Fermilab TS-SSC 93-003

2/10/93

TO: Fred Asner

FROM: Jim Strait

SUBJECT: 1.8 K Tests of Fermilab-Built 15 m SSC Dipole

Attached are several figures that you could use in your presentation at the workshop on High Field Accelerator Magnets in Berkeley next month. I also give below a discussion of our magnet design, how it differs in the magnet tested at low temperature from those used in the ASST in Dallas, and some discussion of the data in the figures. This may be more information than you need for your talk, but I thought that sending you too much information would be better than too little. I will fax this to you now and also send it by Federal Express.

Introduction

Following the successful[1,2] series of nine full-scale SSC dipole magnets, designed and built at Fermilab by Fermilab and General Dynamic personnel, Fermilab has built and tested an additional series of four 15 m R&D SSC dipoles, one of which was tested at 1.8 K in superfluid helium and reached a maximum central field of 9.5 T. These four magnets were of the same fundamental design[3,4,5,6] as the earlier series, five of which are currently part in the Accelerator Systems String Test[7] (ASST) in Dallas. The principal purpose of this series was to test an alternate conductor insulation system.

Magnet Design

The magnet cross-section, shown in Fig. 1, is the same as for the ASST magnets. The collars, made from Nitronic 40 stainless steel, are assembled into left-right spot-welded pairs, and the upper and lower collars are locked together by tapered keys near the horizontal mid-plane. The outer surface of the collars is shaped so that within ±30° of the horizontal mid-plane here is a nominal interference between the collars and the yoke of 0.15(0.08) mm at 293(4) K. In the vertical direction the yoke and collars do not make contact. The yoke is split on the vertical mid-plane, similar to the LHC design. The 5 mm thick stainless steel outer shell is tensioned to 350-400 MPa by a combination of the weld shrinkage at the vertical mid-plane and differential thermal contraction relative to the yoke.

Measurements[8] made on early ASST magnets using strain gauges mounted on the shell indicate that the yoke mid-plane gap remains closed at least to 8 T, and calculations[4] indicate that it should remain closed to >10 T.

The ASST magnets used the "traditional" conductor insulation of a 50% overlap wrap of 25 μm thick Kapton plus a 1 layer spiral wrap of 100 μm thick (before curing) epoxy-impregnated fiberglass tape. The last four R&D magnets used a system in which the fiberglass tape was replaced by a wrap of polyimide film with adhesive coated directly on its surface. (This is a system similar to that used for the Tevatron low-beta quadrupoles used for the final focus at the Collider experiments.) In the first two magnets DuPont Kapton film coated with 3M 2290 epoxy coated on one side was used. In the last two magnets Allied Signal Apical film coated on both sides with Allied Signal Cryorad adhesive was used. (In both cases the inner wrap of polyimide film had no adhesive.) In the inner coil the adhesive coated insulation was a single layer spiral wrap; in the outer coil a 50% overlap wrap was used.

The modified insulation system was thinner than the original fiberglass tape system for which the cross-section was designed, resulting in an inner coil that was 1.5 mm smaller and an outer coil that was 0.4 mm smaller than the original design. Because the coil end parts[5] are rigid, this would result in a significant mechanical discontinuity at the ends if the size difference were taken up by pole shims. Instead shims were distributed among the wedges within the cross-section. A shim of 0.76 mm thickness was placed on the inner coil wedge nearest the mid-plane, and shims of 0.38 mm thickness were placed on the other inner and outer coil wedges. These shims were made of brass and were placed inside the insulation wrap on the wedges before coil curing. A 0.13 mm pole shim was also used on the outer coil of one magnet of this series (DCA321). Several layers of 0.13 mm pressure sensitive adhesive backed Kapton tape were applied to the G-10 coil end parts to build them up to the same thickness as the shimmed wedges, and the ends of the tape layers were staggered to taper the build-up to zero in the curved portion of the coil end.

Test Results

The standard quench test sequence for all magnets consisted of establishing a quench plateau at the SSC operating temperature of 4.35 K following the initial cooldown. On the second cooldown the 4.35 K quench plateau was re-established, and then the magnet was tested at 3.8 K and then 3.5 K. The third of the four R&D magnets was also tested at 3.0 K, 2.3 K, and 1.8 K.

Fig. 2 shows the quench histories[2] for the ASST magnets. All reached their short-sample limits of about 7.3 kA (7.3 T) with very little training. Four magnets had one quench each below the operating current. Three of these are understood to result from a minor design flaw (which was introduced after the first 2 magnets to aid assembly, and which was corrected for the last of the R&D magnets). The cause of the fourth low quench is not known. On re-cooling all magnets went to their conductor limits on the first quench. (The random scatter of the plateau currents reflects the variations in the test temperature.) At 3.5 K all but one reached or exceeded 8.1 kA (8.0 T) on the first quench.

The quench histories of the four R&D magnets are shown in Fig. 3. None exhibited the very low initial training observed in some of the ASST magnets, but they typically required a little more training to reach the short sample limit than did the ASST magnets. The additional training may result directly from the change of insulation system, the presence of the shims on the wedges, or the possible discontinuity in the support of the cable at the coil ends.

The magnet that was ultimately tested to low temperature required 5 quenches to reach the conductor limit and had 2 below the operating current. In this sense this magnet has the poorest initial quench performance of any of the thirteen magnets. On the second cooldown all magnets returned to their conductor limit on the first quench. (The initial slightly low quench of DCA321 resulted from a higher than normal test temperature.)

At 3.8 K and 3.5 K these magnets also trained a bit more than the ASST magnets. At 3.0 K (DCA322 and DCA323) and 2.3 K (DCA322) no plateau was established and the increase in quench current from higher temperatures was small. This may result from the reduced heat capacity of the helium making the magnets more sensitive to small mechanical disturbances.

At 1.8 K DCA322 went to almost 9800 A (9.3 T) on the first quench. It then reached only 7600 A on the next quench before returning to high current. (The reason for this low quench is not understood.) The next two quenches were at just under 10 kA, or 9.5 T. Although an apparent plateau in quench current had been reached, the high current quenches originated in several different locations and none were in the inner coil pole turn. This indicates that the quenches were not at the conductor limit, which is estimated to be several hundred amps higher than the maximum the magnet achieved. Figure 4 shows the quench current versus temperature for this magnet. The difference between the quench currents achieved and what would be expected by extrapolating the results at 3.0 and 2.3 K demonstrates the superior cooling capacity of superfluid helium.

Strain gauge measurements were taken on the ramp to the first 1.8 K quench, and data were recorded up to 8.9 kA (8.6 T). The inner and outer coil prestresses at the pole in two locations along the magnet are plotted versus I^2, which is roughly proportional to the magnetic force, in Fig. 5. (Sorry for the folk units: 1000 psi = 6.9 MPa.) The inner coil prestress is ~45 MPa at $I = 0$, and is still positive (~7 MPa) at the highest current measured. Extrapolating the coil prestress suggests that the pole turn would unload at around 10 kA. The outer coil prestress varies much less strongly with current.

References

[1] J. Strait et al., Magnetic Field Measurements of Full Length 50 mm Aperture SSC Dipole Magnets at Fermilab, presented at the XVth International Conference on High Energy Accelerators, Hamburg, Germany, July 20-24, 1992.

[2] J. Kuzminski et al., Quench Performance of 50-mm Aperture, 15-m-Long SSC Dipole Magnets Built at Fermilab, presented at the XVth International Conference on High Energy Accelerators, Hamburg, Germany, July 20-24, 1992.

[3] R.C. Gupta et al., SSC 50 mm Dipole Cross-Section, *Supercollider 3*, p. 587, 1991, J. Nonte, ed.

[4] J. Strait et al., Mechanical Design of the 2D Cross-Section of the SSC Collider Dipole Magnet, *Conference Record of the 1991 IEEE Particle Accelerator Conf.*, p. 2176, 1991, L. Lizama and J. Chew, eds.

[5] J.S. Brandt et al., Coil End Design for the SSC Collider Dipole Magnet, *ibid.*, p. 2182.

[6] S.W. Delchamps et al., SSC Collider Dipole Magnet End Mechanical Design, *ibid.*, p. 2185.

[7] T. Dombeck et al., presented at the 1992 Division of Particles and Fields Meeting, Batavia, Illinois, November 10-14, 1992.

[8] M. Wake et al., Mechanical Behavior of Fermilab/General Dynamics Built 15m SSC Collider Dipoles, *Supercollider 4*, p. 435, 1992, J. Nonte, ed.

SSC Collider Dipole Magnet
(Fermilab Design)
Principal Design Features

Baseline (ASST) Design

- "Traditional" Kapton + fiberglass/epoxy tape insulation.

- Nitronic 40 Stainless Steel Collars.
  - Spot-welded left-right pairs.
  - Tapered keys.

- Vertically-split yoke design.
  - 0.08 mm yoke-collar interference at 4.35 K near the horizontal mid-plane.
  - Vertical yoke-collar clearance under all circumstances.
  - Shell tension of >350 MPa keeps yoke gap closed to >10 T.

- Solid G10 coil end spacers are the logical extensions of the wedges, i.e. the coil end current blocks match the 2D cross-section.

Modifications for 4 R&D Magnets

- Modified conductor insulation system.
  - Fiberglass tape is replaced by epoxy coated polyimide film (Kapton or Apical).
  - Results in a smaller coil package.

- Shims on all wedges used to compensate for reduced insulation thickness.

- Kapton layers of staggered lengths placed on G10 end parts to match wedge+shim thickness and to taper the additional thickness to zero in the ends.

SSC Collider Dipole Magnet
(Fermilab Design)

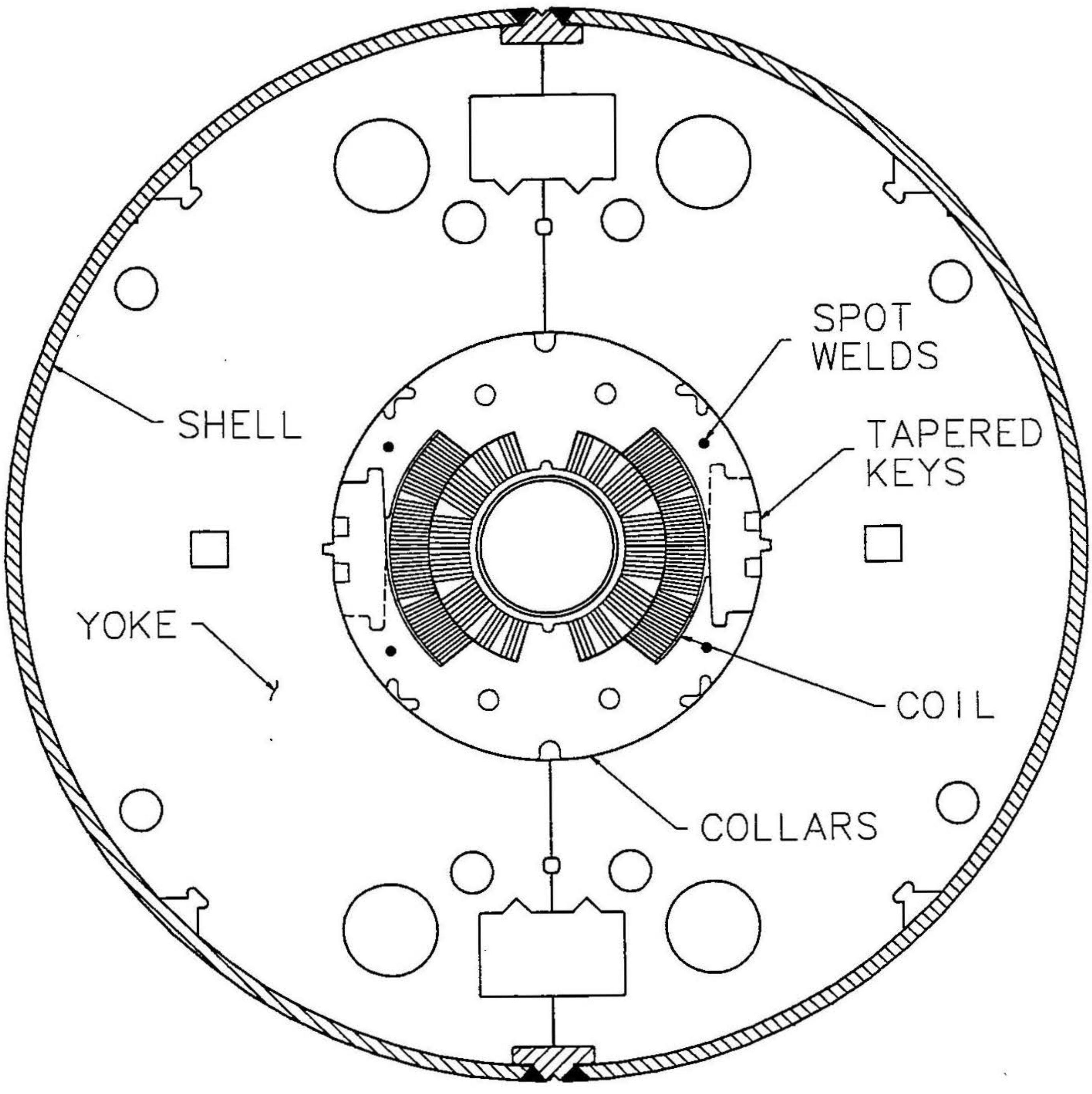
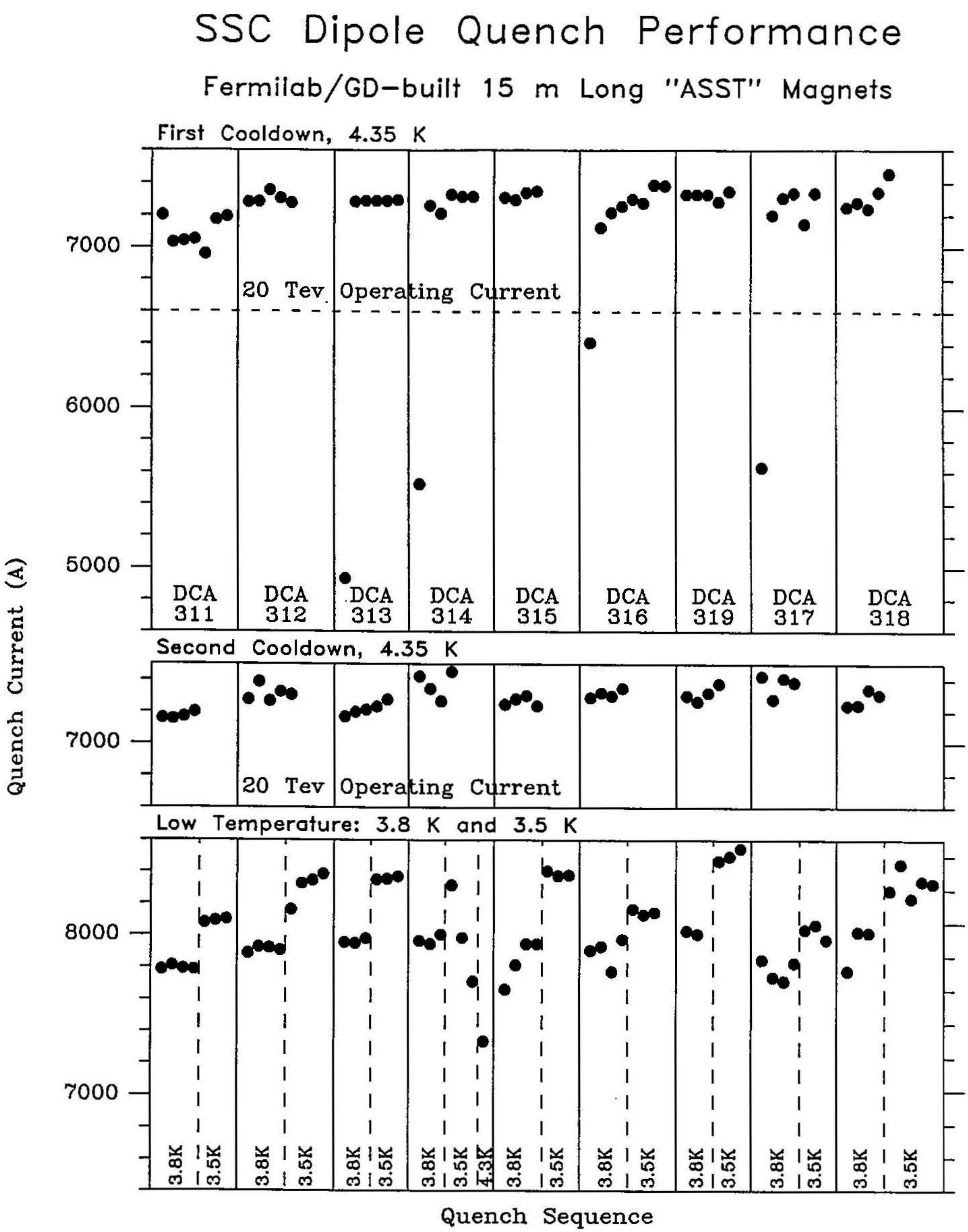


Figure 1
SSC Collider Dipole Magnet Cross Section



SSC Dipole Quench Performance
Fermilab/GD-built 15 m Long "ASST" Magnets
First Cooldown, 4.35 K
20 Tev Operating Current
DCA 311
DCA 312
DCA 313
DCA 314
DCA 315
DCA 316
DCA 319
DCA 317
DCA 318
Second Cooldown, 4.35 K
20 Tev Operating Current
Low Temperature: 3.8 K and 3.5 K
3.8K
3.5K
4.3K
Quench Current (A)
Quench Sequence
7000
6000
5000
8000

Figure 2

SSC Dipole Quench Performance

Fermilab-built 15 m Long R&D Magnets

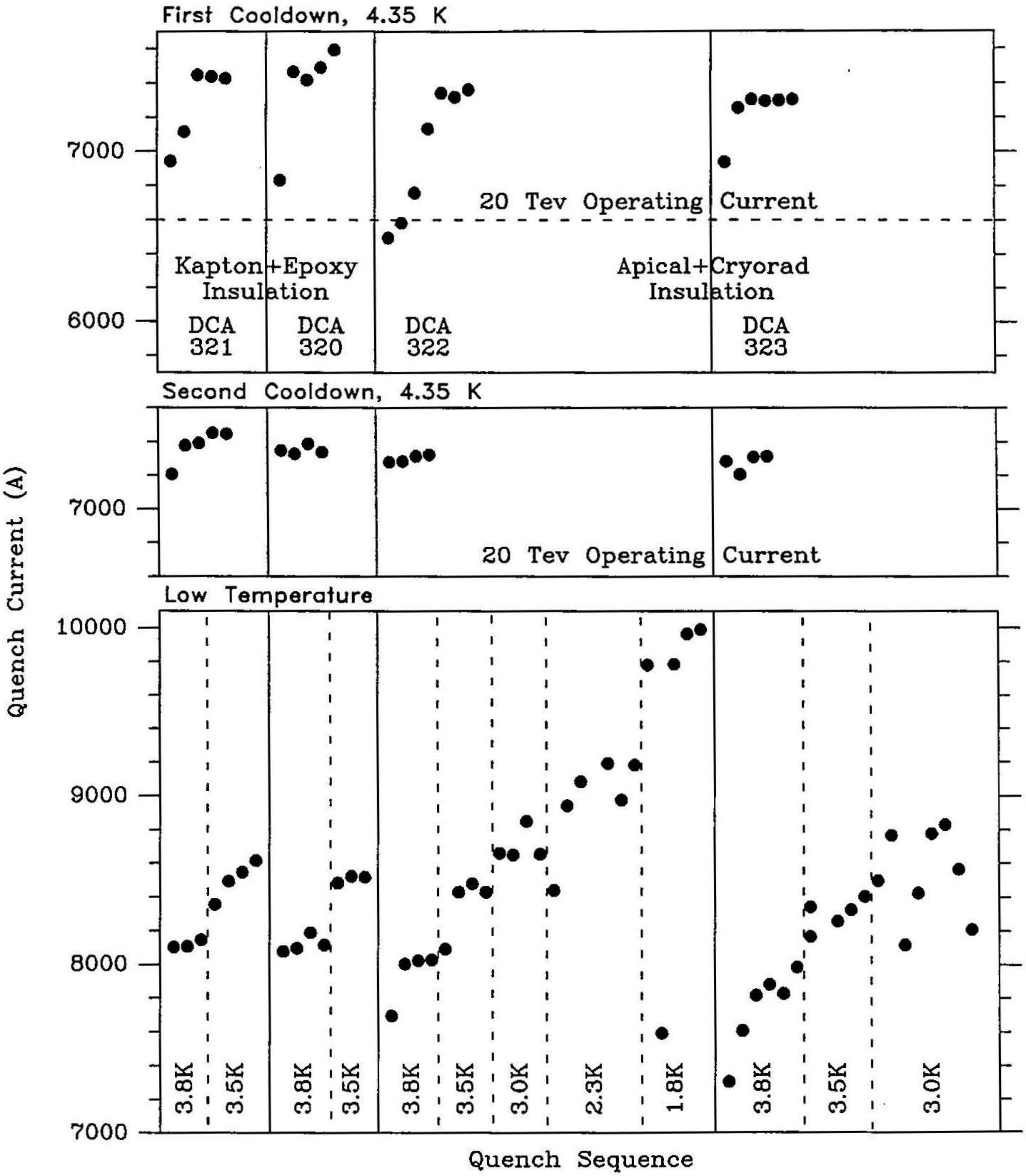


Figure 3

Fermilab-Built 15 m Long R+D SSC Dipole

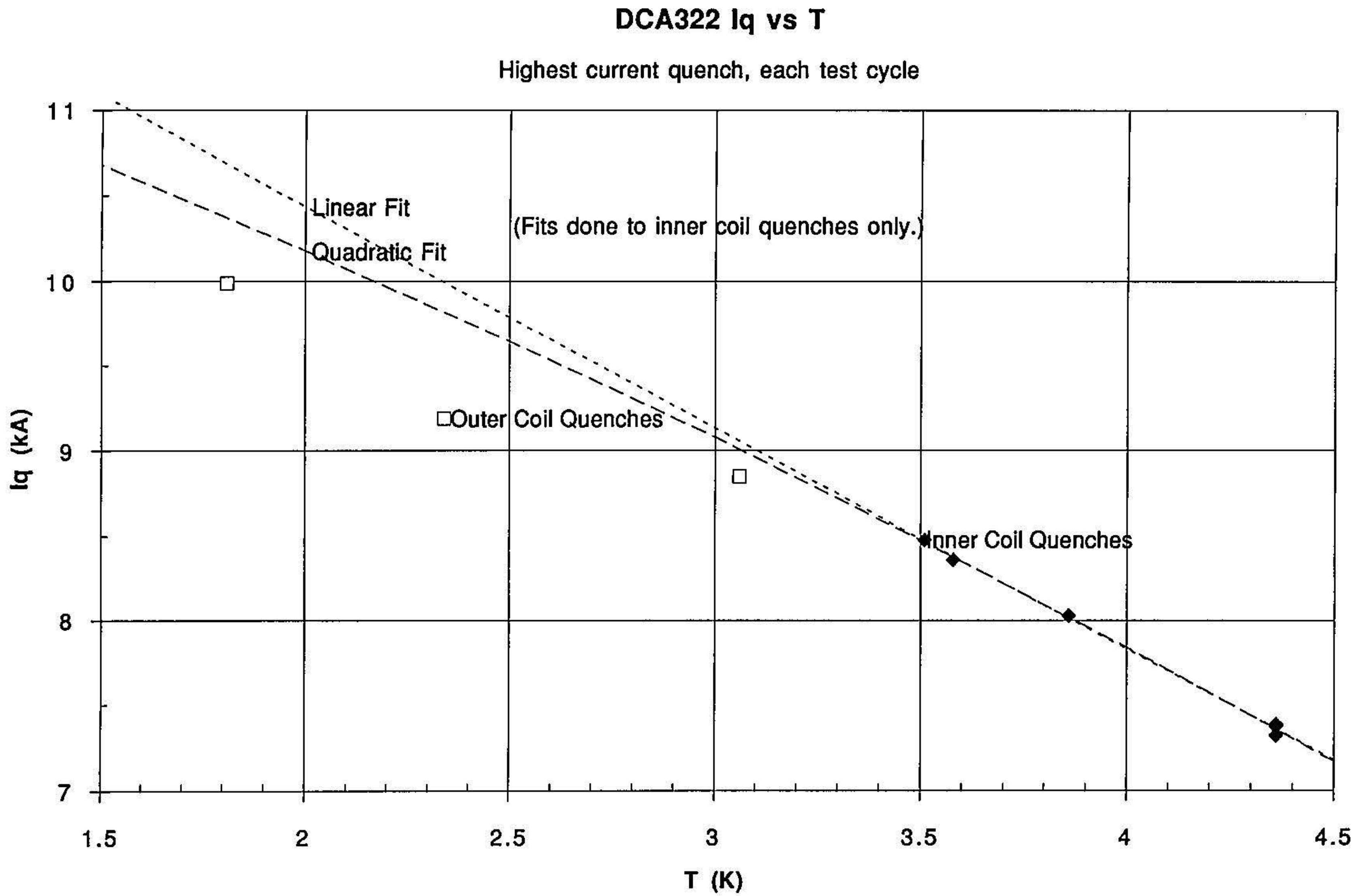


Figure 4

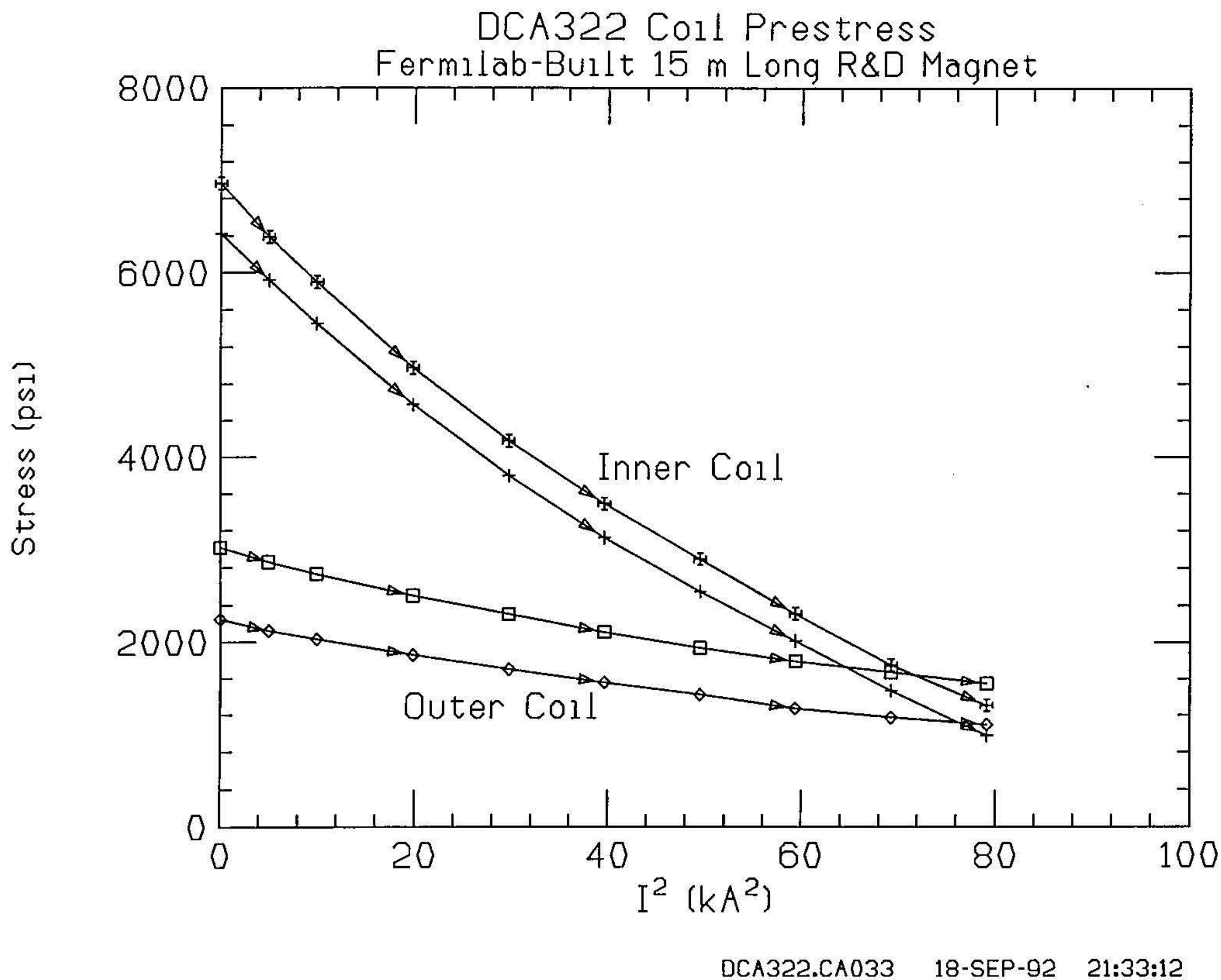

DCA322 Coil Prestress
Fermilab-Built 15 m Long R&D Magnet
Stress (psi)
8000
6000
4000
2000
0
Inner Coil
Outer Coil
0
20
40
60
80
100
I² (kA²)
DCA322.CA033 18-SEP-92 21:33:12

Figure 5