RFD Crab Cavity Contribution from the U.S. Recent Progress and Plans

Leonardo Ristori – Crab Cavity L2 Manager, Fermilab

With input from: ANL, BNL, JLAB, ODU, SLAC

9th HL-LHC Collaboration Meeting – Fermilab 14th-16th October 2019
Outline

- Scope and Deliverables
- RF Design Iterations by AUP
- Technical Achievements and Validations of 2019
- Cavity Prototype Fabrication at Zanon
- Immediate Needs
- Schedule
- Quality Assurance
- Acceptance Plan
- Goals for 2020
- Topics for discussion
Scope and Deliverables

- **Dressed RFD Crab Cavity**
  - **Project Scope** includes 2 Prototypes + 2 Pre-Series + 10 Series
  - **Bare Cavities**: Intermediate Qualification at FNAL at 2K
  - **Integration**: Bare Cavity + Magnetic Shields + Helium Tank + RF Ancillaries
  - **Dressed Cavities**: Final Qualification at FNAL at 2K + RF Ancillaries
  - **Delivery**: 10 qualified dressed cavities (mix of pre-series + series)
Recent RF design change

RF design change was necessary to address two issues:

1. Excessive beam-induced voltage observed at CERN in SPS tests of similar crab cavity (DQW)
   - New requirement by CERN on beam coupling voltage $V_b < 0.3 \text{ V/nC}$
   - (1a) Port rotated by 90 deg, (1b) implemented a hook design

2. Structural integrity of ceramic window subjected to transportation loads
   - (a) Increased inner diameter of ceramic 50 Ohm → 25 Ohm
   - (b) Adjusted overall length

$V_b$: 0.123 V/nC
Design of Feedthrough for Dampers

HOMs feed-thrus RF design change 50 Ohm → 25 Ohm:

- The change has been implemented to reduce transportation risks, increasing structural stiffness of the ceramic at the RF vacuum-RF lines interface.
- CERN and AUP have converged on a design.
- HOMs damping requirements are still satisfied.
Summary of RFD Cold Tests

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- All 14 tests (with and w/o dampers) exceeded nominal voltage of 3.4MV
- Highest voltage achieved with dampers = 5.5 MV
- Highest $Q_0$ achieved at 4.1 MV with dampers = $7.3e9$ (~2x requirement)
RFD cavity + HHOM and VHOM validation

- RFD2 cavity has been successfully tested with all RF ancillaries.
- HHOM RF leakage has been resolved. \( Q_0 \) exceeds requirement, quench \( V_t \) is \( 5.3 \text{ MV} > 4.1 \text{ MV} \).
- HHOM and VHOM dampers design has been successfully tested.
- Fundamental mode rejection has been tuned for both HHOM and VHOM.
Rotational BCP + HPR Validation

- RFD-LARP-001 has been successfully tested at FNAL, after undergoing full processing at APS-TD and ANL facilities: processing and facilities validation is complete

- New rotational Bulk & Light BCP
- 600 C degassing
- HPR and clean assembly
- 120 C bake
- VTS test
Heat Treatments + Cleanroom Assy Validation

600°C Heat Treatment (FNAL)

120°C Bake (FNAL)  VTS preparation (FNAL)

FNAL

RFD-LARP-001 exceeded requirements for HL-LHC
**Fabrication at Zanon**

- PO placed Sep 2018 for 2 Proto bare cavities
- Milestone payments for Prototypes:
  - 20% Fabrication Drawings ✔
  - 20% Forming tooling ✔
  - 30% Sub-components pre-trimming (in-progress)
  - 15% each delivered cavity
- Estimated deliveries of 2x prototypes
  - March 2020
  - April 2020
Fabrication Results: Waveguide Boxes Forming Results

- **Copper H-HOM Box Metrology Results**
  - Shape accuracy after reshaping 300bar:
    - Flat surfaces encouraging ~0.7mm (±0.35mm) shape accuracy
    - Tube interface area to be improve by calibration ~1.3mm (±0.65mm) shape accuracy
  - Minimum thickness: 3.85mm (only local area)
Fabrication Results: Waveguide Boxes Forming Results

- **H-HOM Boxes: EBW**
  - No official fixture used
  - Tight schedule need creativity!
  - Metrology ongoing
  - External weld bead is homogeneous and clean
  - RF side: smooth and constant welding width
  - No undercut
  - No excessive penetration
  - No misalignments
  - No sagging
Immediate Needs

- Drawings for Magnetic Shields and Helium Tank
  - Mechanical Design is CERN responsibility and recently complete
  - Drawings needed by AUP and will be used for launching prototypes only
- Converge on frequency shift estimates for prototypes
  - Necessary to define frequency goal at supplier
  - Frequency as-built is different from frequency in operation
- Converge and approval of revision of Functional Requirement Specification before end of 2019
  - Clarification and addition of certain requirements
- Address (together) open recommendations collected by AUP at past reviews
Delivery Dates

- 2 Bare Cavity prototypes are delayed at supplier
- Zanon recently split in two independent companies. Before the maneuver, it experienced several months of “financial-freeze” which caused a delay for all outsourced work. Currently all business as usual, but ~4 month delays were accumulated.
- As of now, no effect foreseen for launching bare cavity pre-series (April 2020) and series (end of 2020)
- Final delivery dates of 10 dressed cavities remain unchanged (July 2022 – March 2023)

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Quality Assurance

- For each procedure required by CERN, AUP is uploading in EDMS a draft for approval.
- Approval process is managed in EDMS. Despite being still at the prototype phase, certain AUP procedures for bare cavity fabrication are already approved.
- Plan is for AUP to use MTF for all qualification and production data for pre-series and series cavities.
- Convergence on procedures is needed before April 2020 when bare cavity pre-series are launched.
### QA documentation tracking

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**Notes:**
- NA: Not applicable
- ND: Not defined
Acceptance of RFD cavities

- Acceptance Plan (#1744):
  - Describes the process for acceptance between AUP and CERN, including OK to ship from CERN, and final checks at CERN after receiving

- Acceptance Criteria (#1154):
  - Discussions with CERN continuing towards a final version
  - All requirements from FRS will be verified with a test or a set of measurements during cavity production or during final tests at FNAL.

- Electronic travelers (VECTOR):
  - Already in place for several activities (see below)

Vector - Select Travelers - Read Only
Goals for FY2020

- Launch procurement of magnetic shields and Helium tanks for prototypes
- Complete fabrication of 2x prototype bare cavities at supplier
- Assess quality and 2K performance of prototypes
- Converge with CERN on MIP for bare cavity by February 2020 (PRR)
- Launch fabrication of pre-series bare cavities
- Complete fabrication of 3x sets of Proto-HOM dampers at Jlab and assess quality & performance
Upcoming Project Reviews

- **Procurement Readiness Reviews (Raw Materials) ~ Dec-Jan**
  - AUP soon launching procurement of raw materials for pre-series
  - Material List agreed upon and approved a while back, good (next slide)
  - Small “pilot” order placed earlier this year for small batch of Nb sheets, QA documentation recently approved by CERN, good start.
  - AUP will inform CERN of upcoming PRRs as needed

- **PRR Bare Cavities Pre-Series – Feb 2020 (TBC)**
  - Necessary to launch construction April 2020

- **Final Design Review (Dressed Cavities) ~ Summer 2020**
  - Participation of WP4 necessary (at min.) to defend mechanical design
  - Necessary to seek DOE approval for launching series in ~ Fall 2020.
RFD Bare Cavity Material List

- All materials contained in the deliverables, must meet CERN requirements
- Formal agreement between CERN and AUP on materials for bare cavities exists
  - RFD Bare Cavity Material List
  - EDMS 2001102 = US-HiLumi-doc-668

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Topics for Discussion

- Fully integrated test of dressed cavity + dampers + FPC
  - It’s a necessary validation for entire collaboration
  - Who/how/when/funding?
- Best use of AUP Prototypes in early 2021?
- Details of Final 2K tests at FNAL
  - 50 Ohm ↔ 25 Ohm
  - Converge on Traveler for cold test
- Verification at receiving end (Triumf)
  - Cold tests for prototypes?
  - Warm measurements for series?
- Transportation specification
  - CERN recently defined transportation requirement for the
    design of all crab cavity components (10g,…)
  - Transportation will need to be carried out avoiding exceeding
    design requirements
Summary

- Design of bare cavity was recently modified after SPS experience at CERN, and adopted for prototypes at Zanon. Design of HOM dampers was modified to accommodate CERN feedthrough design.
- ANL/FNAL Facilities, tooling and procedures for processing, heat treatment, cleanroom assembly were recently validated thanks to LARP prototype.
- Fabrication of 2 cavity prototypes is progressing well in terms of quality. Heavy oversight of AUP. Delays outside AUP control are not impacting delivery dates originally agreed between AUP-CERN.
- Compliance with CERN QA is defined, tracked and must continue towards a convergence in early 2020.
- Acceptance plan is taking shape but still in draft form with a deadline in mid 2020.
- US RFD Team and CERN WP4 have many topics to discuss this week!
Thank you to the US RFD Team!

Institutions in alphabetical order

- Argonne National Laboratory (Brazing and Processing):
  - Mike Kelly, Mark Kedzie, Tom Reid, Bill Toter
- Brookhaven National Laboratory (Interfaces and MIPs):
  - Silvia Verdu Andres
- Fermilab (RF/Mech Design, Procurements, Cold Tests):
  - Paolo Berrutti, Manuele Narduzzi, Alex Melnichuk, Damon Bice
- Jefferson Lab (HOM Dampers Fabrication):
  - Naeem Huque
- Old Dominium University (General Oversight and RF measurements):
  - Jean Delayen, Subashini De Silva
- SLAC National Accelerator Laboratory (RF Design, Coordination):
  - Alessandro Ratti, Zenghai Li

Comment from Preliminary Design Review

The committee would like to point out that the collaboration between the partner laboratories and Fermilab seems to be very productive and the overall progress should be commended.