PREPARATION OF THE 3.9 GHZ SYSTEM FOR THE EUROPEAN XFEL INJECTOR COMMISSIONING

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Abstract

The 3.9 GHz cryomodule and RF system for the XFEL Injector is being assembled and delivered to the underground building in summer 2015, for the injector commissioning in Fall 2015. This contribution outlines the status of the activity and reports the preparation stages of the technical commissioning of the system.

INTRODUCTION

The European XFEL (E-XFEL) injector hosts a cryomodule composed of 8 SCRF cavities at 3.9 GHz, for the linearization of the longitudinal phase space distortions experienced by the beam in the first 1.3 GHz accelerating module, before the bunch compressor stages [1]. The module design was derived from the FLASH third harmonic section, developed by FNAL [2], with some major modifications in the module and cavity package design, in particular the development of a cavity string with alternate coupler orientation with respect to the beamline, for coupler dipole kick compensation [3]. The cavities have been fabricated and vertically tested as described in other contributions to these Proceedings [4-6], here we describe the module preparation for the tunnel installation.

RF COMPONENTS

The procurement of E-XFEL third harmonic cavities started in 2012, after the fabrication of three prototypes in order to set the industrial production and treatment steps. Long procedures were however required to qualify the design and the fabrication procedures before the cavity production in order to achieve conformance to the European Pressure Equipment Directive (PED) norms, as required by the E-XFEL Project. As a consequence of this, , the first 8 cavities fully qualified in the INFN Vertical Testing (VT) facility reached DESY in the period from mid-December 2014 to mid-March 2015, and the last two at the end of May 2015, in conditions ready for starting the string and module installation.

Power Couplers (PC) are of the same FNAL design as the ones installed in FLASH ACC39, with the antenna length adapted to the different E-XFEL beam structure.

Couplers were industrially procured and processed after fabrication at FNAL. The 8 couplers necessary for the string installation were sent in pairs in their conditioning boxes from FNAL and were available at DESY from mid-February to Mid-June 2015.

CAVITY PACKAGE QUALIFICATION

Early in the development of the E-XFEL 3.9 GHz system planning the possibility to perform a complete cold module characterization before installation in the injector was ruled out. Both the Accelerator Module Test Facility (AMTF) infrastructure for the 1.3 GHz module testing and the smaller Cryomodule Test Bench (CMTB, which was used for the ACC39 2m module) at DESY would have required significant time and work for the adaptation to the nearly 6 m E-XFEL 3.9 module, incompatible with the tight operation schedule of these facilities for the preparation of the main linac components. The decision was taken to characterize the module in the injector commissioning phase, which is planned during the main linac installation, and almost a year before its commissioning.

In the original plans, individual cavity tests in horizontal cryostats (at DESY or elsewhere) were foreseen to achieve cavity qualification in conditions similar to their operation before installation in the accelerating module. As cavities and couplers were delayed the plan was amended and a single horizontal cavity test was performed to qualify the cavity package (including all ancillaries like coupler, tuner, shielding, HOMs) and the assembly procedures. The test was successfully performed in March 2015 and is described in another contribution in these Proceedings [7].

X3M1 MODULE ASSEMBLY

The preparation of RF components was performed at their arrival in DESY: Coupler cold parts were installed on available cavities in order to return the transport and conditioning boxes to FNAL for the successive shipments of further items. With the installation of the last pair of cold coupler parts the preparation of the E-XFEL module string could start at the end of June 2015.

Table 1: Main Assembly Operations of Module X3M1

Phase	Duration	When	Activity
CLEAN ROOM, STRING ASSEMBLY	3 Weeks	Week 25	Clean room tooling preparation (cavities placed on girder), last couplers installed on cavities
		Week 26	Start of string installation, beginning of cavity connections with the intercavity bellows.
		Week 27	Finish installation. Leak check and string roll-out
ROLL-OUT AREA STRING ON GIRDER	2 Weeks	Week 28	Partial magnetic shield installation and tuner installation, deployment of T sensors on cavities
		Week 29	Ti 2 phase line welds, T sensors installation completion, tuner motor installation
ROLL-OUT AREA STRING SUSPENDED FROM COLD MASS	2 Weeks	Week 30	Transfer the string to suspension from cold mass, completion of magnetic shield bottom parts, longitudinal string pre-alignment and first alignment survey.
		Week 31	End of string alignment (2 pass and final survey), transfer with crane to cantilever area, preparation of 2K thermal sinking (HOM, motor), HOM notch filter tuning, warm tuner action check.
MODULE INTEGRATION ON CANTILEVER	4 Weeks	Week 32	Weld of the magnet package current leads, weld of the cooldown/warmup circuit on the cavities.
		Week 33	Closure of the magnetic shield at the cavity interconnections, RF and motor cable installation, connection of the HOM thermal sinks, additional tuner checks, removal of cold coupler support and installation of coupler cones, cable thermalization on 2 K area, start assembly of 4K shield parts
		Week 34	Finalization of 4K shield installation, shield welding and preparation of the 10 MLI blanket, with coupler port cutouts, assembly of the 80 K shield, welding and installation of the 30 MLI blanket, with post and port cutouts
		Week 35	Vessel roll-on, installation of the post bracket and transfer of the Cold Mass on the Vacuum Vessel support, longitudinal pre-alignment of CM to VV, transfer to floor supports
MODULE COMPLETION ON FLOOR SUPPORTS	3 Weeks	Week 36	CM to VV alignment, start of warm coupler part installation
		Week 37	Finish Warm Coupler Part installation on one side, install coupler vacuum pump line. Weld of the magnet current lead box.
		Week 38	WCP installation opposing side, second coupler vacuum pump line, beam vacuum & leak check. Module feedthroughs.
END		Week 39	Transport to Tunnel

Schedule of Operations

The module assembly consists essentially of the same operations needed for the preparation of the FLASH (formerly TTF) modules, now streamlined and consolidated for the series production of the 101 XFEL accelerating modules.

Some small deviations were needed for several reasons: different cavity and ancillary components like tuner and couplers, tighter spaces - the module is only 6 m long but hosts the same number of smaller active components - and increased diagnostics (a large number of temperature sensors has been placed on the cavity string to detect possible temperature increases at the cavity HOM regions during beam operation, due to the smaller cavity aperture).

The module assembly had an overall duration of 14 weeks, from the availability of 8 cavities with installed couplers to the tunnel installation.

The main activities performed during the module assembly are summarized in Table 1 and discussed in additional details in the following paragraphs.

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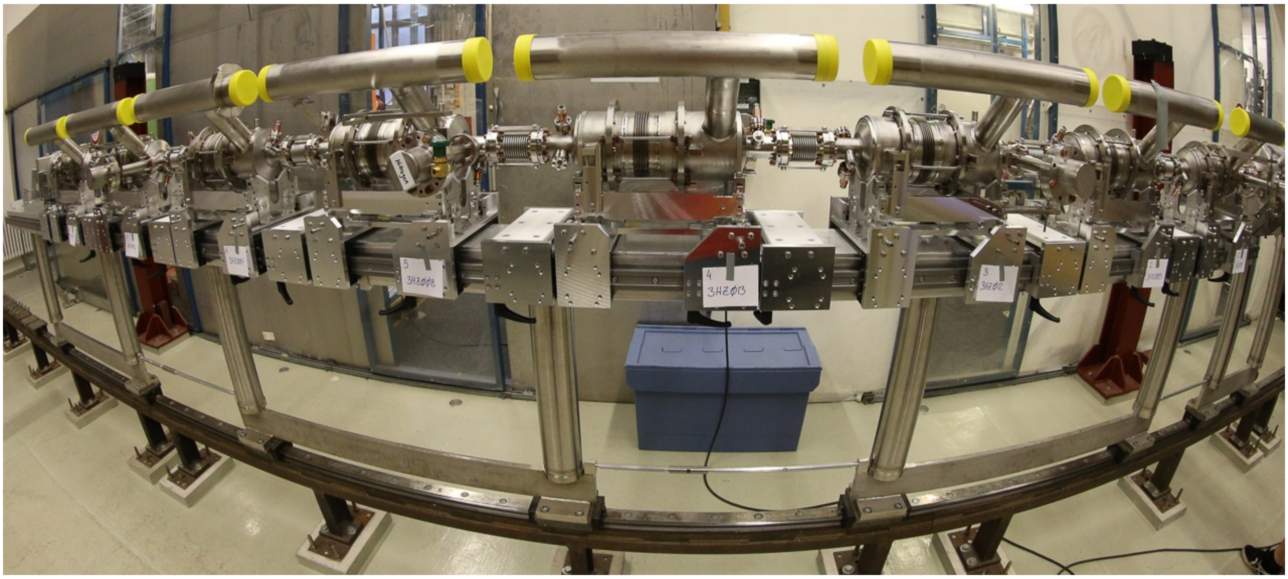

Figure 1: X3M1 string after roll-out from the clean room, supported on the girder.

Clean Room, String Assembly

The cavity and **string assembly** activities, as well as the development of all the tooling needed for the work, are documented elsewhere in these Proceedings [6].

Once all the cavities were equipped with cold coupler parts, two weeks were needed for the connection of the quadrupole package and 8 cavities into the string of module X3M1. Figure 1 shows the full string after roll-out from the clean room.

Roll-out Area, String on Girder

After the roll-out the cavities were equipped with the **magnetic shield**, split into several parts due to the cavity vessel geometry. A few portions of the shielding at the cavity bottom could not be installed due to interference with the cavity supports and were deferred after the string suspension. The **blade tuner** mechanism was then installed, under frequency monitoring from a VNA to avoid cavity potential frequency perturbations due to the assembly. Eight CERNOX **T sensors** were installed on each cavity, two on the helium vessel and three at each HOM region (at the feedthrough flange, on the HOM can close to the weld point of the inner antenna and on the top of the HOM can), for temperature interlocks during operation, to detect excessive heating due to extracted HOM power.

After the preparation work on the cavities, the Titanium **2 phase line** of the cavity string was completed, welding the Ti bellows connection between the cavity 76 mm OD pipes and the two terminal part containing Ti-SS bimetallic transitions, upstream (quadrupole end) and downstream. All these welds were performed with an automated orbital welding machine. The quadrupole connection to the SS portion of the 2 phase line was then welded. Activities in this string configuration terminated with the tuner motor installation, leak check of the 2 phase line and X-Ray inspections of the welds.

Figure 2 shows one of the cavity of the string during installation of magnetic shielding, tuner and temperature sensors (above), and the welding operations on the 2 phase line (below).

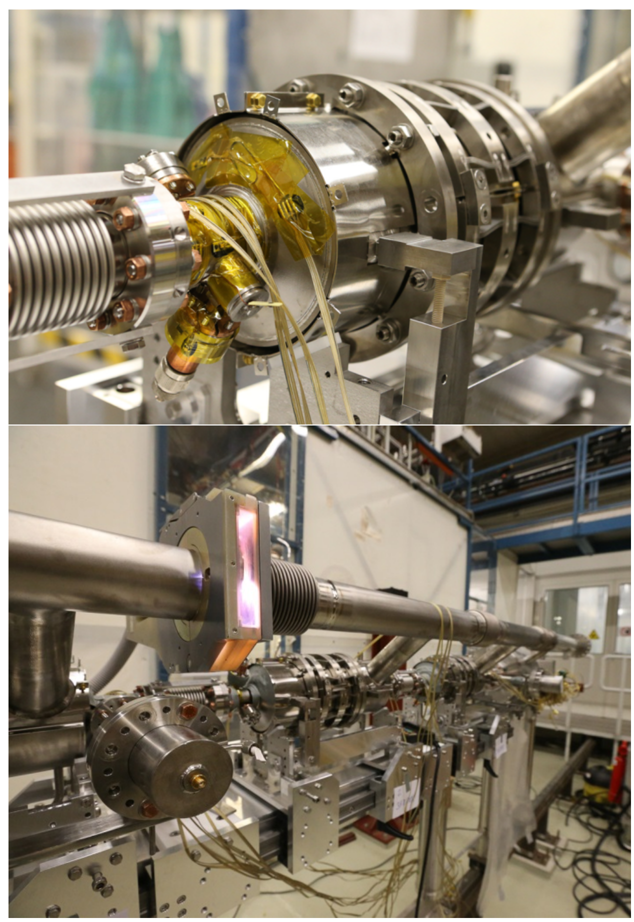

Figure 2: Top: Assembly of the magnetic shielding, blade tuner mechanism and T sensors on the cavity. Bottom: welding operation on the 2 phase line.

Roll-out Area, String Suspended From Cold Mass

After positioning the Cold Mass (CM) on top of the string and performing the first rough alignment, the string was **suspended** on the CM by installing the roller bearing sliding support mechanisms, and secured to the CM invar rod. At this stage, the remaining magnetic shield parts were installed at the bottom of the cavity and the first **alignment survey** was performed, in order to issue the individual cavity alignment instructions, with a procedure similar to the 1.3 GHz modules. Cavities were aligned to their electrical axis (defined by the best fit-line of the cell centers) using eccentricity and transfer measurements performed during the cavity fabrication [4]. Alignment instructions were implemented by acting on the regulation screws of the cavity spring/loaded roller bearing suspension system, similar to the one developed for the TTF/TESLA modules [8], shown in Figure 3.

A second alignment pass was required to bring the cavities within the tolerances, and the final alignment survey took place.

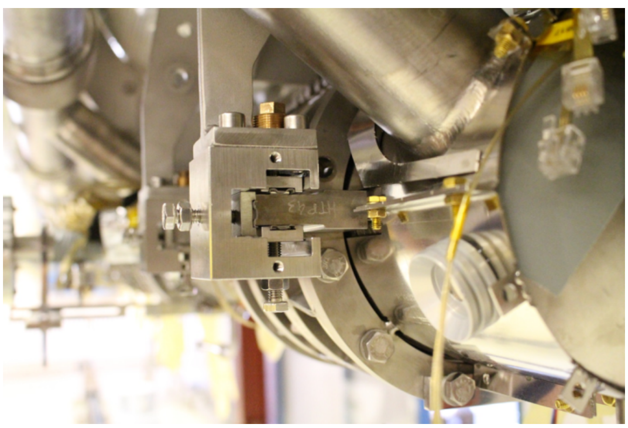

Figure 3: The cavity spring-loaded, roller bearing suspension system.

Module Integration on Cantilever

The cold mass was then transferred with a crane to the cantilever area. The preparation of **2K thermal sinking** (HOM and motors) with copper braids connected to the 2 phase line was started.

One of the first activities on the cantilever area was the final **RF control of the string** before closing the thermal shields. The final HOM notch filter check and tuning for rejection of the fundamental mode was performed, followed by a small range tuner action check.

All **HOM notch filters** were checked and some slightly retuned for good rejection of the fundamental mode except for one. In general, HOM notch filters opposing the main coupler port show a small variation in the notch filter position after the main coupler installation, possibly due to local field pattern perturbations caused by the antenna proximity. In most cases the filter was correctly retuned, except in cavity 3HZ013. For this cavity the HOM can membrane was already heavily deformed during the tuning operation at LASA before shipment to DESY, and the MC installation shifted the notch outside the tuning range. A Q_{ext} for this HOM in the range of the field probe is expected for this cavity, to be confirmed only after cooldown. In case of excessive fundamental power extraction, this cavity will be detuned, and operation with 7 cavities is sufficient to provide the moderate third harmonic voltage for operation.

The one turn small range **tuner action** on all cavities confirmed the expected average frequency response of ~180 kHz/turn, fully confirming the design expectation.

After the RF controls, the **magnet package current leads** were installed and welded at the quadrupole, followed by the installation of the module cooldown-warmup pipe and its weld to the cavity filling lines.

At this point the activities proceeded with the installation of: the **magnetic shield parts at the cavity interconnections** and all **RF and motor cables.** The HOM thermal sinks were connected to the antennas. Finally, **cold coupler supports** were removed, the **coupler 70 K shield cones** and 4 K plates connected. At this stage another tuner action verification was performed, showing no impact of the sliding magnetic shielding interconnections on the cavity frequency response. Results are summarized in Table 2 and Figure 4 shows one cavity at this stage of the assembly.

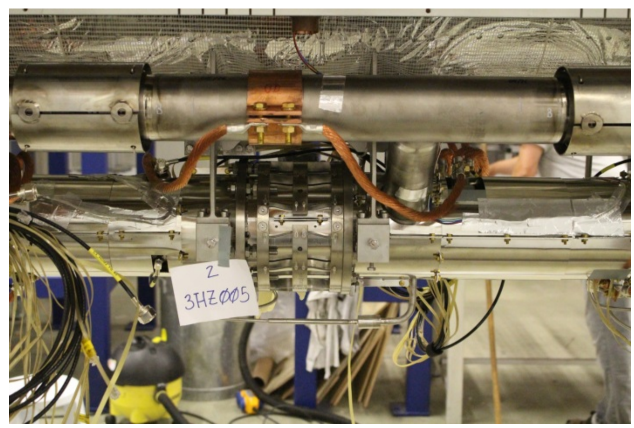

Figure 4: One cavity of the string, after installation of the magnetic shield interconnections between the cavity, the installation of all RF cabling and thermalization braids for the tuner motor and HOM feedthroughs. Motor cables are thermalized on the magnetic shield surfaces.

Table 2: Summary of the Tuner Action Checks (2 Turns)

Position	Cavity	Tuner action [kHz/turn]
1	3HZ010	178
2	3HZ005	193
3	3HZ012	193
4	3HZ013	195
5	3HZ008	184
6	3HZ007	184
7	3HZ004	185
8	3HZ011	183

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Finally **the thermal shields assembly** started, first with the 4 K shield assembly and superinsulation with a 10 Multi-Layer Insulation (MLI) blanket, then 80 K shield with 30 MLI blanket. Once the 80 K shield installation was completed, the **Vessel roll-on** was performed, the post brackets assembled and the Cold Mass was transferred on the Vacuum Vessel (VV) supports and pre-aligned longitudinally.

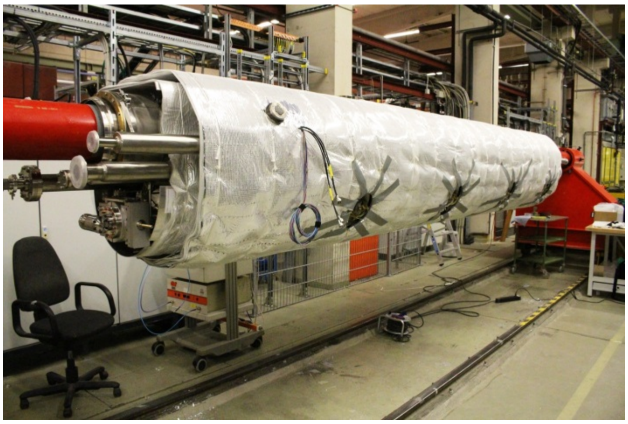

Figure 5: The Module after the installation of the two thermal shields and the cutout of the coupler ports on the MLI blankets.

Module Completion on Floor Supports

The assembled module was transferred on floor supports for the last survey, **alignment of the Cold mass to the VV**, and to start the **warm coupler parts** installation.

As coupler ports are present on both sides of the module, the installation started on one side and proceeded to the other side to allow the concurrent installation of the first of the two coupler vacuum pump lines. At the time of writing this report, all couplers to the left side of the module are installed and installation of the corresponding pump line is starting. Figure 6 shows the module during warm coupler parts installation.

All module flanges (Flange D on vessel for motors and BPM signals and Flange A and B below each coupler port for RF signals, Temperature sensors and coupler electron pickups) are finalized and installed on the vessel ports.

An integral leak check will be performed on the string after pumping with a slow pumping system to avoid particle transport.

Tunnel Installation

Module transport to the underground injector building and the start of its preparation for operation is scheduled after the end of the module completion phase, the week after this Conference.

CONCLUSION

The X3M1 Module has been successfully assembled and will be transported to the underground injector building of the E-XFEL facility in week 39 of 2015, the week after this Conference.

After transportation to the tunnel the RF distribution manifold will be installed on the module and the short injector module string (consisting of a cryogenic feed cap, a 1.3 GHz module, the 3.9 GHz module and an end cap) will be welded. The E-XFEL installation schedule foresees eight weeks of injector preparation work leading to the cooldown and commissioning in November 2015.

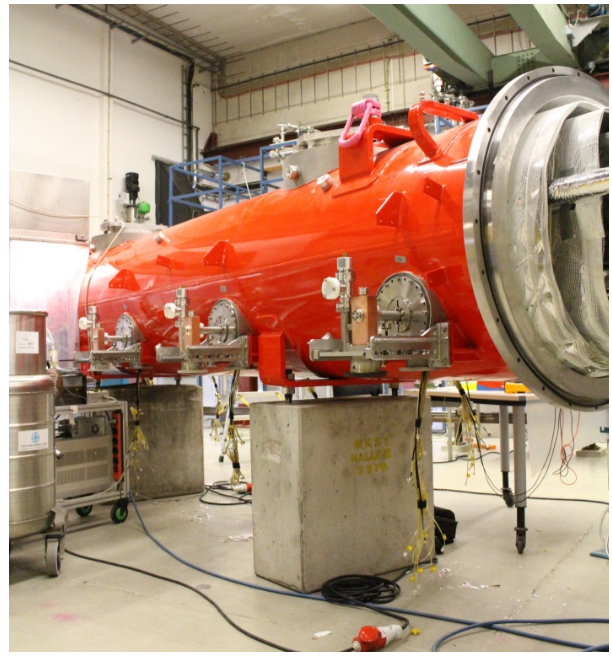

Figure 6: The X3M1 during Warm Coupler parts installation.

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