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## Abstract

This paper describes the mechanical design of the ends of Superconducting Super Collider dipole magnets to be constructed and tested at Fermilab. Coil end clamps, end yoke configuration, and end plate design are discussed. Loading of the end plate by axial Lorentz forces is discussed. Relevant data from 40mm and 50mm aperture model dipole magnets built and tested at Fermilab are presented. In particular, the apparent influence of end clamp design on the quench behavior of model SSC dipoles is described.

## INTRODUCTION

Figure 1 shows a cross section of the end region of the Fermilab baseline dipole magnet for the SSC [1].

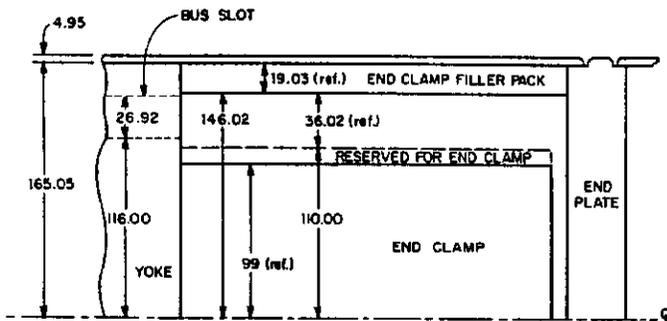


Figure 1. Schematic of the SSC Dipole End Region  
(All dimensions in millimeters)

The 4.95mm thick 304N stainless steel shell is supported by non-magnetic filler packs in the end region. End clamps provide a radial clamping load to the ends of the coil straight sections as well as the turn-around portions of the coils. Axial motions of the coil ends due to Lorentz excitation forces are transmitted to the 304N stainless steel end plate through the end clamps. Each of the components of the end region will now be described in more detail.

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## COIL END CLAMPS

### Design

Figure 2 shows the lead end clamp. Both the lead and the non-lead end clamp<sup>1</sup> have a "collet" design, in which four G10CR<sup>2</sup> quadrant insulators are clamped in place by a surrounding metal cylinder. An end cap of the same material as the cylinder is welded to the cylinder after installation. A .82mm (32mil) clearance is left at each quadrant boundary, so that the insulators do not bind during clamping.

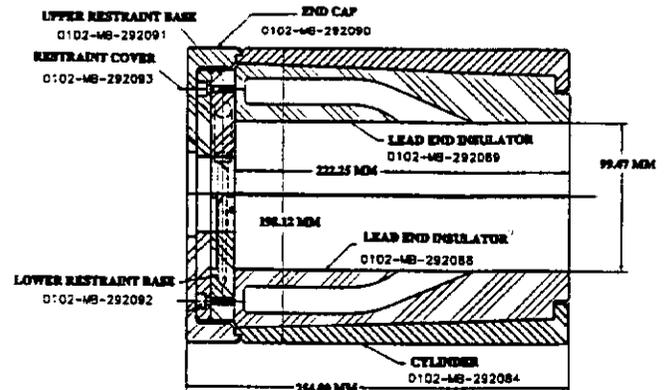


Figure 2. SSC Dipole Lead End Clamp

The inner surfaces of the insulators do not make direct contact with the turns of the upper and lower outer coils. Instead, three to five layers of .13mm (5mil) kapton are wrapped around the coil package prior to end clamp installation. The four kapton-wrapped quench protection heater

<sup>1</sup>Fermilab drawings 0102-MB-292087 and MB-292083.

<sup>2</sup>Glass fiber reinforced epoxy.

strips (one for each quadrant) are brought out to the coil package end as part of this insulating layer.

The inner surface of the metal cylinder has a 2 degree taper (half-angle), so that the cylinder is thickest at the coil end, where it must support approximately 75mm of coil straight section. The outer surfaces of the insulators have a matching taper. It should be noted that the direction of the taper in the 50mm aperture design is the reverse of the 40mm aperture design [2]. The radial "lip" at the coil end of the cylinder is also a new feature of the 50mm aperture design. These changes may have brought about the apparent improvements in performance over the 40mm aperture design which are described in the next section.

Prior to installation, the outer surfaces of the insulators and the inner surface of the metal cylinder are coated with Vydax<sup>3</sup>, a teflon-like lubricant. Next, the insulators are placed around the coil package and the cylinder is fitted snugly over the insulators by hand. Finally, the cylinder is driven over the insulators by a fixture equipped with three 5-ton hydraulic jacks.

At the lead end, the end clamp also holds in place the upper and lower solder-filled ramp splices, which connect the inner and outer coils. (The slots for these splices can be seen in Figure 2.) Before the lead end clamp is installed, the splices are wrapped with a fast-curing "green putty"<sup>4</sup> epoxy. A splice connecting the upper and lower outer coils is also held in place at the lead end by a G10CR restraint base, over which the end cap is welded onto the cylinder.

The clamp shown in Figure 2 employs a 304N stainless steel cylinder approximately 17.5mm thick at the coil end. The final Fermilab design calls for an aluminum cylinder<sup>5</sup> 1.6 times thicker.

Because of the way in which they are manufactured, the G10CR insulators<sup>6</sup> have their fiberglass layers parallel to the magnet axis, so that the elastic modulus is smallest and the thermal contraction greatest in the radial direction.<sup>7</sup> The first of these factors diminishes the initial radial loading; the second leads to large losses in pole and midplane loading on cooldown.

Both finite element analysis [3] and the poor results from the end clamps in the 40mm model dipole program at

<sup>3</sup>DuPont Vydax 550, a fluorotelomer dispersion in Freon.

<sup>4</sup>Ciba-Geigy Araldite Resin AV-1580 and hardener HV-1580, in a 50-50 mixture.

<sup>5</sup>Fermilab drawing 0102-MB-292205

<sup>6</sup>Fermilab drawings 0102-MB-292088, MB-292089, and MB-292085

<sup>7</sup>For standard G10, the thermal contraction perpendicular to the fiber planes between room temperature and 4K is 6-10 mils per inch, 2-3 times as much as 304 stainless steel.

Fermilab described in the next section have motivated the change from stainless steel to aluminum for the end clamp cylinders and end caps in the 50mm aperture dipoles. In addition, insulator materials with higher elastic modulus and smaller thermal contraction than G10CR will be tested on model dipole magnets at Fermilab.

### *Tests on 40mm and 50mm Aperture Model Dipoles*

Two 50mm aperture model SSC dipole magnets, DSA321 and DSA323, have been built and cold-tested at Fermilab [4]. Both of these magnets are equipped with stainless steel end clamp cylinders and end caps, and G10CR insulators. No quenches were detected in the end clamp regions of either of these magnets [4,5]. This is in marked contrast to the behavior of Fermilab 40mm aperture model dipoles equipped with end clamps as described in Reference 2, with stainless steel cylinders and G10 insulators. All but one of these magnets had quenches in either the lead or non-lead end clamp [6,7].

Nearly all of the Fermilab 40mm aperture model dipoles have exhibited quenches originating in the ramp splices at ramp rates above 75A/sec. (An important exception to this was DS0315, which was equipped with aluminum end clamp cylinders and molded Stycast<sup>8</sup> insulators [7]. DS0314, a magnet with the same type of end clamps as DS0315, is about to be cold-tested at Fermilab.) Neither DSA321 nor DSA323 has shown any quenches originating in the ramp splices, including high ramp rate quenches [4,5].

It may be that the more robust stainless steel end clamp cylinder used in the 50 mm aperture model dipoles provides enough loading at room temperature to overcome the loss of loading associated with the large thermal contraction of the G10CR insulators. Nevertheless, the next 50 mm aperture model dipole to be tested, DSA324, has been constructed with the aluminum end clamp cylinders called for in the current design, and in future model dipoles molded insulators will be tried, motivated by the success of DS0315 and by considerations of cost, dimensional control, and ease of manufacture.

### END YOKE CONFIGURATION

As mentioned above, the 304N stainless steel shell is supported by packs made of filler laminations<sup>9</sup> in the regions occupied by the end clamps (262mm at the lead end and 236mm at the non-lead end.) These laminations have the same outer radius as the standard yoke laminations, and an inner radius of 146mm. They are assembled into two half-packs

<sup>8</sup>Emerson and Cuming Stycast 2850FT resin cured at room temperature with curing agent 24LV.

<sup>9</sup>Fermilab drawings 0102-MD-292141 and MD-292152.

which are epoxy-impregnated and sand-blasted, thus forming so-called "monolithic packs" having extra shear strength.

The filler lamination material is Armco Nitronic-33 high-manganese steel. Another high-manganese steel, Kawasaki KHMN30L, has also been proposed. Both of these steels are non-magnetic, so that the magnetic field in the end region is not enhanced, and are well matched in thermal contraction to the standard low-carbon steel yoke laminations.<sup>10</sup>

The filler lamination packs prevent a large stress discontinuity in the shell at the ends of the yoked portion of the cold mass. Thermal bending stresses are avoided (see Reference 8 for details), and the cylindrical shape of the shell is preserved, giving reliable alignment of the end plates relative to the coil ends.

DSA323, the 50 mm aperture model dipole currently being tested at Fermilab, is the first magnet to be equipped with the filler laminations.

### END PLATE

The lead end plate<sup>11</sup> and final assembly of the non-lead end plate and shell are shown in Figure 3. The non-lead end plate has the same overall dimensions as the lead end plate; both plates are welded to the shell following pressing and welding of the shell halves around the collared coil and yoke packs.

Axial loads from the collared coil are passed through the end clamps to the end plate through a group of four set screws at the lead end and a set of four bullet load slugs and associated bushing screws at the non-lead end.

The total axial loadings of the non-lead end plates in DSA321 and DSA323 as measured by strain gages mounted on the bullet load slugs were  $120\text{N}/(\text{kA})^2$  and  $98\text{N}/(\text{kA})^2$  respectively. (The load rises fairly linearly with current-squared in both magnets.)

DSA323 was equipped with a set of shell-mounted strain gages measuring axial and azimuthal strains. Data from these gages are currently under study. DSA321 had no shell strain gages, so that any improvement brought about by the incorporation of the filler packs is difficult to infer from comparisons of these two magnets.

<sup>10</sup>Nitronic-33 has .24% integrated thermal contraction to 4K; Kawasaki KHMN30L has .18%; the yoke iron has .21%. The relative permeability of Nitronic-33 is 1.002 down to 77K.

<sup>11</sup>Fermilab drawing 0102-ME-292113

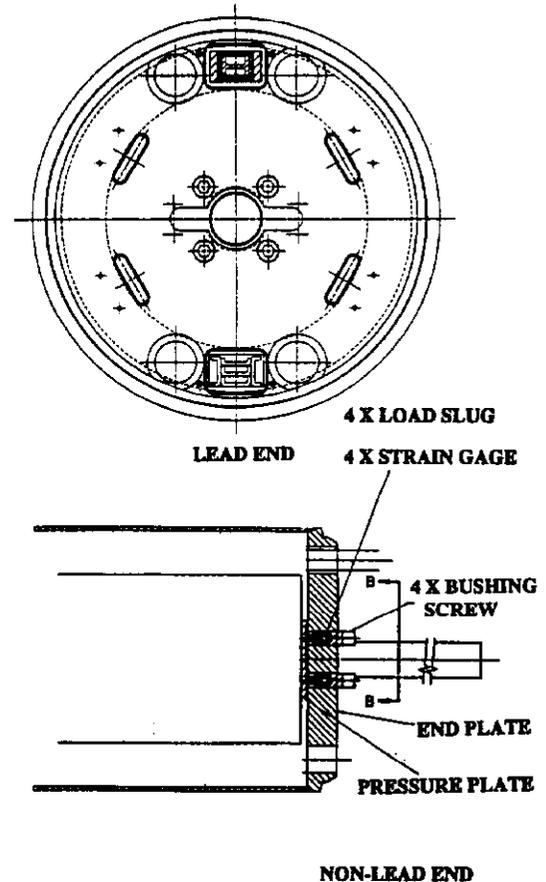


Figure 3. End Plate and Assembly with Shell for SSC Dipole

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