THE SOLAR MAGNETOGRAPH

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ABSTRACT

A new instrument for measuring and recording weak magnetic fields on the surface of the sun has been developed for use with the 150-foot solar telescope and 75-foot spectrograph of the Hale Solar Laboratory. Principal features include: a superior grating of high resolving power for use in the fifth-order spectrum; an electro-optic analyzer for polarization; a double-slit detector for the longitudinal Zeeman effect; and a self-synchronous system by which the disk of the sun is scanned in a raster of parallel traces, the results as to magnetic intensity and polarity being presented conformally on the screen of a cathode-ray tube and recorded by a camera. The noise level (about 0.1 gauss) is such that fields of the order of 1 gauss can be recorded readily. The method of calibration is described, and the possibility is pointed out of using the instrument, with a slight optical modification, for studying small Doppler shifts in the sun's atmosphere.

INTRODUCTION

The first attempts to apply photoelectric methods to the measurements of the general magnetic field of the sun were by G. E. Hale in collaboration with Dunham, Strong, Stebbins and Whitford, about 1933.[1] Essentially, the method is as follows: A powerful spectrograph, equipped with an analyzer for circular polarization, receives light from a selected part of the sun's image. At the focus of the spectrograph, an exit slit is placed on a wing of a Fraunhofer line chosen for sensitivity to the Zeeman effect. Radiation transmitted by the second slit enters a phototube that is connected to an amplifier having a meter or other means of indicating the intensity of the light. If the longitudinal Zeeman effect now occurs, owing to a magnetic field in the sun's atmosphere, a change of the analyzer from the right-handed to the left-handed condition will produce a slight shift in the position of the line and, because of the sloping profile of the wing, will result in a corresponding change in the indication of the output meter.

For a magnetic field of 1 gauss the line shift to be expected in the green region is only 8×10^{-5} A, even for a line having a Zeeman pattern (0) 3. Owing to the weakness of the sun's field and to the difficulty of eliminating systematic errors, Hale and his collaborators did not achieve positive results with the photoelectric method. Later, however, variations of this method have been employed by G. Thiessen,[2] by K. O. Kiepenheuer,[3] and by H. D. and H. W. Babcock.[4] It is the purpose of this paper to describe the magnetograph in the form in which it is now employed daily for recording weak magnetic fields on the surface of the sun. The instrument is designed primarily for measuring and mapping solar fields of from 1 to 20 gauss; the much stronger fields of sunspots have for several decades been adequately observed on Mount Wilson by visual measurements of the Zeeman effect.

The unique features of the magnetograph include: (1) a large plane grating of unusually high resolving power; (2) an oscillating optical analyzer without moving parts, incorporating an electrically excited retardation plate; (3) a detector for Zeeman dis-

[1] "Annual Report of the Director, Mount Wilson Observatory," *Carnegie Institution of Washington Yearbook*, No. 32 (1933), p. 143.

[2] *Ann. d.'ap.*, **9**, 101, 1946; *Zs. f. Ap.*, **30**, 185, 1952.

[3] *Ap. J.*, **117**, 447, 1953.

[4] *Pub. A.S.P.*, **64**, 282, 1952.

placements employing not one but two exit slits and two photomultiplier tubes connected to a difference amplifier, as well as other means to avoid systematic errors; and (4) a system for automatically scanning the sun's disk, with conformal recording by means of a cathode-ray tube and a camera.

Observations with this apparatus have already shown that the scanning technique is practically indispensable because of the complex and detailed nature of the changing magnetic effects to be observed on the sun. It is apparent that considerable new and significant information should be obtainable by continuing such observations throughout the solar cycle.

OPTICAL EQUIPMENT

The telescope of the Hale Solar Laboratory[5] in Pasadena has a coelostat and a second flat mirror followed by a compact off-axis Cassegrain reflecting system with a focal length of 150 feet. The 17-inch image of the sun is formed in a convenient basement laboratory in which is located the head of the spectrograph. The latter is a vertical Littrow instrument in a deep pit. A large plane grating is used in the fifth order, with a lens of 75-foot

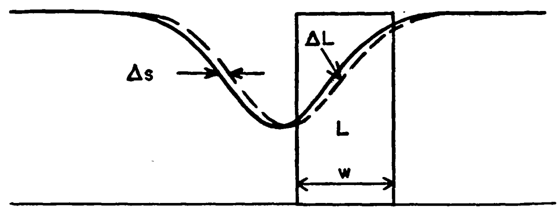

FIG. 1.—Slit on one wing of line transmits varying light to phototube as line shifts in response to reversal of circular analyzer when longitudinal Zeeman effect is present.

focus. This yields a dispersion of 11 mm/A. The grating, ruled at the Mount Wilson Observatory,[6] has a ruled area of $5\frac{1}{4} \times 8$ inches, with 600 grooves per millimeter. It was designed to throw as much of the light as possible into the fifth order, where the available resolving power, measured photographically, is 600,000. This figure was obtained by measurements on close groups of the very sharp absorption lines artificially produced in the solar spectrum by placing in front of the slit a cold tube of iodine vapor. This resolving power, hitherto unavailable without an interferometer, is sufficient to resolve sharp lines in the green region of the spectrum only 0.009 A apart; it thereby ensures that the spectrograph will render nearly perfect profiles of solar lines having half-widths of about 0.1 A. Because of the intrinsic width of Fraunhofer lines, a further increase of resolving power would accomplish very little; an appreciable decrease, on the other hand, would impair the ability of the instrument to measure weak fields.

The reason for this dependence on resolving power may be seen by reference to Figure 1, in which an exit slit of width w is placed on one wing of the line profile. The line now shifts a distance Δs (small compared to its half-width) in response to a reversal of the polarizing analyzer. The resulting change in light, ΔL, is the "signal" to be measured by the phototube and amplifier in the presence of the much larger constant light L under the wing of the line. The small signal has necessarily to be measured in the presence of noise, which in this case, where the light-level is moderate, is almost entirely due to shot effect in the photocurrent and is proportional to $\sqrt{L}$. The signal-to-noise ratio, which sets a lower limit to the field than can be measured, is then $\Delta L/\sqrt{L}$. Now if the optical resolution is inferior, the line profile becomes broader and shallower (usually also asymmetrical), so that if ΔL is to be accepted without loss, the slit width, w, must be increased. But

[5] "Annual Report of the Director, Mount Wilson Observatory," *Carnegie Institution of Washington Year Book*, No. 25 (1926), p. 135.

[6] H. D. Babcock and H. W. Babcock, *J. Opt. Soc. Amer.*, **41**, 776, 1951.

this at once increases the constant component of the light and the noise, with a consequent reduction in the signal-to-noise ratio. It is evident that high resolution is needed and that the width and position of the exit slit, as well as the width of the entrance slit, should be so chosen that $\Delta L/\sqrt{L}$ is a maximum. Also, the optical system should be as efficient as possible if weak fields are to be measured with a short instrumental time constant, as is desirable when scanning the sun's image.

Calculation shows that with a slit length of 2 cm on the 40-cm image of the sun, the light reaching the photocathode will be of the order of 10^{-7} lumens, whereas the dark current of a typical photomultiplier tube is equivalent to about 10^{-9} lumens. Shot effect is therefore the only important source of noise, and nothing is to be gained by refrigerating the tube. Quantum efficiency of the photocathode is important, however, and selection of tubes with this characteristic in mind is worth while.

ANALYZER

The analyzer for circular polarization in front of the entrance slit is required to alternate its sign at a fixed frequency. While a rotating retardation plate in combination with a fixed plane polarizer will fulfil this requirement, it has been found practically impossible to eliminate reliably and completely all traces of false modulation of the light when moving optical elements are used. Trouble may arise from flickering secondary reflections from the moving surfaces, from small imperfections, or from mechanical vibration. A satisfactory solution to the problem is the use of an electro-optic retardation plate in the form of a Z-cut crystal of ammonium dihydrogen phosphate (ADP).[7] Such plates, of good optical quality and with transparent electrodes affixed, may be obtained commercially.[8] Upon the application of an alternating voltage (about 9 kv), the retardation oscillates between plus and minus a quarter-wave at the applied frequency—in this case 120 cycles/sec. A Nicol prism follows the ADP plate, the two fixed elements constituting an oscillating circular analyzer.

DETECTOR

The arrangement of a single slit and phototube as in Figure 1 is subject to a severe drawback, in that any slight false modulation of the whole spectrum at the signal frequency is a source of systematic error. It produces a spurious signal that may be confused with the true Zeeman effect. And, with a tower telescope using oblique reflections, some slight false modulation is almost unavoidable because these reflections result in a slight general elliptical polarization of all the light. This effect varies with the hour angle of the sun, so that compensation of it by a tilted-glass polarizing plate between the retardation plate and the Nicol is hardly practicable.

The detector shown in Figure 2, having two slits and two phototubes, has several advantages. The two slits are placed symmetrically on opposite wings of the line and the corresponding phototubes are connected to a difference amplifier such that their response to a shift in position of the line is additive, but a small change of intensity of the whole spectrum has no effect. Since the useful light is doubled by this method, the signal-to-noise ratio is multiplied by $\sqrt{2}$, but, more important, the detector rejects the effect of elliptical polarization by the telescope mirrors, and the system operates without systematic error.

The width of each exit slit is about 0.56 mm, and they are separated by 0.45 mm. The solar line ordinarily used is *Fe* I λ 5250.218, (0) 3, which has a central intensity of 0.40 and a half-width of about 0.1 A or 1.1 mm. As a check on the performance of the instrument, it is convenient to make control observations using the magnetically unaffected line *Fe* I λ 5123.723 (0) 0.

[7] B. H. Billings, *J. Opt. Soc. Amer.*, **39**, 797, 1949.

[8] Baird Associates, Inc., 33 University Road, Cambridge, Mass.

AMPLIFIER

The signal frequency chosen for this system is 120 cycles/sec. Obviously, the amplifier should have narrow-band characteristics in order to reject noise in so far as possible. The amplifier, phase-sensitive demodulator, and filter circuits are shown schematically in Figure 3. Essentially, these elements are similar to those described by Kiepenheuer,[3] except that we have added a band-pass wave filter in addition to using a peaked amplifier

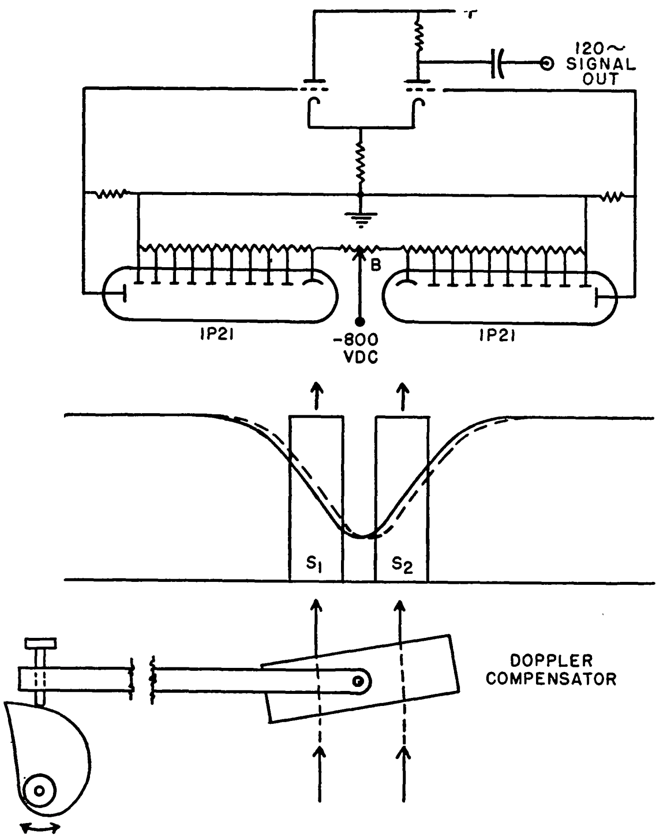

FIG. 2.—Schematic diagram of detector, showing Doppler compensator at bottom, line profile on the two exit slits, photomultipliers, and difference amplifier. This detector rejects the effect of any slight general intensity modulation of the spectrum and is insensitive to a small decentering of the line or to a slight imbalance of phototube sensitivity.

and that a cathode-follower is used to provide a low-impedance source for the demodulator.

The peaked amplifier of Figure 3 is a commercial 2-stage plug-in unit having a 120-cycle twin-T filter in its feedback loop. The driver amplifier likewise is a plug-in unit of two stages with cathode-follower output.[9] It has been found that the amplifier is nearly linear for weak fields up to about 20 gauss but that it saturates above this level. In order to provide for recording a greater range of signal intensity, provision is being made for optional use of a logarithmic attenuator.

The phase of the vibrator-type demodulator must be adjusted with respect to the phase of the electro-optic retardation plate. These units are driven by the 60-cycle line through separate frequency doublers; the vibrator is provided with a phase shifter. By rotating the retardation plate 90° in azimuth, its effective electrical phase may be reversed. This provides a useful check on the response to weak fields.

[9] Kalbfell Laboratories, Inc., P.O. Box 1578, San Diego, Calif.

The two parallel filter circuits with balanced cathode-follower output provide a choice of time constants of 1, 3, and 10 seconds. The d.c. potential appearing across the output terminals is a measure of the polarity and amplitude of the field being investigated. It has been found that, with a time constant of 10 seconds, the root-mean-square amplitude of the noise is equivalent to about 0.1 gauss. With this time constant, a scanning rate of about 3 minutes for the sun's diameter is sufficiently slow to permit recording of all prominent magnetic features. With a longer time constant, the noise is, of course, further reduced, but a slower scanning rate is desirable.

Provided that the instrument is totally free of systematic errors, the limiting field that can be detected is set by the signal-to-noise ratio, and this is a fundamental limit that can be lowered only by presenting a brighter spectrum to the detector, by using photocathodes of higher quantum efficiency, or by working on more than one spectrum line at

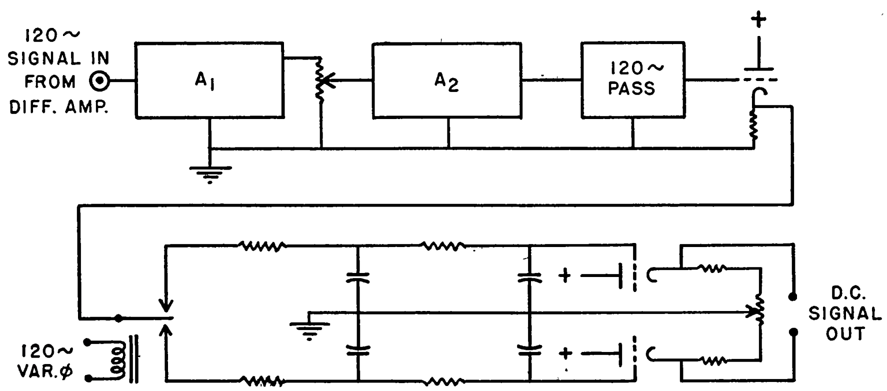

FIG. 3.—Signal amplifier and filter circuits. A_1, two-stage, 120 cycle/sec peaked amplifier (Kalbfell model 107); A_2 two-stage driver amplifier (model 106A). The phase of the demodulator is adjusted with respect to the phase of the analyzer. Parallel resistors in the filter circuits are switched to provide time constants of 1, 3, and 10 seconds.

a time. A new detector, now under consideration, is designed to exploit all three of these possibilities, thereby improving the signal-to-noise ratio by a factor of at least 2.

SCANNING SYSTEM

The foregoing parts of the instrument constitute a "gaussmeter" capable of indicating the polarity and intensity of the magnetic field at any chosen point on the disk of the sun. In order to record the available data in a convenient manner, a scanning system is required which will cause the image to move across the slit in a pattern or raster of parallel traces (usually about 25 in number). This controlled motion of the image is accomplished by two micrometer drives which move the second flat mirror that directs light into the telescope. A cathode-ray tube is well adapted to display the signal as a function of position on the disk. Potentials for the deflection plates of the tube are provided by direct-coupled precision potentiometers. The electron spot on the screen of the cathode-ray tube is thus made to move in a manner conforming to the effective motion of the spectrograph slit on the sun's image. By superposition of the gaussmeter signal voltage on the vertical deflection plates, in a manner to be described, the electron spot is divided into two parts: a fiducial spot that produces a straight trace, and a signal spot that fluctuates in position above or below the fiducial line. A camera, making a time exposure, records the results as in Figure 5.

In scanning the image, a minor complication enters in the form of Doppler effect due to the sun's axial rotation. In passing from the east to the west limb, the velocity difference of 4 km/sec is sufficient to shift the line about 0.07 A, which is comparable to its half-width. Compensation for the Doppler shift is readily accomplished by the device shown in Figure 2. A plane-parallel plate of glass is mounted on a shaft a short distance in front of the exit slits of the spectrograph. By means of a lever and cam, the glass plate is tilted during scanning in such a way as to keep the line centered between the two exit slits. The range of tilt of the half-inch-thick plate is about 9°. Tests have shown that Zeeman measurements are not extremely sensitive to this adjustment and that the equatorial acceleration of the sun may be neglected. Therefore, the required tilt varies linearly with distance (x) from the sun's axis and is independent of heliographic latitude.

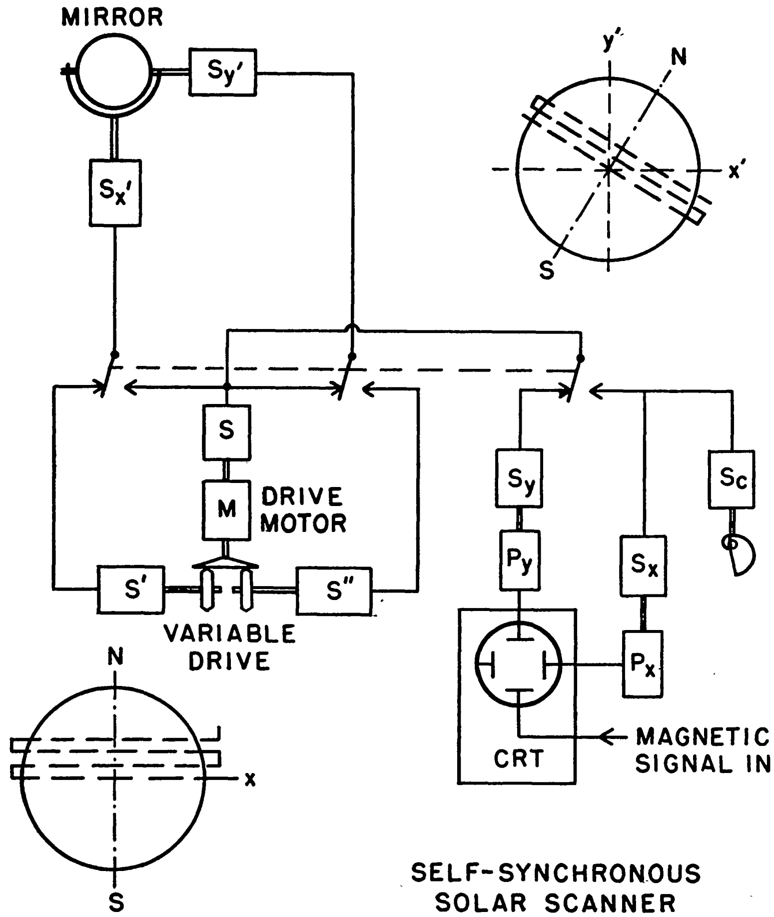

FIG. 4.—Schematic diagram of the scanning system, using synchros. By driving the flat mirror in two co-ordinates, the traces are made perpendicular to the sun's axis. Automatic switching circuits, not shown, govern the scanning of the entire disk.

The scanning operation requires a coupling of the motions of the second flat mirror in the dome with the deflection potentiometers of the cathode-ray tube and with the Doppler compensating cam in the laboratory. It was decided that the coupling of these motions with the desired degree of flexibility and ease of adjustment would be best accomplished by the use of a self-synchronous system employing synchros (Selsyns) of the type ordinarily used in pairs as torque transmitters. A single motor that can be operated over a wide range of speed drives a synchro that serves as a transmitter. Several other synchros connected in parallel to the transmitter may be driven together at the same speed, and any one of the synchro repeaters may have its direction of rotation reversed by the interchange of any two of its three field connections. A system using, altogether, eight synchros with the necessary controls and switching circuits was developed and put into operation early in 1953. The synchro system is shown schematically in Figure 4.

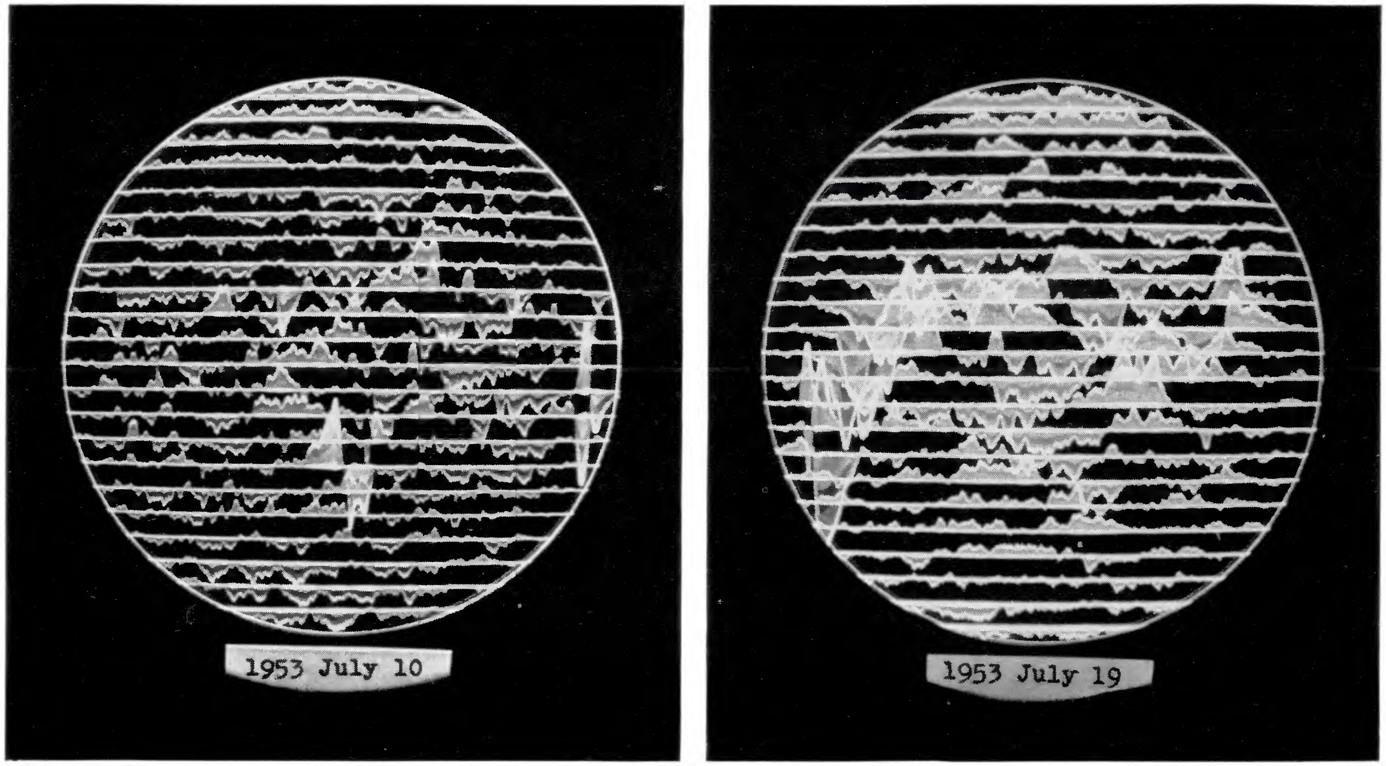

FIG. 5.—Magnetograms of the sun. The axis is vertical, with north at the top. East is at the right. For each trace there is a straight fiducial line. A deflection equal to the interval between traces indicates that $H \cos \gamma$ is about 1 gauss at the center of the disk, 2 gauss at the limb. For upward deflections $H \cos \gamma$ is toward the observer. Evidence for the sun's general magnetic field is shown by the opposite deflections on the traces nearest the north and south poles. The only visible sunspot group on July 19 was at 54° W., 8° S. The length of the slit (0.04 of the sun's diameter) is approximately equal to the interval between traces.

Approximately 300 turns of the primary synchro are required for one traverse of the sun's image. By varying the speed of the driving motor, the time required for one traverse may be varied from about 30 seconds (for making adjustments) to 10 minutes. At the normal speed of about 3 minutes per trace, the complete disk is scanned in about 60 minutes. Once the scan has been started, the entire operation is carried out automatically. Switching from one trace to the next, with appropriate time delay and overrun, is initiated by a monitoring phototube which detects the passage of the sun's limb from the slit. The interval between horizontal traces (Δy) is controlled by a notched disk that is coupled to the y-potentiometer and its driving synchro.

For ready interpretation of the resulting magnetograms, it is highly desirable that the parallel traces should all be perpendicular to the sun's axis, which we take as the y-coordinate, or vertical on the magnetograms. The traces all run in the x-direction, so that,

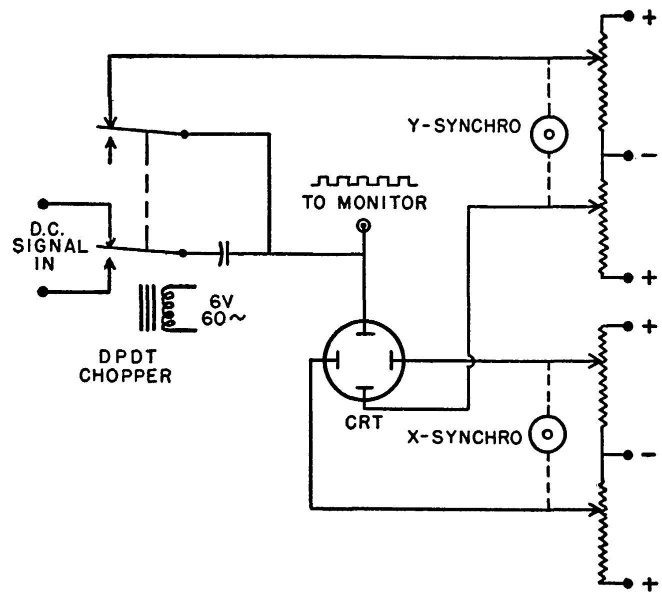

FIG. 6.—Deflection circuits. The d.c. signal indicating the polarity and amplitude of the magnetic field is chopped at 60 cycles/sec to produce a square wave that is superimposed on the y-deflection voltage of the potentiometer.

in making each trace, only the x-potentiometer is rotated by its synchro, the y-synchro being disconnected. The motion of the sun's image, however, requires simultaneous rotation of the second flat mirror about its two axes (x' and y') at different rates. Furthermore, owing to the seasonal changes in the position angle of the sun's axis and the changes in the position of the coelostat caused by the varying declination, the ratio of the two mirror-drive rates must be adjusted almost daily. The system provides, therefore, for driving the x'-motion of the second flat at the primary-synchro rate while making an x-trace, but at the same time for driving the y'-motion at a predetermined slower rate, this y'-rate being developed by an additional transmitting synchro that is driven through a variable-ratio friction transmission by the primary-drive motor. At the end of each x-trace, relays interchange the connections to the x'- and y'-synchros, thus producing a stepwise y-motion of the image. But since, in general, the directions of motion of the image produced by rotation of the second flat about its two axes are not orthogonal, a second variable transmission and transmitter synchro have to be provided for producing the x'-component of motion in making the y-steps.

A standard 5-inch laboratory oscillograph (DuMont type 304A) with its screen masked down to 4 inches is used with a 35-mm camera for recording. For maximum stability, the internal d.c. amplifiers are not used, but push-pull deflection potentials are applied directly to the plates of the cathode-ray tube from precision multiturn potentiometers connected to well-regulated d.c. power supplies, as indicated in Figure 6. This figure also shows how, by means of a DPDT chopper, the d.c. magnetic signal from the gaussmeter is converted to a 60-cycle/sec square-wave whose base is clamped to the y-deflection potential established by the y-synchro. With normal scanning in the x-co-ordinate, the time-collapsed square-wave appears as two slowly moving dots, one tracing a straight fiducial line (y = const.) and the other fluctuating in position to indicate the magnetic polarity and field intensity with respect to this line.

In order to improve the visibility of the records, intensity modulation of the cathode-ray tube is provided so that the recording spot is brightened in proportion to signal intensity, regardless of polarity. This is accomplished through a balanced modulator

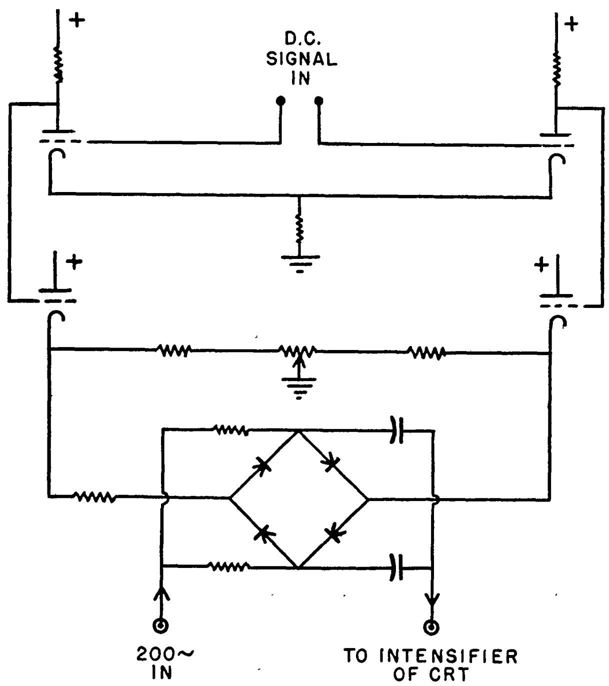

FIG. 7.—Balanced modulator for intensifying record trace in proportion to signal amplitude

(Fig. 7), by which the amplitude of the magnetic signal governs the amplitude of a sine wave (of frequency incommensurate with 60 cycles/sec) that is applied to the control grid of the cathode-ray tube.

Figure 8 is a general view of the equipment in the solar laboratory.

OPERATION

Adjustment of the scanning system involves the following steps:

1. The east-west direction of drift on the image screen (Fig. 8) is established, and the azimuth of the screen is corrected for the position angle of the sun's axis, so that guide lines on the screen are perpendicular to the y-axis.

2. The friction rollers controlling the x'- and y'-drive rates of the second flat are adjusted so that the two motions of the image on the screen occur in the x- and y-directions, respectively.

3. The number of turns (to the nearest 0.01 turn) of the x and y ten-turn potentiome-

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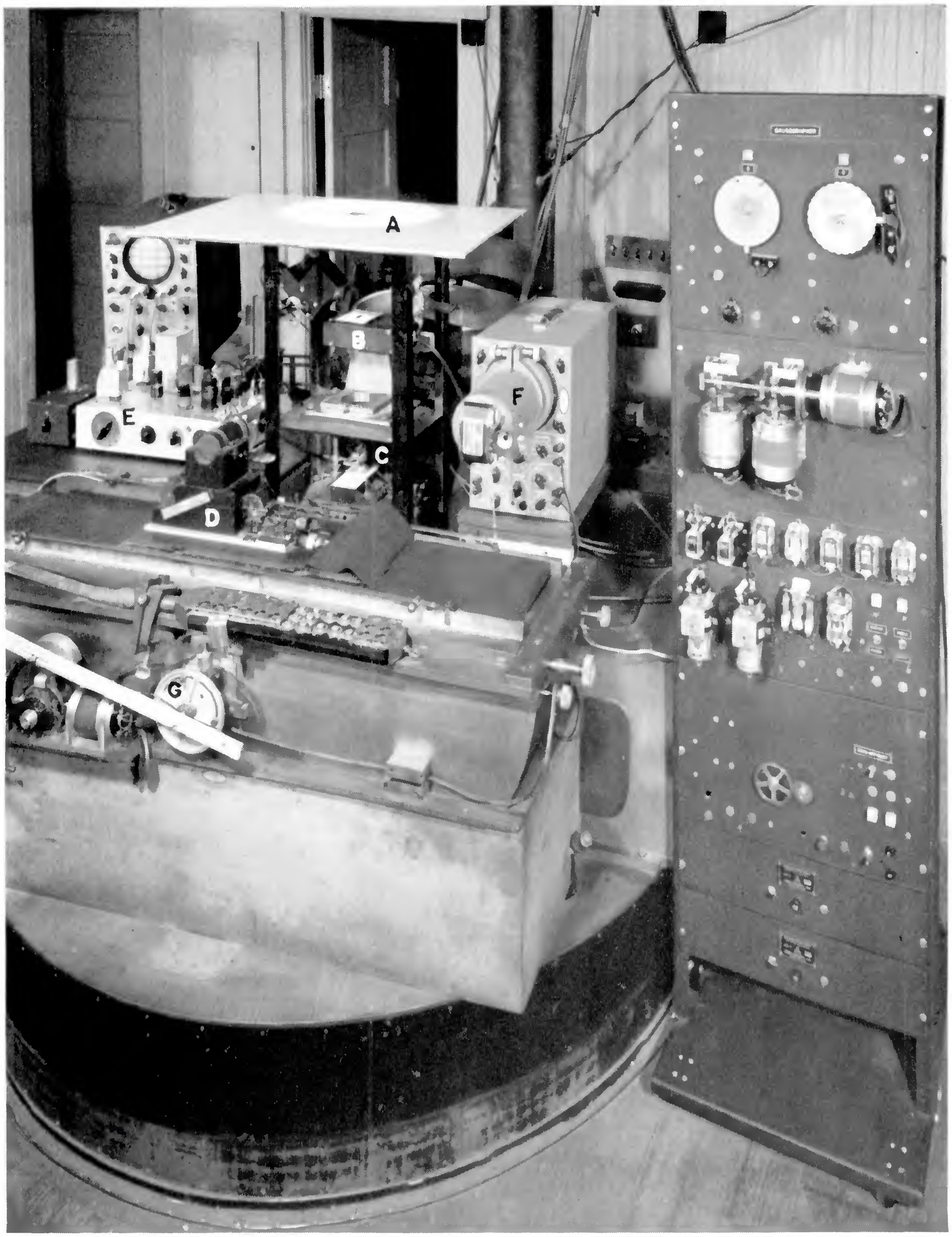

FIG. 8.—The head of the spectrograph, showing (*A*) image screen, (*B*) electro-optic retardation plate, (*C*) Nicol prism above slit, (*D*) detector, (*E*) amplifier, (*F*) recording oscilloscope with camera, and (*G*) Doppler compensator. At right is rack holding scanning controls and switching circuits. The grating and collimator are at the bottom of the 75-foot pit.

ters is determined that corresponds to motion of the image through its own diameter, in each co-ordinate.

4. Supply voltages and potentiometer settings are so adjusted that the visible limits of spot traverse on the screen of the cathode-ray tube correspond to the appropriate position of the sun's image with respect to the slit.

5. With the axis of the sun ($x = 0$) on the slit, the Doppler compensating cam is placed at mid-range and, by means of a micrometer adjustment, the exit slits are placed symmetrically on the spectrum line. This adjustment requires further elaboration.

A circular polarizer, consisting of a Polaroid sheet followed by a mica quarter-wave plate is so mounted that it may be swung temporarily into the light-beam just above the oscillating circular analyzer (B, Fig. 8). With this in place, the intensity of the transmitted light varies sinusoidally between zero and a maximum at a frequency of 120 cycles/sec, i.e., the light is 100 per cent modulated. This is a condition in which the detector is exceedingly sensitive to inequality of illumination at the two exit slits, and it thereby facilitates the following adjustments.

a) By tilting the glass compensating plate, the two exit slits are exposed to the modulated light of the continuous spectrum, and the relative sensitivity of the two photomultipliers is equalized by adjustment of the applied voltages using potentiometer B (Fig. 2).

b) Still using the modulated spectrum, the chosen line is centered between the slits with high precision. Only when it is precisely centered will the output signal of the gaussmeter be zero. If the circular polarizer is then removed from the beam, the instrument is ready to measure the Zeeman effect.

CALIBRATION

The circular polarizer offers a means of calibrating the sensitivity of the gaussmeter. With the modulated spectrum, a slight controlled displacement of the line from its centered position results in an artificial signal whose equivalent in magnetic intensity can be evaluated.

Let the artificial displacement of the line be $\delta\lambda_c$ and let the actual transmission of the circular polarizer be f for circularly polarized light of its own sign. Then the amplitude of the difference signal developed by the two phototubes is proportional to $f\delta\lambda_c$. For the longitudinal Zeeman effect, without the circular polarizer, the amplitude of displacement of the line is

$$\delta\lambda_z = \pm 4.67 \times 10^{-5} \lambda^2 Hz ;$$

and this results in a difference signal proportional to $2\,\delta\lambda_z$. For equal signals we then have

$$\delta\lambda_c = \frac{2}{f}\,\delta\lambda_z , \qquad \text{or} \qquad \frac{H}{\delta\lambda_c} = 39\, f/z \text{ gauss/milliangstrom} .$$

The factor f is readily determined and is about 0.3, while, for the line λ 5250.218, $z = 3$. Therefore, approximately, a shift of the line of 0.001 A or 0.011 mm, by tilting the plane-parallel plate while using the circular polarizer, would produce an artificial signal equivalent to 4 gauss. In observing, calibration is customarily done by repeatedly inserting and retracting a standard 5-gauss shim under the end of the lever that tilts the Doppler compensating plate; this operation, carried out with the image stationary, results in a square-wave pattern that is recorded in the usual manner.

With the circular polarizer in the beam, the instrument can be used for measuring radial velocities at various points on the sun. The signal introduced by the standard shim would in this case be equivalent to a velocity of 70 m/sec. In this mode of operation the instrument is exceedingly sensitive to slight line displacements due to turbulence both in the atmosphere of the sun (through the Doppler effect) and in the spectrograph (through refraction). This leads to a certain amount of drift and irregularity in the calibration records, but it may be overcome by using a larger artificial line displacement for calibrating and by switching to correspondingly smaller load resistors for the photomultiplier tubes. It should be emphasized that this extreme sensitivity to small displacements at low random frequencies does not occur in the course of normal Zeeman measurements, as then the spectrum is essentially unmodulated. In this condition there does remain a very great sensitivity of the spectrograph to vibration at the signal frequency, and every precaution should be taken to see that this does not occur.

INTERPRETATION OF MAGNETOGRAMS

When the Zeeman effect is observed in the manner described here, the displacements measured are proportional to $H \cos \gamma$, the component of the field in the line of sight.[10] Particularly near the limb, the projection factor is unfavorable. Furthermore, the gaussmeter really measures the product of magnetic intensity and light-intensity, so that deflections near the limb are further reduced by limb darkening. Also, when atmospheric transparency is low, the sensitivity suffers. On typical records a deflection equal to the interval between traces is equivalent to 1 gauss near the center of the disk and to 2 gauss at the limb. The root-mean-square noise is about 0.1 gauss.

The magnetic polarity is readily checked on sunspots. In the solar cycle now approaching a minimum, leading spots in the northern hemisphere have negative polarity (the magnetic vector is away from the observer) and the phasing of the instrument has been set so that such deflections are downward.

Some preliminary results obtained with the magnetograph have already been reported.[4] Evidence confirming the existence of a weak general field of the sun, in high latitudes only, was found with this apparatus by Harold D. Babcock in August, 1952. Subsequent observations on nearly every clear day show this persistent field in heliographic latitudes above about $\pm 65°$, with positive polarity in the north, negative in the south. This is opposite to the magnetic polarity of the earth and opposite to the polarity of the leading sunspots in the respective hemispheres in the cycle now drawing to a close. It is also opposite to the polarity of the sun's general field reported by G. E. Hale[11] for the year 1912, which refers to nearly the same phase in the sunspot cycle. The polar fields of the sun are frequently observed without scanning, but with the image fixed with respect to the slit; this permits the use of a longer instrumental time constant. The effective intensity of the field is found to vary from point to point on the surface. The signal reverses polarity when the phasing of the analyzer is reversed by changing the azimuth of the ADP crystal 90°, and it disappears when the exciting voltage is removed from the crystal. These and other tests confirm the reality of the weak fields. The component of these high-latitude fields in the line of sight is of the order of 1 gauss; if allowance is made for the obliquity of the lines of force, the actual intensity may be 2 gauss or more. The lower limit in latitude of these polar fields is variable and rather indefinite; on a few occasions they could be found in one hemisphere only. As yet we have no evidence for systematic changes or for obliquity between the sun's magnetic axis and the axis of rotation.

In heliographic latitudes below $\pm 65°$ a great deal of rather transient solar magnetic activity is found, as previously reported. Extensive areas of weak magnetic intensity, varying somewhat from day to day and of limited duration, are not uncommon. It appears quite plausible that chance distribution of such magnetic areas may have been the source of the difficulty of earlier observers in obtaining consistent results. Further reports on the rather voluminous data regarding magnetic effects on the sun's surface will be postponed for subsequent discussion.

[10] F. H. Seares, *Ap. J.*, **38**, 99, 1913.

[11] G. E. Hale, *Ap. J.*, **38**, 27, 1913.