NSTX CALCULATION

TITLE____Upgraded Center Stack Bakeout Ohmic Heating

CALC. NO.____ NSTXU-CALC-33-01-00________________DATE___7/9/09_____

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PURPOSE:

This calculation determines the ohmic resistance of the NSTX CSU center stack casing, and the requirements for a power supply capable of supplying 5kW of heat to same during bakeout.

During bakeout a current shall be injected at the bottom of the center stack casing (CSC) which shall flow up through the center stack casing, through four jumpers to the outer vacuum vessel (VV) upper dome, down through the VV dome to the cylinder, down through the VV cylinder, down through the lower VV dome, and out.

REFERENCES:

1) INCONEL Alloy 625 data sheet (Huntington Metals)
2) NSTX Preliminary Dimension of CS Casing Drawing (attached)
3) NSTX-CALC-33-1 Center Stack Bakeout Ohmic Heating

ASSUMPTIONS:

1) Neglect resistance of flanges which connect the center stack casing mid section to the end sections, and the flanges at the end sections. Compared to the resistance of the mid and end sections, the resistance of the flanges is not signficant due to their larger cross section and smaller length.

2) Treat the domes as flat disks. Assume that the current enters and exits the domes at the same ID as that of the CSC (in fact the current will not have to traverse the full length.

3) Neglect the effect of contact resistances, the holes/ports in the VV, etc.

CALCULATION:

See attached spreadsheet entitled "CSU Ohmic Heating".

For the CSC, simple $R=\rho l/A$ calculations are performed.

For the domes, treated as flat disks (like washers with inner radius R0 and outer radius R1), the effective resistance is calculated as follows:

Resistance of incremental section of the disk....

$$R=\rho\Delta r/2\pi rt$$

Where:

R	= resistance of incremental disk section
ρ	= resistivity
r	= radius
Δr	= incremental radius
t	= disk thickness

Total resistance...

$$Rt=\int\rho dr/2\pi rt$$

$$= \rho\ln(r)/2\pi t$$

Where:

Rt	= total resistance of disk

The integral is evaluated between R0 and R1 such that:

$$Rt=\rho/2\pi t*(\ln(R1)-\ln(R0))$$

The resistance at room temperature (≈20C) is roughly 0.47 mΩ. The resistance at maximum bakeout temperature (350C) is roughly 0.48 mΩ. To produce 5kW in the CS casing, an rms current of roughly 3.6kA is required at bakeout temperature.

Note: all digital documents stored in NSTX File Share, Engineering Folder, Engineering Calculations Folder. Hard copies of all documents stored in NSTX project file.

CONCLUSION:

Resistance of CS casing is such that ohmic heating using a small power supply is feasible. Resistance does not change very much over the temperature range. A rectifier power supply fed from a 480V input, turned on/off via a thermostat type control, is suitable. The power supply should be rated to deliver on-state current equal to 1/0.0005 ≈ 125 x the voltage rating, due to the 0.5mΩ resistance (e.g. 3 V supply should be able to deliver 3.75kA). The rms rating should be at least 3.6kA.

	A	B	C	D	E
1	**INCONEL DATA SHEET...**				
2	T1	70.0	deg F	70.0	
3		21.1	deg C	=5/9*(B2-32)	
4	T2	800.0	deg F	800.0	
5		426.7	deg C	=5/9*(B4-32)	
6	Inconel Resistivity @ T1	776.0	Ω-circ mil/ft	776.0	
7	Conversion factor	1.97E+05	circ mil/sq cm	1.97E+05	
8	Conversion factor	30.48	cm/ft	=12*2.54	
9	Inconel Resistivity @ T1	1.29E-04	Ω-cm	=B6/B7/B8	
10		5.08E-05	Ω-in	=B9/2.54	
11	Inconel Resistivity @ T2	818.0	Ω-circ mil/ft	818.0	
12	Coefficient of resistance	0.00013	1/deg C	=(B11-B6)/B6/(B5-B3)	
13					
14	**Drawing NSTX EDC 1102/1107..**				
15	ID Mid Section	22.790	in	22.790	
16	Wall Mid Section	0.188	in	0.188	
17	Length Mid Section	89.050	in	89.050	
18	ID End Section	30.000	in	30.000	
19	Wall End Section	0.250	in	0.250	
20	Length End Flange	3.500	in	3.500	
21	Length End Section (each)	12.700	in	=16.2-B20	
22					
23	**CS Resistance Calculations...**				
24	Radius Mid Section	11.395	in	=B15/2	
25	Thickness Mid Section	0.188	in	=B16	
26	Cross Section Mid Section	13.571	in^2	=PI()*((B24+B25)^2-B24^2)	
27	Length Mid Section	89.050	in	=B17	
28	Resistance Mid Section (T1)	3.33E-04	Ω	=rest*B27/B26	
29	Radius End Sections	15	in	=B18/2	
30	Thickness End Sections	0.250	in	=B19	
31	Cross Section End Section	23.758	in^2	=PI()*((B29+B30)^2-B29^2)	
32	L End Section	12.70000	in	=B21	
33	Resistance per End Section (T1)	2.71E-05	Ω	=rest*B32/B31	
34	∑ Resistance Mid + 2 Ends (T1)	3.87E-04	Ω	=B28+2*B33	
35	Bakeout Temperature (T3)	350.0	C	350.0	
36	∑ Resistance Mid + 2 Ends (T3)	4.04E-04	Ω	=B34*(1+B12*(B35-B3))	
37					
38	**Return Path Through VV...**				
39	Resistivity 304SS	7.7E-07	Ω-m	0.00000077	
40		3.03E-05	Ω-in	=B39*100/2.54	
41	VV Dome Wall	0.625		=5/8	
42	VV Cylinder Diameter	134.25	in	134.25	
43	VV Cylinder Wall	0.625	in	=5/8	
44	VV Cylinder Height	74	in	74	
45	R0 Dome	15		=B29	
46	R1 Dome	67.125		=B42/2	
47	Resistance per dome	3.05E-05	Ω	=B40/2/PI()/B43*(LN(B46-B45))	
48	VV Cylinder CSA	131.4928	in^2	=PI()*((B42/2)^2-((B42-B43)/2)^2)	
49	VV Cylinder Resistance	1.71E-05	Ω	=B40*B44/B48	
50					
51	Sum Total Resistance (CS @ T1)	4.66E-04	Ω	=B34+2*B47+B49	
52	Sum Total Resistance (CS @ T3)	4.83E-04	Ω	=B36+2*B47+B49	
53					
54	**Power Supply Calculations...**				
55	Power in CS Casing	5000.000	watt	5000.000	
56	I for P @ T1 (note)	3592.262	amp	=SQRT(B55/B34)	
57	V for P @ T1 (note)	1.672	volt	=B56*B51	
58	Total Power	6007.852	watt	=B56*B57	
59	I for P @ T3 (note)	3515.930	amp	=SQRT(B55/B36)	
60	V for P @ T3(note)	1.697	volt	=B59*B52	
61	Total Power	5965.475	watt	=B59*B60	
62					
63					
64					