Pulsed Taut-Wire Measurement of the Magnetic Alignment of the ITS Induction Cells*

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Abstract

The mechanical and magnetic alignment of the first eight induction-cell, solenoid magnets of the Integrated Test Stand (ITS) for the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility were measured by observing the deflection of a fine, taut wire carrying a pulsed current. To achieve the required alignment (less than 0.25 mm offset and less than 5 mrad tilt), the magnet design uses quadrufilar windings and iron field-smoothing rings. After detailed measurements of each solenoid magnet, the cells are assembled and then mechanically aligned using a laser and an alignment target moved along the cell centerline. After the cells are in final position, the pulsed wire method is used to verify the magnetic alignment. The measurements show an average offset of the magnetic axes from the mechanical axis of 0.15 mm, with a maximum offset of 0.3 mm. The average tilt of the magnetic axes was 0.7 mrad with a maximum tilt of 1.4 mrad. Tilts are corrected to less than 0.3 mrad, using dipole trim magnets assembled into each cell. Correction is limited by power supply resolution and by background noise.

I. INTRODUCTION

The Los Alamos ITS electron beam accelerator is a prototype of the DARHT facility and consists of a 4-MV injector and eight 250-kV linear induction cells. Each induction cell contains a solenoidal focusing magnet and x- and y-dipole steering magnets. A cross-sectional view of the induction cell is shown in Fig. 1. Special care was taken in the cell design to control mechanical tolerances so that good mechanical alignment could be achieved. The magnets are referenced with respect to the beam tube, so a good mechanical alignment should result in a good magnetic alignment. The mechanical specification is for the offsets of the individual cells to be 0.25 mm or less and for the tilts to be 5 mrad or less.

The magnet windings are quadrufilar to reduce field errors produced by winding errors and current feeds. Between the magnets and the beam tube are six axially distributed, iron homogenizer rings to further reduce field errors caused by winding errors.[1,2]

The cells are first assembled and mechanically aligned in blocks of four in an alignment fixture. The procedure uses a HeNe laser measurement system and a cart that travels along the bore of the induction cells carrying an alignment target. After the initial alignment and assembly, two blocks of four cells are moved to their final location and aligned with respect to the injector cathode. The mechanical alignment is measured once again. After final assembly, the pulsed wire method is used to measure and confirm the magnetic alignment.

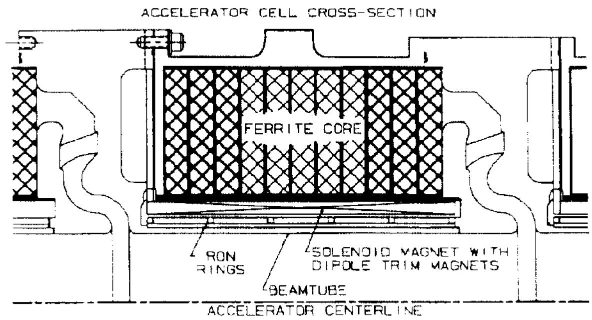

Figure 1. Cross-section of ITS Induction Cell.

II. DESCRIPTION OF THE METHOD

The pulsed taut-wire method of determining magnetic alignment and measuring magnetic field errors has been used by several groups to measure the magnetic fields in accelerator systems.[3,4] Many variations of the basic method have been developed to match the circumstances of the particular experiment. The basic method consists of sending a pulse of current through a taut wire suspended in a steady or quasi-steady magnetic field and observing the motion induced in the wire by the resultant Lorentz force on the wire. If the magnetic field is relatively simple, characteristic patterns of travelling waves are established on the wire that can be easily related to field structure. In particular, the residual magnetic field errors produced by very good solenoidal magnets are typically an offset of the magnetic axis from the mechanical center of the solenoid and a tilt of the magnetic axis from the mechanical axis. The two types of wave patterns produced by these errors are sufficiently different that they can be easily distinguished. Figure 2 shows typical tilt and deflection waveforms before corrections are made. If the fields from several cells are superimposed, however, and if reflections are present due to the ends of the wire, the wave patterns can become too complicated to interpret easily.

Our measurements are done with the induction cells mounted in final position. To accomplish this, we have developed special mounting and positioning fixtures that accurately position the wire with respect to the assembled

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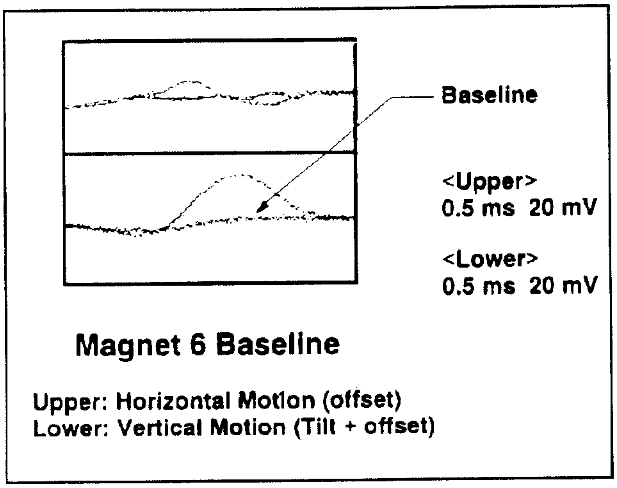

Figure 2. Uncorrected Offset and Tilt Signals

centerline of the cell blocks (to within about 0.05 mm). Also, the measurements must be done with a long wire (over 4 m long) in an acoustically noisy environment, which produces extraneous vibrations in the wire. To subtract these vibrations, we must average over many shots.

Our measurements are made simpler because we only measure the offset of the magnetic axis and correct only for the magnetic tilt. Since we produce a null in the motion detector signal, we do not have to measure the absolute amplitude of the signals. A detailed field map is not produced.

Our procedure consists of the following steps: (1) The wire is carefully tensioned and centered at the centering collars at the two end cells. (2) The optical horizontal and vertical motion detectors and amplifiers are calibrated and set to a region of linear response. (3) Before each cell is examined, a correction is made to the ends of the wire to correct for catenary sag of the wire at the cell of interest. (4) With no power to the magnets of the cell, a zero base line is established for residual room vibrations by applying a pulse of current to the wire and averaging the signal over 20 shots. (5) Current is then applied to the solenoid magnet, the wire is pulsed 20 times, and the averaged waveforms are compared to the reference. (6) The ends of the wire are moved using the x- and y-micrometers until the lack of offset signal indicates the wire is on the magnetic centerline. This measures the solenoid offset. (7) With the wire located on the magnetic centerline, current is applied to the x- and y-dipole steering magnets to null the signals produced by tilt of the solenoid field. (8) The procedure is repeated separately for each cell.

III. HARDWARE DESCRIPTION

The wire used in these experiments is 0.1-mm-diameter BeCu, 4.2 m long. It is tensioned to about 97% of its breaking strength by a system of low-friction pulleys and suspended fixed weights which hold a constant tension. Elongation of the wire is included in the compensation for catenary sag. Sag is compensated by moving the ends of the wire upward to cause it to pass through the center of the test cell horizontally and on the mechanical axis.

The ends of the wire are attached to adjustable slides, which can be moved with respect to the fixed mounting fixture by two micrometers on each end controlling horizontal and vertical movement. The mounting fixtures are fixed to the cells at each end by expansion collar arrangements which locate the fixture with respect to the bore of the end cells. Optical detectors to sense vertical and horizontal motion of the wire are mounted on the adjustable slides. Each has independent x- and y-adjustment micrometers. This arrangement allows the detectors to be moved around the centered wire to position the detectors for linear response, and allows the wire to be centered in the beam tube without affecting the detector alignment.

The motion detectors are a pair of orthogonally mounted GaAs LED-phototransistor detector assemblies (Motorola H21A1 9030), amplified by a single operational amplifier. The overall sensitivity of the detector/amplifier circuit is about 50 mV/μm of deflection. Measured signal levels are 20-50 mV before corrections, corresponding to about 1 μm of deflection at the detector position, and about 5 mV after corrections. Signals produced by room vibrations are typically 20 mV, with a major component at 120 Hz coming mostly from vacuum pumps and ventilation fans.

The current pulse to the wire is supplied by a HP214B Pulse Generator. It produces 0.3 A in the 57-Ω wire. The current pulse is 1 ms in duration and very square in shape, indicating that the risetime of the current pulse is not limited by the inductance of the wire circuit. The signals are recorded on a LeCroy 9450 oscilloscope that provides real time signal averaging and storage of reference waveforms.

IV. EXPERIMENTAL PROCEDURE

Before making a series of measurements, the wire is centered in the bore of the two end cells by moving the wire until it makes contact with a straight edge precisely located by locating pins. The straight edge is then rotated 90° to a second set of pins and the wire is moved until contact is made. Contact is detected by electrical continuity. The continuity check has proved to be a very sensitive indicator of contact between the wire and the straight edge positioning tool. It locates the wire to within one wire radius of the line established by the straight edge.

After the wire has been positioned in the center of the beam tube, the detectors are moved with respect to the wire to establish the range of signal and to select an operating point in the center of the linear range. The ends of the wire are then adjusted to compensate for the catenary deflection at the location of the cell under test. Then, with no current applied to the solenoid magnet, an averaged reference base line is recorded. Current is applied to the solenoid magnet of the cell under test, and the averaged signals are compared to the reference waveforms. The ends of the wire are moved to null the deflection signals. Then current is supplied to the x- and y-dipole steering magnets to null the tilt signal. Usually, about

4-12 adjustment steps are required to null all four deflections. A typical set of signals after adjustments have been made to produce a null is shown in Fig. 3.

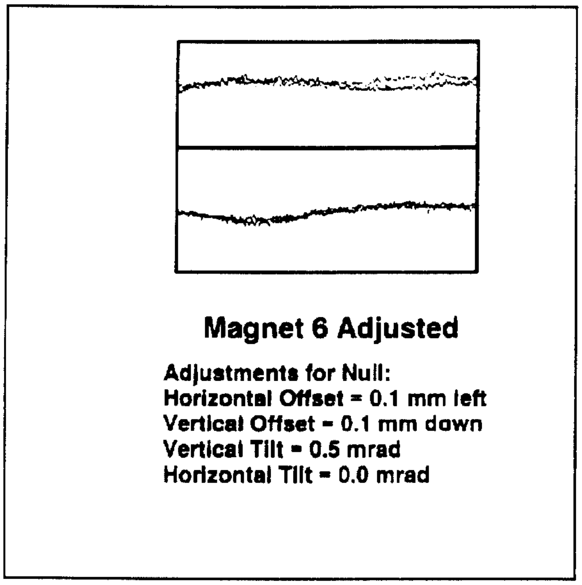

Figure 3. Corrected Deflection Signals

The dipole steering magnet currents needed to correct for tilt are typically very low, about 0.5 A compared to 20 A maximum available from the power supply. Consequently, we are not able to fine tune the steering current better than 0.2 A. However, the full power supply current output could be required if the magnetic tilt were larger. The 20 A current could compensate for 30 mrad tilt.

V. EXPERIMENTAL RESULTS

The results of the alignment measurements on the eight cells are summarized in Fig. 4. The vectors drawn from each point indicate the tilt of the magnetic axis for that cell. The vectors are scaled to indicate the deflection that occurs over the length of the cell (50 cm). The average value of the radial offset of the eight cells is 0.15 mm, and the maximum offset is 0.3 mm for cell #4. The average tilt of the magnetic axes is 0.7 mrad and the maximum tilt is 1.4 mrad for cell #8.

The accuracy of the method is limited at present by background noise, and by the limit in accuracy to which we can set the steering magnet power supplies. We estimate the accuracy of the method to be about $\pm .1$ mm and $\pm .3$ mrad. Hence, after corrections are made for tilt, there could be a residual tilt of 0.3 mrad. This residual tilt error corresponds to a dipole field of about 0.34 G.

After performing the measurements described here, we tried to improve the signal-to-noise ratio (hence the "accuracy" of the method) by using a larger current pulse through the wire. The 0.3 A pulse was increased to 10 A. While this increased the signal levels and reduced the number of shots over which we had to average, it did not significantly

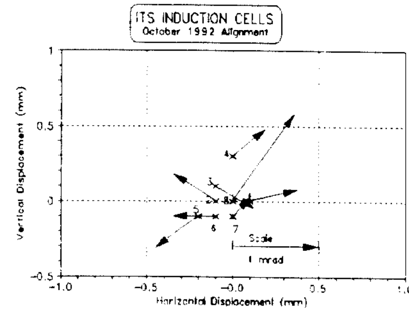

Figure 4. Uncorrected Offsets and Tilts

increase the accuracy with which we could detect the signal null. It introduced the additional complication of frequent wire breakages because of increased mechanical and thermal stress.

VI. SUMMARY OF RESULTS

The pulsed taut wire method was used to measure the magnetic alignment of the eight induction cells of the ITS facility. The offsets and tilts of the magnetic axes were within the design specification. The design approach taken, to control the magnetic alignment by careful control of mechanical tolerances and assembly, and to reduce the effects of winding errors by using multifilar windings and using field homogenizing iron rings, has produced acceptable field errors. We are developing improved pulsed-wire methods to apply to each of the DARHT accelerators, which will be more than 25 m long.

VII. REFERENCES

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