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A new CCD-based Solar Active Region Stokesmeter at the Sayan Observatory (a Project)

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Abstract. After a long "silence" of the Sayan vector magnetograph, we are planning to give a new life to it. We have already at our disposal a high-sensitive 1024x256 CCD and are expecting to receive liquid crystals as a polarization analyzer. The basic setup of observational instrumentation of the new polarimeter and the mode of operation are considered.

1. Introduction

Despite the numerous long-term programs on the study of solar magnetic fields, their origins are still not well understood. Furthermore, magnetic fields of active regions (AR) play a special role in the complicated pattern of interactions between magnetic fields of different spatial scales; specifically, because of the extremely high concentration of strong, kilogauss fields. Therefore, research into AR magnetic fields has been and is of top priority in solar physics.

The principal diagnostic tool for strong solar magnetic fields involves measuring polarization parameters (Stokes parameters) in Frauenhofer lines using polarimeters of different designs (Stenflo 1994). Early polarimeters were developed rather long ago. A descriptions may be found in Babcock & Babcock (1952). Although much time has elapsed since then, their principle of operation has remained unchanged, except for the technical and mathematical methods that have been upgraded. In recent years, a variety of observatories around the world have been implementing programs of upgrading the old instruments, and commissioning new facilities (such as ASP, Zimpol, etc). At the Sayan Solar Observatory (SSO) there is a rather large solar telescope with good optical characteristics that previously was equipped with a vector magnetograph. This paper is concerned with the SSO active region stokesmeter project, seeking launch to begin magnetic fields measurements on a new, modern level.

2. Main features of the telescope

The purpose of the project under development is to construct a new magnetograph on the basis of the Horizontal Automatic Solar Telescope (HAST) of the SSO. The project takes advantage of the operating experience from earlier versions of magnetographs, and incorporates appropriate upgrades according to state-of-the-art technologies. A fundamental difference from the earlier magnetograph implies the use of a dedicated CCD matrix instead of the photoelectric multiplier, which will improve the accuracy of measurement and simplify the data reduction. Thus, modifications will be made to the spectrographs optical system and to the automatic control system.

Table 1. Main characteristics of the telescope and magnetograph

Main characteristics of the telescope	
Diameter of primary mirror, mm	800
Focal length of primary mirror, m	20
Diameter of coelostat's group mirrors, mm	800
Main characteristics of the spectrograph	
Focal length of collimator, m	7
Focal length of camera mirror, m	7
Grating size, mm	200x300
Rulings, 1/mm	600
Spectral order	5
Main characteristics of the CCD array	
Number of pixels	1024x256
Pixel size, μm	26x26
Matrix size, mm	26.6x6.7
Dynamic range, bits	16
Reading frequency, MHz	0.1, 1.0
Wavelength of maximum sensitivity, nm	700

We now turn to the description of the project, starting from the telescopes' optical system (Grigoryev et al. 1985). It is shown in Fig. 1, and its main characteristics are summarized in Table 1. Coelostat group 1 directs the light beam from the Sun onto the telescopes' primary mirror 2 with a focal length of 20 m. The primary mirror constructs, with the aid of flat diagonal mirror 7, the image of the solar disk at the spectrograph's entrance slit 9. It is evident from the figure, that the design of the photoelectric guider is modified in this case when compared with the earlier version. The photoelectric guide consists of objective lens 3 that is placed in the central aperture of mirror 2, and of the semi-transparent glass plate 4 which divides the beam from the objective lens into two perpendicular beams. Thus two identical images are constructed in the photoelectric guider, each of which incorporates one linear CCD-array. The direction of the CCD arrays corresponds to the directions of solar image shifts as the ancillary mirror of the coelostat group is rotated in the vertical and horizontal planes. This makes it possible to rather accurately monitor the position of the solar disk image at the spectrograph slit. The disk center sensor 8 represents two pairs of photodiodes lying on the solar limb in such a way that the disk center is at the slit center. This is necessary for the initial referencing of the frame of reference to the disk center. Let us now consider the spectrograph system in greater details.

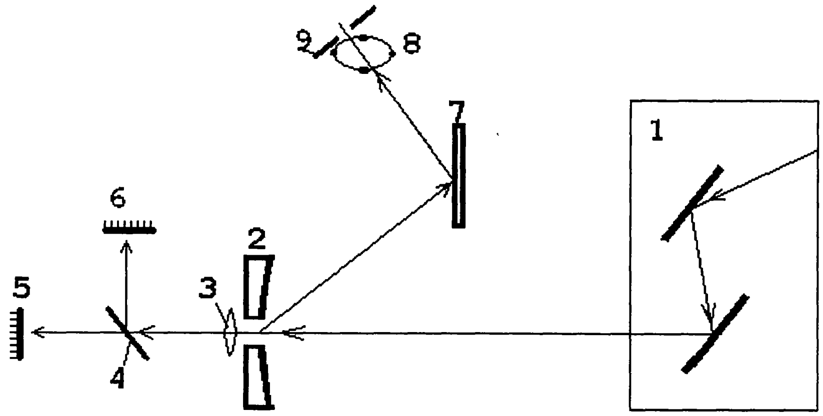

Figure 1. Optical scheme of the HAST.

3. Optical system of the spectrograph

The spectrograph in use is a horizontal instrument, and its main characteristics are summarized in Table 1. Its optical system is presented in Fig. 2, where the collimating mirror, the camera mirror and the grating are designated as 4, 6 and 5, respectively (Grigoryev et al. 1985). Immediately behind the entrance slit is the polarization analyzer (PA) that is described in (Horn & Hofmann 1999). It is composed of two liquid-crystal phase plates 2, and birefringent calcite prism 3. The angle between the principal optical axes of the liquid crystal variable retarders is 22.5°, and the angle between the axis of the first plate and of the prism is 45°. The phase shifts δ_1 and δ_2 that are introduced by each of the phase-rotating plates, vary in direct proportion to the voltages applied to the plates. The advantage of plates of this type over the previously used DKDP crystals is that rather low voltages are sufficient for their modulation, whereas a voltage of about 1000 V is necessary for DKDP.

By combining the voltages on the plates, it is possible to obtain three most interesting total phase shifts, and the respective output intensities $I^{|}(\delta_1, \delta_1)$:

$$I^{|}(\pi, 0) = (I \pm Q)/2 \quad (1)$$

$$I^{|}(0, 0) = (I \pm U)/2 \quad (2)$$

$$I^{|}(0, \pi/2) = (I \pm V)/2 \quad (3)$$

Here $S(I, Q, U, V)$ is the Stokes vector of the incoming beam, and the " $\pm$ " sign corresponds to two beams at the output of the calcite prism. Thus, by subtracting the intensity of one beam from the intensity of the other, it is possible to calculate all Stokes parameters of incident radiation.

The half-wave plate 9 is introduced into one of the beams in order to reconcile the plane of its polarization with the direction of lines in the diffraction grating 5.

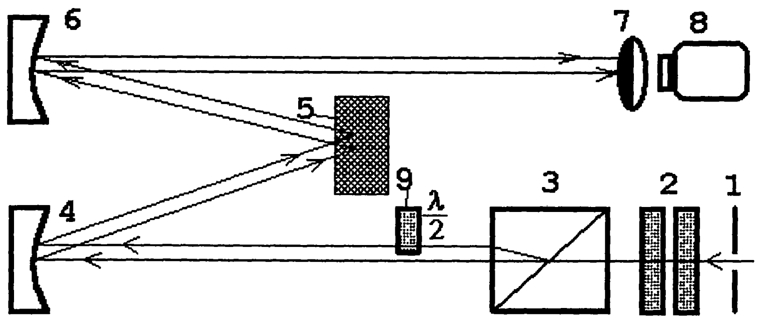

Figure 2. Optical system of the HAST spectrograph.

As has already been pointed out, a special-purpose spectrographic CCD matrix will be used as sensor. Its main parameters are presented in Table 1. The matrix is controlled by a special controller ST-133, which controls the temperature conditions, the synchronization with shutter 7, and the transfer of the image to the master computer via a serial interface. The intensities will be subtracted in the software mode, following a series of "snapshots" and averaging. The matrix exposure must be rigorously synchronized with the operation of the PA, and with the image guiding system. This task will be performed by the magnetograph's automatic control system (ACS).

4. The magnetograph's ACS

It is envisioned that the magnetograph control system will be configured as a three-level distributed ACS. The block diagram of the ACS is presented in Fig. 3. The lower level will incorporate sensors and actuators, the middle level will include data pretreatment and low-level controllers, and the third level will involve the data processing and accumulation, and the interface with the operator. The reason for choosing this type of system is that the control object (magnetograph) represents a spatially distributed system. Three main subsystems are spatially identifiable here: the coelostat group, the photoelectric guider, and the spectrograph. In accordance with these subsystems, it is proposed to employ three MCS-51 microcontrollers.

5. Conclusion

This report has outlined in detail the project of the future magnetograph. The considerations presented above suggest that the pertinent activities should be clustered around three main avenues of inquiry:

1. Development and introduction of the photoelectric guider that would differ from earlier versions and should be based on CCD arrays.
2. Engineering the polarization analyzer on liquid-crystal elements.

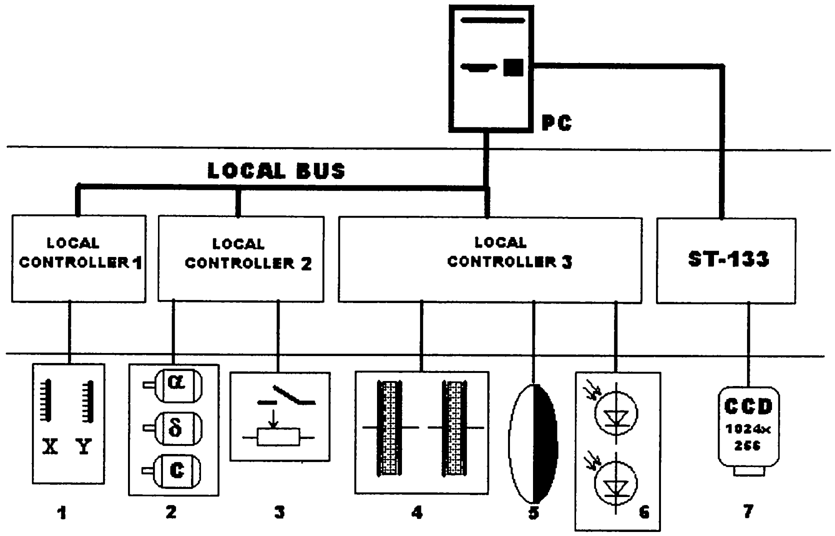

Figure 3. Block diagram of the magnetograph's ACS. Here 1 - two linear CCD arrays, 2 - step motors, 3 - group of sensors of extreme positions of the mirrors, 4 - liquid crystal variable retarders, 5 - shutter, 6 - photodiodes, 7 - CCD matrix.

3. Development of the magnetograph's ACS.
4. Generation of magnetograph operation and data conversion control programs.

The anticipated innovations will simplify the data obtaining procedure and improve the data reliability.

References

Babcock H.D. & Babcock H.W. 1952, Publication Astronomical Society of the Pacific, 64, 282

Grigoryev V.M., Kobanov N.I., Osak B.F., Selivanov V.L. & Stepanov V.E. 1985, NASA Conf. Publ., 2374, 231

Horn Th. & Hofmann A. 1999, 3rd Advances in Solar Physics Euroconference: Magnetic Fields and Oscillations, ASP Conference Series, B. Schmieder, A. Hofmann, J. Staude eds., 184, 33

Stenflo J.O. 1994, Solar Magnetic Fields. Polarized Radiation Diagnostics, Kluwer Academic Publisher