A MOF-Based Full Vector Imaging Magnetograph

A. Cacciani$^1$, M. Comari$^2$, S. Furlani$^2$, A. Hanslmeier$^3$, M. Messerotti$^2$, P. F. Moretti$^1$, Th. Pettauer$^4$, A. Veronig$^3$

$^1$Department of Physics, University of Rome "La Sapienza", Rome, Italy
$^2$Astronomical Observatory, Trieste, Italy
$^3$Institut für Astronomie, Karl-Franzens Universität, Graz, Austria
$^4$Sonnenobservatorium Kanzelhöhe, Treffen, Austria

Abstract. The scheme and the operating principles of a fast, compact, Magneto-Optical Filter-based, full-vector imaging magnetograph, currently under development for solar observations, are briefly outlined as well as planned improvements and possible applications.

1. Introduction

In December 1996 a Magneto-Optical Filter (MOF)-based system was installed at the Kanzelhöhe Solar Observatory (Austria) for experimental and development purposes. In the current configuration it is a compact, stand-alone observing instrument which produces full-disk, simultaneous Dopplergrams and longitudinal magnetograms of the Sun with programmable high time cadence.

2. The MOF System

The MOF system is a stand-alone observing instrument which is mounted on an optical bench piggyback onto the main solar patrol telescope (Figure 1).

2.1. Scheme of the MOF-Based, Full-Vector Imaging Magnetograph

The system consists in a set of specialized sub-units which are cascaded and operate according to the scheme reported in Figures 1 and 2: [A] The magnetic modulator has no moving parts as it is based on fast ferroelectric liquid crystals driven by a square wave modulation to select one polarization at a time (U, Q, V) and alternate orthogonal states at half the standard video rate. [B] The MOF transmits two narrow bands in the wings of the solar line and its output is linearly polarized at fixed orientation. The MOF unit (developed by A. Cacciani) is a cell filled with an atomic vapour (Na or K) located in a static magnetic field between two crossed polarizers. It acts as a polarizer (Righi effect, i.e., inverse Zeeman) and as a retarder (Macaluso-Corbino effect, i.e., Faraday rotation in the proximity of absorption lines) within a narrow spectral range around a spectral line. The temperature and the magnetic field are adjusted in order to obtain

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Figure 1. Mounting of the MOF system on the Kanzel solar telescope.
a double-band spectral transmission tuned on the opposite wings (R-Red and B-Blue) of the solar absorption line. [C] The Doppler Modulator changes the MOF polarization output into its orthogonal state at standard video rate. [D] The Wing Selector (WS) transmits only one of the two wings at a time following the inverse Zeeman effect rules. [E] The CCD Camera acquires the images at video rate. [F] The Timing Control feeds the electro-optical devices with the proper sequence of driving pulses. [G] The Data Acquisition System digitizes the images via a high speed frame grabber and operates an onboard arithmetic processing according to programmed sequences. Different sequences produce different signals (U, Q, V). Integration of many cycles is usually needed to get a suitable signal-to-noise ratio. The four images can be obtained simultaneously, provided four frame grabbers are operating in parallel.

Figure 2. Scheme of the MOF full-vector imaging magnetograph.

The Doppler Modulation at Video Rate  A Doppler image is derived subtracting and normalizing two solar images obtained in the opposite wings of the line (B-Blue and R-Red images respectively, see Figure 3): $D = (B - R)/(B + R)$.

Figure 3. The Doppler modulation at video rate.

The Magnetic Modulation at Half Video Rate  A longitudinal magnetic field image is derived simultaneously by subtracting the two Doppler images obtained using one $\sigma$ component at a time ($D^{\pm} = (B^{\pm} - R^{\pm})/(B^{\pm} + R^{\pm})$): $M_{l} = D^{+} - D^{-}$. 

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Four images are therefore needed which are produced according to the scheme shown in Figure 4. Similarly, the transverse components U and Q are obtained activating two additional liquid crystals in the Magnetic Modulator Package.

![Diagram of magnetic modulation](image)

**Figure 4.** The magnetic modulation at half video rate.

### 2.2. Current Configuration Specifications

The configuration is under continuous development and can be summarized as follows (1997, second semester):

- Operating wavelength: Na-D lines
- Front lens clear aperture: 16 mm (F = 40 cm)
- Spatial resolution: \( \sim 8''/\text{pixel} \)
- Doppler velocity resolution: 5 (m/s)/pixel
- Magnetic field range: 20-2800 G
- Time resolution: 1 image/(160 ms - 3 s)
- Image depth: 15 bits/pixel max (through image summation)
- Image sensor: 640x400 pixels CCD camera @ video rate
- Data acquisition: PC-based system with fast frame grabber card.

### 2.3. Upgraded Configuration Specifications

In order to improve the capabilities of the system the spatial resolution will be increased and an additional electro-optical package for the measurements of solar magnetic fields is presently under development which will realize a full vector imaging magnetograph with programmable high time resolution. The expected time for the first light of the upgraded instrument is January 1998 with the following specifications:

- Front lens clear aperture: 10 cm
- Spatial resolution: \( \sim 1.5''/\text{pixel} \) (seeing-limited)
- Magnetic field measurements: Full vector
- Time resolution: 1 (full vector map)/min.

### 2.4. Image Calibrations

In order to get reliable measurements from the raw data, it is important to adopt a proper data reduction and calibration procedure. This is a key point
in the MOF system which operates sampling the solar line profiles just at two fixed wavelengths. Relevant aspects of this subject are already treated in the literature, sometimes leading to unsolved differences among various authors (see, e.g., Lites et al. 1994, Zirin 1995). Here we give only the general outline of our new calibration method for Dopplergrams and longitudinal magnetograms, recently developed by Moretti and Cacciani. The starting point to consider is that magnetograms are obtained from the difference of two Dopplergrams (the two $\sigma$ components separately), which means that an important part of the procedure is a careful handling and cleaning of the Doppler data. This includes two main novelties: 1) the crosstalk removal between magnetic and Doppler images (Cacciani & Moretti 1997) and 2) a careful use of the geometric parameters and straylight correction (Moretti 1997). The overall calibration procedure gives satisfactory results when compared with measurements obtained by different magnetographs and this reinforces the validity of this direct imaging approach for the study of fast changing solar magnetic fields. Such a study is usually prevented on short time scales in other kind of instruments as, for example, the slower spectrographic polarimeters. The development of the more difficult calibration procedure for the full vector images is under study.

3. Comments and Conclusions

A MOF-based experimental system has been operating at the Kanzelhöhe Solar Observatory producing simultaneous Dopplergrams and longitudinal magnetograms. As it is intended to provide data for helioseismological ground-based projects and space experiments such as, e.g., UVCS/SOHO, it will operate at its maximum cadence ($\sim$ 1 Doppler/Magnetic image/min). The development of a full vector imaging magnetograph is in progress, its polarization analyzer package is under test and the first light is expected in January 1998. The calibration procedure for the full vector measurements is under study but requires the availability of observational data to be properly developed and refined. This system will benefit by the peculiar features of MOF-based devices, i.e., high transmission, high spectral resolution, absolute spectral reference and stability, imaging capabilities and high time cadence. The main goal achievable by the instrument upon the development of a suitable calibration procedure will be the capability to trace the magnetic topology evolution on a short time scale, which is the key feature of such observing technique.

Acknowledgments. A.C. and P.F.M. acknowledge the financial support from P.N.R.A. and M.P.I., M.M. the support from M.U.R.S.T. and A.S.I.

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