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RFQ UPGRADES FOR IFMIF-DONES

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Abstract

In the framework of IFMIF-DONES (International Fusion Materials Irradiation Facility- DEMO-Oriented Neutron Early Source) a powerful neutron irradiation facility for studies and certification of materials to be used in fusion reactors is planned as part of the European roadmap to fusion electricity. A possible RFQ upgrade has been designed. In this article the beam dynamics of an RFQ able to handle CW 200 mA of Deuterium, based on experience of IFMIF RFQ, will be presented.

INTRODUCTION

The IFMIF-DONES facility [1] will serve as a fusion-like neutron source (1×10^{14} neutrons/cm2/s) for the assessment of materials damage in future fusion reactors. The neutron flux will be generated by the interaction between the lithium curtain and the deuteron beam from an RF linear accelerator at 40 MeV and nominal CW current of 125 mA. As far as the RFQ is concerned, the mainstream idea is the use of a copy of IFMIF RFQ [2] for the DONES facility. Nevertheless, a possible RFQ upgrade can handle more current and absorb the experience of the IFMIF RFQ. The experience of the IFMIF/EVEDA commissioning suggests the design of a higher acceptance RFQ, to deal with different than standard distribution, which results in a higher 99% emittance and increase the lifetime of RFQ due to the possible electrodes erosion. The last point has an important impact on maintenance activity that needs to be considered, that can potentially stop the machine for months to exchange the eroded modules.

DESIGN PARAMETERS

Based on the IFMIF RFQ experience the new RFQ for the upgrade of DONES can be:

- Input energy range from 110 keV to 150 keV.
- Output energy=5 MeV
- Input emittance RMS=0.3 mm·mrad (norm.)
- Frequency=175 MHz
- Max surface field of 25.2 MV/m (1.8 kp – 1.88 kp)
- Input Current=200 mA
- Particle=Deuteron

The increase of input energy can help to reduce the beam size, and the space charge effects. The input emittance is a possible realistic value with a LEBT transport of more than 200 mA. The limits on the RFQ design come from the total length (less than 10 meters as IFMIF RFQ) and maximum surface field of 1.8 - 1.9 kp.

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DESIGN METHOD

The design is based on a new tool called VeRDe (Venetian RFQ Design), an optimization toolkit for the RFQ Beam Dynamics design developed at the Legnaro National Laboratories [3]. The core program is given by the Los Alamos RFQ codes [4]: PARMTEQM, PARI, RFQuick and CURLI. VeRDe allows to manage the parameters needed for each RFQ cell definition: the transvers focusing term, the voltage, the modulation, and the synchronous phase. RFQuick estimates the longitudinal capture efficiency, given the current limit by CURLI, through the study of the buncher section characteristics; the PARI designs the RFQ cells based on the RFQuick output (that uses the Crandall tables to estimate the multipoles of the cells); VeRDe also implement on PARI the voltage law shape on the designed RFQ, PARMTEQM performs the simulations based on the PARI output.

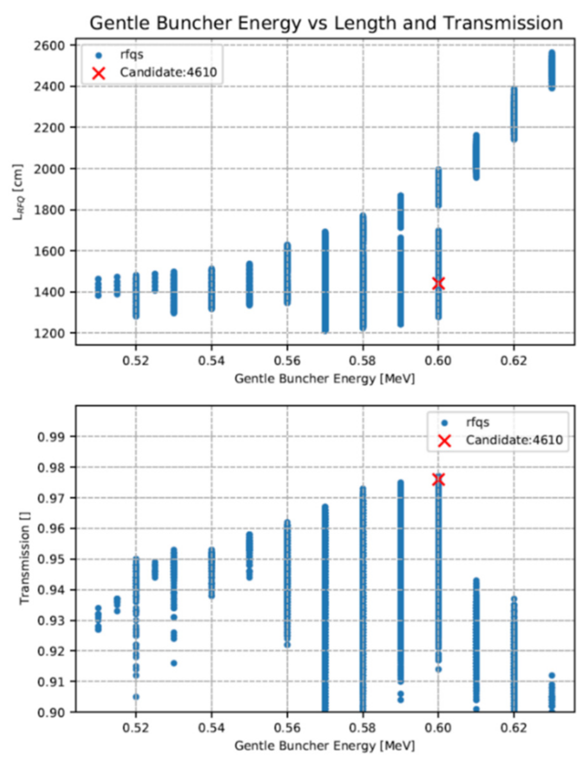

Figure 1: RFQ length (above) and transmission (below) as a function of Gentle Buncher energy.

Considering that the RFQ is composed of 3 sections, Shaper, Gentle Buncher and Accelerator, each composed of several tens of cells, it is straightforward to understand that the degrees of freedom of the process is very large. From hundreds to thousands of RFQ candidates may be produced in parallel on several computers. Each single case is a full

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RFQ multiparticle simulation. In Fig. 1 all the multiparticles run results are shown, and it is possible to notice that, as the Gentle Buncher energy increases, the transmission and the RFQ length increase. At this stage all the simulation runs are made with a constant voltage along the acceleration section.

After the definition of the Gentle Buncher section a voltage law, like IFMIF, is implemented to reduce the total RFQ length, and a reduced focusing force is done at the RFQ beginning.

As the last step a check on the resulting RFQ beam dynamics is made by using the TraceWin/TOUTATIS code [5].

CANDIDATE SELECTION

From the simulation results, the RFQ candidate has been selected considering the best possible transmission and the shorter length. This trade-off produces a small quantitative of suitable solutions, that can be considered.

A fine adjustment on the minimum voltage and power dissipation produces the final best result.

In Fig. 2 is the main RFQ parameters are shown.

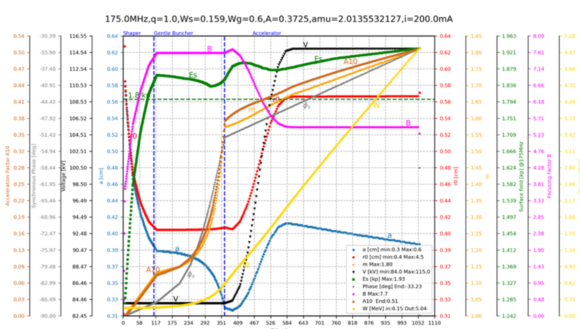

Figure 2: Main parameters of the RFQ.

The evolution of voltage and of the aperture along z induces a change on TE_{21} cut-off frequency of ±3.5 MHz, which could be, in principle tuned via electrode width as for IFMIF RFQ. As for power consumption is concerned, a very preliminary estimation can be drawn, by assuming a shunt impedance per length of 220 kΩ·m (without power margin), as for IFMIF RFQ as well. In this case the cavity power would be about $P^{(2D)}$=500 kW. Therefore, by assuming a margin α_1=1.25 for Q-value and α_2=1.2 for regulation the overall RF power would be equal to

$$P^{(RF)} = P^{(Cu)} + P^{(beam)} = P^{(2D)}\alpha_1\alpha_2 + P^{(beam)}$$

The overall RF power is equal to 1716 kW, of which 746 kW dissipated on the cavity walls (included regulation) and 970 kW of beam power (see Table 1).

Table 1: Comparison with IFMIF RFQ

	IFMIF	New RFQ	
Input/output Energy	0.10-5	0.15-5	MeV
d.c.	cw	cw	
Current	125	200	mA
Frequency	175	175	MHz
Max surface field	1.8	1.9	Ekp
Length (l)	9.78 (5.7 l)	10.5(6 l)	m
Range V	79 – 132	84-115	kV
Range R_0 ρ/R_0=0.75	0.4135 - 0.7102	0.4 - 0.55	cm
$P^{(2D)}$	452	497	kW
$P^{(Cu)}$	672	746	kW
$P^{(RF)}$	1315	1716	kW

RESULTS

The phase space is shown in Fig. 3, where the transmission is about 97.5% of accelerated particles with a total power loss of 1.4 kW.

The final rms longitudinal emittance is 0.27 MeVdeg.

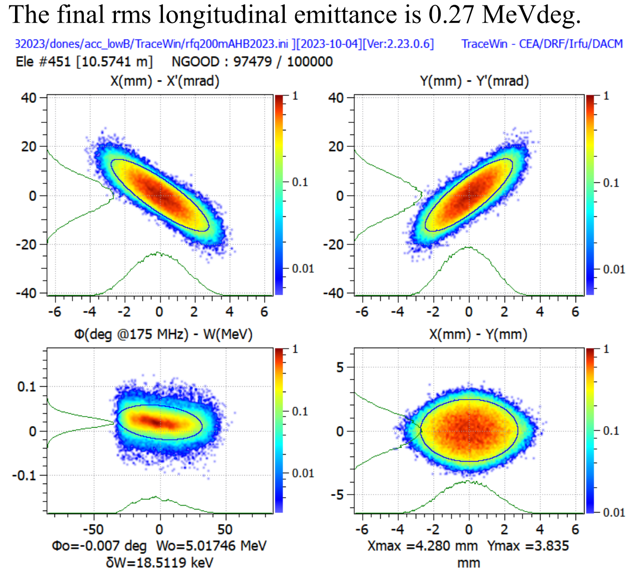

Figure 3: Output Phase Space of the RFQ.

COMPARISON WITH IFMIF RFQ

The main parameters in comparison with IFMIF RFQ are reported on table 1, the main differences being in the input energy, length, and surface field, which are more demanding in the upgraded RFQ.

A comparison with an ideal IFMIF RFQ was made, aimed at checking the advantages of this upgraded RFQ. The main results are reported in table 2, where Et is the RMS normalized input transverse emittance (mm·mrad), WB indicates that the input distribution is WaterBag, and G indicates that the input distribution is Gaussian.

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In the case of IFMIF, the voltage was raised by 10% (V+10%) to simulate the same maximum surface field (1.9kp) as it is in the new RFQ. By using the same max surface field on the new RFQ (V-10%)* i.e. around 1.77 kp, the new RFQ performance is degraded by a big tail on the longitudinal phase space.

The comparison shows that in all the cases the new upgraded RFQ performances in terms of transmission are better.

Table 2: Performance of IFMIF vs New RFQ

Cases	**IFMIF Tr. (%)**	**Up. RFQ Tr. (%)**
I=200 mA, Et=0.3 WB	80.5	98.5
I=200 mA, Et=0.3 G	74.9	90.7
I=200 mA, Et=0.25 WB	82.6	98.0
I=200 mA, Et=0.3 WB	94.9 (V+10%)	98.5
I=200 mA, Et=0.3 G	87.8 (V+10%)	90.7
I=130 mA, Et=0.25 WB	98.6	99.0
I=130 mA, Et=0.25 WB	98.6	96.2 (V-10%)*

CONCLUSION

This preliminary study shows that we have established a method to design a high current RFQ. From the experience of IFMIF RFQ a reasonable set of parameters can be used as base and studied using evolutionary algorithms and optimized, in a parallel fashion, by particle swarm algorithms on a very large parameters space, like energy, modulation, voltage, aperture, with the ability to handle more than 10000 RFQs multiparticle simulation.

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