RFQ DEVELOPMENTS AT CEA-IRFU

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Abstract

Vane RFQs are particularly well suited to high intensity proton acceleration, since they offer minimal RF power losses and best accelerating field accuracy. Cea/Irfu is involved in several developments of 4-vane RFQs namely IPHI, Spiral2, Linac4 and ESS. This paper gives an overview of the design flow and tools developed at Irfu in order to design, tune, condition and commission RFQs.

SPIRAL2 RFQ will be mainly used to illustrate this design flow.

INTRODUCTION

Four such vane-RFQs have been or are under development at CEA-Irfu, namely IPHI, SPIRAL2, LINAC4 and ESS. The main parameters of these RFQs are listed in Table 1.

Table 1: RFQ Projects at CEA/Irfu

Project	IPHI	LINAC4	SPIRAL2	ESS
Location	CEA	CERN	GANIL	ESS
Status	Com	op	Com	fab
F (MHz)	352.2	352.2	88.05	352.2
L (m)	6	3	5	4.5
IB (mA)	100	80	5	70
RF power peak	1200	390	180	1300
Duty cycle	CW	7.5%	CW	4%
W (MeV/u)	3	3	3	3.6
Modules	6 brazed	3 brazed	5 bolted	5 brazed

DESIGN

Step1: Beam dynamics study is firstly done by TOUTATIS CEA code [1]. The fields are computed using 3D grid via a Poisson solver allowing to compute image effect, space charge force. Real shapes (where mechanical defects can be included) of electrodes are taken into account including coupling gaps and RFQs extremities.

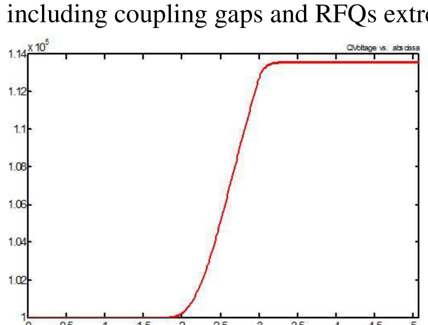

Figure 1: Voltage law of SPIRAL2 RFQ.

For SPIRAL2, geometrical parameters and inter-electrode voltage are continuously varied along the RFQ as the result of an optimization process (Fig.1).

Step 2: 2D and 3D RF calculations are then used to define detailed geometry of the cavity, cross-section (Fig.2), end-circuits, tuning slugs, RF power couplers and power dissipation. Electrical parameters of RFQ 4-wire transmission line model (TLM) [2] are also derived from 2D and 3D simulations, in such a way the model perfectly mimics the physical RFQ.

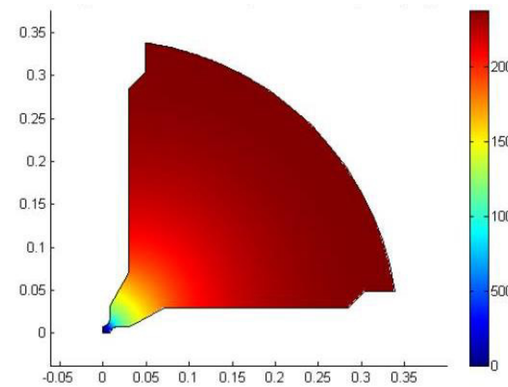

Figure 2: H-Field for RFQ cross section.

TLM (Fig.3) is then safely used in error analysis and slug tuner dimensioning. TLM is also the theoretical background of RFQ tuning algorithm.

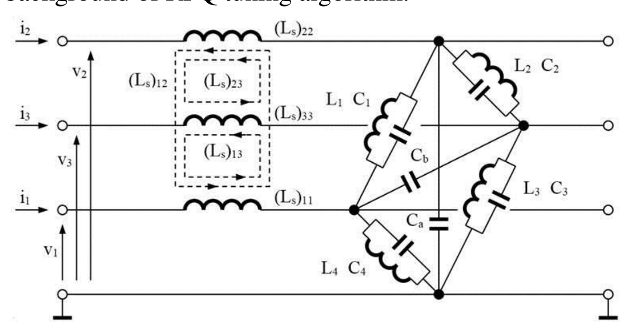

Figure 3: TLM model.

Step 3: The so-called "RF stability", is then evaluated. This allows assigning construction tolerances to the design, including machining errors of individual RFQ components and assembly errors. For SPIRAL2 RFQ, effects of construction imperfections are compensated by a careful adjustment of 40 tuning slugs. Tuning range extends up to 140 mm inside cavity with the specified ±90µm machining/assembly tolerance envelope.

Step 4: 3D thermo-mechanical simulations are used to estimate deformations induced by RF heating (Fig.4), and the cooling system is designed to maintain geometry within bounds compatible with the RFQ specifications, mainly ±1% voltage error and a few tens of kHz detuning.

ISBN 978-3-95450-147-2

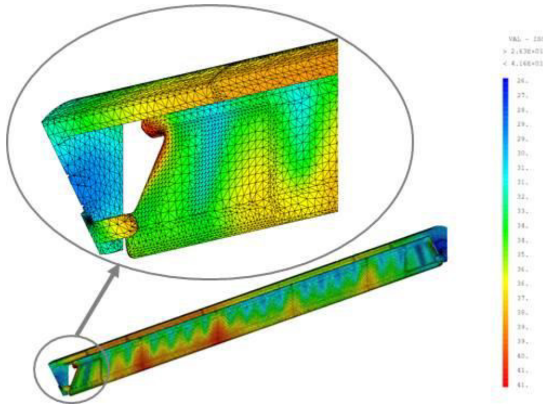

Figure 4: RF induced heating.

Step 5: The machining and assembly processes satisfying tolerance requirements are defined, and detailed drawings are edited.

FABRICATION AND INSTALLATIONG

RFQ machining and assembly is realized in Research Instruments GmbH. Each 1-meter long RFQ module is made of one 800 mm diameter copper tube and four copper electrodes (Fig.5).

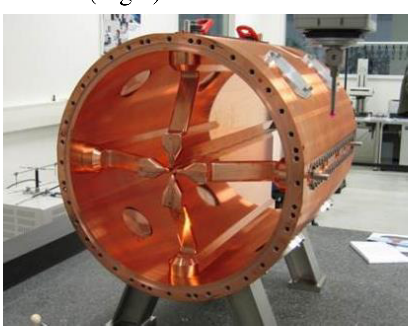

Figure 5: RFQ section.

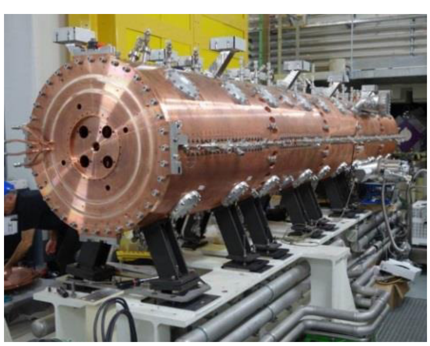

Figure 6: RFQ assembled at GANIL.

Integration at GANIL starts with assembly of the five modules on their support (Fig.6). RF tuning (beadpull) is then performed with the adjustment of the 40 slugs in order to achieve specified voltage profile via the iterated procedure described in [2]. Final measured voltage errors are smaller than 2.1% for the quadrupole component, 0.5% for the dipole S-component and 1.1% for the dipole T-component (Fig.7).

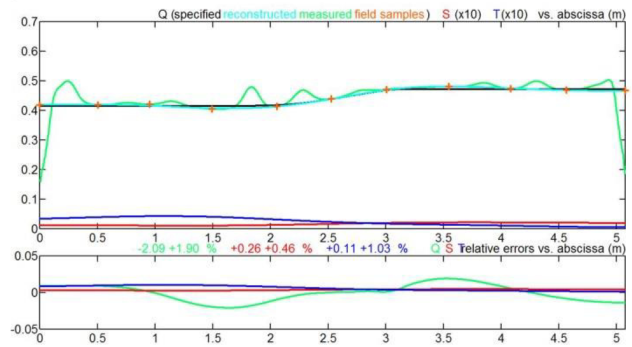

Figure 7: Final voltage profile.

Figure 8: SPIRAL2 RFQ ready for conditioning.

CONDITIONING AND COMMISSIONING

The RF conditioning started on November 15th, 2015 with only 3 amplifiers because one had a failure (Fig.8). It mainly did in CW mode and progressed quite fast up to the maximal possible accelerating field level (85kV for 110kW within the cavity). 16 pick-ups were installed along the RFQ in order to measure the voltage law during RF conditioning [3]. These measurements have then compared to the last beadpull measurement. The variations of voltage errors are bounded by ±0.2% of nominal voltage, as accelerating voltage is varied from 20kV to 80kV. Moreover, the behaviour of the accelerating voltage is repeatable along the time (Fig.9).

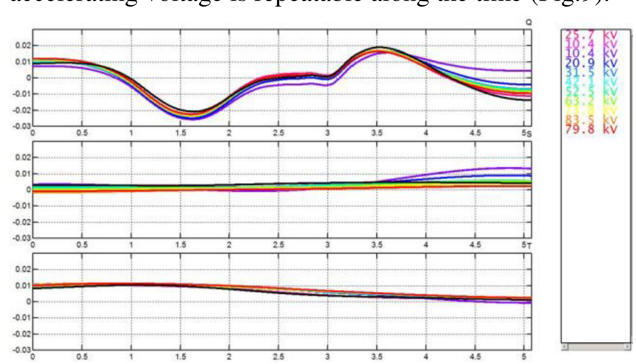

Figure 9: Voltage error according accelerating voltage.

On the 5th December 2015, the first proton beam was accelerated at 1.5MeV (5mA of proton, 200µs/2Hz, 50kV

ISBN 978-3-95450-147-2

for the voltage law). In few days, a 5mA CW proton beam has been successfully performed.
The beam transmission as a function of the RF field level in the RFQ cavity and the beam characteristics was measured, providing the confirmation of a very good agreement between beam dynamic simulations done with TOUTATIS code and measurements (Fig.10 and fig.11).

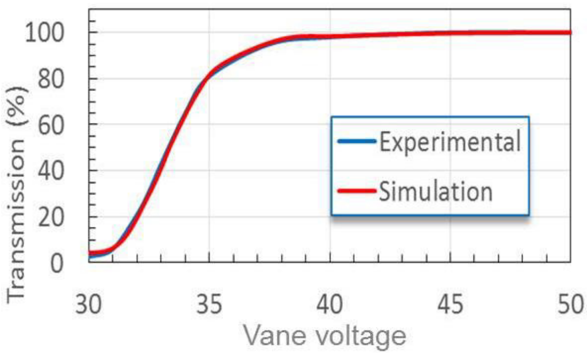

Figure 10: RFQ transmission vs vane voltage.

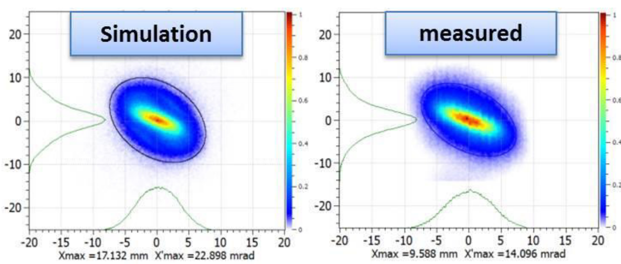

Figure 11: XX' emittance.

STATUS OF IPHI, LINAC4 AND ESS RFQ

IPHI RFQ: First conditioning has started in April 2015 at low duty cycle (1%) because of some limitation of the cooling system. RF Seal of 2 RF couplers have been burned and then replaced by new seal. Conditioning has re-started in February 2016 and on the 25th march 2016 the first beam was accelerated to 3 MeV. The commissioning of the IPHI injector [4] is actually in progress at CEA (Fig.12).
LINAC4 RFQ: Conditioning and commissioning have been done in 2013 without difficulties [3]. Performances are actually limited by the emittance coming out of the source which is bigger than the RFQ acceptance (Fig.13).
ESS RFQ: Design (Fig.14) has been completed and the fabrication will start in the next months [5]. Conditioning at Lund is expected in Jun 2018.

CONCLUSION

CEA is involved in the design and fabrication of 4 RFQs. Specifics tools as TOUTATIS code and TLM have been developed for the design, the control of the RFQ construction, the tuning and the RFQ validation with RF power and beam.

In the next month, CEA has to finish the conditioning and the commissioning of IPHI and SPIRAl2 RFQs and will start the fabrication of ESS RFQ.

Figure 12: Voltage error according accelerating voltage.

Figure 13: LINAC4 RFQ**.**

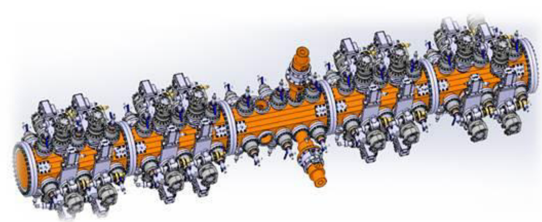

Figure 14: ESS RFQ.

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