Crab cavity HOM testing plan

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1. Introduction

One contributing factor to the High Luminosity Large Hadron Collider (HL-LHC) are the superconducting crab cavities. Project descriptions and deliverables for the crab cavities can be found at:

http://hilumilhc.web.cern.ch/activities/wp4-cc-rf

With reference to the cavity's Higher Order Modes (HOMs) and HOM couplers, several testing procedures are necessary to quantify operation of the couplers and to ensure that the HOMs are being sufficiently damped for use with beam. This document presents the procedures in place to conduct the testing procedures, with corresponding timelines detailed in Section 8.

2. Low power HOM spectral analysis

2.1. Analysis of existing infrastructure

Pre-installation spectral analysis of the Higher Order Mode (HOM) couplers for the Double Quarter Wave (DQW) crab cavity are required to evaluate the operation of the couplers. For the measurements, test boxes were designed to replicate the simulated transmission response of the HOM couplers.

In addition to quantifying whether the HOM couplers met manufacturing specifications and hence preformed as designed, the feasibility of HOM coupler conditioning was to be evaluated. As such, the test boxes were designed to be two port devices; to assess the RF transmission between couplers.

Necessary infrastructure will include two test boxes already built at Lancaster University and CERN.

2.2. Mode tracking during manufacture

During manufacture and tuning, the HOMs are tracked to quantify their deviation in frequency as a result of geometric changes.

These measurements will continue to be carried out and logged and use probes designed specifically for this purpose by J. Mitchell.

2.3. Research and development

In addition to testing the existing HOM couplers, two main areas of investigation will be pursued.

Firstly, a re-design of the on-cell HOM couplers for the DQW will take place. Currently, this is work in progress and the deliverables, in terms of performance and manufacture, have been defined officially with input from CERN, Brookhaven National Laboratory (BNL) and Lancaster University.

Secondly, couplers made with additive manufacture are being experimented with for both measurement purposes and feasibility studies in terms of operational performance on the cavity. For this, printed HOM couplers with electroplated surfaces are being manufactured for testing purposes initially. Following this, full metallic prints will be manufactured and there performance evaluated.

All couplers will be analysed on the test boxes detailed in section 2.1.

3. Vertical tests in SM18

Prior to installation into the SPS, the cavities will undergo tests in a vertical test facility (VTF) to analyse operation at two degrees Kelvin. This will happen at CERN's cold test facility, SM18. In addition to quantifying the cavity's transverse voltage and Q-factor, the tests will allow analysis of several other aspects of cavity performance.

The operations to be carried out which are related to this report are detailed below.

3.1. Bare cavity

Initially, cavity testing in the vertical test facilities with only a fundamental power coupler and pick-up probe. This scenario matches the tests conducted for the Proof of Principle (PoP) cavities for which the procedure and results can be found here:

https://indico.cern.ch/event/326148/contributions/1711490/attachments/633075/871268/SM18_crab_results.pdf

Following a full spectral analysis at cold, the bare cavity tests of CERN-DQW-001 and CERN-DQW-002 will both include resonance tracking of the deflecting mode and five higher order modes which

represent large impedance if excited by an external source. This procedure was carried out by J. Mitchell and R. Calaga for the PoP DQW in previous vertical tests and LabVIEW codes have been developed to automate this process meaning periodic data collection over a few days is possible.

The information gathered will quantify the frequency and Q-factors of the modes over a range of 2 – 300 K. This information will be used for analysis of the cavity's performance in comparison to simulations and also to return quantitative figures of merit representing cavity operation.

3.2. Partially dressed cavity

Following the bare cavity tests, the cavities will then be tested with the HOM couplers and helium tank. This set-up is often referred to as the partially dressed cavity.

3.2.1. Warm measurements (~ 300 K)

Firstly, the HOMs will be monitored with assembly of the helium tank. This will be done using a specific 'warm-probe' already designed, manufactured and tested by J. Mitchell.

- Full spectral measurement (0-2 GHz FPC/PU transmission) using a Vector Network Analyser (VNA) with low IF bandwidth and possibly with averaging if the response is at the noise floor.
- Discrete transmission measurements of modes using a VNA (FPC/PU).
- Reflection measurements for each mode through FPC.
- For each HOM coupler:
    - Full transmission measurement between FPC/HOM Coupler.
    - Discrete transmission measurements between FPC/HOM coupler.
    - Reflection measurements for each mode through HOM coupler.

The procedure defined above will the quality of the damping to be analysed and compared to simulations. Additionally the Qext of each mode can be resulted.

3.2.2. Cold measurements (~ 2K)

The procedures detailed for the warm measurements will also be carried out for the cold measurements.

3.2.3. Other measurements

Monitoring of the HOMs over the warm-up will again be carried out for the dressed cavity.

4. Horizontal tests

For the horizontal tests in the cryomodule, all of the HOM couplers will terminate at the outer surface. Transitions to n-type conections will be used to allow connection of a VNA via cables for which the calibration will be stored in the analyser.

The same measurement campaign as the one described in Section 3.2.1 will then be carried out.

5. HOM coupler conditioning

The DQW HOM couplers are on-cell couplers located in high field regions and are required to act as transmission lines for high RF power at discrete frequencies. As such, a feasibility study into conditioning the couplers before installation onto the cavity will be carried out.

Previously, Lancaster University was involved in the design of a conditioning set-up for the Fundamental Power Couplers (FPCs). This set-up has successfully allowed gradual RF conditioning [1] of the FPCs and as such a similar system will be investigated for the HOM couplers.

Preliminary meetings with E. Montesinos have allowed the similarities and differences in such a system to be realised and as such first steps in defining the type of conditioning (single frequency or multi-frequency) is underway. Following deliverables in terms of operational characteristics, the test box and any resulting modular components will be designed.

The final steps will include control systems (LabVIEW, VBA or C depending on requirements) and mechanical design using CAD software.

If feasible and the need is warranted, manufacture of the conditioning set-up would then follow in a location to be determined.

6. SPS

Currently, HOM measurement plans for the SPS are still in preparation. Whilst installing the devices, frequency tracking will be carried out after each stage.

7. Timeline

A timeline is shown below and is presented as a working document to give a visual representation of the timescales associated with the procedures defined in this document.

	Task Name	Duration	Start	Finish
1	2. Low power HOM coupler spectral analysis	10 days	Mon 20/03/1	Fri 31/03/17
2	2.1 Spectral analysis of Nb HOM couplers	5 days	Mon 20/03/1	Fri 24/03/17
3	2.2 Construction of polymer HOM coupler	5 days	Mon 20/03/1	Fri 24/03/17
4	2.2 Testing of polymer HOM coupler	5 days	Mon 27/03/1	Fri 31/03/17
5				
6	3. Vertical tests in SM18	52 days?	Fri 24/02/17	Mon 08/05/1
7	3.1. CERN-DQW-001 - Tests of bare cavity	6 days	Fri 24/02/17	Fri 03/03/17
8	3.1. CERN-DQW-002 - Tests of bare cavity	6 days	Fri 10/03/17	Fri 17/03/17
9	3.2 CERN-DQW-001 - Tests of dressed cavity	6 days	Mon 17/04/1	Mon 24/04/1
10	3.2 CERN-DQW-002 - Tests of dressed cavity	6 days	Mon 01/05/1	Mon 08/05/1
11				
12	4. Horizontal cryonmodual tests	66 days	Mon 20/11/1	Sat 17/02/18
13				
14	5. HOM coulper conditioning	50 days?	Mon 20/02/1	Fri 28/04/17
15	Feasibility study	10 wks	Mon 20/02/1	Fri 28/04/17
16				
17	6. SPS tests	245 days	Mon 01/01/1	Fri 07/12/18

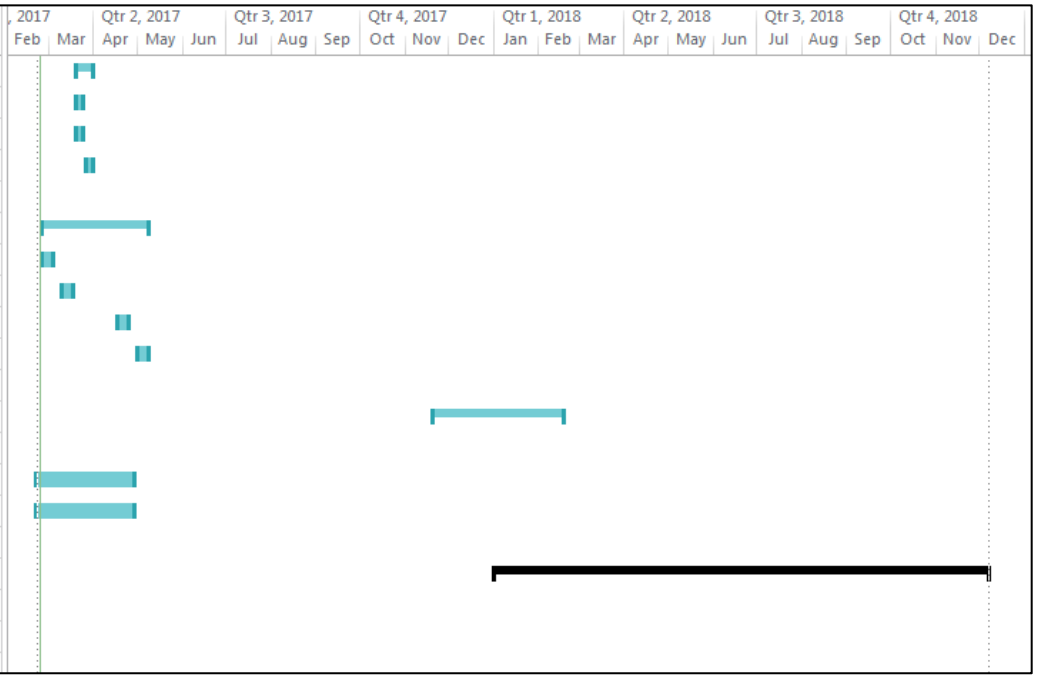

Figure 1: Gantt chart (working document).

8. Bibliography

[1] E. Montesinos, “Construction and Processing of the Variable RF Power Couplers for the LHC Superconducting Cavities,” in *13th International Workshop on RF Superconductivity (SRF2007)*, Peking, 2007.