ILC Cryomodule Heat Load Estimate -- Basis and Summary

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Heat Load Spreadsheet

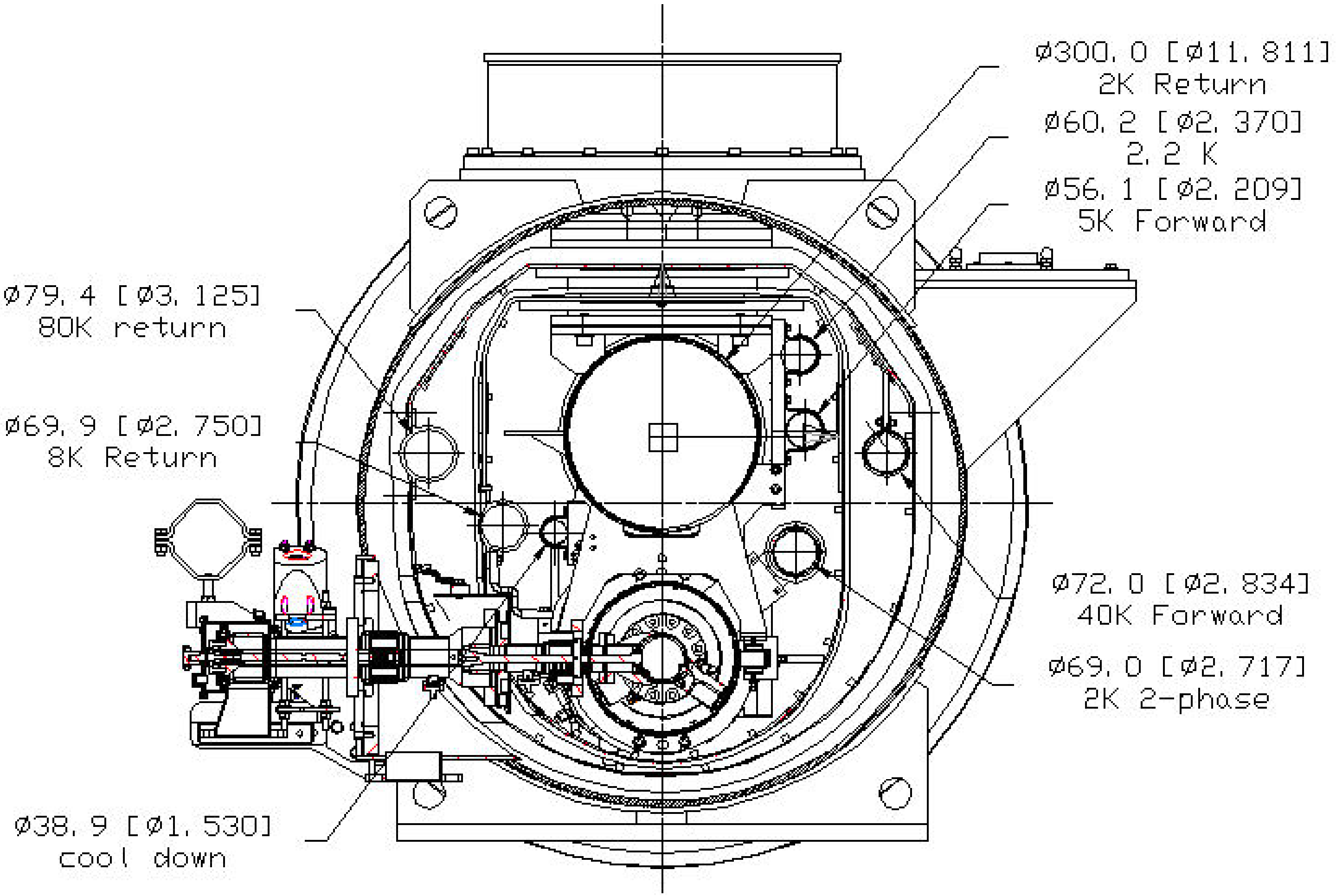
- Static heat loads still mostly scaled from TESLA TDR
- Dynamic heat loads scaled from TESLA TDR by Chris Adolphsen
- A working document (I.e., messy)
- Last updated April, 2008

Revision 6 March 2008 for new input coupler heat data and 23 April 2008 for support heat correction
Iteration of this heat load table with input from Chris Adolphsen, 5 Jan 07
with editing, addition of current leads, and ILC 9-8-9 by Tom Peterson, 9 Nov 06

Note: this is a working document. Contact Tom P. about using these numbers.

Cryomodule	TESLA	ILC 9-8-9					
			ILC 8-8-8 and 9-8-9 refers to the number of cavities in the modules in an RF unit				
E, [MV/m]	23.4	31.5	G				
Q	1.E+10	1.E+10					
Rep rate, [Hz]	5	5					
Number of Cavities	12	8.667	avg number of cavities per module		Mar-08		
Fill time [µsec]	420	597	Tf		Substitute the data below		
Beam pulse [µsec]	950	969	Tb		for the TESLA TDR numbers		
Number of bunches	2820	2670	Nb		Coupler data from Linac 2004		
Particles per bunch [1e10]	2	2.04	Qb		by W-D Moeller et. al.		
Gfac		2.09	Stored Energy Factor = G^2*(Tb + 1.1*Tf)		2 K	4 K	70 K
Pfac		1.54	Input Power Factor = G*(Tb + 2*Tf)*Cfac	0 power	0.02	0.20	1.90
Bfac		0.99	Bunch Factor = Nb*Qb^2	TESLA	0.06	0.50	6.00
Cfac		0.95	Beam Current Factor = Qb*Nb/Tb	my conclusion net dyn	0.04	0.30	4.10

Type 4 cryomodule



Module predicted heat loads -- 2K

- Re-evaluated -- input coupler
  - **Updated coupler numbers from W-D Moeller**
  - **1.7 + 9.7 = 11.4 W --> 1.32 + 10.04 = 11.4 W per CM**
- Current lead estimate based on LHC leads
- No re-evaluation of cable heat loads
- No dark current heat load

Temperature Level	2K		2K				
RF load		4.95		7.46	Dynamic load scaled by the number of cavities and Gfac		
Supports	0.60		0.60	-	Assume independent of number of cavities		
Input coupler	0.24	0.48	0.17	0.53	Static load scaled by number of cavities, dynamic by Pfac also		
HOM coupler (cables)	0.01	0.27	0.01	0.18	Static and dynamic load scaled by number of cavities, dynamic by Cfac also		
HOM absorber	0.14	0.02	0.14	0.01	Dynamic load scaled by Bfac		
Beam tube bellows		0.24		0.36	Dynamic load scaled by the number of cavities and Gfac		
Current leads	0.04		0.28	0.28	Weigh by a factor of 1/3 since only 1 in 3 modules have quads**		
HOM to structure		1.68		1.20	Static load scaled by the number of cavities, dynamic by Bfac also		
Coax cable (4)	0.05		0.05		Assume independent of number of cavities		
Instrumentation taps	0.07		0.07		Assume independent of number of cavities		
Scales as Gfac		5.19		7.83			
Scales as Pfac		0.48		0.53			
Independent of G,Tf	1.15	1.97	1.32	1.68			
Static, dynamic sum	1.15	7.64	1.32	10.04	Total for 9-8-9 RF unit below	Total for one cavity below	
2K Sum [W]	8.8		11.4		34.09	1.00	1.311

Module predicted heat loads -- 5K

- Re-evaluated -- input coupler
  - **Updated coupler numbers from W-D Moeller**
  - **10.56 + 4.37 = 14.9 W --> 10.82 + 7.05 = 17.9 W**
- Current lead estimate based on LHC leads
- No other re-evaluation

	5K		5K		
Radiation	1.95		1.41		Static load scaled by number of cavities
Supports	2.40		2.40		Assume indepent of number of cavities
Input coupler	2.40	3.60	1.73	4.00	Static load scaled by number of cavities, dynamic by Pfac also
HOM coupler (cables)	0.40	2.66	0.29	1.82	Static and dynamic load scaled by number of cavities, dynamic by Cfac alsc
HOM absorber	3.13	0.77	3.13	0.76	Dynamic load scaled by Bfac
Current leads			0.47	0.47	Weigh by a factor of 1/3 since only 1 in 3 modules have quads**
Diagnostic cable	1.39	-	1.39	-	Assume independent of number of cavities
Scales as Pfac		**3.60**		**4.00**	
Independent of G,Tf	**11.67**	**3.43**	**10.82**	**3.04**	
Static, dynamic sum	**11.67**	**7.03**	**10.82**	**7.05**	Total for 9-8-9 RF unit below
5K Sum [W]	**18.7**		**17.9**		53.60

Module predicted heat loads -- 40K

- Re-evaluated -- input coupler and posts
  - Updated coupler numbers from W-D Moeller
  - Updated support post numbers from P. Pierini
  - 59.2 + 94.3 = 153.5 W --> 75.0 + 83.0 = 158 W
- No other re-evaluation

Note: Paolo says post heat at 40 K in TDR was low by factor 3, so 3 X TESLA

	40K		40K		
Radiation	44.99		32.49		Static load scaled by number of cavities
Supports	6.00		18.00		Assume indepent of number of cavities
Input coupler	22.80	49.20	16.47	54.73	Static load scaled by number of cavities, dynamic by Pfac also
HOM coupler (cables)	2.55	13.22	1.84	9.04	Static and dynamic load scaled by number of cavities, dynamic b
HOM absorber	(3.27)	15.27	(3.27)	15.04	Dynamic load scaled by Bfac
Current leads	13.00	5.00	4.13	4.13	Weigh by a factor of 1/3 since only 1 in 3 modules have quads**
Diagnostic cable	5.38		5.38		Assume indepent of number of cavities
Scales as Pfac		49.20		54.73	
Independent of G,Tf	91.45	33.49	75.04	28.22	
Static, dynamic sum	91.45	82.69	75.04	82.95	Total for 9-8-9 RF unit below
40K Sum [W]	**174.1**		**158.0**		473.98

Note: Paolo

Cryogenic unit parameters

RDR (27 Feb 2007)

Heat and Power Summary (9-8-9)

		40 K to 80 K	5 K to 8 K	2 K
Predicted module static heat load	(W/module)	59.19	10.56	1.70
Predicted module dynamic heat load	(W/module)	94.30	4.37	9.66
Number of modules per cryo unit (8-cavity modules)		192.00	192.00	192.00
Non-module heat load per cryo unit	(kW)	1.00	0.20	0.20
Total predicted heat per cryogenic unit	(kW)	30.47	3.07	2.38
Heat uncertainty factor on static heat (Fus)		1.10	1.10	1.10
Heat uncertainty factor on dynamic heat (Fud)		1.10	1.10	1.10
Efficiency (fraction Carnot)		0.28	0.24	0.22
Efficiency in Watts/Watt	(W/W)	16.45	197.94	702.98
Overcapacity factor (Fo)		1.40	1.40	1.40
Overall net cryogenic capacity multiplier		1.54	1.54	1.54
Heat load per cryogenic unit including Fus, Fud, and Fo	(kW)	46.92	4.72	3.67
Installed power	(kW)	771.72	934.91	2577.65
Installed 4.5 K equiv	(kW)	3.53	4.27	11.78
Percent of total power at each level		18.0%	21.8%	60.2%
Total operating power for one cryo unit based on predicted heat (MW)			3.34	
Total installed power for one cryo unit (MW)			4.28	
Total installed 4.5 K equivalent power for one cryo unit (kW)			19.57	

Cryogenic unit parameters

now (15 Nov 2008)

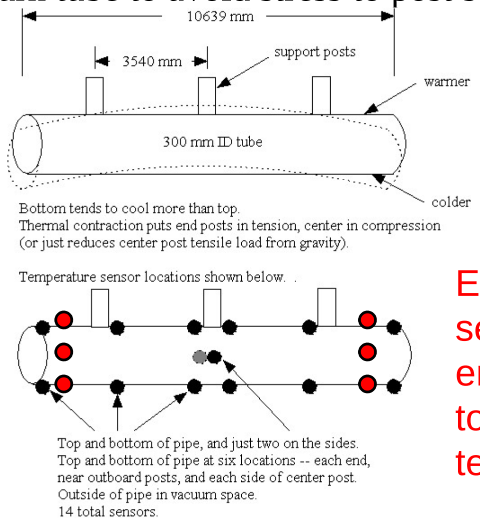
Heat and Power Summary (9-8-9)

		40 K to 80 K	5 K to 8 K	2 K
Predicted module static heat load	(W/module)	75.04	10.82	1.32
Predicted module dynamic heat load	(W/module)	82.95	7.05	10.04
Number of modules per cryo unit (8-cavity modules)		192.00	192.00	192.00
Non-module heat load per cryo unit	(kW)	1.00	0.20	0.20
Total predicted heat per cryogenic unit	(kW)	31.33	3.63	2.38
Heat uncertainty factor on static heat (Fus)		1.10	1.10	1.10
Heat uncertainty factor on dynamic heat (Fud)		1.10	1.10	1.10
Efficiency (fraction Carnot)		0.28	0.24	0.22
Efficiency in Watts/Watt	(W/W)	16.45	197.94	702.98
Overcapacity factor (Fo)		1.40	1.40	1.40
Overall net cryogenic capacity multiplier		1.54	1.54	1.54
Heat load per cryogenic unit including Fus, Fud, and Fo	(kW)	48.26	5.59	3.67
Installed power	(kW)	793.63	1106.62	2578.20
Installed 4.5 K equiv	(kW)	3.63	5.06	11.78
Percent of total power at each level		17.7%	24.7%	57.6%
Total operating power for one cryo unit based on predicted heat (MW)			3.49	
Total installed power for one cryo unit (MW)			4.48	
Total installed 4.5 K equivalent power for one cryo unit (kW)			20.46	

Biggest change is 5-8 K dynamic heat from input coupler -- 4.5% effect on cryoplant size

Cryomodule CM1 instrumentation

CM1 instrumentation

Proposal	Primary Objective
COOLDOWN T-SENSORS **<u>Thermal Shields</u>** 2 CERNOX at bottom of 5 K shield, 2 Pt at bottom of 80 K shield **<u>GHe Return Pipe</u>** **Preferred**: Install 14 Platinum RTDs on the outside wall of GHe Return Pipe (as specified in T. PetersonÕs note of 8/27/07) **Minimum**: 2 CERNOX at lower middle GHe return pipe, 3 CERNOX at each end, inside the pipe, wires coming out of feed and return box.	Control Top-to-Bottom thermal gradient in 300mm GHe return tube to avoid stress to post supports  Ended up with six sensors, three at each end, on inside of pipe, to detect vertical temperature gradient
COOLDOWN STRAIN GAUGES Install a total of 5 Strain gauges: 3 axial on column supports 1, 2, & 3; 1 transverse on the 5K shield and 80K shield at the fingers.	The results of this test are to validate the stress model on cool down with the goal of optimizing the cool down rate.
HOM T-SENSORS Install one CERNOX RTD on each HOM coupler, 16 total	To monitor the temperatures of the HOM cavity couplers.

Comments on CM tests

- Goal of instrumentation in single cryomodule operation is observation and control of cool-down and warm-up
- We do not expect to measure heat loads accurately with a single cryomodule
  - **End effects dominate, such as thermal radiation into the cryomodule from the ends**
  - **We will monitor total system conditions but will not be able to attribute heat specifically to the cryomodule**
- With three cryomodules in NML we may have a measurement on the central CM
  - **But of course a longer string would provide a better heat load signal**

ILC cryogenic system work status

ILC Cryogenics Work Status

- RDR cryogenic system effort totalled less than 1 FTE for the duration of the RDR effort
- Early EDR (now called TDR) work package development (2007) suggested tripling that to 3 FTE's (one from each region) for the duration of the TDR
- For the past year we have had less ILC cryogenics effort than during the RDR
- The current budget indicates that we could get back up to about the RDR level of 1 FTE (1/2 FTE in U.S. plus KEK effort on cryogenics, plus small effort in Europe from INFN and DESY)
- Result -- only a few minor updates to the ILC cryomodule heat load estimates and cryoplant size estimates have been done

ILC cryogenic system priorities for a low-level of effort

- Experimental and analytical reassessment of not only total static and dynamic heat at each temperature level but also the uncertainty factors which should be applied. These parameters have a direct impact on cryoplant sizes and cryogenic system cost estimate.
  - **Note that the relatively small input coupler adjustment described above, mostly at the 5 K level, resulted in nearly a 5% effect on cryogenic plant power.**
- Integration of the cryogenic plant cycle with cryomodule cooling should be studied. Temperature and pressure levels in cryomodules, particularly in the thermal shields, should be evaluated in the context of the full process through the cryoplants. These results may affect cryomodule design via optimized temperature and pressure levels.