A Mechanical System for the Positioning of Accelerator Magnets

Robert Viola and Richard Martin
SSC Laboratory*
2550 Beckleymeade Ave., Dallas, Texas 75237 U.S.A.

Abstract

A mechanical support and adjustment system was developed for the precise positioning of the SSC accelerator magnets. This "Ball/Roller" system was designed to be stable, truly kinematic and capable of accommodating a magnet's thermal expansion or contraction. The system's mechanisms are described in detail and its adjustment range, resolution and performance are discussed. Techniques for interfacing the system to magnets of various geometries are presented. A motorized version of the Ball/Roller system was also developed for applications which require magnets to be manipulated remotely. The design and performance of this motorized system are presented.

I. INTRODUCTION

All particle accelerators require that their lattice elements be located accurately in space. The system which is used to support and position lattice elements is therefore critical to an accelerator's performance. An adjustment system must be capable of micron level movements and yet also be rugged enough to survive the tunnel environment over the life of the machine.

This paper describes a kinematic adjustment system designed to provide stable magnet support while also meeting all key performance requirements associated with alignment. The Ball/Roller design has the flexibility to accommodate either conventional or superconducting magnets with a variety of geometries and weights. Several drive options are available depending on the the particular alignment application.

II. DESIGN GOALS

The Ball/Roller system was designed with the SSC main ring magnets in mind; it therefore needed to be capable of supporting superconducting dipoles with a mass in excess of 14,000 kg. It was required that the system provide true kinematic support: control of all six of a magnet's degrees of freedom without redundancy[1]. The support also had to allow for thermal expansion of a magnet without buckling or tilting. The range of motion needed to be at least +/- 25 mm with resolution of better than 10 microns. Finally, the geometry of the system had to allow for predictable adjustment of each degree of freedom as well as easy access to its actuator.

III. BASIC SYSTEM DESCIPTION

The Ball/Roller is a three-point support and adjustment system patterned after the jack system used to support the LEP dipoles at CERN[2]. A magnet is supported by three identical mechanisms each of which is adjustable in the vertical and one lateral direction but free to move in the other lateral direction. The three mechanisms are arranged to provide a triangular support base with the orientation of one of the mechanism rotated 90 degrees with respect to the other two. By working the mechanisms' actuators in combination, all six degrees of freedom can be controlled.

Details of a single mechanism's design can be seen in Figure 1. A central block slides on a base frame and is threaded to accept a large diameter cup screw. The cup screw

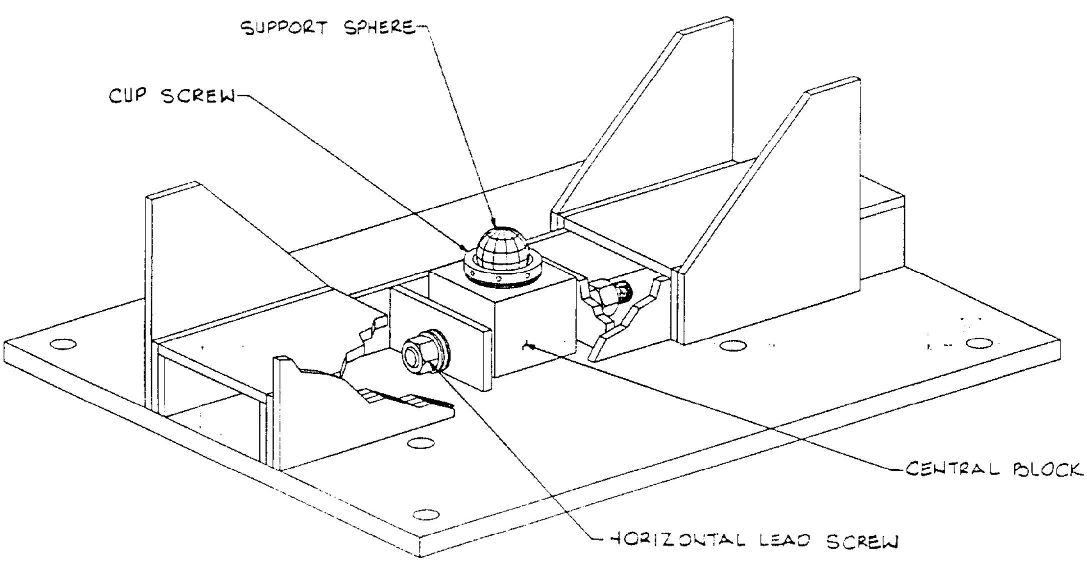

Figure 1. Basic Ball/Roller Mechanism

0-7803-1203-1/93$03.00 © 1993 IEEE

acts as a jack for adjusting an object's vertical position. The screw's diameter is a function of the load being supported, a full size dipole required a cup screw diameter of 60 mm. The horizontal travel of the block is controlled by lead screw fixed within the mechanism's frame. It should be noted that this horizontal lead screw bears no load; the weight of the object which is being supported is transferred directly from the block to the frame.

A hardened stainless steel sphere acts as the interface between the mechanism and the object being supported. This sphere is captured within the cup screw and fits into a groove in the bottom of the object (Figure 2). This groove is oriented at 90 degrees relative to the direction of the adjacent horizontal lead screw. The steel sphere rolls along this groove and allows an object to translate freely in this direction. The original interface plates developed for SSC magnets used a trapezoidal shaped groove. However, current designs use a semi-circular groove for a more even stress distribution[3].

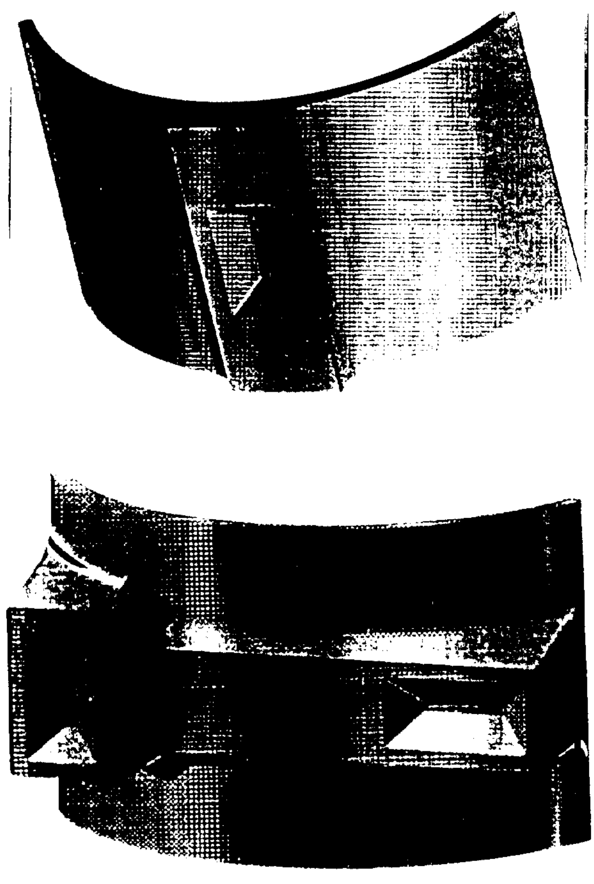

Figure 2. Single and Double Groove Interface Plates

All mechanism components are made of steel and are plated to prevent corrosion and reduce friction. Selected components are hardened as required.

This system is not purely orthogonal, there is cross-coupling between rotations and translations. However, the individual mechanisms *are* orthogonal thus allowing each degree of freedom to be individually and predictably adjusted.

It should be noted that the preceding discussion assumes that the object which is being supported behaves as a rigid body; in practice, accelerator magnets often have a good deal of flexibility. In the case of long conventional magnets it is sometimes possible to adjust a magnet's roll independently at either end when using a traditional four point support system. While this approach may allow fabrication twist to be adjusted out of the magnet it also leads to a statically indeterminate system and is generally considered undesirable. It is not possible to introduce twist into a magnet using the Ball/Roller system.

IV. PERFORMANCE TESTS

Several versions of the basic Ball/Roller adjustment system have been built and tested at the SSC Laboratory. They have been used to support main ring quadrupole magnets as well 40 mm aperture and 50 mm aperture versions of the dipole magnet. Results of these tests indicate that, in general, the Ball/Roller system's performance exceeds design goals.

The geometry of the prototype system was chosen to provide a range of motion of +/- 30 mm in all directions. This value could certainly have been increased but was kept low in order that the individual mechanisms could be made as compact as possible. Motion in all directions was smooth and free of "stiction" over the entire range. The play and run-out of the individual mechanisms was negligible.

The Acme threads used on both the horizontal lead screws and the cup screws had a pitch of six threads per inch. Even with this relatively coarse pitch incremental movements as small as 5 microns were possible after some practice. Since the motion of the magnets was measured directly the Ball/Roller's minimal backlash did not present a problem.

The ball-in-groove interface between the system and the magnet proved to be self centering: magnets could be mounted or removed very quickly with little or no pre-alignment required. The system was stable over time with no locking screws or rings necessary. Lateral and axial "up-set" loads consistent with impact or quench were easily withstood. However, because the Ball/Roll system provides *simple* support some sort of earthquake restraint would be required in a seismic environment.

Inputs to the system's actuator were made using a standard socket wrench for the horizontal lead screws and with a modified spanner wrench in the case of the cup screws. This technique was satisfactory but not optimal. The torque required to raise and lower the heaviest magnets tested was 450 N-m. This high torque necessitated a rather long "cheater" bar on the spanner which would become awkward in confined spaces. Alternative approaches are currently being explored.

V. MOTORIZED ACTUATORS

An automated version of the basic Ball/Roller system has been developed for use in those applications which might require continuous adjustment of an object's position or adjustment of its position in a remote location. An example of this type of application would be the support of the final focus quadrupoles in the SSC interaction regions. The design of this system uses Sumitomo AC Gearmotors to drive the lead and cup screws (Figure 3). The lead screw itself has been

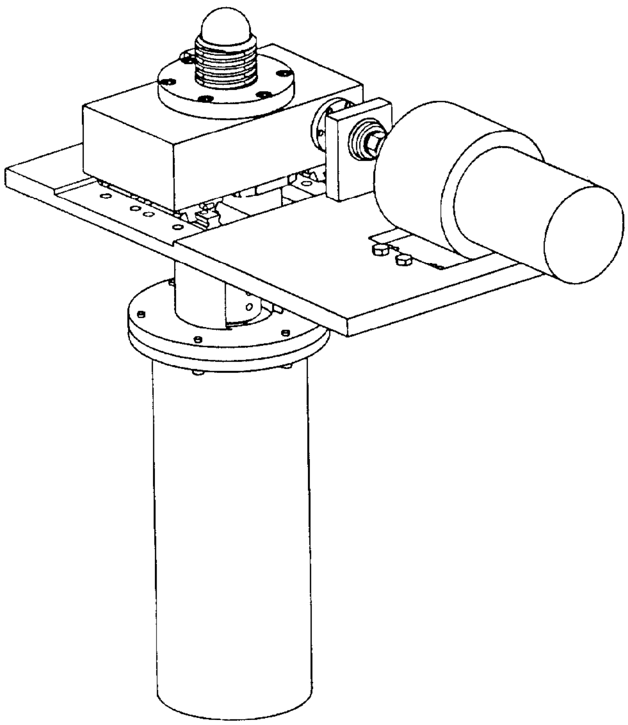

Figure 3. Automated Ball/Roller

off-set in the central block to allow for an in-line connection of the cup screw to to its motor via a spline shaft.

Because sliding surfaces were unacceptable in a system subjected to continuous adjustment they have been eliminated from the motorized Ball/Roller. In this version the central block is support by four THK linear motion guides mounted on a pair of low profile rails. This arrangement not only eliminates sliding friction but also resists the twist which is imparted to the block by the off-set lead screw. The Acme threaded lead and cup screws have been replaced by ball screws of the appropriate sizes which interface to the central block via ball nuts. These ball screw/nut combinations significantly reduce the torque required to move an object, especially in the case of the large diameter cup screw; this in turn reduces the size of the AC motors required.

Results of initial tests on the motorized Ball/Roller system indicate that its range, resolution and load capacity exceed those of the basic system.

VI. POSITIONING AN OBJECT

For both the basic and the motorized system the general strategy for positioning an object is the same. For any configuration of the support system there exists one and only one corresponding object location in space. In the case of aligning a magnet the magnet's external fiducial targets are used to define its initial location. The geometry of the magnet and its interface grooves will uniquely determine the coordinates of the three support spheres. For any arbitrary new location in space (as defined by a new set of coordinates for the external fiducials) a corresponding set of new support sphere locations can be computed. The geometry of a Ball/Roller mechanism can then be used to compute the lead screw rotations required to move the magnet to this new location. This procedure is independent of the system's initial configuration.

A variation of this technique allows for the very accurate pre-alignment of magnets. If the ideal coordinates of the magnets external fiducials are known they can be used to compute the ideal coordinates of the support spheres. Prior to the magnet's installation, the support sphere are replaced with target spheres of the same diameter which are equipped with either optical or laser targets. The configuration of the system can then be rapidly adjusted such that these targets are moved to the ideal coordinates. With the support spheres back in place the magnet is set automatically into its proper corresponding location.

Of course, there are other valid strategies for adjusting an objects position; pure translations and rotations could be made in sequence if desired. This approach would be particularly well suited for an automated system using synchronized motors.

VII. CONCLUSION

It has been shown that the Ball/Roller adjustment system is capable of meeting its performance goals. The design continues to be refined with and eye on improving access to and reducing the torque requirements of the manual actuators. By off-setting the horizontal lead screw in the basic system the cup screw becomes accessible from below. This in turn would allow a standard socket drive to be used rather than the spanner. Incorporating ball screws into the basic system could significantly reduce the torque required to make vertical adjustments. An evaluation of these modifications is currently underway.

The control system of the motorized Ball/Roller will be modified in order to explore "closed-loop" position adjustment.

* Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

[1] D. Vukobratovich, "Component Design Choices," *Newport Optics* 1991, pg. B-2 through B-13.

[2] J.P. Quesnel, CERN, Private Correspondence dated March 26,1992.

[3] E. Kindler, SSCL, "Stress Analysis of Ball Mount Support," 1993