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NEW REFERENCE DESIGN OF THE EUROPEAN ADS RFQ ACCELERATOR FOR MYRRHA

Chuan Zhang#, GSI Helmholtz Center for Heavy Ion Research, Planckstr. 1, Darmstadt, Germany
Holger Podlech, Institute for Applied Physics, Goethe-University, Frankfurt a. M., Germany

Abstract

For demonstrating the technical feasibility of nuclear waste transmutation in an Accelerator Driven System (ADS), the MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) proton driver is under intensive studies. Good performance of the 2 – 4 mA, 1.5MeV RFQ (Radio-Frequency Quadrupole), the start of the accelerator chain, is essential to the reliability of the whole facility, so it must be very well designed. On the basis of the first reference design, further improvements with respect to electrode aperture, emittance growths and output distributions have been performed. The simulation results of the new reference design are presented in this paper.

INTRODUCTION

Kicked off in 2001, a European collaboration on the R&D of the ADS technology for nuclear waste transmutation has been supported by several EURATOM Framework Programmes (FP) continuously. In the period of 2010 – 2014, a dedicated FP7 project, MAX (MYRRHA Accelerator eXperiment Research & Development Programme) [1], is working on an advanced accelerator design for the planned construction of the first European ADS demonstrator in Mol, Belgium, in 2017. Fig. 1 shows the schematic layout of the MYRRHA driver accelerator.

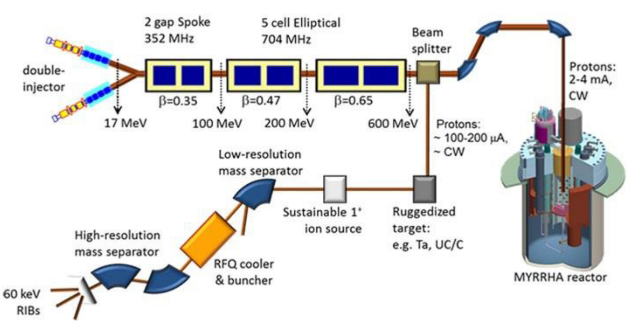

Figure 1: Layout of the MYRRHA proton driver.

For both the previous FP6-project EUROTRANS (European Research Programme for the Transmutation of High Level Nuclear Waste in an Accelerator Driven System) and the current MAX project, the injector part is mainly consisting of an RFQ accelerator and several RT (Room-Temperature) and SC (Superconducting) H-type DTL (Drift-Tube Linac) cavities up to 17 MeV.

c.zhang@gsi.de

By means of Table 1, a brief review of the changes in design specifications for the European ADS RFQ can be made:

- For EUROTRANS [2]: A 352MHz, 3 MeV RFQ should be designed to provide good beam performance at two design beam intensities i.e. 30 mA and 5 mA. For sufficient focusing strength at both intensities, the inter-vane voltage U was chosen as 65 kV.
- From EUROTRANS to MYRRHA [3, 4]: The resonant frequency f was halved to 176 MHz for improving the shunt impedance R_s. To keep the RFQ length still at ~4 m, the input and output energies W_{in} and W_{out} were accordingly decreased to 30 keV and 1.5 MeV, respectively. As only one design intensity, 5mA, will be needed for the MYRRHA facility, a lower U of 40 kV is sufficient.
- For MYRRHA from 2011 to 2013: a new decision has been made to increase U by 10%. The reasons will be explained in the next section.

Table 1: Design Specifications for the European ADS RFQ Accelerator

	MYRRHA (2013)	MYRRHA (2011)	EUROTRANS
Ion	H^+	H^+	H^+
f [MHz]	176	176	352
W_{in} [keV]	30	30	50
W_{out} [MeV]	1.5	1.5	3.0
U [kV]	44	40	65
$\varepsilon_{in}^{t., n., rms}$ [π mm-mrad]	0.2	0.2	0.2
I_{in} [mA]	5	5	30 & 5
L [m]	~4	~4	~4
dc [%]	100	100	100

For avoiding the serious thermal stress and fatal damages to the sub-critical core, only < 10 "long" beam trips (duration period > 1 s) per 3-month operation cycle are allowed for the MYRRHA accelerator. Therefore, to design the CW (Continuous Wave) MYRRHA RFQ with such extremely high reliability is very challenging.

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MOTIVATION & NEW CONCEPTS

From EUROTRANS to MYRRHA, many changes in design concepts were made and led to the first reference design for the MYRRHA RFQ (CZ2011) which can provide a much safer CW operation. For example, it successfully lowered the Kilpatrick Factor (*KF*) from 1.69 to 1.01 and the power consumption P_c from 69.8 kW/m to 23.5 kW/m, respectively [3, 4].

The power consumption of the EUROTRANS RFQ was calculated by Microwave Studio with a safety margin of 20%, while that of the MYRRHA RFQ was estimated using 67 kΩm [5] such a shunt impedance measured from the SARAF RFQ (another 176 MHz, CW, 4-rod RFQ with a similar length). In the SARAF RFQ experiments, reliable CW operations have been reached up to P_c=~60 kW/m [6].

As shown in Fig. 2, a dedicated 4-stem prototype for the MYRRHA RFQ has been built to test the RF performance [7]. Benefitting from the employed new machining and tuning technologies e.g. silver-coated tuning plates for the RF-contact improvement [5], higher power consumption per length up to 70 kW/m has been achieved continuously over a very long test period.

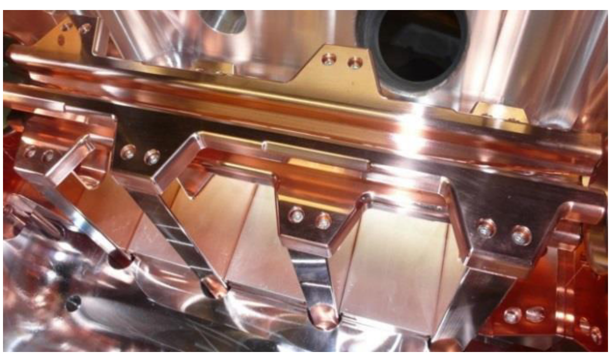

Figure 2: MYRRHA RFQ prototype (~1 m long).

Therefore, a decision to increase the inter-vane voltage by 10% (the estimated power consumption per length is still <30 kW/m) but with almost same transverse focusing strength along the RFQ has been made in 2013. The goal is to result in a bigger electrode aperture and consequently smaller capacitance between the electrodes so that higher stems which are favorable for a better Q value and also for easy tuning can be used to compensate the frequency shift from the change of electrode aperture. Meanwhile, no big influence will be brought to the Kilpatrick Factor as well as the transverse beam dynamics.

Another motivation for a new design is to minimize the output longitudinal emittance $\varepsilon_{out,\ z}$ even at the cost of some transverse beam losses. For a modern large-scale ion accelerator, the SC structure plays always a dominating role. Between the RFQ and the SC cavities, there is no or only a very short RT section as transition. Therefore, $\varepsilon_{out,\ z}$ of the RFQ should be as small as possible to avoid beam losses in the downstream accelerators. As the RFQ output energy, 1.5 MeV, is lower than the threshold energy of the $^{65}Cu(p, n)^{65}Zn$ reaction, 2.16 MeV, transverse beam losses inside the RFQ are however not problematic.

It is always demanding to minimize the longitudinal emittance for an RFQ at low beam intensities, because if the bunching process is performed fast, there will be a lot of empty area in the longitudinal phase space, otherwise the machine will be too long.

DESIGN & SIMULATION RESULTS

For the new MYRRHA-RFQ design, also the efficient NFSP (New Four-Section Procedure) method [8, 9] is adopted. To follow the new design concepts, higher inter-vane voltage is applied and the bunching process is carefully retuned. A comparison of the detailed design and simulation results is given in Table 2. All simulations have been performed using 10^5 input macro-particles, and all transported particles are included i.e. no particles are removed from the simulation in the longitudinal plane.

Table 2: Comparison of New & Old Reference Designs

Parameter	CZ2013	CZ2011
U [kV]	44	40
KF	1.05	1.01
m_{max}	2.2	2.3
a_{min} [cm]	0.31	0.29
$r_{0,\ avg.}$ [cm]	0.49	0.46
$\varepsilon_{out,x,\ n.,\ rms}$ [π mm mrad]	0.21 (100%) 0.20 (99%)	0.22 (100%) 0.21 (99%)
$\varepsilon_{out,\ y,\ n.,\ rms}$ [π mm mrad]	0.21 (100%) 0.20 (99%)	0.22 (100%) 0.21 (99%)
$\varepsilon_{out,\ z,\ rms}$ [keV-deg]	41.0 (100%) 36.7 (99%)	64.6 (100%) 59.7 (99%)
L [m]	4.0	4.0
Number of Cells	244	220
T [%]	98.6	~100

It can be seen that the new design has more losses, but the beam transmission efficiency is still 98.6%. The most remarkable highlight in Table 1 is that the new output longitudinal emittance is only ~60% of the old one. This is a result of an improved bunching process. Both designs have same RFQ length, but the new design has 24 more cells. As shown in Fig. 3, all these additional cells have been added to the pre-bunching section. A slower and smoother formation of the longitudinal emittance can minimize the empty area in the phase space and is very important to result in a small final value. It can be also seen from the figure that a slightly stronger transverse and longitudinal emittance exchange has been deliberately made at the end of the main bunching section to further reduce the longitudinal emittance.

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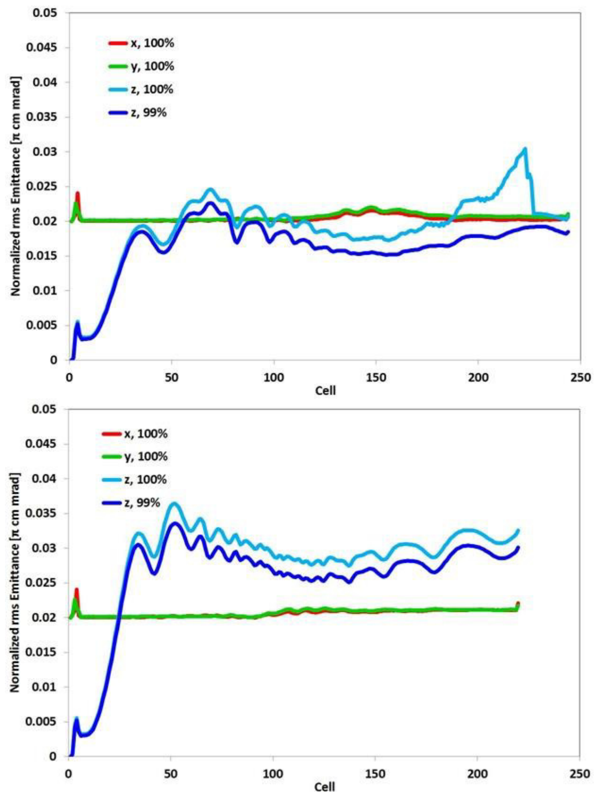

Figure 3: Emittance evolution along the RFQ (top: CZ2013; bottom: CZ2011).

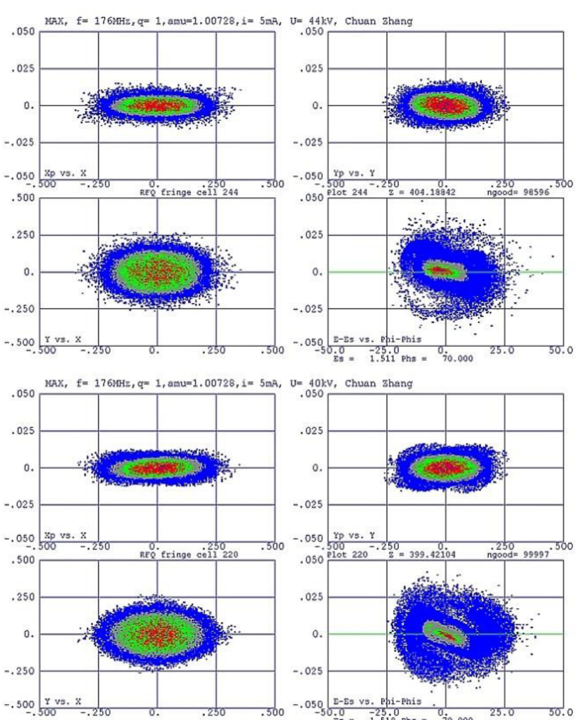

Figure 4: Output phases spaces (top: CZ2013; bottom: CZ2011).

The output longitudinal emittance of the new design is corresponding to 0.65 keV-ns, smaller than 0.8 keV-ns and 1 keV-ns, the upper limits proposed for the Project-X RFQ and China-ADS Injector-II RFQ which will be followed directly by SC cavities, respectively [10]. Therefore, this value is very safe for the MYRRHA injector which has even an RT section after the RFQ.

Using the new RFQ output distribution (see Fig. 4), the beam dynamics simulation of the downstream H-type DTL has been performed. It gives the beam performance better than that based on the old reference design. The results will be presented at the coming LINAC'14 Conference.

CONCLUSION

Using the efficient New Four-Section Procedure, the reference design for the European ADS RFQ accelerator has been updated with 10% higher inter-vane voltage and 24-cell longer pre-bunching. The average mid-cell electrode aperture is 6.5% bigger, which will be helpful for easy tuning and power-consumption reduction. The output longitudinal emittance is 40% smaller, which will provide a better starting point for the MYRRHA accelerator and contribute to a more reliable operation of the whole facility.

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