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MEASUREMENT OF LINE PROFILE STEEPNESS AS A POSSIBLE TOOL FOR DEDUCING A TOTAL MAGNETIC FLUX NEAR A NEUTRAL LINE

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ABSTRACT

For obtaining estimates of a total magnetic flux, we propose to use measurements of $\partial I/\partial\lambda$ obtained by a modulation method which is formally identical to Stokes V-parameter measurements. In this case the polarization is not analyzed. It is advisable to use in measurements two parts of the spectral line wing.

It is well known that, in the magnetographic measurements using a spectrograph, an algebraic addition of different-polarity magnetic fluxes occures that fill the spectrograph entrance aperture. For filter magnetographs, the role of such an aperture is played by a limiting resolution determined under ground conditions by the "atmosphere-telescope" system. In a variety of observing programs involving the magnetic field topology, of the position and shape of the neutral line separating regions of different magnetic polarity is important. The above-mentioned factor leads to a serious uncertainty of these parameters deducible from magnetograms. For instance, parts of a neutral line with true zero of the magnetic field are indistinguishable from parts where strong fields of opposite polarity are extremely close together and intermingled. But energetically, these are totally different objects with a dissimilar probability that an active dynamic process would occur, which is accompanied by considerable energy release. It is well known that the magnetograph sensitivity to $H_{\perp}$ is worse than that for $H_{\|}$ by more than an order of magnitude. In such a situation, additional information about a total energy of the magnetic field in the neighborhood of NL is important. Such a capability is inherent in a method used to measure magnetic fields of stars (Robinson, 1980). The method is based upon measuring magnetic broadening of magnetosensitiv line profiles. Variations of magnetosensitive line parameters are in wide use investigations of fine-structure magnetic fields on the Sun (Stenflo and Lendegrem,1977; Solanki and Stenflo, 1985; Brandt and Steinegger, 1990; Briand and Solanki, 1995). In this case, useful information is most commonly extracted from measurements of the profile width, the intensity in the line core and its asymmetry. The steepness of the magnetosensitive line profile $\partial I/\partial\lambda$ is in our view an equally informative (and, on some occasions, more useful) parameter.

In what follows, in a most simplified form, an analytic justification our proposal is given. The magnetosensitive line profile for the case of $H_{\|}$ can be represented in terms of residual intensity as the sum of profiles of two sigma components

$$r^*(v) = 0.5r(v+v_H) + 0.5r(v-v_H) \qquad (1)$$

where $v = \Delta\lambda_0/\Delta\lambda_d$ is the distance from the line core, $v_H = \Delta\lambda_H/\Delta\lambda_d$ is the value of Zeeman splitting in terms of the line Doppler width. By expanding each of the two terms of Equation (1) as a power series, and limiting ourselves to the second order of terms, we obtain

$$r^*(v) = r(v) + 0.5\frac{\partial^2 r(v)}{\partial v^2}v_H^2 + \ldots \qquad (2)$$

The steepness of the magnetosensitive line profile can be defined in terms of v as a first derivative. To obtain an approximate numerical estimate of the variation of the profile steepness due to magnetic broadening, we represent the initial profile as a Gaussian

$$r(v) = \left[1-(1-r_0)\exp -v^2\right] \qquad (3)$$

Let us further consider the difference between the steepness of a magnetosplit profile and that of the non split profile:

$$\frac{\partial r(v)}{\partial v} - \frac{\partial r^*(v)}{\partial v} = \frac{\partial r(v)}{\partial v}(3-2v)v_H^2 \qquad (4)$$

Upon differentiating Equation (4) and assuming $v_H = 1$, which corresponds to $H \approx 1$ kilogauss for 5250Å, we determine extremum points. One maximum at $v = 0.524$ and one minimum at $v = 1.65$ are present between the line core and the far wing. Thus, the line wing includes two parts, on which variations in line steepness are largest in value and opposite in sign. This fact is useful for separating magnetic field effects from variations caused by other factors (temperature, pressure). In the latter case it is logical to expect that changes in steepness would be of like sign in both parts of the profile.

We suggest that the profile steepness should be measured using a method developed to measure the Zeeman splitting. (Kobanov, 1993).The measurements method is no different from those applied when measuring $H_{\|}$ and allow the use of any type of magnetograph, both one- channel and multichannel ones using CCD-matrices. This makes it possible to achieve the principal advantage of the magnetograph, namely the modulational method of measurement. A gain in sensitivity is no less than 10 compared to the situation where such a steepness $\partial I/\partial\lambda$ would be measured in the mode of subtraction of direct currents of neighboring elements of CCD-matrices.

As a preliminary exercise we examined about 20 spectral lines in the range 5000-7000 Å that are rarely used in magnetic measurements. The 5705 Å and 5197 Å lines have a central component and for the 6213.4 Å and 6336.8 Å lines the circularly and linearly polarized components form two more-or-less compact groups, for the FeII 6149.2 Å line the positions of the σ and π - components almost exactly coincide in a total absence of central components. To determine the parts of the profile which would be most advantageous for the conduct of measurements, we carried out calculations of profiles of all the lines concerned by using an undisturbed photosphere model (Holweger and Muller, 1974) and a sunspot model (Zwaan, 1974). The value of macroturbulent velocity set to 0 or 1.8 km/s and the value of microturbulent velocity is 1 km/s. The line steepness $\partial I/\partial\lambda$ was calculated at steps of 10^{-2} Å for discretely specified magnetic field strengths $H = 0, 100, 300, 1000, 2000$ and 3000 G. The three values of the angle γ : 0, 45 and 90°are employed. As expected, the steepness of line FeI 6149.2 Å depends weakly on the angle γ and shows almost the same sensitivity to both the longitudinal and transverse magnetic field. All of the lines under consideration are characterized by the presence of two parts of the wing, on which variations in steepness as a function of the magnetic field are largest and opposite in sign.

To test the actual capabilities of the method, we conducted a series of experiments using the Sayan observatory solar magnetograph. The object, chosen for the study, was scanned twice: initially, in the mode of magnetic field measurement, and then in the mode of line steepness measurement. Correlation analysis shows that our proposed method of measurement reveals a sufficient sensitivity to magnetic field strength fluctuations. The sensitivity of measurements is comparable that used to measure the longitudinal component of the H. As far as the transverse field is concerned, the sensitivity of our method exceeds one of conventional magnetographic measurements.

It may appear that, because of the availability of two-dimensional CCD-matrices, the problem of measuring all parameters of the magnetosensitive line is resolved. However, it is not the case due to the following reasons: firstly, this paper is concerned with a modulation method to measure $\partial I/\partial\lambda$, whose sensitivityis significantly higher than the constant current measurements and compares quite well with the magnetograph's sensitivity; secondly, the magnetic field effect on this parameter is different in the profile and is most clearly manifested in two parts of the wing where it is a maximum and opposite in sign. The filter magnetographs are offten used to measure wholly particular parts of the wing, rather than the entire profile. The other parts of the profile fall short of this informational content. Moreover, if the entire profile is exploited, this would increase more than an order of magnitude the time of measurement; and thirdly, it is significant that the method discussed in this paper, furnishes an opportunity both to scan in the line profile and to record the signal simultaneously at many points of the profile

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