Oak Ridge Model Magnet Studies

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Model magnet studies at Oak Ridge have followed the usual pattern of establishing the general boundaries for the systems under consideration and then making detailed measurements on the system that appears most promising. The approximately 1/8-scale model has been satisfactory for determining the efficiency, forces, number of sectors, and some estimate of the ampere-turns required in the valley coils, the harmonic coils, and the circular trimming coils, but has not provided suitable data for detailed orbit calculations.

Figure 81 shows the model and the general facilities for making field measurements. You will note that the model is mounted on a milling machine frame and the Rawson rotating coil fluxmeter on the milling machine table. The table has been provided with an automatic advance and stop to position the probe to 1-mil accuracy every 1/4 in. along a chord of the magnet. After data along one chord has been taken the position of the table, and consequently the probe, is moved radially 1/4 in. by hand so that a series of up to 44 points can be measured along the next chord. The intensity of each point is recorded on a Brown chart and later read and punched on tape for input to the computer. It should be pointed out that the data must be converted from rectangular to polar form before properties of the magnet can be calculated. The theoretical group considers this limitation one of the most serious faults of the present model. The accuracy of the present model is another limitation, although the present model tips were never intended for obtaining high precision.

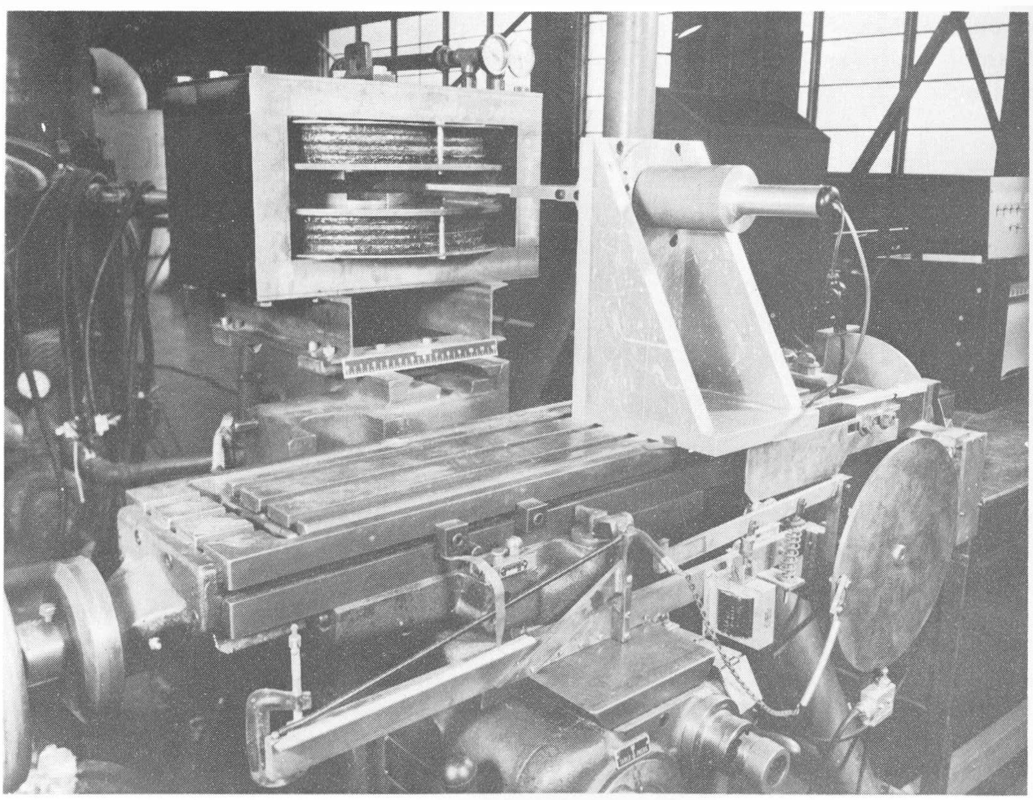

Fig. 81. Oak Ridge model mounted on milling machine.

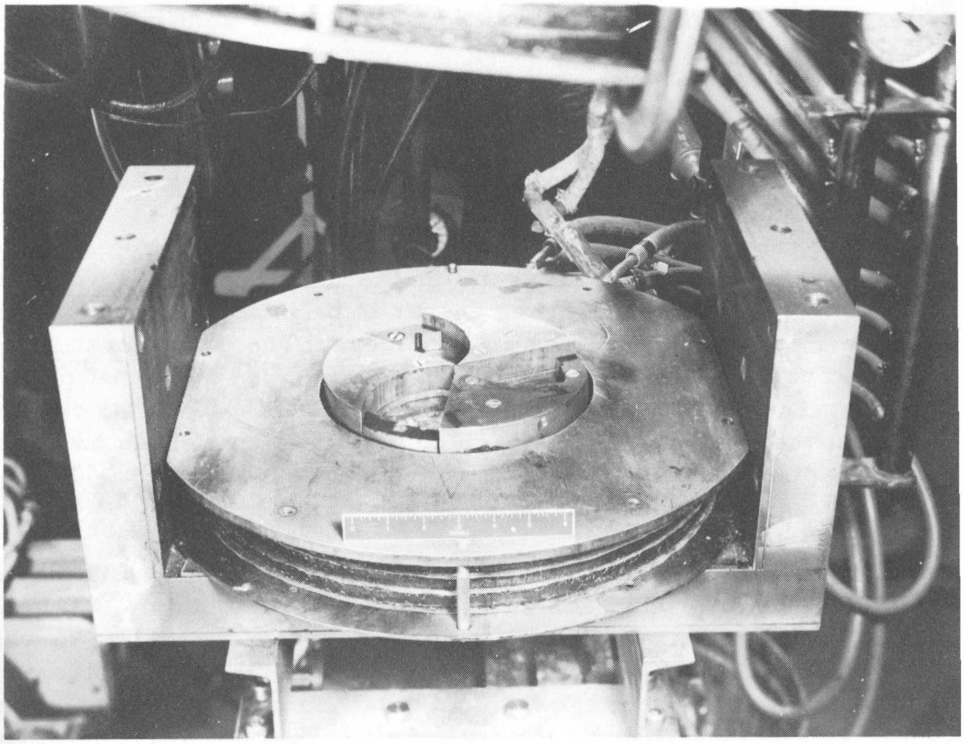

Fig. 82. The three-sector pole tips.

Figure 82 shows the model with the top portion removed so that the sector geometry is visible. A contour plot of the field obtained on the model is shown in Figure 83. Field gradients between the hills and valleys go as high as 18,000 gauss/inch. A 1-mil error in position of the probe in this region gives an error in field of about 0.1%.

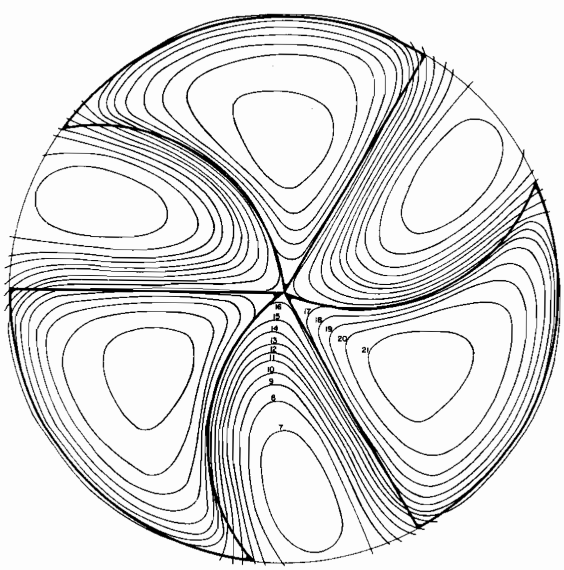

Fig. 83. The three-sector field, in Kilogauss.

The model draws currents of 500 amp supplied from a 1750-kw generator; until recently the current was unregulated. A chopper amplifier-amplidyne type regulator reduces current variations to about 1 in 2,000. The Brown recorder has been assumed to contribute a 0.2% error to the field measurements. The charts cannot be read to closer than 0.1 division which amounts to another 0.2% for an average reading. A repeat run was recently made across a model and each point repeated to 0.1 chart division or to the chart reading accuracy. Earlier test made before the current was regulated gave discrepancies up to 0.4 chart division, although about 80% repeated to 0.1 chart division. Absolute calibration of the field measuring system is made before each test with a nuclear fluxmeter and an L and N K-3

Potentiometer. The Brown is standardized before each scan across the model.

It has been recognized for some time that a larger model was desirable and now that attempts to make detailed orbit calculations from model data have shown the data to be inadequate, it is planned to continue the model program on the full-scale magnet temporarily located next to the model area during the construction on the permanent building.

Before discussing the testing program for the 76-in. magnet, I would like to call attention to how what may at first glance appear to be minor changes on the magnet may result in very large forces on the coil and core. The coils were moved about 10 in. to take advantage of the improved efficiency obtained by operating the coils near the median plane. Figure 84 shows the forces developed on the coils and cores. You will note that the direction of the force on the cores as well as on the coils is not toward the median plane when the coil current exceeds about 3,000 amperes, and that the forces reach 240,000 pounds at 4,500 amperes.

There has been considerable discussion in our group about using the final magnet as the model. The full-scale system will permit us to obtain a maximum field accuracy, to use a polar grid while taking the data, provide a system in which valley coils, harmonic coils, and trimming coils can be installed, and give us several month's start on shimming the magnet before final installation. The time required to obtain data will be larger as will the cost of altering the magnet; however the cost of an intermediate scale model will be eliminated.

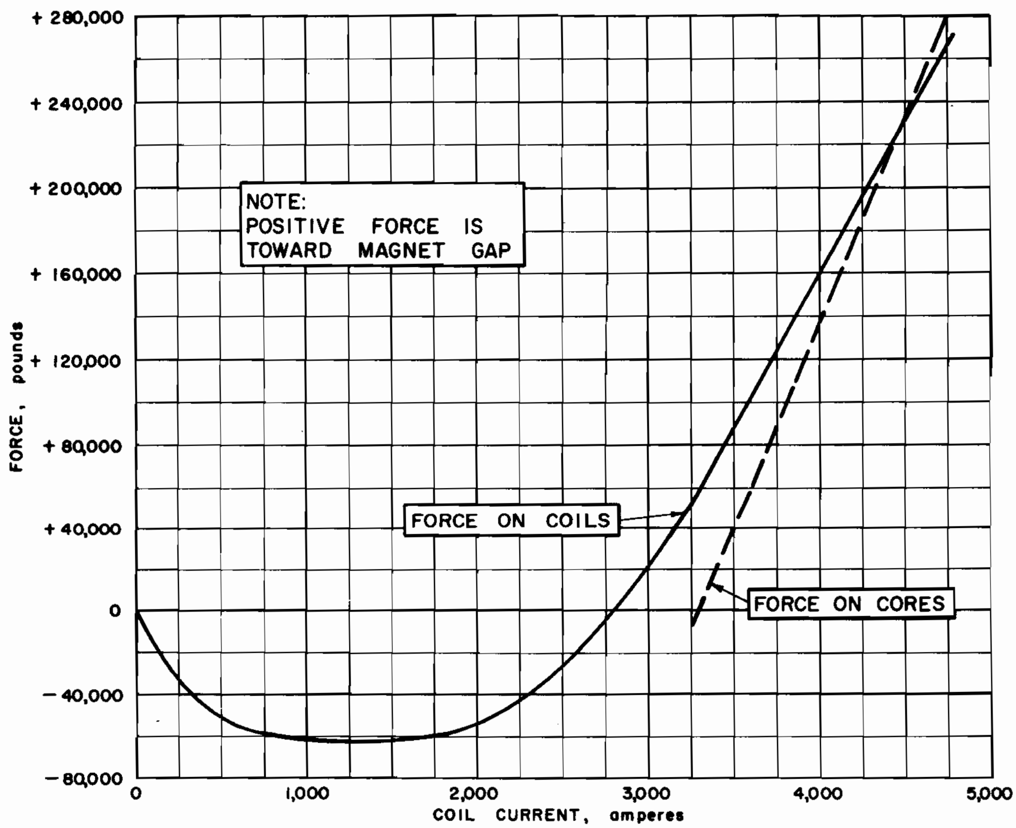

Fig. 84. Forces on magnet coils and cores.

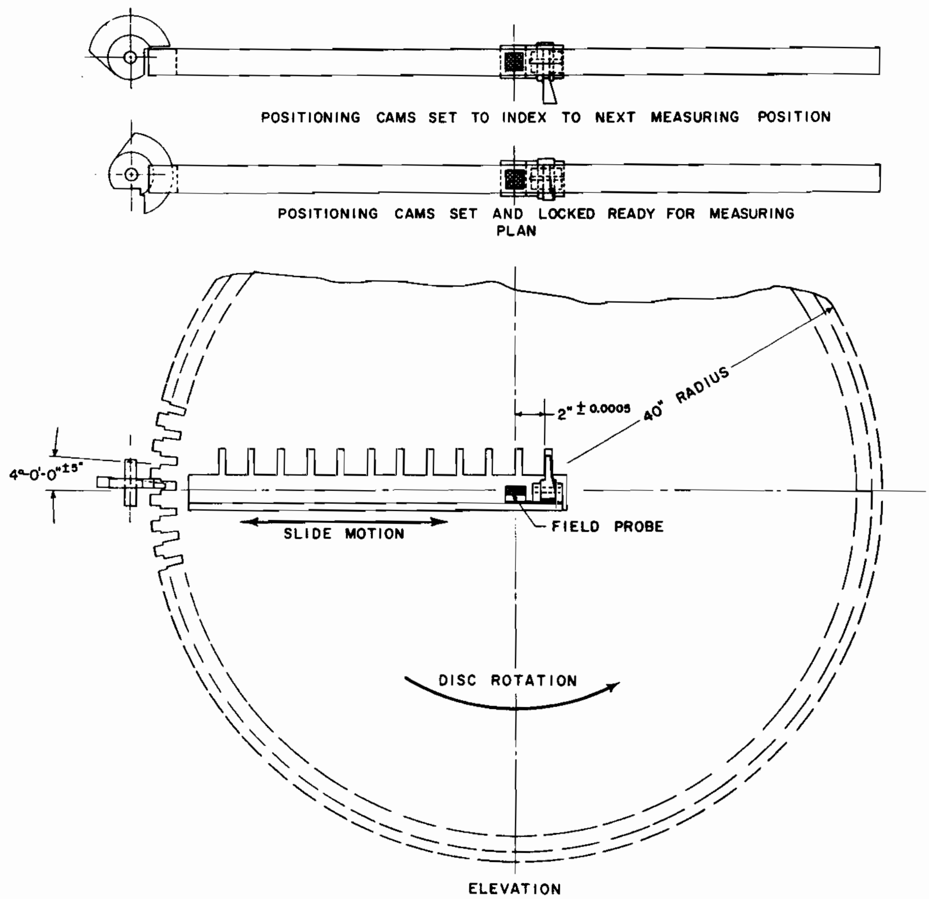

Fig. 85. Probe positioner.

Figure 85 shows the device that will be used to position the Hall probe azimuthally or radially to 1 mil. The positioning device will consist of an 80-in. aluminum disk with precision slots every 4 degrees. The disk will be rotated slightly over 4° and then backed up by a tapered cam until the reference surfaces are matched. A similar cam will be used to position the probe radially. Ninety azimuth points will be measured at each radius. Two-inch increments will be used along the radial line, giving about 1800 data points over the whole poleface. The field can be measured in five hours if a point is obtained every 10 seconds.

A Hall generator will be used as the field measuring device. It is desired to keep the absolute accuracy of the field measurement at each point to 0.01 or 0.02%. The FC-34 Hall generator made by Siemens and Halske has an effective electrical size of 6 x 12 mm. The error in the absolute field measurement due to the size of the Hall generator in the nonuniform field has been estimated to be less than 0.05% and can be corrected to less than 0.01%. The coefficient of Hall voltage with temperature given by the manufacturer is 0.02%. Thus, if we want to limit the errors from this source to 0.01% we must limit temperature changes in the Hall generator to 0.5°C. Ambient temperature changes can be maintained to less than ±0.1°C by a temperature regulating device similar to the one described by Dols, Skiff, and Watson(1). The resistance of the element will change about 180% as the probe moves

(1)Rev. Sci. Inst. 29 (May, 1958).

from minimum to maximum field. If the drive current in the Hall generator is held constant then the power will increase with the resistance, which increases with the magnetic field. Measurements on a Hall generator indicate than an FC-34 can be driven at 25 ma before the change in temperature drop between the sensing element and the element case exceeds 0.1°C as the probe is moved from minimum to maximum field.

At 25 ma, the FC-34 output will be approximately 100 mv at 25 kilogauss. To read this voltage on a 10-volt digital voltmeter, it will be necessary to use a d-c amplifier with a gain of 100.

A block diagram of the data recording system is shown (Fig. 86). One Hall generator mounted at the center of the magnet will detect changes that may occur during the 5 to 8 hours required to make field measurements over the entire magnet. The movable Hall generator will remain at a fixed radius while the positioning disk is moved to each of 90 azimuth points. The drive current will be recorded for each point as well as the reference Hall generator voltage and the movable Hall generator. The temperature of each Hall generator will be regulated so as to eliminate temperature drift. D-c amplifiers with a gain of 100 and with stability to or better than 0.01% will amplify the signal before the scanner. A digital voltmeter will be used to supply a visual readout of the Hall voltage, a signal to a paper tape punch, and a signal to a printer. Position signals will also be supplied through a scanner.

Each element in the field measuring system has been designed to contribute no more than 0.01% error to the field measurement. The over-all accuracy will be no better than a few hundredths of a percent. The accuracy of the measurements does not compare with that obtained with a nuclear fluxmeter in a uniform field; however the system we have described appears to be a practical one for the large gradients in the magnetic fields.

LIVINGOOD: Do you have a rectangular or a polar setup?

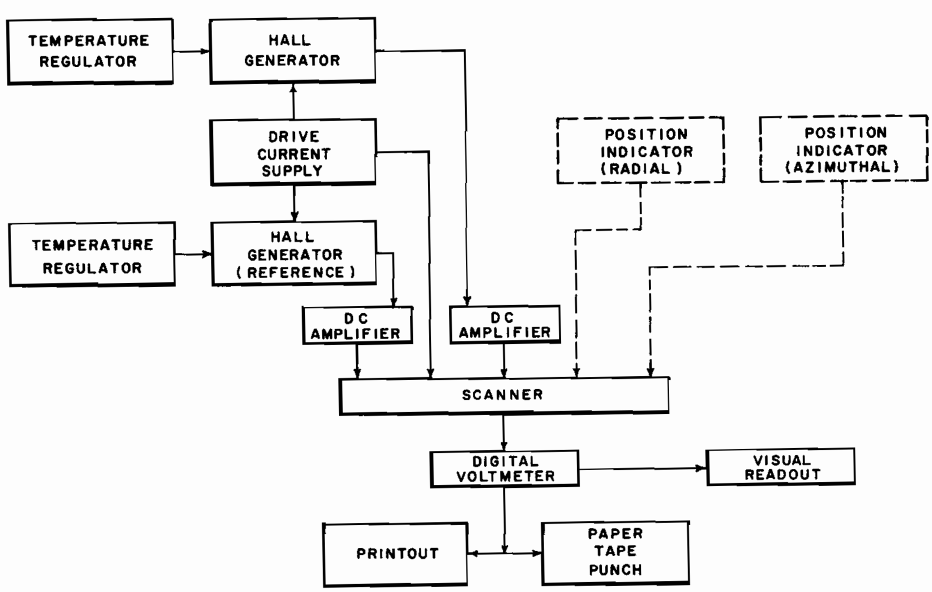

Fig. 86. Data recording system.

HUDSON: Our model work originally was a rectangular setup; this is a really serious limitation to getting data in a useable form. Our theoretical group has a process for converting data form from rectangular to polar form. For the full-scale machine we will use the polar form. The milling machine setup, of course, gives us rectangular form.

BLOSSER: It seems to me it is going awfully far to say that the rectangular grid is a really serious limitation in the present Oak Ridge model. An interpolation process can be made as good as you need to make it - the errors can be made arbitrarily small, if the data points are exact. If the data points have experimental error, the rectangular grid should give field derivatives more accurately than a polar grid if an interpolation process as distinct from a smoothing process is used. Interpolation implies that the field value will approach the measured value as a grid point is approached. For given experimental error and given maximum rate of change of the derivative (which you know from the magnet gap) its easy to see that there is an optimum spacing for grid points. If the grid points are too close together the derivative becomes inaccurate due to the fact that the experimental error in ΔB becomes comparable with ΔX. If the grid points are too far apart the derivative becomes inaccurate because of change in its value over the interval; fine structure tends to get washed out. With the rectangular grid you can pick a spacing near optimum and use it over the whole magnet. With a polar grid if you choose a $\Delta\theta$ small enough to show the fine structure at the outside of the magnet, as you approach the center, the denominator of the important quantity $(1/r)\ (dB/d\theta)$ becomes small and, to maintain the accuracy of the derivative you must either work very hard to get extreme accuracy in the B's or you must change the θ spacing. Both are awkward.