Jenaer Rundschau, **22** (1977) 87-91 (english edition: Jena Review[1])

Measuring Magnetic Stars with a Modified Abbe Comparator

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In general, magnetic fields on stars are ascertained by measuring the very small wavelength shifts, which anticircularly polarized ZEEMAN components of the spectral lines undergo in a magnetic field running parallel to the direction of observation. Many observatories still use the JENA-made **Abbe Comparator** for measuring wavelength differences.

When using ABBE's comparator principle, according to which the distance to be measured and the comparison scale are arranged on one common support in one line, a measuring accuracy of $\pm 1.5\mu$m is achieved if the objects are sharply bounded. As soon as an object has unsharp boundaries such as broad stellar absorption lines, for instance, the measuring accuracy is impaired by the uncertainty to set the line of the scale exactly between the double lines of the micrometer eyepiece; one has then to rely on the estimating capacity of the operator.

Strictly preserving the merits of the Abbe comparator principle, the Central Institute for Astrophysics carried out a technologic improvement of the Abbe comparator with a view to objectify the setting of the line position and thus to arrive at the high measuring accuracy required for ascertaining the magnetic fields, to facilitate the reading of the comparison scale and - later on - to fully automate data logging and processing.

Description of instrument

The original Abbe Comparator was modified in several steps, the most important of which is the objectifying of the line-position setting. To this purpose, a principle stated already in 1962 by GOLLNOW [1, 2] has been used, according to which image and reflected image of the profile of a periodically scanned spectral line are made to coincide on an oscilloscope tube face. When the profile imaged on the screen coincides with its mirror image, the position of the line's symmetry axis is defined by the centre of the interval scanned by forward and backward motion.

In the instrument developed by the Central Institute for Astrophysics, the surroundings of a spectral line of the star spectrogram are periodically scanned by an electro-dynamically driven oscillating slit [3]. GOLLNOW, on the other hand employs a rotating parallel glass flat, by which the bundle of light is parallelly displaced in dependence on the angle of incidence. The resulting scanning curve resembles a sawtooth curve, but only the middlemost part is of approximate linear shape. Also the intensity of the light passing the parallel glass flat indicates a dependence on the angle of incidence which becomes perceptible at large angles. Mirror-symmetric distortions are practically of no importance for the setting of the line position, but they complicate the comparison with a record of the spectrogram. The application of an electro-dynamically driven oscillating slit has the advantage that the line profile is imaged free from distortion.

The modification of the Abbe Comparator's path of rays was carried out as follows (compare Fig. 1): Using a condenser 3, a slit 4 is homogeneously illuminated by means of an incandescent lamp 1 positioned at a greater distance. A heat-absorbing filter 2 in the optical path prevents the formation of excessive heat.

[1]Scanned from original publication by E. Gerth in 2011. Internet-address: www.ewald-gerth.de/49abbe-engl.pdf

Furthermore, the transportation of heat from the incandescent lamp to the remaining instrument components is greatly reduced by an air cooling system, slit 4, which separately limits the partial spectra in vertical direction (either the two anticircularly polarized components of the stellar spectrum or of the stellar and comparison spectrum) (cf. Fig. 3), is imaged in the plane of oscillating slit 6. With the help of the microscope optics 7, this slit is projected into the plane of the spectrogram. Above the spectrogram 8 there is a second microscope optical system 9 with whose aid a 12× magnified picture of the spectrogram is produced. The latter can be viewed on a frosted screen 14 via a beam-splitting cube 10 but, on the other hand, can also be projected onto the edge of a beam-dividing prism 18 which lies in the direction of dispersion. After having traversed the two partial spectra, the light is then separately presented to the two photomultipliers 11 and 12 (PM 1 and PM 2 in Fig. 5).

After having been sufficiently amplified, the electrical signals (proportional to the light flux) are applied to the inputs of a dual-channel oscilloscope (Fig. 5). That way it is rather easy to compare the line profiles of the two partial spectra on the tube face of the oscilloscope.

The spectrogram is fully illuminated by a further lamp 19 in order to have a good general view of the picture projected on the frosted screen. The path can be switched to measuring or viewing by actuating a hinged mirror 13.

A clamping device causes the oscillating slit 6 to be rigidly connected with the electrodynamic oscillator 5. The slit is attached to a rotatable holder which can be clamped to the carrier connected to the oscillating system in the desired inclination relative to the direction of dispersion. A set of oscillating slits of varying width is available to tackle the many problems involved. The oscillator 5 is driven by a sine generator via a power amplifier with a frequency (35 Hz) which is sufficiently away from the natural resonance frequency of the oscillating system (24.5 Hz), to prevent phase instabilities.
Switching in a pulse-shaping stage, the sine generator also supplies the synchronizing pulses for the time sweep of the oscilloscope which can be set to the desired phase position by means of a phase shifter. For the time sweep, that instrument-specific sweep voltage is still used for the time being which is set to twice the frequency compared with the oscillating system, in order to be in a position to alternately image on the screen the forward and return motion of the scanning.

The comparator (all-over view of the instrument combination – Fig. 2, p. 89) is mounted on a rugged base plate seated on vibration isolators on the supporting table, in order to prevent the transmission of unwanted vibrations between slit and spectrogram.

The next step for the improvement of the Abbe Comparator – its complete automation – is still in the period of preparation. To facilitate the reading, we first modified the imaging (according to a proposal by Gollnow [1, 2]), so that the image of the stage micrometer 15 and of the spiral optical micrometer 16 is projected onto a ground glass screen 17 via deflecting prisms and mirrors. That way, the operator's eye accommodation remains unchanged as a whole, when changing over from viewing the image of the spectrogram to that of the spiral optical micrometer.

This was the state of the Abbe Comparator when being subjected to a test. Further improvements are still under discussion and will be materialized in the final design concept. A distortion-free image formation of the line profiles, for instance, is going to be accomplished by using the horizontal deflection of the oscilloscope which is proportional to the motion of the slit. The sweep voltage, being again proportional to the oscillating motion, is picked off the oscillating system by means of an adapter, This voltage may at the same time be utilized for controlling the preamplifier of the oscillating system; that way, the oscillating system is operated in its natural resonance in a feedback circuit. Corresponding experiments with the instrument revealed that the natural resonance vibration is particularly stable and of very little distortion.

In addition, the data recording of the setting values, – still being carried out manually after having taken the readings off the spiral micrometer – is to be automated so that the data are immediately available for the subsequent electronic data processing.

Testing the instrument

The improved version of the Abbe Comparator was mainly tested so far by measuring the spectrograms of magnetic stars. As already mentioned before, modifications of the original Abbe Comparator have been carried out by the Central Institute for Astrophysics first of all, because the very small wavelength differences between right and left-circularly polarized components of the star lines, caused by a magnetic field, can be measured much better. For a normal ZEEMAN triplet, the following relation applies between the wavelength difference $\triangle\lambda$ and the magnetic field strength H:

$\triangle\lambda = \pm$ 4.67$\cdot 10^{-13}$ $\lambda^2 H$,

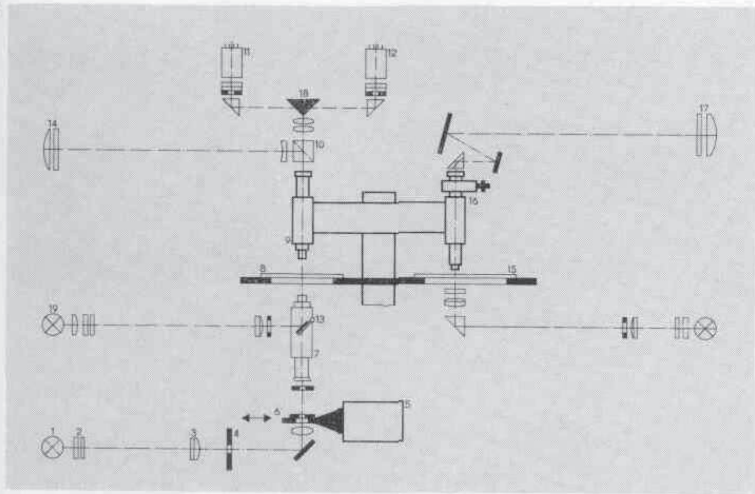
if λ is measured in Å and H in gauss. In a magnetic field of 10^3 gauss (which is representative for magnetic stars) and with a mean wavelength of 4500Å, the wavelength difference amounts to but $\pm 0.95 \cdot 10^{-2}$Å. For the dispersion of the star spectra of 8Å mm^{-1}, frequently used in the Central Institute for Astrophysics, this value corresponds to a displacement of the line centres by 1.2 μm. Even with an anomal ZEEMAN effect, there is hardly a displacement observed which exceeds that of a normal ZEEMAN effect by three times. In order to be in a position to identify this small difference at all when considering the coarse granularity of the sensitive photoplates, the above-mentioned technologic modifications of the Abbe Comparator were initiated. This rendered it possible to include the entire line profile to objectify the setting and to observe at the same time the anticircularly polarized spectra.

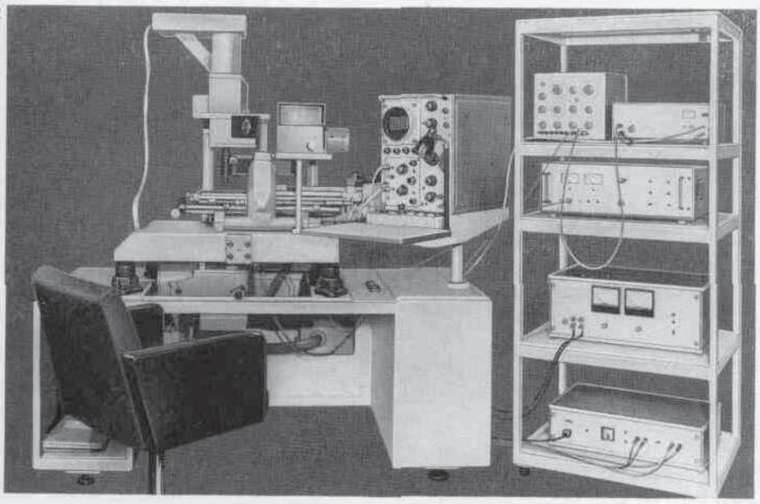
The attainable accuracy depends essentially on the structure of the line profile. Maximum accuracy is achieved with strictly symmetrical lines where, on account of the new measuring method of coincidence between image and mirror image, the whole contour participates in the determination of the line centre so that the plate noise will be less disturbing than with the conventional method. Measurements with asymmetrical contours on the other hand raises many problems.

The object chosen for our tests was the magnetic star 53 Camelopardalis. The lines of this star have widths which are variable with time (0.15 to 0.40 Å); unfortunately their structure is frequently of asymmetrical shape. It suggested itself, however, to employ spectra of 53 Cam as test plates for the new instrument, because ample material obtained by the original Abbe Comparator was at hand for this star for comparison purposes [4]. Fig. 3 shows a cross section of the photograph No. 1551 of 53 Cam which was obtained by ZIENER and LOCHNO with the Coudé spectrograph of the 2-m reflecting teloscope of the Tautenburg Observatory. The reciprocal linear dispersion of the spectrogram is 8Åmm^{-1}. The exploration of the magnetic field necessitated the application of a Babcock analyzer and of a compensator required for compensating the instrumental polarization, both of which had been located in the optical path. What is to be measured is, on one hand, the displacement of the line centres (or cores) between the anticircularly polarized star spectra to ascertain the effective magnetic field strength and, on the other hand, the difference between stellar and comparison lines to identify the star lines and to ascertain the radial velocity.

To compare the inherent measuring accuracy when using the conventional and the improved type of instrument, Table 1 shows the mean error from 4 settings for 5 FeI lines of the stellar spectrum. The width of the oscillation slit employed approximated to that of the line.

The increase of accuracy is quite evident, although the lines are rather broad and partly asymmetric. A far greater gain in accuracy is obtained with the improved instrument when measuring the strong symmetrical comparison lines. The mean setting error of those lines is about 1/10 of that which has been found when measuring with the conventional instrument. In general, the applicability of optionally strong reference lines proved to be of advantage.





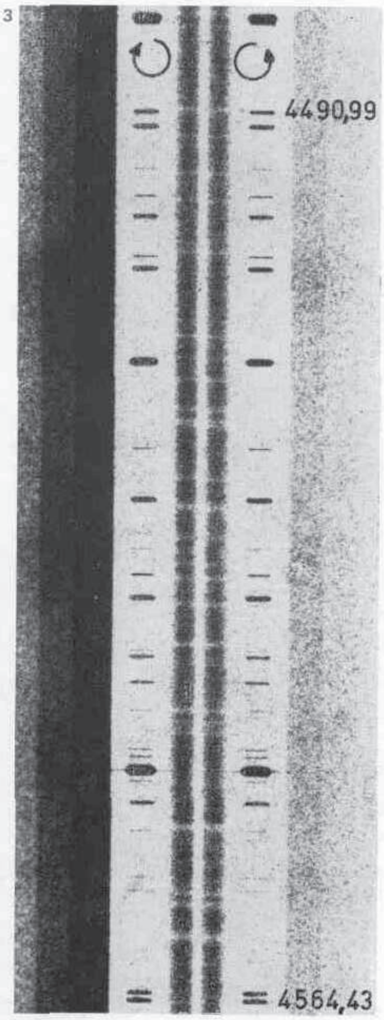


Fig. 1: Diagram of the optical arrangement of the instrument.

Fig. 2: Overall view of the measuring set-up.

Fig. 3: Reproduction of a certain part from the spectrogram of the magnetic star 53 Cam, taken on 18 April 1975 in Tautenburg. Original dispersion 8 Åmm^{-1}.

Fig. 4: Oscilloscope screen image of a line of the 53 Cam magnetic star.
The two upper and the two lower curves display in each case image and mirror image for the anticircularly polarized components.
Coincidence for the main dip is in the upper partial spectrum.

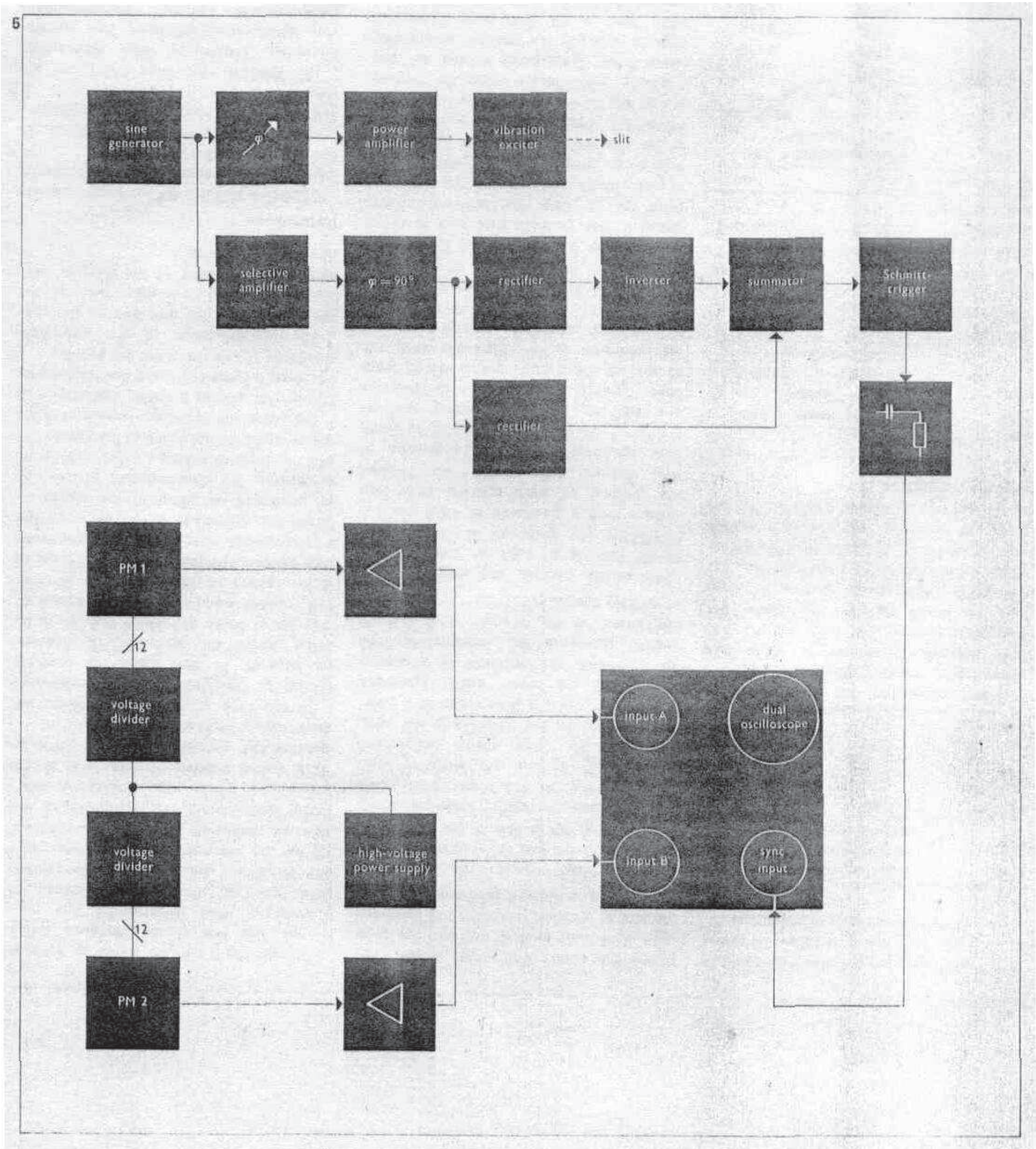


Fig. 5: Block diagram of the electronic arrangement of the instrument.

Table 1

λÅ	mean error [μm] conventional	improved Abbe comparator
4383.547	± 0.82	± 0.28
4384.682	0.40	0.11
4404.752	0.95	0.25
4447.722	0.79	0.27
4494.568	1.04	0.23

When comparing the errors of the ascertained mean effective magnetic field strength, it should be taken into consideration that the form of the line contours is of decisive importance. For the nearly symmetrical profiles of most of the 5 lines of the FeI multiplet No. 152 and of the FeII multiplet No. 37, an increase of accuracy with the new version of instrument is clearly evident. The results are compiled in Table 2.

Table 2

a) Multiplet FeI (152)

λÅ	effective magnetic field strength conventional	(Gauss) improved Abbe comparator
4187.044	5040	3850
4187.802	2820	2080
4250.125	1250	1490
4260.479	2610	2440
4271.159	4380	3360
Average	3220	2640
Mean error[1])	± 670	± 430

b) Multiplet FeII (37)

λÅ	effective magnetic field strength conventional	(Gauss) improved Abbe comparator
4489.185	2170	2590
4515.337	3690	3050
4555.890	2490	3710
4582.835	4010	2430
4629.336	3800	2950
Average	3230	3070
Mean error[1])	± 380	± 260

[1]) of the average value

It is rather difficult, to find a sufficiently great number of symmetrical lines in the spectra of 53 Cam. On account of the presumably spotty atmosphere of the magnetic stars, only lines of one and the same element of identical ionization and excitation state should be allowed to be averaged.

To expound the principle of setting, Fig. 4 displays the face of the oscilloscope tube for a line in the right-hand and left-hand circularly polarized spectrum. Whereas in the upper picture the main dip of the line was made to coincide with its mirror image, image and mirror image do not coincide in the other partial spectrum. To then come to a coincidence in the lower partial spectrum, an additional displacement is necessary which represents the measure for the component of the magnetic field strength in viewing direction.

At certain periods, the magnetic field of 53 Cam is of such an intensity that Preston [5] observed in the spectrogram – with a dispersion of 4.1 Åmm^{-1} – the splitting of some spectral lines into their Zeeman components. The Tautenburg spectrograms with a dispersion of 8 Åmm^{-1} could not be expected to show any splitting. When examining selected lines, however, where the σ components as well as the π components exhibit great displacements in the magnetic field, the oscillograms revealed several extrema. Measuring the distance of those extrema from each other enables even the amount of magnetic field strength to be ascertained.

From 6 lines each in 39 spectrograms it was possible that way to determine for 53 Cam the temporal change of the mean strength of the magnetic field for all phases of the periodic variations of the effective magnetic field. Up to now, PRESTON determined the splitting only during the period of the negative effective magnetic field. When using the conventional Abbe Comparator it was not possible to ascertain the strength of the magnetic field of 53 Cam from Tautenburg spectra. To decide between various models of magnetic stars, the measuring result is of great importance.

The effective magnetic field of ε UMa – a star with absorption lines too wide for conventional measurements – can now also be determined by means of the improved type of Abbe Comparator.

Concluding it can be stated as a result of the first test of the improved Abbe Comparator that, symmetrical line profiles provided, a significant increase of the measuring accuracy has been achieved for the determination of the line position as compared with the conventional Abbe Comparator. The simultaneous representation of the two anticircularly polarized partial spectra on the face of the oscilloscope proved to be of particular advantage in this conjunction.

In the case of asymmetrical lines, the setting of the line position is problematic on account of the measuring principle being based on symmetry. A possible way out of these difficulties (which, however, cannot always be proved physically) is the setting on the line center or other well defined extrema or on other places of a structured line profile, respectively. Since the asymmetry of a line is caused by processes occurring in the stellar atmospheres, the determination of the line position assumes already a definite model on the state and the behaviour of the star.

Generally, the improved version of Abbe Comparator affords a further exploitation of information contained in the spectrograms by measuring the details of the line profiles.

The reconstruction of the instrument was carried out by members of thc precision-mechanical workshop and of the electronics laboratory of the Central Institute for Astrophysics.

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