INSTALLATION AND LOW POWER TEST OF IFMIF-EVEDA RFQ AT ROKKASHO SITE

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Abstract

The IFMIF-EVEDA RFQ is composed of 18 modules for a total length of 9.8 m and is designed to accelerate the 125 mA D+ beam up to 5 MeV at the frequency of 175 MHz. The RFQ is subdivided into three Super-Modules of six modules each. The Super-Modules were shipped to Rokkasho (Japan) at the beginning of 2016, pre-assembled 3.3 m far from their final location and tuned to reach target field flatness requirements. After reaching an intermediate phase of injector commissioning (conclusion of phase A2), the tuned RFQ was disassembled, moved and reassembled in the final location. After confirmation that field flatness was not affected by this movement, high power couplers were installed and tuned and all the structure was baked. Assembling, tuning and coupling results will be presented.

INTRODUCTION

The required acceleration in continuous wave (CW) of 125 mA of deuterons up to 5 MeV poses IFMIF RFQ at the forefront frontier of high intensity injectors [1].

This RFQ is indeed meant to be the injector of a 5 MW deuteron linac (40 MeV final energy) for fusion material irradiation tests. The International Fusion Materials Irradiation Facility (IFMIF) [2] project aims at producing an intense (about 10^{17} s^{-1}) neutron source facility, with spectrum up to about 14 MeV, in order to test the materials to be employed in the future fusion reactors. The facility will be based on two high power CW accelerator drivers, hitting a single liquid lithium target (10 MW power) to yield neutrons via nuclear stripping reactions.

The IFMIF-EVEDA project was funded at the time of the approval of ITER construction (2007); the task is to validate the IFMIF design by the realization of a number of prototypes, including a high-intensity CW deuteron accelerator (called LIPAc, Linear IFMIF Prototype Accelerator) for a beam power exceeding 1 MW.

LIPAc is being installed at the QST site in Rokkasho (Japan). Accelerating structures of the prototype linac, operating at 175 MHz, are the RFQ and the first Half Wave Resonator cryomodule.

LIPAc realization is a strict collaboration between Japan and Europe. The detailed organization of such challenging project is discussed in [3].

Presently injector commissioning data are under evaluation, RFQ is assembled and tuned, MEBT and diagnostic plate are under set up and RF system is under completion [4]. The commissioning plane foresees four phases: Phase A that is the production of 140 mA deuteron current at 100 keV in CW; Phase B that is acceleration of 125 mA deuteron current at 5 MeV at 0.1% duty cycle; Phase C that is acceleration of 125 mA deuteron current at 9 MeV at 0.1% duty cycle; Phase D that is the ramping up of the duty cycle up to CW. In all phases it is planned to characterize and use, together with the deuteron beam, a proton beam with half energy, half current and similar space charge.

Phase A2 commissioning was concluded first week of November 2016. Such phase was extremely important to establish the correct RFQ input conditions and guarantee the required LIPAc performances [5-7]. Unfortunately injector didn't reach specifications at 100% DC. However, considering that a low duty cycle operation for the injector was demonstrated, it was decided to conclude phase A2, that is the characterization of injector parameters at the RFQ input location and move towards phase B. Possibility to have additional time for a phase A3, that is the characterization of injector parameters in the middle of the LEBT, was maintained.

Figure 1: RFQ assembled with high power couplers.

During phase A2 commissioning, RFQ was installed 3.3 m downstream its nominal position allowing its tuning in parallel of injector commissioning. At the beginning of November, RFQ was finally installed in its final position in view of RF conditioning and beam commissioning (phase B). High power couplers completed installation (Fig. 1).

HIGH POWER TEST IN EU

A very important step of our risk mitigation strategy was the implementation of high power tests in Europe. Indeed one of the problems encountered was the lack of experience in CW RFQ operation and the necessity to validate the design and the construction technique, in view of the construction of 18 RFQ modules to be installed about 10000 km far away.

As a preliminary step in 2010, in collaboration with CEA, two modules of TRASCO RFQ (352 MHz designed by LNL and built in Italy for a different project) were installed at Saclay and operated CW. The RF system of IPHI project and an INFN cooling skid for frequency regulation were used [8]. Nominal field in CW mode was reached.

In 2012 it was decided to test in Italy at LNL a 2 m long structure, corresponding to the last three elements of IFMIF RFQ, assembled with a prototype module used for RF field matching. The assembly, the alignment, the tuning and the transportation with a truck to a different building were important procedures test. This structure could be driven by a single 200 kW RF chain. In this way we could check the condition of maximum voltage, maximum field and maximum power density.

For this purpose, a specific test stand was built at LNL, with a light bunker and approximately 600 kW power installed, mainly for RF system and refrigerator. Elements of the RFQ local control and cooling systems were used for this test as well as a circulator kindly borrowed by Ciemat. Unfortunately, just before test starting, a problem was discovered on the high power couplers produced by QST, which caused the impossibility to use those couplers for a power test. In order to keep the schedule and validate the design during module production, two new RF power couplers, both rated 200 kW, were developed at LNL and procured by Italian industry in few months [9].

As a result, it was possible to condition the RFQ in CW mode up to the operating field. This corresponds to a field of 1.8 Ekp and to a power density of 86kW/m [10].

Moreover, from the measurement of the pick-ups field it was possible to verify that the field distribution remained stable, with an error lower than 0.5%, from low field up to nominal field. Finally, it was possible to close the RF frequency feed-back loop and stabilize the natural frequency of the cavity by means of the temperature difference between vanes and external structure checking the resonance control system.

RFQ ASSEMBLY AND TUNING

The RFQ was assembled in Italy in three SMs in January 2016. Before careful packaging, all the SMs were successfully tested in vacuum and filled with nitrogen gas. Shock recorders were screwed on the top of each SM to monitor various transport steps: from LNL to Milan airport by truck, from Milan to Frankfurt airport by aircraft, from Frankfurt to Tokyo airport by aircraft and from Tokyo to Rokkasho site by truck. After SM unpacking, vacuum tests confirmed a vacuum leak lower than $2x10^{-10}$ mbar-l/s.

SMs and their associated support stands were pre-aligned using the rough alignment system able to regulate position with 0.5 mm precision over ±20 mm range in all directions. SMs were then precisely aligned within 0.05 mm respect to nominal references using the precise alignment system.

Just after RFQ assembly, dummy tuners and bead pull system were installed on the RFQ cavity to find the optimum configuration for cavity tuning. Bead-pull campaign to optimize end plates and 108 tuners penetrations started at the end of April 2016 and took two weeks.

From the first measurement with flush tuners the good quality of the cavity appeared, since dipole field components were below 2% and the frequency corresponded to 3D simulations. The geometry of the end plates without dipole correcting fingers was confirmed. After several iterations on dummy tuners positions, nominal field distribution was established, with spurious mode components below 2% target limit (Fig. 2).

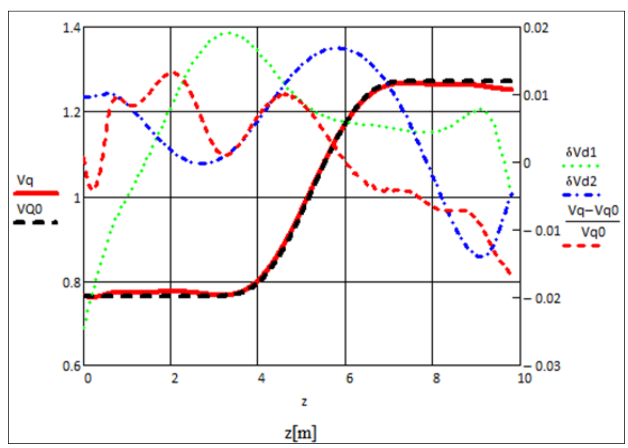

Figure 2: Bead pull measurement of the IFMIF RFQ field. V_{Q0} is the nominal field; V_q is the measured field (left scale); the dipole components and the relative error on the right.

Final tuners and final end plates were machined at required quotes according to RFQ bead pull measurements results. Machining was done in three steps in order to maintain enough tuning margin up to the conclusion of the process. In the first step copper termination plates and 16 copper tuners were replaced to dummy termination plates and dummy tuners. Bead pull measurements showed that final low energy termination plate caused a small change in the field flatness that was

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recovered by changing the penetration of the four tuners located near the plate. In the second step, 43 aluminum tuners were substituted with copper ones and no changes appeared on the field flatness. At the end, the remaining 49 aluminum tuners were replaced with the copper ones without affecting the field [11].

Finally the frequency, rescaled for vacuum and nominal temperature, was measured to be equal to 175.014 MHz and the quality factor Q_0 was equal to 13200±200, 82% of SUPERFISH value with flash tuners, corresponding to a shunt impedance R_{sh} = 201 kΩ*m.

The shunt impedance is clearly a very important parameter for a CW RFQ operating at high inter-vane voltage. The confirmation of the very good design value, in the presence of all the 3D and "as built" details, was an extremely good result.

COUPLERS INSTALLATION

Finally high power couplers were installed on the cavity and right rotational angles for reflected power minimization were identified. This means that, including beam and copper effects, each coupler must present a β=1/8, to have an overall β to be equal to 1. Since Q=13100, Q_{2D}=16000, P_{2D}=452 kW (SF) and P_b=637 kW, $P_{Cu}=P_{2D}*Q_{2D}/Q$= 553 kW, the coupling coefficient β_0, without beam, has to be equal to $(1/8)*(1+P_b/P_{Cu})$=0.27 per each coupler, corresponding to SWR=1/ β_0 =3.72. After coupler installation quadrupole components change was acceptable (Fig. 3).

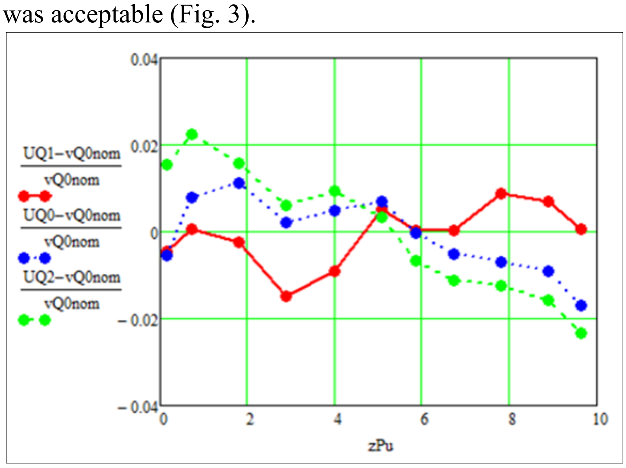

Figure 3: Quadrupole perturbation in different moments: UQ0 are the measurements just after last bead pulling before RFQ displacement, UQ1 are the measurements after RFQ displacement and before coupler installation, UQ2 are measurements after coupler installation at their operating rotating angles.

CONCLUSION

The RFQ construction was concluded, all the modules were accepted after RF and CMM tests completion.

The CW RF performances of the RFQ such as maximum field, power density, water temperature frequency control loop, were achieved in the high power test in Italy.

The air-transportation in three SMs and the assembly in Japan were successful. The RF field was tuned to the nominal shape with specified accuracy (2%).

The excellent shunt impedance of the design has been achieved (Q_0=13200). High power couplers were installed and the end of the last year and RFQ experienced two weeks baking at 100°C at the end of last year (Fig. 4).

Figure 4: RFQ under baking.

Installation is almost completed with final adjustment to be carried out before starting the RFQ conditioning by this summer.

DISCLAIMER

This publication reflects the views only of several of the authors and Fusion for Energy cannot be held responsible for any use which may be made of the information contained therein.

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