LAWRENCE BERKELEY NATIONAL LABORATORY ENGINEERING NOTE	CODE AL-2032	SERIAL M7671	PAGE 1 of 8
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PROGRAM_PROJECT_JOB Bend Magnet Front Ends			
Photon Shutter Assembly			
TITLE Photon Shutter Clamped Stop Thermal Analysis			

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ABSTRACT

Steady-state thermal analysis using the Pro/Mechanica software package was used to evaluate temperature distribution in the modified design of a bend magnet front end photon shutter. Design revisions include replacing the brazed stop and shaft assembly with a clamped-on stop design. Based on the results tabulated here, the proposed design modifications are acceptable for typical bend magnet front end applications.

INTRODUCTION

In efforts to reduce cost and increase design flexibility, a new stop design for the photon shutter was proposed. The existing design employs a wire-brazed OFHC stop onto a stainless steel shaft. The shaft is internally cooled using a helical insert and water tube. Replacing the braze joint with a bolted-on stop significantly reduces cost and facilitates a modular approach to photon stop design, easily accomodating changes to beam width. The new design also replaces the helical insert cooling with a simple squirt tube.

DISCUSSION

Figure 1 shows the new paddle design for the photon stop next to the baseline brazed design. Both designs use a water-cooled stainless steel shaft to support the OFHC stop. Table I shows the power calculations used to determine the heat loads for input to the finite element model. The shaft and paddle (stop) were modelled with an ideal contact surface interface.

Though the heat loading for bend magnet beamlines may be approximated by a line load of 15 W/mrad at 1.9 GeV, at normal incidence a line load approximation is over-conservative. Therefore, a Gaussian distribution was used to distribute the power over the area of incidence with a stepped power load. The finite element model assumed full beam width across the stop, about 70 mm (8 mrad), yielding a total power of 120W. (The final design for the paddle was narrower, accepting only about 7 mrad.)

RESULTS

Table II contains the material property data for the FE model as well as constants used for the contact resistance calculations.[1] (See Figure 2 for FE results.) The contact resistance was approximated using these empirical contants and classical formulations for estimating thermal resistance.[2] The calculated estimate of temperature difference across the contact boundary was used to determine the percent increase in temperature due to the contact resistance. This factor was then applied to the finite element model results giving a range for the predicted overall ΔT (28°C) and resulting maximum temperature (53°C). These predicted maximum temperature with contact resistance included is about 66°C.

The cooling scheme was revised from an expensive helical insert within a large diameter circular channel to a

1. N. Roshenow and J. Hartnett, Handbook of Heat Transfer, McGraw-Hill, 1973.
2. J.P. Holman, Heat Transfer, 6th ed., p.55, McGraw-Hill, 1986.

simple squirt tube arrangement. Convection coefficients for both cases were calculated and the squirt tube was sized to provide sufficient cooling and a comparable film coefficient. (See Table III for details of trials for tubes with various flow parameters. The final design employs a squirt tube with outer wall of 19 mm and inner wall of 17 mm. Table IV. shows the film coefficient calculation.)

CONCLUSIONS

Based on the finite element results along with the empirical factors used for estimating the heating transfer across the contact boundary, the clamped design will satisfy the requirements of the brazed-on paddle design. Although this analysis used a total power load of about 120 W, equivalent to the stop receiving 8 mrad of beam, the resultant temperatures indicate that a wider stop, receiving 150W and 10 mrad would also be acceptable.

It is advisable to add a mechanical locking feature to the paddle design to prevent any possibility of the paddle sliding off the shaft should the clamping force be reduced or lost. With the addition of this feature, the new paddle design is acceptable.

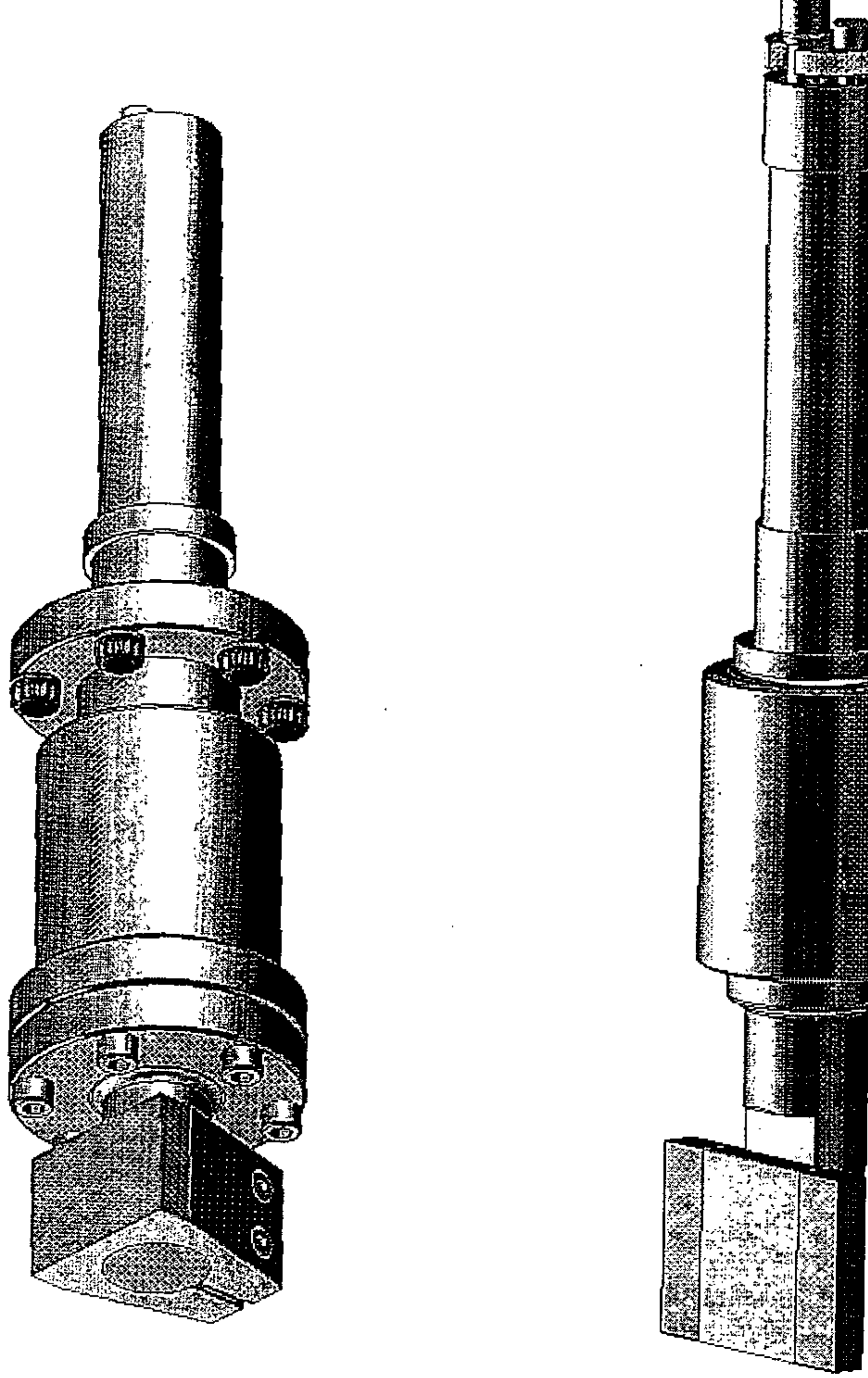

Figure 1. Clamped Photon Stop next to Brazed Design.

Table I. Heat Load Calculations

Heat Load Calculations for the Photon Stop (Bend Magnet Front Ends)						
Assume normal distribution given peak load of .46 W/mm2:						
Normal Distribution Parms		where x, f(x) are std normal d/n, ß=std. dev, μ=mean				
x	f(x)	y = (x-μ)/ß	f(y)			
0	0.3989	0	0.456	0.46	(peak)	
0.5	0.3521	0.95	0.403	0.40		
1	0.242	1.9	0.277	0.28		
1.18	0.19945	2.23	0.227	0.23		
Interval (mm)	Interval dist. (mm)	Load width (mm)	Load (W/mm2)	Total power (W/interval)		
0 - .95	0.95	70	0.46	30.59		
.95 - 1.95	1.00	70	0.40	28.00		
1.9 - 2.23	0.33	70	0.23	5.31		
			Total Power:	64	W (Half Model)	
			(8 mrad * 15 W/mrad = 120 W)			

Table II. Material Property Data and Contact Resistance Results

Material Property Data

Material		k	Area	Δx	E
		W/mm °C	mm^2	mm	GPa
OFHC		0.399	5065	8.4	119
Stainless		0.016	5065	12.2	193

Contact Resistance Estimates and FE Results

Hc[1]	A	$Rcu=\Delta x/(kA)$	$Rss=\Delta x/kA$	$Rc=1/(Hc*A)$	$Rth = \sum Ri$	$\Delta T=Q*Rth$	$\Delta Tc= (Rc/Rth)*\Delta T$	% ΔT due to Rc	Predicted Tmax*
W/mm^2 °C	mm	°C/W	°C/W	°C/W	°C/W	°C	°C		°C
0.003	5065	9.16E-03	0.064	0.06581112	1.39E-01	52.0	24.7	47.5	66.3
0.007	5065	9.16E-03	0.064	0.02820477	1.01E-01	37.9	10.6	27.9	60.8
0.011	5065	9.16E-03	0.064	0.01794849	9.08E-02	34.1	6.7	19.8	58.5

[1] Contact resistance parameters:
0.003 is for dissimilar materials (stainless/alum) at 10 psi contact pressure. (Ref. Handbook of Heat Transfer, p. 3-15)
.007 is for OFHC in vacuum at 10 psi contact pressure. (Ref. Handbook of Heat Transfer, p. 3-15)
.011 is for milled copper in vacuum (contact pressure about 100 psi) (Ref. Holman)

* = {% ΔT due to Rc} x FE predicted ΔT + FE predicted Tmax

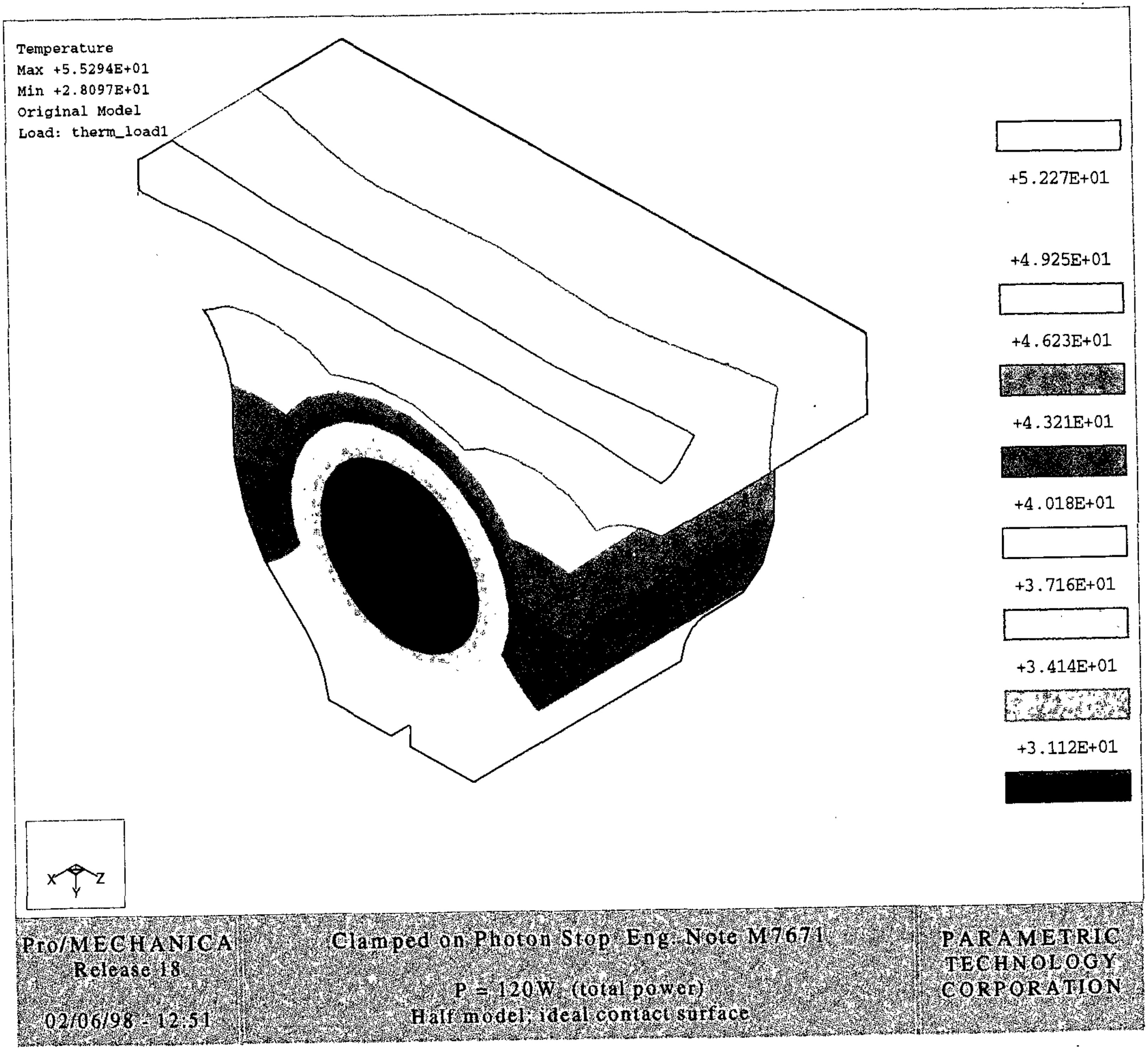
Temperature
Max +5.5294E+01
Min +2.8097E+01
Original Model
Load: therm_load1
+5.227E+01
+4.925E+01
+4.623E+01
+4.321E+01
+4.018E+01
+3.716E+01
+3.414E+01
+3.112E+01
X
Y
Z
Pro/MECHANICA
Release 18
02/06/98 - 12:51
Clamped on Photon Stop Eng. Note M7671
P = 120W (total power)
Half model; ideal contact surface
PARAMETRIC
TECHNOLOGY
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Table. III Flow Paramter Iterations for Squirt Tube

Do	Di	A	P	Dh = 4A	V=q/a	R	Dh (cm)	V (ft/s	A in2	P in	head lo	Delta P=h*g*	Delta P	Total De
					V=q/a (1.5 GPM)									
25.4	15.875	308.77	129.67	9.525	0.31	3377	0.9525	1.01	0.48	5.11	0.01	0.00	2.29	2.29
25.4	19	223.18	139.49	6.4	0.42	3139	0.64	1.39	0.35	5.49	0.04	0.01	2.30	2.30
25.4	22	126.57	148.91	3.4	0.75	2941	0.34	2.45	0.20	5.86	0.21	0.03	2.33	2.36
19	17	56.55	113.10	2	1.67	3872	0.2	5.49	0.09	4.45	1.78	0.26	1.49	1.75
6.35	0	31.67	19.95	6.35	2.99	21950	0.635	9.80	0.05	0.79	1.79	0.26		0.26
					V=q/a (2 GPM)									
25.4	15.875	308.77	129.67	9.525	0.41	4497	0.9525	1.34	0.48	5.11	0.02	0.00	2.30	2.30
25.4	19	223.18	139.49	6.4	0.56	4180	0.64	1.85	0.35	5.49	0.06	0.01	2.31	2.32
25.4	22	126.57	148.91	3.4	1.00	3916	0.34	3.27	0.20	5.86	0.37	0.05	2.36	2.41
25.4	24	54.32	155.19	1.4	2.32	3757	0.14	7.61	0.08	6.11	4.88	0.70	2.67	3.38
19	15.875	85.60	109.56	3.125	1.47	5322	0.3125	4.83	0.13	4.31	0.88	0.13	2.44	2.57
19	17	56.55	113.10	2	2.23	5156	0.2	7.31	0.09	4.45	3.15	0.45	2.64	3.10
2.41	0	4.56	7.57	2.41	27.62	77017	0.241	90.60	0.01	0.30	402.05	58.02		58.02
6.35	0	31.67	19.95	6.35	3.98	29230	0.635	13.05	0.05	0.79	3.17	0.46		0.46
					V=q/a (3 GPM)									
19	17	56.55	113.10	2	3.34	7734	0.2	10.96	0.09	4.45	7.09	1.02	3.09	4.12
19	15.875	85.60	109.56	3.125	2.21	7983	0.3125	7.24	0.13	4.31	1.98	0.29	2.64	2.92
6.35	0	31.67	19.95	6.35	5.97	43845	0.635	19.57	0.05	0.79	7.12	1.03	4.86	5.88
					V=q/a (5 GPM)									
19	17	56.55	113.10	2	5.57	12890	0.2	18.27	0.09	4.45	19.70	2.84	4.52	7.37
19	15.875	85.60	109.56	3.125	3.68	13305	0.3125	12.07	0.13	4.31	5.50	0.79	3.26	4.06
6.35	0	31.67	19.95	6.35	9.95	73075	0.635	32.62	0.05	0.79	19.79	2.86	9.42	12.28
19	6	255.25	78.54	13	1.23	18561	1.3	4.05	0.40	3.09	0.15	0.02	2.40	2.42
20	17	87.18	116.24	3	3.61	12541	0.3	11.85	0.14	4.58	5.53	0.80	3.23	4.03
8	0	50.27	25.13	8	6.27	58004	0.8	20.55	0.08	0.99	6.23	0.90	5.12	6.02

*Assumes f = .05 for stainless tube

** contraction in anulus from 19 to 17mm (other head losses include expansion from 6mm to 19 mm and 180° bend)

TABLE IV. CONVECTIVE FILM COEFFICENT CALCULATIONS FOR WATER

Fluid Flow Heat Transfer Equations 2/6/98

Change only Values that appear in Bold
This sheet for Rectangular Sections

HYDRAULIC DIAMETER Dh = 4A/P

A [sq.in.]	P [in.]	Dh [in.]	equivalent Diam [in.]
0.09	4.45	0.08	0.33

A [sq.cm]	P [cm]	Dh [cm.]
0.57	11.30	0.20

FLOW RATE q = VA
FLOW RATE Q [gal/min] = (q [cu.ft/sec])(60 [sec/min])(7.479 [gal/cu.ft])

V [ft/sec]	A [sq.ft]	q [cu.ft/sec]	Q [gal/min]
7.31	6.11E-04	4.47E-03	2.00E+00

REYNOLDS NUMBER= 4459
Re = (V [ft.sec] x Dh [ft] x rho [lbm/cu.ft]) / mu [lbm/ft.sec]

V [ft/sec]	Dh [ft]	rho [lbm/cu.ft]	mu [lbm/ft.sec]
7.31	6.59E-03	62.3	6.73E-04
		@20 deg.C	@20 deg.C

CONVECTION HEAT TRANSFER
Film Coefficient hf = (k/Dh) x Nu

Conductivity k [W/cm-K] @20°C	Hydraulic. Dia. Dh [cm]	Prandtl Pr @20°C
6.02E-03	0.200916854	8.56

per Seider and Tate Eqn's (+/- 25%)
Eq 6-2 (Conservative w/res to 6-3)

(mu/muW = 1) Nu	TURBULENT Film Coefficent hf [W/sq.mm-K]	Re > 3000	
		1.72E-02	for +25%
45.87	$\boxed{1.37E-02}$	1.03E-02	for -25%

WATER TEMPERATURE RISE
Delta-T [deg.C] = .0038 x P [W] / Q [gal/min]

P [W] *	Q [gal/min]	Delta-T [deg.C]	
400	2.00	0.8	<-Should be less than 40°C
100	2.00	0.2	

*See page 178 of Holman's Heat Transfer (Orange cover)
Recall Nu=hD/K

Eq. 6-5 Nusselt Number LAMINAR (assumes mu/muW = 1)	Channel Length L [cm]	LAMINAR Film Coefficent hf [W/sq.mm-K] (assumes Re Pr Dh/L>10)	hf +/- 25%	
			6.38E-03	for +25%
17.02	10.00	$\boxed{5.10E-03}$	3.83E-03	for -25%

For L= **800** mm
Re Pr Dh/L = 95.9