Water Cooling issue
(Klystron Cooling)

- S. Fukuda

- We're ask to evaluate LCW water system delta T.
- In order to evaluate this (and confirm cost savings), we need more info on the water cooled component and we ask your help in updating or getting more information for each of those items.

Getting the table filled will be helpful, **but as minimum,** the following for each water cooled components are needed

- combination of either one of the following (Load/Flow, or Load/Delta T or Flow/Delta T)
- Maximum allowable temperature
- Pressure drop (corresponding to a given flow)

- If possible, information to be given is agreed upon by the group
- We appreciate Shigeki-san's help in getting the information started

Nov 27b 2006

WATER AND AIR HEAT LOAD (all LCW) and 9-8-9 ML

MAIN LINAC - ELECTRON & POSITRON

Snapshot

Nov 27 2006

Components	Quantity Per 36m	Location	To Low Conductivity Water: Heat Load to Water (KW)	Max Allowable temperature	Supply Temp (variation) (C)	Delta Temperature (C delta)	Water Flow (l / min)	m Allowable Pressure (Bar)	Typical (water) pressure drop Bar	Acceptable Temp Variation delta C	Chilled Water: Heat Load to Water (KW)	keith Jobe load to air Nov 22 06: Power fraction to Tunnel Air (0-1)	Power to Tunnel Air (KW)
RF Components													
RF Charging Supply 34.5 Kv AC-8KV DC	1/36 m	Service Tunnel	2.8		40	40	1.17	18	8	10	0	0.3	1.2
Switching power supply 4kV 50kW	1/36 m		4.5		35	13.6	7.6	13	8	10	0	0.4	3.0
Modulator	1/36 m	Service Tunnel	4.5					28.823			0	0.4	3.0
Pulse Transformer	1/36 m	Service Tunnel	0.7								0	0.3	0.3
Klystron Socket Tank / Gun	1/36 m	Service Tunnel	0.8								0	0.2	0.2
Klystron Focusing Coil (Solenoid)	1/36 m	Service Tunnel	3.6								0	0.1	0.4
Klystron Collector	1/36 m	Service Tunnel	45.8		*35>				2		0	0.0	1.4
Klystron Body	1/36 m	Service Tunnel	0.0		*35>				5	+ / 2.5 C	0		
Klystron Windows	1/36 m	Service Tunnel	0.0		*35>				1		0		
Relay Racks (Instrument Racks)	1/36 m	Service Tunnel	0.0		N/A	N/A		N/A	N/A	None	11.5	-0.2	-1.5
Attenuators	2/36 m	Service Tunnel	0.0										
Circulators	**26/36 m**	**Beam Tunnel**	32.3									0.1	1.7
Loads	**24/36 m**	**Beam Tunnel**								+ - 2.5 C	0		
Waveguide (in service tunnel)	1/36 m	Service Tunnel											
Waveguide (in beam tunnel)	**1/36 m**	**Beam Tunnel**	3.5							+ - 2.5 C	0	0.1	0.4
Total RF			100.0								11.5		26.1

Total Heat load to Chilled water (per RF)	37.6
Total Heat load to LCW (per RF)	100.0

cooled by chilled water

cooled by low conductivity water

Cooling Specification of DESY's MBK

2.0	**Buyer operating conditions:**		
	Water inlet temperature (if not stated otherwise)		25 - 40° C
	Environment		indoor
2.3	Collector cooling water	Inlet temperature	25°-63°C
		Outlet temperature	≤ 87°C
		Inlet pressure	3.5 bar, typical 10bar, max.
		Differential pressure	0.1 bar, typical 0.3 bar, max
		Test pressure	15 bar (design feature 20 bar)
		Water flow: ≤ 85 l/min at 5Hz repetition rate ≤170 l/min at 10Hz repetition rate	

The Klystron must be capable to be operated as diode under these parameters.

1.16	Phase drift as function of inlet cooling water temperature change	≤ 3°/ °C, objective
1.21	Maximum body power dissipation at full rf output power No performance degradation due to body interception shall occur.	≤ 3.5% of DC input power

2.4 Body and window cooling water

Water flow	10 l/min total
Differential pressure	1 bar
Inlet temperature	25°C –40°C
Inlet pressure	5 bar typical 10 bar max.
Test pressure	15 bar (20 bar design objective)

2.18 Focusing electromagnet:

weight	A
water cooling	10 l/min max.
Inlet pressure	5bar typical 10bar max
test pressure	15bar (20bar design objective)
differential pressure	1bar max.
electrical power, voltage and current	<4kW, <100V, <100A objective, A

General Calorimetric Calculation

- P(kW):Average power
- ΔT (deg): delta C
- Q(liter/min) : flow rate

$$P \cdot 10^3 = \frac{4.18 \cdot Q \cdot 10^3}{60 \cdot \Delta T}$$

then

$$14.37 = \Delta T(\deg) \cdot \frac{Q}{P}(liter/\min/kW)$$

put

$$K = \frac{14.37}{\Delta T} = \frac{Q}{P}(liter/\min/kW)$$

If one of three parameters, P, ΔT ,and Q is specified, other 2 parameters are correlated.

At MLI-KOM, Wilhelm pointed out the Thales guide line parameter of cooling K Is 0.8 (liter/min/kW), and this value is a common accepted value from the cooling of the collector (by Toshiba engineer).

Test data of Toshiba MBK

- Conditions

  Pulse width of 1.7 ms, repetition of 10 Hz, Output power of 10MW (with efficiency is 66%). → Beam peak power =15.18MW

  Average beam power=258kW

- Cooling data

  Water flow Q= 170 liter/min, Temperature rise ΔT =22 deg.

  ↓

  K=0.66 liter/min/kW (smaller than K=0.8)

  If we choose K=0.8, then ΔT =26.7 deg, and Q=206 liter/min

So Toshiba has better efficiency of cooling than the K=0.8 case.

Though it is nice data, we use K=0.8 as the standard collector cooling.

Collector power dissipation(1)

- In ILC, diode-mode operation (operation without rf drive) is not performed to reduce the cooling load. About the 35% of the beam power is dissipated at collector if klystron efficiency is 65%.
- From Chris Adolphsen's Cooling informations(2006/11/20 and 26(revised)), average collector load is 45.7-47.2(revised)kW. Worst case of 8.5MW, collector load increased to 57.9-58.9(revised)kW.
- Assuming K=0.8 (liter/min/kW) (this is equal to set ΔT=18 degrees),
  the case of P=45.7kW and Q=37 liter/min (revised 38 liter/min).
- What happens at worst case, P=57.9 and Q=37, then ΔT =22 deg.
- Other parameters from DESY's specification
  Typical pressure drop: Toshiba achieved nominal value of 0.1 Bar for vertical klystron against the maximum allowable pressure drop of 0.3 Bar in DESY. For horizontal MBK, nominal value is increased to 0.3 Bar and Toshiba case, they didn't measure the value but piping got longer by 1m.
  Not different from 0.1 Bar in this case.
- All test pressures for the cooling system are 15 Bar and this should be the maximum allowable pressure.

Collector power dissipation(2)

- Inlet water temperature is specified in the range from 25 deg to 63 deg. Allowable maximum outlet temperature is 87 deg. From this value,

  22 deg= 87 deg -63 deg. is the ΔT for the maximum inlet temperature case.

  Toshiba achieved this as described before and corresponding K value =0.66 liter/min/kW.

- From this data and low pressure drop in the collector, we may have a choice of series connection of the collector within the satisfaction of these data.

Body and Window cooling

- In DESY's specification, water channel of body and window are the same, and it is OK to consider the body cooling mainly because window power dissipation is quite small.
- For body loss of the beam in the klystron, maximum allowable body loss is less than 3.5% of the total beam power.
- This corresponds to 124kW from Chris A 's calculation. 3.5% corresponds to 4.34kW. This is larger than the Chris Adolpsen's estimation.
- Toshiba's test data
  For the vertical MBK, body loss was 1% of total beam loss (corresponds to 1.24kW). For the case of horizontal MBK, it was 1.9% of total beam loss (corresponds to 2.36kW).

- More important issue is the phase variation of MBK. Cooling of the first 3 internal cavities effecting the bunching of the beam has a large effect for the phase shift. Specification is 3 deg. phase shift/1 deg water temperature change.
- From the maximum acceptable phase shift (it depends on LLRF control), acceptable water temperature variation is determined. Slow variation is easy to be controlled by LLRF.

Body and Window cooling (cont)

- Maximum allowable pressure drop is 15 Bar (test only), and nominal is 10 Bar. This is also applied to the window cooling, so that it is amazing specification. Usually window uses the thin copper plate for the brazing with ceramic window, and klystron vendor want to use the low pressure. Typical operation is 5 Bar.
- Inlet temperature range is specified from 25 deg to 40 deg. so if the variation is small, there is no problem for the phase shift of the klystron.

Cooling issues for the MBK Focusing Magnet

- DESY's specification, power is less than 4kW for the vertical MBK and 5.5 kW for the horizontal MBK.
- There are no specification of the inlet temperature range, while magnet has the sensor which sets to 80 degrees as the maximum temperature inside.
- Pressure drop is specified to be 1 Bar.

WATER AND AIR HEAT LOAD (all LCW) and 9-8-9 ML

MAIN LINAC - ELECTRON & POSITRON

Components	Quantity Per 36m	Location	To Low Conductivity Water: Heat Load to Water (KW)	Max Allowable Temperature (c)	Max Allowable temperature	Supply Temp (variation) (C)	Delta Temperature (C delta)	Water Flow (l / min)	Maximum Allowable Pressure (Bar)	Typical (water) pressure drop Bar	Acceptable Temp Variation delta C	to Chilled Water: Heat Load to Water (KW)	keith Jobe load to air Nov 22 06: Power fraction to Tunnel Air (0-1)	Power to Tunnel Air (KW)	Max Space Temp (C)
RF Components															
RF Charging Supply 34.5 Kv AC-8KV DC	1/36 m	Service Tunnel	2.8			40	40	1.17	18	5	10	0	0.3	1.2	
Switching power supply 4kV 50kW	1/36 m	Service Tunnel	4.5			35	13.6	7.6	13	5	10	0	0.4	3.0	
Modulator	1/36 m	Service Tunnel	4.5						28.823			0	0.4	3.0	
Pulse Transformer	1/36 m	Service Tunnel	0.7									0	0.3	0.3	
Klystron Socket Tank / Gun	1/36 m	Service Tunnel	0.8									0	0.2	0.2	
Klystron Focusing Coil (Solenoid	1/36 m	Service Tunnel	5.5>	80.0		55	8	10	15	1		0	0.1	0.4	85 F (a)
Klystron Collector	1/36 m	Service Tunnel	45.8	63.0		38	22	37	15	0.3		0	0.0	1.4	
Klystron Body	1/36 m	Service Tunnel	4.2	40.0		15	6	>10	15	4.5	+ - 2.5 C	0			
Klystron Windows	1/36 m	Service Tunnel										0			
Relay Racks (Instrument Racks)	1/36 m	Service Tunnel	0.0	N/A		N/A	N/A		N/A	N/A	None	11.5	-0.2	-1.5	
Attenuators	2/36 m	Service Tunnel	0.0											0.0	
Waveguide (in service tunnel)	1/36 m	Service Tunnel	0.00											1.166	
Waveguide (in penetration)	1/36 m	Penetration	0.676												
Waveguide (in beam tunnel)	**1/36 m**	**Beam Tunnel**	0.0								+ - 2.5 C	0		5.9	
Circulators	**26/36 m**	**Beam Tunnel**	2.49								+ - 2.5 C	0		0.0	
Loads	**24/36 m**	**Beam Tunnel**	30.05								+ - 2.5 C			0.0	
Subtotal RF unit Only			96.5												
Total RF			98.0									11.5		21.4	

Total Heat load to Air/Chilled water in service tunnel (per RI	32.9 KW	cooled by chilled water
Total Heat load to LCW (per RF)	98.0 KW	cooled by low conductivity water
Total Heat load to air in beam tunnel (ignore rock contribution for r	5.9 KW	pending