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Internal Report

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Investigation of Beam Transport Magnet Coil Failures

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I. Introduction

In order to investigate causes and possible corrections for magnet coil failures it is necessary to review the history of the AGS beam transport coils.

All the magnet coils purchased or in process as of June 1962 were turn insulated with fiberglass sleeving consolidated by impregnation with epoxy. This type of insulation was used by our coil fabricators and met the requirements of our insulation specification.

In 1961 considerable difficulty was encountered in obtaining acceptable coils for the large bending magnets because of turn to turn shorts which were discovered during acceptance tests on the coils. In 1962 eight rectangular quadrupole coils were also rejected because of turn to turn shorts discovered by impulse tests prior to usage.

As a result of the above coil failures the use of glass sleeving as an acceptable insulation was investigated and found to be questionable, since the constant flexing of the sleeving during assembly on the conductor resulted in broken and frayed fibers and corresponding weak spots in the turn insulation. The use of glass sleeving for turn insulation in coils was, therefore, discontinued and fiber glass tape either "B" staged or natural was specified for turn insulation on all magnet coils.

Twenty-five additional magnet coil failures have occurred in the beam transport magnet coils since June, 1962. One coil failed in 1962, two in 1963, nine in 1964 and thirteen in the first four months of 1965. Seventeen of the twenty-five failures occurred in the North area beam No. 3 (which had been in operation for approximately two years) and consisted of fourteen 12 inch quadrupole coils and three rectangular quadrupole coils.

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One bending magnet coil also failed in this beam. Prior to these failures only one 12 inch quadrupole coil failure was experienced and that failure was caused by a copper chip located between turns during fabrication of the coil.

The sudden increase of coil failures in 1965 resulted in a shut down of beam No. 3 and the initiation of a crash program to find the cause of the coil shorts, initiate the necessary corrective procedures, and reinsulate all the quadrupole coils used in beam No. 3 including any other shorted coils.

II. Investigation

A. Magnet Cooling Water Supply

The cooling water originally used in the north area beam No. 3 was supplied from 80 inch bubble chamber water locally treated for corrosion prevention. Use of this water resulted in the deposition of a chemical residue on the conductor wall causing a reduction in the cooling water flow rate and a corresponding increase in the cooling water temperature. This triggered either the flow control or temperature interlock and shut off the power supply to the magnet which resulted in thermal stressing of the magnet coils. The treatment was discontinued and local site water was used but little improvement was noted.

The cooling water system for north area beam No. 3 prior to spring shut down in 1965 had insufficient capacity to permit all the magnets to be operated at their maximum water flow rate. The water flow supplied to the magnets was just sufficient to meet the heat dissipation rate required. The magnets in this beam, therefore, were being operated at their maximum thermal rating even though they were not being operated at their maximum current rating.

Electrolysis in the hose fittings and a few cases of burst hoses caused the coils and cores to be saturated with water which eventually resulted in failure to ground on the magnet coils affected.

Water hoses for the magnet coils were found to be bent to radii smaller than the minimum radius bend recommended by the hose supplier.

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B. Silver Soldered Joints

The coils sent out for reinsulation were to have some of the soldered joints separated and examined to visually check the quality of the joint. The joints on the rectangular quadrupole coils were found to be almost 100 per cent faulty. These joints were not heated sufficiently prior to soldering resulting in a cold joint. Solder preplacements in these joints were almost in their original condition giving visual evidence of poor quality joints.

The joints in the 12 inch quadrupole coils were separated and about one joint in four was found to have insufficient solder resulting in a solder starved joint.

As a result of this evidence all joints on the coils to be reinsulated were resoldered before the application of new insulation.

The coils were examined by the vendor during the insulation stripping process and three coils were also partially stripped of insulation at BNL but no obvious causes of shorts were discovered.

C. Thermal Stresses

Some of the 12 inch quadrupole coils were found to be slightly oversize and tight in the magnet core slot providing insufficient room for shimming and increasing the possibility of higher thermal stresses in the coils during magnet operation.

All of the coils were shimmed (when sufficient room was available) with non-resilient material permitting no room for the coils to flex when subjected to thermal expansion.

A 12 inch quadrupole coil was thermally cycled and checked with indicators to see the distortion resulting when cold water was permitted to flow through a hot coil and vice versa. Results of this test indicated the need for a resilient liner to take up the deformation in the coil resulting from thermal stresses.

Low temperature alloy fuses used in the magnet thermal interlock were found to have excessive cold creepage resulting in power shut off to the magnet. The fuses were also too thin which prevented proper engagement with the micro-switch. Power failure to the magnet from the above causes resulted in thermal shock, and corresponding high stresses in the coil.

III. Conclusions

Coil failures were found to have resulted from the following causes:

1. Saturation of the magnet coils and core with water from burst hoses or fitting failures resulted in failure to ground in most cases. Water also entered the coil along the lead in a few cases causing a turn to turn failure in the coil.
2. Poor quality soldered joints combined with thermal stressing of the coils resulted in internal leakage at a soldered joint and turn to turn failure in the coil.
3. A few coil failures could not be attributed to either of the above causes. These coils were assumed to have failed because of frequent thermal stress cycles in the coils (caused either by restricted water flow paths in the coils or by cold creepage of the thermal fuses which shut off the magnet power supply) in which areas of damaged or very little insulation existed between turns.

As a result of this investigation the following changes have been made:

1. The cooling water system for the beam transport magnets has been changed to a closed loop with the water supplied from a cooling tower system utilizing untreated AGS water for make-up. Sufficient blow down is used to control solids build-up thereby limiting the conductivity of the cooling water. This water system has been in operation approximately twelve months and to date it has been operating satisfactorily.
2. Water flow in all quadrupole coils has been reversed which locates the cool water on the larger side of the coil and minimizes its thermal expansion.
3. Instructions have been issued to keep all hose bend radii greater than the minimum specified by the hose supplier
4. All water manifolds are to be insulated from the magnet core to minimize electrolysis of the hose fittings.
5. All water manifolds are to be mounted on the bottom half of the magnet core (whenever possible) to reduce the possibility of water leakage on the magnet coils.
6. Instructions have been issued to seal all coil lead areas with epoxy resin to seal any possible flow path from external water.

7. Coil specifications are being changed to restrict the number of silver soldered joints in the coils and inspection of the soldered joints has been made more stringent in order to improve the quality of the joints.
8. Wherever room permits turn to turn insulation in the magnet coils is being increased to decrease the possibility of turn failures.
9. Magnet specifications are being changed to specify resilient shims between the magnet core and coils and all old magnets are being changed, whenever possible, to provide resilient shims between the core and coils.
10. The fusible alloy used in the thermal fuses was changed to a slightly higher melting temperature material to reduce the possibility of accidental power failure due to cold creepage in the fuse material. Since April of 1965 we have experienced no accidental shut down in our magnet power supplies.
11. All of the available coils which were originally insulated with glass sleeving have been reinsulated using "B" staged glass tape for turn insulation. The remaining coils with the old style insulation will be reinsulated whenever they become available.
12. Spare coils of all types have either been procured or are on order.

Since coils with old style insulation are still in use we should continue to have a failure rate above normal in these units. Spare coils will be available for replacement, however, if any more failures occur.

As a result of all the changes that have been put into effect it is reasonable to expect that the number of coil failures should decrease considerably from that which we have experienced in the past year.