MAIN MAGNET COIL DIAGNOSTIC TESTS AT THE ZERO GRADIENT SYNCHROTRON (ZGS)*

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Summary

To establish a meaningful history of the electrical condition of our main magnet coils, various instruments and techniques were developed for a diagnostic program.

Introduction

Prior to January 1971, routine maintenance tests consisted mainly of 500 V meggering between main coil and kicker coil, and between each of these coils and ground. If operational problems occurred which called in question the soundness of a coil, 400 Hz impedance tests were made and compared to initial coil data. After coil failures in octant 2 (April 1970) and octant 3 (January 1971), we took a serious look at our diagnostic tests.

A committee was formed of persons who were not a part of the Operations Group whose mission was to determine why the coils failed. One of the conclusions forthcoming was the importance of determining whether corona discharge had contributed to the failure.[1] Of particular interest was the threshold of the relatively new octant 2 coil compared to the older ones. We assumed that corona threshold would be a good indicator of coil integrity.

Corona Tests

A detection sensitivity for 5 picocoulomb (pC) was considered needful for the tests. Two obstacles were soon apparent for obtaining thresholds:

1. How to achieve the needed sensitivity, and

2. what to use for energizing the coil for the tests. Using 60 Hz was questionable since 42 kVA would be required for 1700 V peak.

Detector

The sensitivity problem is basically: how to detect 5 pC discharges within the coil when there is 0.1 μF shunt capacity present. The high sensitivity requirement is compounded by the fact that the magnet location is quite noisy electrically. The voltage sensitivity needed is:

$$V = Q/C = \frac{5 \times 10^{-12}}{1 \times 10^{-7}} = 50\ \mu V$$

To achieve the desired voltage sensitivity, J. Dawson of Argonne National Laboratory used a communication receiver as an amplifier.[2] He also found that the coil was a good transmission line at 8.5 MHz. A quiet frequency band close to 8.5 MHz was used during the tests. The intermediate frequency output from the receiver was rectified and then coupled to a pulse counter. Figure 1 shows a diagram of the setup.

Power Source

A 400 Hz generator and the ring magnet power supply generated harmonics to such an extent that they were useless as power sources for the tests. An octant has a Z_{max} of 1000 Ω at 2.5 kHz with a Q of 2. With this in mind, a 10 kW Ling amplifier designed for shaker table drive was procured along with an output transformer to match to the coil. This system provides a good, corona free, low harmonic, and low power source. It takes only 1.6 kW rms to develop 1700 V peak across an octant at 2.5 kHz. Needless to say, overvoltage and overcurrent protection are necessary.

Results

Figure 2 lists the thresholds measured over a period of four months. The threshold values were affected by how long the magnets were off prior to the tests. Longer off time resulted in lower thresholds. A plausible explanation for this is that moisture and mechanical stress are higher in the cooler magnet. Thresholds were taken with one end of the coil at ground (normally phantom ground) to determine ground corona and with midcoil at ground for internal coil corona. There does not appear to be any striking difference between thresholds for octant 2 and coils which had been pulsed for many years. Differences might have occurred at voltages higher than 1700 V peak, but that was the limit we had set for testing. Seventeen hundred volts is 1.5 times operating potential exclusive of rectifier arc transients.

Corona Tests on G-10 Epoxy Glass Used in ZGS Coils

Description

The purpose of these tests was to gather quantitative data for effects of corona discharge on G-10. This information was considered important to meaningfully evaluate our coil corona tests and to assist in future decisions regarding maximum operating potential.

A section of an original coil prototype was used and the tests were made on a sample of 0.040 in interlayer insulation. Figure 3 shows the layout of the test. Phonograph needles were used as tips because of their hardness and uniform tip radius. The tests were conducted over a seven-week period during which time the temperature was 78° ± 2° and

*Work performed under the auspices of the U. S. Atomic Energy Commission.

relative humidity was 42% ± 4%. Relays K_1 and K_2 provided for voltage interruption, should a point burn through to the copper. The three switches are included so that individual corona thresholds can be determined. The detection apparatus is the same as that used for our main coil corona tests. The detector is common to all three tips and thus registers the combined count. The count is almost entirely due to tip 1 since discharge activity is approximately proportional to V^{10}. This value is determined from test data. The detector threshold was set for 5 pC. Discharge magnitude increased by 15 dB when voltage was raised by a factor of two, thereby giving discharges of 28 pC.

Figure 4 shows typical threshold values from run 3. Three runs were made using all three tips. The applied voltage stayed the same for the duration of a test run. The voltages used were determined by setting tip 3 to its corona threshold. Tip 2 then had 1.33 times tip 3 voltage, and tip 1 had 2 times tip 3 voltage.

The corona thresholds at each tip were recorded at intervals. A run was discontinued when the thresholds leveled off or increased, indicating possible movement of the tips. The plot of corona vs voltage cycles appears linear and seems to indicate saturation in the system. One would expect the corona count to increase as the threshold voltage decreased for a constant voltage applied. Results of test run 4 are shown in Fig. 5. In this test, tip 1 only was set over a void in the insulation and was excited at voltage twice the corona threshold. Note the great increase in intensity for this void, which was about 0.04 in in diam.

The insulation sample used for runs 1, 2, and 3 was examined under a microscope at the completion of the tests. There was no evidence of physical damage; the only visible effect being a slightly darkened ring-like area of about 1/8 in diam around the point-of-tip contact. This was probably due to oxidation by generated ozone. Ultrasonic tests were made by the Special Materials Division to look for subsurface defects, but none were found. The ultrasonic tests were made before and after the copper was cut and etched away. The tips showed some sputtered metal on the shaft above the point.

Summary

Corona discharges of 5 pC intensity affect the electrical characteristics of epoxy glass after a few million voltage cycles. We arrive at this conclusion because the corona threshold dropped. Discharges even as great as 28 pC for 30 million voltage cycles do not show physical damage. According to one authority, epoxy glass stressed with a field of 2.5 kV/0.04 in at 50 Hz should have an expectant lifetime of about one year.[3] Scaling this value for an estimate of electrical lifetime for the insulation within our coils gives a figure of one hundred years. Conclusions regarding corona contribution to our coil failures will be considered in a companion paper.[1]

DC Resistance Tests

The resistance between various elements of the magnet and also between the elements and ground is taken periodically. These readings can be compared with previous data to alert us to an abnormal value. Figure 6 shows schematically how currents are measured in order to determine the resistances. R, M, and K are the ripple, main, and kicker coils, respectively.

R_r is the resistance between ripple coil and ground.

R_{rm} is the resistance between ripple coil and main coil.

R_m is the resistance between main coil and ground.

R_{km} is the resistance between main coil and kicker coil.

R_k is the resistance between kicker coil and ground.

R_m is nominally about 100 kΩ due to cooling water conductivity. In actual practice, the power supply and meters are assembled into a portable unit which has a selector switch for switching meters A_2 and A_3 for the two tests. With the six current readings from both tests, it is easy to determine all five resistance values. The data is taken at 100 V intervals up to 1000 V so that nonlinearity in the resistances can be detected.

From Test 1:	From Test 2:
$I_1 = I_{rm} + I_2 + I_3$	$I_1 = I_{rm} + I_2 + I_3$
$I_{rm} = I_1 - (I_2 + I_3)$	$I_{rm} = I_1 - (I_2 + I_3)$
$R_{rm} = V/I_2$	$R_r = V/I_2$
$R_{km} = V/I_3$	$R_k = V/I_3$
$R_m = V/I_{rm}$	

Resistance values except for R_m are typically 20 MΩ or greater.

Ground Fault Location by Bridge Circuit

Another instrument for improving our diagnostic techniques is a portable instrument for locating faulted anchor rods. Our main coil is held in place by 286 spring-loaded, insulated, anchor bolts that thread into the kicker plates on the outer face of the coil. Occasionally a chip of magnetic material bridges the insulation of a rod and a ground fault results. Figure 7 shows a diagram of the instrument.

An ac bridge was used because it blocks internal galvanic potentials which upset a dc bridge. Eighteen hertz was selected because it increased the sensitivity by a factor of six over dc, due to the kicker coil inductance. However, the frequency is low enough so that errors from capacitive currents are negligible.

The 18 Hz drive voltage is generated by modulating a low voltage, high current 60 Hz supply with high power transistors driven by an 18 Hz oscillator. Active filters with an overall gain of 10,000 are used in the detector circuit. The entire system is packaged into a portable unit of about 30 lb. This includes two retractable coil reels for convenient storage of the connecting cables.

It is possible to locate a faulted rod in a matter of a few minutes. Fault resistance as large as 10 MΩ has been located. The unit can also be used for locating ground faults in other coils.

Acknowledgments

Credit is due to C. Potts for the dc resistance test unit and for his other helpful suggestions. Thanks to D. Bohringer and D. Schmitt for their assistance in taking corona data, and to J. Stapay for the dc resistance data.

References

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[2] J. W. Dawson, Argonne National Laboratory, Method for Detection of Corona Within Ring Magnet Coils of the Zero Gradient Synchrotron, International Conference on Magnet Technology, Brookhaven, New York, September 18-21, 1972.

[3] J. H. Mason, "Discharge Detection and Measurement," Electrical Review (May 1968), p. 802.

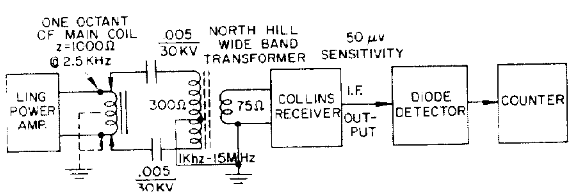

Fig. 1 Diagram of Corona Tests

Values are in Volts Peak

Octant	Ground at Turn 30 (Ground Corona Mostly)				Ground at Turn 15 (internal Corona Mostly)			
	11/2 1971	1/18 1972	2/1 1972	3/9 1972	11/2 1971	1/18 1972	2/1 1972	3/9 1972
1	1130	1060	>1700	1000	>1700	1500	1700	1700
2	1550	>1700	1590	1700	>1700	>1700	1700	1700
3	>1700	>1700	>1700	1700	>1700	>1700	1700	1700
4	>1700	>1700	1630	1660	>1700	>1700	1580	1700
5	1700	>1700	1700	1700	>1700	>1700	1530	1700
6	1415	1300	1200	1200	1560	>1700	1490	1700
7	1700	1600	1420	1560	>1700	1700	1560	1630
8	1270	1270	1060	1060	>1700	>1700	1450	1700
	36 h after shut-down	16 h after shut-down	15 days after shut-down 8% R.H.	20h after shut-down 8% R.H.				

Fig. 2 Corona Thresholds of ZGS Coils

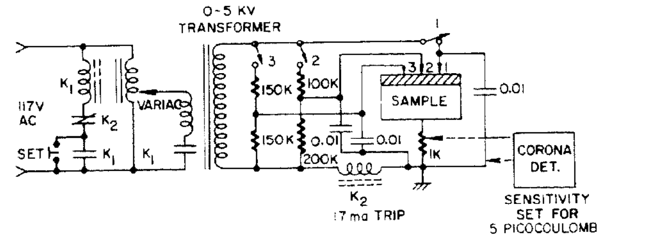

Fig. 3 G-10 Insulation Corona Test Diagram

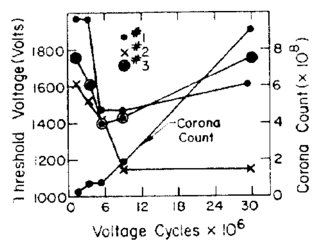

Fig. 4 Insulation Test Results (Run 3)

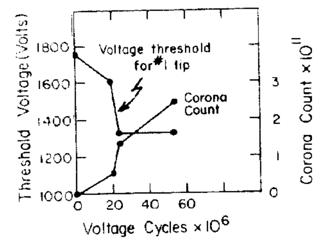

Fig. 5 Insulation Test Results (Run 4)

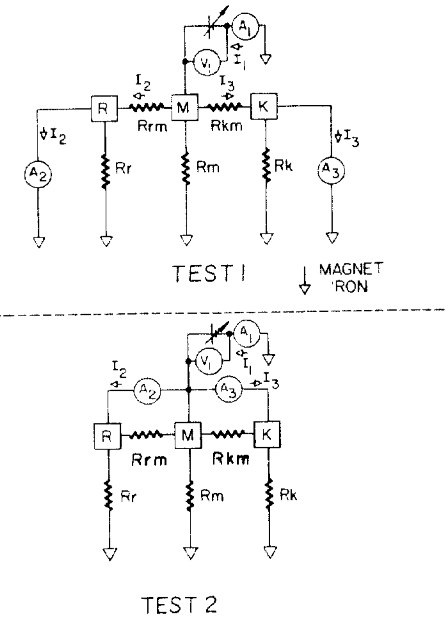

Fig. 6 Diagram of Current Measurement Tests. Intracoil Leakage Resistances are Readily Calculated from these Currents.

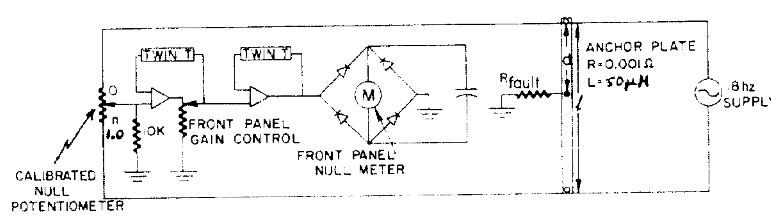

Fig. 7 Eighteen Hertz AC Bridge. Relative Position of R_{fault} = $n\ell$ where n is the Potentiometer Number at the Null (0 - 1.0)