Superconducting radio-frequency virtual cavity for Hardware-In-the-Loop testing

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P. Echevarria, E. Aldekoa, J. A. Neumann, A. Ushakov, J. Knobloch, I. Badillo

(1) University of the Basque Country (UPV/EHU), (2) Helmholtz Zenrtrum Berlin

24-26 October 2018

Second Topical Workshop on Microphonics, LLRF Workshop Series
Motivation

Bring together a diverse group of experts spanning the key disciplines (LLRF, Mechanical and Cryogenic engineering) critical to the design and operation of SRF cavities and cryomodules, in particular those operated with high Q/narrow bandwidth and pulsed conditions.

Provide a basis for understanding the technologies and constraints which drive critical engineering decisions across these disciplines, and in particular the importance of a tightly integrated, cross discipline effort starting at the earliest practical point in a project.

Identify the key microphonic and detuning issues experienced in facilities currently operating, and lessons learned which can inform the design and installation of those under construction and being proposed. Present the latest developments in each discipline with the overall goal of producing quiet cryomodules, and addressing noise via both simple passive methods, and advanced active compensation techniques.

Workshop Organizers

Kevin Smith (BNL)
Curt Hovater (JLAB)

Program Committee

Yuriy Pischalnikov (FNAL)
Mariusz Grecki (DESY)
Alessandro Ratti (SLAC)
Curt Hovater (JLAB)
Kevin Smith (BNL)

Workshop Coordinator

Anna Petway
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Important Dates

Abstract Deadline: September 15, 2018
General Registration Deadline: October 1, 2018

Please register at:
https://www.bnl.gov/llrf18/

Second Topical Workshop on Cryomodule Microphonics and Resonance Control
LLRF Workshop Series
OCTOBER 25–26, 2018
NY Marriott at the Brooklyn Bridge
Brooklyn, NY

Outline

• Introduction
  • Collaboration between HZB and UPV/EHU

• FPGA based simulator for SRF cavities

• Hardware-In-the-Loop testing: microphonics

• Conclusions and future work
Collaboration between HZB and UPV/EHU

in the field of LLRF control since December 2016

- Helmholtz Zentrum Berlin, internationally recognized research center, operating two large scientific facilities, BER II and BESSY II
- University of the Basque Country (UPV/EHU) Laboratory of accelerator technology (IZPIlab)

Experience in modeling and control of electromechanical systems

Collaboration topics:
- SRF Cavity simulator, initially developed in HZB
- Microphonics compensation algorithms studies
- RF phase drifts compensation techniques
- Experimental vibration mode determination
- Mechanical transfer function fitting

Erasmus+ stays in HZB:
Graduate and Post Graduate students from the UPV/EHU
Collaboration between HZB and UPV/EHU

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First Collaboration Result:

Superconducting radio-frequency virtual cavity for control algorithms debugging
P. Echevarria, E. Aldekoa, J. Jugo, A. Neumann, A. Ushakov, J. Knobloch,

- Experimental vibration mode determination
- Mechanical transfer function fitting

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**Simulator for SRF cavities**

Main purpose: Hardware-in-the loop prototyping

- Test of different LLRF control techniques
- Microphonics compensation algorithms studies

Example in this session:

Control system design for SRF cavity based on Kalman Filter observer

Andrey Ushakov
Outline

• Introduction
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• Hardware-In-the-Loop testing: microphonics

• Conclusions and future work
• Implementation details

- LabVIEW based using PXI and FlexRIO technology
- Reconfigurability
- Rapid prototyping
- Compatible with the technology used in la UPV/EHU lab
• Implementation details

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Sampling clock (ADC), 100MHz
Computation clock (FPGA), 10MHz
Communication between host (LabVIEW APP) and FPGA -> DMA based FIFO
• Implementation details: cavity model

Electric part model

\[
\frac{d}{dt} V_{cav} = \begin{pmatrix} -\omega_{1/2} & -\Delta \omega \\ \Delta \omega & -\omega_{1/2} \end{pmatrix} V_{cav} + \begin{pmatrix} R_L \omega_{1/2} & 0 \\ 0 & R_L \omega_{1/2} \end{pmatrix} I_{in}
\]

Mechanics part model

Lorenz force detuning + microphonics effects

\[
\frac{d}{dt} (\Delta \omega_m(t)) = \begin{pmatrix} 0 \\ -\omega_m^2 \end{pmatrix} \cdot \begin{pmatrix} \Delta \omega_m(t) \\ \Delta \omega_m(t) \end{pmatrix} + \begin{pmatrix} 0 \\ -K_m \omega_m^2 \end{pmatrix} (E_{cav}^2 + U_{pert})
\]
Superconducting radio-frequency virtual cavity for HIL testing

FPGA based simulator for SRF cavities

• Implementation details: GUI

Host VI
• Electric model parameters
• Mechanical model parameters
• Non linear effects
  • Q slope
  • Quench

[Diagram showing implementation details with graphs and parameters]
Extensive simulation tests

➢ Individual functionalities
  • Electric model
  • Mechanic model
  • Microphonics
  • Lorenz Force Detuning

➢ Full model

Test of TESLA (9 cells) cavity voltage with different $\beta$
Extensive simulation tests

➢ Individual functionalities
  • Electric model
  • Mechanic model
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  • Lorenz Force Detuning

➢ Full model

Test of TESLA (9 cells) cavity:
Amplitude and phase with different detuning

\[ A = \begin{pmatrix} -\omega_{1/2} & \Delta \omega \\ \Delta \omega & -\omega_{1/2} \end{pmatrix} \]

Results from Eukeni Aldekoa’s Master Degree
Extensive simulation tests

- **Individual functionalities**
  - Electric model
  - Mechanic model
  - Microphonics
  - Lorenz Force Detuning

- **Full model**

Test of TESLA (9 cells) cavity:  

Detuning effect observed in the oscilloscope
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HIL testing of control techniques, possibilities

- Amplitude and phase
- Resonance frequency
  - Feedforward \( \rightarrow \) LFD

and microphonics?

- Test of different disturbances:
  - impulse, step, sinusoidal signals, white noise
Motivation

Analysis and active compensation of microphonics in continuous wave narrow-bandwidth superconducting cavities
A. Neumann, W. Anders, O. Kugeler, and J. Knobloch
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, 13
• New functionalities: Piezoelectric actuator model

Piezoelectric actuator model (discrete version)

\[ \Delta \omega_{DC}(k) = \frac{M_0 T_s}{T_s + \tau} V_{piezo}(k) + \frac{\tau}{T_s + \tau} \Delta \omega_{DC}(k - 1) \]

New possibility: HIL testing of control techniques against microphonics effect
• Initial pure simulation test

Matlab/Simulink

- Amplitude and Phase control
- Feedforward control for LFD
- Active vibration control
• Initial pure simulation test

Matlab/Simulink

- Amplitude and Phase control
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• Initial pure simulation test

Matlab/Simulink

- Amplitude and Phase control
- Feedforward control for LFD
- Active vibration control

Active control using adaptative feedforward algorithm
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Conclusions and future work

- **Reconfigurable simulator**
  - FPGA: real time.
  - Realistic functionalities
    - Reflected wave, Quench, LFD, some disturbances
    - Piezoelectric actuator

- **Applications**
  - HIL Simulations
  - Teaching
  - Kalman filter debugging

- **Microphonics: Future improvements**
  - HIL test of active control techniques
  - New disturbances simulated and real
  - Non colocated control