REMOVAL OF AXIAL TWIST IN RHIC INSERTION QUADRUPOLE MAGNETS*

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Abstract

The focusing triplets located on either side of the six interaction points of RHIC each consist of three 13cm aperture quadrupoles with magnetic lengths of 1.44m (Q1), 3.40m (Q2), and 2.10m (Q3). The field quality and alignment of these magnets are critical to the performance of the accelerator. The maximum allowable axial twist of the cold mass, defined as the standard deviation in the quadrupole roll angle, is 0.5 mrad. This requirement has occasionally exceeded the capabilities of the assembly fixturing and the procedures used to complete the axial welding of the shell halves around the cold mass yoke. A corrective shell welding technique has been successfully employed to remove excessive axial twist of the 13cm quadrupoles. This “custom straightening” method is described along with the mechanical inspection data before and after straightening. The magnetic results which confirm the untwisting procedure are also discussed.

I. INTRODUCTION

The ultimate luminosity of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory depends largely on the field quality in the 13cm insertion quadrupole magnets. These 72 quadrupoles have magnetic lengths of 1.44m (Q1), 3.40m (Q2), and 2.10m (Q3). They are the heart of the focusing triplets and must be held to a level of axial twist such that the variation in field angle along the length of each cold mass does not exceed 0.5 milliradian (rms). Axial twist data from mechanical inspection is acquired on each individual quadrupole unit after shell seam welding, and warm magnetic measurements are performed on the final cold mass assembly (Q1, Q2 mated with a single corrector, or Q3 mated with two correctors). Therefore, an opportunity exists to make corrections for twist after shell welding, and for twist and straightness after final cold mass assembly.

II. WELDING PROCEDURE FOR PRODUCTION

The 13cm quadrupole helium containment vessel includes a two piece stainless steel shell, 6.35mm thick, with longitudinal seams at the twelve and six o’clock locations[1]. The shells of all twelve 13cm quadrupole units installed in Sextant #5 (comprising the first sextant test in January, 1997) have been manually seam welded at BNL using TIG welding equipment and a procedure which calls for two welders operating simultaneously on either side (the cold mass is rotated 90 deg. while clamped straight and securely on the welding platform). It is generally believed that undesirable degrees of twist or bending of the containment vessel can result from an imbalance induced during the welding process (e.g., unequal heat input or rate of filler wire consumption from side-to-side), uneven weld shrinkage, variations in shell straightness, variations in shell weld gap, or the presence of asymmetric welds and discontinuities on the containment vessel necessitated by the placement of such items as fiducials, mounting brackets, cover patches on the shell, or repairs, etc. In the case of the 13cm quadrupoles, the twist and straightness requirements can and often do exceed the practical design limitations of the shell assembly tooling, and cold mass assembly techniques. Experience has shown that despite the fact that the cold mass is firmly clamped against strong and precise fixturing which is designed to keep it straight throughout the duration of the welding process, the cold mass may “spring” upon removal from the fixturing. Much effort has gone into designing the tooling and tailoring the process with one of the primary goals being the control and minimization of this springing.

Most 13cm insertion quadrupoles installed in the tunnel after the first sextant test will have shells that are seam welded via automatic MIG welding utilizing computer controlled wire feed and progression of the weld head. This will involve using the same unit that was previously used successfully to weld all 8cm CQS assemblies at BNL. Although machine welding is clearly a tremendous time saver compared to manual welding, presently it is not yet known whether or not it will result in a reduction of axial twist or bending of the cold masses.

III. REMOVAL OF AXIAL TWIST

Removal of excessive cold mass twist via “flame straightening” methods was first successfully employed by Northrop-Grumman Corp. on 8cm dipole DRG567. This method of “counter-twisting” has since been refined at BNL and is used to efficiently and reliably reduce axial twist of the 13cm quadrupoles to within acceptable limits. A twist bridge is used to monitor the change in inclination of the cold mass at locations where holes in the shell allow access to the flat survey surfaces on the outside diameter of the iron yoke. The twist bridge consists of a precision aluminum frame onto which an electronic level sensor or

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inclinometer is rigidly mounted. The inclinometer has a range of ±20 mrad and is accurate to within .05mrad. The two lower contact surfaces of the twist bridge engage the yoke survey notches which serve as indicators of the mechanical center and level of the magnet. The basic procedure for twist removal is outlined below:

1. Set the cold mass on two pairs of precision steel rollers spaced at approximately 1/4 and 3/4 overall cold mass length. Place the twist bridge on the cold mass so it engages the survey notches at the top pair of shell holes closest to the lead end.

2. Level the cold mass so that the twist bridge reads zero. Use suitable means to lock the cold mass so that this first shell hole location remains level and does not rotate during the untwisting process.

3. Move the twist bridge to the next shell hole location and determine inclination. If the twist is deemed excessive, apply a TIG weld bead between the two shell hole locations and about the horizontal midplane, and angle it approximately 30 deg. in the chosen area to be untwisted. Do the same except in the reverse orientation on the exact opposite side of the cold mass in order to maintain weld symmetry side-to-side and to preserve axial straightness. The length, number of weld beads, and filler wire input depend on the demonstrated effectiveness (i.e., the degree to which they mitigate axial twist in a particular instance). Fig. 1 illustrates the general concept.

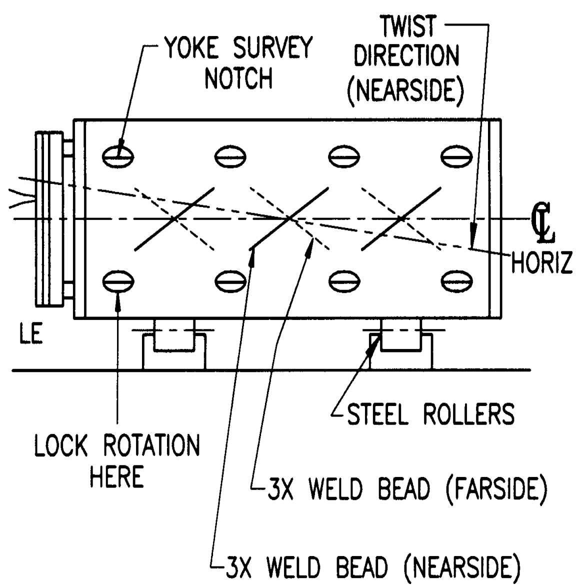

Figure 1. Schematic showing the procedure used to remove axial twist.

4. The twist condition existing at each region between adjacent sets of shell holes is corrected separately and individually. Only a single welder is necessary but weld length, size and filler wire input must be identical on opposite sides or the cold mass will bend.

5. Observe the twist bridge display while welding is in progress so that it is continuously clear that the desired results are being achieved and that no more weld is being laid than is absolutely necessary. Successive welds must be in matched pairs of equal length on both sides and must be adjacent to but not overlapping previous welds. The amount of counter-twist generated by each pair of angled welds is governed by their length and not by varying the angle or size (filler wire input) of the weld, once it is established. Weld lengths should be shortened if necessary to ensure that a matching weld of identical length may be applied on the opposite side of the cold mass.

6. After the cold mass has cooled completely, obtain final twist data by taking inclination measurements at each available shell hole location to verify that the overall twist is within the specified tolerance.

IV. RESULTS

Referring to Fig. 2, it is observed that Q3 quadrupole QRJ114 has an initial twist exceeding 1 mrad rms (dotted line). The corresponding solid lines show that the final twist of QRJ114 after flame straightening is within 0.5 mrad rms. Fig. 3 shows twist measurements on Q2 quadrupoles. Both QRK103 and QRK107 had large twist initially (dotted lines). QRK103 with an initial twist of over 2 mrad rms received three pairs of corrective welds. The final twist of this cold mass was reduced to well within 0.5 mrad rms. A similar result was also obtained for QRK107.

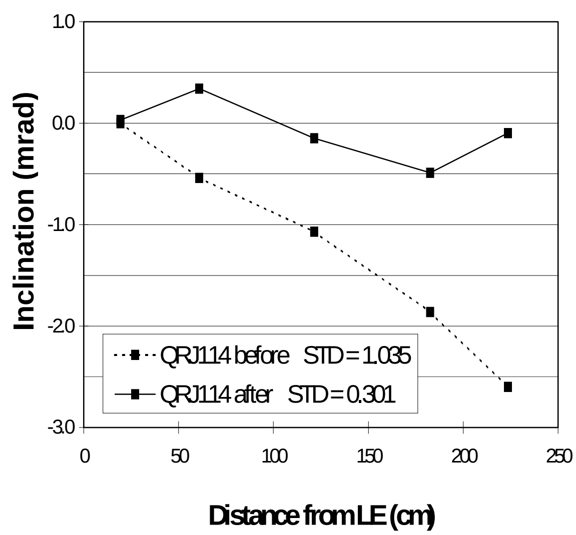

Figure 2. 13 cm Q3 Quardupole Twist Data.

The magnetic field angles of the completed quadrupole assemblies were measured with a 0.91m long rotating coil system. Only one measurement of field angle was possible in the straight section of the Q1 and Q3 magnets so no information on twist could be obtained. In the Q2 magnets the field angle was measured at three axial locations, thus allowing an estimate of the actual twist. The field angle plot shown on Fig. 4 clearly demonstrates that the room temperature magnetic measurements correspond closely to

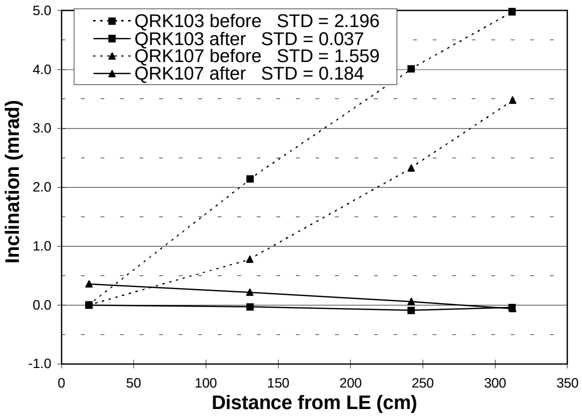

Figure 3. 13 cm Q2 Quadrupole Twist Data.

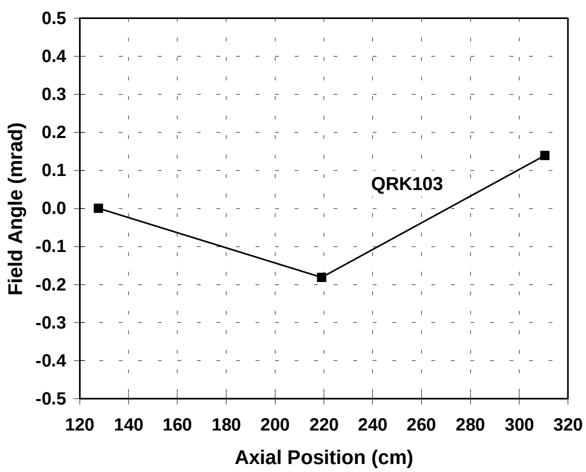

Figure 4. Field angle measured with a 0.91m long rotating coil at three axial locations in the straight section of the Q2 magnet QRK103.

the mechanical data as far as overall axial twist of the cold mass is concerned. In the case of QRK103, the field angle is held to within 0.4 mrad after twist removal. These measurements verify that the yoke is a good indicator of the magnetic field angle, as expected, thereby validating the corrective procedure. Furthermore, this suggests that even in the absence of mechanical means of measurement (the yoke survey notches may no longer be accessible) the variation in magnetic field angle may be read directly and reduced as needed, by careful application of corrective welds.

V. CONCLUSION

A procedure is described to remove axial twist in magnets based on mechanical measurements of the iron yoke and application of corrective welds. Magnetic measurements of twist are in agreement with the mechanical measurements. Therefore, either may be used to reliably monitor the effect of the twist removal process.

REFERENCES

[1] R. Gupta et al., “Large Aperture Quadrupoles for RHIC Interaction Region,” Proc. 1993 Particle Accelerator Conf., Washington, DC, p.2745.