A Technique for Performing the Assembly Alignment of the SSC Dipole Magnets

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Abstract

An optical alignment system was developed for use during the assembly of the SSC dipole magnets. The system is designed to ensure that a finished magnet's cold mass is level, has the correct sagitta, and is in the proper location relative to the magnet's vacuum vessel. Additionally, this system is capable of precisely determining the off-sets between the magnetic center line and the vacuum vessel's external fiducial points. Major system components are described and the alignment procedure is outlined. The uncertainties associated with each phase of measurement are presented.

1. INTRODUCTION

The main ring of the Superconducting Super Collider will require more than 8000 dipole magnets. These magnets will be the bending elements which will confine two counter-rotating proton beams in their orbits. The SSC dipole is a collared, cold iron, 1-in-1 design. Each magnet's cold mass is approximately 15.2m in length and 0.3m in diameter. The cold mass is supported within its vacuum vessel on five composite support posts[1].

In order for the SSC to function, each magnet must be located accurately within the ring. All magnets will carry a series of external fiducial targets on their vacuum vessels with locations which are precisely known relative to the magnetic center line. Survey crews will then use these fiducial targets to properly position a magnet within the tunnel. The exact value of the off-set between each fiducial target and the magnet's center line must be determined during the assembly alignment.

In addition, each dipole cold mass must be "shaped" during assembly. A dipole cold mass will be fabricated straight and the sagitta (a radius of curvature equalling 10.1 km) will be induced by slightly off-setting the internal support posts laterally. During this operation the height of each post will also be adjusted in order to level the cold mass.

The final objective of the assembly alignment procedure is to position the cold mass in its correct location within the vacuum vessel. This step will ensure that there is no interference between the magnet's outer thermal shields and the inside wall of its vacuum vessel.

2. GENERAL PROCEDURE

The procedure used to achieve the objectives stated above requires the creation of a control system of parallel lines of sight. This control system consists of a master line and two sub-master lines all of which are in a very accurately known relationship to one another. The lines are arranged so that the master is used to make measurements within the beam tube and the sub-masters are used to measure the external fiducial targets.

Once the control system has been established, the master line is used to position a pair of locating templates. These templates are in turn used to position a magnet relative to the control system.

After the magnet has been fitted to the control system an optical target is run through the beam tube of the magnet. The position of each of the cold mass support posts is adjusted such that the center of this target will coincide with the master line. The master line is off-set laterally by a set amount at each post location in order to introduce the sagitta.

The sub-master lines are now used to measure the location of the four external fiducial targets. Since the relation of the sub-master to the master is accurately known, the off-set of the magnet's

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center line to each of the fiducial targets can be computed.

3. COMPONENT DESCRIPTION

3.1 Establishing the Control System

All three lines of sight are established using optical alignment telescopes manufactured by Rank/Taylor/Hobson. These telescopes have a fixed magnification and are equipped with built-in optical micrometers which enable target displacements relative to telescope line of sight to be measured in both the vertical and horizontal directions. The three telescopes are mounted in adjustment brackets which are in turn supported by a multi-level platform. This platform is designed to fix each telescope in its correct location.

The lines of sight are made parallel to each other and their separation is measure using a target plate. It has three bulls-eye targets mounted in precisely known locations. This plate is used to measure the separation of the lines of sight at a distance of 1m and at 15m; the pitch and yaw of the sub-master lines are "bucked-in" until these near and far readings agree. This indicates that the lines are parallel and determines their final separation to within +/- 15 microns.

3.2 Fitting the Magnet to the Control System

The two locating templates which are used to fit the magnet to the control system are designed to encircle the magnet's end rings. They are equipped with removable target rods which allow the templates to be positioned on the master line. Once the templates are in their correct locations the magnet is set on supports and its position is adjusted to agree with the templates.

At this stage a measurement is made of the direction of the magnet's dipole field[2]. It is necessary to then roll the magnet so that its dipole field direction is aligned with the vertical coordinates of the control system.

It is essential that the magnet be supported throughout the alignment procedure in the <u>same</u> manner as it will be supported in the tunnel during operation. Even small changes in support locations can have disproportionately large effects on a magnet's shape.

3.3 Making Measurements

The optical target which is run through the beam tube is an aluminum cylinder mounted with a back lit bulls-eye target. This cylinder is centered within the beam tube by two Teflon 'O'rings. The axial location of the target is controlled by a slender steel tether line which is marked with 0.1 m graduations. The target's location in the lateral and vertical directions is determined using the optical micrometer associated with the master line of sight.

The external fiducial targets are removable in order to avoid damaging them during shipping and handling. They consist of a bull-eye target that is set in a rigid frame. This frame can be snapped into a precision steel receptacle which is welded to the external surface of the vacuum vessel. Fiducial target locations in the lateral and vertical are measured using the micrometers associated with the appropriate sub-master line of sight. These off-set values are then entered into a data base and their values become a permanent characteristic associated with a particular magnet.

4. RESULTS AND DISCUSSION

The results of a typical magnet survey are shown in figures 1 and 2. The elevation view of this magnet shows the characteristic arch associated with deflection of the vacuum vessel under load[3]. No attempt was made during the assembly of this particular magnet to adjust the height of the internal posts in order to compensate for this arch. The plan view indicates an attempt to introduce sagitta.

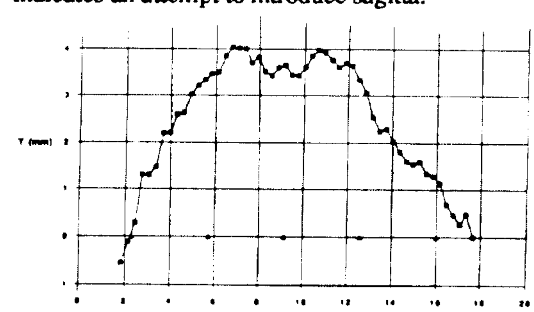

Figure 1. Cold Mass Elevation View

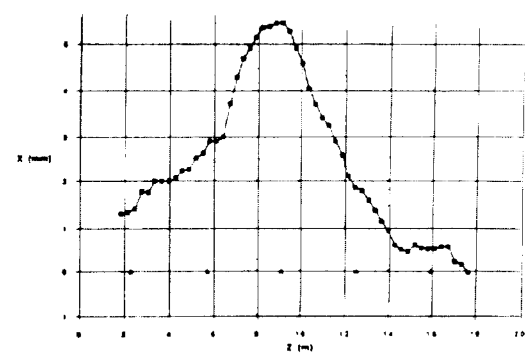

Figure 2. Cold Mass Plan View

When procedure is followed rigorously, the precision of these optical measurements is excellent. Figure 3 shows repeatability data taken in the plan view. This plot shows that subsequent measurements of the beam tube target's position generally deviate by less than 70 microns. Precision of the same order can be achieved when measuring the locations of the external fiducials.

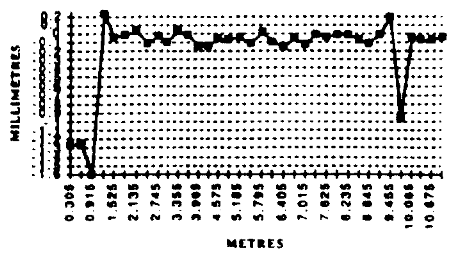

Figure 3. Repeatability Deviation (Plan View)

It should be noted that the off-set distances associated with the external fiducial targets should be measured from a curve that is fitted to the cold mass position data. This curve represents an idealized "magnet equivalent" that will have the same net effect on the particle beam as the actual magnet. By using this fitted magnet equivalent, small "local" perturbations in the cold mass shape will not have any affect on the measured fiducial off-sets. In the same way, the affect of random measurement errors can be minimized.

The step in the alignment procedure which is most prone to error accumulation is the positioning of the magnet relative to the control system. Small imperfections in the locating templates, the target rods or in the magnet end rings will result a magnet which is out of position relative to the lines of sight. Using current equipment the magnitude of this cumulative error does not exceed +/- 0.3mm. However, this error only manifests itself as a mislocation of the cold mass within the vacuum vessel and can be compensated for by the bellows which connect adjacent magnets. The more critical fiducial off-set measurements are unaffected.

5. FUTURE WORK

A key assumption in the above procedure is that the geometric center of the magnet's beam tube coincides with the magnetic center line. However, if the beam tube itself is not well centered within the bore of the magnet this may not be the case. Sugahara et. al. demonstrated that the center of a quadrupole field can be targeted optically by using a special target cell containing a ferro-fluidic solution[4]. A warm SSC dipole magnet can be temporarily rewired to induce a quadrupole field; the location of this field's center could then be measured directly. Whether the gradient of this induced field is sufficient to make accurate measurements will be explored.

Modifications to the current system are underway to make it more suitable to a "rate" production environment. Methods for automatic data collection and handling are being developed. The use of CCD cameras to improve telescope resolution is also being investigated. Motorized adjustment mechanisms which allow the magnet to be quickly and accurately positioned relative to the control system have been built and are being tested.

Warm to cold alignment correlation needs to be checked.

6. REFERENCES

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