Cryomodule Helium Vessel Pressure -- a Few Additional Comments

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Update of Oct 2007 Comments

- October, 2007, slides summarizing helium vessel pressure issues are appended here
- We should review helium vessel maximum pressures in light of DESY "crash test" and pressure tests
- We should review vacuum vessel venting in light of LHC magnet vacuum space overpressure incident

Crash and pressure test comments

- 2 bar warm and 4 bar cold maximum differential pressures (MAWP) were an initial compromise choice
  - **2 bar warm for cryogenic operation**
  - **4 bar cold to accommodate worst-case loss of vacuum pressure rise**
- DESY crash test slow pressure development at 2 K with maximum of about 2.5 bar
  - **4 bar MAWP looks conservatively high**
  - **Still need to evaluate maximum pressure with venting path from string of cryomodules**
- Pressure test indicates possibility of one pressure rating -- 4 bar warm or cold
  - **Means pressure testing at around 5 bar warm**

Vacuum vessel venting

- Can LHC-type accident occur in SRF string?
- LHC (*my unofficial account of the events*) -- electrical arc, rupture of 2 K helium bellows and release of helium into insulating vacuum space at LHC
  - **LHC magnets quenched into insulating vacuum space**
    - Pressure starts at about 1.2 bar nominal
    - Flow driven by higher pressure from magnet string quench
    - In contrast, 2 K RF system starts at 30 mbar
    - 2 K RF system does not have the stored energy of a magnet system
  - **LHC high pressure (~16 bar) thermal shield line also subsequently ruptured into vacuum space**
    - Several sources of pressure due to rupture of several lines
  - **Magnet motion due to pressure in vacuum space**

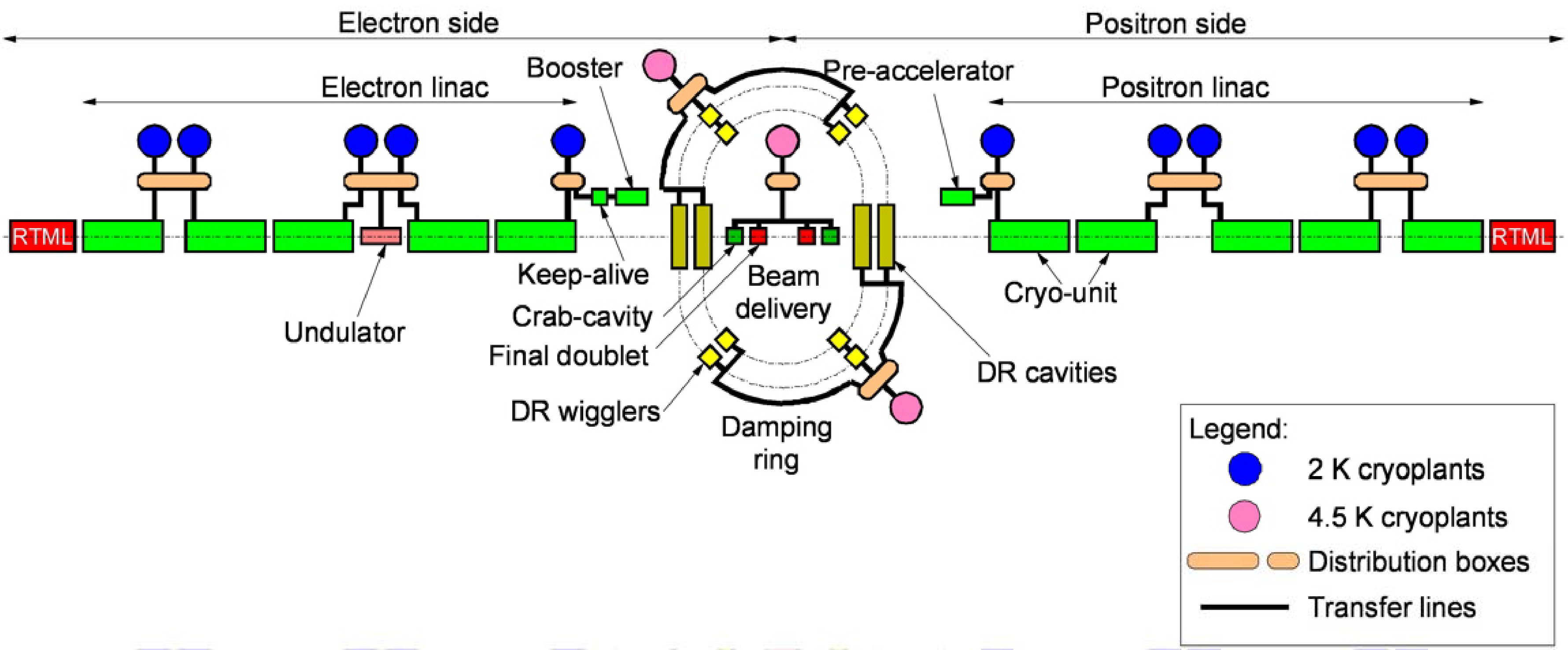
ILC vacuum vessel venting

- Low pressure and low stored energy in 2 K part of SRF system
- However, ILC concept includes high pressure shields
  - **18 - 20 bar is current plan, but pressures need to be evaluated with cryogenic plant cycle**
  - **In any case, shield pipe up to 80 mm ID, so potentially very large flow into vacuum space**
- Cryomodule strings will require large and frequent vacuum relief ports
  - **Need to evaluate path to relief port (through thermal shields, not blocked by MLI, etc.)**
  - **XFEL is also re-evaluating vacuum space venting requirement**

Reference slides

From October, 2007

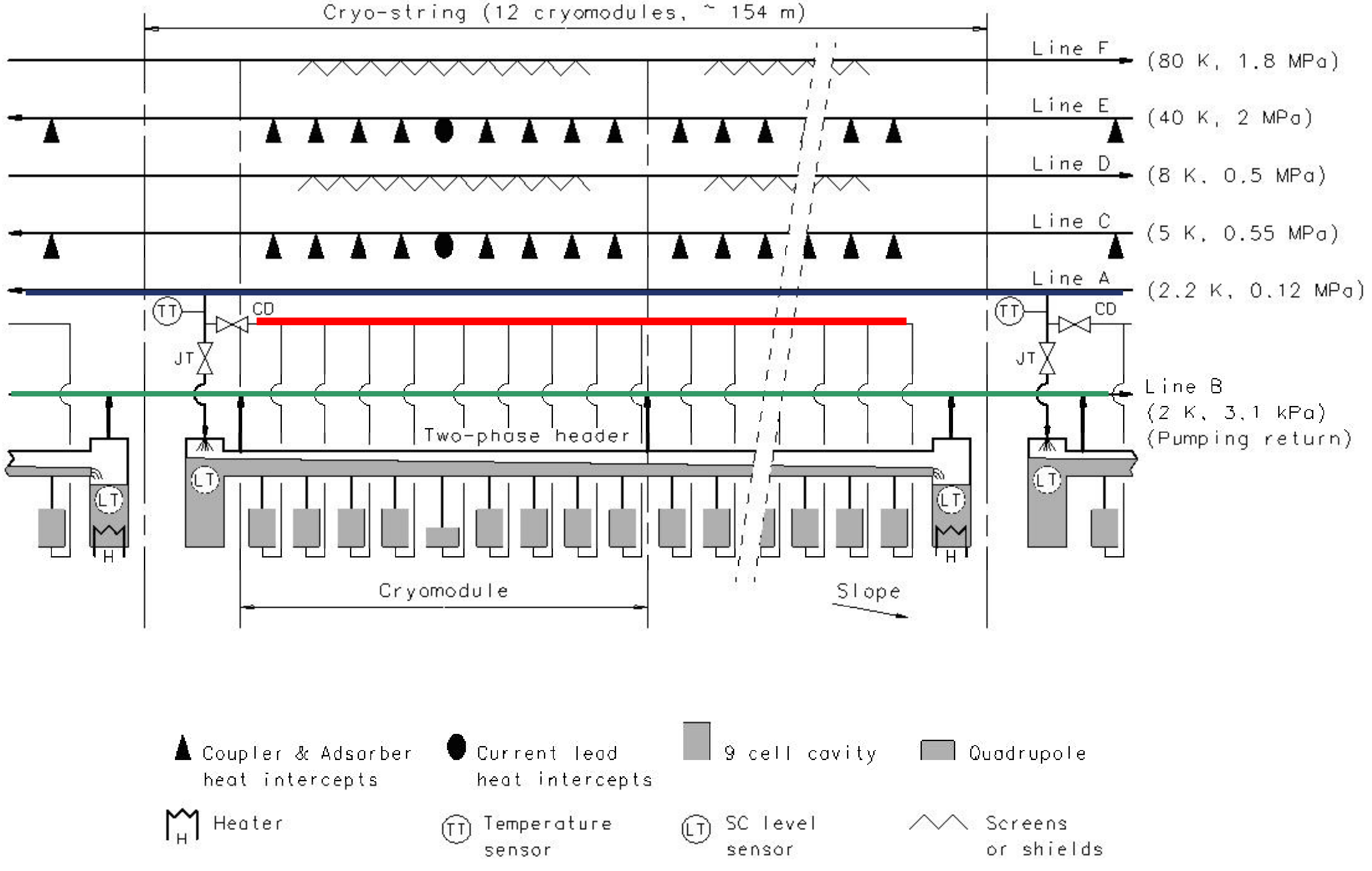
Cryogenic plant arrangement



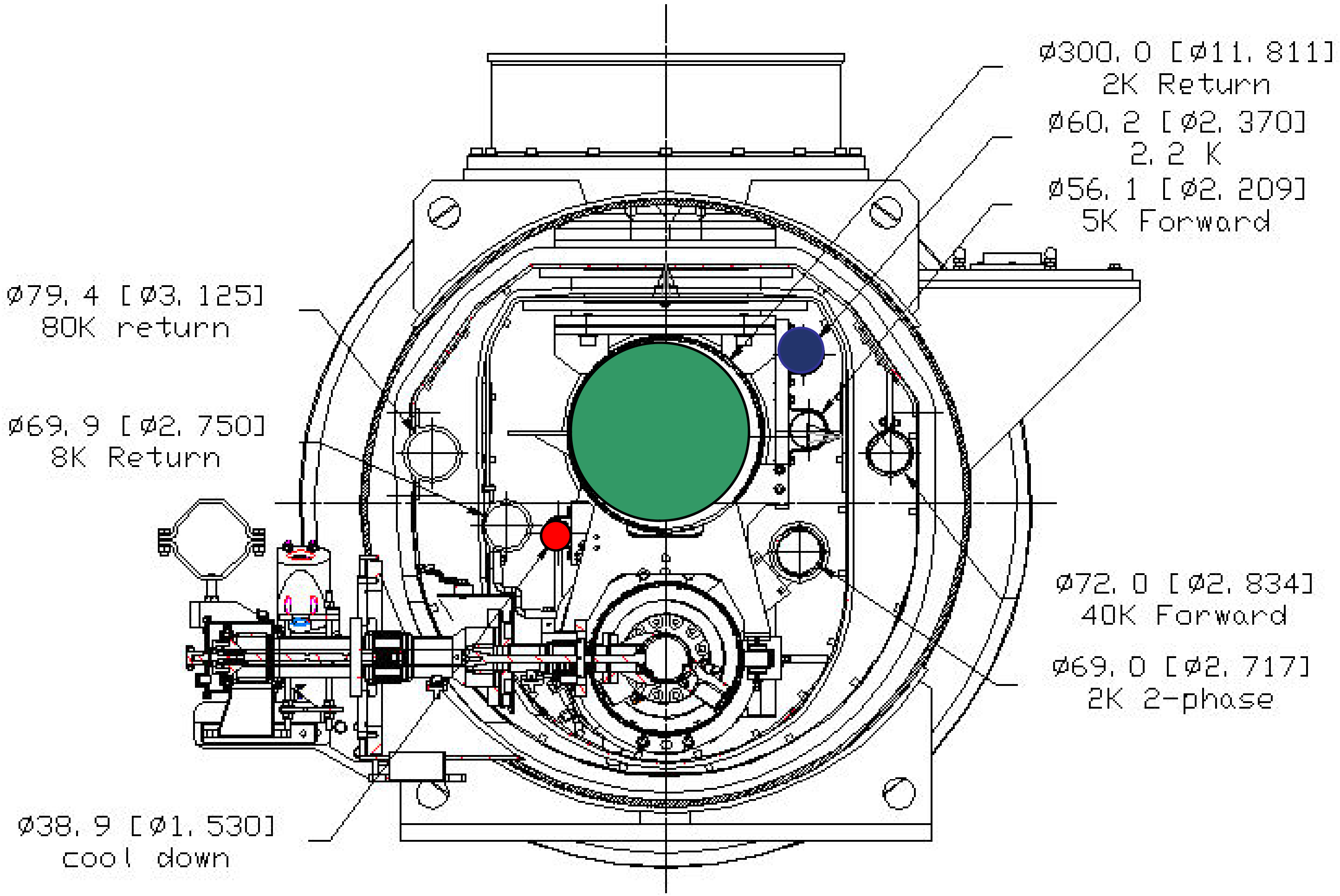
Causes of pressure excursions

- Worst case location is probably always the cavity helium vessels in the string 2.4 km from the cryogenic plant
- Purification and cool-down flow
- Warm-up flow
- Compressor failure (e.g., power outage)
- Control and/or valve failures
- Loss of insulating vacuum while cold
- Loss of cavity vacuum while cold

A cryogenic "string"



Type 4 cryomodule pipe sizes



Pipe size summary as of July 07

Pipe function	BCD name	TTF inner diameter (mm)	XFEL plan inner diameter (mm)	**ILC and T4CM proposed inner dia (mm)**	ILC allowed pressure drop
2.2 K subcooled supply	A	45.2	45.2	**60**	0.10 bar
Major return header, structural supp't	B	300	300	**300**	3.0 mbar
5 K shield and intercept supply	C	54	54	**56.1**	
8 K shield and intercept return	D	50	65	**70**	0.20 bar (C+D)
40 – 80 K shield and intercept supply	E	54	65	**72**	
40 - 80 K shield and intercept return	F	50	65	**80**	1.0 bar (E+F)
2-phase pipe		72.1	>72.1	**72.1**	
Helium vessel to 2-phase pipe cross-connect		54.9	54.9	**54.9**	

Purification and cool-down

300 mm pipe, 2.5 km long
1.5 bar, 300 K

Mass flow (g/sec)	Pressure drop (bar)
100	0.009
200	0.032
300	0.065
400	0.109
500	0.165

60 mm pipe, 2.5 km long
20 bar, 300 K

Mass flow (g/sec)	Pressure drop (bar)
100	1.509
200	5.830
300	-----
400	
500	

- XFEL paper states that the 2.2 K supply line limits flow, confirmed above
  - **Numerical simulations for the cooldown of the XFEL and TTF superconducting linear accelerators by K. Jensch, R. Lange, B. Petersen**
- Appears to be less than 0.1 bar delta P in line B for all possible warm flow conditions as limited by line A.

Compressor shutdown

- Suction pressure rises to the suction relief valve settings
  - **Pressure sits at the suction relief pressure while helium vents**
  - **Unlike higher pressure reliefs, helium must vent outside of system**
    - Large loss of helium inventory
    - Low pressure volume of 210,000 liters per cryogenic unit
    - However, each 0.1 bar helium = only about 26 liquid liters equiv
  - **Need relief set pressure safely above anticipated operating pressures to avoid accidental, unnecessary, loss of helium**

Peak warm pressure

- Compressor suction set pressure
  - **1.2 bar**
- Control margin
  - **+/- 0.2 bar**
- Relief set pressure margin
  - **0.3 bar (a judgment here, would like 0.5 bar)**
- Suction relief set pressure
  - **1.7 bar**
- Pressure drop from far string
  - **0.1 bar**
- Peak warm pressure
  - **1.8 bar (note that 0.5 bar set P margin ==> 2.0 bar)**

Cold peak pressures - 1

- Loss of vacuum to air
  - **“Safety Aspects for the LHe Cryostats and LHe Containers,” by W. Lehman and G. Zahn, ICEC7, London, 1978**
    - “3.8 W/sq.cm. for an uninsulated tank of a bath cryostat”
    - “0.6 W/sq.cm. for the superinsulated tank of a bath cryostat”
  - **“Loss of cavity vacuum experiment at CEBAF,” by M. Wiseman, et. al., 1993 CEC, Advances Vol. 39A, pg 997.**
    - Maximum sustained heat flux of 2.0 W/sq.cm.
  - **LEP tests and others have given comparable (2.0 to 3.8 W/sq.cm.) or lower heat fluxes**
  - **Film boiling of helium with 60 K surface is about 2.5 W/sq.cm.**

Cold peak pressures - 2

- Relief pressure will be suction relief set pressure (for example, 1.7 bar)
- Heat flux of 10’s of KW to liquid helium
- Mass flows of many kg/sec
- Pressure drops to vent may result in peak pressures of 3 - 4 bar locally
- TTF, TESLA, and XFEL analyses have been done
- Fermilab has done analyses of single cavity systems

Cold peak pressures in TTF/ILC

- Analyses of TTF and TESLA back in the early 1990's indicated that worst-case loss of vacuum might lead to pressures near 4 bar cold
- Also have recent XFEL analysis (need to find, but comparable results, no more than 4 bar)
- Input parameters
  - **Heat flux as limited by**
    - Rate of air inleak
    - Suface heat transfer
  - **Total surface area involved**
    - Can be limited by vacuum breaks, fast valves
  - **Initial conditions**
    - Note that 4.5 K just after filling is the worst case!

Ongoing work

- Analyses already done for single-cavity system
  - **Include FEA of helium vessels**
  - **Include venting and pressure drop calculations**
- Working on full cryomodule pressure analysis now
  - **Needed for ILCTA-NML**
  - **Cryogenic end boxes on order**
- Engineers are working on helium vessel design for pressure containment with low stress (Fermilab and INFN)
  - **End group stresses and design**
  - **Bellows stresses design**
  - **Tuner loads, stresses, and design**
  - **RF cavity stresses**
- Venting and pressure limits are a cryogenics WP

Pressure tests

- DESY will do cold vacuum loss studies of a cryomodule at CMTF
- Labs could do warm tests of pressure effect on cavity tune
  - **What pressure warm results in some permanent detuning, some yielding**
  - **Do not yet see from analyses what is yielding at 2 bar -- should validate analytical models**
- Labs could do cold tests
  - **Sequentially pressurize at 5 K, reduce pressure and test at 2 K, (perhaps 4.2 K?), etc.**