Heat Loads of the XFEL accelerator

Measured static values at 2K, 5-8K, 40-80K and dynamic values at 2K

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Outlook

01 Methods of Heat load Calculation

02 Single cryomodule Static and Dynamic heat loads – AMTF

- at 5-8K , 40-80K and at 2K

03 Static and Dynamic heat loads at the XFEL linac

- at 5-8K , 40-80K and at 2K

04 Results comparison and Conclusions

Heat load calculation: methodology

For the single cryomodules and the XFEL linac

- Heat Load estimated for three different temperature levels:
  External Shield: 40-80 K Internal Shield: 5-8 K Cavity Environment: 2 K

- **Static Heat Load calculation at 5-8 K and 40-80K**
  - Stable flow
  - Calculate heat loads from flow and delta enthalpy

$$\dot{Q}_{s,5/80K} = \dot{m}\Delta h = \dot{m}(h_{out}(p_{out}, T_{out}) - h_{in}(p_{in}, T_{in}))$$

- **Static Heat Load calculation at 2K**
  - Stable flow, turn off magnets and RF, subtract heaters
  - For XFEL linac, heat loads from flow and delta enthalpy
  - For single cryomodules in the AMTF hall, cold flowmeters at 2K not very precise, use warm flowmeter after compressor, close the JT valve and measure amount of evaporated LHe at constant pressure. (no losses from 2KR lines).

$$\dot{Q}_{s,2K(XFEL)} = \dot{m}\Delta h = \dot{m}(h_{out}(p_{out}, T_{out}) - h_{in}(p_{in}, T_{in}))$$

$$\dot{Q}_{s,2K(AMTF)} = L\dot{m} \qquad \mathrm{L} = 23.06\ {}^{J}/_{g}\ @\ 2\ K\ ,30\ mbar$$

- **Dynamic Heat Load calculation at 2K**
  - Same method as static measurement, with RF
  - Subtract static component from total value

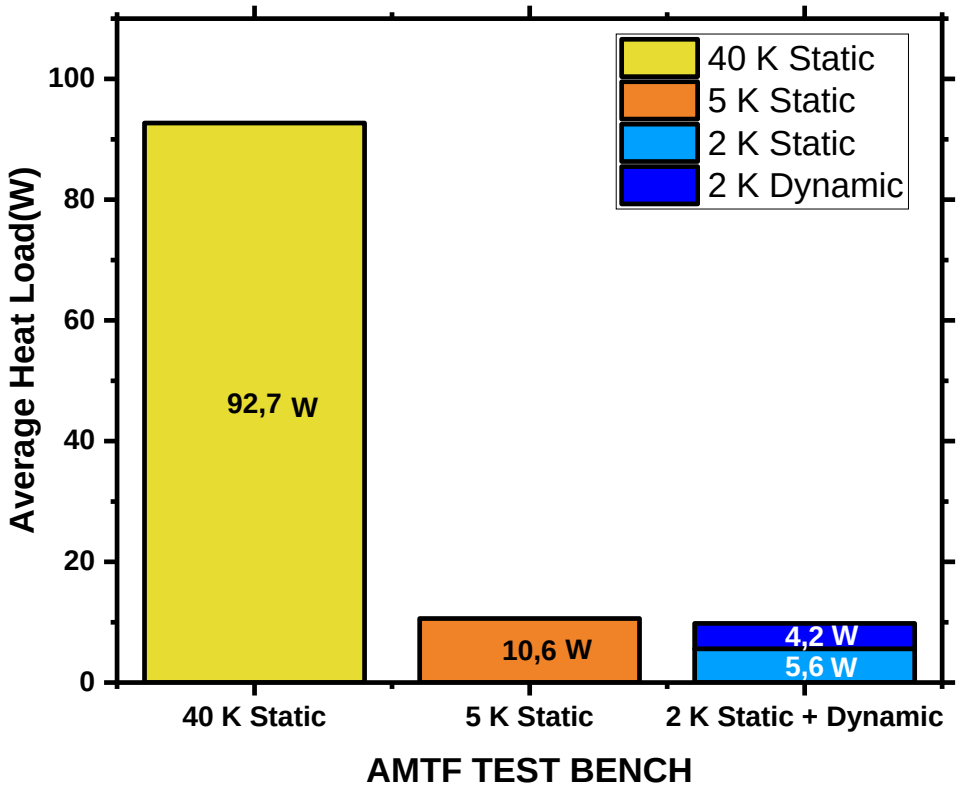
$$\dot{Q}_{d,2K} = \dot{Q}_{total,2K} - \dot{Q}_{s,2K}$$

Static and dynamic heat loads measured in AMTF

40/80 K, 5/8 K and 2 K circuits

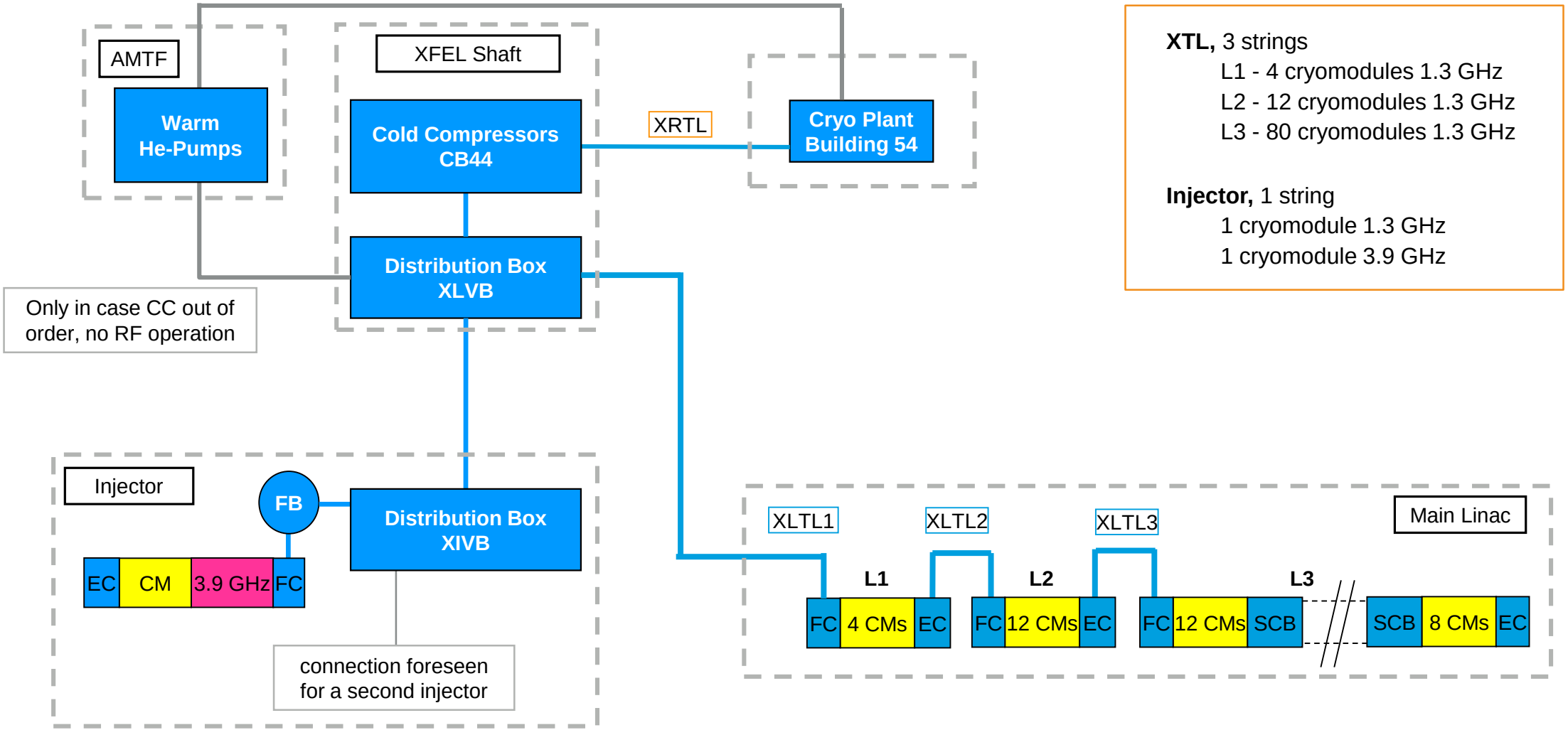
- Three test stands available for cold test of single XFEL cryomodules
- Average value of all 103 tested cryomodules at the three test stands (2014 – 2015)
- 2K dynamic loads value at average cavity gradient of 23 MV/m
- More information: T Böckmann et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 278 012184

Circuit	Average Heat Load per cryomodule (W)
40/80 K Static	92,7 W
5/8 K Static	10,6 W
2 K Static	5,6 W
2 K Dynamic	4,2 W



XFEL overview

From the point of view of the heat load calculations



XTL, 3 strings
- L1 - 4 cryomodules 1.3 GHz
- L2 - 12 cryomodules 1.3 GHz
- L3 - 80 cryomodules 1.3 GHz

Injector, 1 string
- 1 cryomodule 1.3 GHz
- 1 cryomodule 3.9 GHz

XFEL static heat loads at 40-80K, 5-8K and 2K

Measurement at the XLVB box

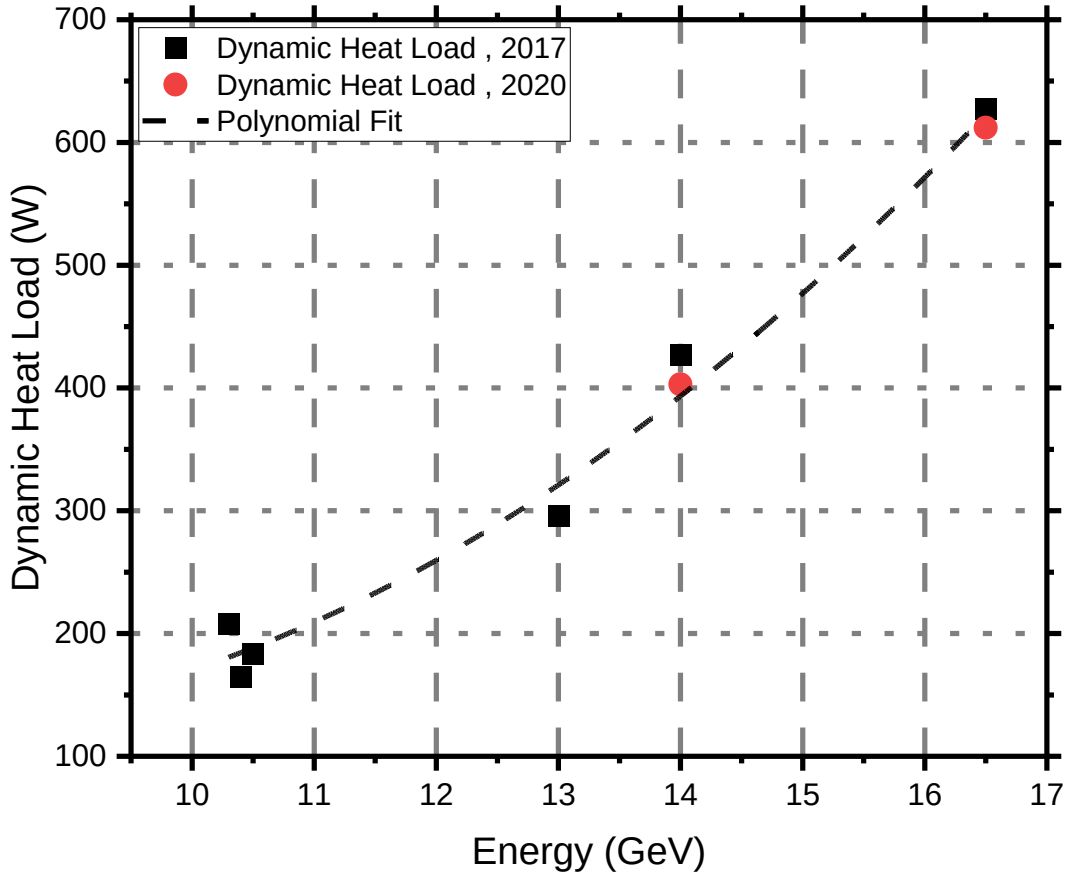
Circuit (at XLVB)	Total heat load (W) 2017	Total heat load (W) 2020	Average heat load / cryomodule (W)
40/80 K Static	9720 W	9750 W	~ 102 W
5/8 K Static	795 W	775 W	~ 8 W
2 K Static	579 W	630 W	~ 7 W

- Measurement performed for the entire linac
  - It includes transfer lines, cryogenic boxes and caps
- The values are an average on different time periods in 2017 and 2020
- Average heat load per cryomodule is approximate calculation
  - it includes the transfer lines XLTL1, XLTL2, XLTL3, the feed and end caps and string connection boxes
  - results are conservative values
- Choice of thermal sensors verified with different methods
- More information: T. Y Bozhko et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 278 012100

XFEL dynamic heat loads at 2K

- $\dot{Q}_{d,2K} = \dot{Q}_{total,2K} - \dot{Q}_{s,2K}\ (630\ W)$

Year of measurement	Dynamic Heat Load, W (14 GeV)	Dynamic Heat Load, W (16.5 GeV)
2017	427 W	627 W
2020	403 W	612 W



Summary

Static and Dynamic heat loads at XFEL linac

Total values for the XFEL

Circuit	Static	Dynamic	
		(14 GeV)	(16.5 GeV)
40 – 80 K	9750 W	-	-
5 – 8 K	775 W	-	-
2 K	630 W	403 W	612 W

Average value of single cryomodules

Circuit	AMTF	XFEL linac
40 – 80 K static	92,7 W	102 W *
5 – 8 K static	10,6 W	8 W *
2 K static	5,6 W	7 W *
2K dynamic	4,2 W	

* conservative values, include ECs, FCs, TLs

Thank you

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Effective (average) cavity Q_0 from measured dynamic load

$$Q_{0,eff} \approx \frac{f_{rep}\left(t_{fill} + t_{flat}\right)}{(r/Q)\,P_{cryo}} \sum_{i=1}^{N_{cav}} \left\langle V_i^2 \right\rangle$$

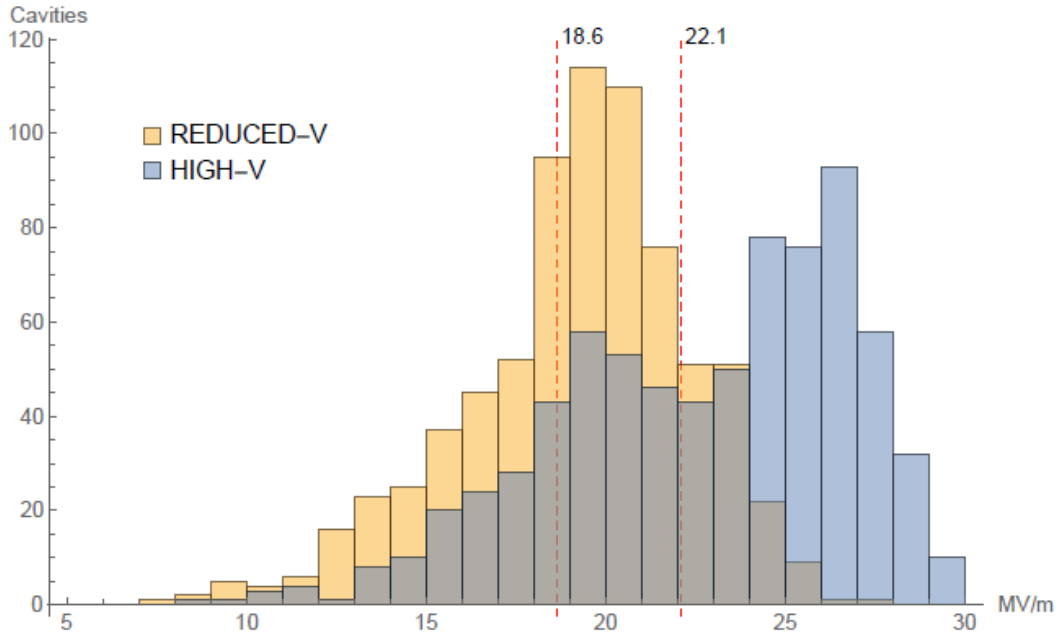
where

$$\left\langle V_i^2 \right\rangle = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} V_i^2(t)\, dt$$

calculated from DOOCS history of probe amplitude sample:

`XFEL.RF/LLRF.CONTROLLER/Cc.Mm.Aa.Ll/PROBE.AMPL.SAMPLE`

RF CONFIG	Time Frame	Average Dynamic Load (W)	Effective average Q_0
REDUCED-V **14 GeV**	01.09—15.10.2020	400	1.04×10^{10}
HIGH-V **16.5 GeV**	20.10—15.11.2020	600	0.98×10^{10}



Courtesy

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DESY - MPY group