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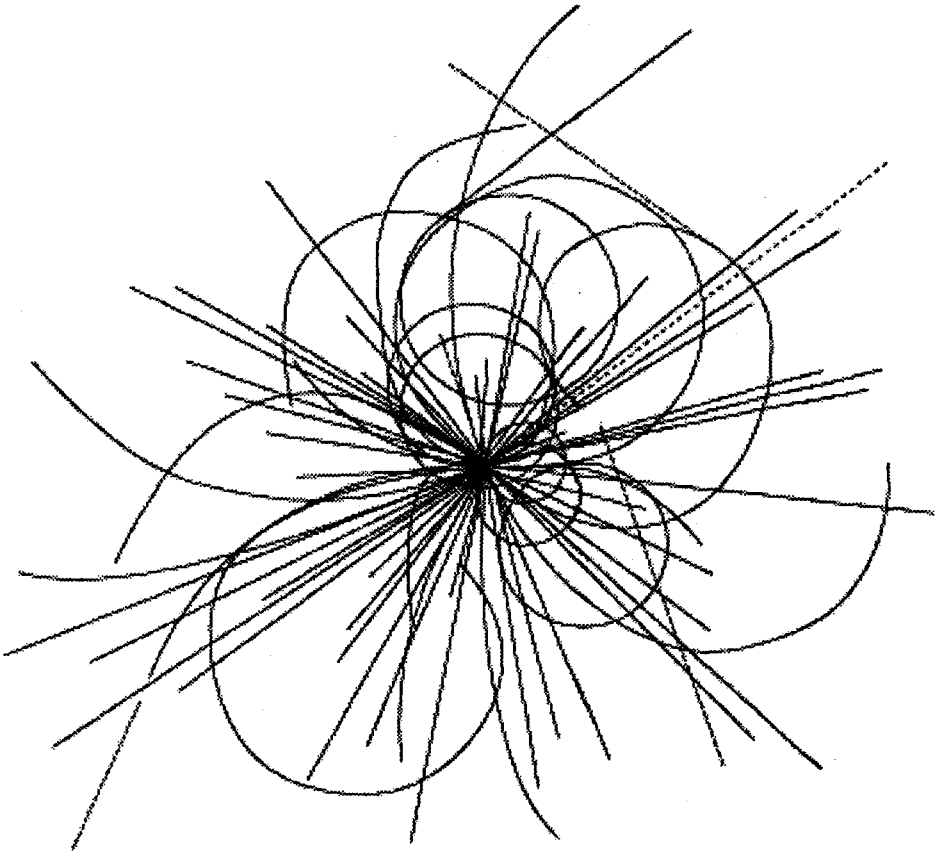

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CRYOGENIC CHARACTERISTICS OF THE SSC ACCELERATOR SYSTEMS STRING TEST (ASST)

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ABSTRACT

A series of static and dynamic tests of the ASST were conducted from July 1992 to the present. These tests included heat leak measurements, as well as, temperature and pressure profiles obtained during quench testing of the string. An accurate assessment of heat leak measurements of collider components requires a stable thermal environment with the minimization of end effects. The string test provides the ideal static environment necessary to conduct these measurements. This report summarizes the results of the heat leak measurements conducted on the cold mass, 20K, and 80K shields of the dipoles used in the ASST assembly. We also report on the rapidly changing temperatures and pressures recorded during the string quench tests.

I. DESCRIPTION OF THE EXPERIMENT

For this evaluation the ASST was a half-cell of a regular structure of the collider and consisted of five full length 50 mm aperture dipoles, one full length 40 mm aperture quadrupole and three spool pieces.[1] The dipole magnets in order of their location in the string were DCA313, DCA314, DCA319, DCA315, DCA316, the quadrupole was QC403. The spool pieces installed in the string were: one-half of the standard collider feed spool (HSPRF), a standard recooler spool (SPR), and a special end spool (SPE).[2] All three spools were equipped with quench valves.

The sensor outputs are monitored by the Research Instrumentation Data Acquisition System (RIDAS). This system consists of amplifiers, multiplexers and high precision digital multimeters. All resistance measurements were made by simultaneously measuring the sensor voltage and current. Polarity switching of the thermometer excitation current was employed to remove thermal emfs and amplifier offsets. All sensors were read once every 5 minutes. During quench this rate was increased to 2 kHz for certain sensors. Approximately 300 RIDAS channels were used to support temperature/pressure monitoring.

The arrangements of sensors used in the ASST thermal measurements is shown on Fig.1. Carbon glass resistors with an accuracy of 2.5 mK were used at the lead end of each dipole's cold mass. At the same locations, the cold pressure transducers (Siemens KPY46A) were installed as well. Germanium resistors with an accuracy of 15 mK were installed at the inlet and outlet of each dipole's 20 K shield cooling line. The 80 K shield cooling line contained platinum resistors with an accuracy of 0.5 K at the inlet and outlet of each dipole. In the single phase (cold mass), 20 K and 80 K circuits of each dipole are resistive heaters with which a known

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amount of heat may be placed into the dipole as a test of the heat leak measuring technique. Silicon diodes and warm pressure transducers are placed in each of the cryogenic pipes at the feed and end spools to determine the inlet and outlet conditions of the cryogenic flows. A Venturi flow rate meter is installed in the single phase line and room temperature volumetric gas meters are installed in the 20 K and 80 K shield lines.

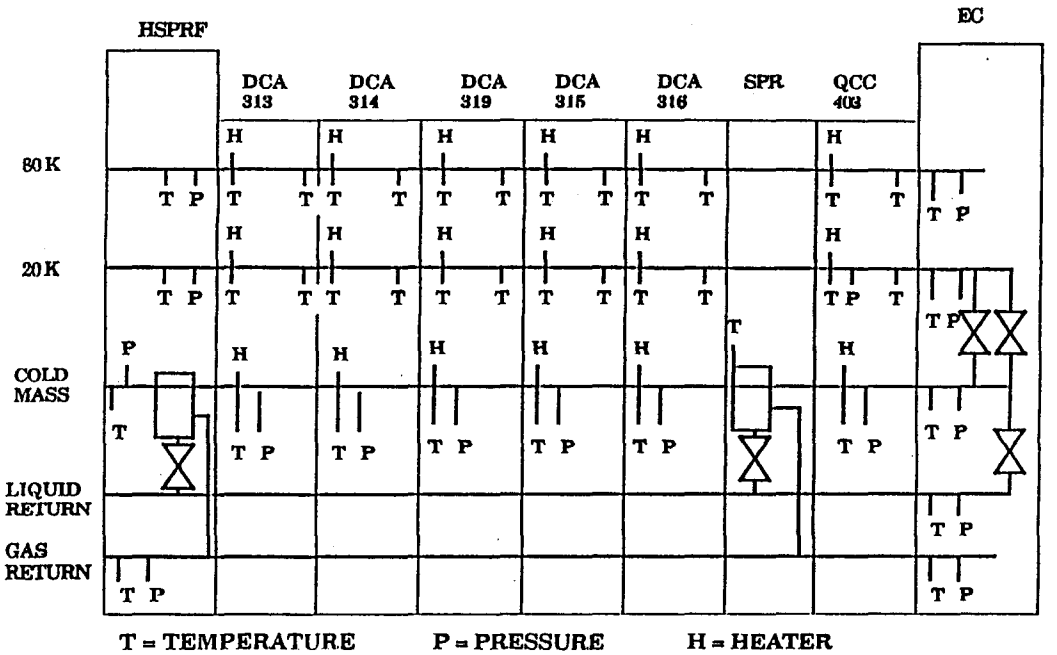

Fig.1. ASST Reduced Instrumentation Schematic.

II. EXPERIMENTAL RESULTS

1. Cryostat Heat Leak

The heat leak measurements were performed during two experimental runs on the string (July-Sept. 1992, Nov.-Dec. 1992). The system was allowed to come to thermal equilibrium and after that the inlet and outlet temperatures, flow rates and pressures of the cryogens flowing through the cold mass, 20 K and 80 K shields were measuring. The heat leak was calculated with help of the energy balance equation:

$$Q=G*(h_2-h_1),$$

where: Q - heat leak;

G - the mass flow rate of cryogen through the magnet;

h_1 and h_2 - enthalpies of the cryogens at the inlet and outlet points of the magnets.

In Table 1 the dipole plus an interconnect heat leak measurement results are presented.

Table 1. The dipole plus an interconnect heat leak results. (All values are in Watts.)

		D313	D314	D319	D315	D316
Cold Mass						
	RUN 1	9.47	2.40	0.42	1.66	4.07
	RUN 2	9.00	2.40	—	1.46	2.15
20K*	RUN 2	9.58	4.83	----	5.18	3.8
80K	RUN 1	26.5	29.0	26.4	16.0	20.3
	RUN 2	22.6	24.9	22.7	12.5	19.0

* 2 phase flow in 80 K shield

Due to operational problems there were no 20 K heat leak data taken in Run #1. As is clear from the cold mass results, the first and fifth dipoles have much higher heat leak than middle magnets. This may be explained by end effects, i.e. heat leaking from the end devices. These devices are spools and their functional requirements result in significantly higher heat leaks than the dipoles. Additional evidence of the presence of end effects is the significant reduction of heat leak in DCA316 between two runs. A thermal short in the end spool was fixed between the two runs.

It's important to realize that the temperature rise across a single dipole in the case of the cold mass measurements is approximately the same size as the absolute accuracy of the thermometers used in the measurement.

The results shown are the average of 2-6 different data sets which were taken during the experimental runs. Mass flow rates used in the experiments were typically as follows: cold mass - 50 g/s, 20K shield - 1 g/s, 80K shield - 15 g/s.

In order to reduce the resulting uncertainty in these measurements as well as the end effects we excluded from consideration the dipoles at either end of the string and looked at the temperature rise across the middle 3 dipoles. From this data the average heat leaks for a dipole plus an interconnect was calculated. Table 2 shows a comparison of these results with the budgeted values.

Table 2. Average heat leaks for the dipoles plus interconnects.

	RUN 1	RUN 2	BUDGET
Cold Mass	1.3 W +/- 33%	1.4 W +/- 28 %	0.36 W
20K shield*	N/A	5.59 W +/- 1 %	5.06 W
80K shield	28.0 W +/- 14%	24.5 W +/- 16 %	37.0 W

* 2 phase flow in 80K shield

The uncertainties shown with these results in Table 2 are calculated by comparing the temperature rise across the middle three dipoles with the absolute accuracy of the temperature sensors. The results in Table 2 show that the average value of cold mass heat leak is significantly over budget. The reason for this is not yet clear. It might be problems with the support posts or thermal shorts between the 20 K shield and the cold mass. Indications are that such a thermal short may exist at the beginning of DCA319.

Inaccuracy of the flow rate measurements and other systematic problems may be estimated by placing a known amount of heat into the cryostat and comparing this to the additional heat measured by the increase of the temperature rise across the dipoles. Several heater tests were conducted and they have showed that these errors are less than 10 % in the cold mass and 80 K cases and less than 30 % in the 20 K case.

2. QUENCH RESULTS

The power test program included a number of quenches at different currents. At each current level, quenches were induced in particular magnets to study the performance of the system and to monitor string parameters.

One of the important goals of the power tests is to measure the magnitude and the time profile of the pressure wave caused by the quenching magnets. In Fig.2 the typical pressure profile is shown as a function of time after quench at 6.5 kA induced by a strip heater in DCA316. The quench protection system then fired the strip heaters in the DCA315 dipole and in the quadrupole. The second pressure peak at 0.9 sec occured when the other three magnets thermally quenched. The maximum pressure of about 205 psia occured during that quench and was observed in dipole DCA313, as shown in Fig.2. The peak quench pressure observed during full current quenches ranged between 180 and 205 psia. The magnets are currently certified to 310 psia and the maximum allowable working pressure is 250 psia. Thus, the observed pressures are within the design limits. Moreover, the typical full current quench pressure was around 180 psia, and the 205 psia is the highest observed to date.

The cold mass temperature during the same quench is shown in Fig.3. The highest temperature is about 6.5 K, and was observed in DCA313, DCA319 and DCA316 dipoles. The temperature sensor in the dipole DCA314 didn't work at that time.

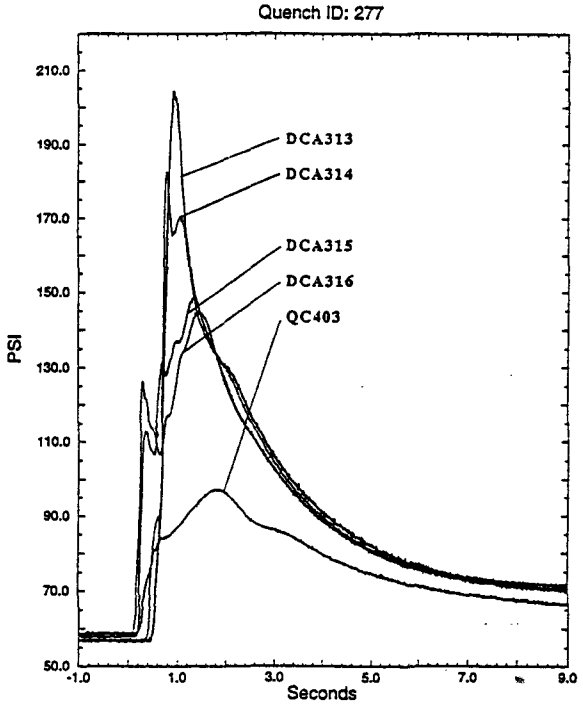

Fig.2 Cold Mass Pressure During Quench.

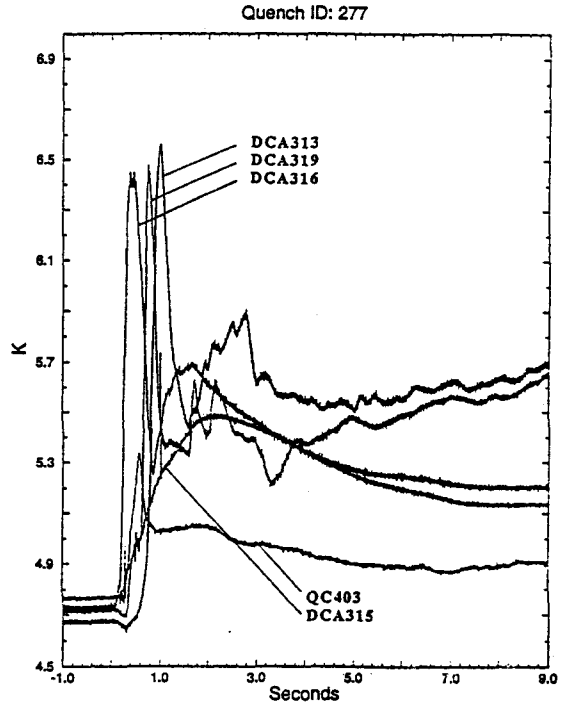

Fig.3 Cold Mass Temperatures During Quench

SUMMARY

During the assembly of these prototypical dipole magnets considerable difficulty was experienced with the positioning of the thermal shields due to the lack of the adequate tooling. It is not known if this has affected the cold mass heat leak, which is significantly over budget. In the planned third run of the ASST experiment, the fourth dipole will be replaced with DCA323, which is highly instrumented. This additional instrumentation and modeling that is currently under way should help us understand and fix the cause of the higher than expected cold mass heat leak. It should be pointed out that small changes in cryostat systems can have large impacts on heat leaks of this magnitude. In the case of the 40 mm dipoles at the FNAL string test facility the cold mass heat leak was within budget.[3]

ACKNOWLEDGEMENTS

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