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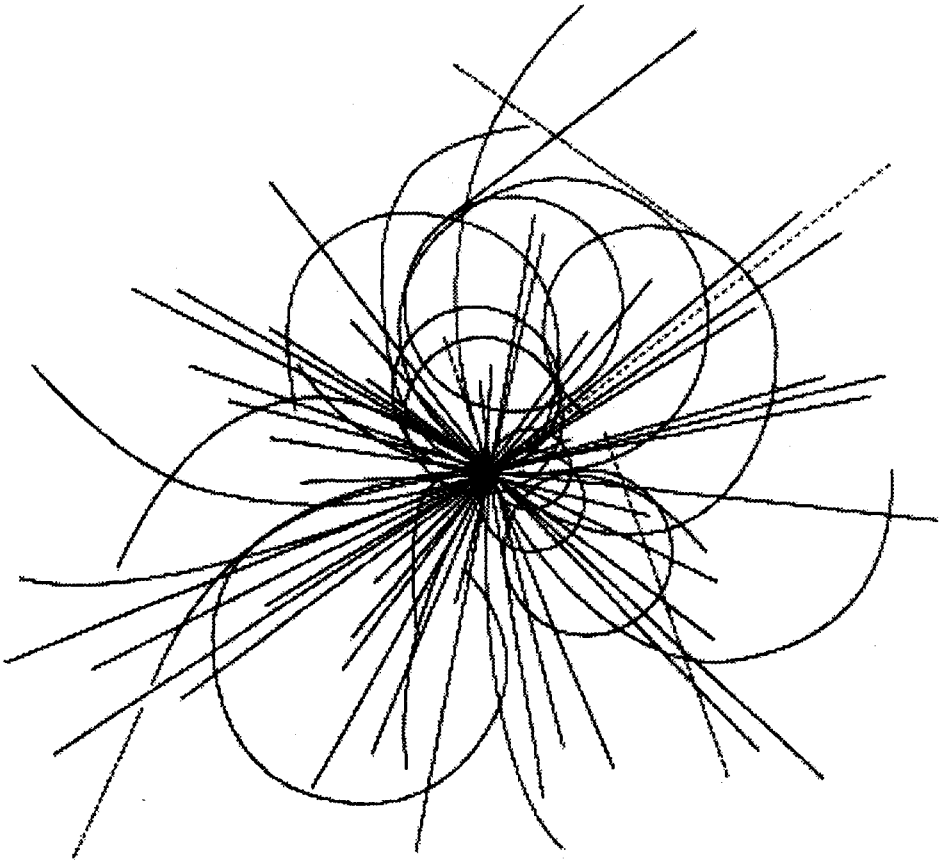

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The Accelerator Systems String Test Cryogenics*

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THE ASST CRYOGENICS

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INTRODUCTION

The ASST magnet string cryogenic refrigeration requirements were planned around an original design and a much smaller, backup, He refrigeration system. The ASST schedule required that the backup, or Plan B, helium refrigerator provide and meet all the requirements of the milestone test. The Plan B design, layout, sub-system commissioning tests, and the performance schedule will be provided. The magnet string cryogenic system pump and purge, cooldown and warmup, central and multiple shield cooling, temperature control and subcooling, and recooler operating experience are reported.

The ASST cryogenic system static performance and the dynamic provisions, response, and recovery to magnet quenches will be described.

SYSTEM DESCRIPTION

The Plan B backup system is a basic CCI Cryogenics model 600 Helium Refrigerator/Liquefier (R/L) outfitted, modified and augmented to provide the cooling for the Accelerator Systems String Test (ASST) half cell string test program.[1] The basic 600-W R/L was modified to allow for series operation of the low temperature expander. Additional equipment included an auxiliary cold box containing a precooler, subcooler, cold compressor, and a boil-off shielded 5,000-liter helium dewar. Custom, 50 g/s supercritical helium feed and return, helium recooler vapor return, 20-K shield return, and quench helium recovery lines and controls provisions were made to support the full energy ASST testing program.[2]

The system includes a 70 g/s Sullair, CM25, 17.5 bar, compressor, special oil removal package, two temperature level, single piston, expander main cold box, cold compressor equipped auxiliary cold box, dewar, associated transfer lines, special in-line quench valving, 200 m^3 warm gas storage, and a set of Moore 351 and 352 electronic controllers. The SSC designed and provided the custom VJ system to provide the string connection and its isolation.[3] The equipment layout was constrained to fit in the magnet "laydown" area,

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located to avoid the Plan A distribution box, and the auxiliary cold box and the storage/recovery helium dewar coupled as closely as practical to the magnet string feed spool. The string and refrigerator were independently operable, after a brief connection installation period.

COMMISSIONING, ACCEPTANCE TESTS

The installed equipment was commissioned and acceptance tested using a calorimeter internal to the precooler and an outlet-to-return VJ jumper to measure refrigeration, and a system gas makeup measurement to measure liquefaction to the 5,000 liter dewar. The measured values were 550 W and 135 l/hr. These values include the load of the auxiliary cold box (refrigeration), dewar and associated lines (liquefaction), but do not include the ASST connecting lines.

ASST CONDITIONING

The 100–m long magnet string was helium pumped and purged to a few ppm of air components, but the water content could not be reduced below approximately (ca.) 50 ppm. In the interests of the schedule the refrigerator cleaned up this situation. This proved successful and constant monitoring of GN_2 and water measured $\leq$ 7 ppm throughout all the subsequent running.

COOLDOWN

The string was cooled down twice from room temperature and once from nitrogen temperature. The total time to reach the string operating temperature was ca. six days in each major cooldown. The cooldowns were preceded by the string and auxiliary cold box nitrogen shield cooldowns.

The nitrogen temperature cooldown rate was to be limited to 20 g/s He flow to keep the gas below the fluidization velocity of the charcoal Neon Adsorber at 80 K.[4] The cooldown rate was later measured by energy considerations to be closer to 25 g/s. The ca 1.3 magnet long, 80–300 K, temperature wave front moved through the string in ca. 60 hrs. Note that the lower the cooldown flow, the greater the magnet temperature gradient. The 25 g/s temperature gradient ($\approx m^{-0.2}$) is 1.31 times that expected for the 100 g/s collider specified nitrogen temperature cooldown flow[5], i.e., the slower cooldown is more stressful.

The low temperature expander flow can be operated in series with the load or recycled to the low pressure side. The choice implies a flow fixed by the engine speed and inlet conditions, and an outlet temperature fixed by the engine inlet temperature, or an adjustable outlet temperature. We chose the adjustable outlet temperature in the initial ASST cooldown. The expander cooldown was operated to approximately halve the source temperature with each successive cooling wave, after the first was set to 50 K. The expanders can deliver 2 kW down to an outlet temperature of ca. 7 K. The string expander cooled to operating temperatures in ca. 40 hours

The first cooldown was conducted at string pressures low enough to allow two phase conditions in the string. The onset of significant two phase quantities and liquid helium surges down the inclined (1 m/200 m) string, led to periodic, widely fluctuating, return flows that strained the compressor pressure control response and range. Pressurization above the critical pressure when the low temperature expander was reconfigured in the series arrangement eliminated the variations.

20 K, 80 K SHIELDS

The 20-K shield flow is provided through a JT valve from the source supercritical helium line at the far end. The flow was fixed by a manual valve and varied from 1–2 g/s dependent on the mode of operation and detailed shield temperature requirements.

The 80 K shield flow was nominally two phase nitrogen, but could be run on saturated nitrogen vapor to support shield heat leak measurements.[6] The saturated vapor generator used could not provide low flow string source temperature values below ca. 90 K. It will be replaced for subsequent runs with a significantly improved version.

SUBCOOLED TEMPERATURE OPERATION

The cold compressor in the auxiliary cold box is a motor driven piston expander with compressor suction and discharge check valves. Its suction is arranged to reduce the return pressure on the subcooler vessel and the shell side of the string feed spool and spool piece recoolers. The subcooler pressure is directly reduced by the cold compressor, while the recooler is effective only if filled to an operating level with liquid helium. The ASST string has been cooled to a vapor pressure temperature of 3. 8 K, 0.63 bar.

RECOOLER OPERATION

The recooler system functioned as expected at a load of 54 W once the liquid level was established.[7] The nominal 100 W duty of the recooler was not tested.

LOAD SUMMARY

The 4 K equivalent load for the first assembly of the ASST as measured or estimated is listed in Table 1. The 20 K shield was provided as a liquefaction load (ambient temperature return) at a considerable refrigeration load to allow accurate room temperature flow measurement. Note the close approach of the total to the full Plan B capacity.

Table 1. The 6500 A load distribution summary of the first assembly.

• Connecting Transfer lines, in-line valves	30 W	
• (5) Dipoles,(1) quad magnet and (3)Spools (2 with a 7 kA power lead pair)	102 W	
• 20 K shield line (2 g/s @4 K)	200 W	
• (4) 120 scfh (air) lead flows, (1.6 g/s@4 K)	160 W	
• SCHe return line	10 W	est.
• He Vapor return line	10 W	est.
• He Dewar and lines	10 W	est.
Total	522 W	est.

QUENCH RESPONSE

The refrigerator quench response is initiated by a quench signal and, in default, by the rise of magnet pressure above 5 bar. The magnet return is isolated from the refrigerator LP side, the 20-K return is isolated from the refrigerator, and the 20 K/quench line is opened to the He dewar through a 2", cooled, VJ line within a second of the receipt of the quench signal. The quench driven He is shunted to the dewar, and the refrigerator LP side is isolated from the high pressures associated with the magnet quench. Each control function is paralleled by one or more reliefs to assure system safety in the event of a controls malfunction. The Plan B refrigerator quench control scheme functioned flawlessly throughout the 34 quench program.

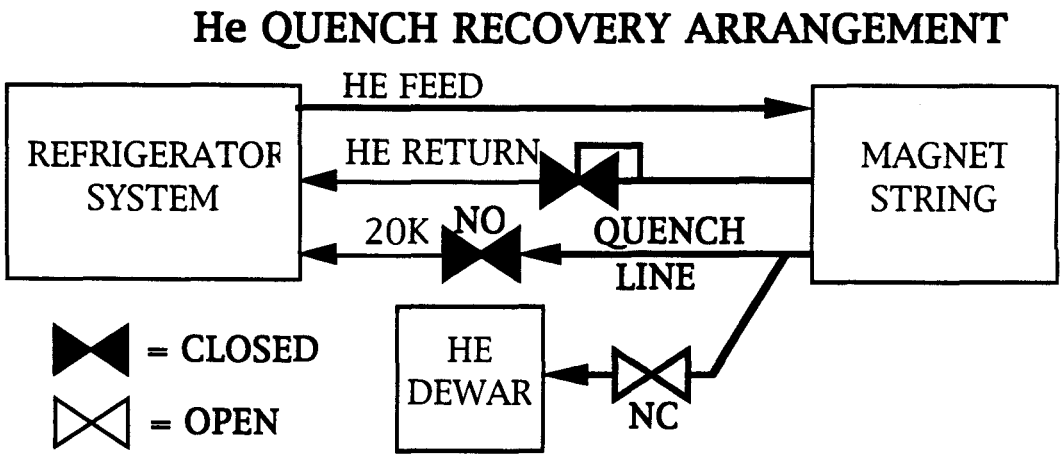

Figure 1. He Quench Recovery Arrangement.

Quench recovery requires a) recovering and refrigerating the contents of the dewar, b) cooling the magnet string, and c) refilling the string operations.

CONCLUSION

The Plan B backup R/L provided the necessary equipment capability, capacity, reliability, and schedule to allow the completion of the ASST half cell, full current, milestone test ahead of schedule. It served to test concepts and understandings, and supported a significant quench study program up to, and including, 6,500 A full string quenches. Although lacking the capacity to make rapid recoveries from quenches, and falling short of containing all the quench helium above ca. 5500 A quenches because of the limited dewar size, it successfully filled an important role scheduled for a unit eight times larger. The complete dedication of Richard Ahlman, Harry Carter, the Plan B crew, and a willing and resourceful supplier, CCI Cryogenics, are directly responsible.

Plan B R/L has since been retired from the N15 site and will return, as the Phoenix from the ashes, as the helium refrigeration source at the SSCL Central Facility for the test stands of the Spool Piece Test Facility in July.

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