Serial testing of XFEL cryomodules: results of the cryogenic heat load measurements

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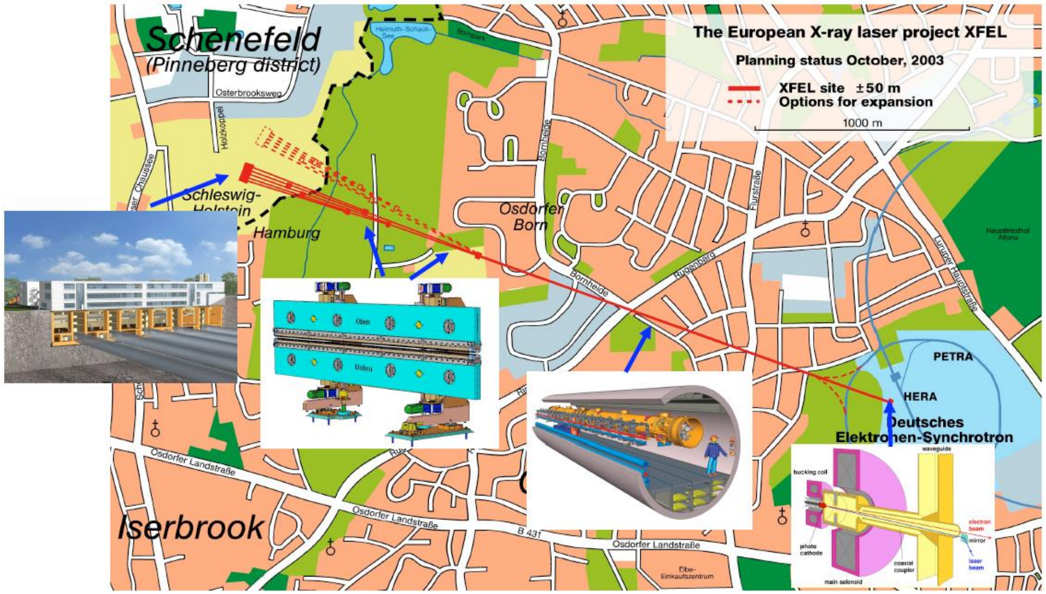
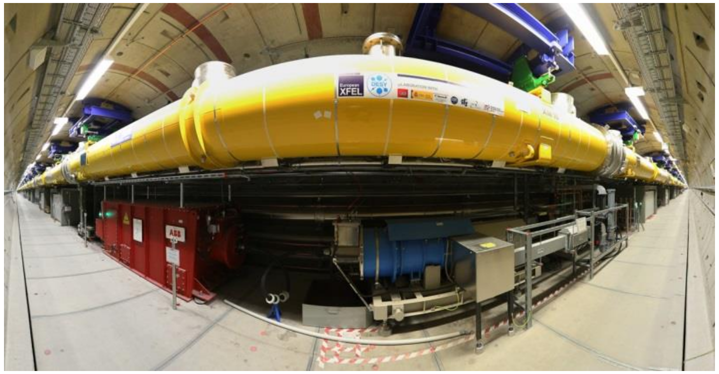
Overview

- European XFEL Project
- Accelerator Module Test Facility (AMTF)
- XFEL Cryomodules Test Program & Schedule
- Methology of Heat Load Measurements in AMTF
- Results of Heat Load Measurements
- Conclusions: Lessons learnt

European XFEL Project - superconducting Linac

3.4km





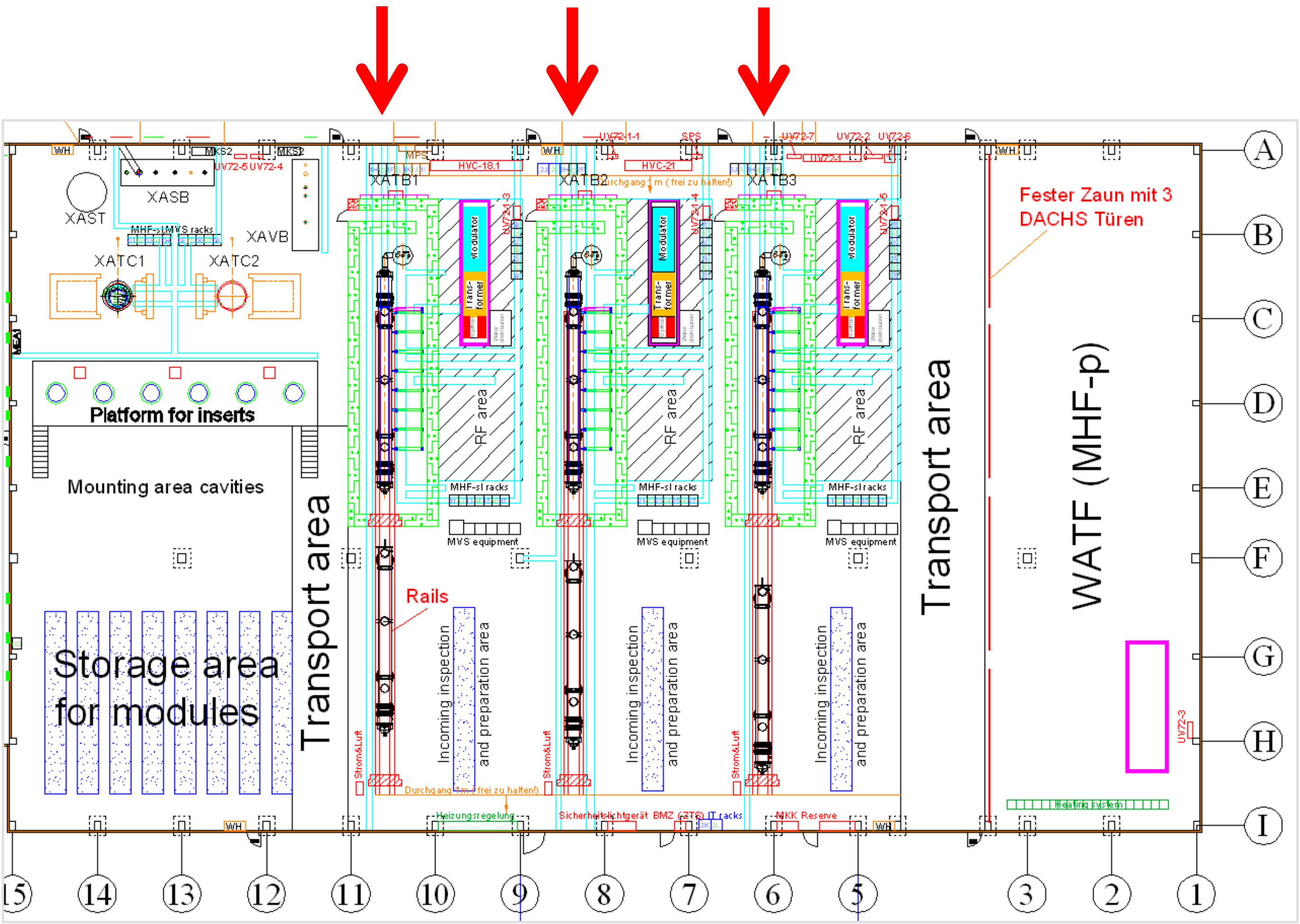
- electron beam energy 17.5 GeV (pulsed)
- FEL Laser 0.2 – 0.05 nm
- Status June 2017 (14 GeV, 0.15nm)

- about 800 sc 1.3 GHz Nb cavities
- Helium II bath cooling at 2K
- **96 cryomodules** (8 cavities + sc Quadupoles)
- linac length 1.5Km

See also talks C2OrD tomorrow

AMTF layout (TDR)

Three test benches (XATB1, XATB2 and XATB3) for XFEL cryomodule tests



XFEL cryomodule
test program & schedule

After RF performance tests of all individual cavities and cryomodule assembly in Saclay,France:

- **Complete performance test of all 103 cryomodules except beam operation**
- (96+1 installed)
- General mechanical and alignment checks, cabling
- Vacuum checks at warm and in cold condition (insulation-, coupler-, beam-vacuum)
- RF cavity performance tests – definition of matching wave guide assembly
- RF coupler performance
- Quadrupole performance
- …..Tuner,LLRF,HOM,…..
- **Cryogenic static&dynamic heat load measurements for 40/80K, 5/8K and 2K circuits**

Unloading of the cryomodule after transport

Cryomodule preparation area

Cryomodule test stand

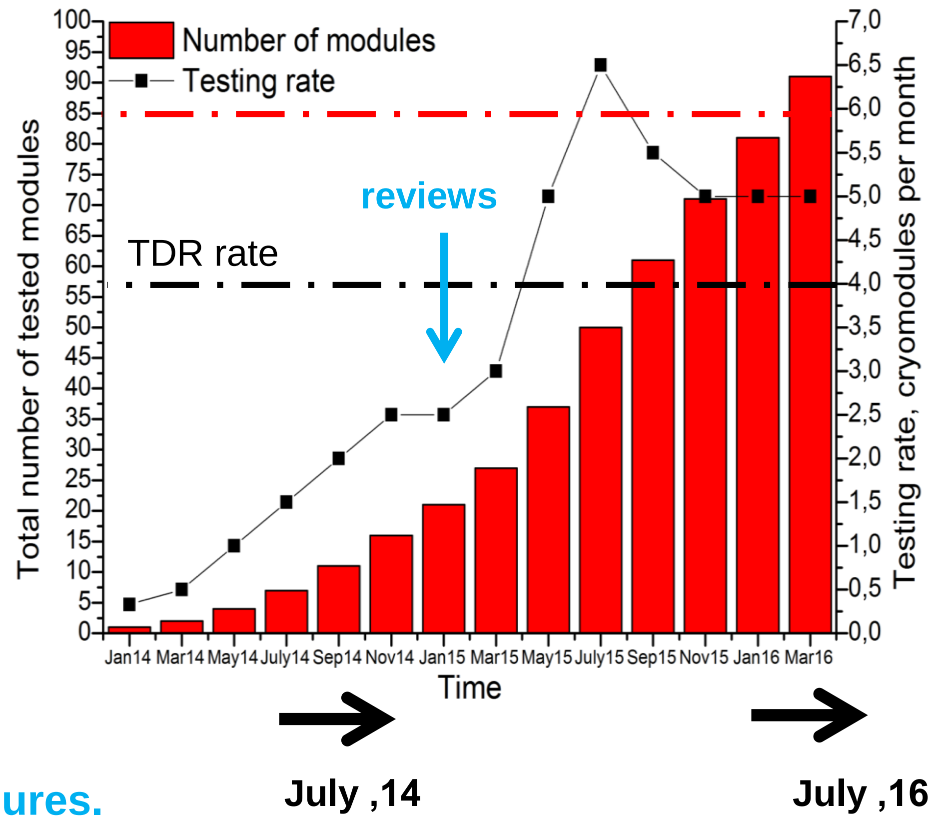
Cryomodule test stand – module inside

Cryomodule test stand – front view

XFEL cryomodule test program & schedule

- **TDR Project schedule**:
  1 cryomodule test/week
- **Estimate**: one module test takes 2 weeks
  -> 2 test stands + 1 spare
- **Management decision**:
  test of 1.5 cryomodules/week
  (because 3 test stands are operational !)

AMTF cryomodules test rate



-> Test procedures had to be optimized strictly for project requirements !

-> Internal & external reviews of procedures.

XFEL cryomodule
cryogenic heat loads acceptance criteria

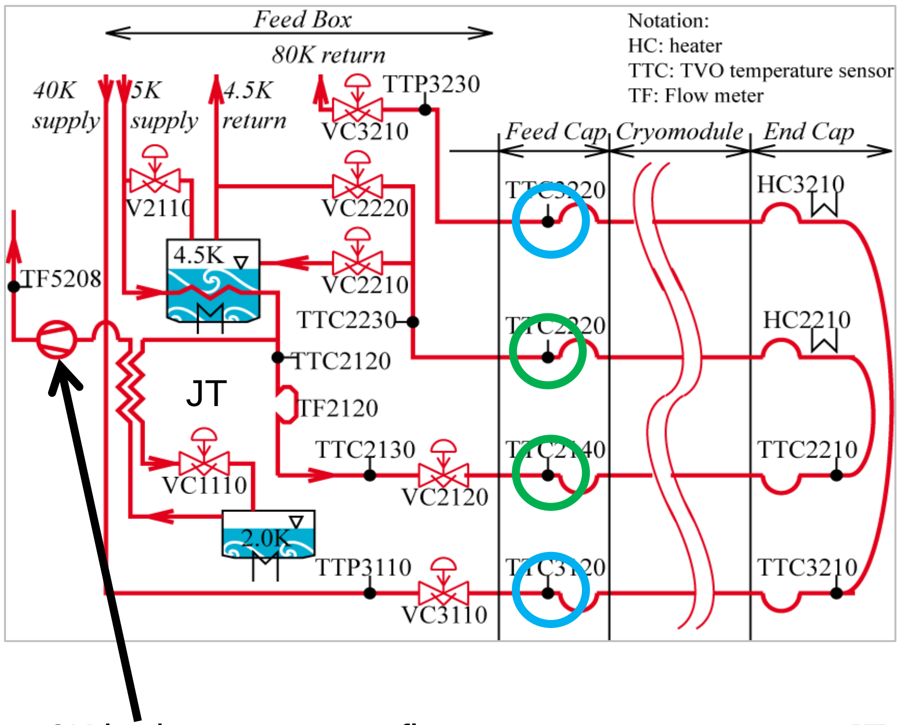
Circuit	Static heat loads [W]		Dynamic heat loads, [W] at 3·50A+23.6 MV/m		Total heat loads [W]		Max. heat loads [W] acceptance criteria
	XRB	XRC	XRB	XRC	XRB	XRC	
40/80K	83	124.5	40	60	123	184.5	125
5/8K	13	19.5	2.3	3.5	15.3	23	16
2K	4.8	7.2	8.6	12.9	13.4	20.1	14

XRB = ‚calculated' refrigerator budget for the operation of one cryomodule
XRC =XRB * 1.5 (design refrigerator budget including margins)

(For 5/8K and 2K circuits additional heat load ‚offsets' were considered in XRB with reference to the cryomodule prototype tests at the date of the last internal review in 2009. Design issues of the current lead thermal intercepts were suspected of the additional losses.)

Methodology of cryogenic heat load measurements

Simplified test stand flow scheme



- Use of coriolis flow meters
- Use of TVO temperature sensors
- Calibration by heater loads

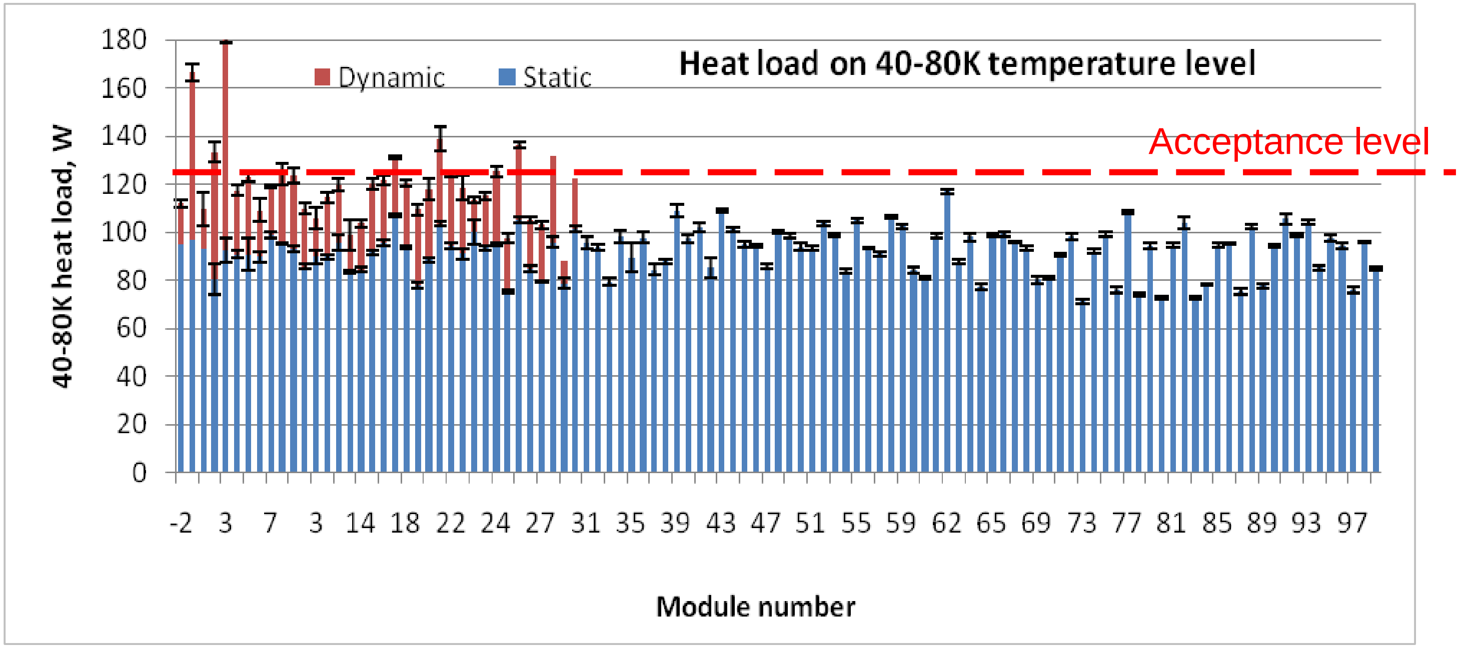
5/8K and 40/80K circuits:

ΔT (return – supply) , mass flow, pressure

-> Determination ΔH

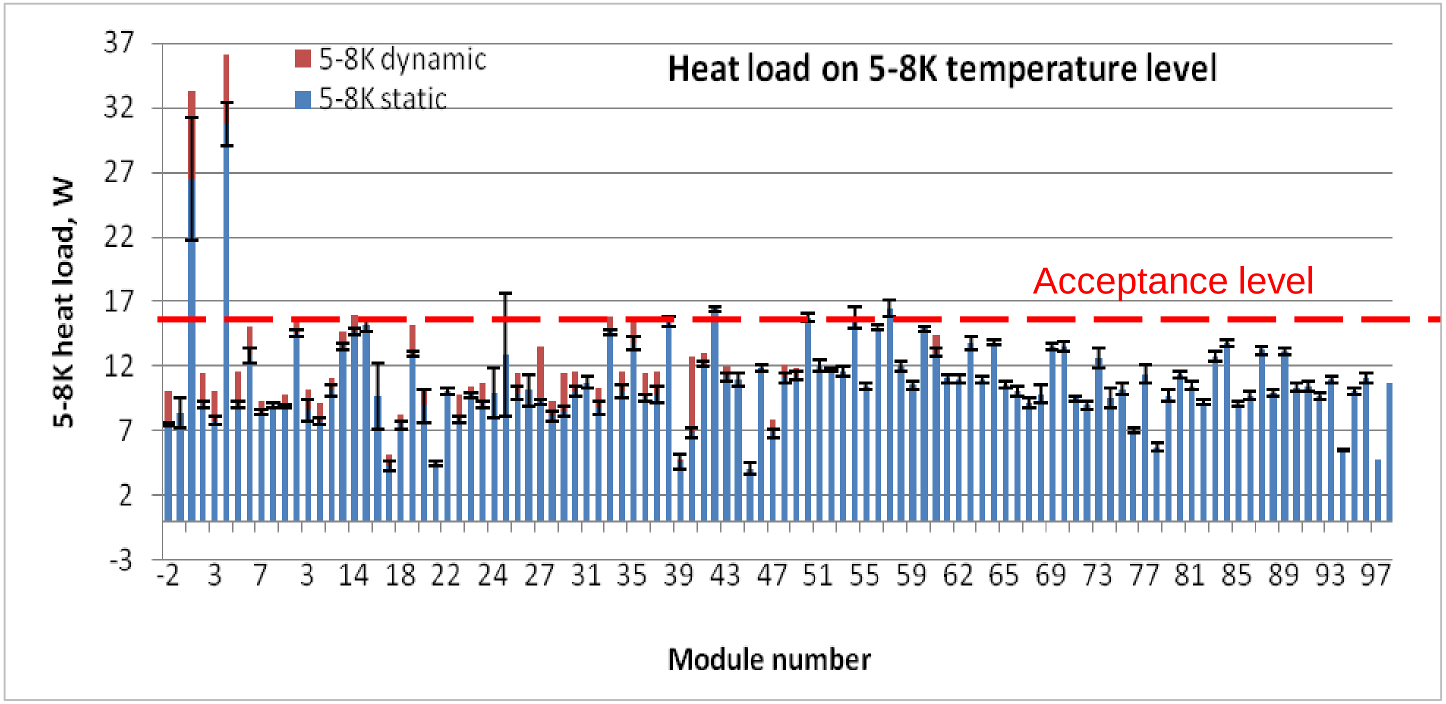
2K bath: vapor mass flow at constant pressure, JT valve (VC1110) closed

XFEL cryomodule
cryogenic 40/80K shield heat loads



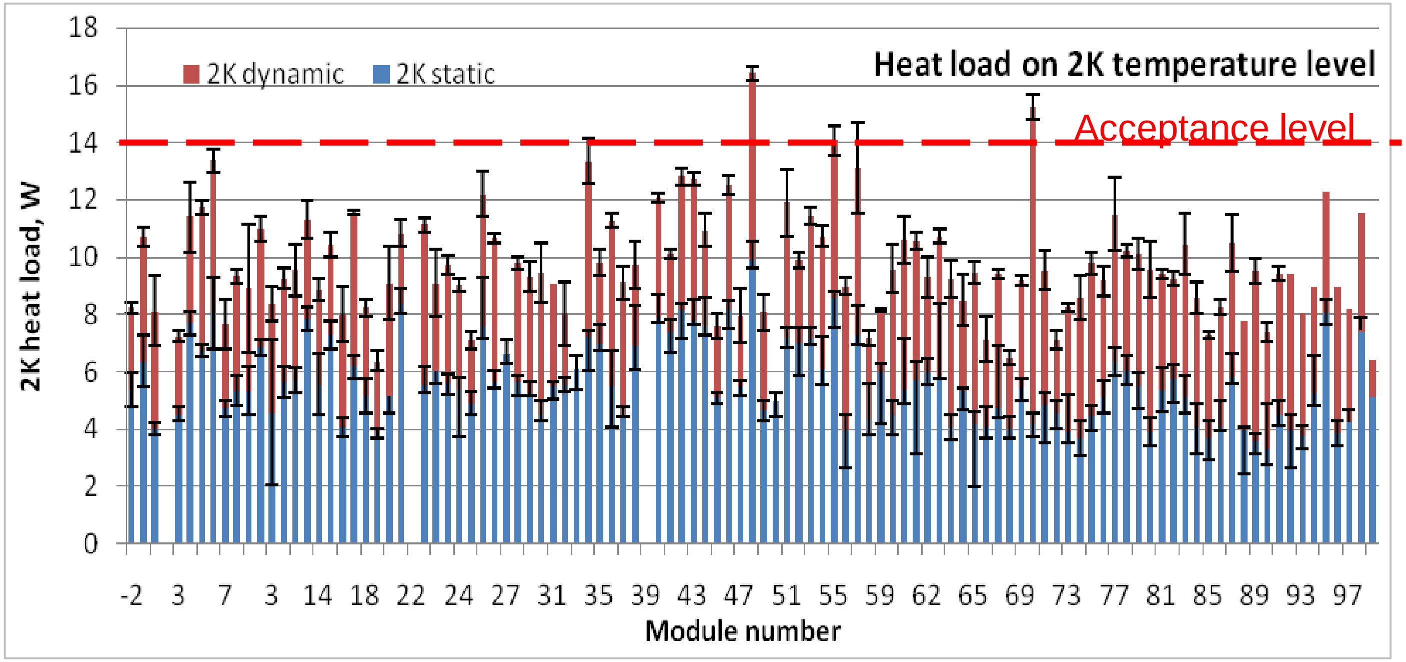
After procedure reviews, long lasting dynamic load measurements were skipped. Static heat load measurements were continued in the background of other measurements during the test run. Main coupler defects caused some excessive dynamic loads. These defects could be identified by RF measurements.

XFEL cryomodule
cryogenic 5/8K shield heat loads



After procedure reviews, cavity RF and sc quadrupole dynamic heat load measurements were combined. The causes of two excessive heat loads could not be identified.

XFEL cryomodule cryogenic 2K heat loads



After procedure reviews, cavity RF and sc quadrupole dynamic heat load measurements were combined.

Dynamic RF loads correspond to 23.6 MV/m 10 Hz operation and Q0=1.4 *10E+10 (average)

XFEL cryomodule
cryogenic static heat loads – comparisons

Static heat load results for 3 Test Stands

	2K circuit, Watt	5/8K circuit, Watt	40/80K circuit, Watt
XATB1, 35 cryomodules	5.67 ±1.35	9.73 ±1.72	96.7 ±5.2
XATB2, 37 cryomodules	5.88 ±2.11	12.7 ±3.19 ←	82.8 ±6.4
XATB3, 33 cryomodules	5.20 ±1.30	9.30 ±1.79	98.6 ±6.8

End-Cap ?

Comparison to XFEL linac measurements

	2K circuit, Watt	5/8K circuit, Watt	40/80K circuit, Watt
Calculations 2009	1.45	9.8	83
Calculations+'Offset'	4.8	13.0	83
AMTF	5.6 ±1.6	10.6 ±2.2	92.7 ±6.1
XFEL linac	< 6.3	7.9	86

- See also talk C2OrD ‚Commissioning & First Cool Down of XFEL Linac'

Lessons learnt

- Compared to prototype cryomodule tests on CMTB (Cryomodule Test Bench) the use of coriolis flow meters at AMTF instead of orifices, contributed significantly to the precision and reproducibility of the heat load measurement results.
- Also the use of, simple and robust TVO temperature sensors, properly mounted on the outer surface of the process pipes, have also greatly contributed to the stability and reproducibility of measurements.

Acknowledgements

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Thank you for your attention !