PPPL Calculation Form

Calculation # NCSX-CALC-132-01 Revision # 0 WP #, if any (ENG-032) 132

Purpose of Calculation: (Define why the calculation is being performed.)

To establish the temperature response and system cooling flow/pressure requirements, perform a thermo-hydraulic analysis of the NCSX PF4,5,&6 Coils.

References (List any source of design information including computer program titles and revision levels.)

1. F.Dahlgren thermo-hydraulic Analysis memo Dated: 21 Feb. 2008 (attached)

Assumptions (Identify all assumptions made as part of this calculation.)

See Refs. 1

Calculation (Calculation is either documented here or attached)

See Refs. 1

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

A thermo-hydraulic analysis of PF4, 5, & 6 for worst case I-sq. x T establishes the minimum pressure and flow requirements for the LN2 coolant system as presented in the attachment (ref.1).

Cognizant Engineer's printed name, signature, and date

Jim Chrzanowski, 22 Feb. 2008

Jim Chrzanowski

Digitally signed by Jim Chrzanowski
DN: cn=Jim Chrzanowski, o=PPPL, ou=Enginering, email=jchrzano@pppl.gov, c=US
Date: 2008.02.26 13:38:06 -05'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

Fred Dahlgren, 22 Feb. 2008

? Signature Not Verified

fdahlgre

Digitally signed by fdahlgre
DN: cn=fdahlgre, o=PPPL, c=US
Date: 2008.02.25 16:23:04 -05'00'

NCSX

Design Basis Analysis

PF-4, 5, & 6 Thermo-Hydraulic Calculations

NCSX-CALC-132-001-00

22 February 2008

Prepared by:

? fdahlgre Digitally signed by fdahlgre
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Date: 2008.02.25 16:23:23
-05'00'

Signature Not Verified

F. Dahlgren, PPPL

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct. I concur with analysis methodology and inputs and with the reasonableness of the results and their interpretation.

Reviewed by:

Jim Chrzanowski Digitally signed by Jim Chrzanowski
DN: cn=Jim Chrzanowski, o=PPPL,
ou=Enginering, email=jchrzano@pppl.gov, c=US
Date: 2008.02.26 13:38:28 -05'00'

J. Chrzanoski, Engineer

Introduction

Performance Requirements and Criteria

Methodology

A thermo-hydraulic finite difference code FCOOL was used which calculates flow based on the specified pressure drop, coolant properties (viscosity, density, conductivity, etc.), and conductor geometry. A full transient (forward difference) solution is performed which calculates the peak, wall, and coolant temperature at regular intervals along the coil coolant hole path. The determination of when the asymptotic solution is reached is based on a comparison of the final exit temperature from the last pulse to the current pulse and then checking the power balance for joule heating against the integrated power out (M-dot x Cp x ∂T).

Assumptions

- LN2 inlet temp. 77 K
- Pressure drop 90 psi -varied
- Current PF4 max. 15.15 kA
- ESW 0.65 seconds

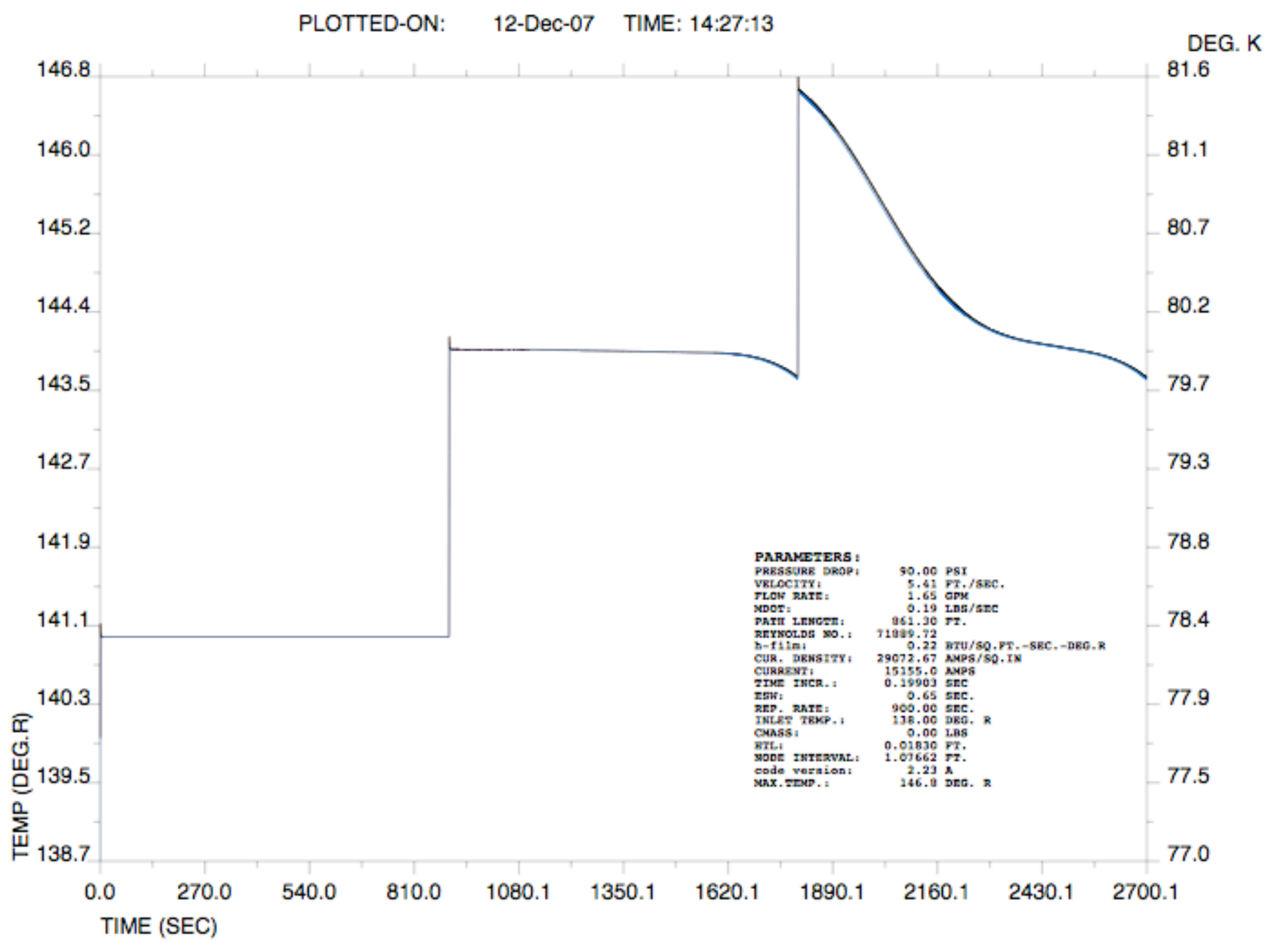
Dimensions & Properties

	PF1-3 U&L	PF4U	PF4L	PF5U	PF5L	PF6U	PF6L	TF
Total R per Coil at 80K (μ-ohms)	788	2030	2030	2594	2594	1852	1852	716
Total R per Coil at 20C (μ-ohms)	5228	13466	13466	17207	17207	12287	12287	4756
Total Conductor Length (in)	4012.8	10335.6	10335.6	13207.2	13207.2	9430.8	9430.8	4263.6
Total Conductor Length (ft)	334.4	861.3	861.3	1100.6	1100.6	785.9	785.9	355.3
Cross Section area (in^2)	0.521	0.521	0.521	0.521	0.521	0.521	0.521	0.608
# Turns	72	80	80	24	24	14	14	12
Current KAmps								
Total Conductor Length (ft)	334.4	**861.3**	861.3	**1100.6**	1100.6	**785.9**	785.9	355.3
Hole Area FT^2		**0.000685**	0.000685	**0.000685**	0.000685	**0.000685**	0.000685	
Gross Conductor Area FT^2 (.787in*.787in)		**0.004301**	0.004301	**0.004301**	0.004301	**0.004301**	0.004301	
ESW	0.76, 0.74, 0.59	**0.65**	0.65	**0.54**	0.54	**0.73**	0.73	
CURRENT (KA)	PF1&2: 23.438 PF3: 15.953	**15.155**	15.155	**7.728**	7.728	**8.195**	8.195	

- Per the reference drawings:

Results:

This is for PF4 @90 psi ∂P:



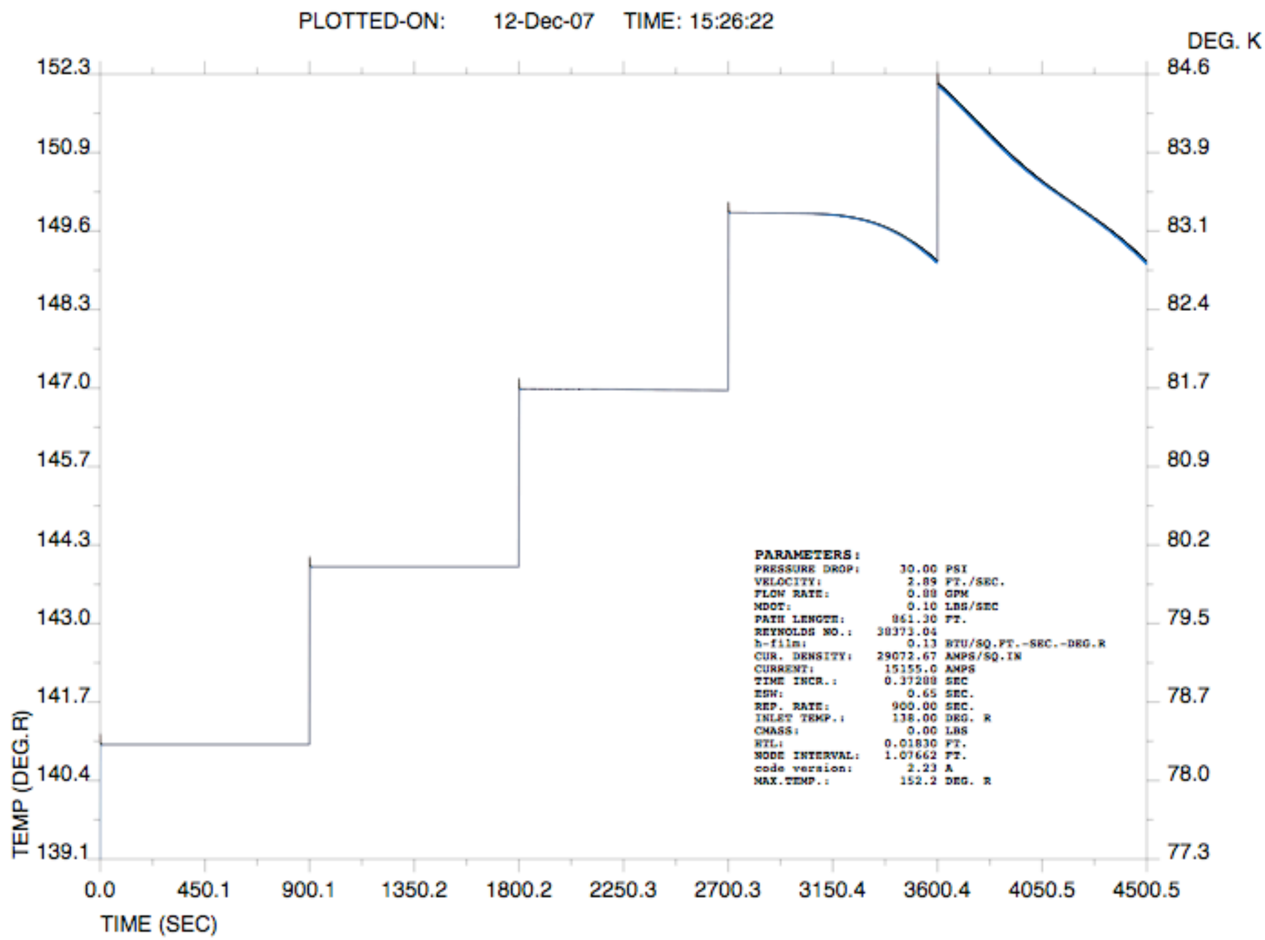
NCSX PF4 Coil LN2-cooling 15.15kA, 0.65 ESW

What is plotted is the temperature at the coil cooling duct exit. The flat response for the first couple of pulses indicates that the cooling wave has not traversed the full 862 foot length during the 900 seconds between pulses. The coil reaches an asymptotic solution over 3 pulses and will cycle between 79.9 and 81.6 deg.K for a regular rep rate of 900 secs.

PF4 @ 30 psi ∂p:

If we lower the pressure drop to 30 psi, the flow rate drops to 0.88 GPM, .1 lb/sec mass flow and we see more ratcheting requiring 5 pulses to reach equilibrium. The coil temperature per pulse will then cycle between 83 and 85 deg.K, again assuming a duty cycle of 900 seconds. The thermal response at the coolant exit is plotted below.

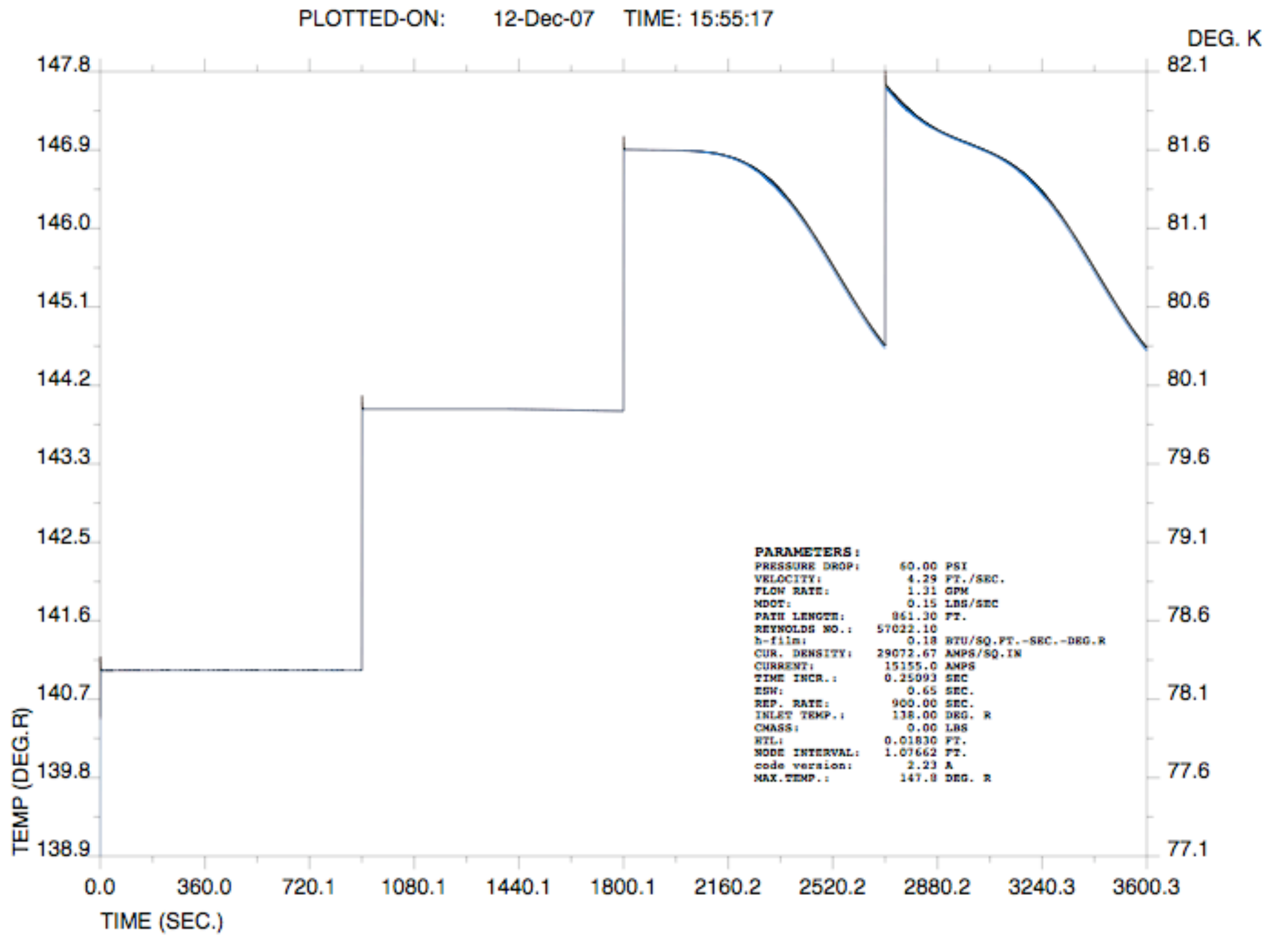
PF4 @ 30psi Pressure Drop (cont.):



NCSX PF4 Coil LN2-cooling 15.15kA, 0.65 ESW

PF4 @ 60 psi ∂P:

The results for a 60 psi pressure drop fall in between the 30 and 90 psi results as expected. The calculated flow rate is 1.3 GPM (0.15 lb/sec.) The coil reaches an asymptotic solution after 4 pulses, and cycles between ~80 and ~82 deg.K. The plot below shows the thermal response at the coolant exit of the coil.



NCSX PF4 Coil LN2-cooling 15.15kA, 0.65 ESW

Summary:

The thermo-hydraulic response for the worst case NCSX PF coil cooling was calculated for PF4 which has the longest cooling path length and highest I^2t for all operating scenarios defined in the GRD. Even for a relatively modest 30 psi pressure drop the maximum temperature rises only 8 deg.K before reaching equilibrium.

Appendix A PF4 @ 90 psi:

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NCSX PF4 Coil LN2-cooling 15.15kA, 0.65 ESW
COOLING ANALYSIS - FCOOL3TC223, COMPILED: 10/06/07
 Run Date: 12-Dec-07
 NOTE: COOLING FLUID: LN2
 starting fcool3t now
VELOCITY BASED ON IMPOSED FLOW OF     2.0 GPM:    6.55ft/sec
calculated velocity=    5.41 ft./sec. based on    1.65 gpm. imposed
pressure drop of  90.0psi.
 this flow will be updated with the mean fluid temperature every   1th
time step
 PL=   861.300 , V=   5.40929 , FLOAT(N)=   800.000
 Corrected DT & DL based on new V:  DT=  0.199033 , DL=  1.07662
 1/2 COND. AREA, COOLANT HOLE AREA, CURRENT, EQ. SQ. WAVE,PATH LENGTH, NO.
OF SEGMENTS:

   0.00362 SQ.FT.  0.000680 SQ.FT.   15155.0 AMPS     0.65 SEC     1.65
GPM    861.3 FT.   800 SEG.

 HEAT TRANS. LENGTH TO COOLANT, TIME BETWEEN PULSES, TIME INCREMENT,
VELOCITY OF COOLANT, LENGTH OF SLUG:

 0.018 FT.    900.0 SEC    0.1990 SEC    5.41 FT./SEC    1.077FT.

PRESSURE DROP:      90.00 PSI
VELOCITY:            5.41 FT./SEC.
FLOW RATE:           1.65 GPM
MDOT:                0.19 LBS/SEC
PATH LENGTH:       861.30 FT.
REYNOLDS NO.:   71889.72
h-film:              0.22 BTU/SQ.FT.-SEC.-DEG.R
CUR. DENSITY:   29072.67 AMPS/SQ.IN
ACOND:          0.003620 SQ. IN.
ESW:                 0.65 SEC.
REP. RATE:         900.00 SEC.
TIME INCR.:       0.19903 SEC
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.01830 FT.
NODE INTERVAL:    1.07662 FT.
HOLE DIAMETER:    0.02942 FT.
CPCU(TI)        0.048800 BTU/LB-DEG.R
CKCU:           0.088056 BTU/SEC.FT-DEG.F
CKFT(TI):      0.0000237 BTU/SEC-FT-DEG.R
CPCF(TI):      0.4857515 BTU/LB-DEG.R
RHOFT(TI):    50.6092940 LBS/CU.FT.
RHOC:         558.000000 (CONDUCTOR)LBS/CU.FT.
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code version: 2.23 A

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 AHTL =  0.212972 , ATUBE =  4.976152E-02
 nnpt =  800
 Beginning main iteration loop
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 starting pulse #:  1
 **********************
 I**2*t=   0.597E+09
 ADJUSTED MASS FLOW =  0.186508
 MEAN TEMP. : 139.3          % INCR. RESISTANCE:   0.016
 TIME=    0.6500
 COPPER TEMP. AFTER PULSE
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 FOR TIME =  157.088 , EXIT CONDITIONS AT NODE  800
     QDOT      QDOT1  TSTORE(I)  TMAX(I)   TW(I)     TB(I-1)     H(I)
    0.000000    0.000016  140.986400  140.986400  140.986400  140.986400
0.224682
 TIME=  900.1683
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0 POWEROUT =      133.8  POWER IN =      275.0 BTU


 INTEGRATED FLUID POWER OUT (MDOT*CPF*DTBULK) =  122.170
 PEAK # OF FILM ITERATIONS THIS PULSE WAS:  5
 THERE ARE  1393663  ANOMALOUS (NEGATIVE) HEAT FLUXES
 **********************
 starting pulse #:  2
 **********************
 I**2*t=   0.597E+09
 ADJUSTED MASS FLOW =  0.186928
 MEAN TEMP. : 141.0          % INCR. RESISTANCE:   0.037
 TIME=  900.8182
 COPPER TEMP. AFTER PULSE
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 FOR TIME =  1056.20 , EXIT CONDITIONS AT NODE  800
     QDOT       QDOT1  TSTORE(I)  TMAX(I)   TW(I)     TB(I-1)     H(I)
    0.000000    0.000000  143.975100  143.975100  143.975100  143.975100
0.228537
 TIME= 1800.1724
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0 POWEROUT =      244.4  POWER IN =      275.1 BTU


 INTEGRATED FLUID POWER OUT (MDOT*CPF*DTBULK) =  243.577
 PEAK # OF FILM ITERATIONS THIS PULSE WAS:  5
 THERE ARE  1150264  ANOMALOUS (NEGATIVE) HEAT FLUXES
 **********************
 starting pulse #:  3
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 I**2*t=   0.597E+09
 ADJUSTED MASS FLOW =  0.187008
 MEAN TEMP. : 141.3          % INCR. RESISTANCE:   0.042
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 TIME= 1800.8230
 COPPER TEMP. AFTER PULSE
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 Completed ESW pulse
 FOR TIME =  1956.04 , EXIT CONDITIONS AT NODE  800
     QDOT       QDOT1  TSTORE(I)  TMAX(I)   TW(I)     TB(I-1)     H(I)
    0.000681    0.000672  145.915430  145.915300  145.914800  145.855500
0.230741
 TIME= 2700.3312
 COPPER TEMP. BEFORE PULSE
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0 POWEROUT =       274.4  POWER IN =       275.1 BTU


 INTEGRATED FLUID POWER OUT (MDOT*CPF*DTBULK) =  275.458
 PEAK # OF FILM ITERATIONS THIS PULSE WAS:  5
 THERE ARE  1042982  ANOMALOUS (NEGATIVE) HEAT FLUXES
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 asymtotic solution. reached
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