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Advances in Space Research 55 (2015) 897–907

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Methodical problems of magnetic field measurements in umbra of sunspots

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Received 26 March 2014; received in revised form 2 August 2014; accepted 5 August 2014
Available online 15 August 2014

Abstract

Visual measurements of magnetic field strengths in sunspot umbra provide data on magnetic field strength modulus directly, i.e., irrespective from any solar atmosphere model assumptions. In order to increase the accuracy of calculation of the solar magnetic indexes, such as $\overline{B}_{max}$ or B_{sp}, the inclusion of all available data from different observatories is needed. In such measurements some methodical problems arise, which bring about inconsistency of the data samples combined from different sources; this work describes the problems at hand and proposes solutions on how to eliminate the inconsistencies. Data sets of sunspot magnetic field strength visual measurements from Mt. Wilson, Crimea and Kyiv observatories in 2010–2012 have been processed. It is found that two measurement modes of Zeeman split, $\sigma \rightarrow \sigma$ and $\sigma \rightarrow \pi$, yield almost the same results, if data rows are long enough (over ~100 sunspots in central area of Sun, $r < 0.7$ R). It is generally held that the most reliable measurement results are obtained for magnetic fields that exceed 2400 G. However, the empirical comparison of the internal data consistency of the samples produced by different observers shows that for reliable results this limit can be lowered down to 1100 G. To increase the precision of measurements, empirical calibration of the line-shifter is required by using closely positioned telluric lines. Such calibrations have been performed at Kyiv and Crimea, but as far as we know, it has not been carried out at Mt. Wilson observatory after its diffraction grate was replaced in 1994. Taking into consideration the highest quality and coverage of Mt. Wilson sunspot observational data, the authors are convinced that reliable calibration of its instrument by narrow telluric lines is definitely required.

Keywords: Sun; Sunspot magnetic fields; Methodical problems; Indexes of solar activity

1. Introduction

Sunspot magnetic field measurements, given the spatial resolution is good enough, yield a "pure" magnetic parameter, a magnetic field strength modulus. This parameter, based on Zeeman splitting, is crucial for solar magnetism research, in particular, for temporal variation of magnetic fields. Conventionally, the CGS system is employed to characterize solar magnetic fields. In specialized works on the subject, Gauss (G) units are used not only to measure magnetic induction, but also magnetic field strength (intensity), because in the solar atmosphere these two parameters are numerically equal.

Long-term temporal variations can be investigated on the basis of continuous rows of observational data, provided that the principles of observational technique remain unchanged. The visual data, which have been used for a

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http://dx.doi.org/10.1016/j.asr.2014.08.006
0273-1177/

hundred years now, represent the longest and most statistically reliable source of information on the solar magnetic fields.

Sunspot magnetic field measurements started in 1915, at Mt. Wilson Observatory (Hale et al., 1919). From the 1940s, such measurements have also been carried out at Potsdam observatory, and from 1955, at Crimea Astrophysical Observatory (Severny and Stepanov, 1956; Stepanov and Petrova, 1958). Currently, routine measurements of sunspot magnetic fields are performed at Mt. Wilson, Kitt Peak, Crimea, Kyiv and Ural observatories.

Before the magnetograph era, the distribution of magnetic fields between active areas of sunspots (used for classifying sunspot groups) was determined from visual and photographic measurements. Later it was revealed that visual measurements are essential for correcting magnetographic data on the sunspots umbra. Severny (1967) discovered that within the range of magnetic fields measuring 1000–3000 G magnetographic data show quite substantial errors – up to 200–300%. It may actually be attributed to the complex magnetic and thermodynamic structure of sunspots, which makes it impossible to use single calibration magnetograph curve for any sunspot configuration. At the same time, magnetograms provide very accurate magnetic field maps outside sunspots. Magnetographic data on non-sunspot areas, when combined with visual measurement data on sunspots, can provide most comprehensive and reliable data on the active areas of the Sun.

Visual magnetic field observations in sunspots harbor many methodical problems that have to be carefully accounted for in routine practice in order to maximize the accuracy of measurements. In this work, we aim to review these problems, by analyzing the data obtained at different magnetometric observatories.

2. Calibration curve adjustments

Visual observations of magnetic field in sunspots are based on measurements of Zeeman splitting with the help of a so-called line-shifter. There are two common measurement modes: measuring wavelength distance between opposite circular σ components of Zeeman splitting ($\sigma \rightarrow \sigma$ mode), and between σ and π components ($\sigma \rightarrow \pi$ mode). The first mode measures double Zeeman splitting $2\Delta\lambda_H$, while the second one yields singular splitting $\Delta\lambda_H$. The line-shifter (or tipping-plate micrometer) is a plane-parallel glass plate with well-known dependence of the shift of the beam from rotation angle of this plate. For small angles (<10°), the value of the beam shift is approximately a linear function of the rotation angle. However, for bigger angles, the shift - angle dependence is non-linear, and the exact pattern of this dependence is needed in order to exclude errors of magnetic field measurements.

'The tipping angle vs. wavelength shift' calibration can be recalculated into 'the tipping angle vs. magnetic field strength' curve for this particular instrument and the known spectral line. The angle to the spectral shift curve can be calculated if the precise optical parameters of the glass plate are known, or obtained empirically, by using narrow telluric lines in the vicinity of the spectral line used, as it is done in Lozitska et al. (2008). In this work, the line-shifters of the Horizontal Sun Telescope at Kyiv Astronomical Observatory (KAO) of Taras Shevchenko National University of Kyiv and of the Tower Sun Telescope (BST-2) at the Crimea Astrophysical Observatory (CrAO) are calibrated for observations of magnetosensitive FeI 6302.5 Å and FeI 5250.2 Å solar spectrum lines. For the first line, telluric lines of O_2 within 6276–6282 Å wavelengths range are used. For the second one we use some nearby solar non-magnetic lines at a distance of ±10 Å. The empirically obtained new calibration curves are slightly different from the previously computed ones, with which the old empirical curves coincided. The differences can be explained by the non-zero eccentricity of the circular scale and change (shift) of the zero-point on it, from which rotation angles are counted. For individual sunspot measurements, effects of these errors are smaller than random errors, but they reveal themselves during calculation of average values of solar magnetic field indexes, using observational data from different observatories. Systematic differences between indexes, calculated with usage of data from different observatories, reveal a necessity of calibrating curve revision.

Livingston et al. (2006) investigated a similar problem, which became noticeable after the upgrade of Mt. Wilson Solar Spectrograph in 1961. The authors studied calibration curves used for processing observations in different years and found that the 'true values' of stronger (at higher angles) magnetic field strengths exceeded the previously assumed ones that had been based on the old calibration diagram 'drawing field' data. The terms 'drawing field' and 'true field' were introduced by Livingston et al. (2006). After the last modernization (installation of a new diffraction grating) in 1994, this bias reaches up to 500 G.

The currently available online observational data were obtained using the old calibration curves; the differences between these biased «drawing field» data and «true field» data (Livingston et al., 2006) can be seen in Table 1.

This Table also lists the corresponding data obtained from measurement held at Crimean Observatory with the use of the old and revised calibration curves. The differences between the two calibrations for the field strengths of less than 3000 G in data of Crimean Observatory were 100–300 G in 2005–2008, and only about 100 G after the year 2008. The sunspot magnetic field data rows from Kiev and Crimean Observatories, based upon revised calibration curves, come to a good agreement.

In this study, we restricted ourselves to a refinement of calibration dependencies only for the last two decades. Livingston et al. (2006) presented calibration curves which begin with 25 units of 'drawing fields' (one unit is 100 G). The range of lower values (<25 units) remained unconsidered. At the same time, the available online observational