The Superconducting Interaction Region Magnet Positioning System for the CESR Phase III Upgrade *

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Abstract

Due to the extraordinary sensitivity of beams to misalignments of the superconducting high gradient interaction region magnets for the Phase III upgrade, a beam-based alignment and active positioning scheme has been designed and is being constructed. Using cams and kinematic mounting, the magnetic centers of the four quadrupole magnets will be independently positioned over a radial range of 1 mm with a resolution below 10 μm. Beam measurements of the closed orbit will determine where to set the position. In principle realignment can be done while beams are stored. The positioning system must withstand considerable dynamic forces due to the interaction of the CLEO detector solenoid field with the current in the dipole windings. It is located almost entirely within the CLEO detector and has a special transition from non-magnetic to magnetic materials so as not to disturb the uniformity of the solenoid field. It allows for retraction of the CLEO pole from the detector without interference.

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Background

In 1998 the CLEO detector will complete another major upgrade to bring its performance up to B factory levels. Taking advantage of the opportunity presented by the re-design of most of the detector, new interaction region focussing and correcting elements were designed to allow the highest possible luminosity [1][2]. To ameliorate the effects of the long range beam-beam interaction at crossing points near the interaction point, the new magnets are designed to be quite short with high gradients.

Misalignment Tolerance

Machine performance depends critically on the alignment of the superconducting interaction region quadrupoles. Sensitivity to vertical misalignments is enhanced due to the high gradient, high β, and rapid phase advance through the interaction region. The result of misalignments is closed orbit errors, and loss of effective physical aperture, and vertical dispersion, that will dilute vertical beam size.

A 1 mm vertical misalignment of one of the vertically focussing quadrupoles, if uncorrected, generates an 80 mm closed orbit error, nearly four time the physical aperture of the machine. Vertical dispersion is most severe when the relative misalignment of quadrupoles on either side of the interaction point is such as to create a closed orbit bump. Since the betatron phase advance between the vertically focussing magnets is approximately 180 degrees, a nearly closed bump is produced when the magnets are displaced vertically in equal but opposite directions.

Because of the large chromaticity in the interaction region, phase advance, and therefore bump closure depends strongly on energy. If the four magnets are alternately displaced vertically by ± 1 mm, peak vertical dispersion in the machine arcs is closed to 7 m. If the orbit error is corrected with steering magnets located 1 m outboard of the cryostat, the residual vertical dispersion is reduced to an unacceptably high 70 cm. (Significant dilution of vertical beam size is evident if vertical dispersion is greater than 5-10 cm.)

While vertical beam size and aperture are quite sensitive to vertical misalignments, effects of horizontal misalignment are much less severe. The strength of the horizontally focussing quadrupoles and the horizontal β in them are both smaller than their vertical counterparts. In addition, the horizontal dispersion in the machine is near 4 m by design, while the vertical dispersion is nominally zero. Finally, horizontal correction near the IR is easier than vertical because of the larger horizontal beta functions there.

Taking into account the sensitivity of the closed orbit and the limited ability of existing corrector magnets to accommodate quadrupole position errors, we have have designed a magnet positioning system that should be able to put the magnetic centers of the quadrupoles on the correct axis to within 100 μm vertically and 500 μm horizontally under all conditions. The run to run tolerance should be an order of magnitude less and vibration amplitudes should be less than 1 μm.

Design

Holding and accurately positioning cryostats containing the superconducting magnets is problematic: they must be deeply inserted into the CLEO detector, there is little space available, there are large electromagnetic forces, materials must be either highly non-magnetic or good magnet steel depending on location within the detector and its steel yoke, and there must be semi-frequent personnel access to the interior of the CLEO detector for maintenance and repair of the electronics. The basic design choice is to either use a cantilevered support [3][4], or to use some portion of the CLEO pole with a column or pylon support. Detector access has been provided for by longitudinally extracting the end poles. Cantilevered support would have to extend over a distance of about 5 meters and would occupy a space that might someday be needed for round beam quadrupoles or two-ring separators. Cantilevered support also implies that the transition from cold to warm cryostats occurs horizontally, which complicates the cryogenics[3]. We chose instead cut a vertical slot out of the pole pieces and suspend each cryostats on a thick steel pylon which hangs from the fixed portion of CLEO return yoke. See Figure 1. The pylon remains in place when the pole is retracted for access. Cryogenics utility lines are located immediately behind the pylon so there is no need to modify or move the interaction region magnets to obtain access to the detector. A pylon rather than a column is preferable for bath cooling of the magnets.

Pylon Mount

Detailed finite element studies were carried out to ascertain the stiffness of various pylon designs [6]. The main cause of flexure was found to be due to twisting of the ring to which the pylon is attached when the CLEO solenoid magnetic load (43,000 lbs) is turned. The twisting is greatly reduced by strategically coupling the inner ring to the next outermost ring. With this improvement the transverse flexure of the pylon and CLEO magnet is kept to less than about 0.005 inches when the CLEO solenoid is energized. Other loads due to the interaction region magnets reacting with the CLEO solenoid produce substantially smaller displacements.

External Forces

In addition to the usual gravitational loads, there are several rather large external forces acting directly on the superconducting magnets which are the result of the CLEO solenoid field acting on the currents in the dipole and quadrupole coils. These forces, which are dynamic, must be carried by the helium vessel, the cryostat and the positioning system. There is also a more or less static force on Q2 due to the nearby steel detector yoke which is due to misalignment of the yoke with respect to the quadrupole [7]. These forces are shown in Figure 2. The weight of each cryostat/magnet assembly is expected to be about 4000 lbs. The electromagnetic forces are larger though to some extent they cancel. Detailed mechanical analysis shows that under some possible conditions the cyrostat could lift off the cams unless an additional 4000 lbs vertical load is applied. These loads will be supplied via pre-loaded spring assemblies. Gas cylinders will be used to energize the springs because they have good force/volume characteristics and are non-magnetic.

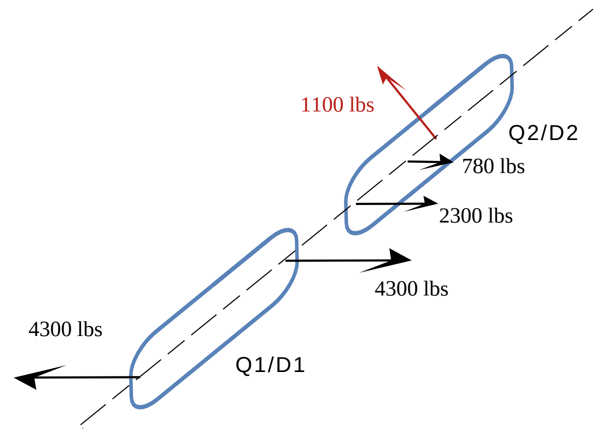

Figure 2: Electromagnetic forces acting on the dipole and quadrupole magnets which must be taken up by the positioning system. The dipole forces are in the horizontal plane, while the quadrupole force could be in any transverse direction.

Cam Configuration

Bearings mounted eccentrically on a shaft (cams) offer several advantages as positioning devices in our application:

- Fine control and limited range of motion
- Heavy load carrying ability
- Simple and tested [5].

By providing kinematic mounting of the cryostat, the axis connecting the magnetic centers of the two quadrupoles can be uniquely and precisely positioned independent of the variable

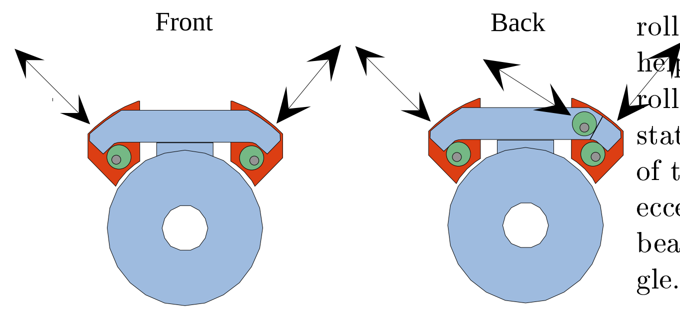

Figure 3: Cam arrangements at the front and back of the cryostat.

forces that will be borne Of course, cam's have some disadvantages too: the system will have to be pre-loaded to insure positive contact at all cam contact points under all load conditions. Also it is somewhat difficult to understand the range of motion of a cam based system, and the range is not exactly suited to the application.

These considerations led to a choice of cam configurations which minimizes the excess motion of the cryostat. The configuration is shown in figure 3. There are two longitudinal planes where the cams are located. The front plane at, 1324 millimeters from the IP, has two cams that are 90 degrees from each other and control the position of one end of the cryostat axis. The back plane of cams, located 2492 millimeters from the IP, is the same except for an additional 'theta cam' which controls the rotation about the cyrostat axis. The theta cam is not independent of the other cams. That is when the cryostat axis is moved the theta cam angle must be adjusted just to keep the rotation about the axis constant.

Two tee shaped brackets attached to the cryostat are set on the cam bearings so that the cryostats effectively hangs on the bearings. If it were not for the theta cam, the cryostat would roll freely about its center. Conceptually it is helpful to imagine the cam bearings to be in rolling contact with a circle centered on the cryostat center and cut into tees attached to the top of the cryostat. Since the bearings are mounted eccentrically on a fixed shaft, the center of the bearings can be moved by changing the shaft angle. This directly translates into a motion of the cryostat center. In practice the difference between a flat rolling surface and a circular one centered on the cryostat is negligable since only small ~ 1 millimeters motions are encountered.

Hence we have five degrees of freedom (the shaft angles) controlling all possible motions of the cryostat except its longitudinal position. The longitudinal position is set at assembly time by the pre-load device. It constrains the longitudinal location of a point on the mounting bracket with only second order constraints on the transverse position or rotation of the cryostat. The second order constraint leads to small but negligable longitudinal motion when a transverse motion is introduced.

Acknowledgements

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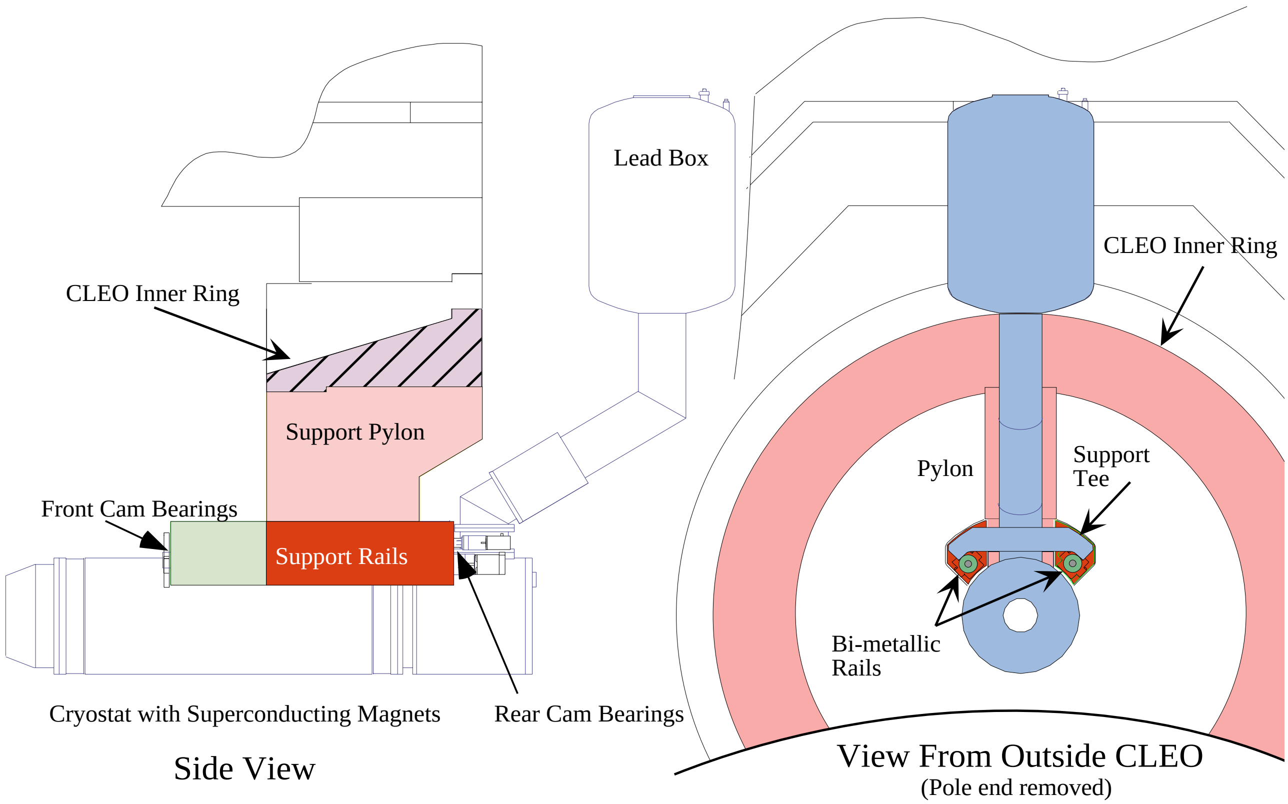

Figure 1: A thick steel pylon attached to the inner steel ring of the CLEO solenoid magnet yoke holds the cryostats containing the superconducting interaction regions magnets. The remaining 'keyhole' shaped portion of the CLEO pole is not shown. It can roll out for detector access. The cryostat is kinematically held by rolling contacts on five cam bearings and one spherical bearing contact for longitudinal location.