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# MAGNETIC-FIELD MEASUREMENTS FOR THE LEWIS RESEARCH CENTER CYCLOTRON

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## SUMMARY

The magnetic field of the Lewis Research Center cyclotron has been mapped using a Hall-effect, magnetic-field transducer. Main-field Fourier coefficients were determined on a polar mesh of 40 radii for each of seven levels of main-field coil current. Incremental fields for eight sets of trim coils and two sets of harmonic coils were also determined at four of these main-field levels. A stored-program, digital computer was used to perform the measurements. The process was entirely automatic: all data-taking and data-reduction activities were specified by the computer programs.

A new method for temperature compensation of a Hall element was used. This method required no temperature control of the element. Measurements of the Hall voltage and Hall-element resistance were sufficient to correct for temperature effects.

## INTRODUCTION

The magnet of the modified Lewis Research Center cyclotron has a three-sector, azimuthally varying field like that of the Michigan State University (MSU) cyclotron described in reference 1. The only differences between the magnets of the two cyclotrons are differences in the winding of the main-field coils and in the thickness of the yoke pieces. At equal levels of excitation, the fields produced by the two cyclotrons are much the same. The purpose of the measurements described herein is to determine the fields produced by the Lewis Research Center cyclotron with sufficient precision for use in calculations of particle orbits and operating parameters.

Figure 1 is a contour plot of the cyclotron main field at a coil current of 380 amperes. The large azimuthal (theta) variations in the field are due to the "hill pieces," large pieces of magnet iron used to produce a strong third harmonic (azimuthally) in the field. Provisions have been included to allow adjustments of this main field. Eight pairs of trim coils are used to adjust the radial variation of the average field by a few percent either way from that due to the main-field coils alone. These trim coils are located in the face of the magnet poles. They are wound concentric with the field center, each coil spanning about 7.5 centimeters (3 in.) in radius. Two sets of harmonic coils are located in the valleys between the hill pieces. These are used to make very minor adjustments in the first harmonic of the field. (The first harmonic is nominally zero.)

In reference 2, it is shown that cyclotron-magnet currents can be precalculated with sufficient precision to provide good particle beams without the need for "knob-twiddling" of prior art. In the procedure described there, a set of ideal fields is determined by orbit calculations for each of the measured main-field levels and for each of the desired particles (as specified by a charge/mass ratio). Then a least-squares fitting is used to calculate coil currents that will most nearly produce these ideal fields. For intermediate field levels, at which measurements have not been made, coil currents can be obtained by a double, three-point Lagrangian interpolation of the measured-field values. The data presented herein are arranged much like those of the MSU cyclotron as given in reference 1 so that these calculational methods can be used with the Lewis cyclotron.

Field measurements were made at seven levels of main-field excitation, with trim coils and harmonic coils turned off. A polar-coordinate grid was used. Then, at four of these same levels of excitation, the incremental fields of each of the eight pairs of trim coils and two sets of harmonic coils were measured by exciting these auxiliary fields, one at a time.

The measurement procedures used in this work were entirely automatic: all data taking and data reduction were specified by computer programs. Included in these procedures were regular checks on power-supply currents and field stability, probe positioning, and Hall-probe behavior. The raw and reduced data were stored on magnetic tape; and the reduced data were also printed out, on line, as they became available.

## APPARATUS

A stored-program digital computer was used to control all data-taking operations and to make all data-reduction calculations. Field measurements were made with a Hall-effect transducer (Hall probe) mounted on the end of a long boom that could be inserted into the magnetic field of the cyclotron. This boom was part of a large X-Y positioning apparatus capable of scanning over the entire region of interest. Voltages from the Hall probe were measured with an integrating, digital voltmeter. A separately determined calibration of the Hall probe (discussed in the following section) was used to convert these voltages into the corresponding magnetic-field strength at each field point. This calibration included a correction to compensate for variations in the probe temperature. Current-regulated power supplies were used to drive all the cyclotron magnet coils. Computer control of the X-Y positioning apparatus, the digital voltmeter, and the magnet-current power supplies was through a CAMAC modular interface system.

## Computer

A PDP-15/30 computer, manufactured by Digital Equipment Corporation (DEC), was used throughout this work. The main features of this machine are:

(1) 800-Nanosecond cycle time

(2) 16 384-Word memory (18-bit words)

(3) Three "DEC-tape" magnetic tape units

(4) Two teleprinters, capable of 10 characters per second

(5) Automatic, priority-interrupt facility

(6) Extended arithmetic element

DEC also supplies with the PDP-15 a comprehensive software package that includes a text editor, a macro assembler, a FORTRAN-IV compiler, and an extensive library of input-output and mathematical subroutines. A number of additional subroutines for the library have been developed at this laboratory. Some of these were written in assembler language and some in FORTRAN, but all are FORTRAN-callable. This extensive software support system makes it relatively easy to write FORTRAN-language programs for jobs such as the field measurements described herein.

The most important addition to our computer is a CAMAC instrumentation system (cf. ref. 3). CAMAC provides a means of interfacing a variety of devices (modules) to the input-output bus of a computer through a single controller. (A full description of the CAMAC controller designed at this laboratory is given in ref. 4.) The CAMAC system features bins that will accept up to 24 modules each. A data bus at the rear of each bin provides for control and data transfers between each module and the computer via the controller. CAMAC specifications provide for a single nonprietary design with both mechanical and electrical standards. As a result, a variety of module types are offered by suppliers on a competitive basis.

## X-Y Positioning

The positioning "table" used in this work was obtained on loan from the U.S. Naval Research Laboratory (NRL). It is described in reference 5. This mechanism consists of two movable carriages, one mounted on the other, capable of performing independent and simultaneous motions in the "X" and "Y" directions. The range of travel of each carriage is 206 centimeters (81 in.). Lead screws are used to convert the rotary motion of drive motors to linear motion of the carriages. Digital shaft encoders, connected through gears to the lead screws, provide an absolute readout of the carriage positions.

Originally, two motors were provided to drive each carriage. A torque motor was used for the major travel, and a stepping motor provided for final positioning; one step corresponding to a linear carriage motion of 0.00254 centimeter (0.001 in.). In the present work, however, only the stepping motors were used. Ultimately, the Lewis cyclotron facility will have a number of stepping motors to drive potentiometers that supply control voltages to power supplies. The stepping-motor system and computer programs supporting it were already available for the magnet measurements.

The stepping-motor controller designed and built at this laboratory operates through a pair of 16-bit, CAMAC driver modules. These 16 bits specify motor direction, motor bank, and which motors in a bank of eight are to be driven one step. The system has a capacity of 16 banks for a total of 128 stepping motors. A computer program for this system provides for running any combination of motors and motor directions, all simultaneously. It uses a countdown table so that each motor can be stopped when it has run its required number of steps. With this system, it is possible to run all motors at once and yet leave time to perform other calculations.

Since a computer was being used to control the X-Y table, the only parts of NRL's automatic data-logging system needed were the encoder readouts. Digital position signals from these were fed to the computer through a 24-bit, CAMAC input-gate module. The procedure followed for moving the X-Y table to a new position was

(1) read the current position from the encoders, (2) calculate the number of motor steps to the new position, (3) run motors the required number of steps, and (4) read the encoders again to make sure the new position is the desired one. This prodecure was repeated if necessary. It was possible to run the stepping motors at a rate of 150 steps per second without appreciable "slipping." This corresponds to a carriage speed of approximately 2.5 centimeters (1 in.) in 7 seconds.

Tests revealed a small amount of backlash in the X-Y table - enough that the true table position for a point approached from below was about 0.01 centimeter (0.004 in.) short of the same point approached from above. But it was found that this backlash could be eliminated by making all position changes in two steps - the first one to a position short of the desired coordinate by 0.1 centimeter (0.025 in.). That way, the final approach to all field points was from the same direction no matter where the previous point had been. An estimate of the reproducibility actually achieved was obtained from an analysis of some of the field data. In repeated scans at the same radius and field, fluctuations in position show up as fluctuations in the measured field. In those regions between the field hills and valleys, the field gradients are of the order of 4 teslas per meter (1 kG/in.) so that fluctuations in position are greatly amplified. Analysis of data in these regions showed that the rms error in azimuth was only about 0.0025 centimeter (0.001 in.).

The X-Y table was carefully aligned so that its plane of motion was horizontal. No other alignments were needed. The plan was to measure the field center coordinates (see the following section) and the angle between the X-axis and a reference surface on the cyclotron vacuum box. These data would then be included in the conversion from the radius and angle field-point coordinates to corresponding X-Y table coordinates. In the course of measuring the X-axis angle, it was discovered that the X and Y motions were slightly nonorthogonal: the angle between the two axes was measured to be 2 minutes of arc different than $90^{\circ}$. This small error was corrected by adding a tiny fraction of the Y-coordinate to the X-coordinate calculated for each field point.

## Digital Voltmeter

A Vidar Corporation, model 521B, integrating digital voltmeter was used to make all voltage measurements. The main features of this voltmeter are

(1) ±10 mV to ±1000 V full scale, selectable in six decades

(2) 0.1, 0.01, or 0.001-percent selectable resolution

(3) Count-to-count variation, <0.004 percent (on 100-mV scale)

(4) 300-Percent overranging (except on 1000-V scale)

(5) Five measurements per second at 0.001-percent resolution

(6) High-impedance, floating input

(7) 60-Hertz noise immunity (except at 0.1-percent resolution)

(8) Digital output using BCD code

(9) Externally programmable

Signal multiplexing is provided by a Vidar Corporation, model 610-01, Master Scanner. This scanner uses reed switches to connect the digital voltmeter to any of 200 three-wire signal channels (the third wire can be used for guarding purposes). It requires only 4 milliseconds to switch from one channel to another.

A controller was designed and built at this laboratory to implement external programming of the Vidar system by the PDP-15 computer. This controller is accessed by the computer as a CAMAC module. When a voltage reading is to be made, the computer writes to the module a control word that specifies the channel number and the range and resolution to be used. When the reading has been completed, the module signals the computer by raising an interrupt flag. The computer can then input the reading from the module and convert it to a floating point number. The use of the computer's interrupt feature allows other calculations to proceed while the voltage measurement is underway.

During tests of the Vidar system, it was found that digitizing errors occurred with a frequency of perhaps one error per thousand measurements. The bad readings were typically low by a large amount and were easy to notice if a large number of nearly equal readings were being made. They were apparently caused by a marginal integrated circuit in the digitizing section of the voltmeter. For the field measurements, errors of this kind were rejected by making each voltage measurement at least twice; if the values were in close agreement, their average was used - if not, they were thrown out and the measurements were made again. This technique cost little in additional time (because of the good sampling rate of the digital voltmeter) and was successful in eliminating data errors. Furthermore, some reduction in the count-to-count variations was achieved as a result of the averaging. Tests showed that random fluctuations in voltage measurements were approximately $2 \times 10^{-6}$

volts; this translates into field-strength fluctuations of $2x10^{-5}$ tesla (0.2 G).

## Magnet-Current Power Supplies

All magnet-power supplies for the cyclotron were current regulated. Potentiometers, driven by stepping motors, supplied reference voltages against which the shunt voltages were compared. Potentiometer and shunt voltages could be read by the Vidar system. Computer subprograms were written for each power supply system so that all coil currents could conveniently be controlled from the field-measuring programs.

The main-magnet regulator was of the series-pass transistor type. A water-cooled, temperature-controlled shunt was used to achieve a short-term stability of approximately 1 in $10^5$. The long-term stability was not measured. No means for directly controlling the magnetic field were available at the time these measurements were made. When a change in magnet current was made, the main field also changed but at a slower rate. At the lowest fields, the apparent magnet time-constant was many minutes. Therefore, whenever field level changes were made, data taking had to be suspended until the field had time to reach the new value.

The 10 trim-coil current regulators also used series-pass transistors. Their stability was approximately 1 in $10^3$. (The cyclotron has only eight pairs of trim coils but two of them, numbers 1 and 7, are connected so that the upper and lower coils of each pair can be excited separately.) In addition to the current-control potentiometer, a relay was provided for each regulator so that it could be turned on or off without changing the current setting. These relays were operated by the computer through a CAMAC driver module. Incremental field measurements were made by turning on one trim-coil pair at a time.

The two harmonic-coil supplies each used two rotating dc generators with the field currents controlled by transistor amplifiers. Each set of three pairs of harmonic coils was wired so that two of the pairs were each driven by a generator and the third pair received the sum current. In addition, sine-function potentiometers were used to control the relative currents in the twc generators and, hence, the phase angle of the resulting first-harmonic field produced. These supplies were also equipped with relays so that they could be turned on or off from the computer without altering the current or phase settings. Regulation of the harmonic-coil supplies was better than 1 percent.

## HALL-PROBE CALIBRATION

The Hall probe was calibrated in a flat-field region of the cyclotron magnet. The probe was alined with the field direction by orienting it for maximum output. The absolute field intensity was measured with a nuclear-magnetic-resonance (NMR) fluxmeter; the resonance frequency being determined with a digital frequency counter, gated by a crystal controlled clock. Proton resonance was used for fields below 0.65 tesla (6.5 kG) and deuterons above that. Both spin samples had natural line widths of $2\times10^{-5}$ tesla (0.2 G); no trouble was experienced in getting clear absorption signals.

A FORTRAN-language program was written for the PDP-15 to facilitate the probe calibration. The entire calibration process was carried out under program control except for setting the cyclotron magnet current and entering the NMR absorption frequency via the teletype keyboard. The program caused the Hall-probe measurements to be made in quick succession, and these data were typed out together with the calculated field. If desired, the experimenter could then repeat the process at another magnet current. This procedure was repeated for a total of 26 field levels approximately evenly spaced between 0.18 to 2.08 teslas (1.8 and 20.8 kG).

### Method of Temperature Compensation

A major disadvantage to the use of Hall-effect magnetic-field-measuring devices is that they are temperature sensitive. The Hall probe used in this study (type BH-200, manufactured by F. W. Bell, Inc.) had a Hall-voltage temperature coefficient of 0.06 percent per $^{\circ}C$. Measurements accurate to 1 part in $10^4$ would therefore imply that the temperature of the probe must be kept constant to approximately $0.1^{\circ}$ C - a level difficult to achieve because the Hall element itself is a source of heat that varies with the magnetic field. An alternate scheme is to use a temperature-sensitive compensating circuit. In this method, a thermistor is placed in contact with the Hall element. This thermistor is part of the circuit used to measure the Hall voltage and is connected so that its temperature coefficient just counters that of the Hall element. The difficulty with this method is that it is only effective over a narrow temperature range.

A Hall-probe design using a combination of these two methods is described in reference 6, where it is reported that reproducible results to within 0.01 percent are routinely obtained and that, with care, this can be improved by a factor of two or three. But several disadvantages exist:

(1) Hall devices are subject to aging after an initial turnon (heating) and to severe sensitivity drift after thermal cycling, as might occur if the oven is turned off for a period of time.

(2) A thermal time constant is observed whenever the probe is suddenly moved to a position where the field is greatly different. This time constant may limit the rate at which data can be taken with 0.01 percent accuracy.

(3) Systems using temperature-control ovens and compensation circuits are expensive to design and build.

Still another approach to the problem of temperature correction has been used in the present work - a method first proposed in reference 7. In this method, two voltages are measured: the Hall voltage and the voltage across the current terminals of the Hall element. These two voltages uniquely determine the magnetic-field intensity.

For constant Hall-element current and magnetic-field direction, there exist functions

$$B = B(V,T) \qquad R = R(V,T)$$

for the magnetic-field strength $B$ and Hall resistance $R$, where $V$ is the Hall voltage and $T$ is the Hall-element temperature. Suppose a Hall probe has been calibrated in order to obtain the functions

$$B_0(V) = B(V,T_0) \qquad R_0(V) = R(V,T_0)$$

and

$$Q_0(V) = \left.\left(\frac{\partial B}{\partial R}\right)_V\right]_{T=T_0}$$

where $T_0$ is the Hall-element temperature during the calibration. Then for other temperatures near $T_0$, we can make the linear approximation for $B$ in terms of the measured quantities $V$ and $R$

$$B = B_0 + \Delta B = B_0(V) + Q_0(V) \cdot \left[R - R_o(V)\right]$$

simply by choosing to evaluate all functions for the same Hall voltage. Temperature does not appear explicitly on the right side of this equation.

In the present work, calibration of the Hall probe was carried out twice: once at ambient temperature and once at a temperature somewhat higher, obtained by a small heater (resistor) in the probe mount. Upon completion of the "cool-probe" data, the probe heater was turned on to increase the Hall-plate temperature about $5^{\circ}$ C. After the probe temperature had reached its new equilibrium, the field levels were remeasured for the "warm-probe" data. The ambient-temperature (cool-probe) data were used to construct the functions $B_0(V)$ and $R_0(V)$. The derivative $Q_0(V)$ was obtained from the differences in B and R between the two runs at equal hall voltages.

## Construction and Circuit Details

The Hall element itself was a flat plate 2 millimeters wide by 5 millimeters long and about 0.1 millimeter thick. This was glued into a slot milled in a cylinder of brass, as illustrated in figure 2. Inside this cylinder was a resistor used to heat the probe a few degrees above ambient temperature for calibration purposes.

These parts were mounted on the end of the long ceramic-fiberglass boom which was part of the X-Y positioning apparatus. A plastic cover protected the probe from stray air currents. This cover was fitted with an off-center hole immediately above the Hall probe, which served to position the NMR fluxmeter used during calibration.

The electrical circuit used with the Hall probe is shown in figure 3. A constant-current supply maintained a current of 60 milliamperes in the Hall element. This current was monitored by measuring the voltage developed across the 1.5-ohm reference resistor. This resistor consisted of a series-parallel group of precision, 1-watt, wire-wound resistors immersed in transformer oil. It was designed to maintain a very constant, though not necessarily well-known, value.

In practice, the three voltages indicated in figure 1 were measured at each field point by using the integrating digital voltmeter. Their magnitudes were such that they could all be read with good resolution by using the 100-millivolt scale of the voltmeter. A correction factor (generally less than 0.01 percent) was calculated from the ratio of the 1.5-ohm reference-resistor voltage to a normal value established for this voltage. This correction factor was then applied to the Hall-voltage and Hall-resistance readings. Errors due to small changes in the Hall-element current or digital voltmeter calibration were thereby eliminated.

Both the Hall probe and the 1.5-ohm reference resistor were assembled several months before use so that they would have a chance to age, hopefully to minimize any drift during the measurements.

## Calibration Results

Figure 4 shows the characteristics of the Hall element used in this work. The Bell BH-200 probe has a bulk-material-type, indium arsenide element. It is expected that these data are representative of this type of probe.

Figure 4(a) shows the Hall voltage and the voltage across the Hall-element current leads versus magnetic-field strength. Nonlinearity of the Hall voltage is so slight that it does not show in a graph of this size. Any nonlinearity, of course, is accounted for in the interpolation calculation. Figure 4(b) shows the field correction derivative

$$\frac{\partial B}{\partial\,(iR)} = \frac{Q_0(V)}{I}$$

as a function of Hall voltage. The line faired through the points was not actually used; values of the correction factor used in reducing the field data were obtained by an interpolation of the measured points.

No attempt was made to measure the probe temperature directly during the calibration runs. But, by assuming a Hall-voltage temperature coefficient of -0.06 percent per $^{\circ}$C, the temperature difference between the warm and cool runs could be calculated. This difference turned out to be approximately $5^{\circ}$ C. More importantly, the computed temperature differences varied smoothly with field level, having random fluctuations amounting to less that $0.1^{\circ}$ C. All measurements reported herein were made in the winter months when the temperature in the cyclotron vault was nearly constant. Analysis of the entire set of main-field data showed that the probe temperature varied less than $1^{\circ}$ C from a mean value over the duration of the measurements. The Hall-probe temperature corrections were therefore always small.

## MAIN-FIELD MEASUREMENTS

The goal of the main-field measurements was to determine the coefficients $\overline{B}$, G, and H in an equation for the field strength B:

$$B(r,\theta) = \bar{B}\left(1 + \sum_i G_i \sin i\theta + H_i \cos i\theta\right)$$

where r is the radius position, θ the azimuthal position, and $i = 1, 2, 3, 6, 9,$ etc. These coefficients are all functions of radius and main-field coil current. (Terms for $i = 4, 5, 7, 8,$ etc. have been deliberately left out of the expression for B. These terms are expected to be very small in amplitude relative to those that are multiples of the third harmonic. Also, the higher harmonics generally have less effect on the particle orbits.)

Measurements were carried out at seven main-field coil currents: 130, 180, 230, 280, 330, 380, and 430 amperes. Values of the coefficients for other field currents can be obtained by interpolation of the measured values, using current as the argument. At each field level, data were measured at 40 radii. Values of coefficients for any arbitrary radius can be obtained by a second interpolation of the coefficients, this time using radius as the argument.

## Main-Field Radius and Azimuth Grid

The magnetic field of the Lewis Research Center's cyclotron is very nearly the same as that of the MSU cyclotron. We have used data from the MSU machine (ref. 1) to debug the particle-orbit codes that are used to calculate magnet currents and other machine parameters. This experience helped to determine the most suitable grid for mapping the main field. Because the radius and azimuth schedules were simply numerical tables in a computer code, there was no reason to make them uniform over the whole grid. Instead, other considerations were allowed to govern the number of azimuth points and the radii of the mapping circles.

Several factors determined the number of azimuth points on a scan circle. For circles with a 50.8-centimeter (20-in.) radius and greater, the field was measured at 199 points; a significantly larger number was inconvenient because of the limit imposed by the amount of computer memory available. For the smaller circles, fewer points were needed as the magnitude of the higher harmonics became insignificant. For circles with a 7.6-centimeter (3-in.) radius and smaller, not all of the coefficients in the field equation were determined. Another factor was the phenomenon of "aliasing." Even though there may appear to be enough data points to solve for the Fourier-series coefficients, wild solutions can occur that have no real meaning. This is because the field equation is incomplete; it does not have terms for $i = 4$, 5, 7, 8, etc. In our case, where the azimuthal points are evenly spaced, it is best to choose a number of points at least as large as that needed to solve the complete series even though some of the coefficients are not actually calculated.

Other considerations for determining the radii of the field-mapping circles were as follows:

(1) The time required to complete a scan is determined largely by the diameter of the scan circle.

(2) Orbit calculations are most sensitive to the field at large radii (near extraction) because the particles spend a greater proportion of time there.

(3) The field-equation coefficients vary rapidly with radius near 73.6 centimeters (29 in.). Therefore, accurate interpolation requires a finer grid there.

A compromise was reached: the radial spacing of the survey circles varied from a maximum of 3.81 centimeters (1.5 in.) to a minimum of 0.76 centimeter (0.3 in.), with the finest spacing near the extraction radius.

## Main-Field Data Reduction

All raw data were recorded on magnetic tape while the main-field measurements were underway. When a survey circle was completed, reduction of those data was begun while measurements on the next circle were being made. Reduced data points and calculated field-equation coefficients were recorded on magnetic tape and were printed out for examination. The factor that limited the rate at which measurements could be made was the slow speed of the X-Y positioning apparatus. Ample computer time was available between grid points to keep the data-reduction and printout operations from falling behind.

At the start and end of each data survey circle, a reference field measurement was made with the Hall probe at the same X-Y position used for its calibration. The average of these before-and-after field values was used to calculate a normalizing factor for all the data taken during the intervening data circle. This normalization minimized effects of magnet hysteresis and long-term drift due to temperature changes or component aging.

showing the largest gradients at the radius of the coil conductors. Therefore, data points for a given trim coil were taken at each interval near the coil radius and at less frequent intervals elsewhere.

Ten radial scans were made at each main-field coil current, spaced uniformly around a full circle. This provided a thorough sampling in azimuth of the incremental fields. All raw data were recorded on magnetic tape while the measurements were underway. In addition, reduced incremental fields were printed out for monitoring purposes.

### Trim-Coil Data Reduction

For each of the four main-field levels, at each radius, and for each trim coil measured at that radius, an incremental field was calculated by arithmetically averaging the 10 azimuth measurements. These measured points were then interpolated to get incremental fields at radial stations that were skipped. Incremental fields divided by $\overline{B}$, the average field coefficient, were used as the function for this interpolation. The azimuthal variations of the trim-coil fields were found to be nearly proportional to the main field, and this was the basis for using the field ratio in the interpolation.

Preliminary examination of the data revealed that the 1.5-minute time allowed for the outer (eight) trim-coil field to reach equilibrium had not been long enough at the 130- and 230-ampere main-field levels. As a result, the measured field increments for trim-coil 8 were too small by 1.2 percent at 130 amperes and by 0.7 percent at 230 amperes. Also, at some radii, the trim-coils-off reference fields were too high because of the residual field remaining from trim-coil 8 having been turned on for the previous radius point. Fortunately, the variety of different coil combinations used at different radii made it possible to calculate corrections for both the reference fields and the trim-coil-8 incremental fields at these two main-field levels. At the 330- and 430-ampere field levels, the 1.5-minute time was more than adequate and no residual-field corrections were necessary. The incremental trim-coil fields for the four main-field levels are given in table II.

## HARMONIC-COIL MEASUREMENTS

Two sets (three pairs of coils in each set) of harmonic coils provide the means for adjusting the first harmonic coefficients of the magnetic field. The inner harmonic coil set has a maximum effect at a radius of 13 centimeters (5 in.), and the outer set has a maximum effect at a radius of 66 centimeters (26 in.). Currents to these coils are supplied from regulated power supplies so arranged that the arithmetic sum of the currents in the three coils of each set is always zero. This way, the harmonic coils have no effect on the average field coefficient $\overline{B}$. These power supplies are also arranged so that the phase angle can be changed without changing the harmonic amplitude, or conversely.

Measurements of the incremental first-harmonic fields from the two sets of harmonic coils were made at the four main-field currents used to measure trim-coil fields: 130, 230, 330, and 430 amperes. It was found that the harmonic-coil fields were nearly independent of main-field level. It is assumed that the harmonic-coil fields are proportional to coil currents; measured values are for an excitation of 100 amperes (e.g., a current of 100 A in the coil pair near $0^{\circ}$ azimuth and 50 A in the other coils of the set). Each harmonic-coil set was measured at a number of radii sufficient to determine its radial profile.

## Measurement Procedure

The incremental fields of the harmonic coils were measured by the same methods used to measure the trim-coil fields. For the inner harmonic-coil set, measurements were made on 20 radial scans, equally spaced in azimuth around a full circle. This procedure was tried for the outer harmonic coils too, but it was found that the angular size of the outer coils is so small that 20 points do not give a fine enough sampling of these coils in azimuth. Instead, 10 radial scans were used to sample the outer harmonic coils near $0^{\circ}$. These scans were spaced $6^{\circ}$ apart in azimuth, and so covered only one-sixth of the full circle. But they did give a good sampling of the one coil pair. The contributions of the other coils in the set were then assumed to be in proportion to the measured coil as the ratio of their coil currents.

## Harmonic-Coil Data

Incremental, first-harmonic field coefficients were calculated at each radius for which measurements were made. A least-squares analysis was used, with all data points given equal weight. In addition to the first harmonic, the harmonic coils also produce higher harmonics (second, fourth, etc.), but these were ignored.

These higher harmonics have negligible effect on the particle orbits.

The amplitudes of the first harmonic produced by the inner harmonic-coil set are given in table III and for the outer set in table IV. In these tables, harmonic amplitudes are given at 2.54-centimeter (1-in.) intervals over the radius range influenced by the coil set even though not all radii were actually measured. Values for the radii not measured were obtained by interpolation of the measured values. The effective angular location of the coil pairs near $0^{\circ}$ (coil 1) are also given in the tables.

The harmonic amplitudes are also shown graphically in figure 5. From these graphs, it is apparent that the amplitudes are practically independent of the main-field level.

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## TABLE I. - MAIN-FIELD COEFFICIENTS

### (a) 130-Ampere current

| RADIUS (IN.) | B (GAUSS) | G1 | H1 | G2 | H2 |
|---|---|---|---|---|---|
| 0.0 | 6875.8 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | 6869.2 | .00002 | -.00003 | -.00001 | .00000 |
| 1.0 | 6850.7 | -.00004 | -.00004 | .00002 | .00001 |
| 2.0 | 6793.5 | .00001 | -.00018 | .00003 | .00002 |
| 3.0 | 6742.5 | .00004 | -.00034 | .00000 | .00012 |
| 4.0 | 6721.8 | .00009 | -.00025 | -.00004 | .00014 |
| 5.0 | 6721.4 | .00014 | -.00019 | -.00005 | .00014 |
| 6.5 | 6713.7 | .00003 | -.00039 | .00014 | .00008 |
| 8.0 | 6688.4 | -.00001 | -.00036 | .00010 | .00022 |
| 9.5 | 6659.6 | .00009 | -.00020 | .00005 | .00025 |
| 11.0 | 6641.3 | .00009 | -.00022 | -.00001 | .00028 |
| 12.5 | 6636.9 | -.00004 | -.00006 | .00004 | .00025 |
| 14.0 | 6642.3 | -.00004 | -.00014 | .00004 | .00037 |
| 15.5 | 6651.8 | .00001 | -.00006 | -.00001 | .00037 |
| 17.0 | 6664.2 | -.00001 | -.00003 | .00006 | .00033 |
| 18.5 | 6680.4 | -.00003 | -.00002 | .00006 | .00037 |
| 20.0 | 6703.0 | -.00001 | .00005 | .00005 | .00037 |
| 21.5 | 6737.3 | -.00005 | .00009 | .00001 | .00032 |
| 23.0 | 6789.5 | -.00011 | .00004 | .00007 | .00029 |
| 24.5 | 6866.7 | -.00014 | -.00002 | .00011 | .00027 |
| 25.5 | 6935.5 | -.00015 | .00000 | .00012 | .00026 |
| 26.3 | 6999.6 | -.00015 | .00003 | .00012 | .00027 |
| 27.0 | 7059.6 | -.00016 | .00002 | .00012 | .00027 |
| 27.5 | 7100.5 | -.00019 | -.00001 | .00014 | .00024 |
| 28.0 | 7135.6 | -.00018 | -.00006 | .00013 | .00020 |
| 28.4 | 7155.6 | -.00018 | -.00008 | .00015 | .00020 |
| 28.7 | 7163.3 | -.00017 | -.00004 | .00015 | .00020 |
| 29.0 | 7162.4 | -.00017 | -.00003 | .00016 | .00016 |
| 29.3 | 7150.9 | -.00016 | -.00003 | .00014 | .00013 |
| 29.6 | 7126.6 | -.00014 | -.00002 | .00011 | .00009 |
| 30.0 | 7069.6 | -.00011 | .00003 | .00010 | .00005 |
| 30.5 | 6952.5 | -.00000 | .00007 | .00004 | -.00003 |
| 31.0 | 6778.6 | .00016 | .00009 | .00001 | -.00002 |
| 31.5 | 6548.8 | .00025 | .00014 | -.00007 | -.00005 |
| 32.0 | 6270.2 | .00040 | .00014 | -.00016 | -.00011 |
| 33.0 | 5619.3 | .00056 | .00022 | -.00031 | -.00035 |
| 34.5 | 4605.7 | .00074 | .00033 | -.00051 | -.00078 |
| 36.0 | 3728.8 | .00123 | .00038 | -.00045 | -.00058 |
| 37.5 | 3033.1 | .00126 | .00061 | -.00057 | -.00062 |
| 39.0 | 2490.8 | .00098 | .00098 | -.00078 | -.00094 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(a) Continued. 130-Ampere current

| RADIUS | G3 | H3 | G6 | H6 | G9 | H9 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | -.00003 | -.00017 | .00001 | .00000 | .00000 | .00000 |
| 1.0 | -.00029 | -.00136 | .00000 | .00000 | .00000 | -.00000 |
| 2.0 | -.00218 | -.01062 | .00002 | .00007 | .00000 | .00001 |
| 3.0 | -.00640 | -.03412 | .00012 | .00044 | .00001 | -.00002 |
| 4.0 | -.01231 | -.07292 | .00056 | .00184 | -.00000 | .00002 |
| 5.0 | -.01778 | -.12046 | .00099 | .00436 | .00002 | .00008 |
| 6.5 | -.02425 | -.19153 | .00094 | .00726 | .00051 | .00112 |
| 8.0 | -.03044 | -.25184 | -.00009 | .00574 | .00182 | .00458 |
| 9.5 | -.03764 | -.29931 | -.00227 | -.00072 | .00397 | .01035 |
| 11.0 | -.04683 | -.33568 | -.00613 | -.01122 | .00728 | .01726 |
| 12.5 | -.05843 | -.36278 | -.01137 | -.02454 | .01186 | .02386 |
| 14.0 | -.07102 | -.38253 | -.01806 | -.03921 | .01710 | .02904 |
| 15.5 | -.08314 | -.39654 | -.02586 | -.05283 | .02219 | .03258 |
| 17.0 | -.09410 | -.40596 | -.03426 | -.06462 | .02649 | .03462 |
| 18.5 | -.10390 | -.41144 | -.04293 | -.07426 | .02991 | .03557 |
| 20.0 | -.11274 | -.41279 | -.05170 | -.08123 | .03219 | .03603 |
| 21.5 | -.12110 | -.40900 | -.06090 | -.08507 | .03309 | .03621 |
| 23.0 | -.12948 | -.39848 | -.07104 | -.08508 | .03222 | .03657 |
| 24.5 | -.13830 | -.37899 | -.08281 | -.07970 | .02871 | .03805 |
| 25.5 | -.14478 | -.35954 | -.09217 | -.07224 | .02424 | .04003 |
| 26.3 | -.15044 | -.33968 | -.10080 | -.06370 | .01914 | .04236 |
| 27.0 | -.15572 | -.31905 | -.10917 | -.05425 | .01346 | .04505 |
| 27.5 | -.15954 | -.30266 | -.11547 | -.04643 | .00878 | .04736 |
| 28.0 | -.16324 | -.28508 | -.12189 | -.03783 | .00362 | .05004 |
| 28.4 | -.16593 | -.27040 | -.12689 | -.03058 | -.00079 | .05241 |
| 28.7 | -.16776 | -.25913 | -.13052 | -.02498 | -.00416 | .05427 |
| 29.0 | -.16928 | -.24781 | -.13383 | -.01934 | -.00744 | .05617 |
| 29.3 | -.17049 | -.23648 | -.13688 | -.01376 | -.01074 | .05807 |
| 29.6 | -.17123 | -.22527 | -.13944 | -.00836 | -.01384 | .05993 |
| 30.0 | -.17145 | -.21064 | -.14202 | -.00146 | -.01760 | .06218 |
| 30.5 | -.17026 | -.19307 | -.14361 | .00616 | -.02157 | .06447 |
| 31.0 | -.16713 | -.17643 | -.14301 | .01249 | -.02456 | .06595 |
| 31.5 | -.16202 | -.16090 | -.14026 | .01725 | -.02632 | .06634 |
| 32.0 | -.15510 | -.14643 | -.13536 | .02051 | -.02707 | .06555 |
| 33.0 | -.13717 | -.12052 | -.12070 | .02313 | -.02590 | .06055 |
| 34.5 | -.10628 | -.08784 | -.09308 | .02086 | -.02025 | .04776 |
| 36.0 | -.07828 | -.06237 | -.06681 | .01626 | -.01421 | .03414 |
| 37.5 | -.05626 | -.04390 | -.04662 | .01186 | -.00956 | .02300 |
| 39.0 | -.04037 | -.03123 | -.03239 | .00841 | -.00620 | .01520 |

## TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

### (a) Concluded. 130-Ampere current

| RADIUS | G12 | H12 | G15 | H15 | G18 | H18 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 1.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 2.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 3.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 4.0 | -.00000 | -.00000 | -.00001 | .00001 | -.00002 | -.00000 |
| 5.0 | -.00000 | -.00003 | .00001 | -.00000 | .00000 | .00002 |
| 6.5 | -.00015 | -.00020 | .00003 | .00005 | -.00001 | .00001 |
| 8.0 | -.00044 | -.00101 | .00003 | .00011 | .00001 | -.00002 |
| 9.5 | -.00081 | -.00185 | -.00006 | -.00005 | .00011 | .00010 |
| 11.0 | -.00073 | -.00225 | -.00058 | -.00063 | .00024 | .00031 |
| 12.5 | .00001 | -.00145 | -.00170 | -.00160 | .00044 | .00049 |
| 14.0 | .00198 | .00085 | -.00336 | -.00265 | .00036 | .00040 |
| 15.5 | .00526 | .00370 | -.00527 | -.00335 | -.00022 | .00018 |
| 17.0 | .00967 | .00665 | -.00692 | -.00362 | -.00142 | -.00004 |
| 18.5 | .01493 | .00936 | -.00810 | -.00342 | -.00322 | -.00008 |
| 20.0 | .02049 | .01166 | -.00865 | -.00301 | -.00538 | .00014 |
| 21.5 | .02597 | .01328 | -.00850 | -.00249 | -.00764 | .00073 |
| 23.0 | .03104 | .01432 | -.00761 | -.00192 | -.00982 | .00179 |
| 24.5 | .03478 | .01497 | -.00639 | -.00151 | -.01171 | .00313 |
| 25.5 | .03608 | .01514 | -.00526 | -.00144 | -.01256 | .00425 |
| 26.3 | .03618 | .01519 | -.00440 | -.00152 | -.01296 | .00529 |
| 27.0 | .03542 | .01524 | -.00373 | -.00165 | -.01310 | .00628 |
| 27.5 | .03436 | .01532 | -.00335 | -.00178 | -.01307 | .00704 |
| 28.0 | .03280 | .01551 | -.00317 | -.00193 | -.01302 | .00777 |
| 28.4 | .03122 | .01580 | -.00312 | -.00206 | -.01292 | .00829 |
| 28.7 | .02988 | .01606 | -.00316 | -.00217 | -.01283 | .00867 |
| 29.0 | .02845 | .01638 | -.00323 | -.00220 | -.01271 | .00898 |
| 29.3 | .02689 | .01676 | -.00337 | -.00231 | -.01262 | .00929 |
| 29.6 | .02538 | .01721 | -.00345 | -.00232 | -.01246 | .00948 |
| 30.0 | .02330 | .01787 | -.00366 | -.00223 | -.01219 | .00964 |
| 30.5 | .02085 | .01882 | -.00376 | -.00208 | -.01184 | .00973 |
| 31.0 | .01875 | .01976 | -.00363 | -.00183 | -.01130 | .00961 |
| 31.5 | .01700 | .02053 | -.00326 | -.00145 | -.01057 | .00917 |
| 32.0 | .01553 | .02093 | -.00261 | -.00104 | -.00967 | .00854 |
| 33.0 | .01318 | .02039 | -.00098 | -.00045 | -.00750 | .00685 |
| 34.5 | .01018 | .01676 | .00091 | .00012 | -.00417 | .00424 |
| 36.0 | .00731 | .01208 | .00125 | .00031 | -.00214 | .00235 |
| 37.5 | .00476 | .00795 | .00102 | .00030 | -.00116 | .00129 |
| 39.0 | .00300 | .00496 | .00076 | .00005 | -.00057 | .00058 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(b) 180-Ampere current

| RADIUS (IN.) | B (GAUSS) | G1 | H1 | G2 | H2 |
|---|---|---|---|---|---|
| 0.0 | 9394.7 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | 9385.6 | .00002 | -.00000 | -.00002 | .00001 |
| 1.0 | 9360.0 | -.00000 | -.00001 | -.00001 | .00001 |
| 2.0 | 9279.1 | .00010 | -.00009 | -.00007 | .00007 |
| 3.0 | 9206.4 | .00012 | -.00021 | -.00001 | .00011 |
| 4.0 | 9176.6 | .00021 | -.00017 | -.00014 | .00016 |
| 5.0 | 9176.2 | .00022 | -.00022 | -.00009 | .00012 |
| 6.5 | 9169.8 | .00006 | -.00023 | .00012 | .00010 |
| 8.0 | 9139.6 | -.00009 | -.00027 | .00013 | .00024 |
| 9.5 | 9102.6 | .00002 | -.00024 | .00006 | .00030 |
| 11.0 | 9078.3 | .00008 | -.00026 | .00005 | .00032 |
| 12.5 | 9072.8 | .00007 | -.00015 | .00006 | .00036 |
| 14.0 | 9080.4 | .00007 | -.00011 | -.00003 | .00040 |
| 15.5 | 9093.5 | .00002 | -.00007 | -.00001 | .00042 |
| 17.0 | 9110.0 | .00002 | .00001 | .00000 | .00037 |
| 18.5 | 9131.5 | -.00003 | -.00002 | .00007 | .00039 |
| 20.0 | 9161.4 | .00000 | .00002 | .00010 | .00035 |
| 21.5 | 9206.7 | -.00002 | .00001 | .00009 | .00033 |
| 23.0 | 9275.3 | -.00008 | .00001 | .00013 | .00033 |
| 24.5 | 9376.2 | -.00010 | -.00002 | .00015 | .00033 |
| 25.5 | 9465.1 | -.00012 | -.00002 | .00013 | .00031 |
| 26.3 | 9548.1 | -.00011 | -.00005 | .00013 | .00026 |
| 27.0 | 9624.4 | -.00013 | -.00008 | .00016 | .00025 |
| 27.5 | 9676.3 | -.00013 | -.00010 | .00017 | .00021 |
| 28.0 | 9719.8 | -.00014 | -.00010 | .00019 | .00021 |
| 28.4 | 9744.5 | -.00020 | -.00009 | .00015 | .00019 |
| 28.7 | 9751.5 | -.00016 | -.00008 | .00018 | .00015 |
| 29.0 | 9747.6 | -.00013 | -.00008 | .00015 | .00015 |
| 29.3 | 9728.8 | -.00016 | -.00002 | .00018 | .00010 |
| 29.6 | 9693.1 | -.00012 | -.00003 | .00013 | .00010 |
| 30.0 | 9612.8 | -.00010 | .00003 | .00011 | .00006 |
| 30.5 | 9450.1 | .00000 | .00010 | .00003 | -.00002 |
| 31.0 | 9211.8 | .00015 | .00015 | .00004 | .00001 |
| 31.5 | 8898.7 | .00036 | .00022 | -.00003 | -.00006 |
| 32.0 | 8520.3 | .00047 | .00024 | -.00012 | -.00012 |
| 33.0 | 7636.9 | .00069 | .00037 | -.00024 | -.00024 |
| 34.5 | 6264.3 | .00069 | .00047 | -.00044 | -.00056 |
| 36.0 | 5077.5 | .00104 | .00049 | -.00047 | -.00037 |
| 37.5 | 4134.0 | .00118 | .00073 | -.00059 | -.00043 |
| 39.0 | 3396.9 | .00115 | .00086 | -.00075 | -.00052 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(b) Continued. 180-Ampere current

| RADIUS | G3 | H3 | G6 | H6 | G9 | H9 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | -.00004 | -.00017 | -.00000 | .00000 | -.00000 | -.00000 |
| 1.0 | -.00027 | -.00133 | -.00001 | .00000 | -.00000 | .00000 |
| 2.0 | -.00207 | -.01056 | .00001 | .00006 | .00000 | .00001 |
| 3.0 | -.00633 | -.03387 | .00012 | .00042 | -.00001 | .00001 |
| 4.0 | -.01210 | -.07232 | .00046 | .00174 | -.00003 | .00003 |
| 5.0 | -.01756 | -.11977 | .00092 | .00423 | .00006 | .00008 |
| 6.5 | -.02425 | -.19105 | .00087 | .00714 | .00052 | .00117 |
| 8.0 | -.03063 | -.25158 | -.00009 | .00571 | .00183 | .00458 |
| 9.5 | -.03779 | -.29914 | -.00222 | -.00068 | .00401 | .01032 |
| 11.0 | -.04682 | -.33554 | -.00609 | -.01117 | .00729 | .01728 |
| 12.5 | -.05826 | -.36269 | -.01135 | -.02450 | .01180 | .02388 |
| 14.0 | -.07076 | -.38242 | -.01800 | -.03907 | .01701 | .02912 |
| 15.5 | -.08302 | -.39641 | -.02579 | -.05275 | .02219 | .03262 |
| 17.0 | -.09403 | -.40591 | -.03416 | -.06453 | .02653 | .03466 |
| 18.5 | -.10392 | -.41153 | -.04284 | -.07418 | .03001 | .03555 |
| 20.0 | -.11270 | -.41312 | -.05156 | -.08125 | .03230 | .03600 |
| 21.5 | -.12099 | -.40967 | -.06075 | -.08532 | .03314 | .03611 |
| 23.0 | -.12937 | -.39973 | -.07088 | -.08563 | .03230 | .03636 |
| 24.5 | -.13817 | -.38114 | -.08257 | -.08074 | .02890 | .03759 |
| 25.5 | -.14463 | -.36258 | -.09179 | -.07372 | .02459 | .03935 |
| 26.3 | -.15028 | -.34357 | -.10026 | -.06560 | .01967 | .04144 |
| 27.0 | -.15547 | -.32386 | -.10841 | -.05660 | .01416 | .04390 |
| 27.5 | -.15925 | -.30811 | -.11456 | -.04913 | .00960 | .04601 |
| 28.0 | -.16289 | -.29124 | -.12080 | -.04090 | .00458 | .04847 |
| 28.4 | -.16561 | -.27700 | -.12572 | -.03391 | .00030 | .05063 |
| 28.7 | -.16734 | -.26620 | -.12916 | -.02853 | -.00294 | .05235 |
| 29.0 | -.16887 | -.25528 | -.13245 | -.02313 | -.00621 | .05410 |
| 29.3 | -.17006 | -.24439 | -.13532 | -.01776 | -.00933 | .05587 |
| 29.6 | -.17081 | -.23354 | -.13784 | -.01254 | -.01237 | .05754 |
| 30.0 | -.17101 | -.21937 | -.14031 | -.00592 | -.01607 | .05963 |
| 30.5 | -.16983 | -.20220 | -.14183 | .00150 | -.01995 | .06170 |
| 31.0 | -.16675 | -.18587 | -.14123 | .00762 | -.02288 | .06301 |
| 31.5 | -.16173 | -.17048 | -.13851 | .01227 | -.02466 | .06333 |
| 32.0 | -.15490 | -.15602 | -.13371 | .01556 | -.02545 | .06245 |
| 33.0 | -.13713 | -.12948 | -.11926 | .01836 | -.02445 | .05752 |
| 34.5 | -.10608 | -.09541 | -.09202 | .01676 | -.01937 | .04517 |
| 36.0 | -.07794 | -.06826 | -.06601 | .01305 | -.01351 | .03215 |
| 37.5 | -.05611 | -.04838 | -.04612 | .00936 | -.00912 | .02170 |
| 39.0 | -.04029 | -.03452 | -.03197 | .00655 | -.00606 | .01434 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(b) Concluded. 180-Ampere current

| RADIUS | G12 | H12 | G15 | H15 | G18 | H18 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 1.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 2.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 3.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 4.0 | -.00001 | -.00000 | -.00003 | -.00000 | -.00001 | -.00001 |
| 5.0 | -.00003 | -.00002 | .00000 | .00002 | -.00000 | -.00001 |
| 6.5 | -.00013 | -.00029 | .00002 | .00004 | .00001 | -.00000 |
| 8.0 | -.00045 | -.00100 | .00003 | .00012 | .00003 | -.00000 |
| 9.5 | -.00081 | -.00186 | -.00006 | -.00004 | .00010 | .00010 |
| 11.0 | -.00075 | -.00224 | -.00059 | -.00063 | .00025 | .00035 |
| 12.5 | .00003 | -.00141 | -.00172 | -.00162 | .00041 | .00049 |
| 14.0 | .00196 | .00082 | -.00338 | -.00266 | .00035 | .00042 |
| 15.5 | .00526 | .00371 | -.00528 | -.00336 | -.00024 | .00017 |
| 17.0 | .00963 | .00667 | -.00697 | -.00363 | -.00144 | -.00007 |
| 18.5 | .01493 | .00933 | -.00813 | -.00341 | -.00323 | -.00007 |
| 20.0 | .02048 | .01162 | -.00870 | -.00301 | -.00538 | .00014 |
| 21.5 | .02595 | .01324 | -.00850 | -.00250 | -.00762 | .00073 |
| 23.0 | .03107 | .01424 | -.00759 | -.00197 | -.00983 | .00176 |
| 24.5 | .03489 | .01478 | -.00625 | -.00159 | -.01170 | .00310 |
| 25.5 | .03624 | .01483 | -.00522 | -.00157 | -.01257 | .00421 |
| 26.3 | .03638 | .01474 | -.00440 | -.00169 | -.01298 | .00522 |
| 27.0 | .03564 | .01467 | -.00375 | -.00189 | -.01310 | .00615 |
| 27.5 | .03460 | .01466 | -.00338 | -.00204 | -.01308 | .00687 |
| 28.0 | .03307 | .01474 | -.00319 | -.00225 | -.01301 | .00756 |
| 28.4 | .03153 | .01486 | -.00311 | -.00246 | -.01291 | .00805 |
| 28.7 | .03021 | .01507 | -.00316 | -.00254 | -.01278 | .00838 |
| 29.0 | .02876 | .01528 | -.00326 | -.00273 | -.01271 | .00868 |
| 29.3 | .02728 | .01558 | -.00338 | -.00276 | -.01257 | .00893 |
| 29.6 | .02571 | .01591 | -.00351 | -.00288 | -.01243 | .00912 |
| 30.0 | .02366 | .01644 | -.00372 | -.00285 | -.01216 | .00922 |
| 30.5 | .02123 | .01723 | -.00385 | -.00278 | -.01178 | .00932 |
| 31.0 | .01911 | .01799 | -.00379 | -.00256 | -.01125 | .00910 |
| 31.5 | .01725 | .01865 | -.00348 | -.00224 | -.01059 | .00873 |
| 32.0 | .01572 | .01903 | -.00291 | -.00186 | -.00970 | .00809 |
| 33.0 | .01317 | .01855 | -.00138 | -.00126 | -.00760 | .00650 |
| 34.5 | .01005 | .01527 | .00043 | -.00048 | -.00437 | .00390 |
| 36.0 | .00710 | .01098 | .00108 | -.00010 | -.00224 | .00220 |
| 37.5 | .00459 | .00723 | .00079 | .00009 | -.00128 | .00111 |
| 39.0 | .00290 | .00446 | .00058 | -.00004 | -.00063 | .00049 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(c) 230-Ampere current

| RADIUS (IN.) | B (GAUSS) | G1 | H1 | G2 | H2 |
|---|---|---|---|---|---|
| 0.0 | 11494.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | 11482.1 | .00001 | .00003 | -.00002 | .00001 |
| 1.0 | 11448.4 | .00001 | .00004 | -.00001 | .00002 |
| 2.0 | 11341.5 | .00003 | -.00006 | .00002 | .00005 |
| 3.0 | 11242.0 | .00010 | -.00027 | .00001 | .00010 |
| 4.0 | 11194.3 | .00018 | -.00019 | .00001 | .00016 |
| 5.0 | 11190.0 | .00021 | -.00018 | -.00005 | .00011 |
| 6.5 | 11187.7 | .00013 | -.00026 | .00020 | .00006 |
| 8.0 | 11161.1 | .00011 | -.00031 | .00019 | .00019 |
| 9.5 | 11123.4 | .00018 | -.00024 | .00007 | .00027 |
| 11.0 | 11098.2 | .00016 | -.00015 | .00004 | .00024 |
| 12.5 | 11094.5 | .00014 | -.00015 | -.00002 | .00033 |
| 14.0 | 11104.3 | .00010 | -.00014 | .00002 | .00034 |
| 15.5 | 11119.5 | .00015 | -.00012 | .00008 | .00038 |
| 17.0 | 11138.1 | .00011 | -.00008 | .00011 | .00035 |
| 18.5 | 11161.4 | .00014 | -.00007 | .00012 | .00036 |
| 20.0 | 11192.6 | .00012 | .00000 | .00011 | .00035 |
| 21.5 | 11240.2 | .00009 | .00003 | .00007 | .00032 |
| 23.0 | 11312.1 | .00005 | .00002 | .00011 | .00028 |
| 24.5 | 11418.6 | .00003 | -.00004 | .00016 | .00026 |
| 25.5 | 11512.1 | -.00000 | -.00004 | .00017 | .00026 |
| 26.3 | 11593.4 | -.00001 | -.00004 | .00020 | .00027 |
| 27.0 | 11676.5 | -.00001 | -.00004 | .00020 | .00027 |
| 27.5 | 11727.4 | -.00002 | -.00003 | .00021 | .00027 |
| 28.0 | 11767.3 | -.00001 | -.00005 | .00024 | .00027 |
| 28.4 | 11785.1 | -.00002 | -.00006 | .00024 | .00026 |
| 28.7 | 11786.3 | -.00001 | -.00007 | .00021 | .00022 |
| 29.0 | 11773.9 | .00000 | -.00007 | .00021 | .00020 |
| 29.3 | 11744.2 | .00003 | -.00008 | .00019 | .00016 |
| 29.6 | 11694.0 | .00006 | -.00009 | .00016 | .00012 |
| 30.0 | 11588.9 | .00014 | -.00008 | .00013 | .00006 |
| 30.5 | 11385.4 | .00026 | -.00011 | .00009 | .00007 |
| 31.0 | 11094.7 | .00043 | -.00007 | .00003 | .00003 |
| 31.5 | 10717.2 | .00054 | .00006 | -.00003 | -.00005 |
| 32.0 | 10263.8 | .00077 | .00009 | -.00012 | -.00011 |
| 33.0 | 9210.6 | .00099 | .00013 | -.00027 | -.00017 |
| 34.5 | 7577.6 | .00132 | .00025 | -.00050 | -.00038 |
| 36.0 | 6164.3 | .00135 | .00032 | -.00057 | -.00028 |
| 37.5 | 5036.0 | .00147 | .00059 | -.00081 | -.00027 |
| 39.0 | 4150.0 | .00145 | .00084 | -.00086 | -.00012 |

## TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

### (c) Continued. 230-Ampere current

| RADIUS | G3 | H3 | G6 | H6 | G9 | H9 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | -.00003 | -.00016 | .00000 | .00001 | -.00000 | .00001 |
| 1.0 | -.00027 | -.00128 | -.00000 | .00001 | -.00000 | .00000 |
| 2.0 | -.00208 | -.01016 | -.00000 | .00006 | -.00002 | .00002 |
| 3.0 | -.00610 | -.03273 | .00009 | .00038 | .00001 | .00001 |
| 4.0 | -.01171 | -.07028 | .00043 | .00163 | .00001 | .00002 |
| 5.0 | -.01708 | -.11695 | .00082 | .00393 | .00007 | .00014 |
| 6.5 | -.02370 | -.18794 | .00080 | .00684 | .00054 | .00120 |
| 8.0 | -.03013 | -.24863 | .00001 | .00577 | .00178 | .00457 |
| 9.5 | -.03752 | -.29605 | -.00208 | -.00028 | .00398 | .01014 |
| 11.0 | -.04654 | -.33223 | -.00575 | -.01041 | .00719 | .01699 |
| 12.5 | -.05787 | -.35931 | -.01092 | -.02364 | .01172 | .02359 |
| 14.0 | -.07028 | -.37890 | -.01744 | -.03781 | .01696 | .02881 |
| 15.5 | -.08229 | -.39286 | -.02506 | -.05122 | .02205 | .03232 |
| 17.0 | -.09306 | -.40240 | -.03323 | -.06285 | .02637 | .03438 |
| 18.5 | -.10274 | -.40820 | -.04171 | -.07242 | .02980 | .03534 |
| 20.0 | -.11148 | -.41016 | -.05022 | -.07944 | .03217 | .03573 |
| 21.5 | -.11975 | -.40744 | -.05918 | -.08366 | .03319 | .03571 |
| 23.0 | -.12799 | -.39873 | -.06890 | -.08441 | .03258 | .03576 |
| 24.5 | -.13667 | -.38198 | -.08017 | -.08031 | .02947 | .03658 |
| 25.5 | -.14301 | -.36509 | -.08900 | -.07412 | .02547 | .03789 |
| 26.3 | -.14854 | -.34768 | -.09710 | -.06684 | .02085 | .03952 |
| 27.0 | -.15365 | -.32952 | -.10489 | -.05868 | .01570 | .04148 |
| 27.5 | -.15734 | -.31501 | -.11072 | -.05187 | .01143 | .04321 |
| 28.0 | -.16093 | -.29936 | -.11663 | -.04433 | .00673 | .04524 |
| 28.4 | -.16355 | -.28622 | -.12123 | -.03789 | .00276 | .04704 |
| 28.7 | -.16524 | -.27615 | -.12449 | -.03296 | -.00030 | .04849 |
| 29.0 | -.16672 | -.26593 | -.12754 | -.02795 | -.00335 | .04996 |
| 29.3 | -.16787 | -.25567 | -.13025 | -.02295 | -.00631 | .05142 |
| 29.6 | -.16861 | -.24544 | -.13257 | -.01807 | -.00916 | .05284 |
| 30.0 | -.16881 | -.23195 | -.13489 | -.01188 | -.01268 | .05457 |
| 30.5 | -.16763 | -.21541 | -.13623 | -.00495 | -.01644 | .05628 |
| 31.0 | -.16463 | -.19947 | -.13560 | .00086 | -.01924 | .05728 |
| 31.5 | -.15961 | -.18427 | -.13296 | .00542 | -.02109 | .05736 |
| 32.0 | -.15290 | -.16959 | -.12829 | .00857 | -.02195 | .05643 |
| 33.0 | -.13508 | -.14213 | -.11432 | .01171 | -.02132 | .05166 |
| 34.5 | -.10429 | -.10566 | -.08781 | .01116 | -.01705 | .04020 |
| 36.0 | -.07592 | -.07599 | -.06274 | .00870 | -.01206 | .02837 |
| 37.5 | -.05389 | -.05395 | -.04342 | .00604 | -.00799 | .01884 |
| 39.0 | -.03840 | -.03830 | -.02989 | .00423 | -.00523 | .01235 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(c) Concluded. 230-Ampere current

| RADIUS | G12 | H12 | G15 | H15 | G18 | H18 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 1.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 2.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 3.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 4.0 | .00000 | -.00001 | -.00000 | -.00000 | -.00001 | -.00000 |
| 5.0 | -.00004 | -.00002 | -.00000 | .00001 | -.00002 | .00001 |
| 6.5 | -.00014 | -.00027 | .00002 | .00004 | -.00000 | -.00001 |
| 8.0 | -.00045 | -.00098 | .00004 | .00010 | -.00000 | -.00000 |
| 9.5 | -.00080 | -.00183 | -.00005 | -.00006 | .00010 | .00010 |
| 11.0 | -.00078 | -.00223 | -.00057 | -.00063 | .00025 | .00034 |
| 12.5 | -.00000 | -.00135 | -.00167 | -.00157 | .00040 | .00047 |
| 14.0 | .00187 | .00073 | -.00334 | -.00262 | .00035 | .00041 |
| 15.5 | .00513 | .00354 | -.00518 | -.00331 | -.00021 | .00019 |
| 17.0 | .00943 | .00646 | -.00686 | -.00359 | -.00139 | -.00003 |
| 18.5 | .01461 | .00914 | -.00805 | -.00341 | -.00317 | -.00008 |
| 20.0 | .02005 | .01134 | -.00864 | -.00302 | -.00527 | .00013 |
| 21.5 | .02551 | .01286 | -.00847 | -.00251 | -.00748 | .00074 |
| 23.0 | .03053 | .01383 | -.00766 | -.00195 | -.00967 | .00172 |
| 24.5 | .03438 | .01414 | -.00634 | -.00165 | -.01151 | .00305 |
| 25.5 | .03578 | .01404 | -.00532 | -.00165 | -.01236 | .00410 |
| 26.3 | .03601 | .01374 | -.00447 | -.00184 | -.01275 | .00506 |
| 27.0 | .03538 | .01343 | -.00382 | -.00211 | -.01286 | .00594 |
| 27.5 | .03441 | .01322 | -.00346 | -.00234 | -.01285 | .00660 |
| 28.0 | .03300 | .01306 | -.00323 | -.00263 | -.01274 | .00722 |
| 28.4 | .03152 | .01301 | -.00318 | -.00287 | -.01263 | .00765 |
| 28.7 | .03027 | .01305 | -.00319 | -.00306 | -.01251 | .00792 |
| 29.0 | .02888 | .01312 | -.00327 | -.00324 | -.01239 | .00815 |
| 29.3 | .02741 | .01321 | -.00340 | -.00338 | -.01223 | .00833 |
| 29.6 | .02589 | .01341 | -.00353 | -.00350 | -.01210 | .00848 |
| 30.0 | .02385 | .01374 | -.00371 | -.00359 | -.01188 | .00859 |
| 30.5 | .02148 | .01427 | -.00391 | -.00358 | -.01150 | .00858 |
| 31.0 | .01932 | .01484 | -.00393 | -.00345 | -.01094 | .00838 |
| 31.5 | .01747 | .01533 | -.00370 | -.00314 | -.01033 | .00800 |
| 32.0 | .01575 | .01559 | -.00324 | -.00288 | -.00942 | .00736 |
| 33.0 | .01315 | .01520 | -.00187 | -.00221 | -.00731 | .00589 |
| 34.5 | .00974 | .01246 | -.00010 | -.00129 | -.00435 | .00362 |
| 36.0 | .00685 | .00898 | .00055 | -.00060 | -.00244 | .00201 |
| 37.5 | .00442 | .00584 | .00060 | -.00035 | -.00126 | .00092 |
| 39.0 | .00277 | .00359 | .00045 | -.00034 | -.00062 | .00054 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(d) 280-Ampere current

| RADIUS (IN.) | B (GAUSS) | G1 | H1 | G2 | H2 |
|---|---|---|---|---|---|
| 0.0 | 12953.6 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | 12935.2 | .00003 | .00002 | -.00002 | .00001 |
| 1.0 | 12895.2 | .00007 | .00003 | -.00006 | .00002 |
| 2.0 | 12767.6 | .00012 | -.00003 | -.00011 | .00005 |
| 3.0 | 12644.9 | .00018 | -.00014 | -.00017 | .00007 |
| 4.0 | 12582.6 | .00019 | -.00026 | -.00024 | .00008 |
| 5.0 | 12573.1 | .00024 | -.00038 | -.00020 | .00004 |
| 6.5 | 12576.0 | .00028 | -.00032 | -.00022 | .00000 |
| 8.0 | 12561.3 | .00029 | -.00040 | -.00007 | .00011 |
| 9.5 | 12528.8 | .00035 | -.00023 | -.00003 | .00011 |
| 11.0 | 12507.8 | .00023 | -.00012 | -.00002 | .00018 |
| 12.5 | 12507.1 | .00021 | -.00010 | -.00002 | .00022 |
| 14.0 | 12519.8 | .00018 | -.00013 | -.00002 | .00025 |
| 15.5 | 12536.9 | .00022 | -.00014 | .00003 | .00027 |
| 17.0 | 12555.9 | .00023 | -.00007 | .00004 | .00033 |
| 18.5 | 12578.1 | .00019 | -.00004 | .00016 | .00027 |
| 20.0 | 12608.4 | .00012 | -.00005 | .00017 | .00027 |
| 21.5 | 12653.0 | .00014 | -.00005 | .00017 | .00030 |
| 23.0 | 12720.6 | .00013 | .00002 | .00016 | .00030 |
| 24.5 | 12820.4 | .00008 | -.00003 | .00019 | .00026 |
| 25.5 | 12907.2 | .00005 | -.00007 | .00023 | .00024 |
| 26.3 | 12986.4 | .00006 | -.00003 | .00021 | .00027 |
| 27.0 | 13054.8 | .00006 | -.00006 | .00020 | .00026 |
| 27.5 | 13096.9 | .00004 | -.00008 | .00022 | .00025 |
| 28.0 | 13126.1 | .00005 | -.00006 | .00025 | .00023 |
| 28.4 | 13132.4 | .00007 | -.00004 | .00026 | .00022 |
| 28.7 | 13123.8 | .00007 | -.00007 | .00023 | .00018 |
| 29.0 | 13100.8 | .00005 | -.00007 | .00021 | .00014 |
| 29.3 | 13059.0 | .00007 | -.00003 | .00018 | .00013 |
| 29.6 | 12995.3 | .00010 | -.00000 | .00016 | .00012 |
| 30.0 | 12869.0 | .00017 | .00003 | .00011 | .00009 |
| 30.5 | 12635.0 | .00024 | .00005 | .00006 | .00007 |
| 31.0 | 12308.5 | .00039 | .00017 | .00000 | -.00000 |
| 31.5 | 11889.9 | .00049 | .00021 | -.00006 | -.00007 |
| 32.0 | 11391.0 | .00061 | .00022 | -.00013 | -.00017 |
| 33.0 | 10240.0 | .00060 | .00030 | -.00031 | -.00037 |
| 34.5 | 8457.0 | .00084 | .00047 | -.00049 | -.00055 |
| 36.0 | 6900.1 | .00107 | .00061 | -.00057 | -.00030 |
| 37.5 | 5669.6 | .00108 | .00086 | -.00081 | -.00045 |
| 39.0 | 4690.2 | .00114 | .00093 | -.00092 | -.00026 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(d) Continued. 280-Ampere current

| RADIUS | G3 | H3 | G6 | H6 | G9 | H9 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | -.00004 | -.00016 | .00000 | .00001 | .00000 | -.00000 |
| 1.0 | -.00025 | -.00124 | -.00001 | .00001 | -.00001 | .00002 |
| 2.0 | -.00196 | -.00980 | .00000 | .00006 | .00001 | .00002 |
| 3.0 | -.00583 | -.03156 | .00008 | .00035 | .00000 | .00002 |
| 4.0 | -.01120 | -.06779 | .00034 | .00145 | -.00001 | .00004 |
| 5.0 | -.01643 | -.11336 | .00065 | .00359 | .00007 | .00014 |
| 6.5 | -.02302 | -.18373 | .00083 | .00651 | .00050 | .00123 |
| 8.0 | -.02955 | -.24415 | .00019 | .00581 | .00169 | .00444 |
| 9.5 | -.03698 | -.29133 | -.00178 | .00027 | .00382 | .00984 |
| 11.0 | -.04619 | -.32725 | -.00526 | -.00946 | .00716 | .01655 |
| 12.5 | -.05727 | -.35406 | -.01025 | -.02211 | .01161 | .02316 |
| 14.0 | -.06939 | -.37348 | -.01657 | -.03592 | .01682 | .02840 |
| 15.5 | -.08109 | -.38729 | -.02392 | -.04894 | .02187 | .03193 |
| 17.0 | -.09171 | -.39683 | -.03188 | -.06033 | .02623 | .03404 |
| 18.5 | -.10125 | -.40254 | -.03998 | -.06954 | .02965 | .03500 |
| 20.0 | -.10985 | -.40480 | -.04828 | -.07660 | .03208 | .03528 |
| 21.5 | -.11792 | -.40272 | -.05688 | -.08108 | .03324 | .03516 |
| 23.0 | -.12602 | -.39512 | -.06626 | -.08222 | .03286 | .03506 |
| 24.5 | -.13454 | -.38011 | -.07702 | -.07890 | .03015 | .03553 |
| 25.5 | -.14076 | -.36483 | -.08536 | -.07341 | .02657 | .03652 |
| 26.3 | -.14616 | -.34897 | -.09295 | -.06686 | .02237 | .03778 |
| 27.0 | -.15112 | -.33239 | -.10018 | -.05940 | .01769 | .03939 |
| 27.5 | -.15469 | -.31906 | -.10553 | -.05308 | .01382 | .04084 |
| 28.0 | -.15812 | -.30450 | -.11094 | -.04600 | .00947 | .04258 |
| 28.4 | -.16066 | -.29231 | -.11510 | -.03997 | .00582 | .04413 |
| 28.7 | -.16233 | -.28290 | -.11804 | -.03528 | .00300 | .04535 |
| 29.0 | -.16372 | -.27331 | -.12082 | -.03057 | .00018 | .04663 |
| 29.3 | -.16482 | -.26361 | -.12328 | -.02582 | -.00259 | .04790 |
| 29.6 | -.16550 | -.25388 | -.12538 | -.02120 | -.00526 | .04915 |
| 30.0 | -.16571 | -.24098 | -.12736 | -.01525 | -.00856 | .05063 |
| 30.5 | -.16453 | -.22504 | -.12847 | -.00862 | -.01202 | .05209 |
| 31.0 | -.16149 | -.20947 | -.12775 | -.00304 | -.01476 | .05287 |
| 31.5 | -.15647 | -.19432 | -.12513 | .00130 | -.01665 | .05283 |
| 32.0 | -.14969 | -.17957 | -.12067 | .00439 | -.01762 | .05178 |
| 33.0 | -.13180 | -.15138 | -.10734 | .00745 | -.01741 | .04716 |
| 34.5 | -.10105 | -.11291 | -.08199 | .00757 | -.01391 | .03629 |
| 36.0 | -.07286 | -.08110 | -.05823 | .00554 | -.00987 | .02529 |
| 37.5 | -.05084 | -.05731 | -.03989 | .00350 | -.00665 | .01654 |
| 39.0 | -.03553 | -.04041 | -.02708 | .00235 | -.00423 | .01055 |

TABLE I. - Concluded. MAIN-FIELD COEFFICIENTS

(d) Concluded. 280-Ampere current

| RADIUS | G12 | H12 | G15 | H15 | G18 | H18 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 1.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 2.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 3.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 4.0 | -.00000 | -.00001 | -.00001 | -.00000 | -.00001 | .00000 |
| 5.0 | -.00002 | -.00003 | -.00000 | .00002 | -.00000 | -.00002 |
| 6.5 | -.00011 | -.00025 | .00004 | .00005 | -.00001 | -.00001 |
| 8.0 | -.00045 | -.00099 | .00006 | .00009 | .00001 | .00000 |
| 9.5 | -.00080 | -.00176 | -.00004 | -.00006 | .00008 | .00011 |
| 11.0 | -.00080 | -.00215 | -.00054 | -.00060 | .00022 | .00030 |
| 12.5 | -.00007 | -.00142 | -.00164 | -.00153 | .00041 | .00047 |
| 14.0 | .00180 | .00065 | -.00330 | -.00254 | .00034 | .00043 |
| 15.5 | .00493 | .00335 | -.00514 | -.00325 | -.00021 | .00022 |
| 17.0 | .00919 | .00622 | -.00684 | -.00354 | -.00139 | -.00001 |
| 18.5 | .01408 | .00881 | -.00803 | -.00340 | -.00305 | -.00010 |
| 20.0 | .01949 | .01092 | -.00858 | -.00299 | -.00513 | .00015 |
| 21.5 | .02487 | .01247 | -.00844 | -.00244 | -.00732 | .00072 |
| 23.0 | .02985 | .01336 | -.00770 | -.00187 | -.00949 | .00170 |
| 24.5 | .03370 | .01352 | -.00642 | -.00160 | -.01126 | .00300 |
| 25.5 | .03513 | .01326 | -.00548 | -.00160 | -.01208 | .00405 |
| 26.3 | .03541 | .01286 | -.00465 | -.00175 | -.01244 | .00496 |
| 27.0 | .03484 | .01241 | -.00403 | -.00204 | -.01254 | .00576 |
| 27.5 | .03388 | .01210 | -.00373 | -.00226 | -.01248 | .00634 |
| 28.0 | .03244 | .01185 | -.00353 | -.00256 | -.01236 | .00688 |
| 28.4 | .03098 | .01170 | -.00346 | -.00280 | -.01217 | .00723 |
| 28.7 | .02971 | .01163 | -.00349 | -.00297 | -.01202 | .00746 |
| 29.0 | .02830 | .01161 | -.00360 | -.00314 | -.01187 | .00765 |
| 29.3 | .02683 | .01165 | -.00374 | -.00330 | -.01168 | .00780 |
| 29.6 | .02532 | .01177 | -.00388 | -.00343 | -.01150 | .00791 |
| 30.0 | .02333 | .01201 | -.00408 | -.00352 | -.01126 | .00797 |
| 30.5 | .02091 | .01237 | -.00429 | -.00347 | -.01089 | .00787 |
| 31.0 | .01871 | .01281 | -.00433 | -.00341 | -.01030 | .00774 |
| 31.5 | .01684 | .01310 | -.00407 | -.00319 | -.00965 | .00736 |
| 32.0 | .01521 | .01330 | -.00359 | -.00289 | -.00890 | .00671 |
| 33.0 | .01270 | .01287 | -.00233 | -.00228 | -.00699 | .00537 |
| 34.5 | .00940 | .01048 | -.00052 | -.00139 | -.00421 | .00346 |
| 36.0 | .00632 | .00751 | .00022 | -.00074 | -.00236 | .00189 |
| 37.5 | .00405 | .00474 | .00037 | -.00054 | -.00122 | .00086 |
| 39.0 | .00266 | .00296 | .00040 | -.00030 | -.00057 | .00047 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(e) 330-Ampere current

| RADIUS (IN.) | B (GAUSS) | G1 | H1 | G2 | H2 |
|---|---|---|---|---|---|
| 0.0 | 13956.2 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | 13940.5 | .00001 | .00003 | -.00002 | .00001 |
| 1.0 | 13895.8 | -.00001 | .00004 | -.00003 | .00001 |
| 2.0 | 13752.0 | -.00000 | -.00004 | .00002 | .00001 |
| 3.0 | 13610.5 | .00011 | -.00025 | .00001 | .00006 |
| 4.0 | 13531.7 | .00022 | -.00014 | -.00008 | .00011 |
| 5.0 | 13515.3 | .00029 | -.00011 | -.00008 | .00004 |
| 6.5 | 13525.2 | .00019 | -.00017 | .00010 | .00000 |
| 8.0 | 13524.3 | .00008 | -.00021 | .00017 | .00013 |
| 9.5 | 13505.2 | .00021 | -.00017 | .00018 | .00023 |
| 11.0 | 13494.8 | .00020 | -.00009 | .00024 | .00019 |
| 12.5 | 13503.7 | .00019 | -.00013 | .00022 | .00027 |
| 14.0 | 13521.7 | .00018 | -.00012 | .00017 | .00034 |
| 15.5 | 13541.8 | .00020 | -.00009 | .00009 | .00030 |
| 17.0 | 13562.3 | .00020 | -.00014 | .00011 | .00028 |
| 18.5 | 13583.6 | .00021 | -.00007 | .00015 | .00029 |
| 20.0 | 13610.9 | .00021 | .00003 | .00012 | .00030 |
| 21.5 | 13650.2 | .00017 | -.00001 | .00014 | .00026 |
| 23.0 | 13709.9 | .00014 | .00000 | .00019 | .00024 |
| 24.5 | 13797.9 | .00012 | .00001 | .00019 | .00027 |
| 25.5 | 13873.3 | .00012 | -.00004 | .00017 | .00024 |
| 26.3 | 13940.0 | .00012 | -.00004 | .00017 | .00021 |
| 27.0 | 13995.5 | .00010 | .00000 | .00018 | .00024 |
| 27.5 | 14026.7 | .00011 | -.00001 | .00019 | .00022 |
| 28.0 | 14041.0 | .00006 | .00002 | .00021 | .00024 |
| 28.4 | 14035.9 | .00006 | -.00000 | .00021 | .00021 |
| 28.7 | 14017.4 | .00010 | -.00000 | .00022 | .00017 |
| 29.0 | 13983.6 | .00010 | -.00001 | .00020 | .00014 |
| 29.3 | 13930.4 | .00012 | .00001 | .00019 | .00010 |
| 29.6 | 13854.5 | .00015 | .00003 | .00017 | .00006 |
| 30.0 | 13711.6 | .00024 | .00006 | .00014 | .00005 |
| 30.5 | 13455.2 | .00031 | .00011 | .00010 | .00005 |
| 31.0 | 13104.6 | .00048 | .00016 | .00004 | -.00001 |
| 31.5 | 12660.7 | .00050 | .00025 | -.00003 | -.00010 |
| 32.0 | 12135.2 | .00066 | .00028 | -.00014 | -.00016 |
| 33.0 | 10928.8 | .00065 | .00040 | -.00030 | -.00037 |
| 34.5 | 9062.3 | .00108 | .00056 | -.00053 | -.00037 |
| 36.0 | 7440.9 | .00125 | .00077 | -.00071 | -.00033 |
| 37.5 | 6134.8 | .00122 | .00090 | -.00083 | -.00023 |
| 39.0 | 5098.1 | .00115 | .00109 | -.00094 | -.00018 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(e) Continued. 330-Ampere current

| RADIUS | G3 | H3 | G6 | H6 | G9 | H9 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | -.00003 | -.00015 | .00000 | .00001 | -.00000 | .00000 |
| 1.0 | -.00024 | -.00118 | -.00001 | .00001 | -.00001 | .00001 |
| 2.0 | -.00188 | -.00936 | .00000 | .00006 | -.00002 | .00003 |
| 3.0 | -.00555 | -.03020 | .00008 | .00032 | .00000 | .00002 |
| 4.0 | -.01083 | -.06523 | .00036 | .00137 | .00002 | .00003 |
| 5.0 | -.01600 | -.10937 | .00071 | .00343 | .00008 | .00017 |
| 6.5 | -.02274 | -.17807 | .00082 | .00633 | .00054 | .00119 |
| 8.0 | -.02948 | -.23793 | .00030 | .00598 | .00175 | .00428 |
| 9.5 | -.03674 | -.28467 | -.00137 | .00106 | .00382 | .00948 |
| 11.0 | -.04550 | -.32002 | -.00475 | -.00804 | .00693 | .01612 |
| 12.5 | -.05625 | -.34629 | -.00952 | -.02022 | .01130 | .02261 |
| 14.0 | -.06808 | -.36531 | -.01548 | -.03346 | .01648 | .02788 |
| 15.5 | -.07949 | -.37879 | -.02241 | -.04596 | .02154 | .03144 |
| 17.0 | -.08981 | -.38810 | -.03003 | -.05692 | .02588 | .03346 |
| 18.5 | -.09908 | -.39397 | -.03778 | -.06597 | .02942 | .03447 |
| 20.0 | -.10745 | -.39641 | -.04570 | -.07286 | .03192 | .03483 |
| 21.5 | -.11542 | -.39484 | -.05395 | -.07730 | .03330 | .03470 |
| 23.0 | -.12339 | -.38813 | -.06287 | -.07867 | .03314 | .03444 |
| 24.5 | -.13177 | -.37457 | -.07307 | -.07588 | .03080 | .03468 |
| 25.5 | -.13787 | -.36062 | -.08091 | -.07088 | .02757 | .03546 |
| 26.3 | -.14322 | -.34598 | -.08803 | -.06470 | .02372 | .03650 |
| 27.0 | -.14814 | -.33046 | -.09479 | -.05760 | .01937 | .03784 |
| 27.5 | -.15161 | -.31789 | -.09982 | -.05161 | .01566 | .03911 |
| 28.0 | -.15495 | -.30415 | -.10475 | -.04484 | .01164 | .04060 |
| 28.4 | -.15739 | -.29251 | -.10866 | -.03907 | .00813 | .04197 |
| 28.7 | -.15900 | -.28346 | -.11141 | -.03456 | .00544 | .04307 |
| 29.0 | -.16035 | -.27421 | -.11399 | -.03002 | .00272 | .04421 |
| 29.3 | -.16140 | -.26484 | -.11627 | -.02545 | .00005 | .04536 |
| 29.6 | -.16203 | -.25540 | -.11821 | -.02101 | -.00254 | .04646 |
| 30.0 | -.16217 | -.24276 | -.12005 | -.01529 | -.00581 | .04779 |
| 30.5 | -.16086 | -.22708 | -.12111 | -.00889 | -.00925 | .04905 |
| 31.0 | -.15777 | -.21165 | -.12037 | -.00354 | -.01195 | .04971 |
| 31.5 | -.15275 | -.19657 | -.11780 | .00067 | -.01386 | .04955 |
| 32.0 | -.14603 | -.18174 | -.11344 | .00360 | -.01485 | .04847 |
| 33.0 | -.12813 | -.15329 | -.10057 | .00651 | -.01489 | .04392 |
| 34.5 | -.09745 | -.11406 | -.07626 | .00640 | -.01202 | .03343 |
| 36.0 | -.06925 | -.08171 | -.05358 | .00455 | -.00835 | .02294 |
| 37.5 | -.04750 | -.05717 | -.03625 | .00278 | -.00543 | .01490 |
| 39.0 | -.03212 | -.03974 | -.02418 | .00150 | -.00357 | .00940 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(e) Concluded. 330-Ampere current

| RADIUS | G12 | H12 | G15 | H15 | G18 | H18 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 1.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 2.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 3.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 4.0 | .00000 | -.00001 | -.00001 | .00000 | .00000 | .00001 |
| 5.0 | -.00002 | -.00004 | .00001 | -.00000 | .00000 | .00001 |
| 6.5 | -.00014 | -.00026 | .00001 | .00005 | .00002 | -.00002 |
| 8.0 | -.00043 | -.00089 | .00003 | .00009 | .00002 | .00000 |
| 9.5 | -.00084 | -.00168 | -.00002 | -.00005 | .00010 | .00008 |
| 11.0 | -.00080 | -.00211 | -.00049 | -.00061 | .00021 | .00030 |
| 12.5 | -.00007 | -.00140 | -.00157 | -.00149 | .00038 | .00046 |
| 14.0 | .00163 | .00059 | -.00320 | -.00250 | .00034 | .00038 |
| 15.5 | .00458 | .00324 | -.00505 | -.00318 | -.00019 | .00016 |
| 17.0 | .00870 | .00590 | -.00667 | -.00345 | -.00129 | -.00002 |
| 18.5 | .01352 | .00843 | -.00791 | -.00328 | -.00294 | -.00007 |
| 20.0 | .01873 | .01051 | -.00853 | -.00292 | -.00494 | .00014 |
| 21.5 | .02403 | .01196 | -.00848 | -.00238 | -.00710 | .00074 |
| 23.0 | .02888 | .01272 | -.00777 | -.00184 | -.00916 | .00172 |
| 24.5 | .03267 | .01287 | -.00659 | -.00149 | -.01092 | .00296 |
| 25.5 | .03406 | .01258 | -.00570 | -.00149 | -.01173 | .00390 |
| 26.3 | .03426 | .01206 | -.00497 | -.00167 | -.01202 | .00476 |
| 27.0 | .03362 | .01155 | -.00440 | -.00187 | -.01206 | .00556 |
| 27.5 | .03265 | .01120 | -.00406 | -.00209 | -.01198 | .00607 |
| 28.0 | .03117 | .01084 | -.00390 | -.00236 | -.01181 | .00657 |
| 28.4 | .02968 | .01066 | -.00385 | -.00258 | -.01163 | .00689 |
| 28.7 | .02839 | .01056 | -.00387 | -.00275 | -.01147 | .00709 |
| 29.0 | .02700 | .01053 | -.00393 | -.00292 | -.01131 | .00724 |
| 29.3 | .02552 | .01053 | -.00406 | -.00305 | -.01113 | .00737 |
| 29.6 | .02399 | .01059 | -.00417 | -.00318 | -.01095 | .00744 |
| 30.0 | .02200 | .01074 | -.00437 | -.00327 | -.01068 | .00748 |
| 30.5 | .01963 | .01107 | -.00455 | -.00329 | -.01030 | .00742 |
| 31.0 | .01748 | .01145 | -.00459 | -.00319 | -.00980 | .00722 |
| 31.5 | .01566 | .01174 | -.00438 | -.00298 | -.00918 | .00688 |
| 32.0 | .01405 | .01190 | -.00398 | -.00274 | -.00837 | .00634 |
| 33.0 | .01158 | .01147 | -.00269 | -.00222 | -.00655 | .00507 |
| 34.5 | .00850 | .00928 | -.00088 | -.00137 | -.00392 | .00321 |
| 36.0 | .00577 | .00649 | -.00003 | -.00076 | -.00225 | .00169 |
| 37.5 | .00373 | .00415 | .00023 | -.00047 | -.00112 | .00077 |
| 39.0 | .00239 | .00257 | .00018 | -.00025 | -.00058 | .00049 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(f) 380-Ampere current

| RADIUS (IN.) | B (GAUSS) | G1 | H1 | G2 | H2 |
|---|---|---|---|---|---|
| 0.0 | 14706.7 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | 14689.6 | .00004 | .00003 | -.00003 | .00001 |
| 1.0 | 14640.7 | .00009 | .00004 | -.00006 | .00002 |
| 2.0 | 14482.7 | .00012 | .00000 | -.00012 | .00004 |
| 3.0 | 14323.8 | .00015 | -.00011 | -.00015 | .00004 |
| 4.0 | 14231.5 | .00019 | -.00021 | -.00010 | .00004 |
| 5.0 | 14205.0 | .00019 | -.00027 | -.00004 | -.00001 |
| 6.5 | 14211.9 | .00020 | -.00022 | -.00006 | -.00001 |
| 8.0 | 14217.9 | .00018 | -.00027 | -.00001 | .00003 |
| 9.5 | 14210.5 | .00014 | -.00008 | -.00003 | .00012 |
| 11.0 | 14212.5 | .00018 | -.00027 | -.00009 | .00021 |
| 12.5 | 14228.9 | .00018 | -.00018 | -.00001 | .00020 |
| 14.0 | 14251.8 | .00021 | -.00004 | -.00000 | .00018 |
| 15.5 | 14275.9 | .00015 | -.00001 | .00015 | .00021 |
| 17.0 | 14297.2 | .00017 | -.00011 | .00010 | .00019 |
| 18.5 | 14317.5 | .00020 | .00004 | .00005 | .00022 |
| 20.0 | 14341.0 | .00021 | .00003 | .00006 | .00023 |
| 21.5 | 14374.7 | .00015 | .00012 | .00009 | .00024 |
| 23.0 | 14425.0 | .00012 | .00007 | .00013 | .00023 |
| 24.5 | 14499.9 | .00012 | .00002 | .00007 | .00027 |
| 25.5 | 14563.4 | .00007 | .00001 | .00012 | .00026 |
| 26.3 | 14618.3 | .00005 | -.00003 | .00015 | .00027 |
| 27.0 | 14661.4 | .00009 | -.00003 | .00025 | .00019 |
| 27.5 | 14682.0 | .00005 | .00003 | .00014 | .00021 |
| 28.0 | 14685.3 | .00005 | .00002 | .00025 | .00021 |
| 28.4 | 14669.6 | .00006 | -.00000 | .00019 | .00015 |
| 28.7 | 14643.3 | .00007 | .00002 | .00018 | .00013 |
| 29.0 | 14600.9 | .00007 | .00005 | .00017 | .00013 |
| 29.3 | 14539.0 | .00008 | .00007 | .00015 | .00011 |
| 29.6 | 14454.0 | .00011 | .00009 | .00011 | .00010 |
| 30.0 | 14298.6 | .00020 | .00010 | .00009 | .00011 |
| 30.5 | 14027.1 | .00029 | .00014 | .00004 | .00006 |
| 31.0 | 13660.7 | .00036 | .00020 | -.00002 | .00002 |
| 31.5 | 13201.1 | .00049 | .00022 | -.00013 | -.00004 |
| 32.0 | 12660.1 | .00052 | .00026 | -.00016 | -.00011 |
| 33.0 | 11423.0 | .00075 | .00038 | -.00036 | -.00038 |
| 34.5 | 9511.3 | .00082 | .00049 | -.00055 | -.00048 |
| 36.0 | 7845.3 | .00105 | .00062 | -.00059 | -.00025 |
| 37.5 | 6499.5 | .00100 | .00072 | -.00075 | -.00035 |
| 39.0 | 5425.4 | .00099 | .00094 | -.00104 | -.00047 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(f) Continued. 380-Ampere current

| RADIUS | G3 | H3 | G6 | H6 | G9 | H9 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | -.00003 | -.00015 | -.00000 | .00000 | .00000 | .00000 |
| 1.0 | -.00023 | -.00114 | -.00000 | .00001 | .00000 | -.00000 |
| 2.0 | -.00182 | -.00899 | -.00000 | .00005 | -.00000 | .00002 |
| 3.0 | -.00538 | -.02900 | .00006 | .00033 | -.00000 | .00002 |
| 4.0 | -.01038 | -.06254 | .00028 | .00130 | .00000 | .00004 |
| 5.0 | -.01549 | -.10518 | .00063 | .00324 | .00008 | .00018 |
| 6.5 | -.02205 | -.17205 | .00085 | .00618 | .00050 | .00119 |
| 8.0 | -.02852 | -.23042 | .00041 | .00632 | .00161 | .00407 |
| 9.5 | -.03598 | -.27637 | -.00111 | .00199 | .00369 | .00903 |
| 11.0 | -.04463 | -.31114 | -.00403 | -.00653 | .00684 | .01541 |
| 12.5 | -.05506 | -.33701 | -.00834 | -.01787 | .01112 | .02191 |
| 14.0 | -.06644 | -.35562 | -.01401 | -.03035 | .01619 | .02717 |
| 15.5 | -.07773 | -.36867 | -.02070 | -.04236 | .02130 | .03068 |
| 17.0 | -.08764 | -.37777 | -.02787 | -.05290 | .02567 | .03291 |
| 18.5 | -.09659 | -.38354 | -.03524 | -.06166 | .02922 | .03402 |
| 20.0 | -.10472 | -.38601 | -.04273 | -.06835 | .03181 | .03434 |
| 21.5 | -.11253 | -.38473 | -.05060 | -.07277 | .03330 | .03419 |
| 23.0 | -.12030 | -.37872 | -.05907 | -.07432 | .03339 | .03393 |
| 24.5 | -.12849 | -.36617 | -.06874 | -.07189 | .03130 | .03394 |
| 25.5 | -.13453 | -.35309 | -.07626 | -.06727 | .02828 | .03448 |
| 26.3 | -.13974 | -.33926 | -.08307 | -.06152 | .02462 | .03535 |
| 27.0 | -.14453 | -.32447 | -.08958 | -.05483 | .02042 | .03653 |
| 27.5 | -.14798 | -.31233 | -.09444 | -.04909 | .01686 | .03763 |
| 28.0 | -.15104 | -.29865 | -.09924 | -.04264 | .01274 | .03889 |
| 28.4 | -.15351 | -.28752 | -.10308 | -.03712 | .00940 | .04021 |
| 28.7 | -.15503 | -.27864 | -.10580 | -.03285 | .00672 | .04121 |
| 29.0 | -.15631 | -.26955 | -.10833 | -.02850 | .00404 | .04226 |
| 29.3 | -.15727 | -.26029 | -.11060 | -.02414 | .00139 | .04332 |
| 29.6 | -.15783 | -.25095 | -.11251 | -.01987 | -.00116 | .04433 |
| 30.0 | -.15788 | -.23842 | -.11436 | -.01444 | -.00437 | .04555 |
| 30.5 | -.15652 | -.22288 | -.11539 | -.00830 | -.00781 | .04672 |
| 31.0 | -.15335 | -.20757 | -.11470 | -.00313 | -.01053 | .04728 |
| 31.5 | -.14832 | -.19252 | -.11219 | .00087 | -.01243 | .04704 |
| 32.0 | -.14146 | -.17779 | -.10793 | .00375 | -.01354 | .04594 |
| 33.0 | -.12373 | -.14928 | -.09528 | .00642 | -.01369 | .04146 |
| 34.5 | -.09298 | -.11013 | -.07159 | .00634 | -.01077 | .03131 |
| 36.0 | -.06501 | -.07768 | -.04969 | .00447 | -.00757 | .02135 |
| 37.5 | -.04343 | -.05331 | -.03305 | .00254 | -.00500 | .01359 |
| 39.0 | -.02833 | -.03619 | -.02178 | .00135 | -.00300 | .00854 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(f) Concluded. 380-Ampere current

| RADIUS | G12 | H12 | G15 | H15 | G18 | H18 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 1.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 2.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 3.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 4.0 | -.00001 | -.00001 | -.00000 | .00001 | -.00000 | .00000 |
| 5.0 | -.00002 | -.00004 | -.00000 | -.00000 | .00001 | -.00000 |
| 6.5 | -.00014 | -.00024 | .00001 | .00004 | -.00001 | -.00001 |
| 8.0 | -.00041 | -.00086 | .00003 | .00008 | .00001 | .00001 |
| 9.5 | -.00080 | -.00158 | -.00003 | -.00009 | .00009 | .00010 |
| 11.0 | -.00085 | -.00199 | -.00051 | -.00056 | .00020 | .00026 |
| 12.5 | -.00027 | -.00144 | -.00151 | -.00142 | .00039 | .00043 |
| 14.0 | .00138 | .00033 | -.00308 | -.00238 | .00035 | .00040 |
| 15.5 | .00424 | .00283 | -.00491 | -.00303 | -.00013 | .00021 |
| 17.0 | .00816 | .00548 | -.00659 | -.00334 | -.00120 | .00001 |
| 18.5 | .01279 | .00795 | -.00783 | -.00325 | -.00279 | -.00007 |
| 20.0 | .01779 | .00992 | -.00848 | -.00286 | -.00469 | .00016 |
| 21.5 | .02291 | .01135 | -.00848 | -.00233 | -.00679 | .00071 |
| 23.0 | .02765 | .01217 | -.00791 | -.00176 | -.00884 | .00160 |
| 24.5 | .03129 | .01223 | -.00679 | -.00138 | -.01048 | .00283 |
| 25.5 | .03265 | .01187 | -.00592 | -.00134 | -.01123 | .00376 |
| 26.3 | .03287 | .01135 | -.00521 | -.00148 | -.01155 | .00460 |
| 27.0 | .03225 | .01082 | -.00469 | -.00170 | -.01163 | .00533 |
| 27.5 | .03127 | .01041 | -.00435 | -.00190 | -.01150 | .00585 |
| 28.0 | .02977 | .01001 | -.00413 | -.00221 | -.01133 | .00628 |
| 28.4 | .02840 | .00980 | -.00412 | -.00245 | -.01116 | .00664 |
| 28.7 | .02715 | .00970 | -.00412 | -.00262 | -.01100 | .00682 |
| 29.0 | .02580 | .00965 | -.00418 | -.00279 | -.01084 | .00697 |
| 29.3 | .02438 | .00964 | -.00428 | -.00295 | -.01067 | .00710 |
| 29.6 | .02292 | .00970 | -.00438 | -.00307 | -.01048 | .00717 |
| 30.0 | .02098 | .00985 | -.00453 | -.00319 | -.01024 | .00722 |
| 30.5 | .01865 | .01013 | -.00467 | -.00319 | -.00988 | .00716 |
| 31.0 | .01657 | .01043 | -.00469 | -.00308 | -.00943 | .00694 |
| 31.5 | .01473 | .01072 | -.00446 | -.00290 | -.00883 | .00658 |
| 32.0 | .01322 | .01083 | -.00402 | -.00263 | -.00813 | .00608 |
| 33.0 | .01084 | .01039 | -.00273 | -.00212 | -.00628 | .00487 |
| 34.5 | .00780 | .00842 | -.00091 | -.00118 | -.00375 | .00302 |
| 36.0 | .00532 | .00593 | -.00027 | -.00071 | -.00201 | .00170 |
| 37.5 | .00329 | .00360 | .00003 | -.00040 | -.00106 | .00071 |
| 39.0 | .00204 | .00216 | .00014 | -.00024 | -.00050 | .00032 |

TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

(g) 430-Ampere current

| RADIUS (IN.) | B (GAUSS) | G1 | H1 | G2 | H2 |
|---|---|---|---|---|---|
| 0.0 | 15315.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | 15296.9 | .00000 | .00001 | -.00001 | -.00000 |
| 1.0 | 15245.7 | .00001 | .00002 | -.00004 | .00000 |
| 2.0 | 15078.7 | .00003 | -.00005 | -.00005 | -.00001 |
| 3.0 | 14907.0 | .00009 | -.00025 | -.00008 | -.00005 |
| 4.0 | 14801.2 | .00017 | -.00031 | -.00009 | -.00004 |
| 5.0 | 14763.7 | .00012 | -.00015 | -.00019 | -.00010 |
| 6.5 | 14763.2 | .00010 | -.00024 | -.00002 | -.00010 |
| 8.0 | 14769.5 | .00004 | -.00024 | -.00005 | -.00003 |
| 9.5 | 14767.8 | .00010 | -.00015 | -.00003 | .00004 |
| 11.0 | 14775.2 | .00013 | -.00009 | -.00002 | .00004 |
| 12.5 | 14799.1 | .00012 | -.00009 | .00002 | .00009 |
| 14.0 | 14827.2 | .00008 | -.00006 | .00004 | .00012 |
| 15.5 | 14852.3 | .00014 | -.00003 | .00003 | .00013 |
| 17.0 | 14874.2 | .00011 | .00005 | .00007 | .00015 |
| 18.5 | 14892.5 | .00010 | .00004 | .00005 | .00017 |
| 20.0 | 14912.5 | .00011 | .00005 | .00003 | .00018 |
| 21.5 | 14939.7 | .00012 | .00009 | .00002 | .00020 |
| 23.0 | 14980.9 | .00010 | .00005 | .00008 | .00018 |
| 24.5 | 15042.6 | .00008 | .00006 | .00009 | .00021 |
| 25.5 | 15094.7 | .00008 | .00004 | .00009 | .00020 |
| 26.3 | 15138.6 | .00007 | .00007 | .00007 | .00021 |
| 27.0 | 15170.3 | .00008 | .00005 | .00009 | .00021 |
| 27.5 | 15181.5 | .00008 | .00001 | .00012 | .00021 |
| 28.0 | 15175.6 | .00008 | .00001 | .00017 | .00018 |
| 28.4 | 15152.0 | .00006 | .00004 | .00018 | .00017 |
| 28.7 | 15119.0 | .00006 | .00006 | .00016 | .00014 |
| 29.0 | 15069.8 | .00005 | .00007 | .00015 | .00010 |
| 29.3 | 15001.0 | .00005 | .00009 | .00012 | .00006 |
| 29.6 | 14909.3 | .00007 | .00012 | .00009 | .00003 |
| 30.0 | 14744.5 | .00017 | .00016 | .00008 | .00005 |
| 30.5 | 14461.9 | .00022 | .00025 | .00000 | .00003 |
| 31.0 | 14084.8 | .00027 | .00035 | -.00007 | .00000 |
| 31.5 | 13614.4 | .00048 | .00043 | -.00011 | -.00009 |
| 32.0 | 13062.4 | .00036 | .00050 | -.00022 | -.00012 |
| 33.0 | 11804.5 | .00054 | .00065 | -.00041 | -.00045 |
| 34.5 | 9862.2 | .00079 | .00070 | -.00052 | -.00045 |
| 36.0 | 8168.8 | .00077 | .00095 | -.00069 | -.00029 |
| 37.5 | 6794.9 | .00078 | .00110 | -.00083 | -.00038 |
| 39.0 | 5692.6 | .00080 | .00121 | -.00099 | -.00028 |

## TABLE I. - Continued. MAIN-FIELD COEFFICIENTS

### (g) Continued. 430-Ampere current

| RADIUS | G3 | H3 | G6 | H6 | G9 | H9 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | -.00003 | -.00014 | -.00000 | .00001 | .00000 | .00000 |
| 1.0 | -.00023 | -.00109 | -.00000 | .00000 | -.00000 | .00001 |
| 2.0 | -.00175 | -.00860 | -.00000 | .00005 | -.00001 | .00002 |
| 3.0 | -.00514 | -.02778 | .00007 | .00031 | .00001 | .00000 |
| 4.0 | -.01004 | -.06006 | .00032 | .00128 | .00002 | .00004 |
| 5.0 | -.01502 | -.10130 | .00066 | .00321 | .00007 | .00015 |
| 6.5 | -.02153 | -.16603 | .00085 | .00618 | .00049 | .00112 |
| 8.0 | -.02796 | -.22310 | .00059 | .00658 | .00156 | .00387 |
| 9.5 | -.03513 | -.26812 | -.00074 | .00281 | .00358 | .00863 |
| 11.0 | -.04363 | -.30239 | -.00336 | -.00489 | .00663 | .01487 |
| 12.5 | -.05388 | -.32782 | -.00751 | -.01560 | .01078 | .02115 |
| 14.0 | -.06505 | -.34610 | -.01275 | -.02756 | .01584 | .02631 |
| 15.5 | -.07575 | -.35899 | -.01895 | -.03893 | .02080 | .02994 |
| 17.0 | -.08553 | -.36784 | -.02584 | -.04905 | .02519 | .03213 |
| 18.5 | -.09429 | -.37353 | -.03286 | -.05748 | .02887 | .03328 |
| 20.0 | -.10216 | -.37606 | -.03996 | -.06402 | .03156 | .03371 |
| 21.5 | -.10970 | -.37502 | -.04745 | -.06840 | .03313 | .03362 |
| 23.0 | -.11735 | -.36942 | -.05560 | -.07004 | .03337 | .03326 |
| 24.5 | -.12541 | -.35763 | -.06494 | -.06796 | .03152 | .03322 |
| 25.5 | -.13131 | -.34516 | -.07222 | -.06371 | .02865 | .03365 |
| 26.3 | -.13643 | -.33182 | -.07885 | -.05831 | .02512 | .03437 |
| 27.0 | -.14106 | -.31750 | -.08525 | -.05206 | .02102 | .03541 |
| 27.5 | -.14437 | -.30570 | -.09005 | -.04667 | .01751 | .03642 |
| 28.0 | -.14746 | -.29253 | -.09484 | -.04054 | .01357 | .03764 |
| 28.4 | -.14972 | -.28137 | -.09865 | -.03531 | .01018 | .03880 |
| 28.7 | -.15120 | -.27267 | -.10136 | -.03123 | .00756 | .03976 |
| 29.0 | -.15242 | -.26373 | -.10386 | -.02706 | .00493 | .04073 |
| 29.3 | -.15334 | -.25460 | -.10612 | -.02288 | .00232 | .04171 |
| 29.6 | -.15383 | -.24534 | -.10804 | -.01877 | -.00022 | .04266 |
| 30.0 | -.15381 | -.23290 | -.10990 | -.01353 | -.00341 | .04380 |
| 30.5 | -.15236 | -.21745 | -.11097 | -.00764 | -.00684 | .04491 |
| 31.0 | -.14914 | -.20221 | -.11034 | -.00265 | -.00956 | .04542 |
| 31.5 | -.14409 | -.18723 | -.10789 | .00119 | -.01145 | .04515 |
| 32.0 | -.13717 | -.17256 | -.10371 | .00399 | -.01253 | .04407 |
| 33.0 | -.11947 | -.14418 | -.09124 | .00655 | -.01276 | .03967 |
| 34.5 | -.08895 | -.10517 | -.06796 | .00633 | -.01009 | .02972 |
| 36.0 | -.06134 | -.07317 | -.04672 | .00443 | -.00701 | .02001 |
| 37.5 | -.04007 | -.04918 | -.03066 | .00247 | -.00449 | .01262 |
| 39.0 | -.02546 | -.03226 | -.01984 | .00136 | -.00271 | .00776 |

TABLE I. - Concluded. MAIN-FIELD COEFFICIENTS

(g) Concluded. 430-Ampere current

| RADIUS | G12 | H12 | G15 | H15 | G18 | H18 |
|---|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| .5 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 1.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 2.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 3.0 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| 4.0 | .00000 | -.00001 | -.00001 | .00001 | -.00001 | .00001 |
| 5.0 | -.00001 | -.00004 | .00000 | .00000 | .00001 | .00000 |
| 6.5 | -.00012 | -.00024 | .00003 | .00004 | .00001 | .00001 |
| 8.0 | -.00040 | -.00079 | .00004 | .00006 | -.00001 | -.00001 |
| 9.5 | -.00078 | -.00150 | -.00003 | -.00006 | .00006 | .00007 |
| 11.0 | -.00090 | -.00193 | -.00047 | -.00055 | .00020 | .00026 |
| 12.5 | -.00029 | -.00145 | -.00146 | -.00135 | .00035 | .00041 |
| 14.0 | .00122 | .00028 | -.00295 | -.00226 | .00032 | .00036 |
| 15.5 | .00383 | .00260 | -.00472 | -.00293 | -.00012 | .00019 |
| 17.0 | .00756 | .00508 | -.00634 | -.00321 | -.00109 | -.00001 |
| 18.5 | .01201 | .00740 | -.00763 | -.00309 | -.00258 | -.00004 |
| 20.0 | .01680 | .00938 | -.00839 | -.00272 | -.00444 | .00015 |
| 21.5 | .02172 | .01078 | -.00847 | -.00223 | -.00645 | .00066 |
| 23.0 | .02636 | .01148 | -.00794 | -.00168 | -.00842 | .00159 |
| 24.5 | .02998 | .01158 | -.00693 | -.00131 | -.01010 | .00276 |
| 25.5 | .03135 | .01122 | -.00610 | -.00127 | -.01085 | .00367 |
| 26.3 | .03158 | .01071 | -.00541 | -.00136 | -.01116 | .00451 |
| 27.0 | .03105 | .01014 | -.00484 | -.00162 | -.01123 | .00522 |
| 27.5 | .03014 | .00976 | -.00453 | -.00183 | -.01116 | .00571 |
| 28.0 | .02875 | .00937 | -.00433 | -.00211 | -.01097 | .00617 |
| 28.4 | .02738 | .00916 | -.00427 | -.00235 | -.01081 | .00647 |
| 28.7 | .02620 | .00904 | -.00425 | -.00251 | -.01069 | .00666 |
| 29.0 | .02488 | .00896 | -.00430 | -.00267 | -.01054 | .00680 |
| 29.3 | .02350 | .00892 | -.00440 | -.00280 | -.01037 | .00692 |
| 29.6 | .02206 | .00897 | -.00450 | -.00293 | -.01020 | .00699 |
| 30.0 | .02019 | .00913 | -.00466 | -.00304 | -.00996 | .00704 |
| 30.5 | .01792 | .00941 | -.00481 | -.00308 | -.00959 | .00698 |
| 31.0 | .01588 | .00971 | -.00484 | -.00299 | -.00912 | .00679 |
| 31.5 | .01410 | .01000 | -.00464 | -.00279 | -.00853 | .00641 |
| 32.0 | .01260 | .01014 | -.00422 | -.00256 | -.00784 | .00597 |
| 33.0 | .01026 | .00969 | -.00298 | -.00204 | -.00600 | .00478 |
| 34.5 | .00732 | .00781 | -.00109 | -.00117 | -.00357 | .00301 |
| 36.0 | .00485 | .00544 | -.00033 | -.00057 | -.00207 | .00159 |
| 37.5 | .00304 | .00339 | .00000 | -.00048 | -.00106 | .00065 |
| 39.0 | .00187 | .00192 | .00014 | -.00023 | -.00055 | .00033 |

## TABLE II. - TRIM-COIL FIELDS

[Gauss-per-100-A trim-coil current.]

(a) 130-Ampere main-magnet current

| RADIUS (IN.) | COIL NO. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 274.9 | 266.5 | 242.5 | 217.3 | 193.6 | 169.5 | 147.1 | 123.9 |
| 1.0 | 270.8 | 265.2 | 241.6 | 216.3 | 192.8 | 168.8 | 146.5 | 123.3 |
| 2.0 | 259.1 | 262.5 | 239.6 | 213.9 | 190.8 | 167.2 | 145.1 | 122.1 |
| 3.0 | 237.4 | 260.8 | 237.8 | 211.7 | 189.0 | 165.6 | 143.7 | 120.8 |
| 4.0 | 203.3 | 259.3 | 237.1 | 210.5 | 188.1 | 164.8 | 142.9 | 120.1 |
| 5.0 | 155.7 | 257.0 | 237.7 | 210.3 | 187.9 | 164.4 | 142.6 | 119.8 |
| 6.0 | 103.2 | 251.0 | 238.6 | 210.6 | 187.9 | 163.9 | 142.3 | 119.5 |
| 7.0 | 57.0 | 238.3 | 238.6 | 210.9 | 187.9 | 163.0 | 141.8 | 119.1 |
| 8.0 | 26.1 | 213.7 | 236.8 | 211.0 | 187.6 | 161.9 | 141.1 | 118.5 |
| 9.0 | 10.3 | 172.0 | 233.9 | 210.8 | 187.3 | 161.0 | 140.6 | 118.0 |
| 10.0 | 1.4 | 117.5 | 229.1 | 210.4 | 187.1 | 160.6 | 140.1 | 117.7 |
| 11.0 | -2.1 | 67.3 | 221.0 | 209.9 | 186.9 | 160.7 | 139.7 | 117.5 |
| 12.0 | -3.0 | 28.3 | 197.8 | 209.4 | 187.0 | 161.4 | 139.6 | 117.5 |
| 13.0 | -3.8 | 8.4 | 161.9 | 209.6 | 186.9 | 162.2 | 139.5 | 117.7 |
| 14.0 | -3.6 | -.4 | 111.9 | 206.8 | 187.2 | 162.8 | 139.7 | 117.9 |
| 15.0 | -3.4 | -5.1 | 60.6 | 196.8 | 187.4 | 163.1 | 140.1 | 118.3 |
| 16.0 | -3.5 | -7.2 | 22.8 | 174.2 | 186.9 | 163.3 | 140.9 | 118.8 |
| 17.0 | -3.4 | -7.9 | 3.2 | 138.0 | 186.4 | 163.7 | 141.8 | 119.3 |
| 18.0 | -3.4 | -7.1 | -5.0 | 89.5 | 182.5 | 165.1 | 142.8 | 119.8 |
| 19.0 | -3.3 | -6.4 | -9.3 | 43.4 | 170.8 | 165.8 | 143.4 | 120.2 |
| 20.0 | -3.2 | -6.4 | -11.2 | 10.9 | 142.9 | 165.0 | 143.8 | 120.3 |
| 21.0 | -3.0 | -6.5 | -11.6 | -4.2 | 103.8 | 161.2 | 144.0 | 120.3 |
| 22.0 | -2.8 | -6.6 | -10.5 | -9.9 | 58.1 | 153.0 | 143.5 | 120.3 |
| 23.0 | -2.6 | -6.7 | -9.5 | -12.3 | 20.3 | 133.5 | 143.1 | 120.6 |
| 24.0 | -2.6 | -6.6 | -9.3 | -12.8 | -.1 | 100.3 | 140.4 | 121.6 |
| 25.0 | -2.6 | -6.4 | -9.3 | -12.9 | -11.1 | 57.8 | 132.7 | 122.4 |
| 26.0 | -2.8 | -6.2 | -9.3 | -12.1 | -14.1 | 21.9 | 116.3 | 123.0 |
| 27.0 | -3.0 | -6.0 | -9.4 | -11.6 | -15.2 | .0 | 87.1 | 121.1 |
| 28.0 | -3.1 | -6.0 | -9.6 | -11.6 | -15.2 | -9.9 | 49.5 | 114.2 |
| 29.0 | -3.3 | -6.0 | -9.8 | -11.9 | -14.8 | -14.8 | 18.4 | 99.1 |
| 30.0 | -3.4 | -6.0 | -9.9 | -12.0 | -13.8 | -15.1 | -3.6 | 69.3 |
| 31.0 | -3.3 | -5.8 | -9.6 | -11.8 | -12.7 | -13.6 | -8.7 | 38.3 |
| 32.0 | -3.1 | -5.5 | -8.8 | -11.0 | -11.6 | -13.1 | -13.5 | 12.6 |
| 33.0 | -2.9 | -5.1 | -7.8 | -10.0 | -10.6 | -12.5 | -13.2 | -1.5 |
| 34.0 | -2.6 | -4.7 | -6.7 | -8.8 | -9.6 | -12.0 | -11.2 | -5.6 |
| 35.0 | -2.3 | -4.3 | -5.6 | -7.8 | -8.8 | -11.6 | -10.0 | -7.1 |
| 36.0 | -2.0 | -4.0 | -4.6 | -6.8 | -8.2 | -11.3 | -8.8 | -7.0 |
| 37.0 | -1.8 | -3.7 | -3.8 | -6.0 | -7.7 | -11.2 | -7.9 | -6.0 |
| 38.0 | -1.6 | -3.5 | -3.1 | -5.3 | -7.4 | -11.1 | -7.0 | -4.3 |
| 39.0 | -1.4 | -3.3 | -2.5 | -4.6 | -7.1 | -11.1 | -6.3 | -2.2 |

TABLE II. - Continued. TRIM-COIL FIELDS

[Gauss-per-100-A trim-coil current.]

(b) 230-Ampere main-magnet current

| RADIUS (IN.) | COIL NO. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 263.8 | 250.6 | 222.9 | 194.6 | 168.3 | 142.5 | 119.5 | 96.9 |
| 1.0 | 259.9 | 249.4 | 221.8 | 193.5 | 167.3 | 141.7 | 118.8 | 96.3 |
| 2.0 | 248.3 | 246.5 | 219.2 | 190.9 | 165.1 | 139.8 | 117.2 | 95.0 |
| 3.0 | 226.8 | 243.8 | 216.9 | 188.4 | 162.9 | 138.0 | 115.6 | 93.6 |
| 4.0 | 192.9 | 241.7 | 216.1 | 187.1 | 161.8 | 137.0 | 114.6 | 92.8 |
| 5.0 | 146.6 | 240.0 | 217.3 | 187.2 | 161.8 | 136.8 | 114.4 | 92.6 |
| 6.0 | 96.0 | 235.5 | 219.3 | 188.4 | 162.7 | 137.0 | 114.6 | 92.7 |
| 7.0 | 52.0 | 225.1 | 220.7 | 190.0 | 163.9 | 137.3 | 115.0 | 92.9 |
| 8.0 | 22.7 | 202.4 | 220.5 | 191.5 | 165.0 | 137.7 | 115.3 | 93.1 |
| 9.0 | 7.5 | 162.5 | 219.4 | 192.5 | 165.8 | 138.1 | 115.6 | 93.4 |
| 10.0 | -.1 | 110.2 | 216.0 | 193.3 | 166.4 | 138.5 | 115.9 | 93.6 |
| 11.0 | -3.1 | 60.9 | 208.4 | 194.0 | 167.0 | 139.1 | 116.2 | 93.9 |
| 12.0 | -3.9 | 23.5 | 187.2 | 194.1 | 167.6 | 140.0 | 116.6 | 94.3 |
| 13.0 | -4.4 | 3.8 | 151.6 | 194.5 | 168.2 | 141.0 | 117.0 | 94.7 |
| 14.0 | -4.2 | -4.8 | 102.3 | 192.0 | 169.1 | 141.8 | 117.5 | 95.2 |
| 15.0 | -4.0 | -8.7 | 52.2 | 182.9 | 169.9 | 142.5 | 118.1 | 95.6 |
| 16.0 | -4.0 | -10.0 | 15.5 | 161.5 | 169.7 | 143.0 | 118.8 | 96.0 |
| 17.0 | -3.9 | -10.5 | -4.0 | 125.4 | 169.5 | 143.7 | 119.5 | 96.4 |
| 18.0 | -3.8 | -9.8 | -12.0 | 77.5 | 165.5 | 144.8 | 120.2 | 96.7 |
| 19.0 | -3.7 | -9.1 | -15.5 | 32.2 | 153.9 | 145.4 | 120.7 | 97.0 |
| 20.0 | -3.6 | -8.9 | -16.6 | 1.1 | 128.0 | 145.1 | 121.4 | 97.3 |
| 21.0 | -3.5 | -8.8 | -16.7 | -13.8 | 88.9 | 142.1 | 122.0 | 97.5 |
| 22.0 | -3.4 | -8.7 | -15.6 | -19.5 | 43.6 | 134.3 | 121.9 | 97.8 |
| 23.0 | -3.3 | -8.6 | -14.7 | -21.5 | 6.9 | 115.5 | 121.6 | 98.1 |
| 24.0 | -3.2 | -8.5 | -14.3 | -21.5 | -13.3 | 82.7 | 119.1 | 98.8 |
| 25.0 | -3.2 | -8.3 | -14.1 | -21.2 | -23.0 | 41.3 | 112.1 | 99.2 |
| 26.0 | -3.1 | -8.0 | -13.9 | -20.3 | -25.7 | 5.9 | 96.0 | 99.0 |
| 27.0 | -3.1 | -7.9 | -13.8 | -19.5 | -26.2 | -15.5 | 66.9 | 96.5 |
| 28.0 | -3.1 | -7.7 | -13.6 | -19.1 | -25.8 | -24.7 | 30.3 | 89.5 |
| 29.0 | -3.1 | -7.6 | -13.5 | -18.7 | -25.0 | -28.3 | -.4 | 73.7 |
| 30.0 | -3.1 | -7.4 | -13.1 | -18.2 | -23.6 | -28.2 | -19.1 | 46.3 |
| 31.0 | -3.0 | -7.0 | -12.4 | -17.3 | -21.9 | -26.3 | -25.0 | 16.0 |
| 32.0 | -2.8 | -6.5 | -11.4 | -16.0 | -20.0 | -24.5 | -26.8 | -7.0 |
| 33.0 | -2.6 | -5.8 | -10.2 | -14.4 | -18.0 | -22.3 | -25.1 | -17.7 |
| 34.0 | -2.4 | -5.2 | -8.9 | -12.7 | -16.1 | -20.1 | -22.1 | -20.1 |
| 35.0 | -2.1 | -4.6 | -7.7 | -11.3 | -14.4 | -18.1 | -19.5 | -19.4 |
| 36.0 | -2.0 | -4.1 | -6.7 | -10.0 | -13.1 | -16.4 | -16.9 | -17.6 |
| 37.0 | -1.8 | -3.7 | -5.9 | -8.9 | -12.0 | -15.0 | -14.6 | -15.2 |
| 38.0 | -1.7 | -3.3 | -5.1 | -8.0 | -11.1 | -13.8 | -12.5 | -12.4 |
| 39.0 | -1.5 | -3.0 | -4.5 | -7.3 | -10.5 | -12.9 | -10.7 | -9.6 |

TABLE II. - Continued. TRIM-COIL FIELDS

[Gauss-per-100-A trim-coil current.]

(c) 330-Ampere main-magnet current

| RADIUS (IN.) | COIL NO. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 240.3 | 219.1 | 187.4 | 157.4 | 130.5 | 105.8 | 84.6 | 66.0 |
| 1.0 | 237.5 | 218.3 | 186.4 | 156.4 | 129.6 | 105.1 | 84.0 | 65.5 |
| 2.0 | 227.5 | 216.1 | 184.2 | 154.3 | 127.7 | 103.5 | 82.6 | 64.4 |
| 3.0 | 208.7 | 213.7 | 182.3 | 152.2 | 125.8 | 101.9 | 81.3 | 63.2 |
| 4.0 | 177.1 | 211.7 | 181.8 | 151.2 | 124.9 | 101.0 | 80.5 | 62.5 |
| 5.0 | 133.5 | 210.3 | 183.1 | 151.8 | 125.2 | 101.2 | 80.5 | 62.4 |
| 6.0 | 85.6 | 206.8 | 185.4 | 153.6 | 126.6 | 102.1 | 81.3 | 62.9 |
| 7.0 | 44.2 | 198.4 | 187.7 | 156.0 | 128.4 | 103.5 | 82.4 | 63.8 |
| 8.0 | 16.8 | 178.5 | 189.5 | 158.7 | 130.5 | 105.1 | 83.6 | 64.8 |
| 9.0 | 2.9 | 142.6 | 191.5 | 161.2 | 132.5 | 106.7 | 84.9 | 65.8 |
| 10.0 | -2.8 | 95.4 | 191.2 | 164.1 | 134.5 | 108.2 | 86.0 | 66.6 |
| 11.0 | -4.9 | 49.1 | 185.4 | 167.2 | 136.8 | 109.7 | 87.1 | 67.4 |
| 12.0 | -5.3 | 15.3 | 167.9 | 169.2 | 139.1 | 111.3 | 88.2 | 68.3 |
| 13.0 | -5.6 | -2.9 | 134.3 | 170.7 | 141.1 | 112.9 | 89.3 | 69.1 |
| 14.0 | -5.3 | -10.5 | 87.4 | 169.2 | 143.4 | 114.5 | 90.4 | 70.0 |
| 15.0 | -4.9 | -13.2 | 40.3 | 161.9 | 145.4 | 116.0 | 91.5 | 70.8 |
| 16.0 | -4.8 | -13.4 | 5.8 | 142.9 | 146.2 | 117.4 | 92.5 | 71.4 |
| 17.0 | -4.5 | -13.3 | -12.4 | 108.1 | 146.5 | 118.7 | 93.6 | 72.1 |
| 18.0 | -4.3 | -12.5 | -19.8 | 62.0 | 143.2 | 120.3 | 94.5 | 72.6 |
| 19.0 | -4.1 | -11.7 | -22.0 | 18.9 | 133.0 | 121.4 | 95.5 | 73.2 |
| 20.0 | -3.9 | -11.2 | -21.9 | -9.9 | 109.4 | 121.9 | 96.7 | 73.8 |
| 21.0 | -3.8 | -10.8 | -21.5 | -23.7 | 71.5 | 119.9 | 97.8 | 74.5 |
| 22.0 | -3.7 | -10.3 | -20.4 | -28.7 | 27.9 | 113.0 | 98.3 | 75.1 |
| 23.0 | -3.6 | -9.9 | -19.3 | -29.8 | -6.7 | 95.8 | 98.7 | 75.8 |
| 24.0 | -3.4 | -9.5 | -18.4 | -29.0 | -25.8 | 64.5 | 97.0 | 76.6 |
| 25.0 | -3.3 | -9.1 | -17.6 | -28.1 | -33.5 | 25.1 | 91.1 | 77.0 |
| 26.0 | -3.1 | -8.7 | -16.8 | -26.6 | -35.3 | -8.7 | 76.1 | 77.1 |
| 27.0 | -2.9 | -8.4 | -16.1 | -25.2 | -34.8 | -28.0 | 49.2 | 75.1 |
| 28.0 | -2.8 | -8.1 | -15.5 | -24.0 | -33.1 | -35.9 | 14.7 | 68.5 |
| 29.0 | -2.6 | -7.8 | -14.7 | -22.6 | -31.4 | -37.2 | -13.5 | 54.0 |
| 30.0 | -2.5 | -7.4 | -13.9 | -21.1 | -29.1 | -36.0 | -29.2 | 28.9 |
| 31.0 | -2.4 | -6.9 | -12.8 | -19.5 | -26.7 | -33.4 | -34.4 | .7 |
| 32.0 | -2.2 | -6.3 | -11.7 | -17.7 | -24.3 | -30.8 | -34.6 | -19.5 |
| 33.0 | -2.0 | -5.5 | -10.4 | -15.8 | -21.8 | -27.7 | -32.3 | -28.4 |
| 34.0 | -1.8 | -4.9 | -9.2 | -14.1 | -19.5 | -24.8 | -29.0 | -29.7 |
| 35.0 | -1.6 | -4.3 | -8.2 | -12.6 | -17.7 | -22.2 | -25.7 | -27.6 |
| 36.0 | -1.5 | -3.8 | -7.3 | -11.4 | -16.2 | -20.0 | -22.4 | -24.7 |
| 37.0 | -1.4 | -3.3 | -6.6 | -10.5 | -15.1 | -18.2 | -19.3 | -21.4 |
| 38.0 | -1.3 | -3.0 | -6.1 | -9.8 | -14.3 | -16.8 | -16.4 | -17.9 |
| 39.0 | -1.3 | -2.7 | -5.6 | -9.2 | -13.6 | -15.6 | -13.8 | -14.4 |

TABLE II. - Concluded. TRIM-COIL FIELDS

[Gauss-per-100-A trim-coil current.]

(d) 430-Ampere main-magnet current

| RADIUS (IN.) | COIL NO. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 216.5 | 189.9 | 158.4 | 130.8 | 106.9 | 85.6 | 68.1 | 53.0 |
| 1.0 | 214.5 | 190.1 | 158.1 | 130.3 | 106.5 | 85.2 | 67.7 | 52.8 |
| 2.0 | 207.5 | 189.8 | 157.6 | 129.3 | 105.5 | 84.4 | 67.0 | 52.1 |
| 3.0 | 192.0 | 189.6 | 157.4 | 128.6 | 104.8 | 83.6 | 66.3 | 51.4 |
| 4.0 | 163.9 | 189.6 | 158.0 | 128.7 | 104.7 | 83.3 | 65.9 | 51.1 |
| 5.0 | 123.2 | 189.5 | 159.6 | 129.8 | 105.3 | 83.7 | 66.1 | 51.1 |
| 6.0 | 77.7 | 187.1 | 162.0 | 131.5 | 106.4 | 84.4 | 66.6 | 51.5 |
| 7.0 | 38.4 | 180.0 | 164.5 | 133.5 | 107.8 | 85.4 | 67.3 | 51.9 |
| 8.0 | 12.4 | 161.6 | 166.6 | 135.9 | 109.4 | 86.6 | 68.0 | 52.5 |
| 9.0 | -.2 | 127.9 | 169.4 | 138.6 | 111.3 | 87.9 | 68.9 | 53.1 |
| 10.0 | -4.9 | 83.4 | 170.1 | 142.1 | 113.6 | 89.3 | 69.9 | 53.7 |
| 11.0 | -6.4 | 40.2 | 166.1 | 145.9 | 116.3 | 91.0 | 71.0 | 54.5 |
| 12.0 | -6.3 | 9.0 | 151.0 | 148.9 | 119.1 | 92.9 | 72.3 | 55.4 |
| 13.0 | -6.2 | -7.3 | 120.1 | 151.6 | 121.8 | 94.9 | 73.7 | 56.3 |
| 14.0 | -5.6 | -13.5 | 76.2 | 151.5 | 124.8 | 96.9 | 75.1 | 57.3 |
| 15.0 | -5.1 | -15.2 | 31.9 | 145.8 | 127.7 | 98.8 | 76.4 | 58.1 |
| 16.0 | -4.7 | -14.7 | -.1 | 128.9 | 129.4 | 100.8 | 77.6 | 58.9 |
| 17.0 | -4.4 | -14.2 | -16.8 | 96.2 | 130.7 | 102.7 | 78.9 | 59.6 |
| 18.0 | -4.1 | -13.1 | -22.9 | 52.6 | 128.5 | 104.8 | 80.1 | 60.4 |
| 19.0 | -3.9 | -12.1 | -24.2 | 11.9 | 119.6 | 106.4 | 81.4 | 61.1 |
| 20.0 | -3.6 | -11.3 | -23.2 | -14.9 | 98.0 | 107.9 | 83.0 | 62.0 |
| 21.0 | -3.4 | -10.7 | -22.3 | -27.3 | 62.1 | 106.9 | 84.6 | 63.0 |
| 22.0 | -3.2 | -10.0 | -20.8 | -31.1 | 20.9 | 101.1 | 85.7 | 63.9 |
| 23.0 | -3.1 | -9.5 | -19.4 | -31.3 | -11.7 | 85.5 | 86.7 | 64.9 |
| 24.0 | -2.9 | -8.9 | -18.2 | -29.8 | -29.2 | 56.2 | 85.8 | 66.0 |
| 25.0 | -2.7 | -8.3 | -17.0 | -28.3 | -35.6 | 18.9 | 81.0 | 66.8 |
| 26.0 | -2.6 | -7.8 | -16.0 | -26.4 | -36.4 | -12.8 | 67.6 | 67.2 |
| 27.0 | -2.4 | -7.3 | -15.0 | -24.6 | -34.9 | -30.7 | 42.2 | 65.7 |
| 28.0 | -2.3 | -6.9 | -14.1 | -23.0 | -32.6 | -36.9 | 10.2 | 60.4 |
| 29.0 | -2.2 | -6.6 | -13.3 | -21.3 | -30.4 | -37.4 | -16.5 | 46.8 |
| 30.0 | -2.1 | -6.2 | -12.4 | -19.7 | -28.0 | -35.8 | -30.8 | 23.4 |
| 31.0 | -1.9 | -5.8 | -11.4 | -18.0 | -25.6 | -33.1 | -35.5 | -3.6 |
| 32.0 | -1.8 | -5.3 | -10.3 | -16.3 | -23.2 | -30.4 | -35.4 | -22.8 |
| 33.0 | -1.6 | -4.8 | -9.3 | -14.7 | -20.9 | -27.5 | -33.1 | -31.0 |
| 34.0 | -1.5 | -4.3 | -8.3 | -13.2 | -19.0 | -24.8 | -29.9 | -31.8 |
| 35.0 | -1.3 | -3.9 | -7.5 | -12.1 | -17.4 | -22.5 | -26.7 | -29.6 |
| 36.0 | -1.2 | -3.5 | -6.9 | -11.1 | -16.2 | -20.5 | -23.4 | -26.5 |
| 37.0 | -1.1 | -3.3 | -6.4 | -10.5 | -15.3 | -19.0 | -20.4 | -22.9 |
| 38.0 | -1.1 | -3.1 | -6.0 | -10.0 | -14.7 | -17.8 | -17.6 | -19.1 |
| 39.0 | -1.0 | -2.9 | -5.7 | -9.6 | -14.3 | -16.8 | -15.1 | -15.3 |

TABLE III. - INNER-HARMONIC-COIL INCREMENTAL FIELDS

[First-harmonic amplitudes, Gauss per 100 A; effective angular location of coil 1, +0.12 radians.]

| RADIUS (in.) | MAIN-FIELD AMPERES 130 | 230 | 330 | 430 |
|---|---|---|---|---|
| [a]0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.0 | 5.1 | 5.2 | 5.0 | 4.8 |
| 2.0 | 11.4 | 11.4 | 11.1 | 10.6 |
| 3.0 | 19.0 | 19.1 | 18.6 | 17.8 |
| 4.0 | 26.1 | 26.0 | 25.5 | 24.5 |
| 5.0 | 28.8 | 28.7 | 28.6 | 26.9 |
| 6.0 | 25.3 | 25.2 | 25.2 | 23.3 |
| 7.0 | 17.8 | 17.7 | 17.7 | 16.1 |
| 8.0 | 10.3 | 10.1 | 10.2 | 9.2 |
| 9.0 | 5.2 | 5.1 | 5.0 | 4.7 |
| [a]10.0 | 2.5 | 2.4 | 2.1 | 2.0 |
| [a]11.0 | 1.0 | 1.0 | .9 | .8 |
| [a]12.0 | .5 | .4 | .4 | .3 |
| [a]13.0 | .2 | .2 | .2 | .2 |
| [a]14.0 | .1 | .1 | .1 | .1 |
| 15.0 | .0 | .0 | .0 | .0 |

[a]Not a measured value.

## TABLE IV. - INNER-HARMONIC-COIL INCREMENTAL FIELDS

[First-harmonic amplitudes, Gauss per 100 A; effective angular location of coil, +0.27 radians.]

| RADIUS (in.) | MAIN-FIELD AMPERES 130 | 230 | 330 | 430 |
|---|---|---|---|---|
| [a]9.0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10.0 | .04 | .06 | .06 | .05 |
| [a]11.0 | .08 | .10 | .10 | .13 |
| 12.0 | .14 | .15 | .15 | .20 |
| [a]13.0 | .21 | .20 | .20 | .23 |
| 14.0 | .33 | .31 | .30 | .31 |
| [a]15.0 | .53 | .50 | .49 | .50 |
| 16.0 | .84 | .82 | .81 | .81 |
| [a]17.0 | 1.28 | 1.30 | 1.28 | 1.25 |
| 18.0 | 1.93 | 1.98 | 1.96 | 1.91 |
| [a]19.0 | 2.90 | 2.95 | 2.91 | 2.93 |
| 20.0 | 4.08 | 4.11 | 4.08 | 4.16 |
| [a]21.0 | 5.45 | 5.48 | 5.50 | 5.53 |
| 22.0 | 6.82 | 6.86 | 6.92 | 6.90 |
| [a]23.0 | 8.04 | 8.07 | 8.10 | 8.14 |
| 24.0 | 8.98 | 9.01 | 8.99 | 9.09 |
| [a]25.0 | 9.44 | 9.51 | 9.48 | 9.54 |
| 26.0 | 9.46 | 9.58 | 9.56 | 9.59 |
| 27.0 | 9.04 | 9.19 | 9.19 | 9.29 |
| 28.0 | 8.23 | 8.47 | 8.47 | 8.46 |
| 29.0 | 7.09 | 7.33 | 7.32 | 7.34 |
| 30.0 | 5.76 | 6.02 | 5.98 | 5.93 |
| [a]31.0 | 4.35 | 4.65 | 4.59 | 4.52 |
| 32.0 | 3.07 | 3.37 | 3.31 | 3.23 |
| [a]33.0 | 2.13 | 2.35 | 2.28 | 2.21 |
| 34.0 | 1.43 | 1.56 | 1.48 | 1.41 |
| [a]35.0 | .94 | 1.01 | .93 | .86 |
| 36.0 | .66 | .69 | .61 | .54 |
| [a]37.0 | .41 | .44 | .38 | .33 |
| [a]38.0 | .26 | .28 | .24 | .21 |
| [a]39.0 | .17 | .18 | .15 | .14 |

[a]Not a measured value.

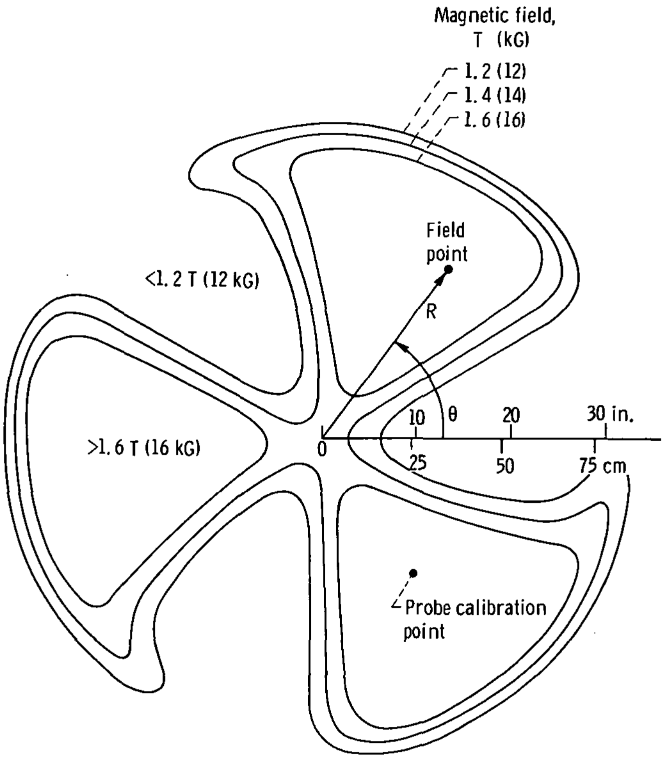



Figure 1. - Contour plot of cyclotron main-magnet field at current of 380 amperes. Also shown is polar-coordinate system used to describe field with scale in centimeters (in.) on the θ = 0 axis.

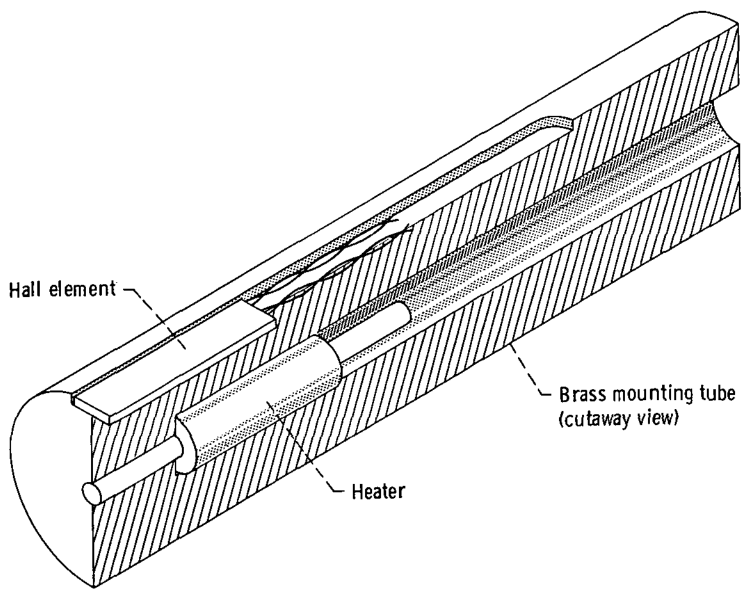



Figure 2. - Construction detail of Hall probe. (No scale.)

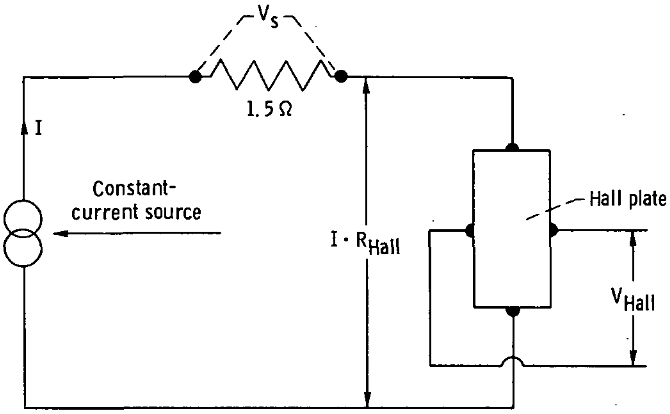
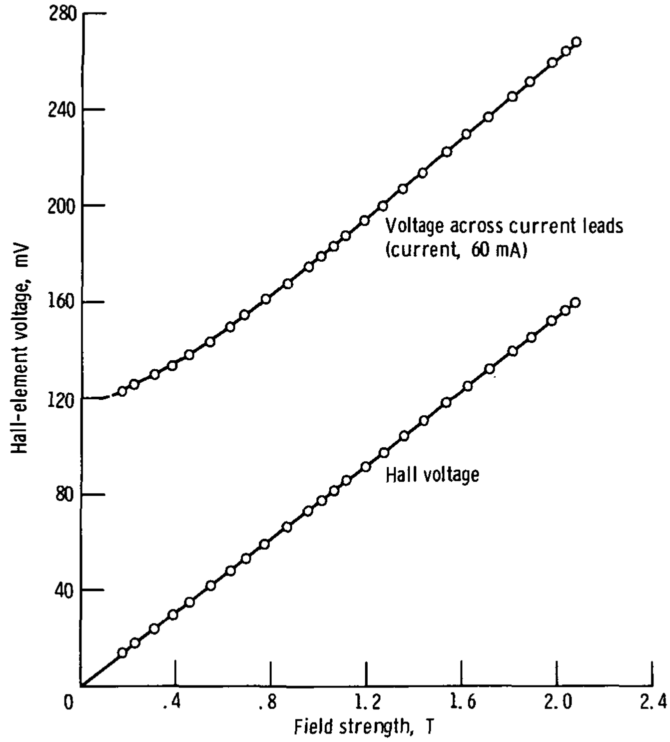
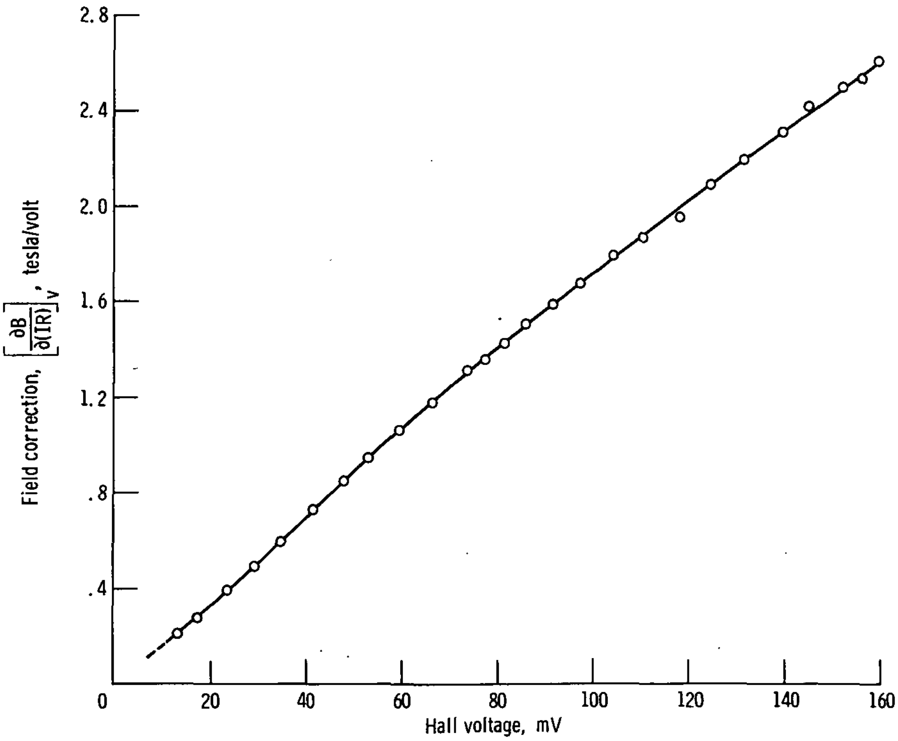


Figure 3. - Hall-probe electrical circuit.




(a) Hall element voltages as functions of magnetic field strength.




(b) Variation of field-correction term as function of magnetic-field strength.

Figure 4. - Characteristics of Hall element used.

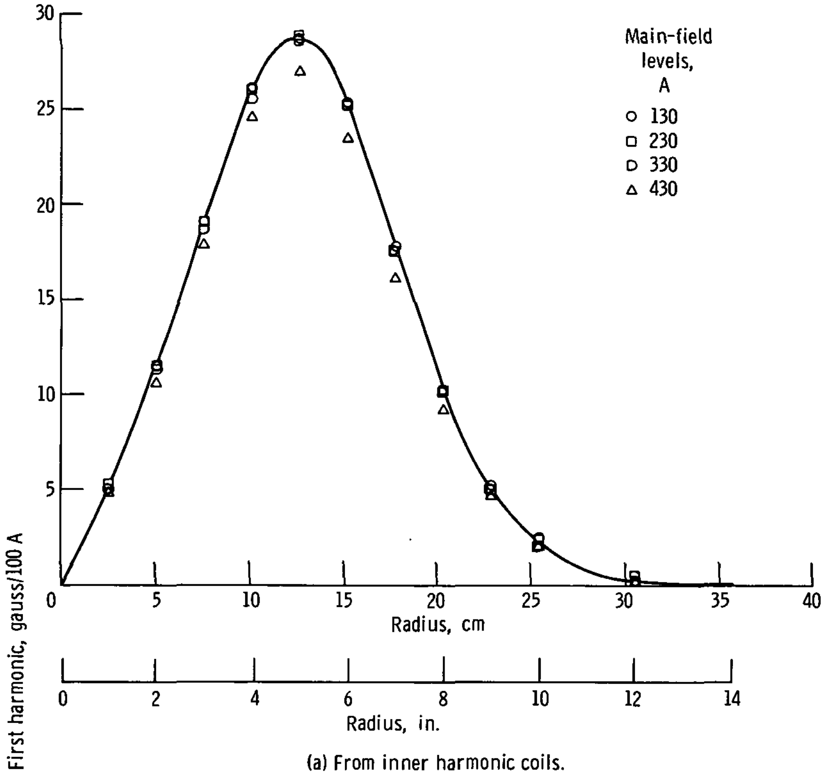



Figure 5. - Amplitude of first harmonic.



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16. Abstract

The magnetic field of the Lewis Research Center cyclotron has been mapped by using a Hall-effect magnetic-field transducer. Main-field Fourier coefficients were determined on a polar mesh of 40 radii for each of seven levels of main-field coil current. Incremental fields for eight sets of trim coils and two sets of harmonic coils were also determined at four of these main-field levels. A stored-program, digital computer was used to perform the measurements. The process was entirely automatic; all data-taking and data-reduction activities were specified by the computer programs. A new method for temperature compensation of a Hall element was used. This method required no temperature control of the element. Measurements of the Hall voltage and Hall-element resistance were sufficient to correct for temperature effects.

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