The Focal Plane Package (FPP) of the Solar Optical Telescope (SOT) includes the first precision Spectro-Polarimeter (SP) for solar space observations. The FPP/SP will provide high precision measures of the vector magnetic field in the solar photosphere. Here we present some as-built performance specifications for the entire system of telescope + polarimeter. The FPP-SP system represents significant gains in several aspects over existing spectro-polarimetric systems; notably, angular resolution, polarimetric accuracy, spectral purity, and most importantly, temporal continuity of stable, high angular resolution. In this short summary of the poster, a few of the performance characteristics of the SP are presented.

1. SP REQUIREMENTS

The SP will observe Stokes profiles only in the pair of Fe I lines at 6302 Å. The desired FWHM of the spectral response is 35 mA, and the pixel sampling should be less than 25 mA. The typical S/N of the polarization signals $Q,U,V$, relative to the continuum intensity, should be of the order 1000.

The desired polarization accuracy matrix for the full system response matrix is given by:

$$\Delta X = \begin{pmatrix} - & - & .333 & .333 & .250 \\ .001 & .050 & .007 & .005 \\ .001 & .007 & .050 & .005 \\ .001 & .007 & .007 & .050 \end{pmatrix}$$

(1)

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2. POLARIZATION CALIBRATION

Throughout the fabrication of the entire SOT and FPP systems, the polarization properties of individual optical components and full optical systems were measured. These tests were used to evaluate the performance of components for certification and for selection of the best components for the flight instrument. System-level polarization tests of the FPP and the full system can only be carried out using natural sunlight, as the frame rate of the cameras (10 Hz) is too high to gather meaningful flux from lamp sources. The calibration of the entire SOT + FPP system was carried out with sunlight at NAOJ in August 2004, then June 2005. The latter data, providing the polarization calibration for flight operations, are described below.

2.1. Calibration Data

The data consist of standard mode observations (4.8 s integrations) of clear (no polarizer), four stations with the right-handed circular polarizer (45° rotations), four stations of the left-handed circular polarizer, four stations of the linear polarizer, and a final clear. Additionally, dark frames were occasionally recorded. The standard data acquisition gathers profiles of only half of the 224-pixel range of each side of the CCD; this being sufficient to encompass the two Fe I lines. For polarization calibration of the entire sampled spectral range, data were collected separately for two spectral regions which together cover the entire range. This set of observations provides enough information to specify the 15 independent elements of the system Mueller matrix at each position in the focal plane of the FPP/SP. These observations were carried out sequentially at nine samples over the entire 328 arcsec range of the slit scan mirror.

2.2. Analysis Procedure

The spectral images were binned spatially along the slit (16x) and spectrally (2x) to reduce the data volume and to increase the S/N. Each pixel of the binned sampling was subjected to a non-linear least-squares inversion procedure that adjusts the 15 independent system polarization response matrix (X) elements, plus the error in the mount angle for the left- and right-handed circular polarizers. The Mueller matrices for the polarizers were determined by separate laboratory measurements. Furthermore, a model of the heliostat based upon measurements of that device provided the input Stokes vectors at the time of each measurement (although the calibration results are not very sensitive to the polarization of the incoming light beam).

2.3. Polarimeter Response Matrix

The dual-beam SP images the two orthogonal linear polarizations onto two separate areas of the SP CCD (CCDSIDE1, CCDSIDE2). A typical system response matrix $X_{SP}$ for CCDSIDE0 is presented in below. For CCDSIDE1, the matrix has a similar structure, but with signs reversed for elements having significant values.
\[ X_{SP} = \begin{pmatrix} 1.00000 & 0.21996 & 0.01587 & 0.00437 \\ -0.00033 & 0.48083 & 0.07739 & -0.00125 \\ -0.00072 & 0.06002 & -0.47494 & -0.00561 \\ -0.00028 & 0.00437 & -0.00792 & 0.52939 \end{pmatrix} \] (2)

Several properties of this matrix are notable: Most off-diagonal terms are at or below the corresponding values of the polarization accuracy matrix \( \Delta X \). Thus the design goal is nearly met even if no polarization calibration were applied! The off-diagonal \( Q \rightarrow U \) and \( U \rightarrow Q \) elements represent a simple rotation of coordinate system, in this case by only about 2.5°. The second element of the first row shows the large value of \( Q \rightarrow I \) crosstalk typical of a single-beam polarimeter. When the two CCDSIDEs are combined, this response is largely cancelled. Diagonal elements are close to their anticipated values. Intensity to polarization crosstalk (first column of the matrix) is very small. One may anticipate the final calibrated data to contain polarization errors more than an order of magnitude smaller than the error limits specified in the polarization accuracy matrix.

Variations of the matrix elements across the spectral field of view are generally very small. Only variations of the first column of \( X_{SP} \) exceed \( \Delta X_{SP} \), and these may be calibrated easily on-orbit via measurements of the continuum polarization.

3. Spectral Resolution

The SP spectral response profile was measured (Fig. 1) using a tunable laser. Because of wavelength drift of the laser, short exposures were necessary to achieve reliable measures of the profile. Further, a rapidly rotating diffuser placed in front of the laser minimized the laser speckle pattern, and allowed more uniform illumination of the slit.

The curvature of the spectral lines along the slit is used to obtain a spectral response that is finely-sampled in wavelength. Each row of the spectrum is shifted to center the peak of the laser profile at a specified pixel, and its amplitude is normalized. This results in the spectral profiles shown in Fig. 1 (dots). Gaussian fits to profiles are shown by the dashed lines, and the FWHM for each beam is indicated. These profiles, sampled near the center of the spectral range of the CCD, have FWHM 25 mA. Note the slight asymmetry in the blue wing (expected from the off-axis spectrograph optical design) and somewhat elevated inner wings of the profiles relative to the Gaussian fits. Detailed measurements of the spectral response will be used in the analysis when fitting observed Stokes profiles.

4. Polarization Signal-to-Noise (S/N)

SP flux levels were measured during tests with natural sunlight in August 2004 and June 2005. Additionally, measurements were made of the transmission of the heliostat and window and the solar radiance during these tests. Furthermore, the radiance measurements were calibrated to zero airmass using standard atmospheric transmission as applied to measurements taken on days of exceptionally
clear skies. These measurements allow one to extrapolate to the on-orbit S/N in polarimetric measurements of natural sunlight. The anticipated S/N for a typical 4.8 sec integration is: continuum, quiet Sun: 1100; line center, quiet Sun: 580, line center, Umbra: 164.

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