INSTRUMENTAL CAPABILITIES OF THE SAYAN OBSERVATORY FOR THE STUDY OF OSCILLATORY PROCESSES ON THE SUN

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Abstract. During the past decade a number of instruments designed for studying solar oscillations have been developed at the Sayan observatory. A double solar telescope using two Jensch-coelostats and two objective lenses provides the capability to filter lower-order modes. This instrument is also used (in the single-telescope mode) for making observations of the mean magnetic field of the Sun. Spatially-differential methods based on polarization separation of images are best suited for investigations of local oscillations and higher-order modes. These methods make it possible to carry out narrow-band spatial filtering of large wave numbers. They are useful when investigating contrast oscillations as well as the oscillations and rotation of sunspots and other solar features.

1. Introduction

Investigations of physical processes in the solar atmosphere usually require relative measurements. The line-of-sight velocity has, for instance, contributions from a whole variety of motions, e.g., large-scale flows, solar rotation, diurnal rotation of the Earth, and the orbital motion of the Earth. The notion of a wave implies the relativity of the motion at different points in space. In order to observe a wave it is necessary to measure the velocity for at least two pixels and then compare the results.

2. Spatially-Differential Methods for Investigating Local Oscillations

The above-mentioned conditions are automatically satisfied by using a spatially-differential method (Kobanov, 1983), based on polarization separation of images in the plane of the spectrograph entrance slit. The method can also provide differential intensity measurements. In this case one may say that what is being measured is the contrast, because the measured value of $(I_1 - I_2)/(I_1 + I_2)$ is, by definition, the mutual contrast of two pixels with intensities I_1 and I_2. Of greatest interest are simultaneous differential measurements of line-of-sight velocity and intensity. To do this, it is necessary that at the spectrograph output the light from the continuum can pass through the analyzer to get to an additional photoelectric photometer. In this case the signal, whose amplitude is proportional to the contrast, is measured at the modulation frequency (Kobanov, 1985a).

An important feature of the spatially-differential method is its selectivity with respect to spatial harmonics; the instrumental response function to different spatial waves of

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wavelength λ is, for a simple case, described by the expression $S = A_0 \left| \sin \pi L/\lambda \right|$ (Kobanov, 1985a), where A_0 is the true value of the observed wave amplitude, L is the value of linear separation between the sampled pixels, and λ is the spatial wavelength.

A significant improvement of the method's selective capability can be achieved if several, rather than one, pairs of pixels are involved in the formation of the differential signal (Kobanov, 1985b). In order to accomplish this, the images are separated from each other in the direction along the spectrograph entrance slit, in front of which is placed a spatial filter composed of alternating transparent and opaque bands. A conventional, one-element photoelectric receiver is employed. The filter parameters are related to the value of L by the relationship

$$(P + N)/2 = L\,,$$

where P is the transparent bandwidth, and N is the opaque bandwidth.

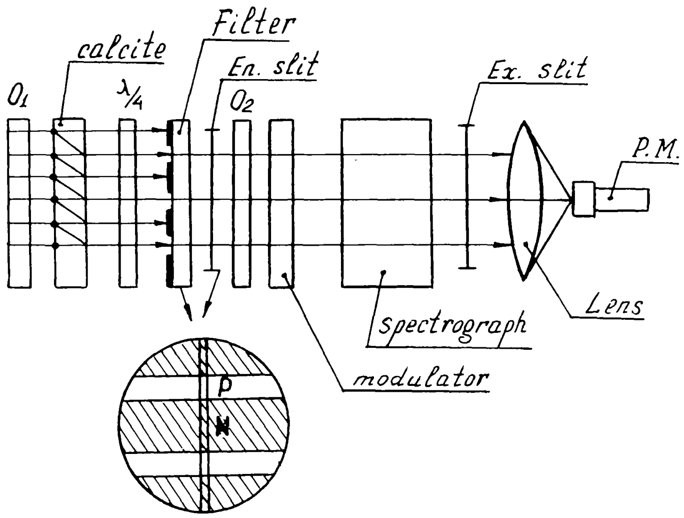

Fig. 1. A general conceptual diagram of the instrument for narrow-band filtering of spatial harmonics in differential measurements.

A general conceptual diagram of the instrument is presented in Figure 1. The instrumental response to the spatial wave is, in this case, described by the expression

$$S = \frac{\lambda_0}{\pi P} \sin\left(\frac{\pi P}{\lambda_0}\right) \sum_{n=1}^{n=2M} (-1)^n \sin\left[\frac{\pi}{\lambda} L(2n-3)\right],$$

where M is the number of pairs of bands with respect to the slit height, λ is a current value of spatial wavelength, and λ_0 is the selected wavelength; units of measurements of P, L, λ, and λ_0 are the same. A graphic representation of this function has the form of a narrow peak symmetric about λ_0 (Kobanov, 1985a, b). In this way it is possible to achieve narrow-band spatial filtering without the need to utilize a multi-element photoelectric receiver. Figure 2 presents an example of filter observations for $\lambda_0 = 24''$.

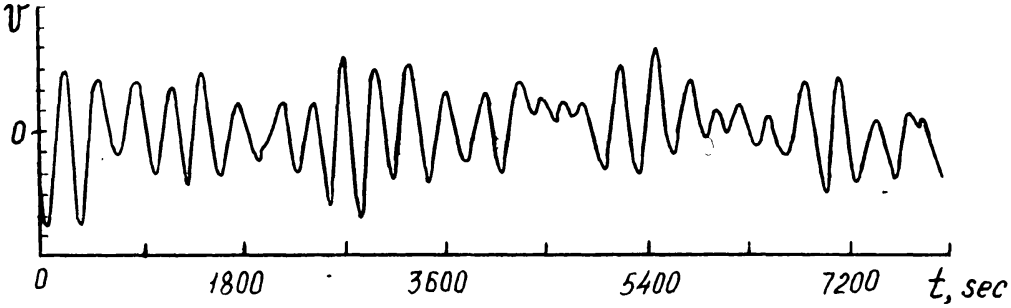

Fig. 2. A portion of a line-of-sight velocity recording in the quiet photosphere with a spatial filter set for $\lambda_0 = 24''$.

Both the velocity and brightness or both together can be the parameters measured. In this case the result is not affected by spatial inhomogeneities inside the spectrograph. A disadvantage of the method is the loss of about half the light flux due to the spatial filter. However, subsequent improvements (Kobanov, 1986) make it possible to avoid these losses. This has led to an increase of the selective capabilities of the method as well as a lowering of its sensitivity to noise.

The spatially-differential method is being used not only for observations at a fixed pixel but also in a scanning mode. It is possible to achieve a scanning mode in which only one of the separated images is being scanned, while the other remains fixed. A very simple example of such scanning is the rotation of the polarization prism around the optical axis of the telescope. Alternative methods to implement such a scanning mode (Kobanov, 1985a) are based on using additional optical-mechanical devices.

The spatially-differential method can be used for investigating rotational-oscillatory motions of sunspots. When a rotating sunspot lies near the limb, its northern and southern parts have line-of-sight velocities of different signs. Differential measurements in the scanning mode can successfully be used for investigating the limb-darkening curve, the differential rotation, and the spatial distribution of other observed parameters.

3. A Double Solar Telescope for Measuring Global Solar Oscillations with Different Spatial Filters

The idea of differential methods (Kalinyak and Vasilyeva, 1971; Kotov, Severny, and Tsap, 1978; Severny, Kotov, and Tsap, 1976; Kobanov, 1983) forms the basis for the double solar telescope design. The optical system and structure of the telescope (Figure 3) are such that global oscillations of the Sun can be measured with different spatial filtering.

The telescope consists of two Jensch-coelostats and two objective lenses. The optical axes of the two telescopes are parallel to each other, and the objective lenses are identical. The second objective lens is 70 cm from the first one and directs the light onto the spectrograph slit via a diagonal mirror and a prism cemented on a calcite plate. The light beam from each objective lens, when passing through the calcite plate, is separated into two orthogonally linearly polarized beams. The calcite plate with the prism

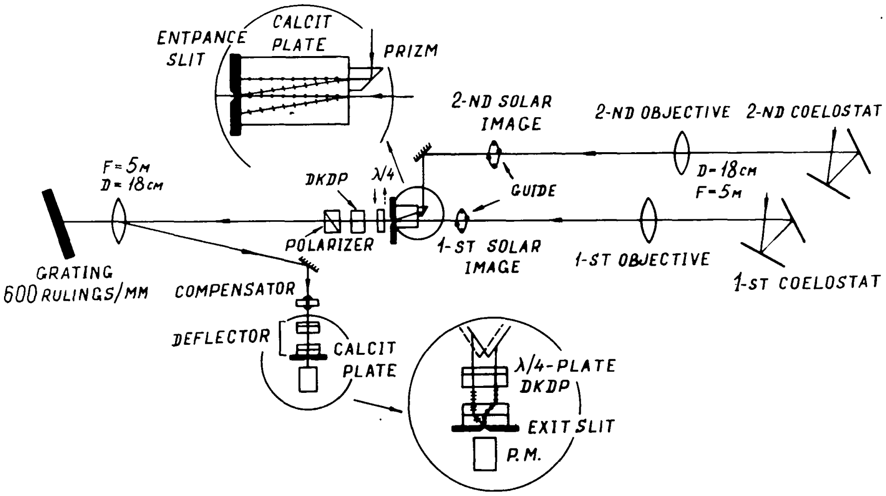

Fig. 3. General optical scheme of the double solar telescope, which is used for measuring global oscillations of the Sun as well as the mean magnetic field of the Sun as a star.

cemented on it, is adjusted in such a way that only one beam from each objective lens can enter the spectrograph slit. These beams, after passing through the $\lambda/4$-plate placed behind the slit, become orthogonally circularly polarized. Subsequent measurements of the differential displacement between spectral lines formed by each beam are done in a similar way as measurements of the longitudinal component of the magnetic field (Grigoryev and Demidov, 1987).

Since each objective lens forms its own solar image, it is possible by varying the degree of defocusing of the images on the spectrograph slit to vary the size of the areas of signal averaging (spatial resolution).

The solar image position in each telescope is controlled by means of photoelectric guiders. In this way it is possible, for instance, to achieve observing modes in which the Doppler shift of the line from a given area of the solar image is measured with respect to the Sun as a star. It is then also possible to obtain any combination of averaging apertures which look like concentric zones of radius R_i and R_j, and to make differential measurements of velocity. The combination of two such concentric averaging areas may be regarded as a certain spatial filter (Kotov *et al.*, 1982; Christensen-Dalsgaard and Gough, 1982; Hill, 1978; Balandin, Grigoryev, and Demidov, 1987). Using observations of oscillations obtained with different spatial filters, and comparing amplitudes of oscillations of the same frequency with theoretically calculated relationships, it is possible to obtain an estimate of the degree l of the oscillations (Balandin, Grigoryev, and Demidov, 1987).

4. Measurement of Variations of the Mean Magnetic Field of the Sun as a Star (SMMF)

Measuring the SMMF as a star is a complicated observational problem because a typical value of the SMMF strength is 1 G, and variation amplitudes at different time-scales are in the range 10^{-2}–1 G.

The method of measuring the SMMF at the Sayan observatory is described in detail by Grigoryev and Demidov (1987) and is a further development of earlier methods (Severny, 1969; Scherrer, 1973; Dittmer, 1977).

We use the main objective lens of the double solar telescope (Figure 1), which forms a solar image at a distance S from the spectrograph slit defined by the expression

$$S = (F^2 \tan \beta)/(D - F \tan \beta)\,,$$

where the objective lens diameter $D = 18$ cm, its focal length $F = 5$ m, and β is the angular size of the Sun. With these parameters, the distance $S = 180$ cm. The cone angle of the light beam entering the spectrograph is $1\overset{\circ}{.}52$, or slightly smaller than the angular aperture of the spectrograph ($2\overset{\circ}{.}06$) but, on the other hand, significantly larger than the visible angular size of the Sun. The light efficiency is considerable. As compared with the 'parallel beam' solution (Severny, 1969) having the above parameters of the optical system, our spectrograph receives about 8 times more light.

Measurements of the mean field are made in the line Fe I 5250 Å, the signal storage time is 100 s, and the typical r.m.s. noise level is 0.08 G. There is continuous zero-level control of the magnetograph. The measurement is first made normally and is then repeated with a $\lambda/2$-plate introduced into the light beam incident on the coelostat. The half-wave plate reverses the polarization directions of the Zeeman split σ-components. This leads to a change of sign of the magnetograph signal, but only of the part that is caused by the magnetic field. The zero displacement signal caused by instrumental polarization and electronic effects remains the same. The half-difference of the two measurements yields a result which is free from zero-displacement errors. Measurements with and without the $\lambda/2$-plate alternate every 32 s. The $\lambda/2$-plate is automatically controlled.

The power spectrum analysis of observational data from the Sayan observatory, together with long sequences of measurements from the Crimean and Mt. Wilson observatories, reveal the existence of weak variations in the SMMF strength, with periods of 270, 160, 80–90, 55–60, and 45–50 minutes. The oscillation amplitude is in the range 10^{-1}–10^{-2} G (Demidov, Kotov, and Grigoryev, 1988). Five-min oscillations of the SMMF have also been observed. The 5-min oscillation spectrum of the SMMF depends on the structure of the background magnetic field on the solar disk, so one should expect a time variation of the character of the 5-min oscillations of the SMMF (Grigoryev and Demidov, 1988).

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