Kryo-Betrieb beim XFEL (Betrieb am Limit/Wechselwirkung mit RF Betrieb)

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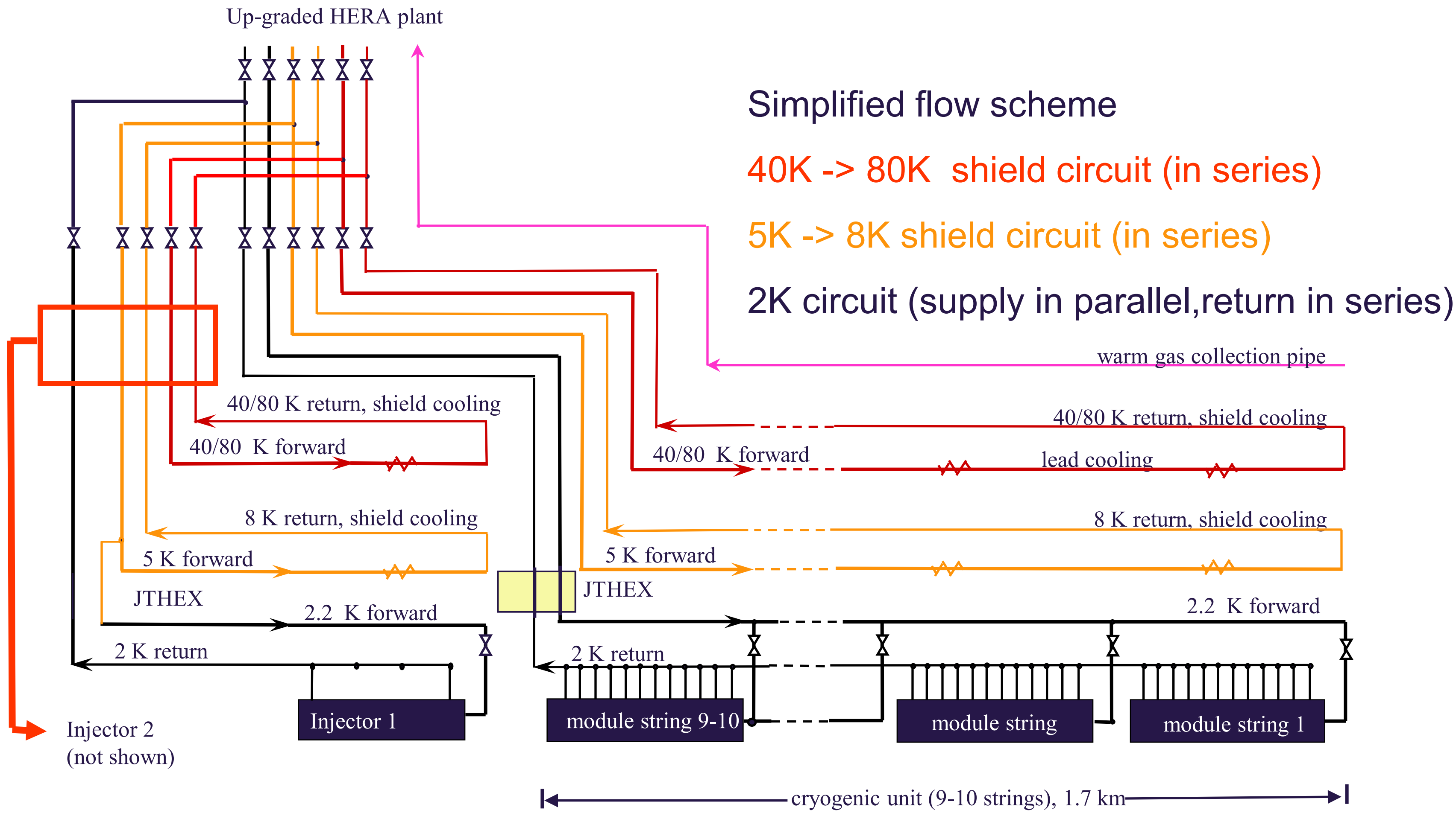
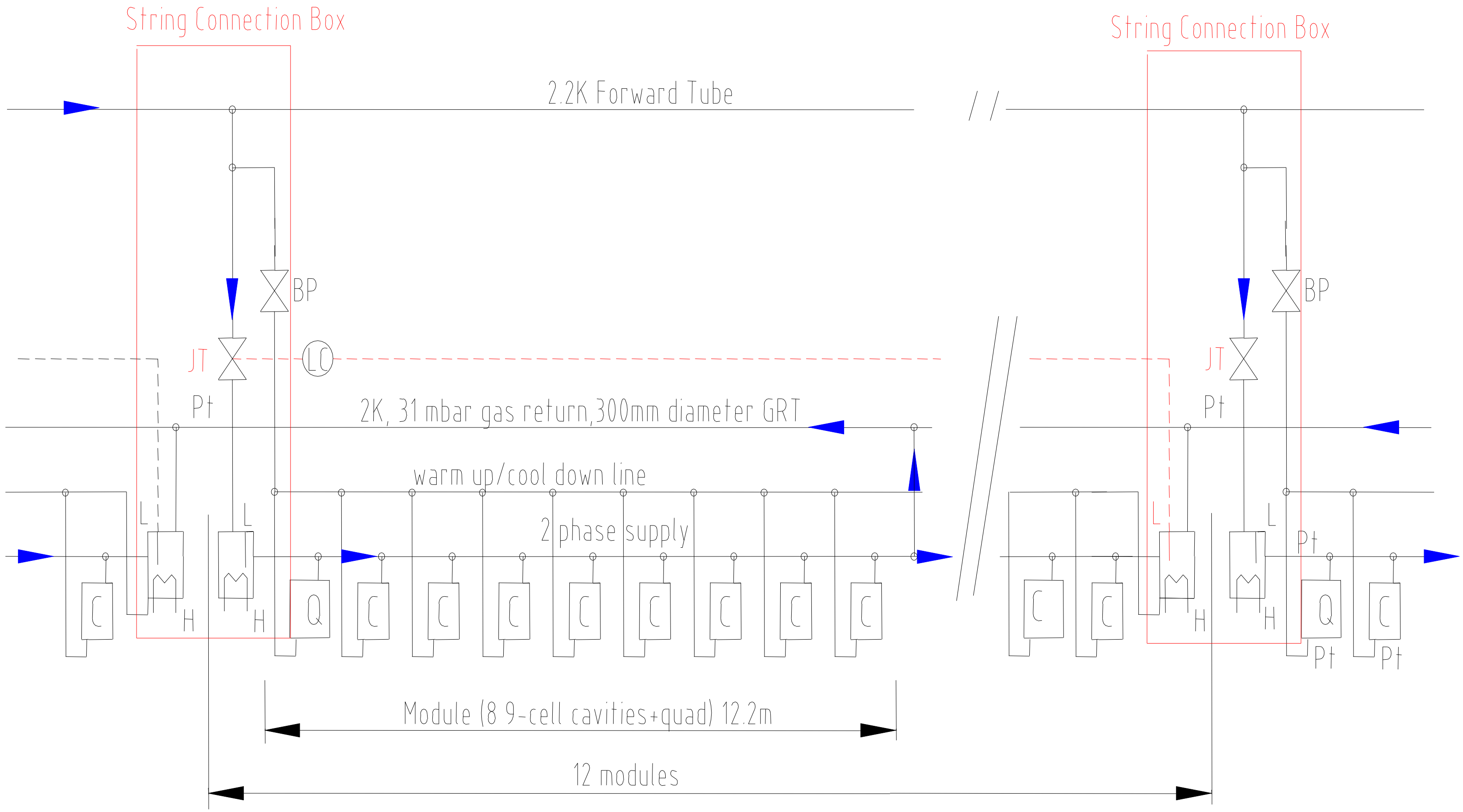
Very simplified cryogenic flow diagram of XFEL accelerator

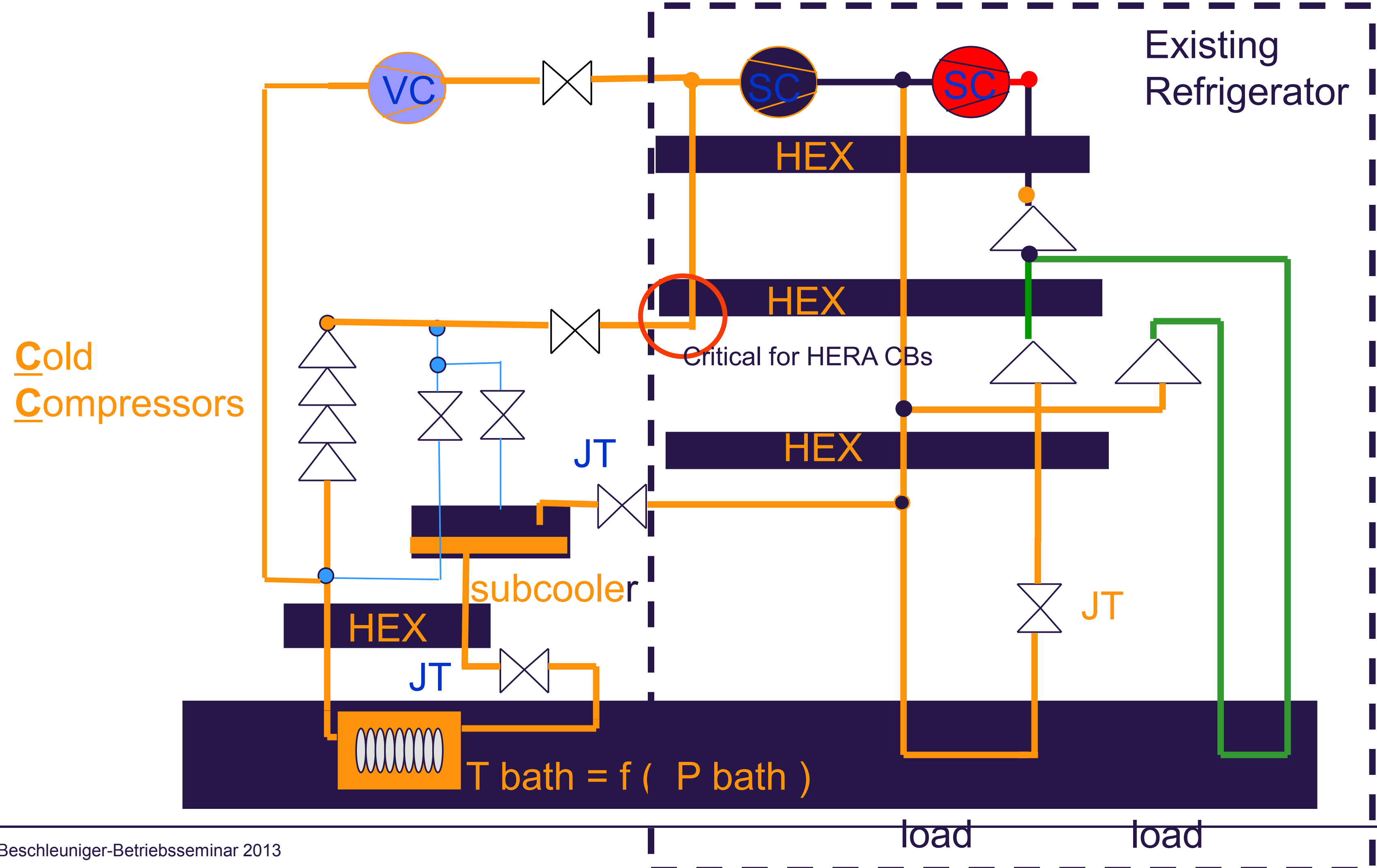


Simplified flow diagram of cryomodule string



String connection box contains all cryogenic instrumentation.

2K operation (very much simplified)



Operation principles for the 2K cryogenic system at FLASH

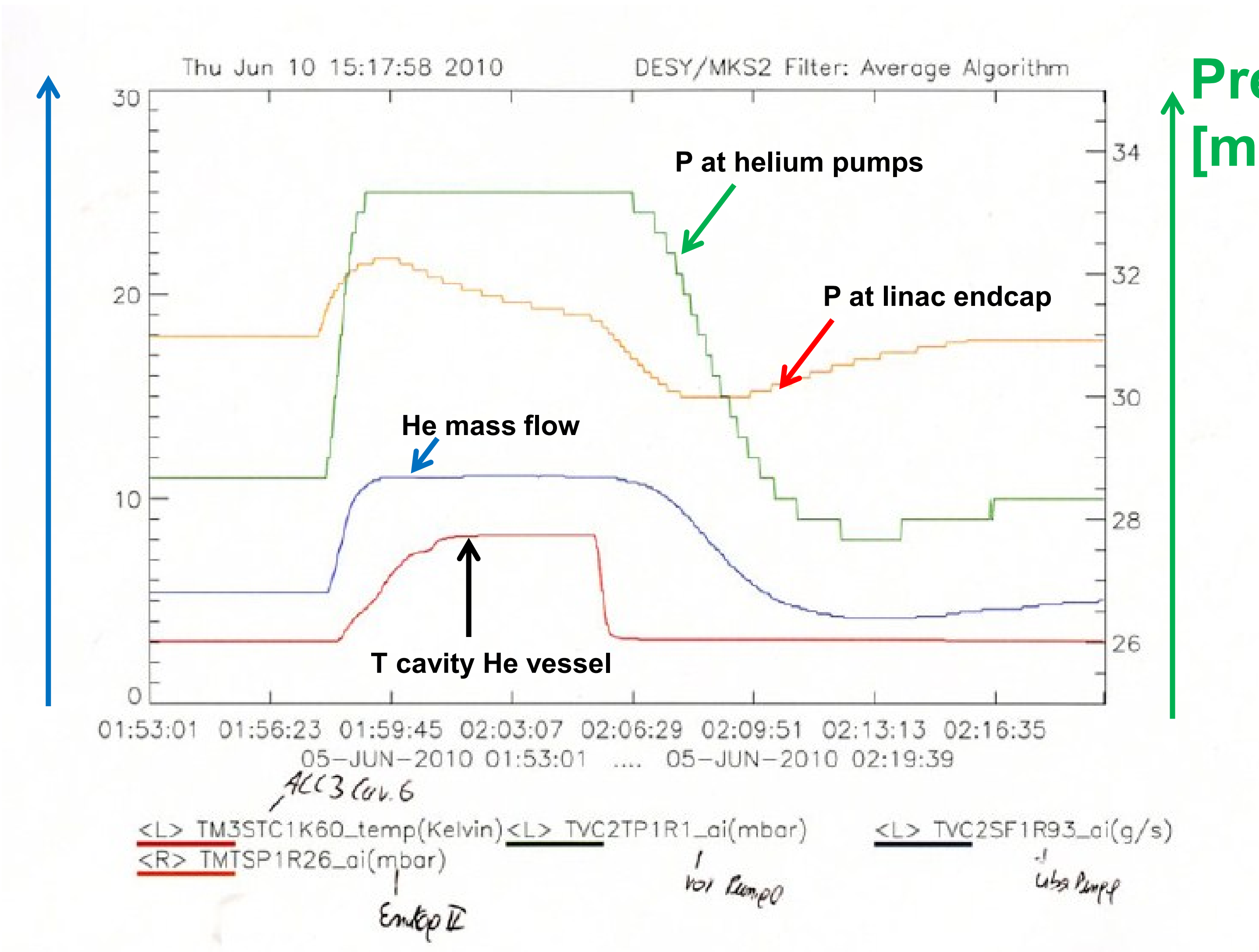
FLASH: Principle applied for compensation of heat load variations

- Variations of heat loads are monitored on the changing of LHe level
  - **LHe level** is the **controlled variable**. **JT valve** (regulation of helium supply flow) and **heaters** (regulation of helium evaporation) are the **actuating variables** for stabilizing the LHe level at a (quasi-) constant value.
- How to reach 2K at **FLASH**:
  - The temperature of the liquid helium is given (regulated) by the pressure of the helium vapor (at two phase helium in equilibrium)
  - For regulating the helium vapor pressure robust **warm helium pumps** (rotary vane pumps and roots blowers) are used.
    - Warm helium pumps have a large dynamic operating range and tolerate ‘sudden’ mass flow changes (within their operating range).
  - Pressure of helium vapor is regulated by means of a cryogenic valve (DN80)

Experiences at Flash accelerator

Mass flow rate [g/s]

Temp. [K]



Pressure [mbar]

Operation principles for the 2K cryogenic system at XFEL

XFEL: Principle applied for compensation of heat load variations

- Variations of heat loads are monitored on the changing of LHe level
  - **LHe level** is the **controlled variable**. **Heaters** (regulation of helium evaporation) and **JT valve** (regulation of helium supply flow) are the **actuating variables** for stabilizing the LHe level at a (quasi-) constant value.
- How to reach 2K at **XFEL**:
  - The temperature of the liquid helium is given (regulated) by the pressure of the helium vapor (at two phase helium in equilibrium)
  - For regulating the helium vapor pressure **cold compressors (CCs)** are used.
    - Cold compressors are very sensitive towards pressure and/or mass flow variations at the inlet of the machines
      - Cryo plant sensitive to load and mass flow changes in 3 circuits
    - A (re-)start of CCs is very time-consuming (for example, more than 12h for restart at LHC after 3 years operation experience)!

Operation principles for the 2K cryogenic system at XFEL

XFEL: Cryogenic operation at 2K

- Why not using warm compressors at XFEL:
  - Investment costs
  - Operating costs
  - Thermodynamic efficiency of refrigerating plant
  - Cold Compressors are established for cryogenic operation of superconducting accelerators

Stability requirements on pressure and mass flow rates

Stability requirements from RF point of view:

- RF change of TESLA cavities versus pressure change : ca. 50 Hz / mbar
- Note from DESY RF experts: fluctuations should be limited to +/- 35 Hz to avoid RF phase shifts

=> pressure stability better than **+/- 0.7 mbar** required

Stability requirements on pressure and mass flow rates - Hard requirements on LLRF Group for stable Cryo-Operation at XFEL

Stability requirements from cryogenics point of view:

- For enabling the basic cryogenic operation concept of the XFEL (level will be controlled by heaters and JT-valves) and the **stable operation** of the Cold Compressors, the following **requirements** have to be fulfilled by the LLRF group:
  - Planned dynamic procedures which lead to large variations a of the heat load, e.g. switching on/off (all) klystrons, powering cavities, etc. must be communicated with and agreed on by cryo operateurs.
    - Dynamic heat loads can be compensated with heaters to minimize variations at inlet of CCs. This needs to be practiced at FLASH !
    - In order to avoid large variation of the helium mass flow towards the cold compressors, we will need ca. 1 hour for refrigerator for adjusting of the equivalent maximal RF power from zero to maximal value. Respective preparation time will be very important.
  - Long-lasting strong quenches **must** be avoided to prevent (sudden) large heat load variations.

Stability requirements on pressure and mass flow rates - Other useful information for optimized Cryo-Operation at XFEL

Useful information for handling (protracted strong) quenches:

We steadily work on concepts to improve the cryogenic operation

- Real-time Information about the happening of a quench
- Real-time information about location of quench
- Information about additional heat load of quenching cavity
    - Information about Heat Load versus Accelerating Voltage for each single cavity in module
- Calculations about perturbance propagation (pressure variations) in 2K circuit due to additional (sudden) heat loads - work in process
- => To get the better information on Q (heat load) over Eacc for each module (and if possible for each single cavity) and => to reach better stabilization of Linac.

But !!!

- Practicing heater compensation of planned dynamic procedures, e.g. switching on/off (all) klystrons, powering cavities, etc. has the first priority

Stability requirements on pressure and mass flow rates - Other useful information for optimized Cryo-Operation at XFEL

Actual information about quenches (at FLASH and XFEL):

- Thermometers, mounted on the LHe vessel with cavities for rough temperature monitoring (LHe vessel is filled or empty due to quench) – ‘post mortem measurement’
- LHe level meter can detect large variations of LHe level. This is an direct detection heat load variations, but it is impossible to detect the location of heat load release.
- Increased helium mass flow (2K return flow) to be pumped with warm pumps (FLASH), cold compressors (XFEL)

Tests on FLASH and CMTB (some examples)

For stable operation of cryogenic system at XFEL, it will be necessary to test the influence of new “hardware” and “software” on operating parameters at FLASH accelerators, e.g.:

- Heat load compensation scheme with electrical heaters in order to reach constant mass flow towards compressors
- Pressure stabilization at accelerator after variation on heat load
- To develop procedure for the testing of single components *in-situ*, e.g. electrical heater, JT-valves, in order to facilitate the commissioning of XFEL cryogenic system.
- ….

Note: It is not necessary (and it is not in the planning!) to make any hardware changings on FLASH or CMTB! Sufficient time should be assigned to experiments at FLASH and CMTB.

Conclusion

The system will be very complex and

we all, i.e. Cryogroup, LLRF group, etc.,

need time for its understanding, commissioning and operation !

Thank you for your attention !

Heat load summary of PXFEL2_1

Heat load summary of PXFEL2_1 (04-21,05,2011)							
Area	Static load, W			Dynamic load, W			
	Measured	XFEL Budget	Estimated	Measured			XFEL Budget
40/80K	102	83	105-120	RF 15,3MV/m	RF 25,1MV/m*	Current leads (3*50A)	23,8MV/m, 1*10E10, 10Hz, FEL beam
				12,0	41,2	7,8	40,36
5/8K	6,6	13	6-7	0,4	2,2	4,8	2,3
2K	5,8	4,8	2	1,6	3,9	1,4	8,56

*: Cavity 3 is detuned and 25.1 MV/m is the average value from 7 cavities.

Estimated: Values from our technical note on 29,11,2010

XFEL Budget: Values from Mr. Petersen's table on 15,09,2009

European XFEL

Appendix B: Variation ranges of mass flow rates and heat loads

Heat load on single cryomodule (values used for the specification of refrigerators)

	2K statisch	2K dyna-misch	5K-8K statisch	5K-8K dyna-misch	40K-80K statisch	40K-80K dyna-misch
Σ	≈4.8	≈8.5	≈11	≈6	≈71	≈43
statisch + dynamisch		≈13.3		≈17		≈114

Note: it was assumed that quality factor of s.c. cavities with acceleration field of 23.6 MV/m is $Q_0=10^{10}$ and repetition rate is 10Hz

Total Heat Load (values used for the specification of refrigerators)

Circuit	Total heat load [W]	Heat load only on HeII [W]	Flow rate at supply line [g/s]	Flow rate at return line [g/s]	Ratio of total to static heat loads [W/W]
2K	559-1896	459-1746	29-85	30-96	1.9
5-8K	1812-3593		69-141	68-130	1.1
40-80K	10377-23923		49-114	49-114	1.3

Note: 50% overcapacity margin for 5/8K and 40/80K circuits as well as 30% for 2K circuit are included.

Wide operation range of heat loads at 2 K circuit!

Large ratio of total to static heat loads at 2 K circuit!