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Half Cell "SSC" 40MM Aperture Magnet String

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Abstract - **The data given here were obtained during a controls and system check out run. This run basically had all of the proper accelerator controls as well as, in the background, an independent magnet test facility monitor and protection. Early data are presented on the heat loads of some circuits and quench performance of the two magnet string used. The heat loads found were high and the quench performance appeared to be better than expected. After disassembly occurred, obvious causes were present for some of the heat load.**

I. INTRODUCTION

Fermilab and SSCL personnel have constructed near the Tevatron's E-4 service building, a Superconducting Super Collider "SSC" size tunnel section with a prototype control room, ER-4, which is capable of operating one or more cells of the "SSC" lattice. The data presented here were taken during an early controls checkout run using only two of the five dipoles then available. The ER-4 operating system consists of A) computer controlled and monitored 5 Atm ab helium gas refrigerator producing 4.6K for up to a 1 kw load; B) 7.5 kA computer controlled [1] power supply for magnet ramping; and C) a quench protection monitor or "QPM" [2] which determines the status of the superconducting string (resistive or not) and systems that effect it (i.e. refrigerator, heater circuits, etc.). In addition to this "ACNET" [3] based accelerator system, there is in the background, a UNIX operating environment Research Instrumentation Data Acquisition System (RIDAS) [4] which obtains and monitors long term cryogenic data and obtains fast transition data with three different data loggers through a CAMAC interface. These are written on a high speed 96 channel data buffer. This system has its own quench detection circuits "QDC's" and can operate independently from the "QPM" by firing the protection heaters in parallel through a TTL "OR" gate. Presently there is an operating string of 5 dipoles (a half cell #). The future phase of the experiment will include a spool piece correction package as well.

II. EXPERIMENTAL PROCEDURE

The primary test objective is to verify that "SSC" magnets (dipoles) can be installed, leak checked, cooled to LHe temperature, energized, and quenched as a string in a tunnel type environment. The secondary objectives include sub-system development, i.e., controls and data acquisition and gaining familiarity with the operational aspect of the devices. Expediency dictates that upgraded Tevatron systems be used where there are not clearly developed SSCL systems available. The operational data thus generated will serve as a future reference for actual SSC magnet support system development. The magnets being installed have been each individually cryo tested, then after receipt, they are mechanically and electrically checked at room temperature. These tests include vacuum, physical inspection, high voltage (insulation), continuity, inductance and resistance checks. They are then modified for use in the string (proper power busses added, instrumentation busses, continuity of cooling channels, new cold mass bellows, and instrumentation mountings). The magnet mounting plates are surveyed and grouted into the tunnel floor. The magnet is put into place. The interfaces are then electrically connected and verified. The various cryogenic circuits are welded and separately leak checked. The vacuum enclosure is then leak checked, re-opened, then the various cryogenic circuit shields are installed and it is reclosed. Afterwards, the system is pressure tested while connected to leak detectors at 1.25x the maximum pressure anticipated to be present in the string (20 Atm.gauge).

The cooldown to final operating conditions of 5 Atm ab, 4.5K and 50g/s helium flow was accomplished only limited by the conservative criteria of 100K gradient, across any given magnet. The daily power up check list included a standard lockout procedure of all the gates and interlocks. All equipment and personnel protection systems are verified daily as well as the voltage integrity of the magnet string and power supply system. The string is powered in a step-wise manner to insure the minimum number of unknowns are being dealt with at any given time. The test quenches were initiated with the protection strip heaters and the maximum coil temperature and quench pressure determined before proceeding with another current increase. The cryogenic load tests were performed with the system being held stable for at least a day or two and the majority of which occurred after being cold for more than a week.

The heat load data were obtained on the two 40mm aperture dipoles using a VXI [4] based data acquisition system. It recorded string temperatures, pressures, and flows every 5 minutes throughout the 2.5 month run. It was off only for short time periods for software upgrades and maintenance. The heat leak into the 80K and 20K magnet cryostat shields were determined by measuring the temperature rise in the helium or nitrogen gas streams cooling them. Platinum and germanium resistance thermometers are used for the 80K and 20K shields respectively. Flow rates were determined by room temperature

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precision gas meters. There were sensors in the cold mass to determine an upper bound of it's heat load as well. The sensors were situated such that the heat leak of a single dipole interconnect can be determined. The operations were conducted with forced flow supercritical helium at 4.5 - 4.7K and 5 Atm ab in four shield conditions: 1) 20K shield @ 7K and 80K shield @ 77K; 2) 20K shield @ 13K and 80K shield @ 77K; 3) 20K shield @ 7K and 80K shield @ 115K; 4) 20K shield @ 13K and 80K shield @ 115K.

Data were taken during each dump (power supply phased back to 0 volts but strip heaters not energized) or quench (power supply phased back and strip heaters fired) of the magnet string. These data were acquired by the QPM circular buffer, and in the case of the quench pressure rise, by the high speed digital scopes. These data consist principally of magnet voltage tap and current measurements, and cold mass helium pressure and temperature rises. The data events recorded are listed: 1) 0.5kA dump; 2) 1.0kA dump; 3) 1.0kA dump; 4) 1.5kA quench; 5) 2kA quench; 6) 3kA quench; 7) 4kA quench; 8) 5kA quench; 9) 6kA quench; 10) 6.5kA quench; 11 - 14) 6.5kA quench heater induced and natural. Note that in the last two cases, data were also acquired by CAMAC high speed data loggers. In the last quench, the cold mass Kautzky relief valve on the feedcan was held open for 90 seconds to allow a measurement of the venting rates.

The logic diagram of a quench "event" is given in Fig. 1. During these events, there were two 32 channel data loggers, (1.0 KHz and 10Hz), QPM 60 Hz circular buffer, 2 four channel 100 KHz storage scopes, and 2 two channel 10 KHz storage scopes on line recording data as well. The later being primarily devoted to cold pressure transducers, current, and magnet voltage traces respectively.

The block diagram for the "RIDAS" system is shown in Fig. 2. The system is typical of those presently envisioned for SSC research data acquisition and expands easily.

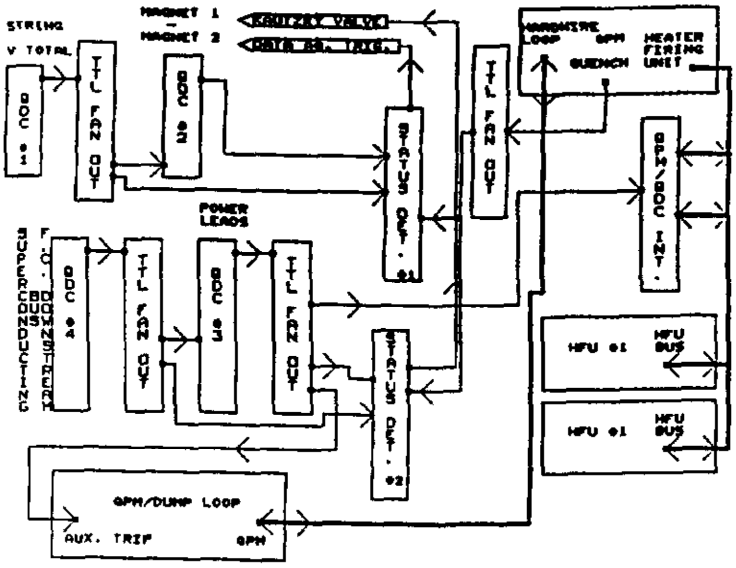


Fig. 1. The TTL logic diagram for an "event" in the two independent quench monitoring systems.

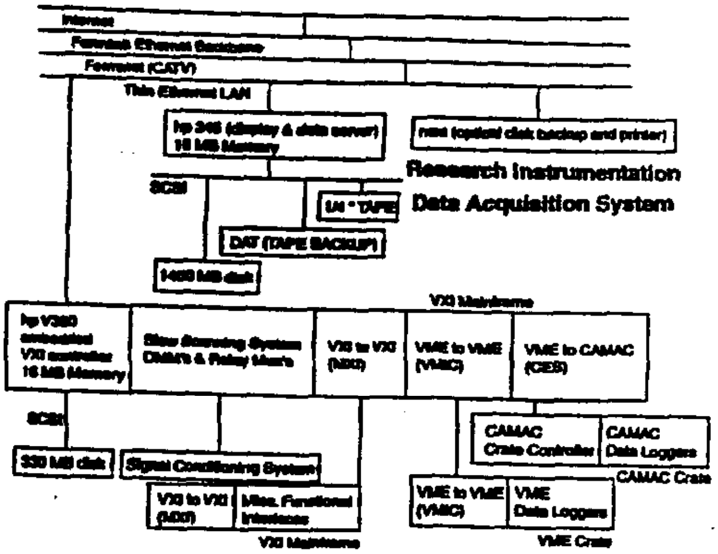
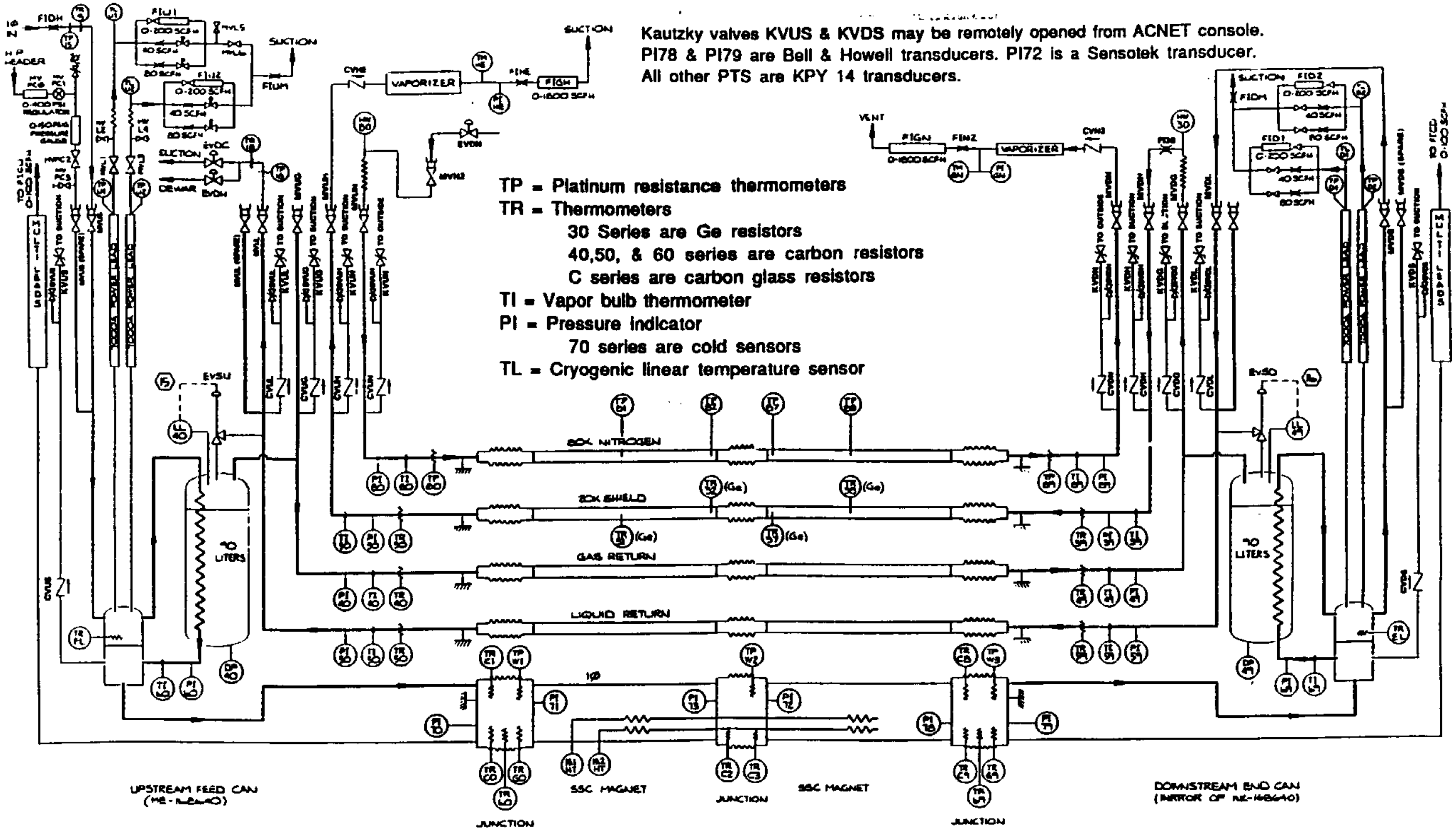


Fig. 2. The ER string test data acquisition system.

Data pertaining to quench recovery were obtained. During and after most quenches, the pressure and temperature data in the string were recorded every 5 minutes. These data had interesting features at magnet current levels of 4kA and higher. The quench recovery data were available from both the HP system for string parameters and the refrigerator parameters from a separate data logger in the "ACNET" control system as well. These data included pressures, temperatures, and valve settings. After the last 6.5kA quench, LHe from a Tevatron central liquefier transfer line was used to facilitate a rapid recovery of the system. After the last quench, temperature and pressure measurements were made during a warm-up. The warm-up was accomplished using warm helium gas only. The cryogenic circuits for the string are shown in Fig. 3. It is of interest to note that the pressure in the shell side of the upstream feedcan controls the temperature input to the string. This point provided a limit on the minimum operating temperature obtainable during this run because it was connected to the return pressure of the compressors.

III. RESULTS

The period used to cooldown the string was 7 days, but if certain operational difficulties were disregarded, such as oil pump failures on the compressors, the actual cooldown would be 5.5 days [5]. The typical temperature data for the heat load calculation is shown in Fig. 4. The largest experimental uncertainty is in the determination of the mass flow. The uncertainty has been reduced on the present run by the inclusion of a heater in each interconnect of a known value, therefore providing an accurate cross-check. The magnet cryostat plus interconnect heat loads are summarized in Table I. When the magnet string was disassembled, there were problems found in the second and third interconnects requiring a redesign of the 80K and 20K interconnect shields. The multilayered superinsulation (MLI) had developed gaps, thus indicating a need to change the method used in assembling and insulating. The most annoying problem encountered during



Kautzky valves KVUS & KVDS may be remotely opened from ACNET console.
PI78 & PI79 are Bell & Howell transducers. PI72 is a Sensotek transducer.
All other PTS are KPY 14 transducers.

TP = Platinum resistance thermometers
TR = Thermometers
30 Series are Ge resistors
40,50, & 60 series are carbon resistors
C series are carbon glass resistors
TI = Vapor bulb thermometer
PI = Pressure indicator
70 series are cold sensors
TL = Cryogenic linear temperature sensor

Fig. 3. SSC String Cryogenic Diagram

the actual accelerator type power operation of the string was the inability to obtain sufficient cooling in the power leads and still stay below 4.5K in the cold mass stream. This, of course, will be corrected by independently controlling the shell side pressure of the feed can heat exchanger. The additional temperature control has been made possible by the addition of a reciprocating cold compressor which will discharge to the shell side of the lower heat exchanger on the refrigerator.

The quench and dump data are stored in files which maybe accessed through any Tevatron control console or any other station on the Ethernet computer network. The HP UNIX based data is also available on Ethernet. The data from the high speed digital scopes can be directly viewed or transferred from floppy to the IBM AT's and analyzed using VU-Point. The typical quench pressure response is shown in Fig. 5. There is sufficient time resolution in the digital scope data to locate, within a meter, the quench origin along the length using the pressure front time of arrival [6].

The quench data can be summarized as shown in Table II. Thermal diffusion time is defined as time from heater firing until a resistive voltage is detected. The maximum voltage to ground is a sum of the voltages of 1) the virtual ground in the center of the circuit and the coil to coil inductive and resistive voltages. The highest coil to coil (1/2 to 1/2) voltage was just below 400 volts and at that point, the virtual ground was +28 volts. Therefore, the maximum voltage to ground was less than 230 volts with the other half approximately negative 170 volts. "MIITS" is a common abbreviation which means "million-ampere squared seconds." This is the energy/ohm absorbed by the initial volume which goes resistive. This determines the maximum temperature reached by that volume. The maximum temperature in Table II refers to that observed, not calculated, i.e., 30K measurement corresponds to ~ 75K.

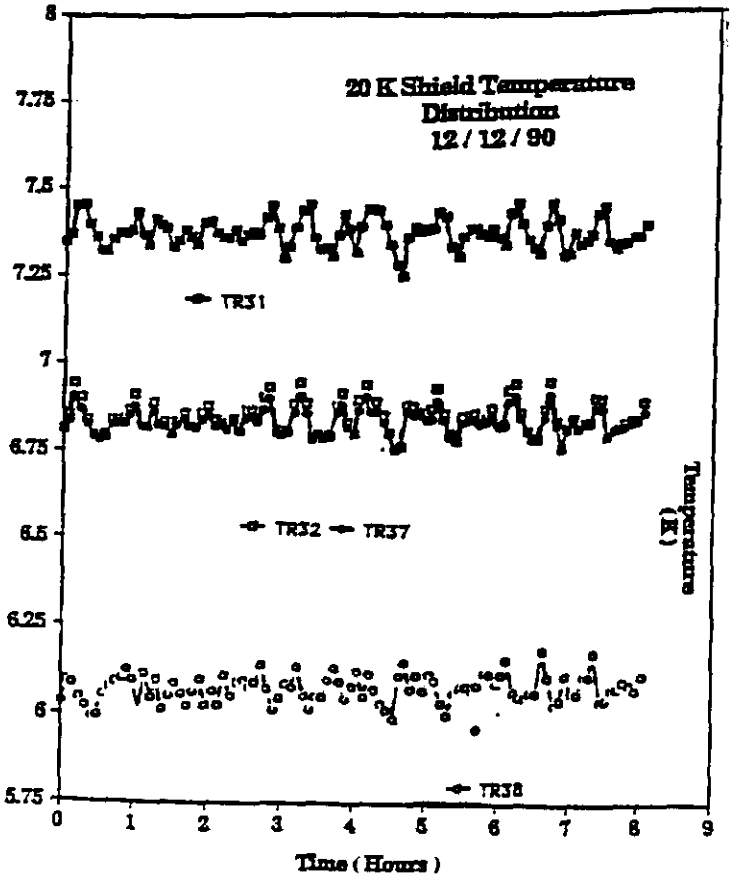


Fig. 4. Temperature data for heat load 20K shield.

TABLE I
HEAT LOAD SUMMARY
(Heat Loads represent a magnet and one interconnect)

80K SHIELD

Date	Flow Rate	Heat Leak
12-17-90	1.06 g/s	36.7 W
12-22-90	2.34 g/s	40.2 W

80K DESIGN BUDGET IS 27W

20K SHIELD

Date	Flow Rate	Heat Leak
12-12-90 (Shield @ ~ 7K)	1.30 g/s	10.1 W
12-18-90 (Shield @ ~ 7K)	1.18 g/s (80K Shield @ ~ 100K)	12.2 W
12-27-90 (Shield @ ~ 13K)	1.41 g/s	10.1 W

20K DESIGN BUDGET IS 3.3W

The magnet's actually quenched a couple of times due to exceeding their critical temperature for the operating field and current. The string operated reliably within 50mK of the maximum. The peak quench pressures and temperatures were moderate and were approximately equivalent throughout the string.

IV. FUTURE PLANS

The next run will include five dipoles and be essentially a repeat of the two dipole run. In addition there will be localized quenches used to check QPM sensitivity. Furthermore, there are two MLI blankets which are fully instrumented to study gradient, vacuum questions, and different shield assemblies. There are also two different sets of "U" tubes equipped with cold relief valves or quench valves whose performance will be checked. During this run, there will also be studies of venting rates, model refrigeration operation, protracted high field runs (at field for a long time), and cooldown/quench recovery studies. There is another run also planned for late '91 with five dipoles and a spool piece.

ACKNOWLEDGMENTS

It is not possible to list all of the technicians and staff of the Tevatron who have contributed to the successful operation of "ER". The authors would like to recognize the efforts of Roger Nehring and Charles White in leading the two dipole run SSCL technicians working group.

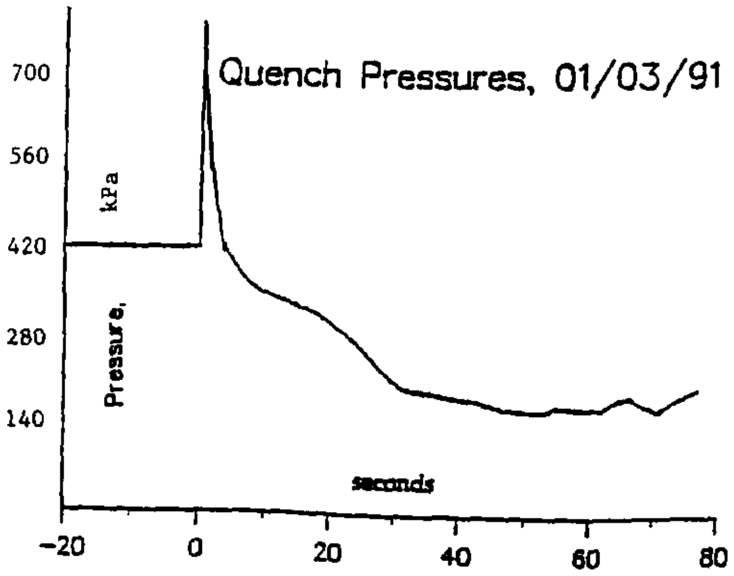


Fig. 5. Upstream cold mass pressure rise.

TABLE II
POWER TEST SUMMARY TWO MAGNET STRING

	1kA	2kA	3kA	4kA	5kA	6kA	6.5kA		
Thermal Diff (MS)	420	235	160	80	66	55	~40	20	
P (Max) (kPa)	497	662	669	669	718	780	828	842	
ΔP (kPa)	3.5	62	72	69	48	41	117	55	
Max Temp (K)	-	-	6.3	9	9.1	-	18	26	30
MIITS	1.43	3.4	3.6	4.4	4.5	6.7	5.9	5.8	

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