PLANS FOR MAGNETIC MAPPING OF THE NSCL K800 CYCLOTRON MAGNET*

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Abstract

A magnet mapping method for the K800 cyclotron is currently being developed. The peak magnetic field in this cyclotron will be 5.8T and will be mapped on the median plane in 1 degree angular increments and 12.5 mm radial steps to cover the 1 m radius magnetic field. The plan is to measure the field at the center of the cyclotron with a D_2O NMR probe and then to determine the fields elsewhere relative to the central field via a search coil. The maximum field change to be read by the search coil is 0.8 T. This scheme should have an absolute accuracy of ± 1 G and should require less than 1 hour to produce a 360° map at at given field setting.

Introduction

The NSCL K500 superconducting cyclotron was mapped in 2° angular intervals and 12.5 mm radial intervals by using 55 flip coils mounted on a radial bar.[1] Each coil had its own precision voltage integrator which was multiplexed into a single digital voltmeter. This system produced high quality data for the K500. The 60% larger radius of the K800 cyclotron magnet increases the scale of the mapping hardware and calibration and mapping times by the same factor. Hence the present scheme is being developed to make the absolute calibration less time consuming and more accurate as well as to decrease the time required for mapping.

Present Scheme

A schematic view of the apparatus to be used to map the K800 cyclotron magnetic field is shown in figure 1. The new method involves two types of magnetic magnetic measurements: 1) a D_2O NMR probe to read the absolute field at the center of the cyclotron where the peak field will be about 5 T, and 2) a search coil which only needs a dynamic range of ± 0.8 T to read the fields elsewhere on the median plane relative to the value at the center. A map at a given azimuth will be recorded by moving the search coil radially along a track from the center of the machine to the inner cryostat wall (a plan view of the interior of the K500 cyclotron is shown in figure 11 of paper A3 in these proceedings. The interior of the

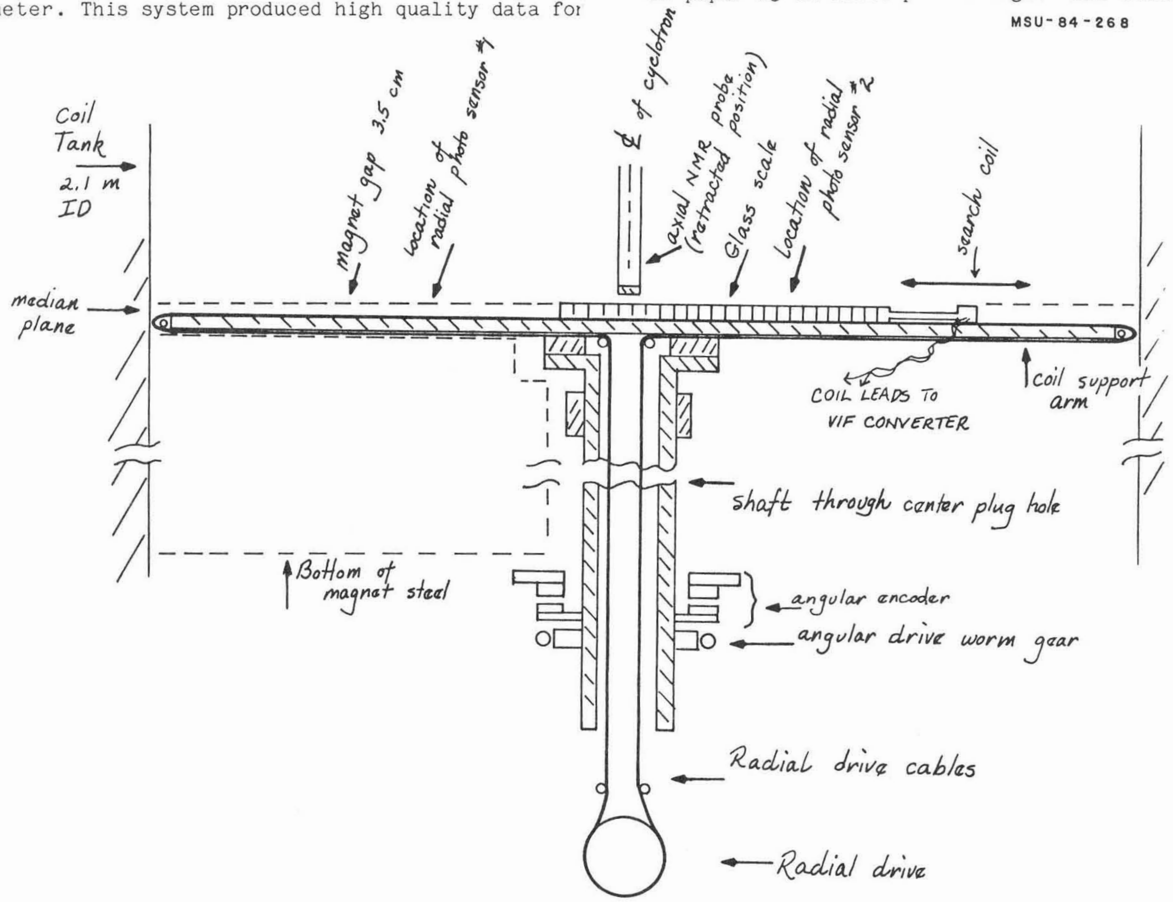

Fig. 1. A schematic view of the apparatus to be used to map the K800 cyclotron.

K800 magnet is similar except for its larger radius.); the field change is determined by counting pulses from a precision bipolar voltage-to-frequency (v/f) converter. The v/f scaler will be read "on-the-fly" when strobed by signals from a radial position sensor. At some angles there will be holes through the cryostat so that field data along the extraction channel can also be obtained. The mechanical and electrical components of the system, the mapping sequence, and data handling are described below.

Hardware

NMR Unit

The magnetic field at the center of the cyclotron will be measured with a SENTEC model 1000 nuclear magnetic resonance apparatus[2] using the SENTEC axial deuterium probe (model 1013-7) which covers a field range from 3.0 to 6.8 T. The signal to noise ratio of the NMR signal will depend on the field uniformity at the center of the cyclotron where the field has a saddle-point (a relative minimum radially and a relative maximum axially). The field shape in the center is dominated by the iron center plug. Data from the K500 indicate that the second-order gradiant at the center should be small enough to produce a visible NMR signal. The absolute accuracy of the field measurement will be determined by the quality of this signal, and it is expected to be better than ±1 G over the range of 30 to 50 kG. The intrinsic accuracy of the SENTEC NMR electronics is approximately 1 part in 10^5 and should not significantly limit our measurement.

The NMR probe will be located on the central axis of the cyclotron and will be moved vertically a small distance to read the central field value at the beginning of each map. In its retracted position (about 3 cm above the medean plane) it will not interfere with the search coil motion.

Search Coil and Electronics

The radial field profiles will be determined by integrating the voltage output from a search coil as it is moved from the center of the cyclotron to its outer radius. This integration will be accomplished by counting the pulses from a 1 MHz voltage-to-frequency (v/f) converter as the coil is moved between two points. Since the frequency output is proportional to the voltage induced due to the changing magnetic flux through the coil, the number of pulses output is proportional to the integral of the voltage, i.e. the net magnetic field change.

We will be using a precision bipolar v/f converter developed recently at Berkeley[3]. This circuit delivers pulses from one output if the field is increasing and from another if it is decreasing. If these output pulses are stored in two separate scalers, then the net field change is proportional to the difference between the readings of the scalers. The accuracy of this circuit is approximately ± 1 part in 10^4 of full scale. Since the dynamic range of the radial maps is only ± 0.8 T relative to the central field value, this measurement should be accurate to about ± 1 G. The search coil and v/f converter can be calibrated conveniently in a conventional dipole with a field of about 1 T using a conventional NMR for reference.

Angular Drive and Encoder

The coil arm will be moved in nominally 1° angular steps via a worm gear drive. The precise values of the angles at which data are recorded will be determined via an Inductosyn angular encoder[4] attached directly to the angular drive shaft just below the cyclotron. The electronics of this incremental encoder generates 1000 pulses per degree and the encoder also has an accuracy of about one thousandth of a degree (± 4 arc sec). The angular orientation of the mapper relative to the cyclotron steel will be determined by sighting the coil with a telescope through one of the rf holes.

Radial Drive and Photosensor

The search soil will be driven radially at a uniform velocity of about 40 cm/sec by an AC gearmoter. The moter will be about 2 m below the cyclotron and shielded from the fringing field. The moter drive will connect to the coil via braided dacron string through the hollow angular drive shaft to the radial arm in the medean plane of the cyclotron. The accelerations required to do radial scans in about 3 seconds are less than 10 m/sec^2(1g)so the tension in the string is reasonable. This has been tested in a model and no problems were encountered.

The radial position of the search coil will be indicated by photosensors mounted on the coil track and a scale attached to the coil "truck". The scale will have reflective stripes to trigger the photosensors at fixed radial increments of 12.5 mm.

The photosensor we have chosen is the NANO-SKAN fiber optic scanner (model S2005-3) made by the SKAN-A-MATIC, Corp.[5] This unit has a rated resolution of ±0.001 in. and a reproducibility of $\pm 5\times 10^{-6}$ in. An LED in the unit produces light which is transmitted to the scanning snout by a fiber-optic light-guide. Reflected light is collected into a fiber bundle which transmits the light back to a photodiode. We initially purchased the SKAN-A-MATIC model T41300 high-speed controller for our circuit. With only wall power supplied to it, the T41300 provides all other circuitry to run the photosensor and produce an usefully sized output of the state of the photosensor; unfortunately, it has a response (delay) time of 0.8 msec. This long response time proved to be quite inconvenient; we are therefore designing new circuitry that will get the response time down below 100 μsec and possibly down to 10 μsec. There was some question about whether the sensor would work in a high magnetic field; therefore we tested it in the K500 cyclotron magnet and found that it indeed works in a high (4.2 T) magnetic field.

Mapping Sequence

Mechanical Sequencing

I) At the beginning of each map, the NMR probe is inserted into the center of the magnet and the field measured. The probe is then withdrawn from the magnet.

II) The automatic mapping sequence is started. This sequence results in a map of the differences between the field at the center and at all points on a grid with one degree angular steps and 0.5 inch radial steps over the entire 360° azimuthally and from the origin to 1.05 m radially. The sequence is:

a) The coil "truck" (on which are mounted the search coil and the scale) is positioned off-center in the magnet; the angular position is then read by the computer. The "truck" then moves, at constant velocity, through the center of the magnet and on to the outer edge of the magnet (about 1 m) in about 2.5 sec.

b) The radial positions of the mapping are set by reflective stripes on the scale at 12.5 mm increments. The edges of the stripes serve as the triggering point for the photosensor. The scale will be 61 cm long so 2 photosensors positioned about 56 cm apart will make it possible to cover the entire radial scan, with some overlap between the 2 sensors.

c) When the "truck" reaches the end of its travel, it reverses direction and returns to the center of the machine. The angular drive is then engaged, the "mapper" moves by one degree to the next position, and it is allowed to mechanically settle. (It may be possible to increment the angle while the coil is at full radius and map the next angle on the way in. If this is possible the scanning time will obviously be reduced.)

d) The process then restarts at the new angular position.

Electronics sequencing

The basis of the system, as described above, is the voltage-to-frequency (v/f) convertor. To get the difference in the fields at two positions, it is only necessary to know the net number of pulses from the v/f convertor when the search coil moves between the two locations and a scaling factor. The v/f convertor has a maximum frequency of 1 MHz; therefore an accurate reading can only be done if reading the scaler happens very quickly so as not to lose pulses during the scaler reading. Two options are viable which let the scaler be read without losing pulses: 1) a latching scaler could be used (a latching scaler will, on request, transfer the current value of the scaler into a register and hold it there so that it can be read without inhibitting the scaler from counting and 2) to "flip-flop" between two scalers, alternately reading one while the other counts. We have chosen the second option since it involves no special-purpose hardware that is not available in the laboratory.

The circuitry to accomplish the mapping is relatively simple. When the photosensor detects the edge of one of the stripes on the scale, it produces a logic signal that goes to a flip-flop gate and to the computer. The signal at the flip-flop makes the state of the flip-flop change. The state of the flip-flop determines which of two scalers (in the CAMAC crate, with the v/f output going into both) is inhibited and which is counting. The signal that goes straight to the computer (actually to an interrupt register in the CAMAC crate) tells the computer to read the scaler that has just been inhibited, calculate the field, enter the field value into the table, and update the Fourier analysis integrals. (These integrals will be described in more detail below.) The angular position is recorded whenever the computer is strobed (again with a signal to the interrupt register); typically this will only occur just before the "truck" starts the motion outward. The computer records the angular position by reading a third scaler in the CAMAC crate, which is never inhibitted, into which go the pulses from the angular encoder.

Data processing

One of the goals of this mapping procedure is to continuously check the data and thus to have some measure of the quality of the data very quickly. This is greatly facilitated by the availability of the computing power of the VAX-11/750 that will be used for the mapping. It not only records all the scaler values and turns them into positions and field values, but also begins analysis of the data before the map is complete. The analysis consists of extracting the harmonic content of the field by doing a Fourier analysis of the field at each radius. The radial dependence of each harmonic is examined for anomalies. Unlike other systems in which the mapping and the analysis must be done on different computers, we can start calculating the Fourier integrals before the map is finished, ie. as each new angular value is added to the table at a given radius, the next step in each integral at that radius can be added. Since there are about five seconds of time at each angular setting when the computer would otherwise be idle, there is sufficient time for most, if not all, of the integrals to be updated before the next angular step must be done. An attempt will also be made to look for anomalous points before the map is finished. This will be done by testing the continuity of the data, ie. whether a given data point is arbitrarily close to an interpolation of neighboring data points. This procedure is currently under test and review using maps of the K500 cyclotron magnet as the data and adding anomalous data points; if it proves accurate, then we should be able to quickly find the problem part of a map and remeasure only that part of the magnet. The final result is that we should have an analysis of the map essentially as soon as it is finished. This greatly simplifies finding problems with the system both during the testing and during the mapping itself.

Summary

The scheme for mapping described here is straight-forward and holds the promise of giving outstanding results since few "absolute" positions are needed, mechanical design efforts can concentrate on these critical points. Likewise, there are but three critical electronic components (NMR, V/f converter, and photosensor) vs. many for most other schemes. This scheme should be readily adaptable to other systems.

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References

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1. P. Miller, et al, IEEE Trans. Nucl. Science NS-26 2111, 1979.
2. SENTEC, 13 Ave. Saite-Clotilde, Ch-1205, Geneva, Switzerland, Marketed in the U.S.A. by GMW Associates, 1060 Lakeview Way, Redwood City, CA 94062, based on the design in Cern report: CERN 77-19 by K. Borer and G. Fremont.
3. W.E. Hearn, M.I. Green, D.H. Nelson, and D.J. Rondeau, Proceedings of the 1981 Nuclear Science Symposium, San Francisco, CA, October, 1981.
4. Farrand Controls, 99 Wall Street, Valhalla, NY 10595, U.S.A.
5. Skan a matic Corp., P.O. Box S, Elbridge, NY 13060, U.S.A.