PRELIMINARY MODELING AND TESTING OF RAMPED SUPERCONDUCTING DIPOLES FOR THE NAL DOUBLER

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Introduction

After a review of the types of magnets that were applicable to our goals for a superconducting accelerator ring, we have concentrated on two types of construction for dipoles, the first being a multiplayer pancake geometry and the second being a concentric shell configuration. The main construction features of these magnets are shown in Figs. 1, 2, and 3. The pancake style was at first thought to be easier to fabricate; however, on the basis of our experience in fabricating one of each type, Mark I - S4A, we now feel that the difference in fabrication cost may be minimal. The horizontal width of the shell type is less than that of the pancake type, due to a higher packing factor for the shell. This is due to the fact that less of the cross sectional area is taken up by cooling passages in the shell, and there is no waste space at the corners. There is, however, a school of thought that the pancake coils can be placed more accurately, and that the pancake coils are more adaptable to present winding techniques that industrial firms use. We now believe, however, that with adequate tooling design, the shell type would also present few difficulties to industrial coil firms.

Our present thinking is to use a warm iron configuration. There are two arguments for warm iron. Firstly, the time required to cool down and warm up a cold iron magnet was considered to be prohibitive. In an operating synchrotron, particularly during initial start-up, one must anticipate a certain number of magnet failures. Secondly, we wish to have the steel far enough away from the coil to prevent saturation in parts of the steel. In practice, this means something like a 3/4" space between the O.D. of the coils and the I.D. of the steel. Obviously, this space can be put to good use for the coil superinsulation.

DC Power Tests

A brief description of tests and the results obtained with these two magnets follows. Both were tested under dc and pulsed conditions in a vertical dewar and are now being reassembled in horizontal dewars for further testing. In the tests completed so far, results from the ed tests were most encouraging as both magnets achieved the maximum current density expected and operated at higher field than anticipated. A note of caution however, these higher current densities were obtained at fields about 2/3 less than would be experienced in the final design and the coil clamping system withstood considerably less force than it will be required to do in that design. In pulsed tests on both magnets the peak currents were about half those of the dc test due to power supply limitation, and, although the results with the pancake models were disappointing, those of the shell were most encouraging in terms of sensitivity to ramp rate. The tests to be done over the next months will not only be in the horizontal dewar but with a warm iron shield and a pulsed power supply that can go to higher peak currents than required by the design.

The unshielded Mark I Pancake model was tested in a vertical position; suspended in a pool of boiling Helium from a flange by an extension of the main beam tube. The test assembly was filled with a pair of helium counter-cooled current leads. Voltage leads were placed at the top of the cooled leads, at the junction of the cooled leads and the magnet leads, and at the magnet just before the potting.

Before the cooldown each of the coils was subjected to a ringing test for shorts, an inductance test, a dc resistance measurement and a megger test. The resistance was continuously monitored during cooldown using the coil as a temperature sensitive resistance by measuring voltage across the coil produced by a carefully regulated current source. The ringing, inductance, and megger tests were repeated at both liquid Nitrogen and liquid Helium temperatures.

Cooling was accomplished by first immersing the coils in liquid Nitrogen. The Nitrogen was pumped from the system and the Helium transfer began. The total time for cooldown was about three hours.

During all dc power tests x-y plots were made of coil voltage vs. current. In addition, voltage across the power supply as well as other portions of the lead assembly were monitored with a storage scope. A safety circuit, consisting of a precision voltage comparator and relay driver, was installed across the output of the power supply and automatically shut off the supply whenever the onslought of a quench caused voltage drop across the coil to exceed a preset value. This let the coil back emf forward bias a normally reverse biased diode and dump the stored energy into a special load resistor constructed of stainless steel tubing.

On the first runs the pancake magnet could not be energized above 825 amps. Training was evident and was thought to be from movement of the leads. The test assembly was removed from the cryostat and lead separation was found. This was repaired and all parts of the current lead assembly were reinforced by potting with epoxy. On subsequently energizing the coil it was found that the quench current could be "trained" to 1500 amps which corresponds to a field of 2.7T in the center of the two inch base or over 90% of the short sample critical current. This occurred in about 100 amp steps during repeated cycling of the magnet. As expected, the quenches showed no evidence of current sharing because of the high current density in the wire as well as the low copper to superconductor ratio. An average quench consumed about three to five liters of Helium since the stored energy was low. It would be noted that the wire is not intrinsically stable

*Operated by Universities Research Association Inc. under contract with the U.S. Atomic Energy Commission.

since the filament size is large, the copper to superconductor ratio small, and the twist length, ℓc, is relatively large.

The power supply used for dc tests contributed a fair amount of noise. The supply itself is a reconditioned electroplating supply consisting of a six phase transformer and copper oxide rectifier system controlled by a three phase variac on the input side of the transformer. There was no other regulation or filtering.

Preliminary field plots for the pancake magnet were obtained with a Rawson probe, and confirmed that the calculated transfer constant was correct. Measurements taken along the axis of the magnet show a small rise in field in the ends of about 1% and then a fall to zero field in about eight inches.

The apparatus for magnet ramping consisted of a low frequency saw tooth generator, a signal conditioner of NAL design and an HP 6464A power supply operating in the remote programmed, current regulation mode. The signal conditioner which clipped the output from the signal generator to give us an "injection" and "flat top" field, provided the remote programming voltage for the Hewlett-Packard supply. The HP 6464A is an SCR controlled type and suffers from severe turn-on transients when operated with the SCR's phased back for low level output. Damped vibrations in the coil were observed at turn on and several times during some ramps.

A series of current ramps were run on the magnet. Although the statistics are far from complete, it can be inferred that the coil showed severe ramp rate sensitivity. To some extent this was expected. The filament size is twice as large as that required for intrinsic stability at the ramp used. The twist rate is also too low to provide decoupling of the filaments. Nitrogen removal from this coil was incomplete and from dc data it was established that the buck of the coil only reacted 5°K during the ramp tests.

Although the pulse tests were disappointing with the pancake magnet, it appeared from evidence found on disassembly that we still suffer from motion of the connecting leads. We have now eliminated cause for motion by further improving the clamping of the lead assembly. The magnet will be tested again in a horizontal cryostat which should improve the cooling. In addition, in these later tests we will be able to add warm iron shielding.

The shell magnet was tested using the same procedure as for the pancake magnet. This magnet showed very little training and reached a peak current of 1500 amps after only two quenches. This corresponds to a magnetic field of 3 Tesla in the center of the 1.5 inch bore or again over 90% of the short sample critical current.

This magnet was not sensitive to ramp rate and could not be driven normal even when subjected to peak ramp voltage of 10 volts or 100 A/second. These tests were run repeatedly up to the maximum critical current found in the dc tests by presetting the plating supply to the desired current and pushing the "ON" button. A second test of this magnet was run with the Hewlett-Packard supply described previously. The magnet was pulsed at many different rates of rise and ultimately at a six second repetition rate to a field of about 1.7T for over an hour from a low field of 0.2T. This field corresponds to a maximum energy of 400 GeV in the present NAL machine. Appropriate waveforms are shown in Fig. 4.

This magnet is also being assembled into a horizontal cryostat and will be tested with and without a warm iron shell.

Further results as well as a design concept report of the doubler will be available from the NAL publications office.

Acknowledgements

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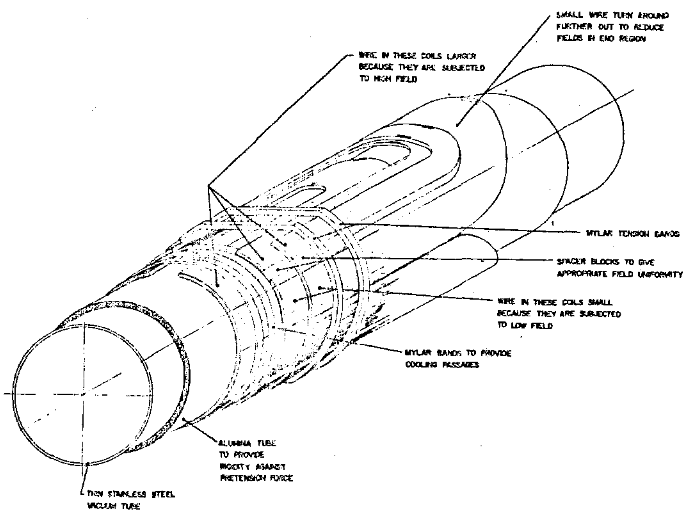

Figure 1 A View of the Shell Magnet Showing the Banding Structure

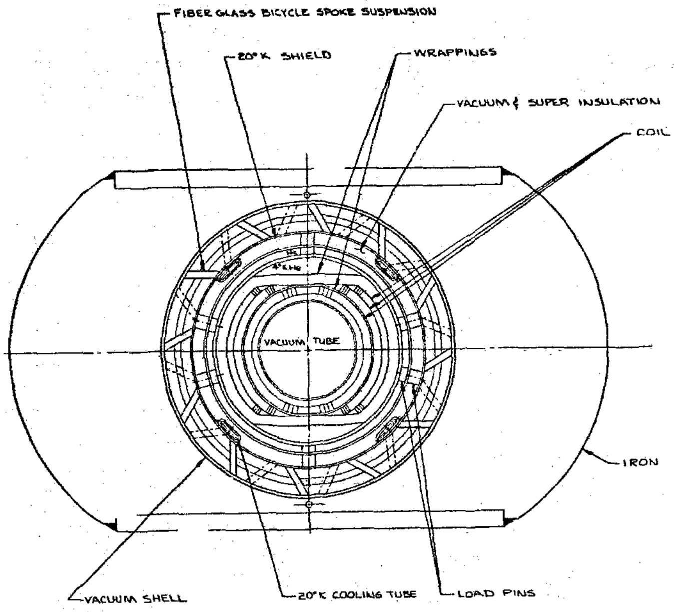

Fig. 2. A typical cross section of a "Shell" type magnet showing details of both the support and cooling systems.

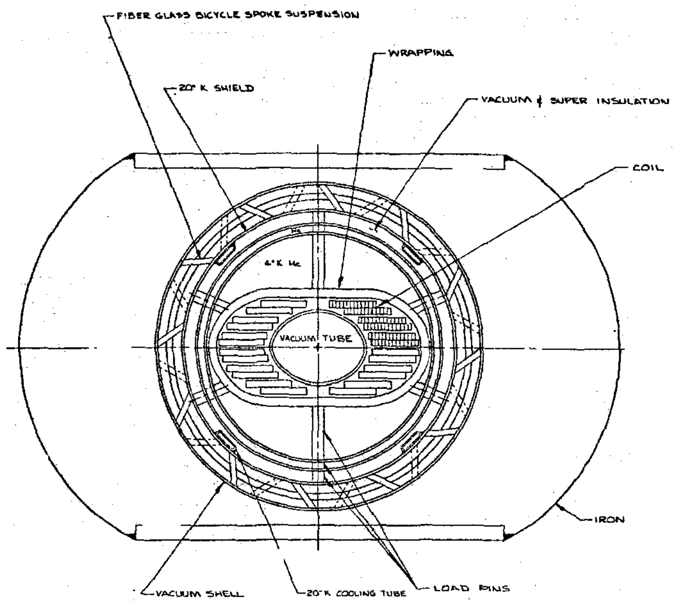

Fig. 3. A typical cross section of a "Pancake" type magnet.

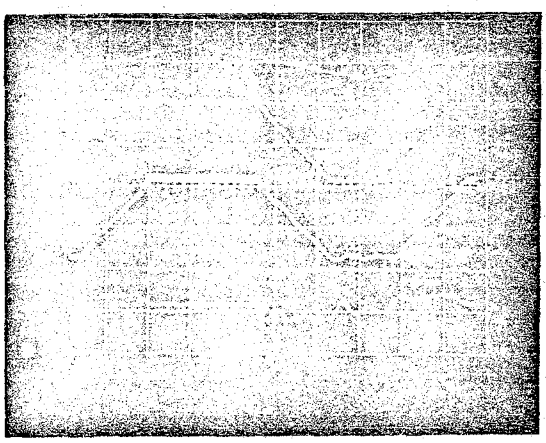

Fig. 4. Oscilloscope trace showing typical ramping run with the pancake magnet. The traces from top to bottom are the oscillator drive voltage, the programming voltage to the current supply, the coil current, and the current supply output voltage. The horizontal scale is 1 second/division.