WP2: Low Level RF controls 10.01.2025

DESY, HZB, CNRS
Convener & deputy: Holger Schlarb (DESY) & Julien Branlard (DESY)
Main contacts with other partners: Axel Neumann (HZB), Christophe Joly (CNRS)

Task 2.1: **Coordination of R&D on LLRF –** ***M1-M48***

Task 2.2: **Efficient field control for high loaded-quality factor cavities –** ***M1-M48***

Task 2.3: **Vibration analysis and detuning control of cavities –** ***M1-M36***

Task 2.4: **Integrated LLRF control using Ferro-Electric Fast Reactive Tuners–** ***M13-M48***

Task 2.5: **Energy efficient supervisory control and fault diagnosis–** ***M1-M48***

Task 2.1: Coordination of R&D on LLRF – *M1-M48*

- *A couple of meetings took place since last status update*

→ *Status update of the different labs*

→ *Reporting about iSAS project activities (website, next in-person meeting)*

- *Communication structure established*

→ *Email distribution list*

→ *Shared repository (meeting minutes, status reports, presentations)*

- *Identified test possibilities in each lab*

→ *Test stands, facilities, type of cavities, tuning systems, power sources, etc.*

Task 2.1: Coordination of R&D on LLRF – *M1-M48*

Opened position to support R&D activities including iSAS

➔ candidate found, position about to be finalized

→ *Reporting about iSAS project activities (website, next in-person meeting)*

• *Communication structure established*

→ *Email distribution list*

→ *Shared repository (meeting minutes, status reports, presentations)*

• *Identified test possibilities in each lab*

→ *Test stands, facilities, type of cavities, tuning systems, power sources, etc.*

Task 2.2: Efficient field control for high loaded-quality factor cavities – *M1-M48*

- *Identify optimal loaded-quality factor (Q_L) to achieve efficient field control for various operation scenarios.*

→ *Investigated impact of choice of Q_L on efficiency through simulation*
→ *Challenges for long pulsed and CW are different (in particular efficient filling)*

- *Evaluate methods for changing Q_L (at the cavity coupler and waveguide level).*

→ *Tests done at HoBiCat (HZB) with 3-stub tuner*
→ *Modify test stand (DESY) for operation with SSA : done and approved by TUEV*
→ *Currently preparing for tests with high Q_L (end of 2024, beginning of 2025)*
→ *2x 8kW SSA purchased for further tests at AMTF*

- *Investigate benefits of advanced ML-based combined RF and mechanical feedback controllers.*

→ *Started investigation to model transfer function PZT → RF (ongoing)*
→ *New position awarded at HZB + PhD at DESY.*

- *Demonstrate RF-efficient control in continuous wave (CW) and long pulse (LP) operation.*

→ *i.e. Final demonstrator (milestone) expected towards the end of iSAS timeframe*

Task 2.2: Efficient field control for high loaded-quality factor cavities – *M1-M48*

This month, installation of the Q-tuner (waveguide Qext adjustment) at our tests stand *is operation*

➔ high power with LLRF tests planned for end of Jan. 2025

→ *Investigated impact of choice of Q_L on efficiency through simulation*

→ *Challenges for long pulsed and CW are different (in particular efficient filling)*

• *Evaluate methods for changing Q_L (at the cavity coupler and waveguide level).*

→ *Tests done at HoBiCat (HZB) with 3-stub tuner*

→ *Modify test stand (DESY) for operation with SSA : done and approved by TUEV*

→ *Currently preparing for tests with high Q_L (end of 2024, beginning of 2025)*

→ *2x 8kW SSA purchased for further tests at AMTF*

• *Investigate benefits of advanced ML-based combined RF and mechanical feedback controllers.*

→ *Started investigation to model transfer function PZT → RF (ongoing)*

→ *New position awarded at HZB + PhD at DESY.*

• *Demonstrate RF-efficient control in continuous wave (CW) and long pulse (LP) operation.*

→ *i.e. Final demonstrator (milestone) expected towards the end of iSAS timeframe*

Task 2.3: Vibration analysis and detuning control of cavities – *M1-M36*

- *Characterize environmental disturbances and transfer to the cavity perturbation.*

→ *Test using ext. geophones at CMTB (PhD thesis Uni. Lodz, thesis submitted)*

→ *First tests with beam at SeaLab (BerLinPro) planned for October '24 (microphonics evaluation)*

- *Investigate and develop detuning counter measures based on advanced feedforward, feedback and active noise cancellation including AI methods.*

→ *Successfully demonstrated Luenberger Observer to estimate bandwidth and detuning*

→ *Demonstrated in pulsed and CW*

→ *Module implemented in firmware, (currently verification phase), test in the field beg. of 2025*

Task 2.3: Vibration analysis and detuning control of cavities – *M1-M36*

1. **Looking into an approach using a real-time power PC (simulation + feasibility study)**
2. **Setting up real CW data acquisition (i.e. guaranteeing phase continuous data buffers)**

→ *First tests with beam at SeaLab (BerLinPro) planned for October '24 (microphonics evaluation)*

• *Investigate and develop detuning counter measures based on advanced feedforward, feedback and active noise cancellation including AI methods.*

→ *Successfully demonstrated Luenberger Observer to estimate bandwidth and detuning*

→ *Demonstrated in pulsed and CW*

→ *Module implemented in firmware, (currently verification phase), test in the field beg. of 2025*

Task 2.4: Integrated LLRF control using Ferro-Electric Fast Reactive Tuners– M13-M48

- *Integrate a ferro-electric fast reactive tuner (FE-FRT) with a digital LLRF system*

→ *Hardware development 2026/27 within WP1*

→ *Simulation on effect and operation range can be carried out*

→ *When type and actuation is defined, digital interface can be defined*

- *Demonstrate microphonics compensation using a FE-FRT at a horizontal test stand*

→ *Depends on WP1 outcome*

→ *Development of Matlab/Simulink model of RF control loop to simulate resonance control for PERL (ICJLab) ongoing*

→ *FE-FRT can be included in model*

no new results since report in July

Task 2.5: Energy efficient supervisory control and fault diagnosis– M1-M48

- *Develop schemes to adjust solid state amplifier (SSA) parameters for efficient RF generation.*

→ *Contacted Cryoelectra GmbH to assess feasibility and interest*

→ *IB meeting during German holiday (neither Holger nor myself can attend)*

- *Investigate RF control parameters for energy-efficiency optimization using ML methods*

→ *Developed improved algorithm for more efficient Lorentz force detuning compensation*

→ *Double sine (instead of single) and smooth start to limit AC power and current on piezo*

→ *Tested and deployed at XFEL*

- *Develop fault diagnosis and anomaly detection of LLRF systems using ML approaches*

→ *1st milestone delivered and approved : (D35) ML implementation plan*

→ ***Demonstration of quench detection in CW using Luenberger Observer***

→ *Implementation of real-time fault detection on FPGA, firmware done, test phase*

→ *Implementation of a real-time fault detection on server, deployed in 1 RF station at XFEL (observation phase)*

Task 2.5: Energy efficient supervisory control and fault diagnosis– M1-M48

1. **ML-based fault detection developed in FPGA**
2. **Deployed at XFEL last week → gathering experience in next 6 months**

→ *IB meeting during German holiday (neither Holger nor myself can attend)*

• *Investigate RF control parameters for energy-efficiency optimization using ML methods*

→ *Developed improved algorithm for more efficient Lorentz force detuning compensation*

→ *Double sine (instead of single) and smooth start to limit AC power and current on piezo*

→ *Tested and deployed at XFEL*

• *Develop fault diagnosis and anomaly detection of LLRF systems using ML approaches*

→ *1st milestone delivered and approved : (D35) ML implementation plan*

→ ***Demonstration of quench detection in CW using Luenberger Observer***

→ *Implementation of real-time fault detection on FPGA, firmware done, test phase*

→ *Implementation of a real-time fault detection on server, deployed in 1 RF station at XFEL (observation phase)*

WP2 – LLRF: points of attention

- ***Personnel setback***

→ *key person for R&D left DESY in Fall 2024*

→ *mitigation: opened replacement position but challenging to find qualified personnel*

- ***Dependence of iSAS R&D on laboratory schedule***

→ *availability of test stands is not always predictable (delay, warm up, etc..)*

→ *mitigation: compiled a list of tests capabilities in partner labs*

- ***Future hardware development – on going***

→ *Evolution step :*

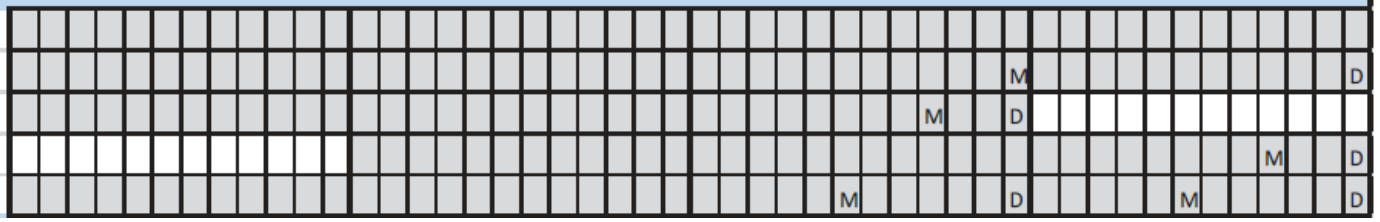
Development of next generation digitizers (heterodyne detection mode)

→ *Revolution step :*

First successful test of CSI (carrier suppression interferometer) integration with LLRF system at test stand with cavity

WP2 – LLRF: plans to achieve milestones & deliverables

WP2	Low Level RF Controls
2.1	Coordination of R&D on LLRF
2.2	Efficient field control for high loaded-quality factor cavities
2.3	Vibration analysis and detuning control of cavities
2.4	Integrated LLRF control using Ferro-Electric Fast Reactive Tuners
2.5	Energy efficient supervisory control and fault diagnosis



D2.1	ML based MC	Report on microphonics study & ML-based mitigation	2	DESY	R	PU	36
D2.2	SSA	Report on interface study of LLRF with SSA	2	DESY	R	PU	36
D2.3	LLRF control	Report on LLRF RF control studies	2	DESY	R	PU	48
D2.4	FRT based MC	Report on integration of FE-FRT in LLRF	2	HZB	R	PU	48
D2.5	Anomaly det.	Report on anomaly detection & LLRF optimization	2	DESY	R	PU	48

M2.1	Demonstration of energy-efficient SSA operation	WP2	30	Test report/publication
M2.2	Demonstration of detuning control techniques	WP2	33	Test report/publication
M2.3	Demonstration of RF control for CW/LP ops	WP2	36	Test report/publication
M2.4	Demonstration of ML and anomaly detection	WP2	42	Test report/publication
M2.5	Demonstration of FE-FRT Microphonics compensation	WP2	45	Test report/publication

→ Deliverables and Milestones are still fine and in reach

→ To support the WP2 program additional position will be open: 1) at DESY ~Q4/24 2) HZB done

Candidate found, next: contract signature

WP2 – LLRF: budget plans

WP	WP Subject	CNRS	CERN	ESS	DESY	VUB	CEA	HZB	INFN	UKRI	UL	*EPFL*	EU-budget kEUR	Matching personnel kEUR	Matching materials kEUR	Total budget kEUR
	Technology Areas															
WP.1	Ferro-Electric Fast Reactive Tuners							LEAD					989,3	784,0	277,8	2051,1
WP.2	Low-Level RF Controls				LEAD								498,9	612,0	204,0	1314,9
WP.3	Nb3Sn-on-Cu films for 4.2-K cavity operation								LEAD				871,4	616,0	232,0	1719,4
WP.4	HOM Dampers & Fundamental Power Couplers	LEAD											572,2	620,0	296,0	1488,2
	TOTAL FOR iSAS Technology R&D												2931,8	2632	1009,8	6573,6

→ No deviations