INSTRUMENTATION FOR MEASUREMENT OF STELLAR MAGNETIC FIELBS WITH THE 6-M TELESCOPE

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ABSTRACT. The instrumentation, designed and built at Special Astrophysical Observatory for measurements of stellar magnetic fields on the 6-m telescope is described. The instrumentation includes Zeeman achromatic analyzer, photoelectric stellar magnetometer with the Fabry-Perot interferometer (the metallic-line magnetometer) and photoelectric magnetometer of the prime focus (the hydrogen-line magnetometer).

1. INTRODUCTION

Investigations of stellar magnetism, based mainly on the Zeeman effect measurements, are the most complex ones in astrophysics. Such work can be performed only at a few observatories in the world as it requires the use of the largest telescopes and complex polarimetric equipment. To study the stellar magnetism a special system for measurements of stellar magnetic fields has been designed and built for the 6-e telescope of the USSR Academy of Sciences Special Astrophysical, Observatory.

The system includes: circular polarization analyzers to obtain Zeeman spectra on photographic plates, a photoelectric stellar magnetometer with a Fabry-Perot interferometer on the basis of the Bain stellar spectrograph (MSS), and a photoelectric magnetometer-spectropolarimeter for the main focus (MF) of the 6-m telescope. Such variety of equipment being available allows to get observational data for the wide class of objects and in case of necessity to change flexibly the observational program during a night.

The main purpose of this paper is to give a brief description of this instrumentation and to show the possibility of magnetic field measurements on the 6-e telescope.

2. THE CIRCULAR POLARIZATION ANALYZER

It is built around MSS for measurements of the magnetic field longitudinal component from Zeeman splitting of spectral lines using the photographic method. The telescope and the spectrograph optics can operate within 3100-12000 A wavelength range, so the classical Zeeman analyzer with the mica phase retarder (Babcock, 1963) operating in the narrow spectral range did not satisfy us. Fresnel's rhomb is the simpliest phase element and at the same time the best one for the wide wavelength range. The calculations showed that the rhomb made, for example, of LK-4 glass provide the phase retardation by 90°±2° within 3200-7000 A.

The achromatic analyzer with Fresnel's rhomb has been built in 1977 (Naidenov and Chuntonov, 1976; and Chuntonov, 1982). To diminish the grating polarization influence one more rhomb is aaunted at the' analyzer output which converts both orthogonal polarized beams into beams polarized circularly. In such case the polarization effects in the spectrograph influence equally the both beams and Zeeman spectra of equal intensity. Besides, in this case the beam returns to the optical axis of the spectrograph. To diminish the light losses all the optical elements in the analyzer are made at the optical contact, they glued together with an acrylic glue. We made two more achromatic analyzers, one of them being installed at the 6-m telescope and the other one at the 2-m Bulgarian telescope. These analyzers split beams by 4.5 mm, that corresponds to 5 seconds of arc at the 6-m telescope spectrograph slit. Such splitting allows to get well widened (up to 0.35 mm) spectra at the Il-nd caaera of HSS with a reciprocal linear dispersion of D = 6.7, 9 and 13.4 A/mm, and at I-st camera with a dispersion of 1.7, 2.6 and 5.2 A/mm, each of Zeeman spectra can be widened up to 1 mm.

The light beam, when observed in the Nasmyth focus, and before it gets into the analyzer, suffers one reflection from the flat diagonal mirror with constant 45° inclination, therefore the instrumental polarization compensator is of no use and the field value decrease by 5% is corrected in the course of measurement reduction.

To test the efficiency of this analyzer and calibrate the results we measured many times α^2 CVn, β CrB and 53 Cam magnetic fields, which have rather precise curves of magnetic field variations. These measurements have shown that within the accuracy there is no considerable systematic differences between the data obtained on the 6-m telescope and the data of Lick, Mt Wilson and Mt Palomar observatories. The procedure of observations slightly differs from the one used for receiving ordinary spectra. But in this case there are strict requirements for the guiding quality in order to prevent overlapping of Zeeman spectra.

During the whole time of the 6-m telescope operation more than 1000 Zeeman spectra have been obtained. They are measured with the "Astrospidometer" (Antropov, 1972). It is a specially reconstructed microphotometer with the precise rule which allows to measure when moving along the spectrum with an accuracy of 0.5 eke. The instrument is equipped with an oscilloscopic device on whose screen the right and the reverse pictures of any part of the line profile (Gollnow principle) coincide and, thus, it is possible to measure the line splitting from both the whole profile (according to its gravity center) and from its separate segments.

3. THE MAGNET0METER WITH A FABRY-PEROT INTERFEROMETER

The magnetometer with a Fabry-Perot interferometer was designed and built on MSS spectrograph for measurements of the weak magnetic fields of metal lines. The procedure of photoelectric Measurements of magnetic fields is as follows: the light entering the spectrograph goes through the electrooptical modulator which admits the light with a frequency of modulation equal to 2S0 Hz of right or left circular polarization in turn.

The working order of interference with a spectral range of 0.1 A obtained with the Fabry-Perot interferometer in the focus of the I-st camera is cut out by the exit slit and comes to the photocathode of the photomultiplier EMI 9789B. Synchronously with switching of the electrooptical modulator the electronic key switches over the output of the pulse amplifier to the first counter and then to the other one. When the measurements at one wavelength are finished the interferometer and the exit slit are switched over for measuring another spectrum segment. The measured profiles and distribution of V-Stokes parameter inside them are used for magnetic field calculation by the well-known differential or integral methods (Borra and Vaughan, 1977).

To use maximally the stellar light and to preserve a high spectral resolution the Fabry-Perot interferometer is mounted in the magnetometer. It makes possible to open the spectrograph slit up to 5". This interferometer and the modulator are installed in the common mechanical unit in the parallel light beam generated by the collimator. The same unit contains a source of circular polarized light to control the equipment efficiency. The use of this interferometer increases 7-8 times the sensitivity.

He have chosen the pneumatic method of transferring the interferometer along to the wavelength. The time of the pulse counting equals usually to some minutes and the time of the interferometer and exit slit transformation is several seconds. Thus, the time losses are unimportant. To ensure the chosen spectral resolution of ~ 0.1 A the retarder thickness must be equal to **-0.3 mm,** therefore it is not necessary to use the temperature stabilization during the observational cycle. The stable and reliable pneumatic method of the interferometer transformation has completely proved its value. When using the compressed carbonic acid the pressure change in the interferometer camera by 1 atm causes

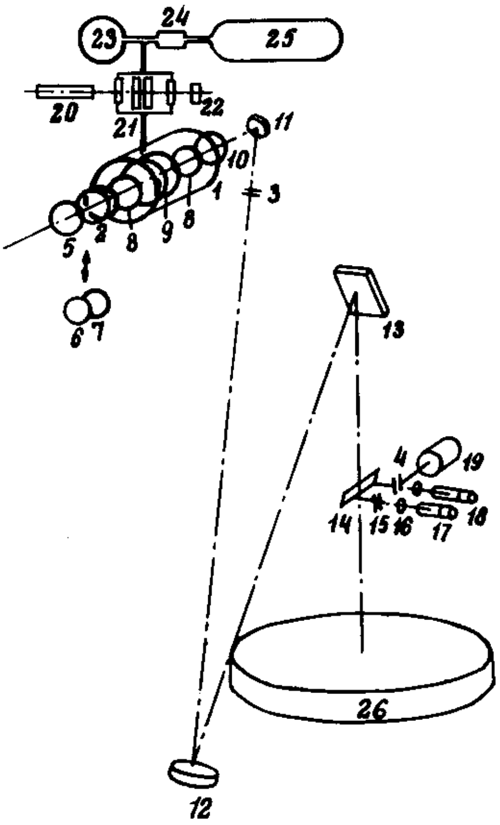

Fig. 1. Optical diagram of MSS magnetometer.
1 - camera with a Fabry-Perot interferometer, 2 - electrooptical modulator KDP and a polarizer, 3 - spectrograph slit, 4 - exit slit of the main channel, 5 - negative lens, 6 - quarterwave mica plate, 7 - polaroid (elements of circular polarization source), 8 - windows of interferometer camera, 9 - Fabry-Perot interferometer, 10 - objective lens, 11 - diagonal 60° flat mirror, 12 - collimator, 13 - grating, 14 - diagonal 45° mirror, 15 - square diaphragm of the supporting channel, 16 - Fabry lens, 17 - 18 - photomultipliers of the main and supporting channels, 19 - step driver for slit moving, 20 - laser - light source of dosimeter, 21 - camera of dosimeter interferometer, 22 - photodiode, 23 - manometer, 24 - electromagnetic valve of dosimeter, 25 - compressed carbon acid.

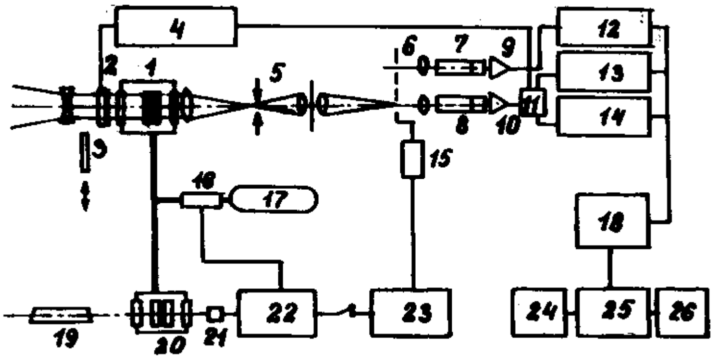

Fig. 2. Block-scheme of magnetometer.
1 - camera with a Fabry-Perot interferometer, 2 - electrooptical modulator_ KDP, 3 - standard circular polarization source, 4 - high voltage square-pulse generator, 5 - spectrograph slit, 6 - exit slits of the main and supporting channels, 7 - 8 - photomultipliers of the main and supporting channels, 9 - 10 - amplifiers of the main and supporting channels, 11 - electronic switch, 12 - electronic counter of the supporting channel, 13 - electronic pulse counter of the left circular polarized light, 14 - electronic pulse counter of the right polarized light, 15- step driver for the exit slit moving, 16 - electromagnetic valve, 17 - container with pressed carbon acid, 18 - create controller, 19 - laser, 20 - camera with a Fabry-Perot interferometer of dosimeter, 21 - photodiode, 22 - dosimeter control unit, 23 - step driver control unit, 24 - display, 25 - CM-4 computer, 26 - typer.

its transformation approximately by 1.5 A. The stability at the given wavelength is about 0.1 of the passband and the accuracy of the pressure supporting is not lower than 0.01 ate. These values can be ensured by using the measuring device on the basis of the auxiliary Fabry-Perot interferometer which is transferred by one order if the measuring interferometer is transferred by 0.1 A. Transformation of the auxiliary interferometer is registered by the photodiode, and as a source of monochromatic light a helium-neon laser is used. The electromagnetic valve is switched off when the certain transmitted light level is achieved.

We refused from the lamp square-pulse generator for modulator supplying due to its large size and considerable heat scattering. Now we use a compact transistor-transformator generator with the output voltage regulated within 2-4 kV.

The supporting channel is used in the magnetometer to minimize the errors caused by the stellar oscillations and shortcomings in guiding. The light for this aim is cut off by the corresponding diaphragm at a distance of ~ 100 A from the principle channel. The spectral range in the supporting channel is equal to 20 A. The profile of the measured line is being determined from the ratio of the light intensity in the principle and supporting channels.

The photopulses from the photomultiplier, operating in the regime of photon counting, pass to the pulse-amplifier, then to the pulse shaper, and via a cable about 250 m in length they are transmitted to the electron switch and counters - CAMAC register units. The accumulated pulses are read out at definitely field time intervals. Three registers are used, two of them are used for counting the pulses of the polarized light, and the third one for counting the pulses in the control channel. After the data reduction with the CH-4 computer the following parameters are determined:

- the number of registered pulses,
- magnetic field value,
- circular polarization degree,
- statistical accuracy of the resulting magnetic field B_e, calculated from an assumption of Poisson pulse distribution,
- real root-mean-square error of B_e,
- count ratio of the principle and the supporting channels.

The operation system RAF0S and macroassembler and Fortran-4 languages are used.

4. THE MAIN FOCUS MAGNETOMETER

The main focus (MF) magnetometer is used for field measurements in hydrogen lines of rapidly rotating stars. In contrast to the above mentioned devices which can be used only for investigations of slowly rotating stars with relatively sharp spectral lines of less than 0.4 A in width, this magnetometer using hydrogen lines can measure fields of wider class of objects. The accuracy of this method is lower because the profiles are flatter than those of metallic lines: in the mean 1% of the measured polarization corresponds to 12-15 kGs as compared to 0.4-0.5 kGs for polarimetry of sharp metal lines. However, a rather broad passband can be used in measurements on hydrogen lines up to 10 A as against 0.1 A for lines of metals. This makes it possible to measure the magnetic field of faint rapidly rotating stars.

The spectropolarimeter-magnetometer for measurements in hydrogen lines is built around the polichromator with a diffraction grating for operation both on the 6-m telescope and on other telescopes.

The scheme of this magnetometer is analogous to that of MSS magnetometer only without the Fabry-Perot interferometer. In the analyzer Iceland spar crystal is used instead of polaroid, therefore, there appear two images on the slit, and in the focal plane of the polichromator there are consequently two spectra. For cutting the measured spectral regions the block of exit slits is installed on the support with micrometric movement in dispersion. When a control voltage of both polarities is applied to the crystal, the spectra will contain the opposite-polarization Zeeman components of the line, i. e., they will be shifted in opposite directions. The exit slits cut the left wing of the line out of one spectrum and the right wing out of the other. So when a control voltage of one polarity is applied to the crystal, light from the wings of the components, which are shifted in opposite directions from the wavelength of the unshifted line, will arrive at the slits. In Fig. 3, one of these cases is represented by the solid line and the other by the dashed line. Thus, the use of this method increases twice the efficiency. More often magnetometer is used for measurement in H_β and H_γ lines, therefore the efficiency increases by a factor of 4.

The process of measurements has two stages. First, measurements are perfomed with slits which cut the left wings out of the first spectrum and the right wings out of the other. When accumulation of the signal of definite value is completed another system of slits is replaced into the focal plane which cut the opposite segments of wings and measurements continue the cycle. The accumulated photoreadings produce the curve of V Stake's parameter variation, and weak polarization is excluded. In the MF magnetometer as in the MSS magnetometer a pulse amplifier is used which provides a gain of 900 at pulse duration of 50-100 ns. The pulse shaper at the output of the amplifier shape pulses of 100 ns duration. There is a discriminator with regulating threshold. All these devices are placed in a common housing on the barrel of the PH. The signal is delivered via a cable about 250 meters in length to the apparatus room where the electronic switch controlled by generator with quartz stabilization reverses the pulses of right and left polarized light to the respective counters. One of the counters is switched on up to the definite number of pulses with

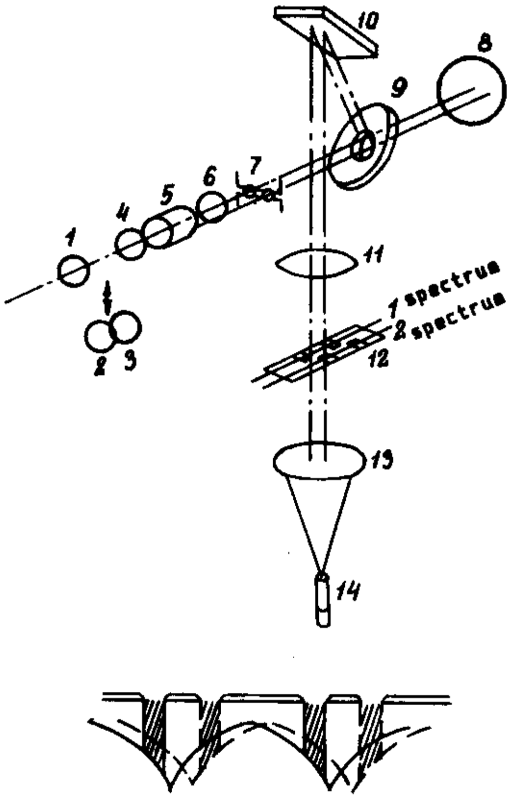

Fig. 3. Optical diagram of the prime focus magnetometer. 1 - negative objective, 2 - 3 - quarterwave mica plate and polaroid (circular polarization standard source), 4 - electrooptical crystal KDP, 5 - Island spar crystal, 6 - objective lens, 7 - polichromator slit, 8 - collimator, 9 - diagonal mirror, 10 - grating, 11 - camera, 12 - exit slits, 13 - light collector, 14 - photomultiplier, 15 - diagram of exit slit operation.

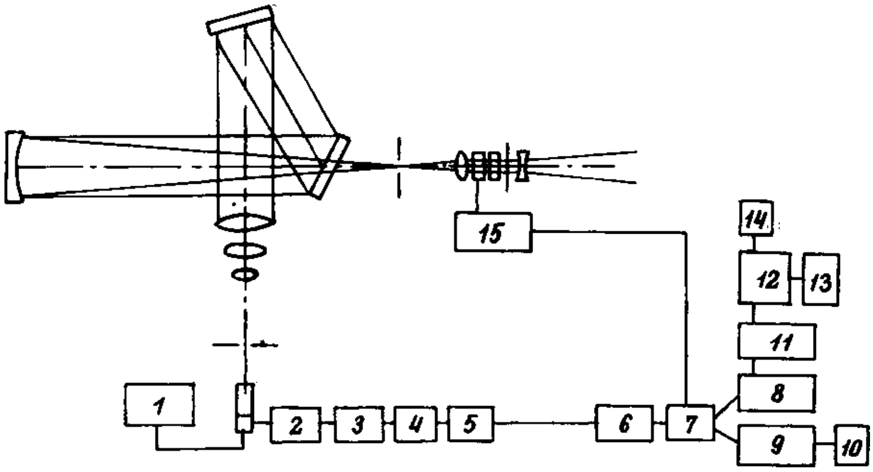

Fig. 4 Block-scheme of the prime focus magnetometer.
1 - stabilizator for photomultiplier, 2 - pulse amplifier, 3 - amplitude discriminator, 4 - pulse shaper, 5 - output pulse amplifier, 6 - input pulse amplifier, 7 - electronic switch, 8 - measuring counter, 9 - exponometric pulse counter, 10 - impulse number controller, 11 - create controller, 12 - CM-4 computer, 13 - typer, 14 - terminal, 15 - generator.

the help of a special control device. The second counter, the measuring one, is connected via a creyt-controller with CH-4 computer where all the entering information is processed and then printed. As a result of data processing the following parameters are determined:

- photoreading values;
- circular polarization values (V Stoke's parameter);
- magnetic field values;
- magnetic field error (according to Poisson pulse distribution);
- mean-root-square error.

The observational experience shows that if the apparatus operates well, then the statistical accuracy and the real mean-root-square error discrepancy is not more than 5-10X. The repeated tests confirm the Poisson character of pulse number distribution. So, the coincidence of these both errors is an additional test of apparatus stability.

In conclusion we present the data on efficiency of all the three method of magnetic field measurements under typical seeing conditions.

Device	mag (max)	6s ±σ	Spectral resolution	Accumulation time	Detectors
Circular polarization analyzer	9	200	0.2 A	1 hour at $\beta \leqslant 1.5$	Photoemulsion Kodak II aO
MSS magnetometer	4.4	10	0.1 A	6 hours $\beta \leqslant 5''$	Photomultiplier
MF magnetometer	6.5 8.4	200	10 A	1 hour 6 hours $\beta \leqslant 5''$	Photomultiplier

β is the size of the star evaluated by an eye. Accumulation time of 6 hours is the maximum reasonable exposure time.

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