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Magnetic Verification of the G0 Superconducting Magnet System

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An automated field measuring apparatus was constructed to provide a magnetic verification of the G0 superconducting toroidal magnet by determining the locations of a pre-specified set of magnetic 'reference points'. These reference points correspond to the zero-crossing locations of specific field components at selected points of symmetry around the toroidal magnet, and they are a sensitive function of the coil positions. Determination of these zero-crossing points then allows the 'actual' coil positions and, in principle, the magnetic fields to be completely determined. The measurements are carried out by scanning over a pre-defined set of 'zero-crossing' lines, and determining where specific field components reverse signs. The system must be capable of providing a position determination of $\pm$ 0.2 mm and a field determination of $\pm$ 0.2 Gauss, in order to reach the design goal of $\pm\ 0.2 - 0.3$ mm for the zero-crossing determination. Considerable effort went into the design, construction and commissioning of this magnetic field measuring apparatus or 'magnetic verification device' at TRIUMF, the University of Manitoba and UNBC. The device consists of a programmable gantry with full 3D motion anywhere within a 4m x 4m x 2m volume, and a set of high precision Hall probes, thermocouples, and clinometers (which measure 'tilt-angles') is mounted at the end of a probe boom on the gantry (see Fig. 1). Procurement of parts commenced in early 2000, and final assembly and testing began in late spring 2000. With the support of TRIUMF Engineering and the TRIUMF summer/co-op student program, the magnetic verification device was completed in mid-summer 2000 and transported to the University of Illinois (UIUC) where the magnetic measurements would be carried out. In late 2000 and early 2001, much effort went into commissioning this device at UIUC and upgrading and modifying the motion control and data-acquisition software. In the spring of 2001, a series of test measurements were carried out with the magnet energized at room temperature and very low currents. The magnetic verification device yielded remarkably consistent results. Shown in Fig. 2 is the magnetic verification device and the G0 superconducting spectrometer.

In late 2001, after significant effort by the UIUC group to cool the G0 magnet to superconducting temperatures, the transition to superconducting mode was achieved and a set of magnetic field measurements were carried out. Due to limited cooling capacity and related difficulties, the magnetic verification measurements were carried out with the coils energized at 1000 A (20% of the 'full-field' value) and only a subset of the scans could be performed. Three sets of background magnetic field measurements were made, interleaved with two sets of foreground magnetic field measurements at 1000 A. In all, 30 zero-crossing points were scanned for each magnet sector, for a total of 240 zero-crossing values per data set. Preliminary processing of these data involved applying corrections for: Hall probe offsets and the background magnetic field; clinometer readings; and Hall probe misalignments. Various

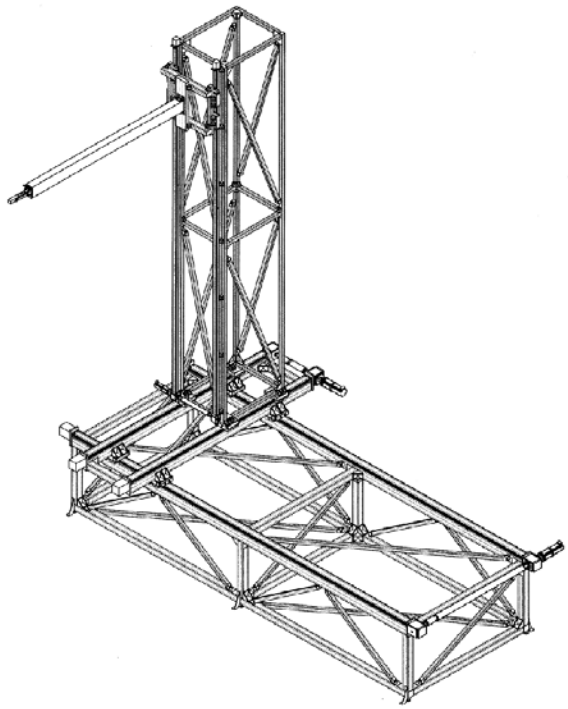

Figure 1: Layout of the Magnetic Verification Apparatus.

combinations of these corrections were applied and a total of 18 different 'raw' data sets were generated. The zero-crossing points of the various field components were subsequently determined for each of these 18 different data sets. Measured uncertainties associated with these zero-crossing points varied widely, depending on the particular location of the scan. Typical errors were $\pm$ 0.15 mm, but in regions where the field gradients were small (down an additional factor of 5 due to the lower magnet currents) the errors were significantly larger.

The analysis procedure used to extract the coil positions from the zero-crossing points was tested against computer simulations, where known coil displacements were used to generate simulated data. Not only were the 'displaced' coil positions correctly extracted, but the relative orientations and positions of the Hall probes themselves could also be extracted. This was due in part to the symmetry of the setup and the large number of zero-crossing points involved. Analysis of the actual experimental data quickly revealed that the gantry frame was offset with respect to the toroid frame by about $\delta X = 0.62$ cm and $\delta Y = -0.33$ cm. Allowing the analysis procedure to correct for this, results in the residual coil displacements shown in Fig. 3. Most of the angular displacements are about 0.1°, and the linear displacements less than 0.2 cm. This is well within the specifications for the tolerances on the coil positions laid out in the original design. The behaviour of dZ requires further study. The shape of the curve suggests that the X-Y plane mapped out by the gantry (with constant Z) was not parallel to the toroid X-Y plane. A value of 0.11° was extracted for this angle between

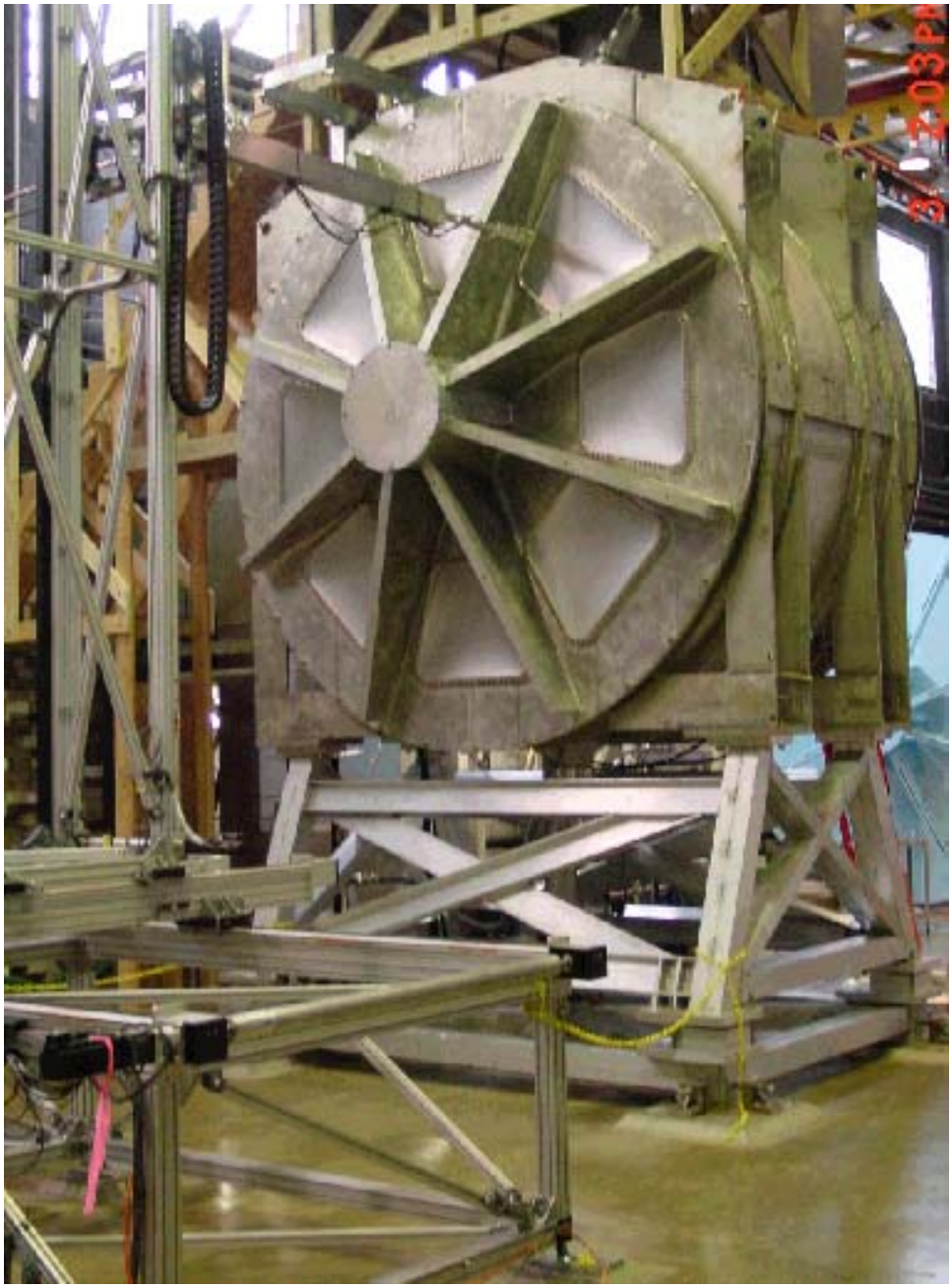

Figure 2: The Magnetic Verification Apparatus and G0 Superconducting magnet at UIUC.

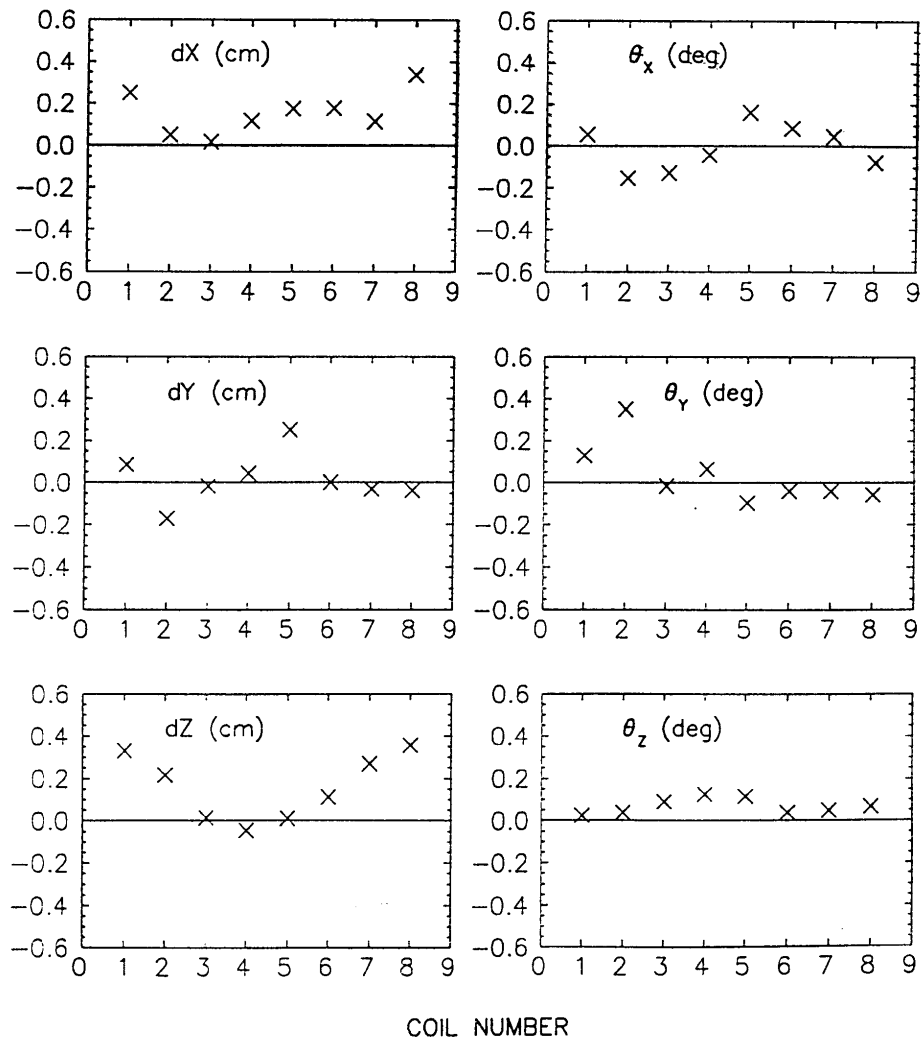

Figure 3: Coil Displacements for the G0 toroid extracted from the zero-crossing data.

the planes. In addition, the fact that, except for coil 4, all dZ values are positive, suggests that there is also an offset in the Z-coordinate between the gantry and toroid frame. Indeed, further analysis revealed that the experimental data recorded with a Z-coordinate of 187 cm were actually recorded at 185.95 cm. When the magnet endcaps were later removed during repairs at The University of Illinois it was observed that the coils were closer to the downstream endcap by about 1/2 in, in good agreement with the 1.05 cm found above.

It should be noted that, although this magnetic verification device was designed, built, and tested by the Canadian subgroup at TRIUMF and the Universities of Manitoba and Northern BC, funding for hardware components of this subsystem was provided by NSF through the University of Illinois.