13-970203-CLN-02

TO: DISTRIBUTION
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SUBJECT: PF/OH CURRENT AND VOLTAGE RATINGS

References:

1) NSTX Action Item List , Action Items #5

2) NSTX-CALC-13-002-0, " PF Coil Parameters"

3) 72-970129-SMK-01, "Inductive Discharge Scenarios"

4) PF Equilibria Data (private communications/S Kaye)

5) 72-970131-SMK-01, "CHI Single Null Startup Configuration"

6) 72-970203-SMK-01, "Disruption Modeling"

7) NSTX-SRD-5X (open Rev 0 dated 1/31/97)

8) NSTX-RQMT-GRD-018

9) NSTX-CALC-5X-002-0, "OH Electrical Performance"

The purpose of this memo is to outline the procedure used to derive the current and voltage ratings of the PF and OH coils.

Peak Currents

Peak current in the OH coil is set by the required flux swing (0.6 volt-sec) and the inductance of the coil, which in turn depends on its geometry. The inductance is 12.4mH and the required peak current rating is 24kA (see reference 2).

Peak current in the PF coils is set by the plasma equilibria calculations (ref. 4). At the time of this writing the single null calculations are incomplete, and the results in general have not been documented by formal memo. Final documentation of all equilibria is anticipated within a few days. The following table summarizes the equilibria as they are presently specified.

ID	Config	κ95	δ95	li	β	Ioh	Ipf1au	Ipf1al	Ipf1b	Ipf2u	Ipf2l	Ipf3u	Ipf3l	Ipf4
						(kA)	(kA)	(kA)	(kA)	(kA)	(kA)	(kA)	(kA)	(kA)
0122E	ND	2	0.52	0.2	0.25	0.000	0.000	0.000	0.000	0.000	0.000	5.833	5.833	3.364
0122F	ND	1.99	0.52	0.2	0.25	10.000	1.250	1.250	0.000	0.000	0.000	7.600	7.600	3.227

0122C	ND	2	0.36	0.2	0.25	0.000	3.333	3.333	0.000	0.000	0.000	4.800	4.800	3.614
0122D	ND	2	0.36	0.2	0.25	10.000	5.313	5.313	0.000	0.000	0.000	6.233	6.233	3.545
0122A	ND	1.6	0.53	0.2	0.25	0.000	0.000	0.000	0.000	0.000	0.000	9.333	9.333	2.477
0122B	ND	1.6	0.53	0.2	0.25	10.000	2.083	2.083	0.000	0.000	0.000	10.667	10.667	2.455
0121A	ND	1.6	0.29	0.2	0.25	0.000	11.979	11.979	0.000	0.000	0.000	4.733	4.733	3.227
0121E	ND	1.6	0.33	0.2	0.25	10.000	11.979	11.979	0.000	0.000	0.000	7.467	7.467	3.136
0130A	ND	2	0.47	0.6	0.25	0.000	-2.604	-2.604	0.000	0.000	0.000	2.333	2.333	5.250
0130B	ND	2	0.49	0.6	0.25	10.000	-1.250	-1.250	0.000	0.000	0.000	4.133	4.133	5.091
0131A	ND	2	0.3	0.6	0.25	0.000	0.000	0.000	0.000	0.000	0.000	1.633	1.633	5.409
0131B	ND	2	0.3	0.6	0.25	10.000	2.604	2.604	0.000	0.000	0.000	3.033	3.033	5.341
0131C	ND	1.6	0.5	0.6	0.25	0.000	-5.208	-5.208	0.000	0.000	0.000	6.867	6.867	4.091
0131D	ND	1.6	0.5	0.6	0.25	10.000	-3.125	-3.125	0.000	0.000	0.000	8.233	8.233	4.068
0131E	ND	1.6	0.3	0.6	0.25	0.000	3.229	3.229	0.000	0.000	0.000	4.467	4.467	4.591
0131F	ND	1.6	0.3	0.6	0.25	10.000	5.938	5.938	0.000	0.000	0.000	5.600	5.600	4.614
0123E	DN	2.11	0.55	0.2	0.25	0.000	0.000	0.000	0.000	-7.786	-7.786	11.633	11.633	2.432
0123F	DN	2.11	0.53	0.2	0.25	10.000	1.667	1.667	0.000	-5.107	-5.107	11.100	11.100	2.705
0123C	DN	2.14	0.41	0.2	0.25	0.000	4.792	4.792	0.000	-6.821	-6.821	9.300	9.300	2.909
0123D	DN	2.14	0.39	0.2	0.25	10.000	6.875	6.875	0.000	-4.714	-4.714	9.167	9.167	3.114
0123A	DN	1.86	0.58	0.2	0.25	0.000	0.000	0.000	0.000	-16.929	-16.929	18.700	18.700	1.364
0123B	DN	1.86	0.59	0.2	0.25	10.000	1.250	1.250	0.000	-14.750	-14.750	18.833	18.833	1.477
0121F	DN	1.9	0.41	0.2	0.25	0.000	9.896	9.896	0.000	-16.821	-16.821	15.100	15.100	2.091
0121G	DN	1.9	0.41	0.2	0.25	10.000	11.354	11.354	0.000	-14.786	-14.786	15.200	15.200	2.227
0128A	DN	1.88	0.4	0.6	0.25	0.000	-4.167	-4.167	0.000	-4.464	-4.464	5.367	5.367	4.773
0128B	DN	1.92	0.38	0.6	0.25	10.000	-2.396	-2.396	0.000	-1.750	-1.750	4.800	4.800	5.045
0128C	DN	1.99	0.29	0.6	0.25	0.000	0.000	0.000	0.000	-3.571	-3.571	3.367	3.367	5.205
0129A	DN	2	0.27	0.6	0.25	10.000	2.354	2.354	0.000	-1.714	-1.714	3.433	3.433	5.364
0129B	DN	1.73	0.4	0.6	0.25	0.000	-2.813	-2.813	0.000	-9.107	-9.107	8.933	8.933	4.182
0129C	DN	1.74	0.4	0.6	0.25	10.000	-1.458	-1.458	0.000	-7.107	-7.107	9.167	9.167	4.295
0129D	DN	1.77	0.36	0.6	0.25	0.000	0.000	0.000	0.000	-9.536	-9.536	8.267	8.267	4.318
0129E	DN	1.77	0.36	0.6	0.25	10.000	1.458	1.458	0.000	-7.643	-7.643	8.567	8.567	4.455
	SN					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SN					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SN					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SN					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SN					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SN					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SN					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
72-970131-SMK-01	CHI SN					0.000	-0.744	-7.146	7.939	-1.000	-2.496	-0.503	-0.330	-0.248

Maximums from the above are as follows.

	Ioh	Ipf1au	Ipf1al	Ipf1b	Ipf2u	Ipf2l	Ipf3u	Ipf3l	Ipf4
Min I	0.000	-4.167	-7.146	0.000	-16.929	-16.929	-0.503	-0.330	-0.248
Max I	10.000	11.354	11.354	7.939	0.000	0.000	18.833	18.833	5.364
Max |I|	10.000	11.354	11.354	7.939	16.929	16.929	18.833	18.833	5.364

In order to provide margin compared to the above the following peak current ratings are selected:

Circuit	Max Current

	(kA)
OH	24.0
PF1au	15.0
PF1al	15.0
PF1b	20.0
PF2u	20.0
PF2l	20.0
PF3u	20.0
PF3l	20.0
PF4	20.0

∫i^2(t)dt and Equivalent Square Waves

The OH ESW is set by the third of the four inductive scenarios described in reference 3. The requirement is 3.02 x 10^8 amp^2-sec, corresponding to an ESW of 0.525 seconds.

For all PF coils except for PF1b, they must be capable of providing the equilibrium, shaping, and vertical and radial control as required for all NSTX plasma operations, for plasma flat top durations up to 4.5 seconds per the NSTX GRD (ref. 8). A conservative approach to ensure that all conditions can be satisfied is to rate the coils for 5.0 seconds ESW at their rated peak currents, allowing 0.5 sec ESW for ramping up and down. This is the approach taken. It is generous, since a 0.5 sec ESW corresponds to a 0.7 sec ramp up and ramp down.

For PF1b, its prime purpose is to form the special SN x-point which is required at the initiation of a CHI discharge. While an ESW of 100mS or so would be adequate for this purpose, the 1.0 ESW rating is chosen to provide flexibility. Also, as a practical manufacturing/procurement matter, it corresponds to the use of the same conductor as in PF1a.

Voltages

The selection of OH voltage rating is set by the need to drive the coil through the required scenarios, as well as the need to provide the loop voltage necessary to initiate the plasma. As described in ref. 9, a 4kV power supply configuration (4 series connected D-site rectifiers each rated 1012.85 volts no-load) is adequate to drive the coil through the required scenario, but may be slightly lacking in terms of the ability to provide the required breakdown voltage. The latter issue may or may not be relevant in NSTX operations depending on the success of ECH preionization. So, a 6kV option is reserved, and the OH coil is rated accordingly.

The remaining PF coils are rated for 2kV. This level is chosen in order to permit a power supply configuration consisting of up to two series connected D-site rectifiers on each coil. In practice, particularly for those coil sections which are series connected (e.g. 2a upper in series with 2b upper), the actual voltage will be substantially less. In any case the coils which were built for the S-1 machine have sufficient insulation to easily handle this level of applied voltage.

To confirm that this voltage rating is adequate, an analysis was performed against a design basis scenario (see the WBS5 Power Systems SRD, ref. in which all PF coils are ramped to their full current in 0.2 seconds (corresponding to the minimum NSTX plasma ramp time given in the GRD, ref. 8), held at flat top, and then ramped down in 0.2 seconds such that they experience their rated ∫i^2(t)dt. Coil self and mutual inductances, and coil resistances (based on the final coil temperature) were used to calculate the required driving voltage. This analysis demonstrates that in most cases a 1kV power supply is adequate (maximum voltage demand was 813 volts; only in PF4 is a 2kV supply required (the voltage demand reached 1.4kV). Therefore, allowing for a connection of up to 2kV there is substantial voltage margin available for control, beyond the basic scenario requirement.

An additional concern in the context of voltage is that which may result from disruption. If, in any circuit, a power supply is connected which is driving a certain initial current at the time of disruption, then that power supply will act as a short circuit on the coil as long as the current is not driven through zero by the disruption. If it is, then the power supply will appear as an open circuit and the voltage will rise up to the protective level of the power supply surge arresting non-linear resistors (MOVs in each of the D-site power supply sections will begin to conduct at ≈ 1.2kV).

To address wheter or not this could be an issue on NSTX, the disruption scenario given in ref. 6 was taken as a driving term against the PF coil mutual inductance matrix. Passive structure (vacuum vessel, etc.) was neglected; this would have a beneficial shielding effect. The following is a summary.

	OH	PF1au	PF1al	PF1b	PF2u	PF2l	PF3u	PF3l	PF4	
|V|max	1.892	0.078	0.078	0.074	0.402	0.402	1.398	1.398	5.181	kV
∑VΔT	12.593	0.521	0.521	0.495	2.677	2.677	9.308	9.308	34.489	V-sec
ΔI	1.016	1.387	1.387	0.923	1.355	1.355	1.798	1.798	4.028	kA

The above result shows that, even if the disruption voltage was able to reverse the polarity of the coil current, the voltage would be quite benign in all cases except for PF4. In this case the voltage would be high enough to engage the aforementioned surge arrestors (2 x 1.2kV = 2.4kV). The coil voltage ratings (six series coil subsections rated 2kV each) would not be endangered.

The above is a crude analysis of disruption. Various types of disruption (vertical, radial, etc.) need to be analyzed, along with the shielding effects of the passive structure, to see the complete picture of possibilities. In any case the surge arrestors located in the safety disconnect switch compartments of the power supply system as well as in the rectifiers themselves will limit the voltage.

Summary

The following table summarizes the various current and voltage ratings versus the requirements.

		OH	PF1au	PF1al	PF1b	PF2u	PF2l	PF3u	PF3l	PF4	
|V|max	Ind Scenarios	3.931	0.000	0.000	0.000	0.000	0.000	0.184	0.184	0.595	kV
	DB Scenario	3.377	0.167	0.158	0.066	0.147	0.165	0.813	0.803	1.444	kV
	Rated	6.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	kV
|Imax|	Ind Scenarios	24.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	11.6	kA
	Equilibria	10.0	11.4	11.4	7.9	16.9	16.9	18.8	18.8	5.4	kA
	DB Scenario	24.0	15.0	15.0	20.0	20.0	20.0	20.0	20.0	20.0	kA
	Rated	24.0	15.0	15.0	20.0	20.0	20.0	20.0	20.0	20.0	kA
∫i^2(t)dt	Ind Scenarios	300.8	0.0	0.0	0.0	0.0	0.0	3.1	3.1	88.1	kA^2-sec
	DB Scenario	98.4	1124.9	1124.9	399.7	1999.7	1999.7	1999.7	1999.7	1999.7	kA^2-sec
	Rated	300.0	1125.0	1125.0	400.0	2000.0	2000.0	2000.0	2000.0	2000.0	kA^2-sec
Max S	Ind Scenarios	99.5	MVA								
	DB Scenario	169.7	MVA								
	Rated	475.0	MVA								

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