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DETECTION OF LOCATIONS OF SHORTS FOR FAILED MAIN RING BENDING MAGNETS

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I. Introduction

Various analyses have been made of failed Main-Ring bending magnets in order to determine causes of failures and to build better magnets for replacement. In recent tests, one of the major causes was found to be water leaks from butt joints in inner coils. A static watter-pressure test at 2500 psi for at least 24 hours reveals an apparent water leak in a coil that has a short to ground. Since then, sleeve joints have been used in the inner coils for newly rebuilt Main Ring bending magnets and much stringent quality control has been performed in the process of coil production in order to avoid any failures caused by water leaks in the inner coils.

The outer coils of all bending magnets have always been made with sleeve joints so that this problem does not occur with them. It is, however, very clear that water leaks from butt joints alone cannot explain all magnet failures. A large fraction of the failed magnets did not show any water leaks for the static water-pressure test. Eight out of thirteen failed integrally impregnated mica magnets, so-called "super-magnets", did not show water leaks. Of course, it is not clear that a static water-pressure test can uncover all modes of water leaks, because thermal conditions for magnets during operation are quite different from those at room temperature.

Failed magnets with high residual radioactivity must be cooled down before they are burned and opened for rebuilding. Opening of magnets before burning is very difficult and can destroy a large fraction of magnet parts. It, therefore, takes a relatively long time before one can inspect the insides of magnets to study further the causes of failure.

We have developed a method to locate the positions of shorts in failed magnets without opening the magnet. This method is based upon the sudden change of magnetic field with distance across the short when a dc current is applied between one of the coil leads and ground.

II. Procedures and Results

The magnetic-field change across a short is given by

$$\Delta H \approx 1/2 \cdot \frac{4\pi}{10} \cdot \frac{I}{D} \quad \text{(Gauss)}, \qquad (1)$$

where I is the dc current applied in Amperes, and D is the magnet gap length in cm, 3.8 cm and 5.1 cm for B1 and B2 magnets, respectively. This formula follows directly from Ampere's Law. Because of small variations, about 1 Gauss, in remanent field along the magnet and because of large remanent fields from end packs (usually about 5 Gauss higher than that of the normal laminations), the current, I, is set higher than 50 Amperes to give a better signal.

The analysis procedures are as follow:

1. Identify a shorted coil by hi-potting after removing a manifold.

2. Perform the static water-pressure test at 2500 psi for at least 24 hours.

3. Make the short harder so that a large dc current (> 50 Amperes) can be applied through it by a low-voltage welding power supply. This procedure allows us to confirm locations of shorts from clear burned marks after magnets are burned for rebuilding. One failed magnet did not break at an applied voltage less than 1500 volts, but most failed magnets broke at 500 volts or less. For convenience, two medium-size power supplies of 500V-0.5A and 150V-20A were used when a welding supply alone could not make a hard short.

4. Apply 50 Amperes or more current from one lead to ground and measure field along the magnet, particularly any field change. Apply the same amount of current from the other lead to the ground and measure field. The current directions for the above measurements should be adjusted so that the field direction is always upward. This constant direction is required to maintain constant remanent fields for both measurements. The sum of magnetic fields at any given location after subtracting remanent field components should be

$$H_{sum} = \frac{4\pi}{10} \frac{I}{D} \cdot N, \qquad (2)$$

   where N is the number of coil turns, 4 for all inner coils and B1 outer coils and 6 for B1 outer coils. In addition to the location of the short, we can determine which turn in the coil is shorted. Table I shows a typical example of measurements:

Because of the large remanent field from the end pack at the return end, the measured field changes at 11 inches from the return end for the two current directions are not quite consistent, but it is very easy to determine the location of the short.

When a short is very close to the magnet ends, it is very difficult to measure field changes due to the short. However, from eg. s (1) and (2), it is rather straightforward to determine which end has the short.

Occasionally, smoke was observed from the magnet ends where shorts were located. When shorts between inner coils and the ground were close to the magnet ends, the results by field measurements are often confirmed by finding heated spots of vacuum chambers by touch.

Table II shows summary results of 20 magnets that were measured in September and October 1973.

A different method was also tried to determine locations of shorts. It utilized measured voltage drops between coil leads and the ground. This method was found to be very unreliable because larger voltage drops usually appeared at the shorts themselves rather than in coils. As a result, the voltage drop method did not give any useful information.

Table I

Magnet 1251 (B1)

Failed:	July 31, 1973	
Measured:	September 6, 1973	
Shorted Coil:	Inner Coil	
Excitation Current:	75A	

Top Lead-to-Ground

Lead End:	55G	All Way
Return End:	74G	< 11"
	54G	> 11"

Ground-to-Bottom Lead

Lead End	85G	All Way
Return End	78G	< 11"
	84G	> 11"

Remanent Field 18G

Short: 13" from the return end and inner-lower turn.

Table II

	Magnets		Water Leak	Estimated Location of Shorts and Comments**
1.	2284*	8-18-73	No	Inner; 4" from l.e.
2.	1264	8-11-73	Yes	Inner; 38" from l.e.
3.	2657	7-15-73	No	Inner; Fire from r.e. No meas.
4.	1634	8-28-73	No	Lower-Outer; Did not break at 500V. No meas.
5.	1251	7-31-73	No	Inner; 11" from r.e.
6.	2132	7-11-73	No	Upper and Lower-Outer; Smoke from r.e. No meas.
7.	2292*	6-29-73	Yes	Inner; 12" from r.e.
8.	1730	5-03-73	No	Inner; Breaks at 1500V. No meas.
9.	1762*	8-31-73	No	Inner; 7" from r.e.
10.	2019	7-27-73	Yes	Inner; 10" from r.e.
11.	2167	9-14-73	No	Upper-Outer; 6" from r.e.
12.	2707	9-14-73	No	Inner; 4" from l.e.
13.	2681	10-14-73	No	Inner; 10" from r.e.
14.	2677	10-14-73	No	Inner; 4" from l.e.
15.	2014	9-30-73	No	Lower-Outer; 6" from r.e.
16.	1200	9-30-73	No	Upper-Outer; 6" from l.e.
17.	1699	9-29-73	No	Inner; Vac. Chamber burned at 17" from r.e. No meas.
18.	1572	9-26-73	No	Upper-Outer; 6" from l.e.
19.	2779*	9-21-73	No	Inner; 6" from l.e.
20.	1756*	9-14-73	No	Inner; 34" from r.e.

* Integrally impregnated mica magnets.

** l.e. = lead end; r.e. = return end; No meas. = no field measurements made.