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PRESSURE DEVELOPMENT DURING ENERGY DOUBLER QUENCHES

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Introduction

The emergency de-energizing scheme for a helium circuit of the Energy Doubler calls for a group of four superconducting dipole magnets to deposit their magnetic energy as heat into the helium while the magnetic energy of the rest of the superconducting magnets in the circuit is dissipated externally in the energy fountain structure (a large .5Ω resistor).

Internal heaters were incorporated in the dipole magnets to permit fast spreading of normal zones in the superconducting wire in order to keep the wires from melting during the internal dissipation of the magnetic energy. The final temperature of the wires under this operation is quite safe. Vent pipes were incorporated in the cryostats to keep the pressure within the cryostat limits. In this situation the pressure rises to values that depend mainly on the heat transfer rate, amount and condition of helium present, the vent pipe dimensions, the relief valve settings and plumbing.

Magnet Description

The liquid helium in contact with the windings of the magnet occupies the volume between the beam vacuum tube and the coaxial tube that separates this pressurized liquid (also referred to as subcooled or single phase) from the returning boiling liquid (two phase) See Figure 1.

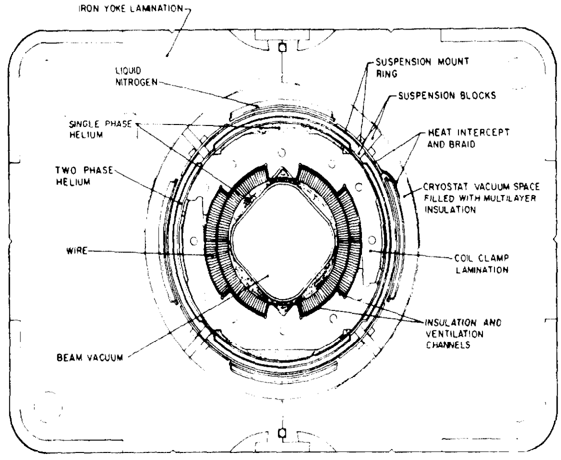

Figure 1. Dipole Magnet Cross Section

A major part of this 6.7m long space is occupied by the coil itself, with its superconducting cable windings and stainless steel restraining collars. At the extremities of the magnet this cross section is radically changed to permit interconnection of magnets by means of bellows and Conoseal[1] flanges. In the downstream extremity connecting this volume to room temperature plumbing is the vent pipe. As shown in Figure 2, the vent pipe is localized in a plane perpendicular to the beam direction. It contains a check valve to reduce thermoacoustic oscillations, two internally sleeved bellows to allow for thermal contraction movements and a region heat sinked to LN_2 by means of a copper braid.

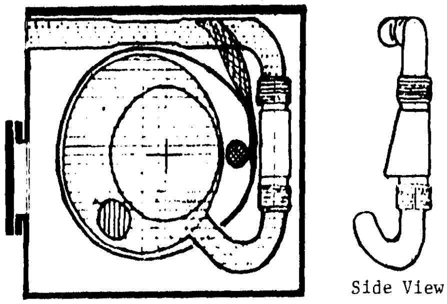

Figure 2. Dipole Magnet Vent Pipe

When pressure develops in the single phase of a magnet, the fluid can only vent into neighboring magnets or leave through the vent pipe. The path to the neighboring magnets is not a very low impedance one since the connecting bellows are filled with the superconducting cable splices and their G-10 insulators.

The amount of helium in the single phase space of a magnet is 30 liters for coils with Type IV collars and 15 liters for coils with the stronger Type V collars.

Vent Pipe Design

The transient nature of the flow through the vent pipe prescribed a semi-experimental approach to the vent pipe design. The first prototype presented too high an impedance to flow, the second was an expeditious compromise while the final one was being built. The first consisted of 1" tube with ball check valve and mitered joints. The second contained rounded elbows instead of mitered joints and the final one was built with 1¼"OD tube, flap-type check valve and other details for minimizing flow impedance (streamlining sleeves inside bellows, no sharp transitions, minimum room temperature plumbing impedance).

The heat leak due to this vent pipe is now being estimated as 1.7W to the LN_2 shield and .11W to the helium environment. More careful heat leak measurements of the cryostats are now underway, but the value 1.7W is based on measurements[2] made in a horizontal pipe simulating both in conduction and convection the upper section of the vent pipe.

Tests

The first series of measurements, made with pressure transducers[3] connected to different sections of the first vent pipe prototype by means of capillary tubes, was carried out in a four magnet test. In this test the string of four magnets was energized to a preset steady current. The energy extraction circuit and the electrically actuated vent valves were kept deactivated. A 9900μF bank of capacitors charged to 290V was discharged through the 17Ω internal heaters of the magnets and the output of the transducers recorded on fast chart recorder. Figure 3 shows these data. Not all the passive check valves[4] at the room temperature plumbing discharged; some of the vent pipes were plugged with solid nitrogen and the highest current attempted was 2500A. To eliminate questions relative to the capillary tube effects, a cold transducer[5] was used in another run of the same setup which confirmed

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the data of Figure 3.

The interesting thing to observe from these data is the relative slow development of the pressure pulse compared to the safety circuit response. For the two highest currents the maximum pressure is proportional to the square of the current, or the magnetic energy that was stored in the magnets.

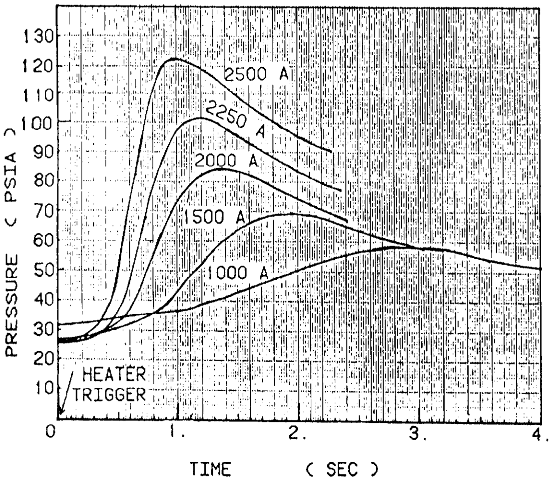

Figure 3. Quench generated pressure pulses in the first test.

A substantial reduction on the maximum pressure was obtained by reducing the impedance to flow of the vent pipe and of the room temperature plumbing, as later tests on a particular magnet (PAH-98) revealed. This magnet was fitted with the Type 2 vent pipe design (see Figure 2) and was subjected to a variety of quenches at the Magnet Test Facility. The resulting data are shown in Figure 4.

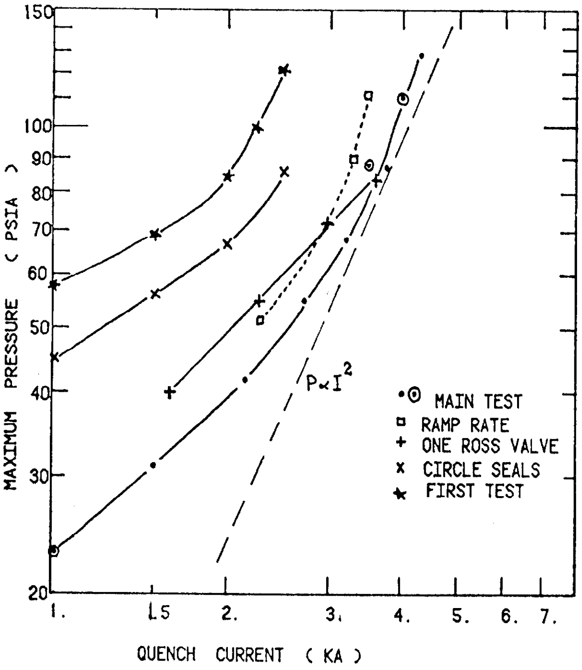

Figure 4. Data collected with magnet PAH-98 at Magnet Test Facility.

For comparison, the data of the first test ✱ is also included. The main test data were collected on two different days and correspondingly indicated by • and ⊙ . These quenches were started by discharging the capacitor bank into the internal heater. Higher pressures were reached when the quench was provoked by ramp rate □. In this case some energy is deposited in the coil before the safety circuit is actuated, discharging the capacitor bank and operating the room temperature vent valves. The importance of the vent valves[6] is made clear by the extra pressure when they are reduced to only one +. Two of these vent valves were used in parallel in the main test. When only the two passive Circle Seal[4] check valves are used, x , the maximum pressure approaches that of the first test.

The above data were collected with a cold transducer[5] installed in the flat plate end of the single phase space, sufficiently away from the vent pipe entrance to avoid pressure flow effects. Another pressure transducer[3], connected through a short tube to the exit of the vent pipe, permitted us to record the pressure drop across the vent pipe, as well as across the room temperature plumbing which includes the vent valve. These data just confirmed the importance of the room temperature plumbing impedance, which can be inferred from Figure 4, when the Type 2 vent pipe is used.

Conclusions

For magnets equipped with Type 3 vent pipes, the desired pressure pulse limit of 100 psia should be easily reachable, provided the room temperature plumbing impedance is adequate. A vent valve of large throughput (CV=50) capable of withstanding cold shocks close to the vent pipe exit is sufficient. It does not have to be very fast, an opening time of 250 msec is acceptable according to Figure 3.

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References

1. Conoseal - Vacuum-tight flanges based on metallic conical "O"-rings manufactured by Aeroquip Corp., Los Angeles, CA.

2. This measurement makes use of a heat flow meter device described by M.Kuchnir in the Proceedings of the Miami Meeting of AIChE (Nov. 1978).

3. Model LX17306, manufactured by National Semiconductor Corp., Santa Clara, CA.

4. Model 520B-10MP-20, manufactured by Circle Seal Corp., Anaheim, CA.

5. Type 4-356-0003, manufactured by Bell and Howell Corp., Pasadena, CA and calibrated at 4.2K by Fermilab.

6. Model 2173A8012, manufactured by Ross Corp., Detroit, MI.