RF Power and Cooling Requirements

Overview from “Main Linac Power and Cooling Information” document, Chris Adolphsen Jan 07 and Chris Nantista “ILC-NOTE-2007-035”

Components	Location	Total Heat Load (KW)	Average Heat Load (KW)	Heat Load To Water (KW)	Heat Load to Air (KW)
RF Charging Supply 34.5 Kv AC-8KV DC	Service Tunnel	4.0	4.0	2.8	1.2
Switching power supply 4kV 50kW	Service Tunnel	7.5	7.5	4.5	3.0
Modulator	Service Tunnel	7.5	7.5	4.5	3.0
Pulse Transformer	Service Tunnel	1.0	1.0	0.7	0.3
Klystron Socket Tank / Gun	Service Tunnel	1.0	1.0	0.8	0.2
Klystron Focusing Coil (Solenoid)	Service Tunnel	4.0	4.0	3.6	0.4
Klystron Collector/ Body/Windows	Service Tunnel	58.9	47.2	45.8	1.4
Relay Racks (Instrument Racks)	Service Tunnel	10.0	10.0	0.0	-1.5
Circulators, Attenuators & Dummy Load	Accelerator Tunnel	42.3	34.0	32.3	1.7
Waveguide	Accelerator Tunnel	3.9	3.9	3.5	0.4
Subtotal Main Linac RF unit Only			120		

Basic System Parameters

- Pulse rep rate = 5 Hz
- RF pulse length = 1.565 ms (flattop)
- Duty = 0.78%
- Bunch train length = 0.969 ms
- Beam Current = 9.0 mA
- Klystron peak power after window = 10.0MW
- Klystron efficiency = 65.0%: this is the ILC design goal, and has been achieved (and exceeded).

Modulator Efficiency

- Modulator efficiency = 82.8% : this efficiency, which is the ratio of the average power in the flattop portion (1.565 ms) of the modulator HV pulses divided by the average charging supply input power, is based on Chris Jensen's estimate of losses including those in the charging supply, modulator and transformer and those from rise time effects.
- (See below: 120.4+11.5+8.5+5.0=145.40 , Efficiency: 120.4/145.40= 82.8%)

Some Assumptions

- To compute the AC and cooling loads, assume all modulators run at nominal power and that on average, the beam absorbs a fixed amount of power. The power lost in the klystron (mainly the collector) and the RF distribution system (i.e., attenuators, waveguides, circulators and loads) depends on the average RF power level.

- For the klystron collector heat load, **assume 8.5 MW rf output power** as a worst case, and

- for the distribution system, **assume 10.0 MW klystron operation** and a 25.0 MV/m average rf unit gradient. From these assumptions, the cooling capacity required for each of these systems can be computed –

- the **total capacity will thus be larger than the average heat load**, which equals the modulator output power minus the average increase in beam power.

Non-routine operation

- Note that for non-routine operation at klystron power levels below 8.5 MW (e.g. with the rf off but the modulator on), the ***HV pulse would be shortened, the modulator voltage lowered or the repetition rate decreased*** so the klystron collector heating does not exceed that for 8.5 MW RF operation at the nominal klystron voltage pulse width and pulse repetition rate.
- For beam operation at lower than nominal gradient and/or current, the modulator voltage would be lowered to limit the average heat load. When operating below 25.0 MV/m on average in an RF unit with large cryomodule gradient differences, the RF power (and hence average gradient of some cryomodules) may need to be lowered to limit the attenuator load heating.

123.3 kW

- With these assumptions, the wall plug AC capacity is equal to the wall plug AC power consumption: that is, CF&S should not assume any average reduction in consumption relative to capacity as had been suggested in the past.
- For the cooling, the capacities should match the maximum heat loads that are discussed below. However, the total rf-related heat load per rf unit will not exceed the wall plug power (160.4 kW - see below for other AC related loads) minus the nominal power absorbed by the beam (9.0e-3 A * 26 * 1.038 m * 31.5e6 V/m * 5 Hz * 0.969e-3 sec = 37.1 kW per rf unit), or 123.3 kW.

AC power for rf generation:

- Using the above specifications,
- Wall Plug (34.5 kV) Power = 10.0e3 * 1.565e-3 * 5 / (65.0%* 82.8%) = 145.4 kW

HV source heat loads

- The charging system dissipation is 11.5 kW, which is 11.5/145.4= 7.9%
- The modulator/pulse transformer dissipation is 8.5 kW, which is 8.5/145.4= 5.8%
- The rise time losses, which dissipate 5.0 kW in the klystron collector, is 5.0/ 145.4= 3.4%
- So the total is 17.1% including rise time effects, and 13.7% excluding them. The average modulator output power during the rf pulse is 10.0e3 * 1.565e-3 * 5 / 65.0% = 120.4 kW.
- The rise time losses can be accounted for by assuming the HV pulse is square and is 5.0 kW / 120.4 kW = 4.2% longer than the rf pulse (i.e. 1.631 ms)

Klystron heat loads

- With our rise time assumption, the average modulator output power is 10.0e3 * 1.042* 1.565e-3 * 5 / 65.0%= 125.4 kW, and this power is either dissipated in the klystron or transmitted as RF from the klystron. As our worst case, with 8.5 MW RF pulses just after the klystron windows, the power dissipated in the klystron equals the modulator output power (125.4 kW) – average klystron RF output power (8.5e3 * 1.565e-3 * 5 = 66.5 kW) = 58.9 kW.

- The average load should be computed assuming 10.0 MW output power as this will likely be close to the nominal running conditions (the power assumed for this purpose is not critical as long as the klystron + rf distribution losses = modulator output – beam input power on average). In this case, the klystron heating is 47.1 kW.

RF distribution heat loads

- With 10.0 MW klystron output power and the nominal beam energy gain (at 31.5 MV), the average losses in the RF distribution system are equal to the klystron output power (10.0e3 * 1.565e-3 * 5 = 78.3 kW) – minus the beam energy gain (37.1 kW – see above) = 41.2kW. As noted above, the ***maximum losses*** should assume 10.0 MW klystron power and 25.0 MV/m average gradient. In this case the attenuator + circulators + loads + waveguide losses are 48.9 kW.
- For the waveguide losses, assume 5.0% *(8.5% CN)* of the specified klystron output power of 78.3 kW = 3.9 *(6.7 CN)* kW (average and maximum), while the remainder (*34.5 CN* 37.3 kW average, 45.0 kW maximum) goes to attenuators, circulators and loads.

RF Distribution Detail

(Chris Nantista ILC-NOTE-2007 November 2007)

The RF power from the klystron is

Nominal	8.363 MW pk.	65.44 kW avg.
Estimated (12% overhead)	9.38 MW pk.	73.4 kW avg.
Maximum	10 MW pk.	78.25 kW avg.

The nominal power needed at the accelerator cavities is 59.85 kW.

The nominal power that goes into the beam is 37.10 kW.

The power reflected from cavities to circulator loads (or absorbed in attenuators) is:

Nominal	22.75 kW
Estimated (12% overhead)	30.03 kW
Maximum (full power)	34.47 kW + 1.43 kW per detuned cavity

RF Distribution Detail --- 2

(Chris Nantista ILC-NOTE-2007 November 2007)

The additional power dissipated in transmission is:

Nominal	5.59 kW
Estimated (12% overhead)	6.27 kW
Maximum (full power)	6.68 kW

RF Distribution Detail --- 3

(Chris Nantista ILC-NOTE-2007 November 2007)

RF PDS Heat Loads by region	service tunnel	penetration	accelerator tunnel
Nominal	1.01 kW	0.607 kW	26.72 kW
Estimated (12% overhead)	1.13 kW	0.679 kW	34.49 kW
Maximum (full power)	1.21 kW	0.725 kW	39.22 kW

Accelerator Tunnel Heat Load to Air (including reflect. attn., w/out WR770 cooling)

	Perfect cooling	90% efficient cooling
Nominal	2.83 kW (1.39 kW circ.)	5.08 kW
Estimated (12% overhead)	3.22 kW (1.56 kW circ.)	6.19 kW
Maximum (full power)	3.46 kW (1.81 kW circ.)	6.87 kW

RF Distribution Detail --- 4

(Chris Nantista ILC-NOTE-2007 November 2007)

REMOVING THE HEAT

The total heat load per RF station for the PDS should fall in the range 28.3–41.2 kW, probably around 36.3 kW. Approximately 3% of this will be in the service tunnel and must be dealt with as a small part of that tunnel's large heat load. Approximately 2% will be in the penetration and should be removed by water-cooling the penetration waveguide, as air circulation here would presumably be negligible with the service tunnel end blocked by radiation shielding. Roughly 86% goes into water-cooled circulators and loads. This leaves about 9% (~3.3 kW) going to the accelerator tunnel air. This percentage can significantly increase, as seen above, if the water-cooling is not perfect. It needs to be removed from the tunnel by some combination of air conditioning and additional water cooling

Other rf related AC power:

- Solenoid power - assume 4.0 kW, which is the Toshiba spec (3.6 kW) plus cable /PS losses – the table lists 8.4 kW.
- 1.0 kW for the klystron filament heat losses –
- Finally, the latest rack heat load estimate is 10.0 kW.

Total rf related AC power and heat loads

- The total rf-related AC power = 145.4+ 4.0 + 1.0 + 10.0 = 160.4 kW, and the total average (nominal) heat load is 123.3 kW.
- The table below summarizes the loads derived above and the heat dissipated to air based on Keith Jobe's guesses for the various fractional losses (with the exception of the Attenuators, Circulators and Loads, which I reduced from 15% to 5% since they can be readily insulated).

The Table

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