NSTX

52-960306-CLN-01

***TO: DISTRIBUTION***
***FROM: C NEUMEYER***
***SUBJECT: PRELIMINARY ANALYSIS OF TF PERFORMANCE***

A preliminary analysis of the TF system performance was conducted in order to verify the latest selection of TF conductor cross sections and overall dimensions. Simulations were performed using crude models of the C-site MG sets, which are planned to be used for the power supply for the TF system.

*Coil Description*

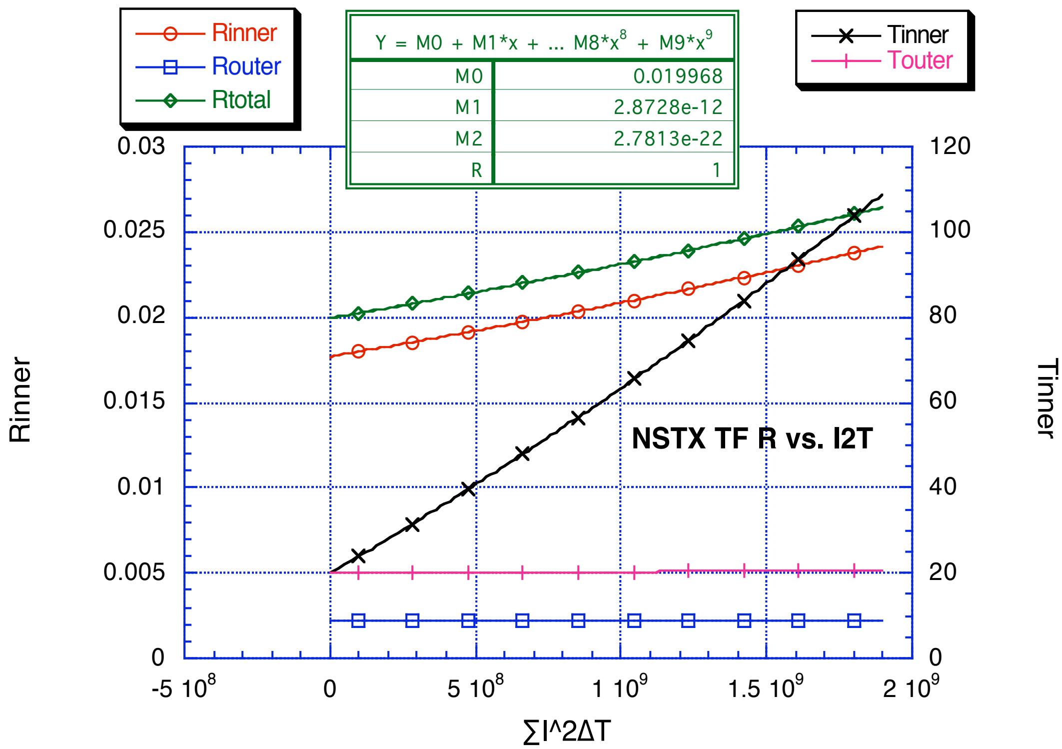
The latest coil dimensions were provided by A. Brooks, along with a value for inductance. These are summarized in the following spreadsheet, along with some derived parameters.

| | | |
|---|---|---|
| # TF Coils | 12 | |
| # Turns/coil | 6 | |
| Ro | 0.8 | m |
| B @ Ro | 0.32 | T |
| I | 17777.77778 | amp |
| Inductance | 0.017 | henries |
| Stored Energy | 2.69E+06 | Joule |
| Inner Leg Cu CSA per Coil | 0.00212 | m^2 |
| Inner Leg Cu CSA per Turn | 0.000353333 | m^2 |
| Inner Leg Length | 5.04 | m |
| Outer Leg Cu CSA per Coil | 0.0232 | m^2 |
| Outer Leg Cu CSA per Turn | 0.003866667 | m^2 |
| Outer Leg Length | 7.03 | m |
| | | |
| Conductor resistivity @ 20C | 1.7240E-06 | Ω-cm |
| Conductor res temp coeff | 0.0041 | 1/degC |
| Conductor heat capacity | 0.386 | J/gm-degC |
| Conductor density | 8.94 | gm/cc |
| | | |
| Total Inner Leg Res @ 20C | 0.017705805 | Ω |
| Total Outer Leg Res @ 20C | 0.002256775 | Ω |
| Total Coil Res @ 20C | 0.019962581 | Ω |
| | | |
| Total Inner Leg Heat Capacity | 442458.4228 | Joule/deg C |
| Total Inner Leg Heat Capacity | 6753818.408 | Joule/deg C |
| | | |
| Initial Temperature | 20 | deg C |

The coils are water cooled; however the water cooling is intended only to remove the heat between pulses. For all practical purposes it is adiabatic during the pulse. No credit for the water is taken in the simulations.

Since the operation is assumed adiabatic, and since the coils consist of two discrete constant cross section elements (the inner and outer legs), an equation for resistance vs. ∫i^2(t)dt may be derived and used in general to compute resistance during a simulation run.

The following figure depicts the resistance and temperature rise of the inner and outer legs, as well as the total coil resistance, vs. ∫i^2(t)dt.




A equation fit to the above curve is as follows:

$$R = 0.019968 + 2.8728e\text{-}12 * X + 2.7813e\text{-}22 * X^2$$

where:

R = total coil resistance

X = ∫i^2(t)dt

At the moment no information is available concerning the inner/outer leg joint resistance; it is assumed equal to zero.

*Power Supply*

The C-site MG sets are separately DC generators. The excitation is generated via cascade rotating machines acting as magnetic amplifiers. A feedback control system is provided to close the loop on load current. The voltage response of the generators is relatively slow since the generated voltage is proportional to the field current, and the time constant of the field circuit is on the order of seconds. At the same time the time constant of the load circuit is less than one second. This makes the feedback control problematic.

An initial attempt was made to model the generators, their excitation systems, the feedback control, and the coils via a simulation. Although the simulation is working the precise machine parameters are not yet available to the writer, and the simulation is really not ready for use. Further work is required.

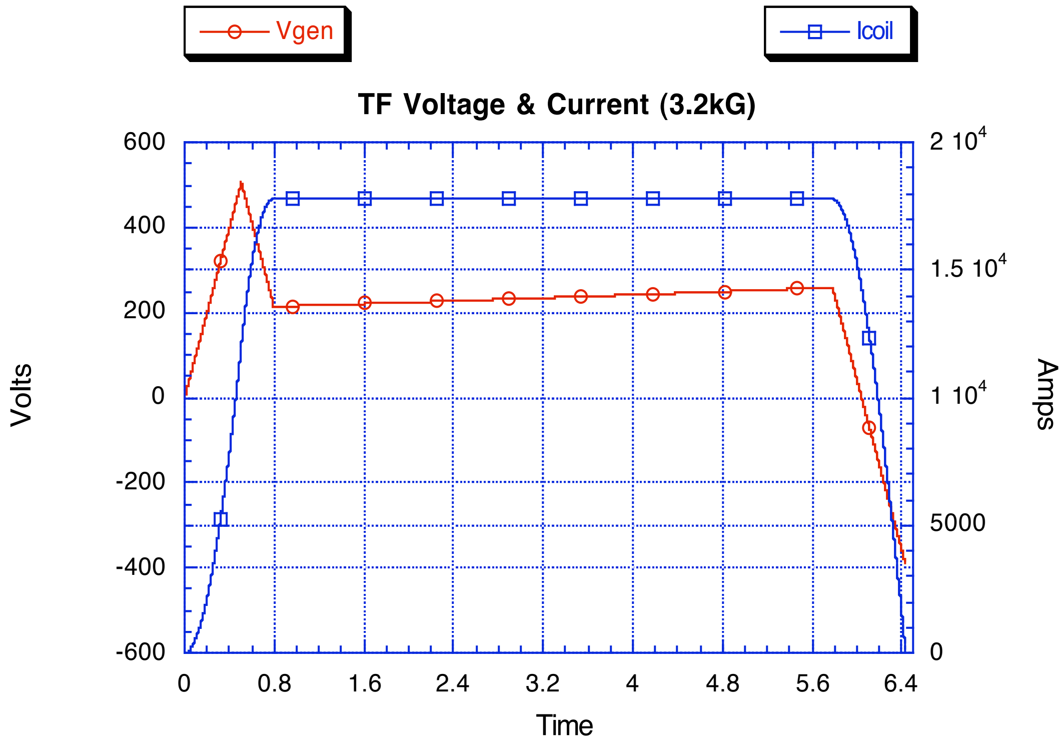
In addition, a very detailed simulation developed some years ago by the MG Section is available, and needs to be run with the above coil model to refine the results described herein and provide further insight into the development of a simplified model as described above for general purpose NSTX use.

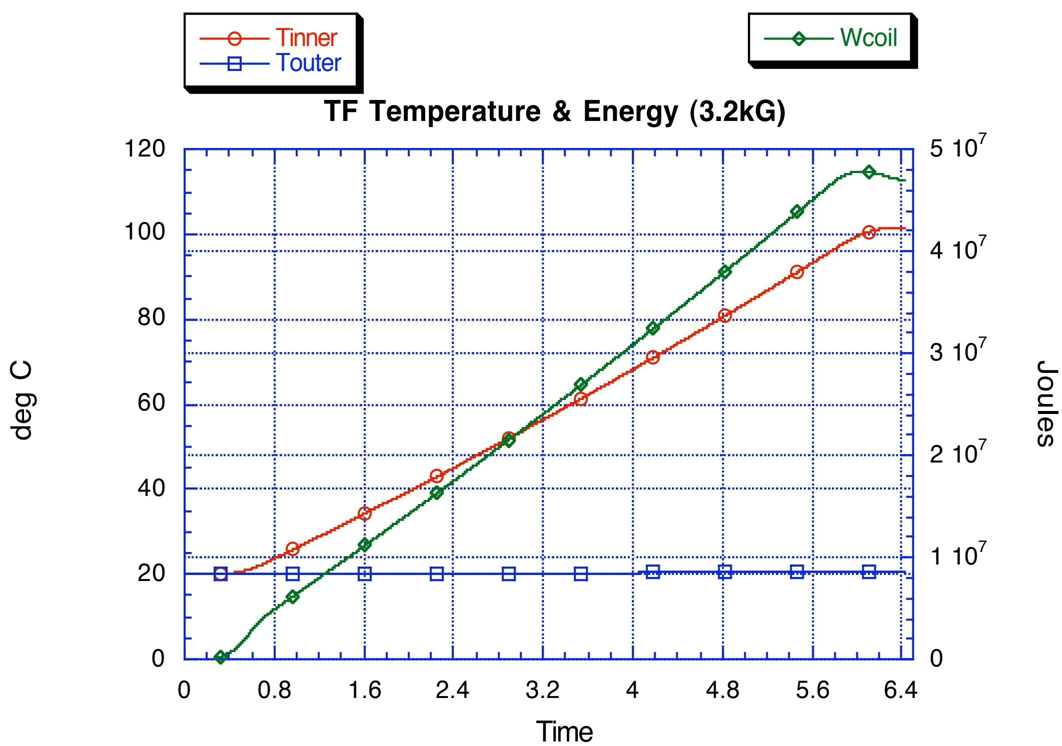
To approximate the behavior of the system a linear ramp voltage source was used. A ramp rate of 1000 volts/second per generator was used for both up and down ramps. This rate is somewhat less than known to be achievable in practice. The voltage was ramped up, and then switched to ramp down in such a way that the coil current reached its flat top value just as the generator voltage had ramped down to the coil I * R drop.

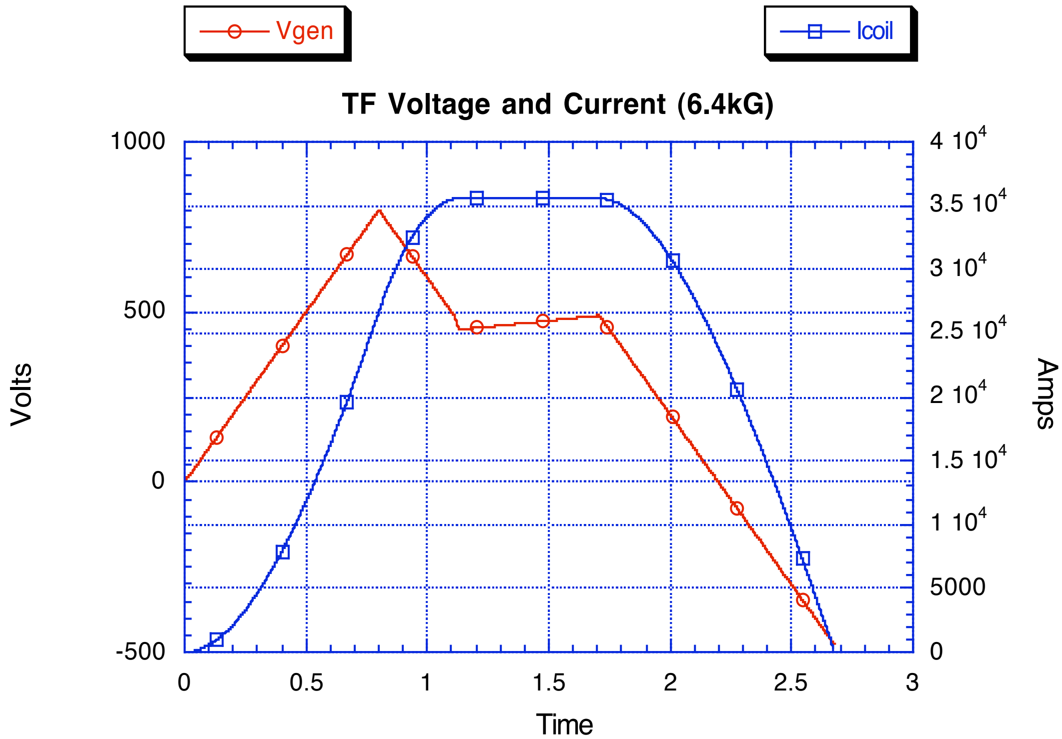
No bus bar resistance was included in the simulations.

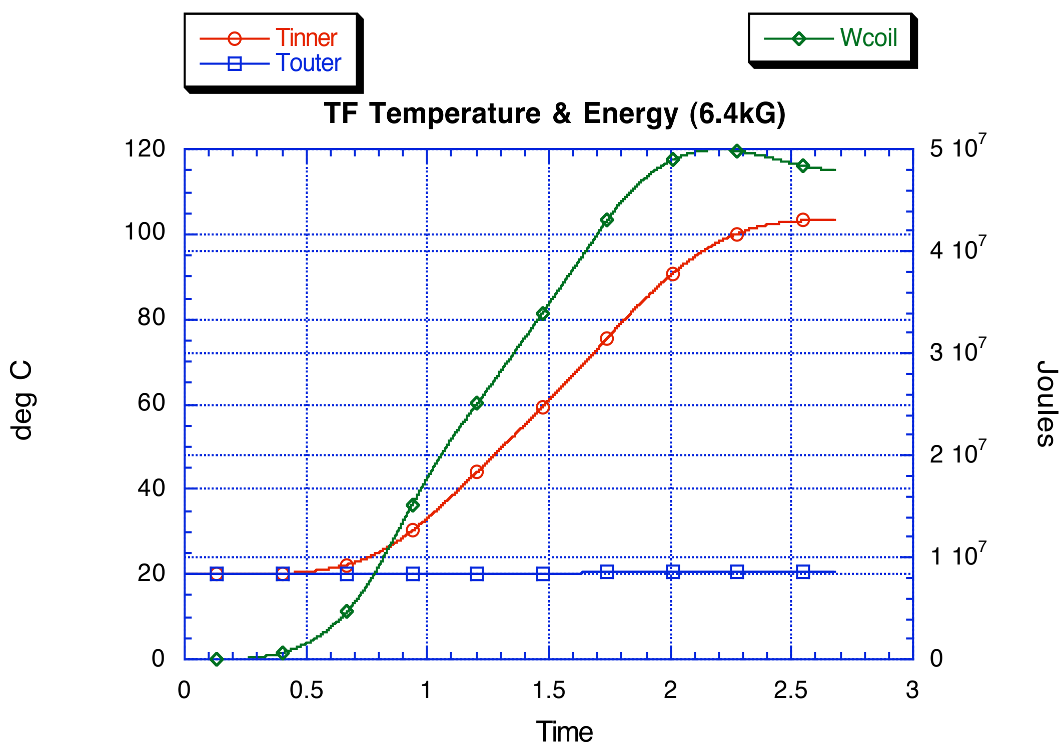
Two series sets of two parallel generators were assumed. Since the simple ramp voltage model (independent of load current and generator speed) was used, the only effect of the inclusion of parallel generators was to include the appropriate net armature resistance and inductance.

Results for the 3.2 and 6.4kG simulations are given in the following figures.


Vgen
Icoil
TF Voltage & Current (3.2kG)
Volts
Amps
Time
600
400
200
0
-200
-400
-600
2 10^4
1.5 10^4
1 10^4
5000
0
0
0.8
1.6
2.4
3.2
4
4.8
5.6
6.4


Tinner
Touter
Wcoil
TF Temperature & Energy (3.2kG)
deg C
Joules
Time
120
100
80
60
40
20
0
5 10^7
4 10^7
3 10^7
2 10^7
1 10^7
0
0
0.8
1.6
2.4
3.2
4
4.8
5.6
6.4


Vgen
Icoil
TF Voltage and Current (6.4kG)
1000
500
0
-500
Volts
4 10^4
3.5 10^4
3 10^4
2.5 10^4
2 10^4
1.5 10^4
1 10^4
5000
0
Amps
0
0.5
1
1.5
2
2.5
3
Time


Tinner
Touter
Wcoil
TF Temperature & Energy (6.4kG)
120
100
80
60
40
20
0
deg C
5 10^7
4 10^7
3 10^7
2 10^7
1 10^7
0
Joules
0
0.5
1
1.5
2
2.5
3
Time

The results are summarized in the following spreadsheet:

| | 3.2kG | 6.4kG | |
|---|---|---|---|
| Flat Top Current | 17777.8 | 35555.6 | amp |
| Flat Top Time | 5.0 | 0.6 | sec |
| ∫i^2(t)dt | 1.769E+09 | 1.802E+09 | A^2-sec |
| ESW | 5.597E+00 | 1.425E+00 | sec |
| Max Inner Leg Temp | 101.6 | 103.3 | deg C |
| Max Outer Leg Temp | 20.6 | 20.6 | deg C |
| Peak Energy | 4.780E+07 | 4.997E+07 | Joule |
| Dissipated Energy | 4.700E+07 | 4.801E+07 | Joule |

The above results show that the baseline 5 second flat top pulse can be achieved with a maximum temperature slightly over 100C (a 120C allowable has been mentioned), as well as a double field, 0.6 second flat top pulse.

With a 5 minute repetition period the rms current and average power would be:

| | 3.2kG | 6.4kG | |
|---|---|---|---|
| Repetition Period | 300 | 300 | sec |
| Irms | 2428.3053 | 2450.8502 | amp |
| Pavg | 156666.67 | 160033.33 | watt |

The above results (peak current, rms current, peak energy) would imply that one generator parallel would be sufficient for the 3.2kG, but two would be required for the 6.4kG.

*Action Items:*

*M Awad requested to run the detailed MG simulation using the coil parameters described above, including the variation of resistance with ∫i^2(t)dt.*

M Awad A Brooks P Heitzenroeder R Myslinski M Ono
J Spitzer NSTX File