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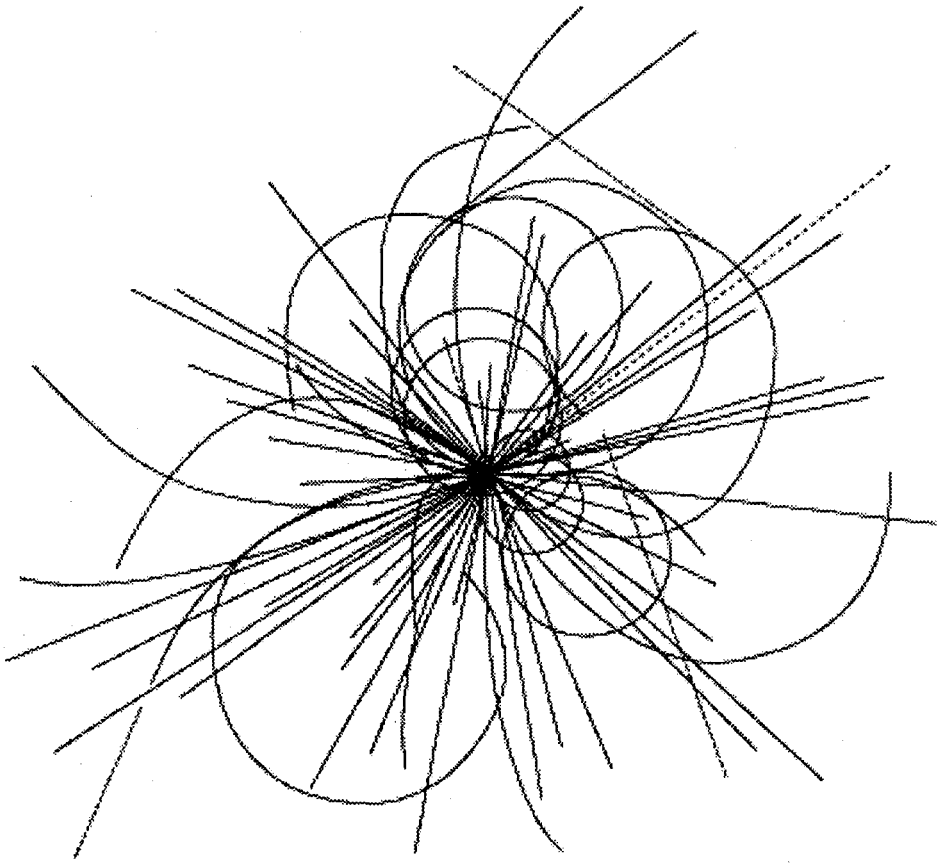

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The Accelerator Systems String Test: Objectives, Problems, Results, Anecdotes, and Reflections*

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THE ACCELERATOR SYSTEMS STRING TEST:

OBJECTIVES, PROBLEMS, RESULTS, ANECDOTES, AND REFLECTIONS

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INTRODUCTION

The Accelerator System String Test (ASST) was a congressionally mandated milestone for the Superconducting Super Collider Laboratory (SSCL) to demonstrate powered operation of a half-cell of industrially-fabricated collider magnets before mass production could begin. In this paper I describe the installation of the string components and the results from the full-powered tests of the magnet string, consisting of five dipole magnets having an aperture of 50 mm and a single quadrupole having an aperture of 40 mm. Power and cryogenic connections were made to the string through spool pieces that were prototypes for SSC operations. The string was cooled to cryogenic temperatures in early July, 1992 and power tests were performed at progressively higher currents up to the nominal SSC operating point near 6500 Amperes.

ASST COMPONENTS

The construction of the ASST buildings and installation of critical equipment was completed in a little over one year's time in a rural area of Texas rangeland that was the first SSCL site to be developed. The cryogenic refrigerator began installation in March and was commissioned in April of 1992. Magnet and spool piece installation in the string took place over the period from February to early June. Installation and commissioning of the power supply, quench protection, and controls equipment was completed in late June. By the beginning of July, the string had been cooled to cryogenic temperatures, the final safety reviews had taken place, and the final stage of commissioning the magnet quench protection system leading to the power tests of the string had begun. Power tests were performed at progressively higher currents over a three week period leading to the test at the nominal SSC operating point of 6500 Amperes in mid-August. The completion of the ASST milestone is a continuation of string tests dating back over 15 years as shown in Table 1.

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

Table 1. Significant Superconducting Magnet String Tests that Have Been Performed:

ESCAR (LBL)

November 1977 to June 1978
Twelve 1-m Long Dipoles

B12 (FNAL)

1976 to 1981
One 3-m Long Dipole, Up To Sixteen 7-m Long Dipoles

A SECTOR (FNAL)

January 1982 to June 1982
One-Eighth of the Tevatron Ring

CBA/ISABELLE (BNL)

February 1982 to May 1983
Six 4.4-m Long Dipoles and Two 1.4-m Long Quadrupoles

HERA (DESY)

1988
Three 9-m Long Dipoles and Two 2-m Long Quadrupoles

RHIC (BNL)

1990
Two 9-m Long Dipoles and Two 1-m Long Quadrupoles

SUPER COLLIDER (FNAL)

1990 to 1991
Two to Five 17-m Long Dipoles (40-mm Aperture)

SUPER COLLIDER (SSCL)

1992
Five 15-m Long Dipoles (50-mm Aperture) and
One 5.2-m Long Quadrupole (40-mm Aperture)

The half-cell of magnets comprising the ASST is the basic subunit of the SSC collider. A general description of its cryogenic and electrical operation is discussed in ref. [1]. The ASST string was designed to be as close as possible to a prototype half-cell for the collider in order to test the general features of magnet interconnection to determine cryogenic heat loads under different operating conditions, and to demonstrate the safe operation of the string under normal powered conditions and during magnet quenches. The dipole magnets were fabricated by the General Dynamics Corporation using tooling in place at Fermi National Laboratory (FNAL). The quadrupole magnet was fabricated at Lawrence Berkeley Laboratory (LBL) and placed in its cryostat at the SSCL.

The string was assembled in the front half of a 200-m long enclosure building with associated electronics installed in a niche area off to the side of the string and in a controls trailer outside the enclosure. The refrigerator was installed in a building attached to the

enclosure with its compressor and storage dewars mounted outside on a concrete pad. The power supply and its associated equipment were installed in a room about 80 m away from the string. The basic parameters for the ASST components are summarized in Table 2.

Table 2. Parameters of the ASST Magnets and Equipment.

Dipole Magnet	
Inductance	75 mH
Aperture	50 mm
Length	15 m
Operating Field	6.5 T
Nominal Operating Current	6506 A
Stored Energy	1.6 MJ
Quench Heater Energy	3.5 kJ/heater pair
MIITs Limit on Inner Coils [2]	20
MIITs Limit on Outer Coils [2]	15
Mass	13.6 metric tons
Anticipated Cold Mass Heat Leak	363 mW
Quadrupole Magnet	
Inductance	7 mH
Aperture	40 mm
Length	5.2 m
Operating Field	206 T/m
Nominal Operating Current	6506 A
Stored Energy	0.15 MJ
Quench Heater Energy	1.2 kJ/heater pair
MIITs Limit on Inner Coils [2]	12
MIITs Limit on Outer Coils [2]	10
Mass	1.32 metric tons
Spool Pieces	
Mass Flow on Power Leads	2 g/s
Refrigerator	
Mass Flow	54 g/s
Liquefaction Rate	150 l/hr
Power Supply	
Maximum Voltage	10 V
Maximum Current	8,000 A
Maximum Ramp Rate	6 A/s
Dump Time Constant-all 6 Magnets	24 s
Dump Time Constant-3 Dipole Magnets	13 s

RESULTS OF THE POWER TESTS ON THE ASST

A detailed account of the operating principles of the string components and the cryogenic data and the results of the many power tests and magnet quenches induced in the string are presented in ref. 3. Throughout the program to bring the string progressively to higher currents we did not observe any natural quenches in the magnets, though we induced quenches at various current levels to study the response of the quench protection (QPM) and cryogenics systems. We also studied quench propagation from one magnet to another.
For instance in a quench at 5500 A induced in the quadrupole magnet, the quench was isolated to the last three magnets in the string. However in a test at 4500 A where the quench was induced in the third dipole magnet, all six of the magnets in the string quenched in what appears to have been the result of thermal propagation of the quench from the first three magnets to the last three magnets.

The quench at 5500 A was initiated in one of the pairs of strip heaters in the quadrupole magnet and was quickly detected by the QPM and activated the firing of all the heaters in the fourth and fifth dipole magnets as well as the other set of heaters in the

quadrupole magnet. The power supply was turned off and the dump switch opened placing the dump resistor into the circuit to extract the current still flowing in the first three dipole magnets in the string that remained superconducting throughout the whole quench sequence. The string current exhibited an exponential decrease with a 12 s time constant, consistent with only half of the magnets and therefore one half of the inductance of the entire string as opposed to the 24 s time constant expected for a dump of the whole string. The maximum number of MIITs generated in the dipole magnets was 7.5. The MIITs in the quadrupole magnet was 4.7. This was well below the estimated cable limits given in Table 2 for these magnets.

No matter in which magnet in the back half of the string we initiated the quench, the largest voltages were generated in the fifth dipole (DCA316). We also observed the highest voltages in the third dipole magnet (DCA319) if the quench was initiated anywhere in the first half of the string. We believe this was due to the smaller Residual Resistivity Ratio of the copper used in the outer coil cables in these two magnets that was about one-half the value of the cable used elsewhere in the string. The smaller ratio implies a higher resistance in the copper that carries the current after the superconducting strands in the cable go normal in a quench and therefore higher resistive voltages will be generated.

The pressures generated in the string in the 5500 A magnet quench reached a maximum of about 0.83 MPa occurring as a pressure spike just after the quench. It was observed in the interconnect region between the fourth and fifth dipoles and was caused by the rapid heating and expelling of the helium vapor from the magnet coils where the quenches occurred. This pressure measured about twice that seen in single magnet tests at FNAL because of the rush of hot gas from the quenching dipoles on either side of the interconnect in the string.

The highest cold mass temperatures reached above 9 K and appeared in the quadrupole and the fifth dipole magnets immediately after the quench. This reflects the flow of hot gas down the string toward the quench valve in the end spool piece. After exiting the string, this hot helium gas was diverted to the refrigerator storage dewar. Immediately the refrigerator began to recool the string requiring about 3.5 hrs to stabilize the string temperature to that where current could be run again. Much of this recovery process was controlled manually by the refrigerator operators.

In mid-August the string was ramped up at 4 A/s to 6000 A and the current held steady for many minutes. Then the string was ramped up at 2 A/s to a current of 6520 A, a little above the ASST milestone goal of 6500 A. Again the current was held constant for a number of minutes and then the string was ramped down at 4 A/s. There were no quenches during this sequence and the string components performed as designed.

REFERENCES

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