

ASSEMBLY OF THE DQW CRAB CAVITY CRYOMODULE FOR SPS TEST*

M. Garlaschè[†], K. Artoos, R. Calaga, O. Capatina, T. Capelli, D. Lombard, P. Minginette, M. Narduzzi, J. Swieszek, P-F. Marcillac¹, L. Renaglia¹, N. El Kbir², J. Roch²,
CERN, Geneva, Switzerland

A. Krawczyk, B. Prochal, IFJ-PAN, Kraków, Poland

¹ also at Groupement KA, Heidelberg, Germany

² also at AlteAD, Vernier, Switzerland

Abstract

RF Crab Cavities are an essential part of the High Luminosity Upgrade of the LHC accelerating complex. Two concepts of such superconducting systems are being developed: the Double Quarter Wave (DQW) and the RF Dipole (RFD). A prototype cryomodule - hosting two DQW cavities - has been fabricated and assembled for validation tests to be carried out in the Super Proton Synchrotron (SPS) at CERN. An overview of the main cryomodule components is presented, together with the system features and main fabrication requirements. The preparatory measures for cryomodule assembly, the execution and lessons learned are also discussed.

INTRODUCTION

In the framework of the High Luminosity upgrade project for the LHC (HL-LHC) at CERN, large sections of the accelerator will be modified [1]. As core enhancement to the accelerating complex, the so called crab cavities will be installed in correspondence of the beam interaction points at the Atlas and CMS experiments [1]. The crab cavities are novel SRF systems aimed at increasing integrated luminosity via reduction of the beam crossing angle. Two different cavity designs are foreseen - one for horizontal (RF Dipole, RFD) and one for vertical (Double Quarter Wave, DQW) crabbing of the beam.

Specific tests are foreseen in the SPS accelerator at CERN, in order to validate the operating principle of both cavity designs [2]. The RFD prototypes needed for such tests are currently being manufactured at the CERN Main Workshop, whereas two DQW cavities have already been manufactured [3] and subsequently assembled in a dedicated cryomodule. This paper recalls the main features of the DQW cryomodule and reports on its assembly.

THE DQW CRYOMODULE

The core elements of the DQW cryomodule are the two dressed cavity systems (central in Fig. 1). These enclose the crab cavities and the minimum set of components directly interfacing with them (Fig. 2): helium tank, cold magnetic shield, internal tuning mechanism, powering and RF control equipment; the latter includes High Order

Modes suppressors (HOMs), pickup field antenna, Fundamental Power Coupler (FPC). Power to and from the RF systems is transported via custom-made coaxial lines.

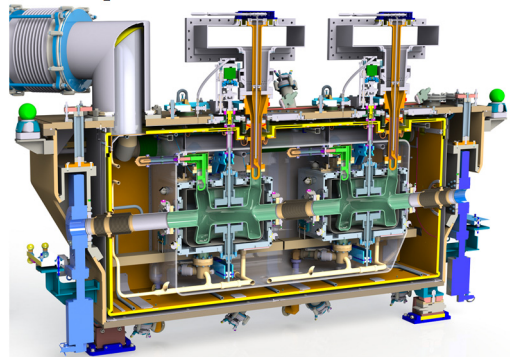


Figure 1: Cut view of the DQW cryomodule.

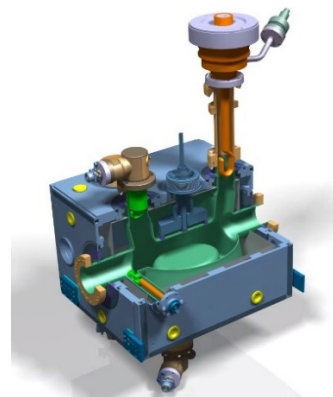


Figure 2: Dressed cavity.

In addition, the cryomodule comprises the following main subsystems:

- *Cavity support and alignment:* the dressed cavity is supported and aligned via a three-rods system, consisting of two fine stainless steel blades and of the FPC itself. All three supporting elements are equipped with gauges for live acquisition of induced thermal and structural stresses. In order to ensure the robustness of alignment measurements both during assembly and during tests in SPS, redundant position monitoring

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[†] Marco.Garlasche@cern.ch.

systems have been installed. The two systems, consisting of a Frequency Scanning Interferometer and of a BCAM (Brandeis Camera Angle Monitor), detect position of multiple targets integral with the dressed cavity [4];

- *Insulation vacuum*: a stainless steel vessel encloses the cryomodule equipment. Four windows are present on the lateral sides of the vessel, in order to allow access during assembly and eventual repair. The vessel design and its division between a low container and a top plate stems from the philosophy chosen for cryomodule assembly, which foresees mounting the systems below the top plate – which thus serves as support for most internal devices – and then lowering the sub-assembly into the container;
- *Beam vacuum*: the inner cavity volume and the connecting beam lines are sealed via two lateral gate valves. The corresponding subassembly is referred to as string assembly;
- *Magnetic shielding*: in addition to the cold magnetic shield, installed between the cavity and the helium tank, the needed magnetic field reduction is reached via a warm magnetic shield in mu-metal – directly attached to the internal surface of the vacuum vessel;
- *Tuning*: movement of the internal tuning mechanism is obtained via tubes and a frame – assembled around the helium tank – which is in turn actuated via a stepper motor system sitting outside the top cover of the vacuum vessel [5];
- *Cryogenics*: helium is driven into the system through a jumper located on the top cover of the vessel; it is then fed to the tanks, the HOMs and the thermal shield via dedicated cryogenic lines. On the top part of the line, two reservoirs ensure that the superconducting systems of each dressed cavity are always filled with coolant at the liquid state. Embedded measurement equipment allows the constant monitoring of gas pressure and liquid minimum level; while heaters are installed in the tank, FPC and tuner actuation in order to counteract eventual condensation;
- *Thermal screening*: radiative heat losses towards the vacuum vessel are reduced via a thermalized copper shield and sets of Multi-Layer Insulation (MLI) installed on the cold elements (helium vessel and adjacent components, thermal screen, embedded cryogenic system);
- Given the prototype nature of the system, *additional instrumentation* has been installed in order to monitor the magnetic flux in correspondence of the helium tank (thus external to the cold magnetic shield) and the temperature of some critical equipment (FPC, HOMs, tank, powering lines).

A more detailed description of the cryomodule, its requirements and the corresponding design choices may be found in [6].

CRYOMODULE ASSEMBLY

The following examines some of the main aspects in the cryomodule assembly, starting from the string line until the complete system; further information may also be found in [7]. Information on the dressing and string line assembly of the cavities – performed in ISO4 cleanroom – may be found in [8]; while information on the assembly of cavity, cold magnetic shield and tank (thus prior to cleanroom) may be found in [9].

Work Preparation

In order to attain the complete DQW cryomodule, a total of around ninety assembly actions are required. A master assembly sequence has thus been devised, grouping all actions into fifteen macro-steps (Fig. 3). The break-up has been defined so to:

- Cluster interventions by the same assembly actor on a given equipment, thus streamlining manpower and planning;
- Allow parallel work on different steps;
- Minimize the entropy of each assembly step, namely the disassembly steps to be performed in case of issues encountered. In this framework, for example, priority has been given to maximizing the number of assembly steps performed prior to insertion of the top cover sub-assembly into the lower vacuum vessel; as the latter step entails lengthy and critical procedures for smooth insertion, tightening and leak control;
- Comply with the fabrication planning of the different components.

The granularity defined in the assembly sequence has also been used for the creation of assembly procedures dedicated to each step. These procedures accurately lay out the sequence of events for all assembly sub-steps and control hold points, also detailing additional information needed (e.g. components reference numbering, quantities, tightening torques, major criticalities to be looked out for).

Meticulous assembly and control procedures are clearly necessary in order to keep track in the construction of a system with thousands of heterogeneous assets as the DQW cryomodule. The preparation and control of such procedures, though, have also proven fundamental for defining a common strategy between the design and assembly teams, and for spotting possible issues and lack of information prior to each step rather than on the field.

Assembly Area and Tools

Figure 4 shows the area dedicated to the cryomodule assembly, located in the SM18 building at CERN. The total active surface amounts to 100 m². Such space comprises an area situated right in front of the cleanroom exit (on the right with respect to Fig. 4) and linked to the latter via a shared rail system: once ready, the carriage on which the cavity string is assembled can be directly pushed outside the cleanroom towards the cryomodule area. The remaining space has been used for parallel assembly of equipment – i.e. offline with respect to cavity string – and the storage thereof. The assembly area, in addition to a 45 m² storage

space, has proven sufficient for the orderly assembly of the DQW prototype cryomodule. Further space considerations should be made for the more intense material flow during eventual series assembly.

Many different tools have been designed and produced, not only for direct assembly purposes but also for transport, leak checks, protection of critical equipment. One of the

most prominent amongst these tools is the lifting portal, which can be seen in Fig. 4. The portal must provide stable support during assembly of equipment on the top cover (loads varying up to 2.2 tons); it must also ensure even and precise movement (± 0.2 mm range) of the top cover subassembly as it is finally lowered into the vacuum vessel.

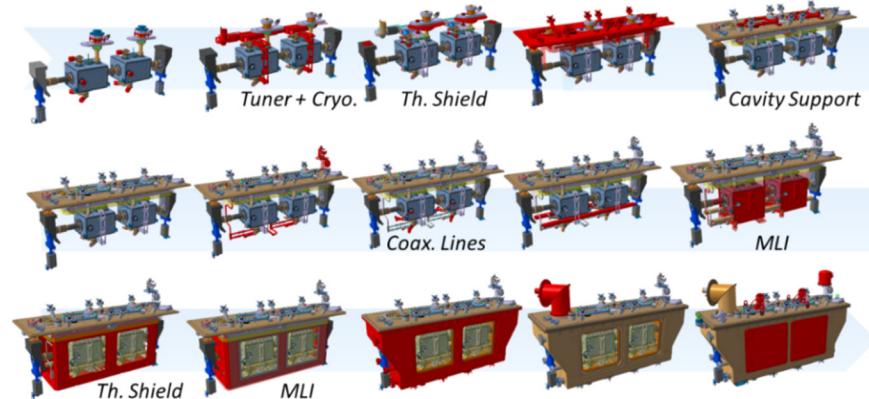


Figure 3: Macro-steps for cryomodule assembly.



Figure 4: Assembly area.

Assembly and Lessons Learnt

Cryomodule assembly has been completed in a span of eleven weeks during the third quarter of 2017. Such short schedule has been kept in light of a crash program effort; a more standard timeline would indicatively set around sixteen weeks. Five technicians were needed, divided among the tasks of mechanical assembly, welding, logistics and coordination. Assembly steps have been parallelized as much as possible, thus allowing teams to work at the same time on different equipment. This solution has proven most useful when given components were reserved for welding/safety-related checks.

In addition to the core assembly team, regular support was needed from at least one expert per field (vacuum, cryogenics, RF, alignment, transport); experts have been involved both for ad-hoc assistance in the assembly of critical equipment and as equipment responsible providing greenlight at hold points.

Due to the tight schedule of the project, many design, fabrication and assembly activities have been performed in concurrence. In particular, day to day assembly has been performed in synergy with the design team, who provided immediate feedback to address questions and issues arising.

The overall assembly procedure has proceeded smoothly. Nevertheless, experience gained has triggered slight modifications for the series design and assembly choices. Here below are few examples.

Some components shall be adjusted in order to allow for more assembly space and to further ease the steps after insertion of the top cover subassembly in the lower vessel. In general, maximum ease of disassembly until the latest assembly steps shall be further sought. Additional intermediate checks have also been implemented in the updated assembly procedure, so to mitigate detection of errors at late stages.

The MLI shall be designed to be less geometry-dedicated: more universal sheet shapes shall better account for unavoidable geometrical inaccuracies (occurring for example in the welded assembly of the cryogenic piping).

Due to their direct interface to delicate parts of the cavity, some details of the tuner frame and actuation shall also be redesigned, in order to reduce undesired effects on the cavity during mounting.

Full traceability of material and control of magnetic permeability -especially regarding standard off-the-shelf equipment- has proven highly useful in avoiding non-conformities.

CONCLUSION

Thanks to the great effort of all stakeholders, assembly of the DQW prototype cryomodule has been successfully accomplished, in compliance with the tight schedule required for installation in the SPS.

Though no major showstoppers have been encountered, experience gained is already being implemented for the design and manufacturing activities of the RFD prototype and future series productions. The documentation available for each assembly step shall also prove useful for the upcoming ventures.

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