Wayne Koska
6/6/91

TS-SSC 91-112

Expected Error on Coil Resistance when Determined by Short Sample Measurments

I have done a simple error analysis for the calculated resistance of a coil using as input the short sample measurement for the resistance per foot of cable. The expression used to calculate the resistance of a cured coil is:

((R+dR)*(1+(C0+dC)*(DelT+dT)))*(L+dL)

where R is the resistance/foot of cable, DelT is the difference between the temperature at which the short sample measurement was made and 68°F, (the temperature of the compensated Valhalla measurments), C0 is the constant which relates resistance to temperature, L is the length of the coil, and dR, dC, dT and dL are the associated errors on these values. If we expand the above expression and keep terms only to first order we obtain the following for the error term:

DelT*L*R*dC + R*dL + C0*DelT*R*dL + L*dR + C0*DelT*L*dR + C0*L*R*dT

Typical values for the above variables are:

L= 2570 ft (the length of a long coil)
dL= 10 ft
R= 0.7250 (resistance/foot for outer cable)
dR= 0.017
C0= 0.0019
dC= 0.0003
DelT= 7°F
dT= 2°F

where dR is obtained from round-off error in the Q.C. determination of R, dC is the difference between the constant used by the Q.C.

Distribution: S. Delchamps, S. Gourlay, M. Lamm, J. Strait, M. Wake department and what I found in my Fundamentals of Physics book by Halliday and Resnick*, and dT is a guess at how well the thermometers are calibrated relative to each other. Putting these values into the error equation I get a value for the error of 62 mΩ. This value is dominated by the round-off error, dR. This analysis is very conservative and it is unlikely that we will ever see discrepancies between the measured resistance of a coil and that calculated from short sample measurements of 60 mΩ, however it does suggest that the discrepancies of 25 mΩ which we are observing are not unreasonable. I recommend that we place limits on the difference between the measured resistance of the coil and that expected from calculations based on short sample measurments of 50 mΩ, a deviation outside this limit requiring a physicist sign off. This could probably be tightened up if someone were to take the time to go over the procedure used by the Q.C. department when they make their short sample measurement to see if it could be improved. It would be nice if we could reduce this error to less than 35 mΩ since we would then always be able to detect a dead short between turns (a dead short gives a drop in resistance of about 70mΩ). Once a coil resistance has been established by direct measurement we should put a limit on deviations from this value of 10mΩ. This value is obtained by assuming a difference between the Valhalla temperature compensator probe and the true temperature of the coil of 2.5°F at 78°F and placement of the leads on the coil with an accuracy of 1 ft from the designated position. It seems reasonable that these criterion can be met, especially if the temperature compensator probe is embedded in a heat sink so that it does not respond to fluctuations in the air temperature. Finally, once a pair of inner or outer coils has been designated for a maget, we should require that their resistance match to within 10 mΩ at all times. This assumes that the same cable was used in both coils, a temperature difference between the coils of 1°F at 78°F and a difference in length in cable used of less than 10 feet.

*(I have not found anyone who knows exactly where the value of C0 the Q.C. department is using comes from but it appears to be historical. My guess is that it was empirically determined for the cable used in the Saver magnets.)

Memo to: D. Tinsley
From: W. Koska
Subject: Tolerances on Electrical Measurements in Coil Inspection and Coil Prep Travelers.

Don,

I am sending a note in which I propose (and justify) tolerances for the resistance measurements made on coils which are called out in the Coil Inspection and Coil Prep Travelers. After reviewing the most recent data I would like to relax one of these tolerances from (10 mΩ to 15 mΩ) until we place the temperature compensating probe in a heat sink. To summarize, the tolerances are:

Measured coil resistance should be within ± 50 mΩ of the predicted value from short sample measurements.

Once a measured value of coil resistance has been established and accepted (i.e. the value established in the Coil Inspection Traveler) all subsequent measurements of that coil should be within ± 15 mΩ of that value.

Once a pair of coils (inner or outer) have been assembled for a magnet, the difference in resistance should be established and this difference should not vary by more than ± 10 mΩ from measurement to measurement.

In addition, I would like to establish the following values for the measurements of inductance and Q made in these travelers. The values I propose for inductance, obtained from averaging the values obtained in the coils to date and using approximately 3 std as the acceptable limits, are:

L_S (inner coil) - 3.00±0.03 mH
L_S (outer coil) - 8.05±0.1 mH

The values for Q have somewhat larger tolerances since they are dependent on resistance:

Q (inner coil) - 2.1±0.2
Q (outer coil) - 3.3±0.2

Once these tolerances are incorporated into the travelers the requirement that a physicist sign off on these electrical measurements can be removed, except in the case in which a measurement falls outside of the range.

Wayne Koska

	A	B	C	D	E	F	G	H	I
1									
2		Coil Inspection Log							
3									
4									
5	Traveler	Coil Number	Rp (predicted	Rm(measured	Rm-Rp	Ls (120 Hz)	Q (120 Hz)	Date	
6	Free Coil Ins	1001	1179	1179	0	2.99	2	25-Apr	
7	Free Coil Ins	1002	1174	1178	4	2.98	2	4-May	
8	Free Coil Ins	1003	1100	1099	-1	2.99	2.1	29-May	
9	Free Coil Ins	1004	1101	1098	-3	3	2.1	1-Jun	
10	Free Coil Ins	1005	1110	1090	-20	3.003	2.07	10-Jun	
11	Free Coil Ins	1006	1118	1076	-42	2.99	2.1	14-Jun	
12	Free Coil Ins	1007			0				
13	Free Coil Ins	1008			0				
14	Free Coil Ins	1009			0				
15	Free Coil Ins	1010			0				
16	Free Coil Ins	1011			0				
17	Free Coil Ins	1012			0				
18	Free Coil Ins	1013			0				
19	Free Coil Ins	1014			0				
20	Free Coil Ins	1015			0				
21	Free Coil Ins	1016			0				
22	Free Coil Ins	1017			0				
23	Free Coil Ins	1018			0				
24	Free Coil Ins	1019			0				
25	Free Coil Ins	1020			0				
26	Free Coil Ins	1021			0				
27	Free Coil Ins	1022			0				
28	Free Coil Ins	1023			0				
29	Free Coil Ins	1024			0				
30	Free Coil Ins	1025			0				
31	Free Coil Ins	1026			0				
32	Free Coil Ins	1027			0				
33	Free Coil Ins	1028			0				
34	Free Coil Ins	1029			0				
35	Free Coil Ins	1030			0				
36									
37					Ave	2.99216667			
38					STDEV	0.00825631			
39									

	J	K	L	M	N	O	P	Q
1								
2								
3								
4								
5		Traveler	Coil Number	Rm(measured	Rm-Rp	Ls (120 Hz)	Q (120 Hz)	Date
6		Coil Prep	1001	1184	5	2.99	2	3-May
7		Coil Prep	1002	1182	4	2.98	1.9	16-May
8		Coil Prep	1003		-1099			
9		Coil Prep	1004	1099	1	3.01	2.06	8-Jun
10		Coil Prep	1005	1079	-11	3.01	2.06	12-Jun
11		Coil Prep	1006	1078	2	3	2.1	17-Jun
12		Coil Prep	1007		0			
13		Coil Prep	1008		0			
14		Coil Prep	1009		0			
15		Coil Prep	1010		0			
16		Coil Prep	1011		0			
17		Coil Prep	1012		0			
18		Coil Prep	1013		0			
19		Coil Prep	1014		0			
20		Coil Prep	1015		0			
21		Coil Prep	1016		0			
22		Coil Prep	1017		0			
23		Coil Prep	1018		0			
24		Coil Prep	1019		0			
25		Coil Prep	1020		0			
26		Coil Prep	1021		0			
27		Coil Prep	1022		0			
28		Coil Prep	1023		0			
29		Coil Prep	1024		0			
30		Coil Prep	1025		0			
31		Coil Prep	1026		0			
32		Coil Prep	1027		0			
33		Coil Prep	1028		0			
34		Coil Prep	1029		0			
35		Coil Prep	1030		0			
36								
37					Ave	2.998		
38					STDEV	0.0130384		
39								

	A	B	C	D	E	F	G	H	I
40									
41	Traveler	Coil Number	Rp (predicted	Rm(measured	Rm-Rp	Ls (120 Hz)	Q (120 Hz)	Date	
42	Free Coil Ins	2001	2575	2583	8	8.05	2.4	9-May	
43	Free Coil Ins	2002			0	8.07	3.3		
44	Free Coil Ins	2003			0	8.12	3.31		
45	Free Coil Ins	2004	1852	1823	-29	8.07	3.3	4-Jun	
46	Free Coil Ins	2005	1855	1826	-29	8.12	3.31	6-Jun	
47	Free Coil Ins	2006	1845	1828	-17	8.09	3.28	11-Jun	
48	Free Coil Ins	2007	1834	1792	-42	8	3.3	17-Jun	
49	Free Coil Ins	2008		1793	1793	8.08	3.3		
50	Free Coil Ins	2009			0				
51	Free Coil Ins	2010			0				
52	Free Coil Ins	2011			0				
53	Free Coil Ins	2012			0				
54	Free Coil Ins	2013			0				
55	Free Coil Ins	2014			0				
56	Free Coil Ins	2015			0				
57	Free Coil Ins	2016			0				
58	Free Coil Ins	2017			0				
59	Free Coil Ins	2018			0				
60	Free Coil Ins	2019			0				
61	Free Coil Ins	2020			0				
62	Free Coil Ins	2021			0				
63	Free Coil Ins	2022			0				
64	Free Coil Ins	2023			0				
65	Free Coil Ins	2024			0				
66	Free Coil Ins	2025			0				
67	Free Coil Ins	2026			0				
68	Free Coil Ins	2027			0				
69	Free Coil Ins	2028			0				
70	Free Coil Ins	2029			0				
71	Free Coil Ins	2030			0				
72									
73					Ave	8.075			
74					STDEV	0.03891382			

	J	K	L	M	N	O	P	Q
40								
41		Traveler	Coil Number	Rm(measured	Rm-Rp	Ls (120 Hz)	Q (120 Hz)	Date
42		Coil Prep	2001	2583	0	8.05	2.4	23-May
43		Coil Prep	2002	2585	2585	8.01	2.4	23-May
44		Coil Prep	2003		0			
45		Coil Prep	2004	1829	6	8.05	3.31	10-Jun
46		Coil Prep	2005	1830	4	8.1	3.31	11-Jun
47		Coil Prep	2006	1808	-20	8.05	3.3	17-Jun
48		Coil Prep	2007	1807	15	8.08	3.3	19-Jun
49		Coil Prep	2008		-1793			
50		Coil Prep	2009		0			
51		Coil Prep	2010		0			
52		Coil Prep	2011		0			
53		Coil Prep	2012		0			
54		Coil Prep	2013		0			
55		Coil Prep	2014		0			
56		Coil Prep	2015		0			
57		Coil Prep	2016		0			
58		Coil Prep	2017		0			
59		Coil Prep	2018		0			
60		Coil Prep	2019		0			
61		Coil Prep	2020		0			
62		Coil Prep	2021		0			
63		Coil Prep	2022		0			
64		Coil Prep	2023		0			
65		Coil Prep	2024		0			
66		Coil Prep	2025		0			
67		Coil Prep	2026		0			
68		Coil Prep	2027		0			
69		Coil Prep	2028		0			
70		Coil Prep	2029		0			
71		Coil Prep	2030		0			
72								
73					Ave	8.05666667		
74					STDEV	0.03076795		

← Systematic offset due to Valhalla Calibration.