EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
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CERN PS DIVISION

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Second Inspection and Testing of BNL (AGS) Dipole Coils at Sigmaphi

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INTRODUCTION

Following an initial series of high voltage tests on the 10 BNL dipole coils in 2001 (see PS / PO / Note 2001-025 Tech. "Inspection and testing of BNL (AGS) dipole coils at Sigmaphi"), the magnet coils were transported to Brookhaven where the HV tests were repeated. During these tests, five out of ten coils failed at various levels of applied voltage. BNL decided to return the complete assignment to Sigmaphi in Vannes, for repair or remoulding where necessary. Sigmaphi proceeded with the necessary repairs, which involved removal of existing epoxy insulation from five coils followed by complete remoulding. This note describes the results of HV insulation testing of the finished coils as part of the acceptance procedures stipulated by BNL.

COIL HISTORY

Since five of the original coils have been dismantled and remoulded, the coil numbering has changed and the following table lists the new numbering.

Original Coil Number (2001)	New Coil Number (2002)
1	1
2	2
6	3
7	4
10	5

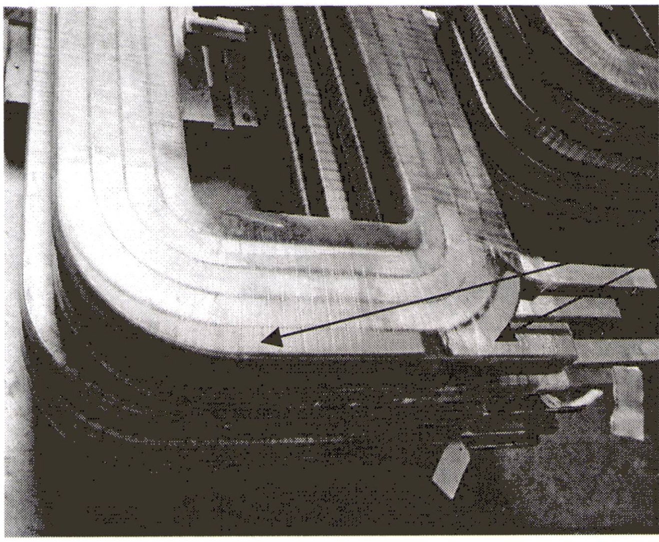
HIGH VOLTAGE GROUND INSULATION TESTS

The testing procedure as specified by BNL involves ramping the voltage between coil and ground up to 32kV and maintaining this applied voltage for 60 seconds minimum. The leakage current should be measured during this period and should not exceed 50 µA.

The power supply used to perform the tests was a SEFELEC 50kV, 2 mA unit, type GLHT 1150 P2.

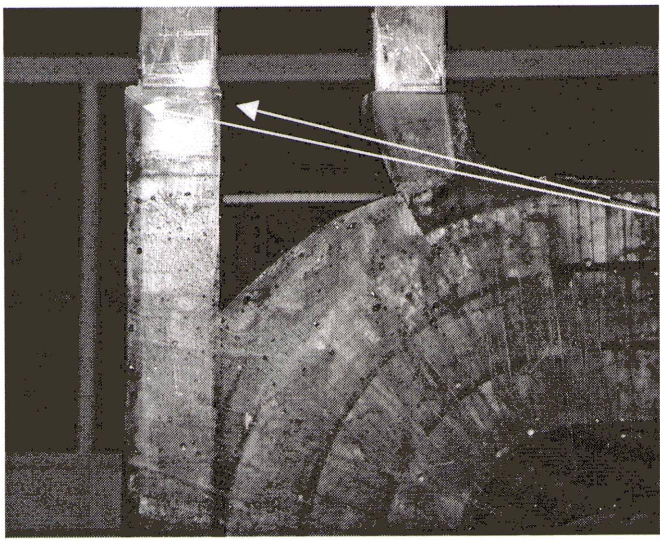
NEW COIL No.1
(remoulded and designated as New coil no. 1)

This coil was slowly ramped to 32kV and showed no signs of breakdown.
(See photos below)



Filler blocks appear to have been machined in accordance with the BNL drawings.

Coil No. 1

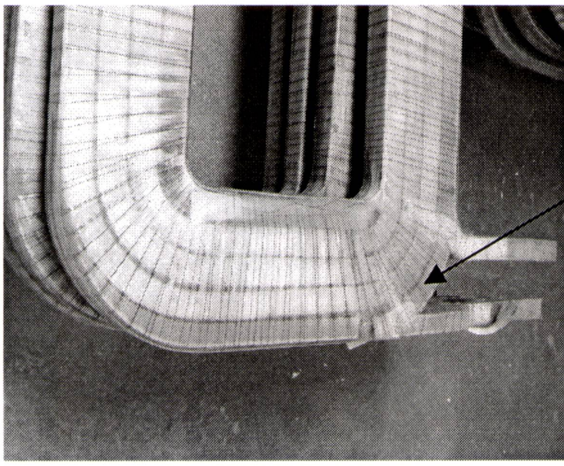


Coil windings.
The copper conductors were not correctly centered within the epoxy insulation layer and in one case (New coil No.2) the minimum thickness of the insulating layer was approximately 0.6mm.

Coil No.1

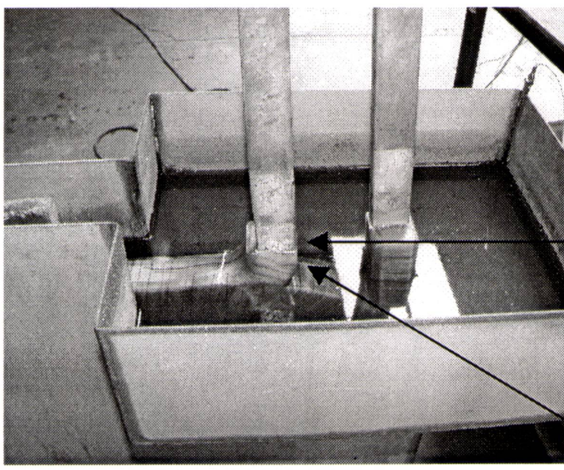
NEW COIL No. 2
(Remoulded and designated as New coil no. 2)

Voltage was ramped to 32 kV but during the 60 second test period there were four instances when the coil end connections flashed over to the water surface.
(See photos below)



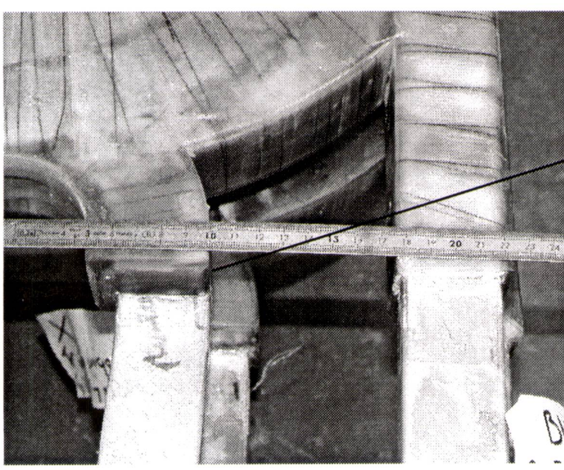
The filler blocks appear to be in accordance with the drawings provided by BNL but I was not able to verify the exact geometry.

Coil No.2



When a flashover occurs, it is generally in this area and the arcing takes place between the exposed copper conductor and the surface of the water.

Coil No. 2

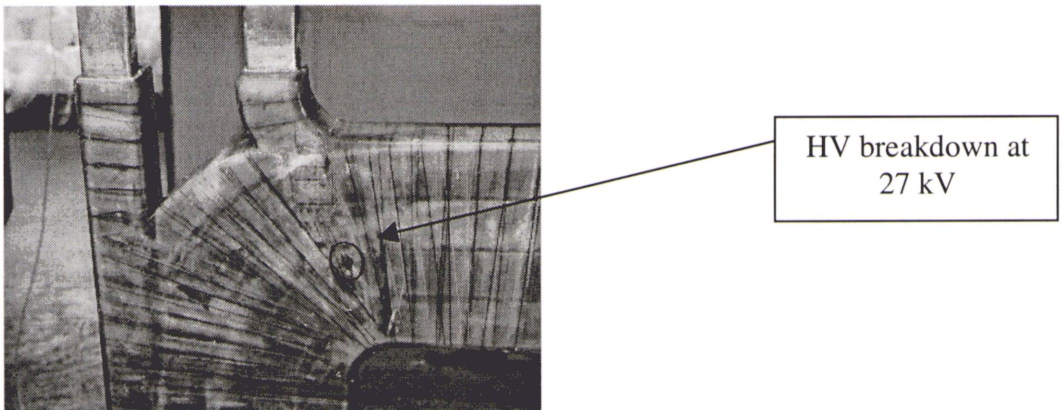


The thickness of the epoxy insulation on the inner surface of this conductor is approximately 0.6 mm which is not sufficient. This will be corrected by Sigmaphi and HV testing will be repeated.

Coil No. 2

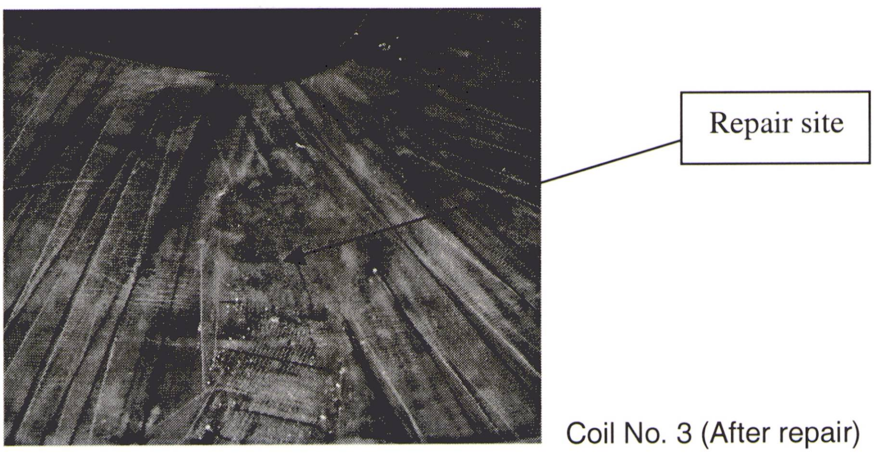
NEW COIL No. 3
(Originally coil No. 6 from first series production 2001, but remoulded)

The coil voltage was slowly ramped up but at 27 kV there was a flashover between the exposed copper conductor and the water surface. The test was stopped and the connections were cleaned up. During the second test the coil itself failed at 30kV between the coil body and ground. In the photo below we can see the location of the breakdown at 27 kV. The exact location of the breakdown was found using a dielectric tester at 3 kV which produced a leakage current in excess of 1mA.



Coil 3 (Before repair)

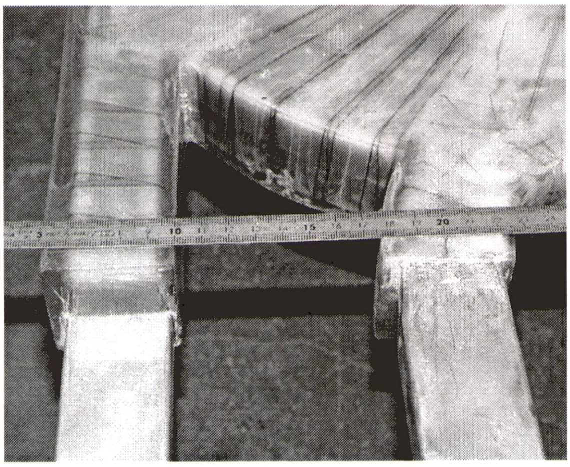
It was decided to attempt a repair on this coil and the following day (after the repair), a new HV test was performed on this coil. The coil was ramped to 32 kV, slowly, and held for 65 seconds without any breakdown. During the test an slight audible buzzing could be heard which was probably due to corona effects in the region of the end connections.



Coil No. 3 (After repair)

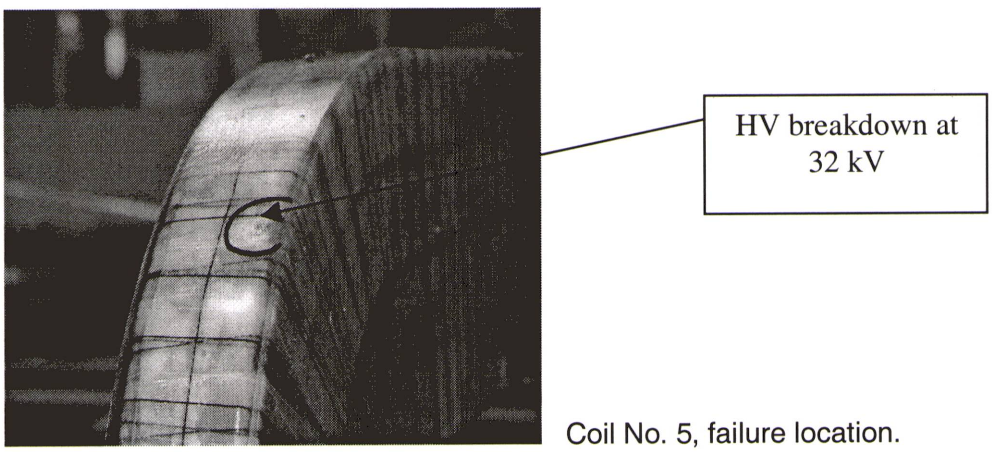
NEW COIL No. 4
(Originally coil No.7 from the initial series production 2001)

During the ramping up of the voltage, there was one flashover between the exposed copper end connections and the surface of the water but the coil held 32 kV for the required 60 seconds without any failures.



NEW COIL No. 5
(Originally coil no. 10 from the initial series production 2001)

This coil was ramped up to 32 kV and held for 45 seconds, after which there was a breakdown between the coil and ground. The failure location was localised using the dielectric tester and can be seen in the photo below,



Coil No. 5, failure location.

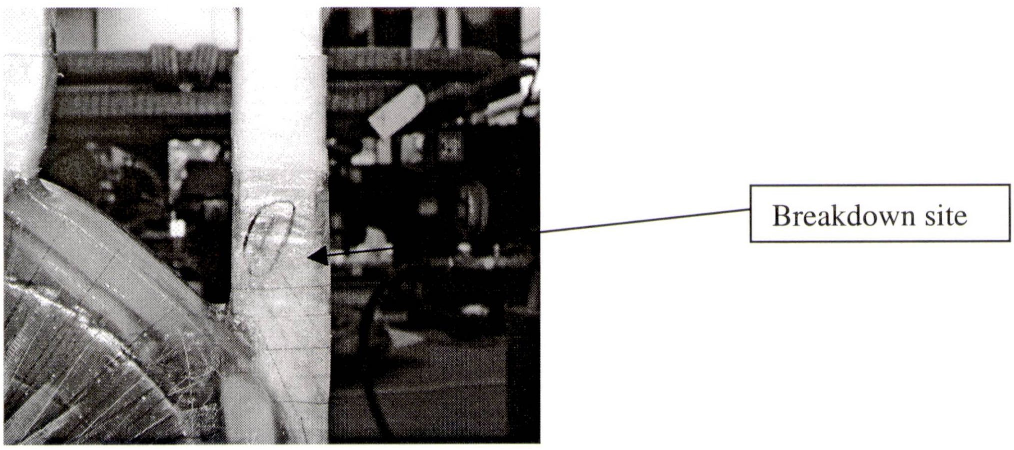
It was decided to attempt a repair on this coil and perform another HV test the following day. The results of the repair were satisfactory and the coil held the required 32 kV for 60 seconds, although there was one flashover between the exposed copper end connections and the surface of the water during the voltage ramping stage. During the 60 seconds test period, the coil was stable.

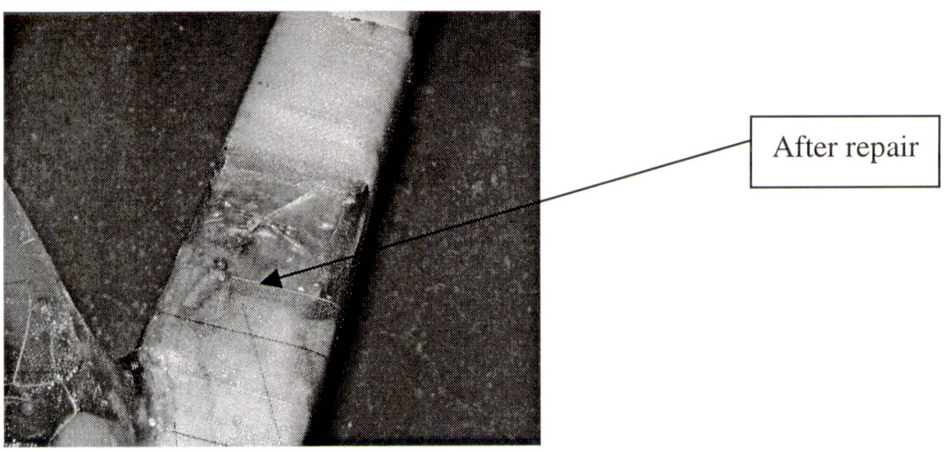
TESTING OF THE ORIGINAL PRODUCTION SERIES OF COILS

After consultations with the Mr. Badea, (BNL), it was decided to repeat the HV testing of the 5 remaining coils from the original batch of ten which were delivered to BNL in 2001. These coils were previously tested in 2001 and showed no signs of breakdown when tested at Sigmaphi. However, when the coils were delivered to BNL they were subjected to the HV testing and several of the coils failed. The coils which failed, were numbers, 1, 2, 6, 7 and 10.

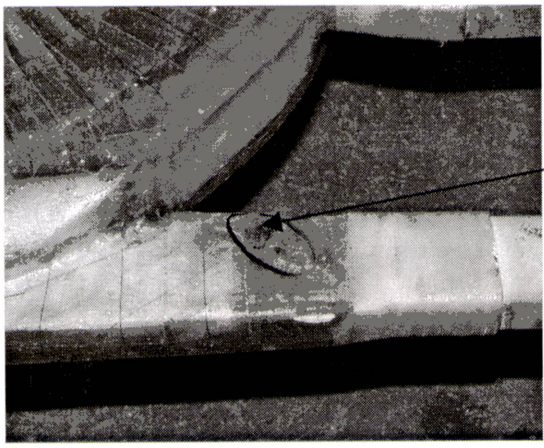
OLD COIL No. 3

During the voltage ramping stage of the test, the coil failed in the region of the connections at 27 kV, and was repaired by Sigmaphi staff.

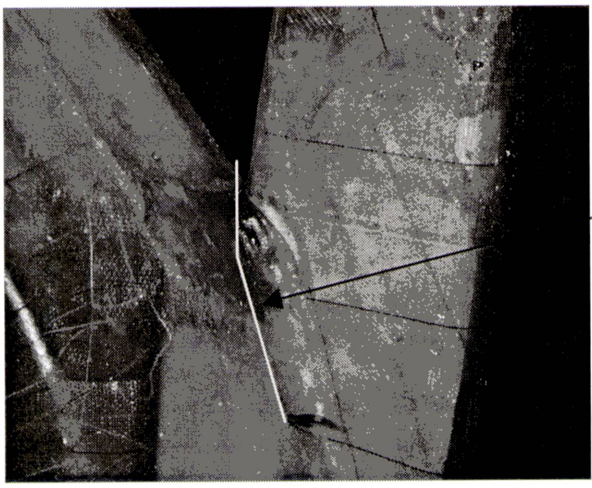




The repaired coil then underwent a second test when it failed again in the same location at between 4 kV and 5 kV.



Following another repair the coil again failed the HV test at 10 kV where a leakage current caused visible arcing below the water surface in the test tank. The voltage was increased to 25 kV where the arc increased in intensity and eventually following another increase in voltage to 32 kV the coil failed. This failure was traced to the main connection / racetrack junction which was completely cracked from one side to the other, (See photo below)



The line in the photo is the approximate position of the crack.

This crack in the insulation would be typical of a handling error as the crack has propagated from the front side in the photo to the rear side.

Further testing of this coil was considered to be pointless.

OLD COIL No. 4

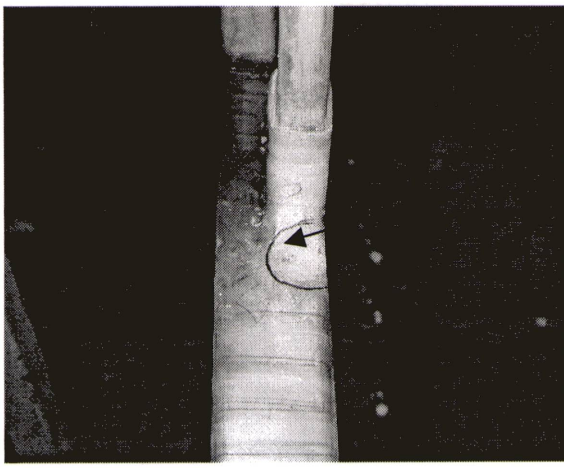
This coil was ramped up to 32 kV and although there was some audible indication of corona effects the coil held and was kept at 32 kV for 60 secs.

OLD COIL No. 5

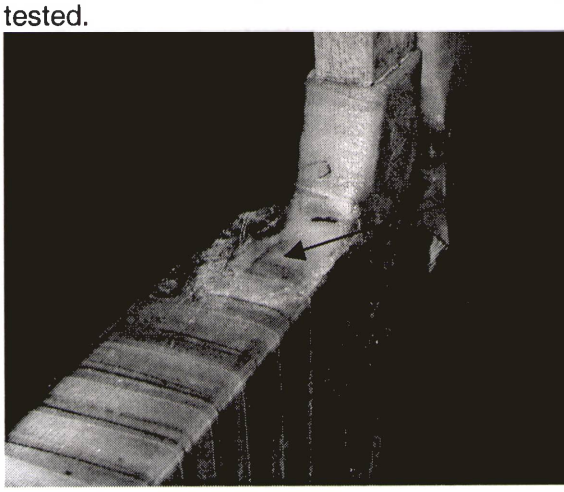
This coil showed no signs of any insulation weakness during the 60 seconds at 32 kV.

OLD COIL No. 8

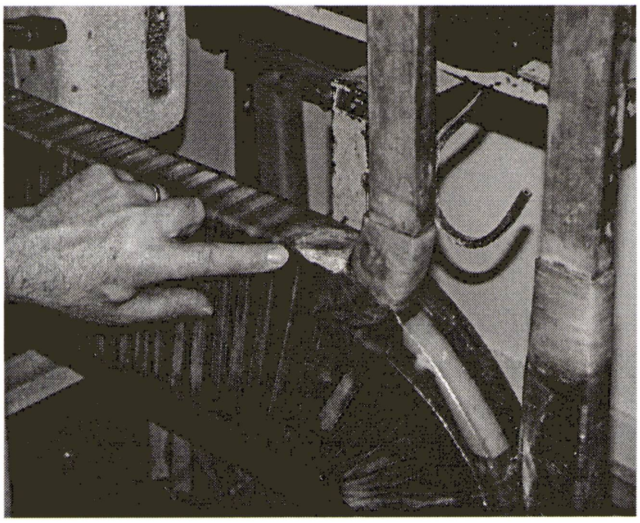
Coil 8 was ramped slowly up to 32 kV but after 30 seconds there was an insulation failure on the inner connection, outer edge of the racetrack assembly, see photo below for exact failure location.



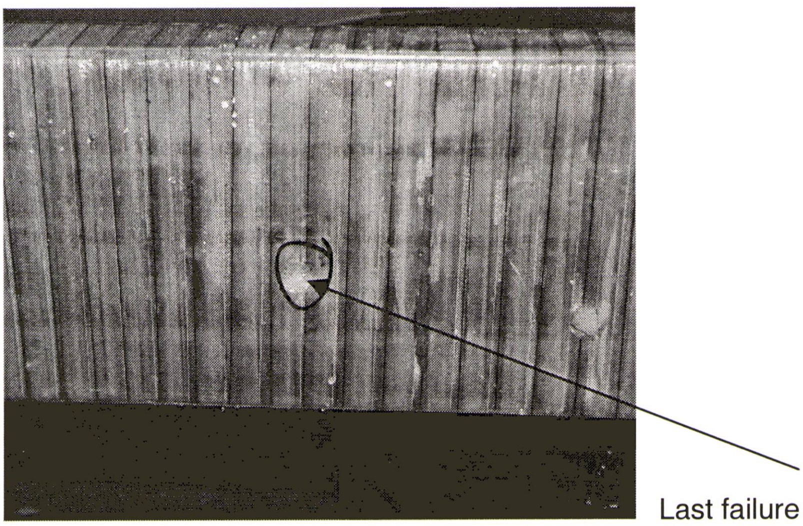
It was decided to repair this coil immediately and following the repairs the coil was again tested.



The voltage was applied slowly and at 28 kV there was another breakdown in the same location. This was again repaired in-situ and the test was repeated. Again the coil failed in same area but on the edge of the racetrack. This was then ground and completely re-insulated, see photo below.



The test was then repeated but unfortunately failed again in a different location. The location was determined again using the dielectric tester and was found to be at the opposite end of the racetrack, in a previously repaired area of the coil, see photo below.

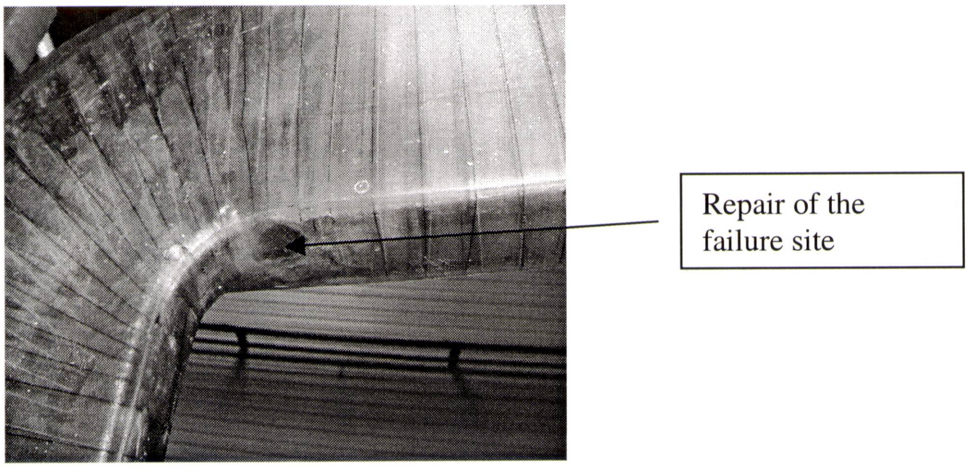


Last failure site on old coil 8

The testing of this coil was suspended as there was not enough time to implement repairs and repeat the test. Sigmaphi have agreed to repair this coil and perform the necessary testing at 32 kV.

OLD COIL No. 9

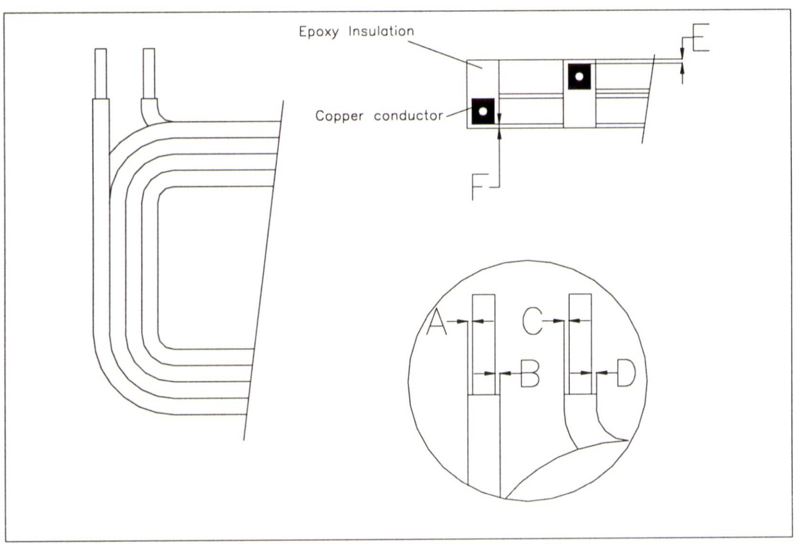
After ramping this coil to 32 kV the insulation held for 58 seconds and then failed on the inner edge of the racetrack assembly, at the connection end of the coil, see photo below.



The coil was subsequently repaired and subjected to the standard voltage ramping up to 32 kV and it held for 60 seconds, with no audible or visual signs of breakdown.

MECHANICAL MEASUREMENTS

In order to verify the insulation in the region of the end connections, a series of dimensional controls were made. The table below gives the results for the measurements, (in mm), A to F.



Some arcing occurred between the exposed copper of the connections and the surface of the water during voltage ramping, which could possibly be due to the fact that the insulation thickness is not sufficient in these regions. The coil terminals, in some cases, appear to have been poorly positioned, (i.e. not centered correctly), prior to moulding with the result that the thickness of the epoxy is as little as 0.6 mm in one instance, (New coil 2). For this reason I measured, approximately, the thickness of the insulation for the new coils and have tabulated measurements below. Refer to the drawing above for the measurement positions, A to F. (Dimensions are given in mm).

Coil No.	A	B	C	D	E	F
1	7	2	4	4	1.5	3
2	5	2	0.6 **	10	2	1
3	6	2	3	5	2	2
4	6	2	7	5	2	2
5	7	2	2	5	2	2

**Coil No. 2 to be repaired.

Conclusions

The initial testing of these coils in 2001 was carried out in accordance with the specifications from BNL and no insulation failures were recorded. Following the transport to BNL, five out of ten coils failed the HV test. The reasons for these failures are unknown but could possibly be due to damage resulting from improper packaging or handling, leading to a degradation of the insulation properties of the epoxy. It is clear that successive testing of the coils at 32 kV induces extra stresses in the coils with eventual failures.

New coils

During the testing of the new series of coils (i.e. remoulded coils), only coils 1 and 4 passed the HV test on the first attempt. Coils 3 and 5 had to be repaired and subsequently passed the test. Coil 2 failed as there was insufficient insulation in the region of the end connections, (0.6 mm). This coil has not been retested and will be repaired and retested by Sigmaphi.

Original coils

Only two, (coil no's 4 and 5), out of five coils passed the first test without incident, coil no's 4 and 5. Coils 3 and 8 failed, and had not been repaired by the end of the visit. Coil 9 failed but following the subsequent repair, passed the test.

It is highly possible that the coil no. 3 end connections have received a mechanical shock causing the fracture in the end connection insulation. This causes an immediate short circuit during the testing and will have to be correctly repaired before any further testing can be carried out.

The problem of arcing between the exposed copper end connections and the water surface was clearly in evidence. This could be eliminated, by increasing the length of the insulated part of the conductor, and ensuring there are no sharp surface asperities on the copper leading to increased field amplification effects and eventual flashovers.