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ELECTRICAL INSULATION REQUIREMENTS AND TEST PROCEDURES FOR SSC DIPOLE MAGNETS.

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ABSTRACT

The development of the basic requirements for the turn-to-turn, coil-to-coil, and coil-to-ground insulation for SSC dipoles is discussed. The insulation method is also described along with test procedures for verification of insulation integrity.

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"
- Hypot
- 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, the coil resistance will vary somewhat with changes in room

*Work performed under contract with the U.S. Department of Energy.

(or coil) temperature. Therefore, difference voltages and temperatures are comparedwith 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".

- INNER COIL HAS 16 TURNS.
- OUTER COIL HAS 20 TURNS.
- TOTAL WINDING = (2 x 16) + (2 x 20) = 72 TURNS.
- INNER COIL VOLTAGE DROP IS APPROX. 82 mV/TURN
  82 mV x 16 TURNS - 1.312 VOLTS
- OUTER COIL VOLTAGE DROP IS APPROX. 95 mV/TURN
  95 mV x 20 TURNS = 1.900 VOLTS
- TOTAL MAGNET WINDING = (2 x 1.312) + 2(1.90) = 6.424 VOLTS
- CABLE VOLTAGE DROP IS 60-75 μV/INCH
  (DEPENDS ON CABLE COMPOSITION & TEMPERATURE)

Figure 1. Typical DC Measurements
SSC Dipole Coils

Typical Values, Series Mode, f = 1 KHz
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 Hz
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

Hypot 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.

The most common insulation used in magnet construction is Kapton film in various forms. Figure 3 is a list of the many types of Kapton that are used at BNL for magnet insulation.

BNL Code	Width (in.)	Thk. (in.)	Adhesive Type	Adhesive Thk.(in)	Vendor Name	Vendor Part No.
Kapton NA-1	3/8	.005	None	-	E.I. DuPont Co., Inc.[1]	500BH
Kapton NA-2	1.0	.001	None	-	E.I. DuPont Co., Inc.	100H
Kapton A-1	1/2	.005	Silicone	.0005	CHR/Carlson[2]	K104
Kapton A-2	1/2	.001	Silicone	.0005	CHR/Carlson	K105
Kapton A-3	3/4	.001	Silicone	.0005	CHR/Carlson	K105
Kapton A-4	3/8	.001	Polyester	.001	Sheldahl[3]	T320
Kapton A-5	1.0	.001	Acrylic	.0015	CHR/Carlson	K102
Kapton A-6	1/2	.001	Silicone[5]	.0015	CHR/Carlson	K250
Kapton A-7	1.0	.001	Silicone	.0015	DW/Canis[4]	304-1-1
Kapton A-8	1/2	.002	Silicone[5]	.0015	CHR/Carlson	K350
Kapton A-9	3.0	.002	Silicone[5]	.0015	CHR/Carlson	K350
Kapton A-10	3/4	.002	Silicone	.0015	DW/Canis	304-2.75
Kapton A-11	3/4	.005	Silicone	.0015	DW/Canis	304-5
Kapton A-12	1.0	.005	Silicone	.0015	DW/Canis	304-5-1
Kapton A-13		.001	Teflon Each Side	.0001	E.I.DuPont Co., Inc.	Type 120 FN 616
Kapton A-14		.001	Teflon	.0005	E.I. DuPont Co., Inc.	Type 150 FN 019
Kapton A-15		.005	None	-	E.I. DuPont Co., Inc.	Type 500 FN 131
Kapton A-16		.003	Silicone	.0015		

NOTES:

[1]E.I. DuPont Co., Inc.
Polymer Products Dept.

[3]Mfd. by: Sheldahl Inc.
P.O. Box 170
Northfield, MN

[5]Fire Retardant

[2]Mfd. by: CHR Industries
New Haven, CT

[4]Mfd. by: Dewal Industries
Saundestown, RI

Figure 3. Kapton Film Material Description.

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 4 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 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.

Figure 5 shows two typical waveforms from insulation breakdown during the impulse test. A partial short was made in an old outer coil from magnet DD-016 using a metal probe to pierce the insulation between adjacent turns 9/10 near the return end of the coil. The insulation breakdown voltage spike can be clearly seen occurring at the peak voltage points in the waveform. Near the end of the waveform, a sustained arc is seen, and in photograph 2, it completely dissipates the remaining stored energy.

The impulse test can also show up a more subtle type of coil defect. Figure 6 shows three photographs (30-32) of impulse tests done on magnet DD018.[1] In addition to the impulse voltage waveform (upper trace) the impulse current (lower trace) was measured using a Pearson Electronics, model 110, current monitor. Photograph 31 is a superposition of the impulse waveforms obtained from the upper and lower inner coil blocks. These waveforms don't lie on top of each other. The current crest in the lower inner coil is clearly earlier in time and higher in amplitude than that in the upper inner coil. This indicates a lower inductance in the lower inner coil and thus a dielectric failure. The inductance of the lower inner coil was computed to be 39% lower than the upper inner coil inductance and clearly indicates a defect. This method of quarter coil comparison testing is now under consideration for use in future magnet production.

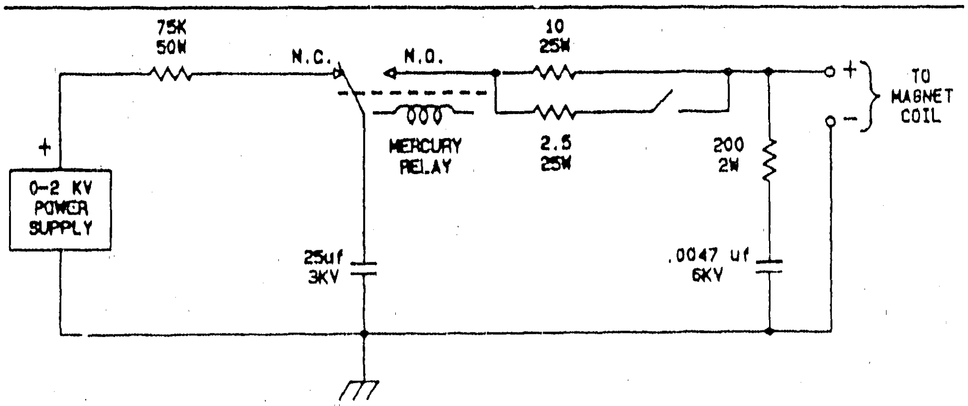


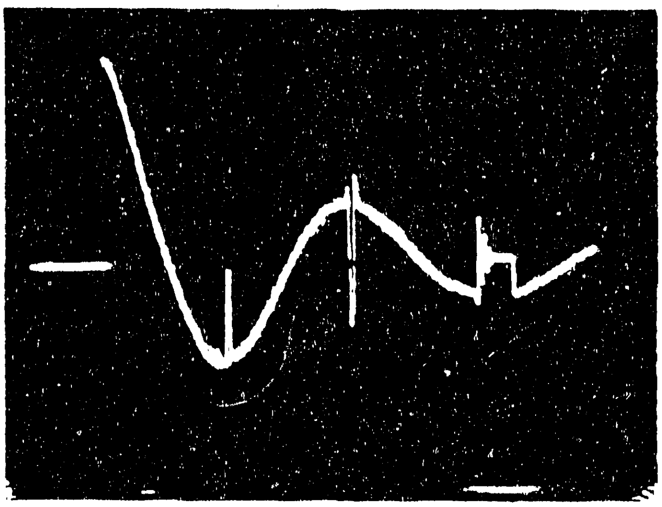
Figure 4. High Voltage Impulse Generator

[1] J.G. Cottingham and G. Sintchak; Turn-To-Turn Fault Location In Magnet DD0018, SSC Technical Note No. 87 (SSC-N-681); Nov 9, 1989.

High Voltage Impulse Test

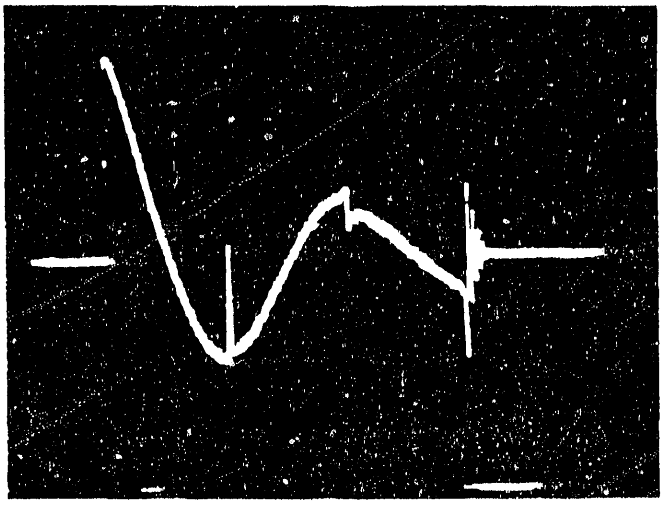
Insulation Breakdown

Probe Induced Short



Photograph 1

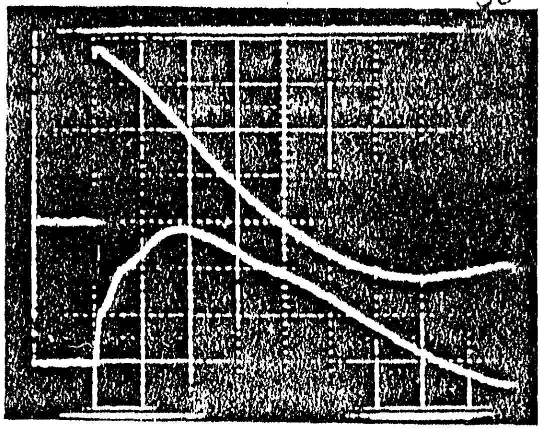
500 V /Div
0.5 mS/Div



Photograph 2

Figure 5. Magnet DD016, Lower Outer Coil, LLN-024, 3-31-89

30

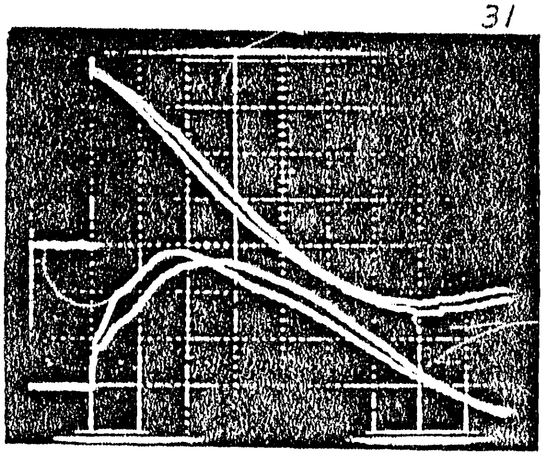


#30 Lower Inner Coil

Note: Higher current peak occurs sooner in t[illegible].

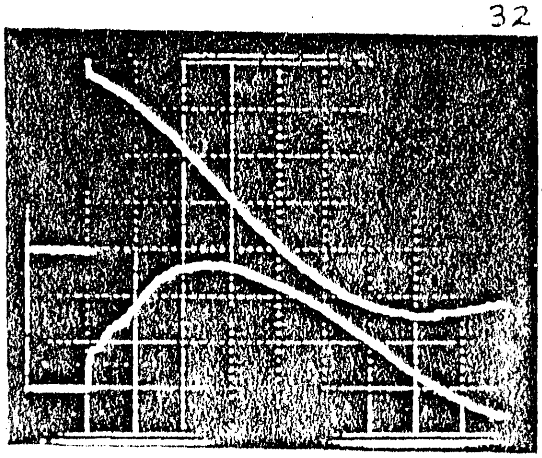
Indicates lower induct[illegible]

31



#31 Upper/Lower Coils Overlay

32



#32 Upper Inner Coil

All photographs:
500 V /Div
50 A /Div
0.1 mS/Div

Magnet DD-013 [illegible]

Figure 6

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 7. 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, 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.

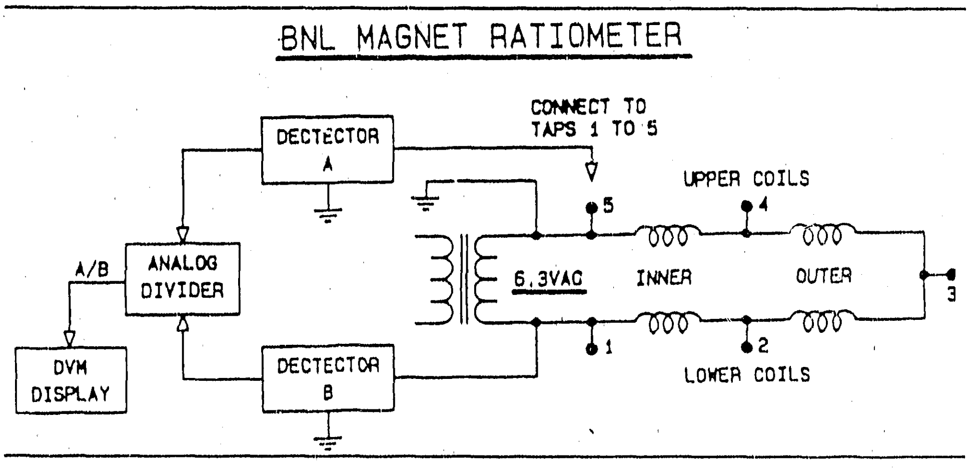


Figure 7

- END -

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