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ELECTRICAL MEASUREMENTS DURING MAGNET CONSTRUCTION

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ABSTRACT

Throughout the construction phase of the cold mass for SSC magnets, electrical tests are made to determine that no faults in the coil structure have developed. These tests include ones designed to measure turn-to-turn voltage hold-off, hypot tests to ground, coil resistance, and instrumentation checks. These various tests will be described and the test parameters that are used will be covered.

Electrical tests are performed throughout the magnet assembly and fabrication process to verify that coil integrity and insulation quality of the various components and sub-assemblies are within nominal limits. These tests are also required to certify each dipole for SSC acceptance before it is installed in the cryostat and leaves the factory for final installation. The following series of tests, which are conducted at room temperature, are listed below.

- Resistance
- Inductance and "Q"
- Insulation
- Impulse
- Ratiometer

Resistance Tests

Resistance measurements are performed using a one ampere (usually) precision constant current power supply and measuring the resultant voltage drop across the element under test. This is analogous to a four-wire ohmmeter. This test is easy to perform and is uncomplicated. The maximum output voltage required from the power supply is less than ten volts.

The main coils are connected in series as per the final wiring configuration, and, with the one ampere current flowing in the coils, the voltage drop across each coil is measured and recorded. The DC resistance test will usually indicate a turn-to-turn short. However,

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the coil resistance will vary somewhat with changes in room (or coil) temperature. Therefore, difference voltages and temperatures are compared with previous readings. Also, the resistance of the two inner (or outer) coils should track each other closely. A voltage drop change (or difference) of 80 - 90 mVolts is usually an indication of a shorted turn.

Refer to Figure 1 for typical voltage drop DC measurements of SSC dipole coils with one ampere current flowing in the coils. Please note that the voltage drop per turn for inner and outer coils is different because of a slight difference in the superconductor cable composition.

This resistance test of the main coils is repeated frequently throughout the assembly process, and in particular, before and after the collaring operation, impulse testing, iron yoke installation, shell welding, Helium leak test, and for final testing.

Inductance and "Q" Test

The inductance and "Q" measurement provides another low voltage test on individual coils that will check for turn-to-turn shorts. This test is particularly sensitive to "soft" shorts. Q is the quality factor of the coil and is defined as the ratio of inductive reactance divided by the effective resistance of the coil. The effective resistance includes the DC resistance of the coil plus all the other resistive and eddy current losses due to the core (if any) material and manner in which the coil is wound. The inductance and "Q" measurement is done using two test frequencies. 1 kHz is used for individual open coils in an air medium, and 120 Hz is used when the dipole coils are in their final wired configuration within the yoked iron core. See Figure 2 for typical values of inductance and "Q" for various coil configurations. Turn-to-turn shorts will show a reduction of 10 - 20 % in the value of "Q".

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- INNER COIL HAS 16 TURNS.
 - OUTER COIL HAS 20 TURNS.
 - TOTAL WINDING = $(2 \times 16) + (2 \times 20) = 72$ TURNS.
 - INNER COIL VOLTAGE DROP IS APPROX. 82 mV/TURN
 $82 \text{ mV} \times 16 \text{ TURNS} = \underline{1.312 \text{ VOLTS}}$
 - OUTER COIL VOLTAGE DROP IS APPROX. 95 mV/TURN
 $95 \text{ mV} \times 20 \text{ TURNS} = \underline{1.900 \text{ VOLTS}}$
 - TOTAL MAGNET WINDING = $(2 \times 1.312) + 2(1.90) = 6.424$ VOLTS
 - CABLE VOLTAGE DROP IS 60-75 $\mu\text{V}/\text{INCH}$
(DEPENDS ON CABLE COMPOSITION & TEMPERATURE)

Figure 1. Typical DC Measurements
SSC Dipole Coils

Typical Values, Series Mode, $f = 1 \text{ KH}_2$
Uncollared Coils - No Metal

	L	Q
Inner Coil	2.35 mHy	10.25
Outer Coil	5.29 mHy	17.2

Typical Values, Series Mode, $f = 120 \text{ H}_2$
Collared & Yoked, Magnet Winding in Iron

L	Q
49.75 mHy	2.89

Data taken with a General Radio 1657 Bridge.

Figure 2. Inductance & "Q" Measurements
SSC Dipole Magnet Coils

Insulation Tests

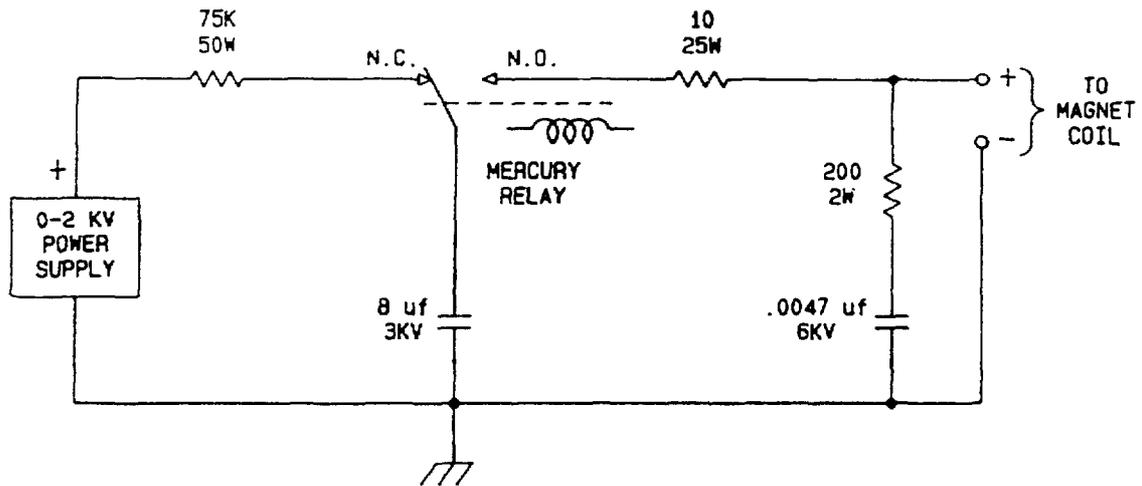
There are several insulation tests done to insure there are no shorts or excessive leakage currents between various components and sub-assemblies within the magnet dipole assembly. The high voltage, or hypot, leakage tests are done at a voltage level that exceeds what the magnet may experience during operation. In general, this test voltage is determined by doubling the expected voltage, and adding 1000 volts. The maximum test voltage required is 5000 volts, and the short circuit current should be limited to 2 mA to avoid damaging any magnet components should a flashover occur.

Simple low precision ohmmeter tests are done before making any high voltage test to be sure that the resistance between the components under test is greater than 20 megohms. The insulation hypot test requirements are as follows:

- Main coils to all other components and ground at 5 kV.
- Main lower coils to upper coils (midplane) at 3 kV.
- Trim coils to all other components and ground at 5 kV.
- Quench protection heaters to other components and ground at 5 kV.
- Ground is defined as the collar/yoke/shell and beam tube.
- Leakage current should be less than 50 μA after one minute of the applied test voltage.

Impulse Test

The impulse test is a high voltage test that checks the turn-to-turn voltage hold-off insulation integrity. This simulates the conditions that may occur during a quench. The coil winding insulation is stressed by discharging a capacitor that delivers a 2 kV pulse to produce (approximately) a 50 volt per turn voltage drop. See Figure 3 for a simplified diagram of the High Voltage Impulse Generator that is used for the impulse test. The resulting damped oscillation is stored on a digital



HIGH VOLTAGE IMPULSE GENERATOR
Figure 3

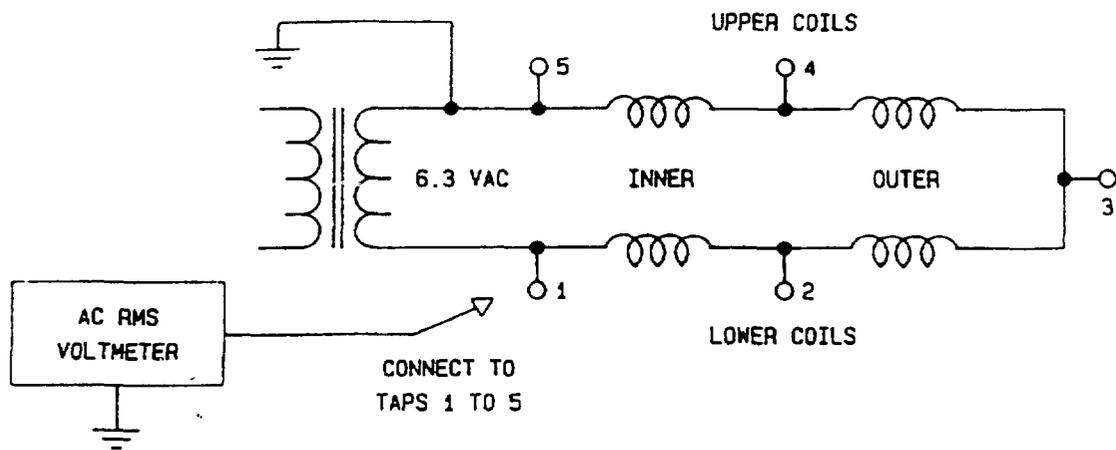
storage oscilloscope and photographed or plotted. Any change in the waveform will indicate a turn-to-turn breakdown of insulation. This test is usually done before and after the collaring operation, and should not be repeated any more than necessary to avoid stressing the insulation. As mentioned before, a resistance test of the main coils is made before and after this test.

Ratiometer Test

The ratiometer test checks the turns ratio of the coils in a dipole magnet. By comparing turn ratios, it is possible to check if a coil has a shorted turn. The advantage of this method is that it is insensitive to temperature and may be used in a liquid helium environment. The test is performed with coils in iron (yoked) at 60 Hz with approximately one ampere AC current flowing in the magnet. The coils are connected in series as per the final configuration to form an autotransformer as shown in Figure 4. An AC RMS voltmeter is used to measure the voltage developed across the four individual coils using the voltage taps.

The inner upper and lower coils should develop 0.1885 of the total excitation voltage measured. The outer upper and lower coils should develop 0.3115 of the total excitation voltage. If the computed ratio is different by more than +/-0.007 from the given ratio, it indicates there may be a shorted turn in the coil in question. Because the magnet coils are not closely coupled as in a transformer, the inner and outer ratio numbers were determined experimentally using a known good magnet at room temperature and at liquid helium temperature.

In conclusion, some of the tests may seem redundant, but, in many circumstances a cross check or different method of testing is very helpful when interpreting test results. Proper safety procedures should be followed when making any electrical tests and the equipment should be properly grounded. Following the final electrical testing, warm magnetic measurements are done to check magnetic field quality.



MAGNET RATIO METER

Figure 4

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