NSTX CALCULATION

Page 1 of 1

TITLE OH Coil Thermal Behavior

CALC. NO. 13-3 DATE 7/31/00

ORIGINATOR C Neumeyer CHECKER Rev. 1

PURPOSE:

This calculation presents an analysis of measurements of the OH water outlet temperature, and provides an update of the simulation of the OH coil heating and cooling for three different repetition periods, 300, 450, and 600 seconds. See rev. 0 of this calculation for description of the simulation.

REFERENCES:

NSTX-CALC-13-3-0 gives the detailed description of the simulation.

Memo 71-000731-CLN-01 interprets the results from this calculation.

ASSUMPTIONS:

CALCULATION:

See attached

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:

See memo 71_000731_CLN_01.doc

NSTX

71-000731-CLN-01

TO: DISTRIBUTION
FROM: C NEUMEYER
SUBJECT: ANALYSIS OF OH WATER OUTLET TEMPERATURE DATA

References:

[1] 71-000302-CLN-01, "Study of OH Cooling vs. Repetition Rate"
[2] 71-000627-CLN-01, "Guidance on OH Protection Settings"
[3] D-NSTX-ISTP-270, "NSTX OH Rep Rate Interlock System Commissioning"
[4] NSTX-CALC-13-3, "OH Coil Thermal Behavior"

This memo documents the analysis of the recent OH outlet water temperature measurements and the adjustment of the simulation of OH coil thermal behavior to fit the measurements. This is a required step of the ISTP [3] which commissions the OH repetition rate interlock system. The details have been incorporated into rev. 2 of the formal calculation [4].

Data was taken from shot #102190 by P. Sichta from the EPICS data and provided in spreadsheet form. The waveforms of the eight temperature measurements are shown in figure 1. A magnification during the beginning of the cool down period is shown in figure 2. A plot showing the simulated result versus the minimum, maximum and average of the path measurements (minimum and maximum at each time sample) is shown in figure 3. The simulated result shown differs from that originally presented in references [1] and [4] in that the average of the eight winding path lengths was used instead of the longest, and the actual flow was used instead of the low flow drop out setpoint. These changes were found to produce a better match to the observed measurements.

The following points are noted:

1) From figure 2 it is noted that there seem to be four distinct pairs of cool down waveforms which correspond to the four layers of the coil wound two-in-hand. However, the numbering of the measurements (1X, 1Y, etc.) does not match the expected behavior. It appears that 1Y and 4Y seem to be from layer 1, 2Y and 3X seem to be from layer 2, 2X and 3Y seem to be from layer 3, and 1X and 4X seem to be from layer 4. This would correspond to 1X and 4Y being swapped, and 2X and 3X being swapped. Testing recently performed in which the cooling hoses were pinched off at the point where they are attached to the machine and labeled, causing the flow detector on the pinched path to trip, confirm this finding. At the next opportunity the hoses will either be reconnected or the naming of the paths will be swapped to correct this discrepancy. Also, clear unmistakable labeling of both the hose ends and the connection points needs to be implemented to avoid this problem in the future.

2) From figure 1 it is noted that there appears to be a radial gradient in temperature, with the innermost layer being the coolest. This could be explained by inward radial cooling which could be expected to be most significant on the inner layer which faces the OH tension tube which in turn faces the TF inner legs. The TF inner legs cool down very rapidly after a pulse

due to the large flow of water and the short water path length. Further, it is noted that little outward radial cooling would take place because the outer surface of the coil is covered by the Microtherm insulation.

3) As shown in figure 3, using the average OH winding length instead of the maximum winding length, and the actual flow instead of the low flow setpoint, the waveshape of the simulated temperature fits the measurements reasonably well.

4) As seen on figure 3, the simulated temperature during the plateau period, when the cooling wave has not yet propagated through the coil, exceeds the measurements by about 5°C. Possible explanations for this include:

a. errors in the thermocouple measurements, individual or systemic
b. cooling of the water between its point of exit from the winding, through the hose, to the manifold where the thermocouples are located
c. error in the $\int i^2(t)dt$ used in the simulation
d. error in the conductor dimensions used in the simulation
e. error in the copper or water properties used in the simulation
f. simulation neglects heat absorbed by epoxy/fiberglass insulation
g. simulation neglects radial cooling

Concerning a. above, the measurements performed for the ISTP show that at 50°C the t/c instrumentation reads about 2 °C on the low side. Concerning b., since the thermal resistance of the rubber hose material and the surrounding air is large, this should be minimal in the judgement of the writer. Concerning c., the writer has performed this calculation very carefully using a spreadsheet with actual data from the MDS Tree. Concerning d., the writer has double-checked this number and, besides, the calculated resistance of the coil agrees with the measurement. Concerning e. and f., a simple energy balance spreadsheet which takes the energy dissipated during the pulse in the copper, and then distributes it in the combined heat capacity of the copper, entrained water, and epoxy glass insulation does indeed yield a plateau temperature in between the simulation and the measurement (measurement average = 46 °C, spreadsheet = 49 °C, simulation = 54 °C). Concerning g., there is in fact evidence of radial cooling as noted in 2) above.

Based on the above discussion, it is concluded that the simulation overestimates the water temperature rise over the inlet (13 °C) during the plateau period by (54-(46+2))/(46+2-13)*100=17%, due mainly to the fact that the it does not include the heat capacity of the epoxy glass insulation or the inward radial cooling.

The reader is reminded, however, that *during* a pulse, the heat dissipated in the copper does not immediately equilibrate with the entrained water and the epoxy glass insulation, so that the actual peak *copper* temperature is considerably in excess of the plateau *water* temperature (for the shot analyzed, with a starting temperature of 13 °C the copper temperature at the end of the pulse under adiabatic conditions is calculated to be 61°C). So the key features of the protection are that 1) the SOP temperature measurement feeding the interlock is accurate, and 2) that it is properly coordinated with the RIS $\int i^2(t)dt$ setting. The fact that the simulated plateau temperature is higher than the actual is not really very important. It simply means that the actual temperatures will fall below the interlock value a bit sooner than predicted by the simulation.

Based on this analysis the recommended approach is to adjust the $\int i^2(t)dt$ and Start Of Pulse (SOP) temperature allowables previously stated [1,2] for the three repetition periods based on the modified simulation results which use the average winding path length instead of the maximum and the actual flow instead of the low flow setpoint. Due to the fact that the simulation does not include the heat capacity of the epoxy glass insulation, or the inward radial cooling, the actual cooldown will occur more rapidly then predicted by the simulation. This represents a slightly sub-optimal utilization of the capacity of the system but is judged to be a reasonable compromise. The revised settings, which result in a nominal EOP copper temperature of 90 °C, maximum EOP copper temperature of 100°C in case of fault at 24kA, are given in the following table.

Repetition Period	300 sec	450 sec	600 sec
Allowable $\int i^2(t)dt$	160 kA^2-sec	265 kA^2-sec	280 kA^2-sec
Allowable $\int i^2(t)dt$	57%	95%	100%
T_{sop}	42°C	14 °C	12.4 °C

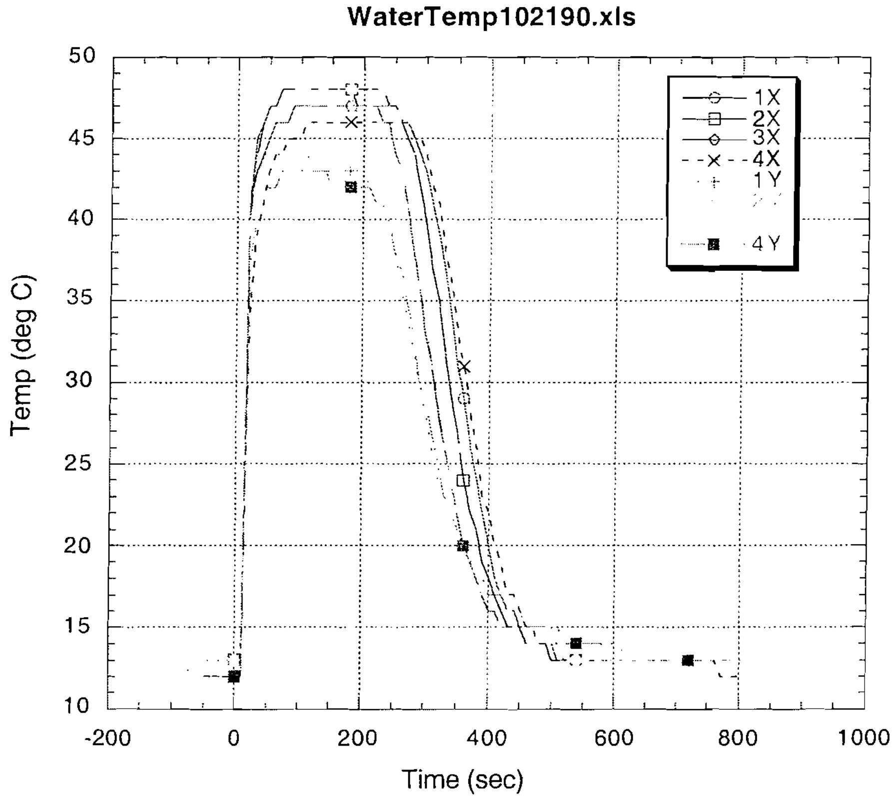

Figure 1: Eight Cooling Water Measurements

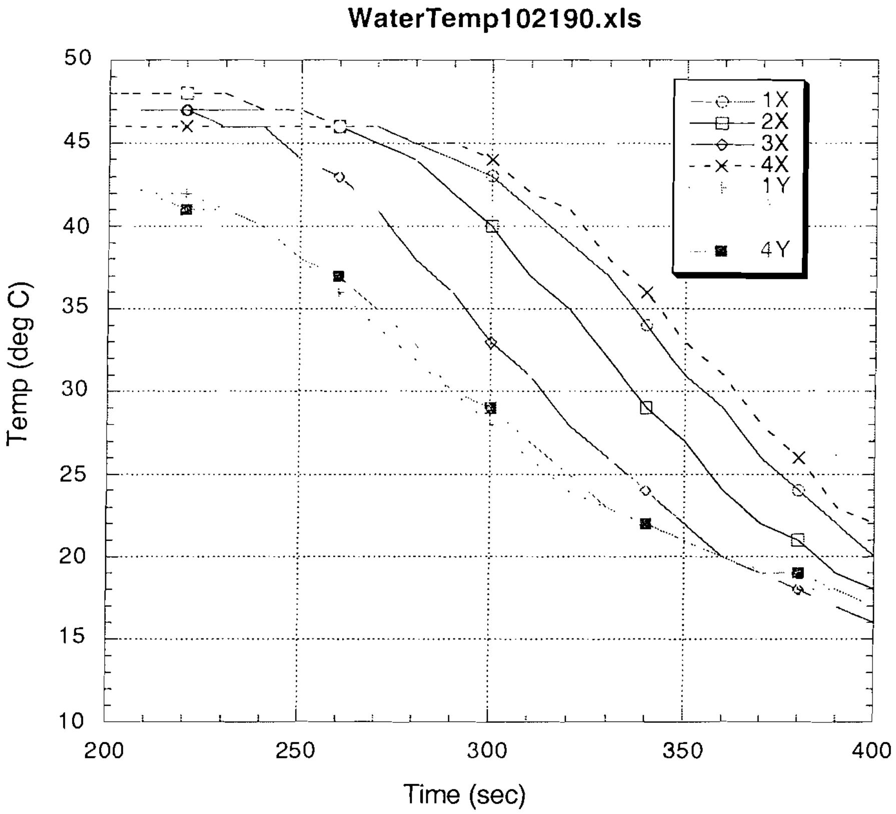

Figure 2: Zoom of Eight Measurements During Cool Down

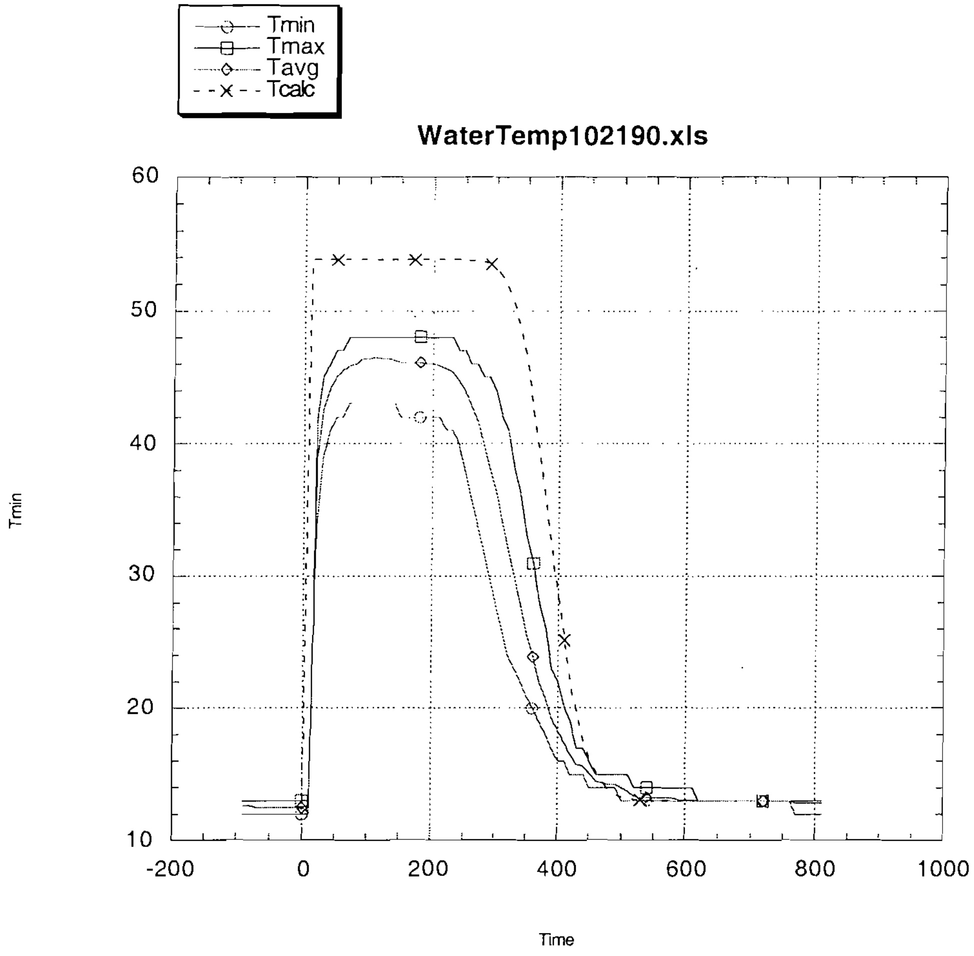

Figure 3: Comparison of Simulation Against Min, Max and Avg At Each Time Step

cc:

E Baker	M Bell	R Herskowitz	M Kalish	R Marsala	D Mueller
M Ono	G Pearson	S Ramakrishnan	P Sichta	A Von Halle	M Williams

NSTX File

CSA-Cu	0.2192	in^2
Hole Dia	0.188	in
CSA-H2O	0.027759113	in^2
L	31440	in
RESIST	1.7241	μΩ-cm
R20	0.097357794	Ω
COEFF	0.0041	
SH-Cu	0.386	J/gm-C
Dens-Cu	8.94	gm/cc
Vol-Cu	112933.8768	cc
Mass-Cu	1009628.859	gm
HC-Cu	389716.7396	J/degC
SH-H20	4.186	J/gm-C
Dens-H20	1	gm/cc
Vol-H20	14301.7528	cc
Mass-H20	14301.7528	gm
HC-H20	59867.13721	J/degC
SH-E/G	1.1506	J/gm-C
Dens-E/G	1.41950617	gm/cc
OH DR	4.6533	cm
OH DZ	426.2628	cm
OH Rcenter	13.19	cm
OH Vol	164385.3648	cc
Vol-E/G	37149.73519	cc
Mass-E/G	52734.27833	gm
HC-E/G	60676.06064	J/degC
HC-Net	510259.9374	J/degC

G-Function Calc:

Tinlet	13	degC
G0	2.74E+15	(A/m^2)^2-sec
CSA	1.4139	cm^2
∫i2t	1.79E+08	A^2-sec
G	8.9512E+15	(A/m^2)^2-sec
Tfinal	6.06E+01	degC

Alternate Calc w/water & epoxy/glass:

Final Temp	Final I2T	Iesw	Tesw
48.59	1.79E+08	24000.00	0.31

ACTUAL SHOT DATA, I2T AND TEMP CALC FOLLOWS (NOT PRINTED, ROWS HIDDEN)....

Rel_Time	ck_plusoffLO	ws_OH1X_AI	ws_OH2X_AI	ws_OH3X_AI	ws_OH4X_AI	ws_OH1Y_AI	ws_OH2Y_AI	ws_OH3Y_AI	ws_OH4Y_AI	Time	Tmin	Tmax	Tcalc
-90	8	12	13	13	12	13	13	13	12	-90	12	13	
-80	8	12	13	13	12	13	13	13	12	-80	12	13	
-70	8	12	13	13	12	12	13	13	12	-70	12	13	
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20	8	41	40	41	34	42	40	36	37	20	34	42	53.821025
30	8	43	44	45	39	44	44	42	40	30	39	45	53.821025
40	8	44	46	46	41	44	45	45	42	40	41	46	53.821033
50	8	45	47	47	43	44	46	46	42	50	42	47	53.821037
60	8	46	47	47	44	44	47	47	42	60	42	47	53.82102
70	8	46	48	48	44	44	47	47	43	70	43	48	53.82102
80	8	46	48	48	45	44	47	47	43	80	43	48	53.821025
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100	8	47	48	48	45	44	48	48	43	100	43	48	53.821033
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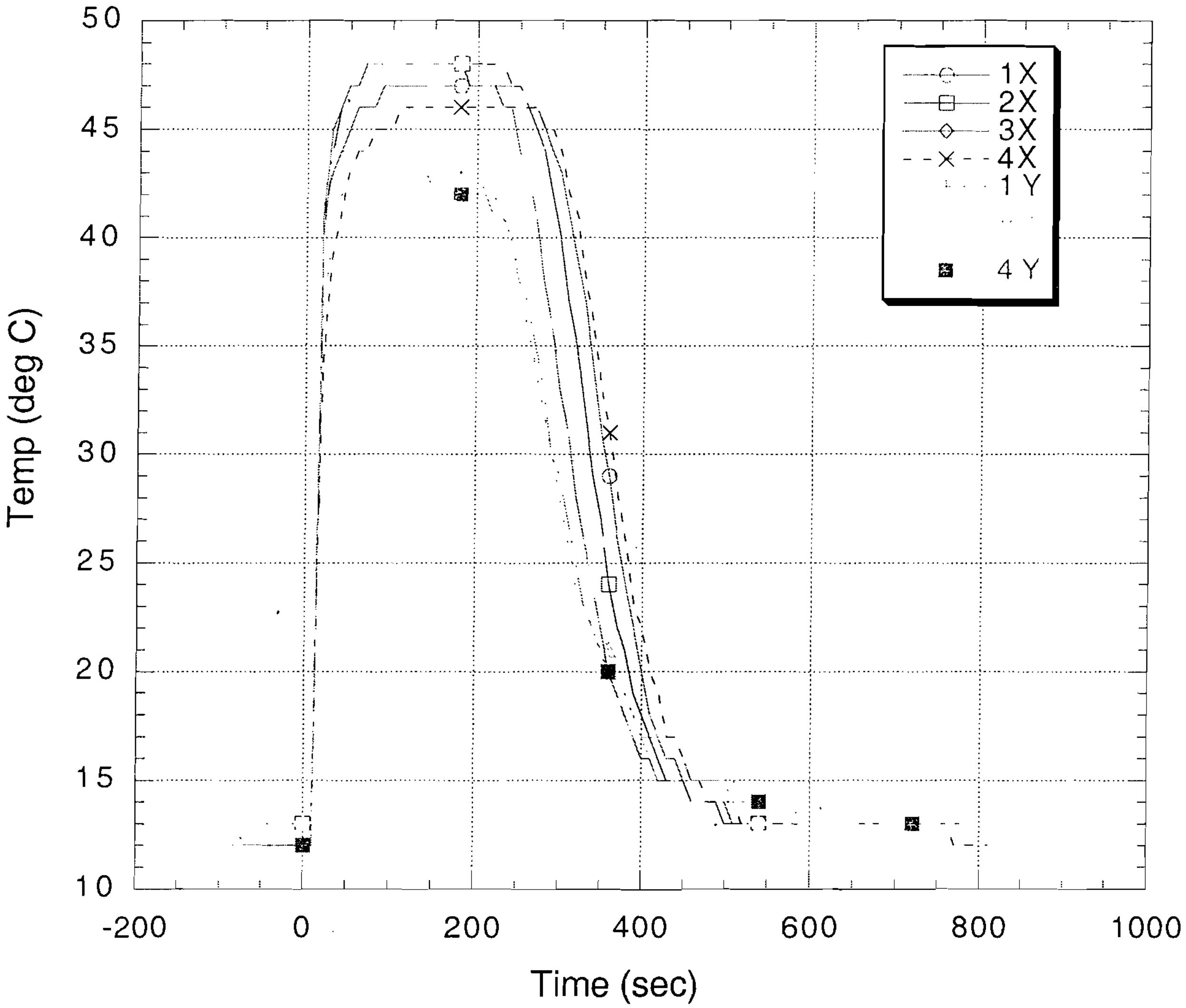

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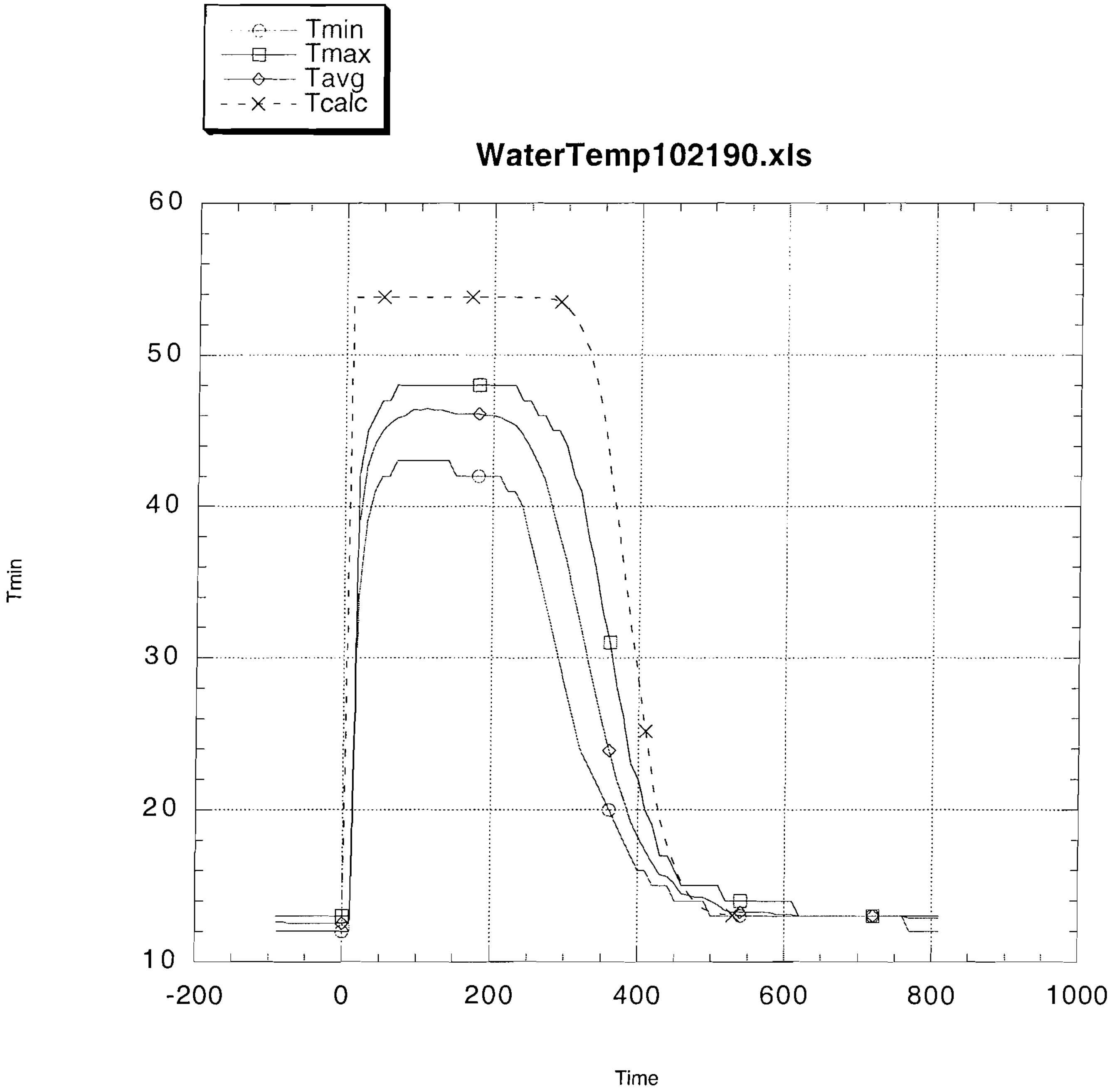
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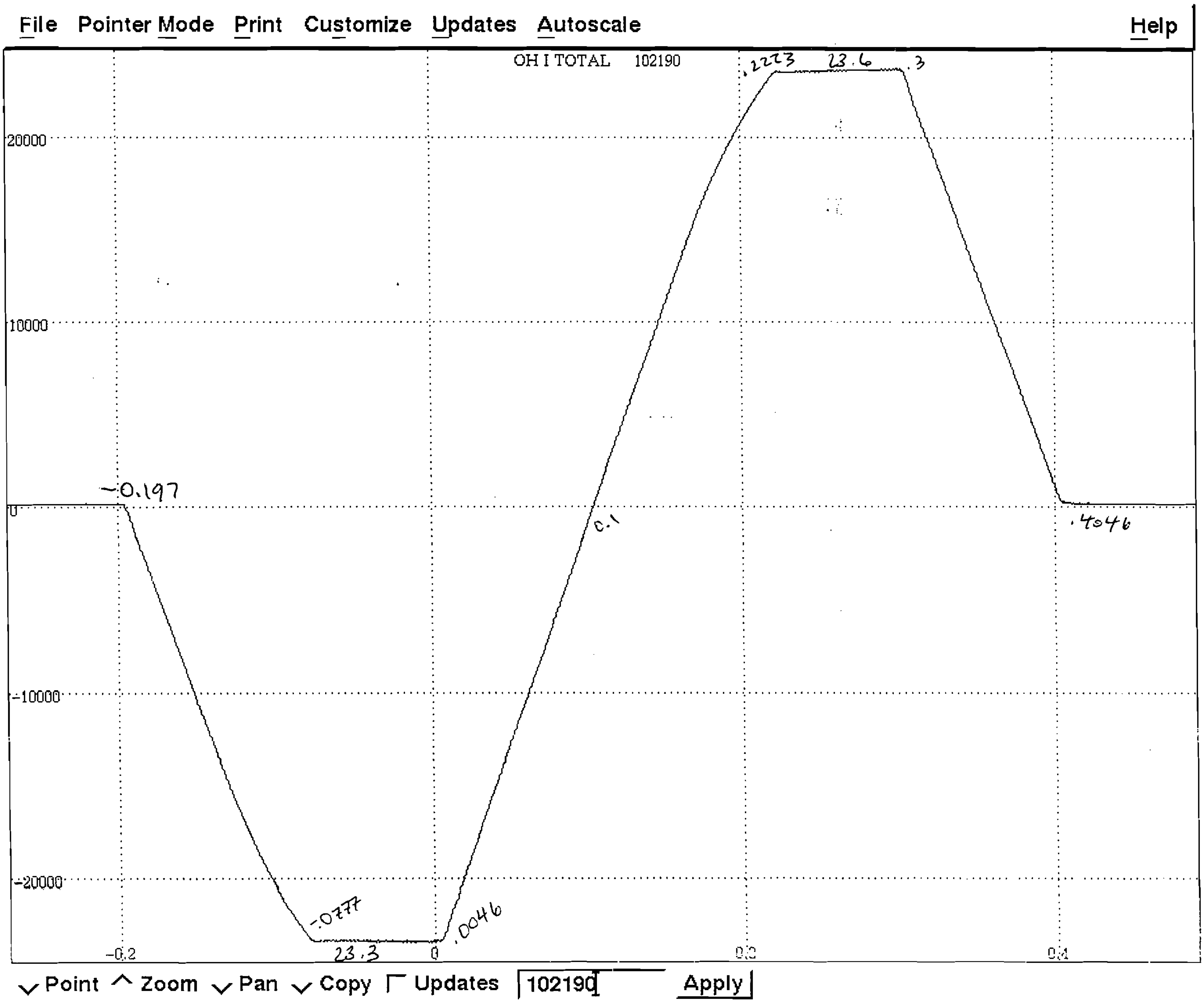
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