PRELIMINARY STUDIES ON A MAGNETO-OPTICAL PROCEDURE FOR ALIGNING RHIC MAGNETS*

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Abstract

Colloid dispersions of magnetite were used at SLAC and KEK to locate multipole magnet centers. We study here possible adaption of this method, to align RHIC magnets. A procedure for locating magnetic centers with respect to external fiducial markers, using electronic coordinate determination and digital TV image processing is described.

I. INTRODUCTION

Direct measurement of magnetic centers of certain RHIC superconducting quadrupoles and sextupoles is of interest. Mechanical fiducial referencing of coils to external magnet fiducial markers is difficult, and may not be possible after magnet cryostats are sealed. One wishes, for example, to check co-alignment of the low-beta quadrupoles of the insertion region quadrupole triplet, or co-alignment of beam PUE's with sextupole and quadrupole magnets in the arc QSC assemblies, in particular. If one can make such measurements optically, at low magnetic fields and room temperature, installation and alignment of these assemblies is significantly simplified.

Here we examine possibilities for extending magneto-optical alignment methods developed by Cobb and Muray [1], based on work of Johnson [2], and developed by Sugahara, Kubo and Oosawa [3], to alignment of RHIC multipole assemblies. These methods use a cylindrical optical cell containing colloidal magnetite between crossed polaroid filters, illuminated by a collimated light beam, to generate a target pattern. The pattern is produced by field-induced optical anisotropy, caused by alignment of magnetite particles along the local magnetic field. An alignment telescope typically views the target pattern, which is symmetric about the magnetic axis of the magnet.

We examine the possibility of using TV digital image processing, together with electronic coordinate measurement, to extend the method to the problems mentioned above.

II. DESCRIPTION OF THE ALIGNMENT PROCEDURE

Multipole magnet centers are determined as follows. An optical fluid cell is placed in the magnet bore. The cell has accurately flat and parallel windows at each end, and is oriented approximately parallel to the magnet axis. A fiber optic illuminator, with 2 to 5 mm dia. aperture at the end of the fiber cable is placed at the focal point of a 15 cm focal length, f#4, achromatic lens to generate the collimated light beam. Polarizing filters are set before and after the cell. Variable iris stops placed along the beam path assist in optical alignment. The cell is observed with a Farrand type 3560 alignment telescope, equipped with horizontal and vertical tilt plate optical micrometers, which displace the image by a calibrated amount, up to ± 0.12", with precision of 0.2 milli-inch.

The measurement method is shown in Fig. 1. The telescope is mounted to sight the magnet bore. A line of sight is first established on a boresight close to the magnet's geometric axis; precise boresight on axis is not needed. Boresight is established with telescope micrometer tilt plates set for null image displacement reading. This boresight is referenced spatially to external reference fiducials, by setting two Taylor-Hobson balls, each containing a microscopically-centered surveyor's target, along the boresight. The balls sit on kinematic-locating spherical seats, on 2-axis transverse motion translators. The balls can be removed to clear the line of sight and then replaced, or rotated in position, to allow viewing by theodolites, without shift of position of survey target centers.

The cell is mounted on a rail support in the magnet bore, and aligned, by back reflection, with windows normal to the beam. Prior to inserting the cell in the bore, the polarizers are crossed, to give sharp extinction of the light beam. When the magnet is energized, a characteristic cross or spoke shadow pattern is seen, centrally-symmetric about the magnetic axis. Vertical and horizontal components of the axis' displacement from the previously established boresight are measured directly, by displacing the viewed pattern (by tilt of the micrometer plates) until the telescope reticle center (previously set on boresight) coincides with the pattern's center, and reading the micrometers. One can rotate and recross the polarizers to generate a rotated shadow pattern with the same center point, to get an independent remeasurement of the axis. This provides a check, to verify the measurement of transverse displacement of the magnetic axis from boresight.

As an aid to focus the telescope on the cell, we found it helpful to leave an air bubble in the cell. A bright spot is seen in the bubble. One focuses on the spot. Tests involving repeated measurement of location of the shadow pattern center, after defocusing and refocusing the telescope, have demonstrated that parallax is not a problem.

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At RHIC we use a LEICA (Heerbrugg, Switz.) ManCAT coordinate measuring system, together with type T-3000 electronic digital-readout theodolites, to acquire, log, and analyze survey data. Typical accuracy of transfer of target position coordinates to external fiducials is 1 to 3 milli-inch. This system can be used to transfer boresight coordinates from Taylor-Hobson ball targets to an external reference coordinate frame. In this system, two or more theodolites equipped with digital angle readout in turn simultaneously view: one another, a calibrated length reference bar, a set of known survey reference fiducial targets and, finally, survey points whose coordinates are to be determined. Theodolite directional data is entered directly into a computer, for coordinate determination in a coordinate frame of choice.

viewing the cell in collimated light, while crossed Ronchi grills were placed in front of the cell window, through the telescope. Refraction gradients appeared as curve distortions of the grill pattern.

Relaxation time for the colloid particles to align to a magnet field was about one second. This was seen by setting the cell onto a V-block, in collimated light, between crossed polarizers. A permanent magnet was held near the cell so that a field of 50 to 100 Oersted passed transversely through the cell, generating a bar shadow pattern. The cell was rotated manually about its axis. The shadow pattern initially co-rotated with the cell, but returned to its initial orientation within two seconds.

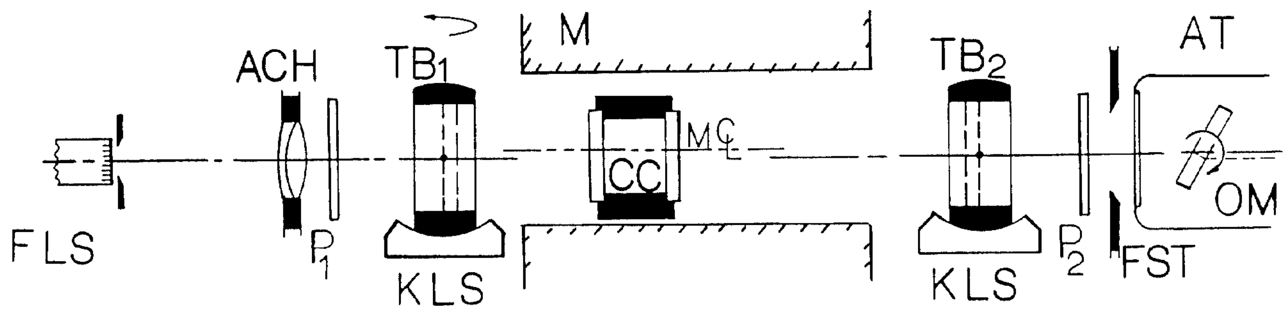

Figure 1. FLS - Fiber Optic Light Source, ACH-Achromatic Collimator Lens; TB - Survey Target Ball, KLS-Kinematic Ball-Locating-Surface; M - Magnet, CC-Colloid Cell, P1 P2 - Polarizer Plates; FST - Field Stops, AT-Alignment Telescope, OM-Optic Micrometer.

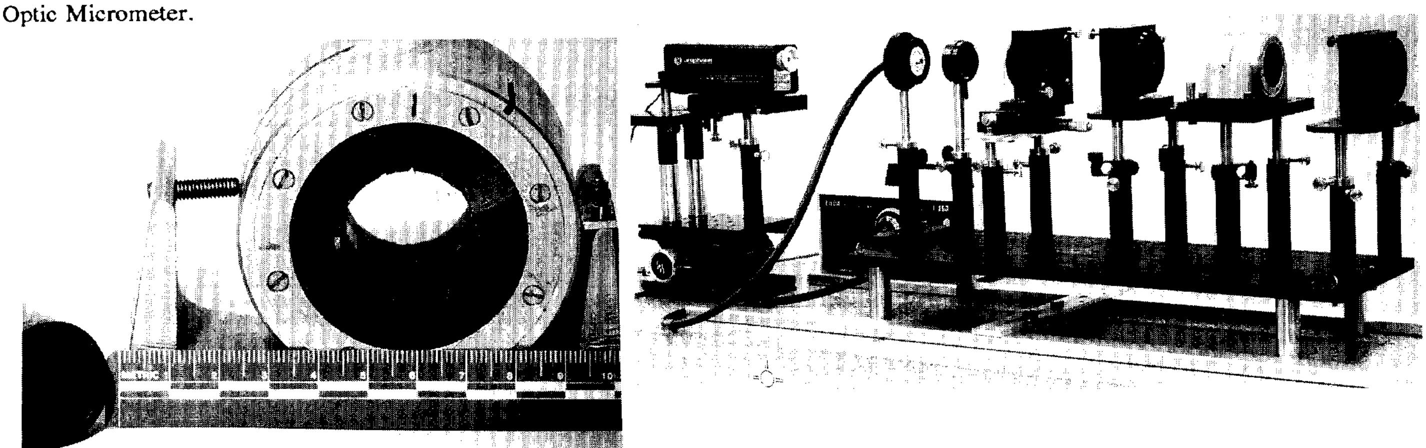

Figure 2. Cell, Magnet, and Optical Setup Used for Colloid Tests.

III. PREPARATION OF THE COLLOID CELL

The fluid is a suspension in glycerol, of magnetite particles, coated with polydextrose (Pfizer Specialty Chemicals, Clifton, NJ), to prevent aggregation. The suspension was prepared by E. Norton, of the BNL Chemistry Department, using the protocol in [3].

Our fluid differed from that reported in [3] by the fact that the particles could pass through a 0.5 micron Millipore filter; this did not affect optical properties of the fluid adversely, and in fact may have decreased any tendency for particle separation in the strong field gradient of our magnet.

The fluid was checked to eliminate inhomogeneity due to coexisting unmixed aqueous and glycerol phases, so that it was of uniform refractivity, free of striae. This was done by

The cell was tested for separation out of particles in a strong gradient field. The cell sat in a permanent magnet quadrupole's field gradient of 6.6 kOe/cm for 3 hours. No separation to the walls or any change of the optical shadow pattern was seen.

Sensitivity of the cell to low fields was tested by placing a 1.5" long cell inside of a loosely wound solenoid coil, with the cell's axis perpendicular to the solenoid axis. The cell was observed in collimated light, between crossed polaroids. With no solenoid current, the optical field was uniformly dark. At a current sufficient to produce 20 Oersted throughout the cell, the optical field brightened significantly. (Light transmission through a cell depends of course on the particular fluid, and cell length, as well as on magnetic field intensity. Quantitative studies to optimize cells have not yet been made, but are of future interest.)

IV. TEST MEASUREMENTS

Measurements were made first on a permanent magnet quadrupole of type designed by Halbach [4], using a test setup and 1.5" long cell shown in Fig. 2. Development work was done with this simple test set. During development, an opportunity appeared to test the colloid method on a cold SSC 4 cm quadrupole, at BNL. A ¾" long cell using our fluid was built by R. Viola (SSC, Dallas). This cell was built with integrally cemented crossed polaroids, attached collimating lens, and illuminating bulb, and was placed in a warm finger in the bore of a cold SSC 4 cm quadrupole magnet.

The cell was viewed with a jig transit, at 10 meters distance (the alignment telescope was unavailable). The magnetic center was visually located to 0.002" in each coordinate. [We note that the cell, collimation, and telescope had not been optimized for this test; prior observation of the ¾" and 1.5" cells, in the permanent magnet quadrupole showed, in fact, that the shadow pattern for the 1.5: cell was appreciably sharper than for the ¾" cell used in this test.]

A weak trim sextupole magnet was also observed, under conditions of 5 cm pole radius, 72 turns/pole, 24 ampere current. The bore field profile is comparable to that available for warm RHIC sextupoles. A 2.5" long colloid cell was used. A clear shadow pattern was visually observed, but was too wide for direct optical micrometer measurements.

V. USE OF PHOTOGRAPHY AND VIDEO DIGITAL IMAGE PROCESSING

The resolution claimed for colloid localization of magnet axes is about 20 micro-meter [1,3]. But published photographs [1,3] show shadow patterns with apparently far worse resolution. Our optical micrometer measurements are consistent with the claimed resolution. To investigate this apparent paradox, we photographed shadow patterns, with a range of exposure times. Photos of a 1.5" long quadrupole cell were taken, both directly behind the polaroid analyzer and at 3m distance, through the alignment telescope. [Figure 3].

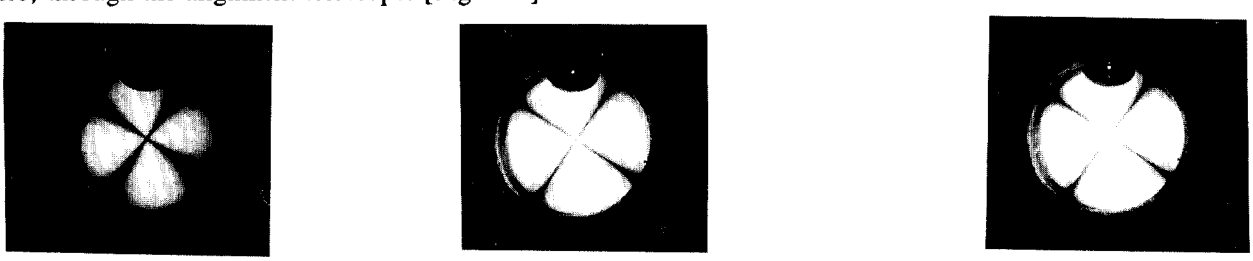

Figure 3. Permanent magnet quadrupole shadow pattern, viewed directly.
a. Exposure ⅛ sec. b. Exposure 3 sec. c. Exposure 6 sec.

Photographic resolution improves greatly when long exposure is used. This is due to the enormous dynamic range of illumination in the viewed pattern; the crossed polaroids have extinction ratio exceeding 10,000. The brightly illuminated area of the field saturates the film, while the shadow interior remains underexposed unless long exposure is used. Intrinsic resolution of the measurement is in fact good, when bright illumination is employed. This result encouraged us to examine the possibility of using digital television image processing to extract the axis' location from a digitized TV image of the shadow pattern. This could be of particular value in attempting to perform warm magnet co-alignment of beam pickup electrodes with the RHIC arc sextupoles. Sextupole patterns are wider than quadrupole patterns, because of quadratic dependence of magnetic field intensity with radius; digital image processing then becomes advantageous. Also, when viewing sextupole patterns, the visually dark core of the pattern may exceed the scan range of the optical micrometer. This is not a problem if video digital image processing is used. Preliminary tests with TV imaging are encouraging; work is still in progress. A camera is easily aligned behind the telescope. After the telescope reticle and colloid cell are visually focused on the reticle plane, a real image of cell and cross hair is formed beyond the eyepiece lens of the telescope. The image can be viewed with a target card placed after the telescope eye lens. The camera can be centered on this image. When using video, it is important that no automatic gain control, or other image servo, be employed, so that the fine dark shadow pattern will not be washed out by averaging with adjacent brightly illuminated pixels.

VI. DISCUSSION

The fact that our colloid cells switch from light to dark at fields of tens of Oersteds, and that intrinsic resolution is good, as indicated by photographic exposure series, suggests that warm alignment of RHIC insertion quadrupoles, and beam PUE's with arc section QSC assemblies is practical. Studies to optimize optical design are in progress.

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