LARGE SCALE TESTING OF SRF CAVITIES AND MODULES

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Institute of Nuclear Physics (IFJ) located in Kraków, Poland was founded in 1955 on the initiative Prof. Henryk Niewodniczański. After reorganization in 2004 the full name is The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN).

For Cavities and Cryomodules tests are involved:

- AMTF Technical Coordinator
- 18 engineers
- 24 technicians

Currently the work is organized on two shifts

Organizational structure of the IFJ-PAN Team performing cavity and cryomodule test at DESY
In December 2010 IFJ PAN signed the agreements with XFEL Company and National Centre for Nuclear Research, Świerk – Poland for performance of qualification tests:
**Location:** DESY campus at Hamburg

AMTF HALL is equipped with:

- Two cryostats
- Preparation area for cavities (6 Inserts)
- Three test stands for cryomodules
- Preparation areas for cryomodules
- Storage areas for cavities and cryomodules
AMTF Hall - Cavity

Vertical Cryostat
Radiation protection shielding
Cavity preparation area

Cavity storage area
Cavity incoming check area
Clean room
Unloading of the cryomodule after transport – see POSTER MOPP021

Cryomodule preparation area

Cryomodule test stand

Cryomodule test stand – module inside

Cryomodule test stand – front view
The test program is realized according to the written procedures.
Cavity Testing

Preparation and assembling

Main tasks:
- Incoming checks
- Assembling Cavity to the Insert
- Connecting Cavity to the vacuum line (in cleanroom conditions)
- Tuning of Fundamental Mode Rejection Filters of both HOM couplers + Cables connection
- Leak check of the Cavity
- Transport of the Insert to the cryostat + vacuum connection
Main tasks:
- Unload the cryomodule from the truck
- Incoming checks
- Load the cryomodule to the movable support
- Assembling Cryomodule at the test stand
- Connecting Cryomodule beam line to the test stand under clean room conditions
- Leak check of beam line interconnections and mass spectroscopy of the beam line
- Connecting of the waveguides
- Connecting of all electrical cables
- Connect of all cryomodule process pipes to the test stands
- Leak check of cryomodule vessel (ISO-VAC)
- Leak check of cryomodule cryogenic lines
- Assembly and isolating thermal shields
- Pumping down of isolation vacuum
Cavity and Cryomodule testing

Cool down and Warm up

**XATC1, XATC2**
- Pump and purge manual
- Cool-down to 4K, liquid helium transfer and warm-up **process automatized** by use of SNL scripts
- Pump-down to 2K manual

**XATB1, XATB2, XATB3**
- Pump and purge manual
- Complete cool-down and warm-up **process performed manually** by cryo-operators

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Cryogenics operation sequence for vertical cryostat

1. Cool-down to 100K
2. Liquid helium transfer to the cryostat
3. Pump-down to 2K
4. Measurement at 2K
5. Warm-up to 300K
6. Liquid helium transfer from the cryostat
7. Pressure rise to 1 Bar

Cryogenics operation sequence for cryomodule test stand

1. Cool-down to 70K
2. Cool-down to 4K, helium liquefication
3. Pump-down to 2K
4. Measurement at 2K
5. Warm-up to 300K
6. Liquid helium evaporation
7. Pressure rise to 1 Bar
Cavity Testing

Measurements at 2K

- Cavity performance test in 2K (QvsE measurement)
- HOM spectra measurements

Vertical test application
Analysis of vertical acceptance tests includes
- Series Cavities + “ILC HiGrade”-Cavities
- NO infrastructure commissioning tests

- So far delivered: 404 cavities
- Total RF tested: 382 cavities

Average:
> 9 tests per week since Oct 2013
(full operation of AMTF)
Cavity Testing

Vertical RF test conditions + acceptance criteria

- **Cavity “full equipped” refers to**
  - Dressed with He-tank (except of “HiGrade” cavities)
  - Equipped with fixed High Q-antenna, Pick-up and two HOM-antennas

- **Only Q(E)-measurement at 2K + fundamental mode frequencies**
  - All cavities checked for Q-disease by parking at 100K

- **Definition of usable gradient:**
  - Gradient of Quench or
  - Gradient at Unloaded $Q_0 < 1 \times 10^{10}$ or
  - Gradient at X-ray level: upper detector > $1 \times 10^{-2}$ mGy/min; lower detector > 0.12 mGy/min (empirical limit from FLASH cavities for different detector locations)

- **Acceptance criteria:**
  - OLD: Usable gradient > $26 \text{ MV/m}$ (10% margin for 23.6 MV/m design gradient)
  - NEW: Usable gradient > $20 \text{ MV/m}$ (after analysis of retreatment results for optimized number of tests and energy gain)
Yield of usable and maximum gradient of 339 cavities “as received” (EZ: 185; RI: 154)

Average maximum gradient:
(30.4 ± 7.6) MV/m
EZ: (28.4 ± 7.1) MV/m
RI: (32.4 ± 7.6) MV/m

Average usable gradient:
(26.6 ± 7.6) MV/m
EZ: (24.8 ± 7.0) MV/m
RI: (28.6 ± 7.9) MV/m
given errors are standard deviation

Detailed vertical test analysis see Poster THPP021
Cryomodule testing

Measurements at 2K

- Cold cables calibration
- Spectra measurement
- Cavities tuning
- HOM spectra measurements
- Couplers tuning
- Cavities calibration
- Cavities Flat-top measurement
- Heat Loads Measurements
- LLRF => Talk by J. Branlard WEIOA06
Sorting of cavities for string assembly according to
- gradient
- mechanical constraints

RF power constraints
- Equal RF power to cavity pairs
- Module: Maximum gradient 31 MV/m by available RF power
- Module: Allowed gradient spread ± 20% of average gradient

Seven modules tested so far (XM-2 to XM5)

- worse cavity of pair
- 0.5 MV/m below quench limit
- empirical radiation limit of > $10^{-2}$ mGy/min at both endcaps
- above power limit
Cryomodule testing

Summary of results

<table>
<thead>
<tr>
<th>XM</th>
<th>average max. gradient module [MV/m]</th>
<th>average max. gradient vertical [MV/m]</th>
<th>Average operational gradient module [MV/m]</th>
<th>Average usable gradient vertical [MV/m]</th>
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<tbody>
<tr>
<td>XM-2</td>
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All results above XFEL specs. 23.6 MV/m
Comparison of maximum vertical vs. module gradient

Few cavities show significant performance reduction

From individual max. gradient to operational module gradient:

~20% reduction
In total 840 cavities and 103 cryomodules are foreseen to test

Testing of the cavities established, 382 tested - Status Jul 31, 2014

Testing of the cryomodules started, 7 cryomodules tested - Status Jul 31, 2014

Cavity and Cryomodule testing and all work flows at AMTF are well established

Cavities and Cryomodules acceptance test performance are in average above specification

Testing in large scale requires development of many test procedures, software improvements and trainings. It is also a big logistic challenge. This have been succeed with help of DESY experts.

I strongly invite You to look posters:

- A New Type of Waveguide Distribution for the Accelerator Module Test Facility of the European XFEL
- TUPP019 - Qualification of the Titanium Welds in the XFEL Cryomodule and the CE Certification
- THPP022 (TALK + POSTER!) - Efficiency of High Order Modes Extraction in the European XFEL Linac
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    - DESY
    - IFJ-PAN
- and others

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Thank You !!!