DC0305 Turn-to-Turn Short: Examination of Lower Inner Coil 17M - 1007 - R

TS-SSC 91-033
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Introduction: Coil 17M-1007-R, which experienced a turn-to-turn short during the first keying attempt on collared coil DC0305[1,2,3], was inspected on February 6 - 7, 1991. The initial plan was to follow the inspection procedure specified by TS-SSC 91-022. At several stages in the inspection, reasonable deviations from the specified procedure were made. The procedure **TS-SSC 91-022** will nevertheless be referred to in this memo step by step, and so is included as an appendix to this memo.

Initial Steps: Steps 1 - 4 of 91-022 were completed before February 6.

Before any coils were removed from the package, the four quarter coil resistances were measured. All four resistances were 3 - 4 mΩ higher than the January 23, 1991 values from the traveller, consistent with a slight change in temperature[4].

The lower outer coil ground wrap layers except for the "caps" were removed; then the lower outer coil was removed from the package and laid aside on blocks (**Step 5 of 91-022.**) The ground wrap of the lower inner coil had a crease approximately six inches long at the return end midplane, probably due to the outer and inner coil ground wraps having become snagged during the package assembly.

Coil 17M-1007-R, in which the turn-to-turn short had been detected, was then laid aside on a holding mandrel (**Step 6 of 91-022.**)

Midplane Hipot: Instead of proceeding directly to steps 7 and 8 of 91-022, it was decided to hipot the miplane surfaces of 17M-1007-R, to see whether there were any places in the cap where the kapton had been severely weakened by the keying pressure. This test was motivated by observations made during the autopsy of DC0303, which appeared to have suffered a midplane short during impulse testing ("ringing") after keying and yoking[5].

When the hipot test was done, one spot was found (in section 427 at the lead end of the coil) where arc-ing occurred. Once the arc-ing had taken place, a small hole could be seen in the kapton midplane cap. A small burned spot could also be seen on the coil insulation underneath the hole. This arc-ing was in the region at the very end of the collared portion of the magnet, where the midplane cap is seen to be scored heavily due to the higher load applied at the magnet ends by the keying press.

Closer examination revealed a fiber-glass-like filament embedded in the coil insulation; this filament later came loose and was saved. There is no indication that the filament had anything to do with the arc. (See Figure 1.)

Tests with Sizing Fixture: On February 7, 1991, **Step 7 of 91-022** was carried out on coil 17M-1007-R. The initial values of the full coil resistance (R1) and 0A - 9A resistance (R2) were 1375 mΩ and 774.5 mΩ, within several mΩ of their nominal values.

Step 8 of 91-022 was then begun. The plan was to press each 3" section of the coil with the coil sizing fixture at 5000 pump psi, meanwhile monitoring the full coil and 0A - 9A resistances. When sections 1 and 4 were pressed, large changes in R1 and R2 were seen as shown in Table 1. No other sections up to section 10 showed any resistance loss when pressed.

Detailed measurements were then made on the cable turns in section 4, while pressing the coil in this region with the sizing fixture at 0 and 5000 pump psi (as per addendum to 91-022.) The measurements for section 4 are shown in Table 2, and a similar set of measurements for section 1 are shown in Table 3. The turns are numbered as on the voltage tap drawing, with turn 1 being the midplane turn and turn 16 the pole turn.

a. Section 4 Short: When section 4 was pressed, a decrease in resistance of 45.2 mΩ between turns 1 and 2 was seen immediately. Over a period of 20 minutes or so, the resistance degraded further, so that the eventual resistance decrease due to the short between turns 1 and 2 was 57.5 mΩ. This decrease alone cannot account for the turn-to-turn short resistance loss observed in the coil during keying (87 mΩ.)

b. Section 1 Short: When section 1was pressed, a decrease in resistance of 32.7 mΩ between turns 1 and 2 was observed. The sum of the section 1 and section 4 resistance decreases is 90.2 mΩ, which is consistent with the total decrease in resistance seen during keying. As with section 4 , the section 1 change in resistance increased over time, from 27.3 mΩ to 32.7 mΩ over 20 minutes or so.

Further Visual Evidence: Visual examination of sections 1, 4, and 5 showed problems of various kinds:

1) The inside edge of the midplane turn of section 1 was scored and darkened, and there were several bare conductor spots (see Figure 2a.)

2)The inside edge of the midplane turn of section 4 was similarly darkened (in fact, the whole region near the lead of the coil, that is regions 1 through about 10 was darkened and scored), and there was a dark dimple which appeared to press into the turn just below the midplane turn (see Figure 2b.)

3) In region 5, which however showed no evidence of shorting when pressed with the sizing fixture, therer was scoring and blackening and a large patch of what appeared to be crushed superconducting filaments on the inside edge of the midplane turn (see Figure 2c.)

Another important observation was that the cable of the quadrant 4 midplane turn appeared to be wider than normal out to section 10 or so.

All of these features would appear to be related to the rewinding process and/or the re-curing process of the coil.

Further Sizing Fixture Tests: Following the above detailed investigations of sections 1 and 4, the entire coil was tested with the sizing fixture. The resistances R1 and R2 were recorded when each section was pressed.

Table 1. Full Coil (R1) and 0 A - 9 A (R2) Resistances for 17M - 1007 - R During Pressing with Sizing Fixture

Section Number pressed with sizing fixture	R1 (mΩ)	R2 (mΩ)
none	1375	775
1	**1338**	**737**
2	1375	775
3	1375	775
4	**1321**	**721**
5	1375	775
6	1375	775
7	1375	775
8	1375	775
9	1375	775
10	1375	775

Table 2. Turn-to-Turn Resistance Measurements for Section 4 of 17M - 1007 - R. (Resistances are measured between the 0 A voltage tap and the turn in question.)

Turn Number	R (mΩ) at 0 pump psi	R (mΩ) at 5000 pump psi	Time
1	1.3	1.1	1028
2	87.8	**42.6 (45.2 mΩ decrease)**	
3	174.1	126.7	
4	260.4	210.3	
5	346.5	296.0	
6	432.4	381.6	
7	518.4	467.4	
8	604.3	553.2	
9	690.2		
10	776.1	720.2 (55.9 mΩ decrease)	1044
11	861.9	805.5	
12	947.7	891.3	
13	1033.3	976.3	
14	1119.0	1062.1	
15	1204.3	1147.5	
16	1289.7	1232.9	
2		**30.3 (57.5 mΩ decrease)**	1053

Table 3. Turn-to-Turn Resistance Measurements for Section 1 of 17M - 1007 - R. (Resistances are measured between the 0A voltage tap and the turn in question.)

Turn Number	R (mΩ) at 0 pump psi	R (mΩ) at 5000 pump psi	Time
1	0.9	0.8	1116
2	87.2	**59.9 (27.3 mΩ decrease)**	
3	173.6	146.5	
4	260.	232.	
5	346.1	317.8	
6	432.1	403.6	
7	518.1	489.6	
8	604.1	575.5	
9	690.1	661.3	
10	775.9	746.9	
11	861.8	832.3	
12	947.7	917.3	
13	1033.4	1002.6	
14	1119.9	1087.7	
15	1204.6	1172.6	
16	1290.1	1257.4	

Notes

[1]S. Delchamps, "Recommendations for DC0305 following Turn-to-Turn Short in Keying Process," TS-SSC 91-020, January 29, 1991.

[2]S. Delchamps, "Turn-to-turn Short in Collared Coil DC305 During Initial Keying Attempt," TS-SSC 91-021, January 29, 1991.

[3]S. Delchamps, "Procedure for Locating Turn-to-Turn Short in Lower Inner Coil of DC0305," TS-SSC 91-022, January 30, 1991.

[4]The change in the resistivity of copper with temperature at room temperature is 6.7×10^{-3} $\mu\Omega$–cm/K. The resistivity of copper at 0 C is 1.545 $\mu\Omega$-cm. Therefore, the fractional change in the resistance of a length of copper cable at 23 C (296 K) will be:

$$[\ 6.7 \times 10^{-3}\ \mu\Omega\text{–cm/K}\ ]\ /\ [\ 1.545\ \mu\Omega\text{-cm} + 6.7 \times 10^{-3}\ \mu\Omega\text{–cm/K} * 23\ \text{K}\ ] =$$

.394 % / K, so that a change of 4 mΩ over 1833 mΩ (the amount the lower outer coil had changed) is consistent with a temperature change of .554 K.

[5]W. Koska, "Failure of DC0303 During Impulse Test", TS-SSC 91-011, January 21, 1991.

17M-1007-R Examination

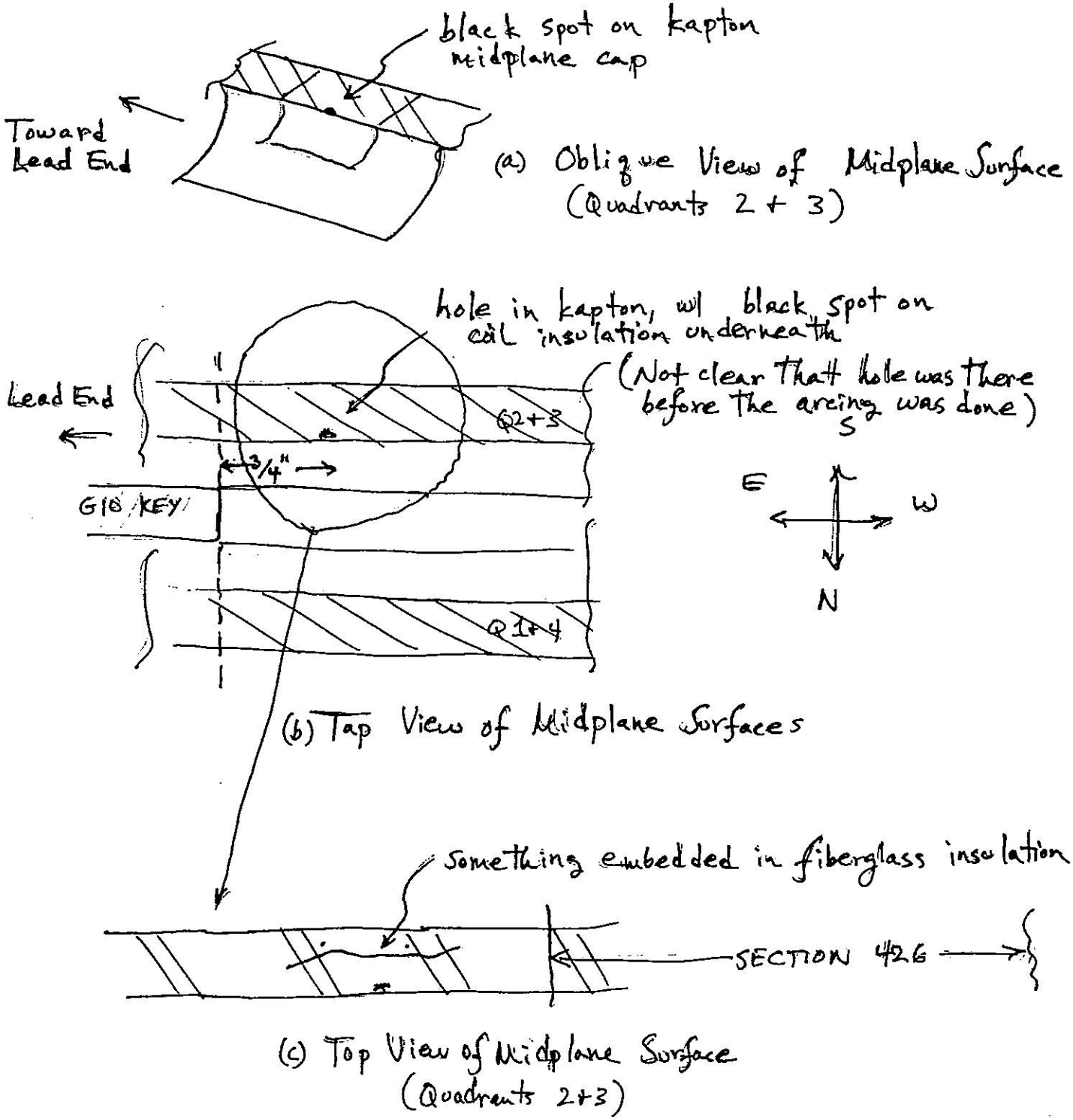
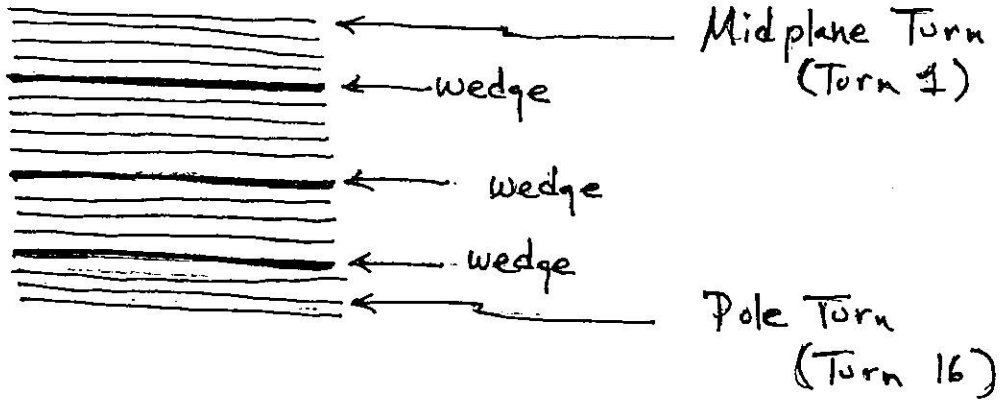
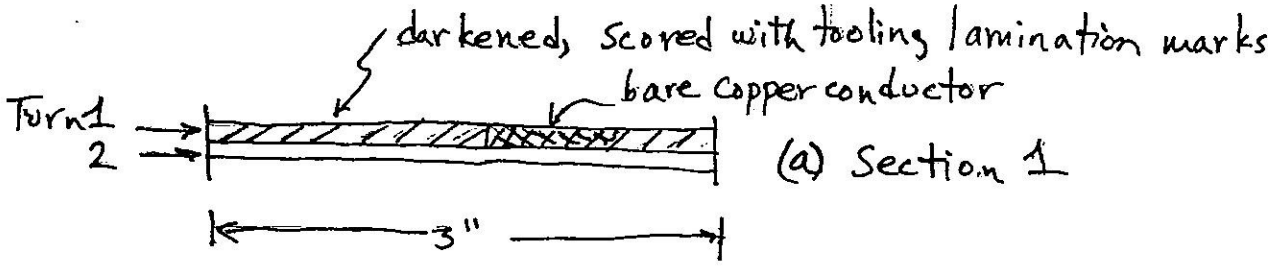
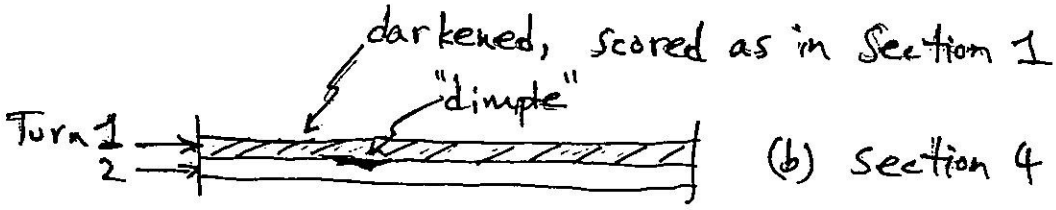


Figure 1

17M - 1007 - R Examination







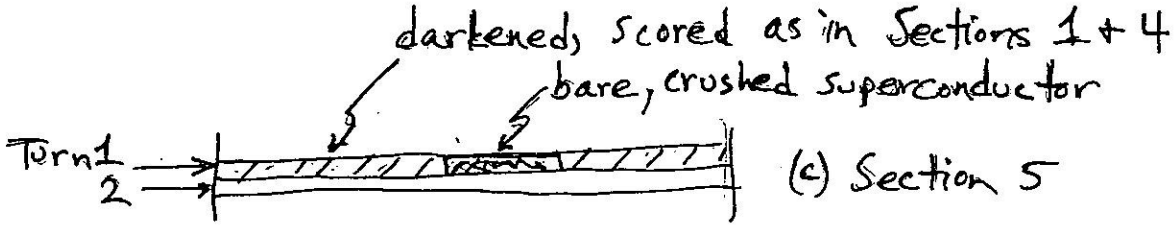


Figure 2