Progress in the Realization of the IFMIF/EVEDA RFQ

A. Pisenti¹, L. Antonazzi¹, G. Bassato¹, M. Comunian¹, J. Esposito¹, E. Fagotti¹, F. Grespan¹, A. Palmieri¹, C. Roncolato¹, A. Pepato², R. Dima³, F. Scantamburlo³, P. Mereu³, D. Dattola³, G. Giraudo³, A. Margotti³, M. Guerzoni⁴.

¹ INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy. ² INFN, Sezione di Padova, Padova, Italy. ³ INFN, Sezione di Torino, Torino, Italy. ⁴ INFN, Sezione di Bologna, Bologna, Italy.

INTRODUCTION

Within IFMIF/EVEDA project, INFN has in charge the construction of a linear structure of RFQ kind (Radio Frequency Quadrupole) able to accelerate 130 mA of deuterons up to 5 MeV. This structure is part of a prototype accelerator that will be installed in the Broader Approach site in Rokkasho (Japan). The building is almost ready and the various parts of the accelerator are under development in Europe.

IFMIF EVEDA (International Fusion Material Irradiation Facility-Engineering Validation and Design Activity) is part of the international program for the test of the materials for the reactors based on Nuclear Fusion.

RFQ DEVELOPMENT

In the last year important results have been achieved, with the participation of LNL and of the INFN sections of Padova, Torino and Bologna.

The design has evolved with the implementation of the so called low B option: a new modulation law has been adopted for the first part of the RFQ with a gradual increase of the focusing strength (B factor). In this way it was possible to decrease the risks associated with the beam matching between the injector Low Energy Transport Line and the RFQ. This beam dynamics improvement has involved many changes in the mechanical design, like the electrode width and module length. The following main results on prototypes have been achieved

1. For the full scale low power prototype the bead pulling measurements have been concluded, showing the validity of our tuning algorithms for such a long structure [1].
2. The technological prototype of a module, machined in INFN and in local industries, has been successfully brazed at CERN. The prototype is completed and the geometrical and vacuum measurement are satisfactory.
3. Two technological prototypes, with reduced transverse dimensions, have been machined and brazed in Italy, with a different brazing procedure (one step, vertically). The prototypes are completed and the geometrical and vacuum measurement are satisfactory [2].
4. A second full scale module is being completed. It will be brazed at LNL and will be used for the High power tests at CEA Saclay.
5. The cooling skid prototype, able to master 300 kW with two independent water temperatures for frequency tuning, has been tested off line, and will be tested in the next using an RFQ previously developed by INFN (TRASCO project).

All these prototypes have been built in collaboration between INFN and Italian industry. The design has been developed internally, and the construction process has now been validated in the critical phases.

In this way INFN has acquired all the competences and the tools necessary both for the internal construction of the modules and for the verification of the parts commissioned to industry. The key processes mastered range from EDM rough machining, precision milling, 3d continuous measurements and RF measurements for quality control, to chemical treatments, thermal annealing and brazing.

It is foreseen to realize the 18 modules of the RFQ part within INFN structures and part in the industry. In November 2010 the tender for the construction of 6 RFQ modules has been launched between the main European producers, and the 20 December the company has been selected. The result has been approved by INFN central body in January 2011.

ACCELERATOR AND MECHANICAL DESIGN

All the RFQ parts have been determined to the detail necessary to launch the module construction. The RFQ is composed by 3 supermodules (fig 1),

Fig. 1. Lay-out of the RFQ.

Each RFQ Super-Module is supported by a dedicated mechanical frame, whose purpose is to provide a
transportation structure and a volume to house most of the services (i.e. feedwater distribution pipes). The RFQ Super-modules are supported by a mechanical structure, fixed on the concrete of the accelerator vault, that can be installed at BA site before the final delivery of the supermodules.

The integration with the cryogenic vacuum pump groups, the fixed tuners housing the RF pick up loops, have been defined, for the two end plates and the coupler loop flanges a proposal is ready for a deeper discussion of the interfaces.

As mentioned above the modulation law has been modified, so to improve the matching and diminish the risk at the interface with the LEBT. The beam dynamics in the main part of the RFQ is characterized by a strong focusing (small beam dimensions), that guarantees good control of space charge non linearities for the preservation of beam quality. The improvement has been implemented in the first part of the RFQ, where the beam dimensions decrease gently (see fig. 2).

It is important to observe that this improvement of beam dynamics could be implemented without any impact on production schedule. Indeed the production started from the high energy supermodule (the one with larger power density will be used for high power tests in Europe), while the geometrical modifications are concentrated in the first modules. On the other hand this redesign of the RFQ had an heavy impact on the conclusion of the EDR.

The mechanical design is based on vacuum brazing, which represents probably the most risky production aspect, both for vacuum tightness and geometry preservation. The subdivision in many tanks has various advantages: each tank can be machined with very precise (and diffused) milling machines; vacuum ovens of these dimensions are also more diffused. The cavity wall interruption has almost no consequence on power consumption, while the vane interruption with a gap of about 100 µm can be made without increasing the local surface field.

To minimize the use of Ultra-pure CUC2 and to limit the induced stresses on the raw material, and the deformation during thermal cycles, a rough-cut of the shape of the sub-module components from a starting block of about 500x280x570 mm is performed, by using a EDM (wire electro-erosion).

A complete prototype (full scale transversally, 30% shorter) has been machined in INFN and brazed at CERN, proving the production method (fig. 3 left). This prototype has been brazed following the same steps used for TRASCO RFQ, horizontal brazing for the four electrodes and the other copper details, vertical brazing for flanges and stainless steel details. The construction was successful, with geometrical deformations below 0.02 mm and vacuum tightness below 10-10 mbar/l/s.

Moreover two smaller prototypes have been built, cut by EDM in the remainder of the copper blocks. Such prototypes have been brazed in Italy; in particular in fig. 3 right the first small prototype is shown in LNL vacuum oven after brazing, with all the springs and jigs used to keep the relative position of the pieces during brazing. The brazing in this case has been done in a single step (RFQ in vertical position as shown). Vacuum is tight and the results are very promising.

Concerning the ancillaries, the vacuum system is now defined, based on cryogenic pumps (turbo and ionic pumps as auxiliary) and during 2011 the procurement of the various components will start. For the cooling system the specifications and the general design of the skids are ready. The tests of the prototype skid at CEA Saclay using two TRASCO RFQ modules, will be very important to test the tuning with cooling water, the local control system for conditioning and the actual achievement of cw operation at 1.8 Kilpatrick field. The skid, waveguides in charge of INFN and the vacuum system have already been sent to Saclay, while the two RFQ modules, the couplers, the bridge cavity and the control system rack are foreseen to be delivered in February to CEA Saclay [3].

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