Fiber Optics Device for Solar Spectroscopy – First Measurements

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Abstract. In 1996 we introduced the fiber optics device designed for 2D solar spectroscopy (Kučera et al. 1997). Now we present the first results obtained within last year. First experiences with wavelength calibration, light transmission through the fibers, noise reduction, software for reduction of observations and preliminary results of reduced scientific data are presented.

1. Introduction

Balthasar et al. (1982) investigated the solar rotation using slowly evolving sunspots. They found a braking of the order of 0.3 m/s to 0.8 m/s per day for the rotation velocity. Other publications reporting the braking of the velocities for all types of sunspots appeared in the last decades (c.f. Lustig and Wöhl 1993 and references there). The investigation of such type of motions is important to determine the interaction of the strongly magnetized plasma (sunspots) and "unmagnetized" plasma (photosphere). Because of this very weak effect, the collection of observations of many sunspots is necessary for theoretical interpretation of the braking mechanisms. Due to turbulent fields and proper motions of the sunspots the velocity information should be taken simultaneously from the whole surrounding of the sunspots. For this purpose we suggest to use a fiber optics device (FOD) for the collection of light from the focal plane of the telescope and its relay into a spectrograph. The aim of this paper is to describe the original FOD used for solar spectroscopy. We will also present the final setup for observations, data collection, data reduction as well as first preliminary results.

2. The FOD

A brief description of the FOD was already made by Kučera et al. (1997). Here we will point out only the most important facts. During the years 1996-1997 the

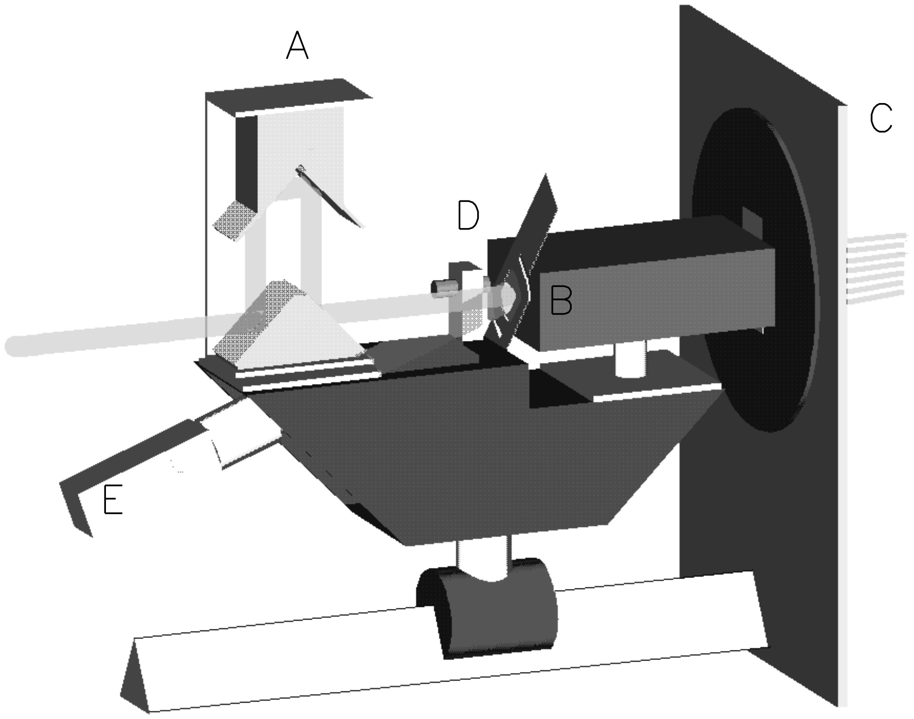

Figure 1. General design of the FOD. The light passes through the focus compensator (A) to the focal plane where the entrance 2D fiber optics matrix (B) is placed. The collected light from the 2D area is transmitted via fibers to one-dimensional "line" in the entrance slit of the spectrograph (C). The reference iodine spectrum produced by the solar light and by iodine cell (D) is simultaneously transmitted by additional fiber optics to the spectrograph. The slit-jaw image is taken by a TV CCD camera (E).

FOD was manufactured by Kodyš brothers according to the design suggested by Kučera et al. (1997). The general design of the FOD is shown in Figure 1. The FOD was mounted on the Horizontal Solar Telescope with Spectrograph (HSTS) at Stará Lesná Observatory (see, Kučera et al. 1990).

Entrance 2D matrix: The entrance 2D matrix was designed to have a configuration of the fibers to cover different positions of the sunspots on the solar disc. It would be optimum to have a matrix with movable fibers to have the possibility to arrange the fibers positions for every particular case of sunspot location. However, due to technical and mainly financial limitations we decided to manufacture a compromising matrix (see Figure 2). It is designed for four optimal positions of the sunspots on solar disc. These positions are in longitude $l = \pm 50°$ and in latitude $b = \pm 20°$. If the sunspot is located out of these four optimal areas the fibers will be placed at different positions in the sunspot surrounding (due to projection) comparing to the optimal case. These positional differences are taken into account when the velocity map of the spot surrounding

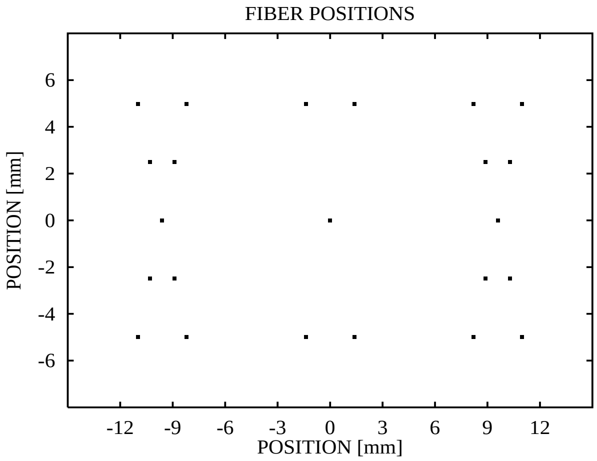

Figure 2. The 2D entrance matrix. The points show the positions of the fibers. During observations the sunspot is positioned at the central point-fiber. Distance 1 mm correspond to 6 arcseconds.

is constructed. Before the final realization of the matrix 18 different types of optical fibers were tested. The best combination of the diameters and appropriate level of the focal degradation of the fiber was found for Polymicro Technology CMS fiber with 200 μm, 242 μm and 269 μm for diameters of core, cladding and covering respectively. This fiber was used for construction of the matrix.

Spectrograph: The optical fibers at end of FOD (including four fibers for calibration), arranged into a 1D line, are placed 2 mm in front of the spectrograph entrance slit, which is opened to 1 mm width. Thus the fibers simulate a 200 μm width spectrograph slit. There are two filters inside the spectrograph, namely the color glass filter GA-48 (Carl Zeiss) and the interference filter 25-5453 (Ealing) which blocks unwanted spectral orders. The line Fe I 557.6 nm was selected for observations. We observe in the fourth order with dispersion of 0.04 nm/mm. The height of the spectral image (25 mm) is too large for the CCD elements of the TV camera. Therefore, additional optics (objective) was mounted in the front of the camera to reduce $\sim$ 3 times the height of the spectrum. The spectrum image is recorded by a TV CCD camera placed in the focal plane of the spectrograph. The final spectral scale is 0.00073 nm/pixel $\approx$ 390 m/s/pixel

3. Observations and data reduction

The system for detecting and storing of data consists of two CCD TV cameras, a frame grabber and a PC. Two CCD TV cameras (Elvia, Czech republic) are equipped with Phillips chip (604 x 588 pixels, 6.5 x 4.0 mm). The TV signal is in CCIR standard. The spectra are stored on-line to the RAM of the computer with TV digitizer Matrox Meteor (Matrox, Canada) with 8 bit resolution. The controlling program is written in C^{++}.

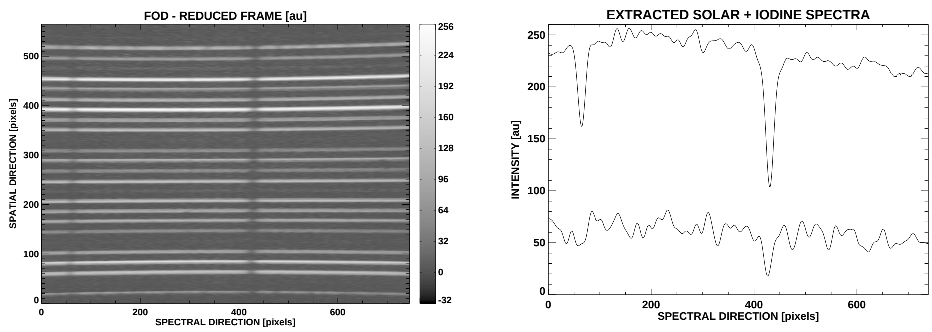

Figure 3. Left panel: The reduced fiber optics spectrum. The wavelength increases from right to left. The spectral line Fe I 557.6 nm (dark, in the middle) is visible in every bright strip (row), corresponding to a spectrum belonging to each fiber. One more spectral line (Ni I 557.9 nm) is discernible on the left side of the image. Right panel: The line profile of Fe I 557.6 nm derived from fiber optics spectrum (upper profile) and mixture of reference iodine spectrum with the Fe I line (bottom profile).

Observations: It is necessary to have the sunspot in selected areas on the solar disc to measure the horizontal velocities projected to the radial (Doppler) velocities. Therefore, we measure sunspots mainly in the areas $l = \pm(45^\circ - 55^\circ)$ and $b = \pm(15^\circ - 25^\circ)$. We prefer to observe symmetrical sunspots with a well developed penumbra. One observational run consists of several steps: a) The x axis of the 2D entrance matrix is adjusted to be perpendicular to the projection of the rotational axis of the Sun; b) The sensitivities of the cameras are adjusted to maximum at the disc center; c) Dark current and flat-field images are recorded; d) Calibration for all fibers is made using the iodine cell placed in front of 2D matrix. (During the observation of the sunspot this cell is placed in front of the calibrating fibers only); e) The measured spectra are recorded. An average of 32 frames during 1.3 second is stored as one spectral image. This image consists of 24 spectra which belong to the selected positions in the sunspot surroundings (see referenced matrix configuration) and of two calibrating spectra placed at the top and at bottom of the spectral image (see Figure 3). A set of 35 such spectral images is stored within 12 minutes. We repeat each observational run several times per day for every particular sunspot; f) Several reference slit-jaw pictures are taken to have information about the position of the sunspot at the 2D matrix; g) Sunspot drawings are made during observations to estimate rotational velocities of the sunspots. The accuracy of such estimation is sufficient and is comparable with the photographic estimation.

Data reduction: Each spectrum is represented by a matrix of real values with resolution of approximately 8000 levels (see final spectrum in Figure 3). Due to low illumination of the chip an additional noise appeared in the spectrum. We recognized (in the power spectrum) that the noise has very stable frequencies. Therefore, we use a Gaussian high frequency filter to remove this noise. The next step of the reduction is to get a spectral line profile for every particular fiber (iodine reference lines including). Due to distortion of the image (caused by the additional optics) we can't simply use the image rows as spectral scans. A special procedure is applied to the image to remove the distortions. An example of one final spectral profile resulting from one fiber as well as the calibrating iodine spectrum is shown in Figure 3 (right panel).

4. Results and discussion

The main results of our measurements should be the line-of-sight velocities which belong to every particular position in sunspot surroundings. These represent local horizontal plasma velocities as a mixture of different motions, (namely the solar rotation, supergranular motions, Earth-Sun relative motion, etc.). Each observational run has r.m.s. errors in the range of 50 m/s to 600 m/s, depending on the quality of the adjustment of the particular fiber. Four fibers transmit no light due to defects brought by manufacturing of the FOD. Four additional fibers transmit extremely low intensity light which produce r.m.s. error greater than 1000 m/s. Nevertheless, the preliminary results (cleaned from Earth-Sun relative motion) show significant deviations of the line-of-sight velocities from pure rotational ones.

The following conclusion can be summarized after the first observational period made with the FOD: 1) The suggested method using fiber optics is suitable for 2D solar spectroscopy; 2) The accuracy of the results strongly depends on the intensity transmitted via the fibers. Perfect perpendicular positions of the entrance 2D matrix as well as the 1D output to the axis of the telescope and spectrograph is required; 3) Additional noise was brought to observations using our combination of the camera and the frame-grabber; 4) Additional optics (to reduce the height of spectrum) makes distortion of the image.

After this experience we started with improvements of the whole system. The second FOD was manufactured with better positioned and fixed fibers. It will be used for the next observational season. New additional optics was suggested to use in front of the CCD camera. Better electronic adjustment of the CCD camera and the frame-grabber is under investigation. It is planned to buy a better camera to exclude the problems with noise and image distortion.

Acknowledgments. A.K. and H.W. thank for support by the bilateral German-Slovak scientific-technical cooperation project X261.1. A.K. and J.R. are grateful to the Slovak grant agency for science (grant No. 2/4154) for partial supporting of this work. A.K., J.R. and A.H. thank for support by the Aktion Austria-Slovakia project no: 22s31.

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