XFEL Accelerator R&D Status / Final Report
RP-212 SRF Gun

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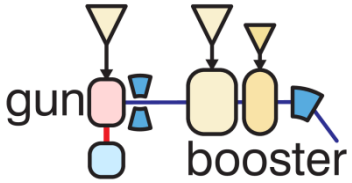
Scope of the R&D activity

- feasibility study & prototype for high gradient gun based injector operating CW



  - 'pancake' emission
  - direct matching into subsequent linac
  - no buncher cavity!
  - possible with L-band SRF technology

- interfaces with other XFEL R&D: R&D for high duty cycle (HDC) operation / R&D Pillar CW

- promised deliverables: SRF gun cavities with peak field on axis ≥ 40 MV/m

Preliminary remark(s)

- this work is supported by a lot of committed, very good and very professional working colleagues
  - in the last years this was concentrated on the SRF gun cavities: MSL + external collaborators like KEK, HZDR, HZB
  - plus some early preparations towards a SRF photoinjector test stand, e.g. by FS-LA + MEA + MVS
  - after finalizing the FLASH shutdown, activities extended to the cold integration: mainly MKS + MSL
  - now the complete DESY accelerator division is involved, in particular
    D3 + FS-LA + MCS + MDI + MEA + MHF + MIN + MKS + MPC + MPS + MSK + MSL + MVS + Z_PITZ + MKK + IT + …

- **Thank you very much to all contributors!**

Achievements in 2022 (1/3)

- consolidated the cavity treatments and tested new methods, IPAC23 paper JACoW-IPAC2023-WEPA145
  - cavities still show high gradients around 55 MV/m peak on axis
  - cavities 16G09/10 fabrication continued – first VT expected in upcoming weeks

- laboratory tests with the cathode laser for localizing the cathode are delayed
  - test vacuum chamber has been finished well in time
  - person for laser hired end 2019 left in Summer 2022 to another DESY group

- cold integration
  - October 2022 FLASH shutdown successfully finished: required colleagues became available
  - meeting series started, still ongoing, goals:
    - identifying basic requirements
    - answering design questions

Achievements in 2022 (2/3)

- reception of the SC solenoid magnet from the vendor was delayed (arrived at DESY in April 2023)
  - in summer 2022 the vendor discovered leaks
  - magnet winding needed to be re-done

- person taking care of SC magnets was withdrawn by the DESY directorate without any prior information
  - at the moment, no one is taking care of the SC solenoid magnet work package
  - if the position is not filled timely, this constitutes a major risk, not only delaying the SRF photoinjector R&D
  - this constitutes also a major risk for all SC quadrupole magnets in the XFEL accelerator
  - reminder: after the XFEL construction the experts went into retirement

Achievements in 2022 (3/3)

- next cavities 16G11/12 should be optimized to minimize effects diluting the beam quality
  - considered: coupler kicks, HOMs and RF field asymmetries in general, IPAC23 paper JACoW-IPAC2023-WEPA144
  - design readiness review including all stakeholders in Q4/2022, now preparation of fabrication ongoing

- special R&D program on SRF compatible photocathodes started in 2022
  - need to be robust against exposition to the air and also against SRF cavity cleaning procedures
  - interdisciplinary collaboration together with colleagues from CFEL, NanoLab and the University of Mainz
  - nano-structuring according to pre-calculation done at NanoLab and successful first measurement at CFEL
  - hired a PhD student to further investigate the different options – started at DESY in April 2023

Comparison with the original Plan (2018 – 2022)

- the history of this R&D: 2005 proposal published at PRST-AB, 2007 first results reported at PAC07, Albuquerque
- in 2014 and 2016 cavity 16G2 showed maximum peak on axis gradients in the rage of 55 MV/m
- 16G2 had mechanical weaknesses
- in 2018 this XFEL R&D activity started with mechanically improved cavities 16G3/3
- treatment methods known from the XFEL 9-cell cavity production turned out being unsuccessful
- we had to work for several years to improve our SRF gun surface treatment methods
- the cavity geometry challenges plus pandemic restrictions delayed our activities in the order of about three years
- setup of horizontal cavity testing infrastructure delayed on purpose until cavity geometry challenges solved
- cavity geometry challenges solved at a time when FLASH shutdown started, adding further one year delay

Timeline of this R&D activity

Proposed Date	Milestone Description for this R&D activity ("SRF Gun")	Updated Date
Q1/2018	**purchase of cathode laser – obtained Q3/2018**	**done**
Q4/2022	tests with the cathode laser for localizing the cathode – delayed, s.a.	ongoing
Q4/2018	SRF gun vertical tests after improved surface treatments – successful	done
Q1/2023	SRF gun vertical tests with different cathode plug materials – successful	ongoing
Q1/2020	coaxial input coupler – idea abandoned due to the studies	done
Q3/2022	input coupler design and strategy fixed	done
Q2/2023	gun prototypes with frequencies within laser acceptance – delayed, s.a.	ongoing
Q4/2022	cavity end group design optimized for beam dynamics	done
Q1/2023	production preparation of cavities with optimized end group started	done
Q3/2022	SRF gun cryomodule design and incl. cold integration design started	done
Q3/2022	design of diagnostic beam line for SRF photoinjector tests stand started	done
Q1/2023	overall planning of the SRF photoinjector tests stand started	done
Q2/2023	SC solenoid purchase – delayed and person withdrawn, s.a.	ongoing
Q3/2022	R&D on new cathodes which are robust against SRF cavity cleaning procedures (e.g. by nano-structuring of bulk metal) started	done

Proposed Date	Milestone Description shifted to succeeding R&D activity ("SRF Photoinjector")	Updated Date
Q4/2023	**finish SRF gun cryomodule design and start procurement**	
Q4/2024	SRF gun cryo-module available	
Q4/2024	XATB3 prepared for SRF gun test with cathode laser	
Q3/2025	horizontal test of cavities generating beam	

Risks to R&D Project

- risks associated with the R&D project that prevent or limit the success
  - shortage of manpower
  - even more severe:
    - people leaving the project
    - withdrawing people from tasks without coordination and without immediate replacement

Outlook / Summary (1/4)

- planned activities for the this year
  - concerning the SRF photoinjector stand (Ts4i)
    - work breakdown structure (done)
    - schedule for next years (done)
    - budget planning (ongoing)
    - presentation of XFEL R&D proposal for "SRF Photoinjector" foreseen in autumn
  - in 2023 we plan in particular
    - 16G11/12 production start
    - 16G09/10 testing, later horizontal EP at one of this cavities at KEK
    - working further on Ts4i cold integration questions with the goal to start purchasing "big" parts End 2023
    - freezing Ts4i diagnostics beam line design in Summer 2023
    - finalizing Ts4i bunker design
    - otherwise, see Confluence

Outlook / Summary (2/4)

- planned activities for the this year - continued
  - concerning personnel
    - re-gaining SC magnets coordinator
    - re-gaining cathode laser engineer
    - getting the required support for the project organization and to deal with a lot of technical aspects, for example to produce documents and information's needed for the authorities, etc.
- also very important activity for the this year
  - taking up more pace with the R&D on cathodes!
    - requires more people joining – this is already happening!

Outlook / Summary (3/4)

- achievements of the entire "SRF Gun" R&D project
  - cavities reach systematically maximum peak on axis gradients in the rage of 55 MV/m
- do you plan a **follow-up proposal**
  - **yes**, see previous slides

Outlook / Summary (4/4)

- **list of some publications** / conference proceedings connected to this activity

  - E. Vogel et al., “Surface Treatment Experience of the All Superconducting Gun Cavities”, in Proceedings of IPAC2023, Venice, Italy, 2023. JACoW-IPAC2023-WEPA145
  - D. Bazyl, D. Klinke, J.-H. Thie, and E. Vogel, “RF and Beam Dynamics Considerations for the Cavity End Group of the All Superconducting DESY Gun”, in Proceedings of IPAC2023, Venice, Italy, 2023. JACoW-IPAC2023-WEPA144
  - B. Van Der Horst et al., “Development and Adjustment of Tools for Superconducting RF Gun Cavities”, in Proceedings of SRF2021, East Lansing, MI, USA, 2022. 10.18429/JACoW-SRF2021-TUPTEV006
  - H. Qian and E. Vogel, “Overview of CW RF Guns for Short Wavelength FELs”, in Proceedings of FEL2019, Hamburg, Germany, 2019. 10.18429/JACoW-FEL2019-WEA01
  - M. Krasilnikov et al., “PITZ Experimental Optimization for the Aimed Cathode Gradient of a Superconducting CW RF Gun”, in in Proceedings of FEL2019, Hamburg, Germany, 2019. 10.18429/JACoW-FEL2019-WEP051
  - E. Vogel et al., “Status of the All Superconducting Gun Cavity at DESY”, in Proceedings of SRF2019, Dresden, Germany, 2019. 10.18429/JACoW-SRF2019-THP080
  - E. Vogel et al., “SRF Gun Development at DESY”, in Proceedings of LINAC2018, Beijing, China, 2018. 10.18429/JACoW-LINAC2018-MOPO037

  - for further info, see https://www.desy.de/~evogel/srf-photoinjector.html and https://ts4i.desy.de/