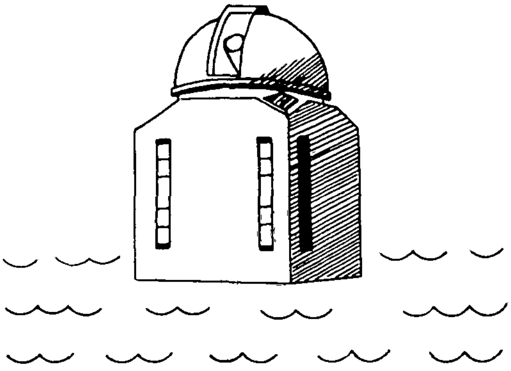

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THE CALIBRATION OF DOPPLERGRAMS AND MAGNETOGRAMS AT BBSO

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ABSTRACT

The calibration procedure for the BBSO videomagnetograph in which the radial velocity of the sidereal rotation of the Sun is used as a calibrator is described in this preliminary report. One of the key points of the procedure is to eliminate the effects of the Earth's motion relative to the Sun and the temperature instability of the birefringent filter by tuning the bandpass of the birefringent filter. The other is to make the light level of the direct image of the videomagnetograph the same both in Doppler and in Zeeman modes in order to reduce the errors introduced by imperfect linearity of the transfer curve of the camera tube. Some practical problems of calibration are discussed for further improvement.

INTRODUCTION

The videomagnetograph at BBSO was built by Smithson and Leighton (Smithson and Leighton, 1971; Smithson, 1972). In 1979 it was rebuilt with a digital image processor, and in 1981 the capability was improved by installing RCA cameras with Newvicon tubes, replacing the KDP crystal, and introducing computer programs for accumulation of an almost unlimited number of frames. The calibration procedure using solar rotation was begun by Patterson (Patterson, 1983). The principle of this method is well known, however, several practical problems were not resolved completely, and quantitative work could not be done at that time.

Practical calibration is a difficult problem for many reasons. The profile of the spectral line used by the videomagnetograph is modified by the presence of the magnetic field and by temperature changes. Neither the profile of the bandpass of the birefringent filter nor the spectral line are perfectly symmetrical. Also the transfer curve of the camera tube is not perfectly linear. Moreover, the spectral line is shifted by both resolved and unresolved Doppler effects and the central wavelength of the filter bandpass is also shifted by temperature instability within the birefringent filter. However, the videomagnetograph has the advantage of high temporal and spatial resolution. This final point convinced us to resolve the difficulties and attempt quantitative work. In the following, a practical calibration procedure is described in detail, and some remaining problems are discussed.

THE VIDEOMAGNETOGRAPH

The BBSO videomagnetograph has an optical arrangement that is shown in Figure 1. The elements comprise a prefilter and trim filters, a circular polarizer, a KDP crystal, a quarter wave plate, a Zeiss birefringent filter and a TV camera. The TV signal is fed to a Quantex digital frame store and processor, which is controlled by a PDP 11/44 computer. The videomagnetograph system can be operated in both Doppler mode and Zeeman mode.

When the KDP is preceded by a circular polarizer the videomagnetograph is converted into a dopplergraph. In the Doppler mode images obtained in the red and blue wings of a single spectral line are differenced to produce a Doppler image. The KDP crystal, acting as an electronically switched quarter wave plate, changes the bandpass of the birefringent filter by tuning the narrowest bandpass element. The other elements are not tuned. Therefore the spectral profile of the filter is different when tuned to the two wings. But the two bandpasses are mirror images of each other so each line wing is treated equally.

For the dopplergraph the best spectral line to use is one that is not sensitive to magnetic fields, i.e. one that has a Lande factor of zero. However, apart from the few Universal models, birefringent filters have a limited tuning range. The VMG at BBSO makes use of a Zeiss filter tuned for the Ca I line at 6102.727 Å, a magnetoactive line with a lande g factor of 2.0 . To generate magnetograms the "Doppler mode" circular polarizer is removed.

at known positions in the east and west hemispheres and calculate the average signal in the central part of each frame. This gives a calibration by which we relate our digital signals to the solar rotation velocity at these points, calculated according to the standard differential rotation equation.

In practice, considering that the bandpasses in the red and blue wings of the line may not be perfectly symmetrical and that the Dopplergrams are not uniform, we often took three Dopplergrams, one each in the east, west and central parts of the Sun. Each frame was divided into square areas of approximately 100 arcseconds on a side and the data within each square was averaged. The averages from each of the squares within one frame were averaged, giving more weight to the squares in the central part of the frame. The least squares method was used to get the calibration value. In all cases we avoided calibrating on active regions so that the calibrations were not distorted by the active region velocity fields. Usually the region to be observed is not at the disc center, so its average Doppler signal is not zero. After the calibration and at the start of the observations on the region we retune the filter to adjust the average Doppler signal to the half scale value. In this way the velocity signal caused by solar rotation is eliminated. However, as the Doppler signals from an active region are typically complex we do not retune the filter while observing an active region at latitude B and longitude L, but we retune the filter at a quiet region whose rotation velocity is the same as the interested active region. We can simply use the region of latitude -B and longitude L if this region is quiet.

3. Magnetogram calibration

The magnetogram calibration is done by way of the Doppler calibration. For Doppler observations there is a circular polarizer ahead of the KDP crystal. This selects one linear polarization of light and converts it into purely circularly polarized light. For magnetic field observations the circularly polarized light is detected directly by the equipment. The magnetograph system behaves like two Doppler measuring devices in parallel, one sensing right circularly polarized light and the other left circularly polarized light. The calibration value of the Dopplergram can almost immediately be translated to a magnetic calibration value.

The circular polarizer has a transmission of 30% so the intensity of light at the TV camera in magnetic mode is three times the intensity found in the Doppler setup. Because the transfer curve of the TV camera is not exactly linear and because of variations in the signal due to the internal gain and automatic black level circuitry of the TV camera, the intensity correction is much more complicated. The best way to correct for these differences is by taking magnetograms with a 30% transmission neutral filter (NG-4 1mm) in the light beam. The magnetograms obtained in this way can be simply calibrated by the previously described Doppler calibration procedure. For a velocity of 1 km/s the Doppler shift is 0.02034 Å at 6102.727 Å. For Zeeman splitting the wavelength shift of each component from the central wavelength is

$$\Delta\lambda_H = 4.67 \times 10^{-13} \lambda^2 g H$$

DISCUSSION

This calibration method has been used since July of 1983. For quiet Sun magnetic field observations it has proved very successful. For long integrations (requiring 512 pairs of Zeeman frames and 68 seconds) in very good seeing conditions, the noise level is less than 5 gauss. When the integration time is increased further the noise is reduced by a factor of square root of the ratio of frame numbers which is used to create the final magnetograms. One example of calibrated magnetograms has been presented by Wang J. et al. (1985). Their Fig. 1b shows a calibrated magnetogram for 4 September 1983 taken at Big Bear Solar Observatory and a Kitt Peak magnetogram taken earlier that day. The two magnetograms match each other quite well. Although we have made progress in defining a calibration system some problems still remain. We would like to mention these problems to end this report.

1. The signals generated by the videomagnetograph are not only affected by the Doppler shift that results from the Earth's motion and other factors, but are also sensitive to the shape of the spectral line. Our calibration is based on the average profile of quiet regions which is certainly very different from the line profile in places of strong magnetic field such as active regions and sunspots. The temperature enhancement in an active region also affects the line shape so there is some error in applying the described procedure to active region observations.

2. The overall accuracy of the Doppler calibration is limited by local motion and non-uniformity in the videomagnetograph filter. Such non-uniformities could be reduced by using a telecentric optical arrangement, but space requirements prevented this. The magnetograms, however, are much less sensitve to the non-uniformities.

3. There is still no good method of reconstructing the magnetograms of sunspots by evaluating the effect of stray light and nonlinearity of the transfer curve of TV camera at low signal levels. When the magnetic field strength is greater than several hundred gauss the measured field strength is sensitive to the intensity correction adopted. We have measured the transfer curves at several light levels. Further work needs to be done to see how much the magnetic signal is affected by stray light, and how it is affected by the flattening of the transfer curve at low light level. As we mentioned in section 2, the simultaneous measurement of Zeeman splitting and magnetograms in regions near the disc center of the Sun provides an empirical way of estimating the intensity correction.

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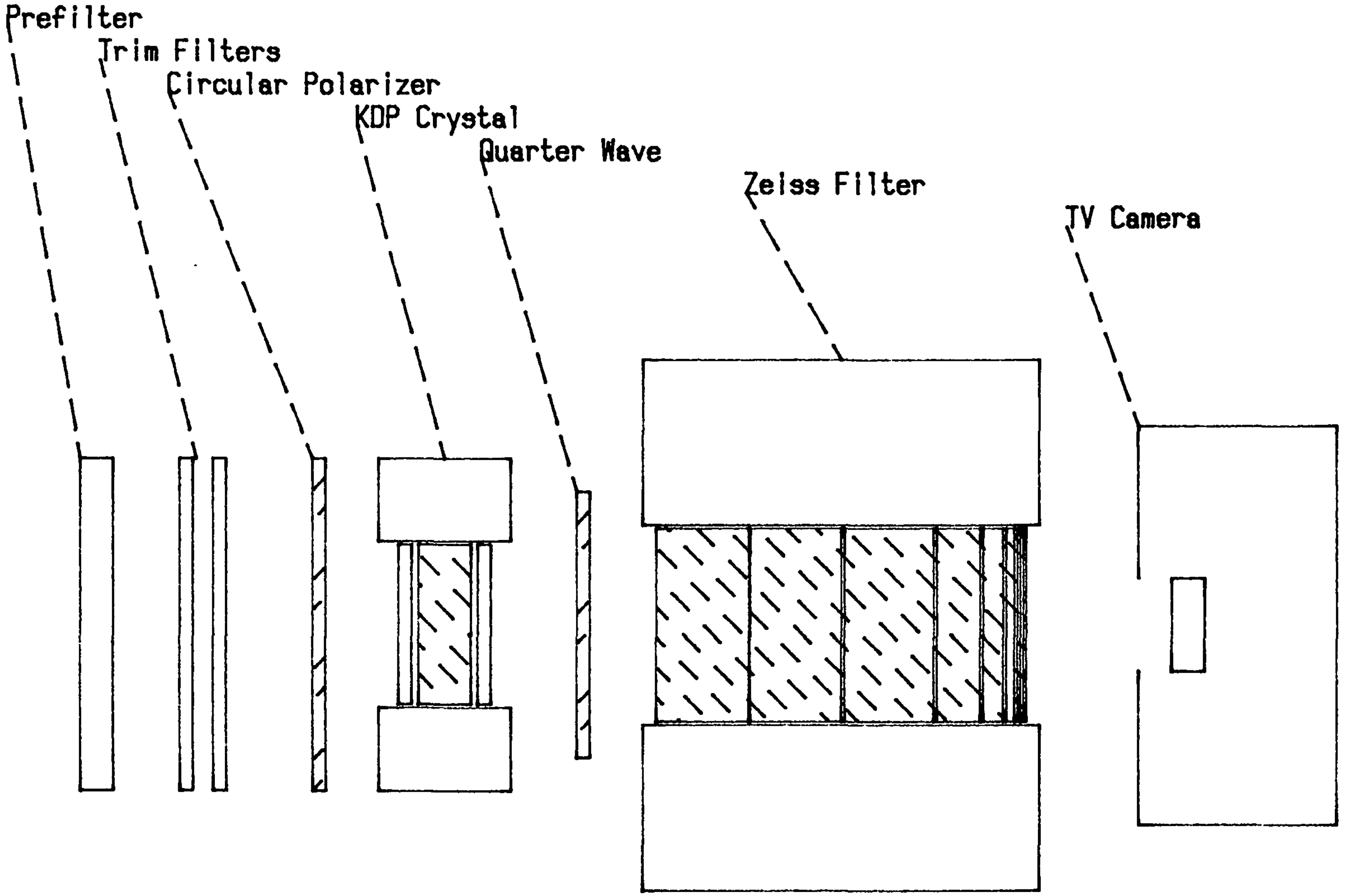

Fig. 1. Optical Arrangement of the Videomagnetograph at BBSO.

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