THE NBS-LANL RTM END-MAGNET FIELD MAPPER*

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Abstract

A computer-controlled magnetic field mapper is under construction at the National Bureau of Standards to map the end magnets of the NBS-LANL racetrack microtron (RTM).[1] The mapper consists of a large, two-dimensional translation stage which simultaneously positions a nuclear magnetic resonance (NMR) magnetometer probe in the 55 cm x 135 cm uniform field region and a temperature-compensated Hall effect probe in the fringe field region. A computer-based control system automatically positions the probes at points on a selected grid and records the measured field values and positions in computer memory. In this paper we describe the field mapping requirements, the mapper, its operation, and the field measurements and analysis that are to be performed.

End Magnet Mapping Requirements

The two end magnets[2] being constructed for the NBS-LANL RTM have been designed to produce a magnetic field of uniformity $\Delta B/B = \pm 2 \times 10^{-4}$ or better throughout a volume of 6 cm x 55 cm x 135 cm over an operating range of 0.8 to 1.2 T in the nominal field, B_0. Mapping will be performed over a wider B_0 range of 0.4 to 1.6 T in order to test the limits of this new magnet design.

Within the operating range, the uniform field region of the magnets will be mapped on the midplane at several B_0 values to determine whether the required uniformity is achieved. If the measured field uniformity is unacceptable, the upper and lower pole faces will be field-mapped at B_0 = 1.0 T in order to design pole-face correction coils. The correction coils would be fabricated from printed circuit board material, with series-connected conductive paths corresponding to intervals of equal field value in the pole-face map. Coils of this type[3] have been demonstrated to reduce field inhomogeneity by a factor of 25 in a magnet operating at fixed B_0.

Mapping for corrective-coil design will be done on a rectangular grid with a step size as small as 1 cm. A contour line interpolation routine will then be used to calculate lines of constant B with a contour interval of 5×10^{-5} B_0. The large number of points in such a map (up to 10,000) requires automatic probe positioning and data taking. The ability to map the entire uniform field region in one pass without repositioning the mapping equipment is highly desirable.

As shown in figure 1, the end magnets have active field clamps, consisting of auxilliary poles and coils to produce a field of polarity opposite the main field.[4] For operation of the RTM, the current in the active field clamp coils must be adjusted to produce a fringe field which does not significantly focus or defocus the beam in the vertical direction, i.e., a fringe field with a vertical focal length in excess of the RTM orbit circumference.

The fringe field of the end magnets must be mapped for several reasons. First, it is important to compare the measured fringe-field shape with design calculations and to verify that the shape is independent of the distance, x, along the magnet edge. Second, the effective field boundary must be determined. Third, the correct field clamp coil currents, which correspond to large vertical focal lengths, will be determined by mapping the fringe field at different currents. The focal length for each current will be evaluated by ray tracing. This procedure will be repeated at several values of B_0. Features that are required for fringe field mapping include: a step size of about 5 mm in z and 8 cm in x; a measurement accuracy of 0.1 mm in z and 10^{-3} B_0 in the field; and a field probe which operates in a non-uniform field and which has a sensitive area with a diameter small relative to the 5 mm minimum step size.

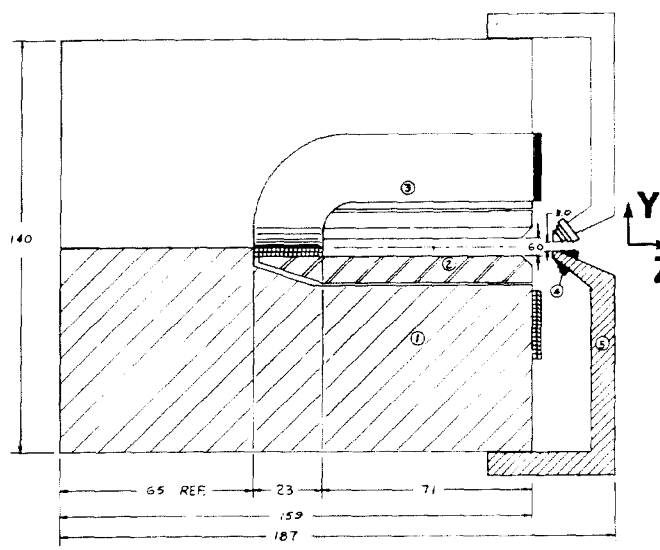

FIGURE 1. Side view of NBS-LANL RTM end magnet with the lower half shown in section. The magnet is 158 cm. long in the direction, x, perpendicular to this view. The y-z section of this magnet is x-independent. All dimensions are in centimeters. Parts shown are: 1) main yoke, 2) main pole piece, 3) main coil, 4) active field-clamp coil, and 5) active field-clamp.

Mapper table

We are building a mapping table, shown in figure 2, to meet the end magnet mapping requirements. It is being built using an existing two-dimensional (xz) translation stage which is large enough to map the field of an end magnet in a single pass. A probe arm is attached to the stage by means of a manual height (y) adjustment mechanism. The probe arm was designed to allow simultaneous mapping of the fringe field with a Hall probe and of the uniform field with either one or two NMR probes. Performance specifications of the mapper are given in table 1.

The good initial uniformity expected in these high quality magnets permits NMR probes to be used. This satisfies the need to measure the uniform field with an accuracy of 50 ppm or better. The probe arm accommo-

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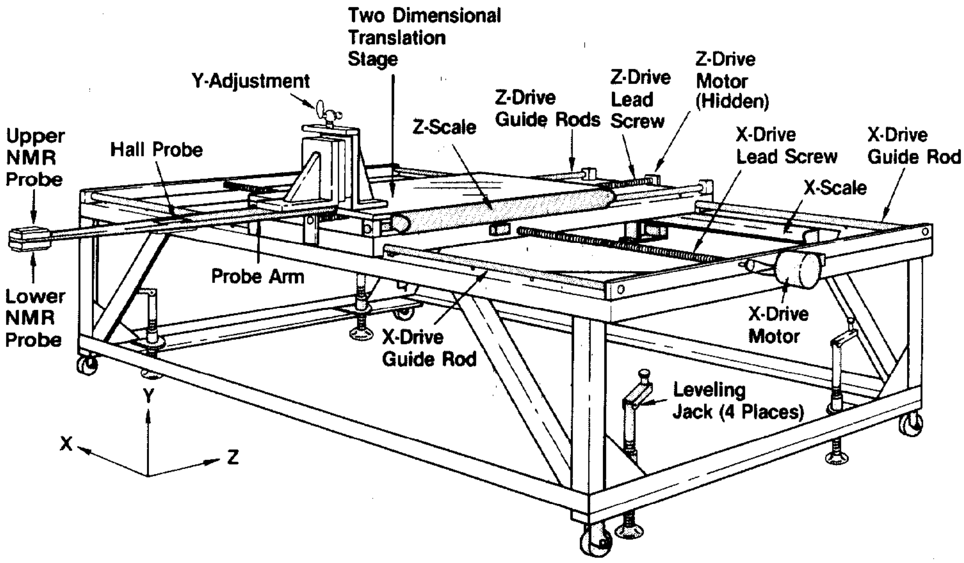

FIGURE 2. Artists' concept of mapper table.

dates either one or two NMR probes: one for measurements on the magnetic midplane, or two for simultaneously mapping at a distance of 5 mm from the upper and lower pole faces, near the intended location of the correction coils. A third NMR probe is used to monitor the magnetic field at a fixed position during mapping. A temperature-compensated Hall probe* which meets our requirements is used for fringe field measurements.

The probe arm is positioned in x and z using lead screws driven by stepping motors. Motors were chosen which have maximum practical values of speed and torque in order to minimize the time between measurements. Two parallel guide rods are used in each direction. Commercially available digital scales are used for positive measurement of x and z positions. The scales operate on the principle of counting lines in a Moiré fringe pattern which is produced by the relative motion of two optical rulings. The scales are accurate to better than ±20 μm, which exceeds our requirements.

TABLE 1. Mapper System Performance Specifications

1. Probe Positioning

x-range	178 cm
y-range	7.6 cm
z-range	91 cm
x- and z- drive step size, min.	32 μm
x- and z- drive speed max.	10 cm/s
x- and z- measurement resolution	13 μm
Accuracy of x- scale	±20 μm
Accuracy of z- scale	±13 μm

2. Uniform Field Measurements (NMR)

Range	$0.2 < B < 2.0$ T
Accuracy - absolute	±10 ppm
relative	±1 ppm
Resolution	1 μT

3. Fringe Field Measurements (Hall Probe)

Range	$-3.0 < B < 3.0$ T
Accuracy, relative	0.1%
Resolution	10 μT

*On loan from the University of Maryland.

Data Acquisition and Control

The data acquisition and control system shown in figure 3 is designed to provide fully automatic field mapping. A PDP-11/44 mini-computer is used to control mapping runs and to store and analyze data. A local control station is located near the mapper table and instrumentation rack at a distance of 200 m from the mini-computer. The mini-computer and the local control station are both components of the RTM accelerator control system[5]. Wherever possible, instrumentation was chosen to satisfy the requirements of both mapping and accelerator operation. Programs executed in the mini-computer control a complete mapping run, which consists of moving the field probes over a predetermined grid in x and z. At each grid point the field measurements are repeated and tested for convergence, following which the position and field measurements are recorded in disk and/or tape files. A mapping run may be initiated either remotely, from the mini-computer console terminal, or locally, from a CRT terminal located in the mapper-instrumentation rack.

The primary function of the local control station is to control the mapper instrumentation, with or without direction by the mini-computer. In addition, it has provisions for software development. The local control station is built around a Multibus (IEEE-796) crate containing seven boards. All boards are commercially available except the panel-controller board and motor-controller board, which were developed at LANL for the RTM control system. Both central processor unit (CPU) boards are based on the 8085 microprocessor. During a mapping run, requests from the mini-computer are stored in the local control station memory. CPU board 2 controls the instrumentation in response to the stored requests. Data received from the instruments is stored in memory for transmission to the mini-computer. CPU board 1 manages communication between the memory and the mini-computer, the CRT terminal, and the control panel. The CRT terminal and control panel provide local, manual control for testing individual instruments. Disks and extra memory are included for software development and testing from the CRT terminal using commercial languages and debugging packages.

An IEEE-488 interface bus is used to attach most of the instrumentation because of the availability of devices with this interface. Instruments which are not bus-compatible are interfaced with bus couplers. An RS-232 link is used between the local control station and the instrumentation rack because, in the final installation, the distance between these units exceeds the range of the IEEE-488 bus.

Commercially available instrumentation is used where possible; the exceptions are the Hall probe voltage amplifier and temperature compensation circuitry, and some electronics to overcome deficiencies in the NMR unit interface. Scale counters keep track of the net travel measured by the x and z scales, from an absolute reference point. The reference point is established by selecting one of several permanent marks on each scale.

The NMR unit has the capability of searching and tracking the field in any one of the three probes. The unit is attached to the 488 bus through interface electronics which allow both local and remote controls to function. The Hall probe system consists of the probe, a current source, temperature compensation circuitry and a Hall voltage amplifier. The digital to analog converters (DACs) in the main and field-clamp magnet power supplies are used to establish the desired current through the windings of each magnet. A 6-1/2 digit DVM and multiplexer are used to measure the Hall voltage and current, and to monitor the main magnet and field-clamp power supply currents.

Conclusion

All instrumentation has been purchased or built with the exception of the NMR unit interface. The mapper table is presently under construction. System tests are planned for this summer (1983).

References

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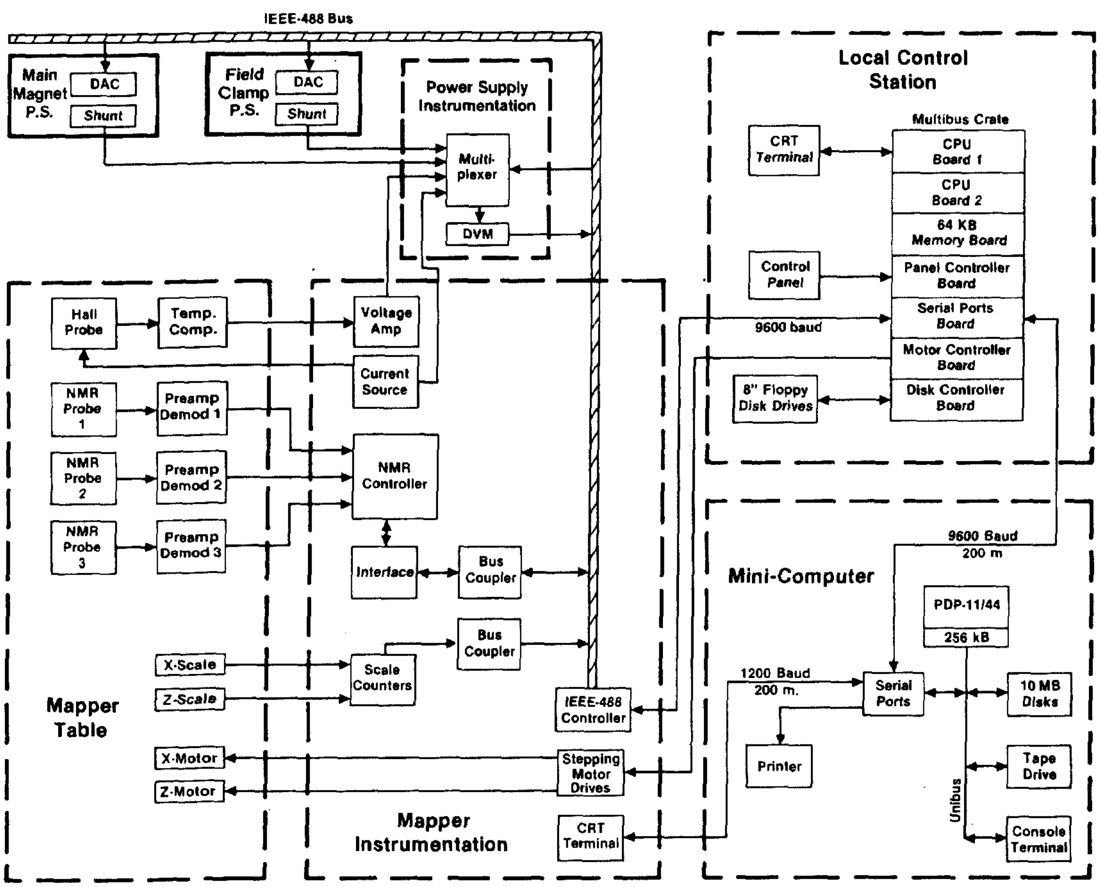

FIGURE 3. Block diagram of the data acquisition and control system.