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# Conceptual design of LEBT and RFQ for the HIAF linac

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ABSTRACT

In this paper, we present conceptual design and beam dynamics analysis of the Low Energy Beam Transport (LEBT) and Radio Frequency Quadrupole (RFQ) for the linac section of a heavy ion accelerator facility, high intensity Heavy Ion Accelerator Facility (HIAF) project, which is promoted by the Institution of Modern Physics (IMP) of the Chinese Academy of Sciences (CAS). A novel scheme is prompted that a Multi-Harmonic-Buncher (MHB) is used for bunching the continuous beam up-stream of the RFQ. The modulation $m$ and synchronous phase $\psi$ of the RFQ do not start from 1.0 and $-90^\circ$ but 1.05 and $-45^\circ$ instead. The results indicate that it is possible to keep transverse emittance growth within tolerable limits while the longitudinal emittiance is much smaller than the design without an external buncher.


## 1. Introduction

The development of superconducting cavities for low and medium beta ion acceleration in recent years gives rise to several proposals for high intensity accelerators based on superconducting (SC) technology [1]. High intensity Heavy Ion Accelerator Facility (HIAF) proposed by IMP will be a national facility. The HIAF [2] project is based on a heavy-ion linac with a minimum energy of 100 MeV/u for all ions and a beam current 1.0 mA. This advanced facility will provide high intensive ion beams for high energy nuclear science to understand the fundamental forces and particles of nature. The HIAF project will include three parts: ion linac injector, the rings and experiments facility.

The proposed linac design is based on the goal of constructing a reliable, low-maintenance, state-of-the-art accelerator with proven technology and robust operating stability to minimize downtime and ensure production of intense beams for world-class experiments. As shown in the Fig. 1, HIAF-Linac will be consisted of front end, superconducting accelerating segment one, stripping and matching section, and superconducting accelerating segment two.

The design of the driver linac is largely determined by the requirement of a 100 MeV/u, 1.0 mA uranium beam and the need to accelerate a wide range of ions while limiting the uncontrolled beam loss below 1 W/m for the high power SC machine to facilitate hands-on maintenance. In the preliminary design we choose U34+ as the reference particle. Generally speaking, the beam quality in the whole line is mainly decided by the low energy transport part, in which the space charge affects a lot. In this paper, we mainly focus on physical and structural design of LEBT, MHB and RFQ part. The MHB is simulated using CST with Microwave Studio [3]. The RFQ is designed using the code DesRFQ [4]. The Track Code [5] is used for the beamline design and 6-dimensional simulation study for the whole line with full 3D space charge effect.

In Section 2, the lattice of LEBT is prompted. In this lattice, the LEBT mainly has two functions, one is to select the charge state from hybrid charge beams, the other is to provide proper transverse and longitudinal matching to the RFQ to avoid appreciable halo formation [6,7].

In Section 3, the structure design of an external MHB is discussed. The effects of MHB on the beam are also shown. Continuous beam injected is painstakingly and efficiently pre-bunched before being injected into the RFQ. This MHB–RFQ scheme produces a much smaller longitudinal emittance [8] and enhances the acceleration efficiency of the RFQ which means this RFQ could be much shorter compared with conventional design [9].

In Section 4, an unconventional RFQ design is outlined. Because the beam has been bunched already, the basic parameter modulation $m$ and synchronous phase $\psi$ of the RFQ do not start from 1.0 and $-90^\circ$ but 1.05 and $-45^\circ$ instead. This RFQ is proposed to accelerate various beams with a beam current 1 mA and 20 KeV initial kinetic energy to 0.4 MeV, as a compromise of the length of RFQ and a better acceptance of following SC Quarter Wave Resonator (QWR) linac. Therefore, to be operated at the frequency of 81.25 MHz, it must be able to operate with a wide range of power levels to accommodate the different ion species. The basic physical and structural parameters of this RFQ are listed.

Conclusions and ideas for future studies are given in Section 5.

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## 2. LEBT system

The schematic layout of the LEBT lattice is shown in Fig. 2. For the simplest method, a 90° analysis magnet system is used to separate unwanted ions from the ideal obit and a charge state selection aperture is used to collect them. The radius of curvature of the bending magnet is 60 cm. To maintain the beam envelops within a reasonable range and make the beam matched with the external buncher, which requires a smaller beam size to keep the nonlinear field that particles feel as small as possible, a total of 4 quadrupoles are adopted between the charge selection system and the external buncher. These quadrupoles will be able to accommodate a large range of Twiss parameters of the incoming beam. Following the bunching system, a group of triplet and two groups of doublets are used to achieve the required matching condition decided by the following RFQ.

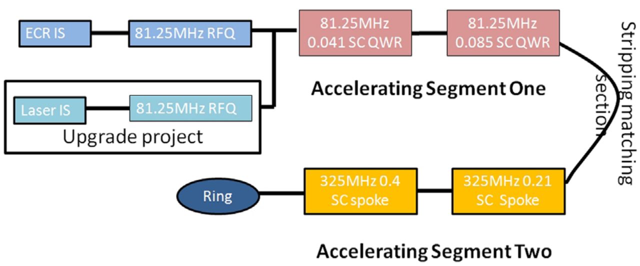


**Fig. 1.** Schematic layout of the HIAF project.

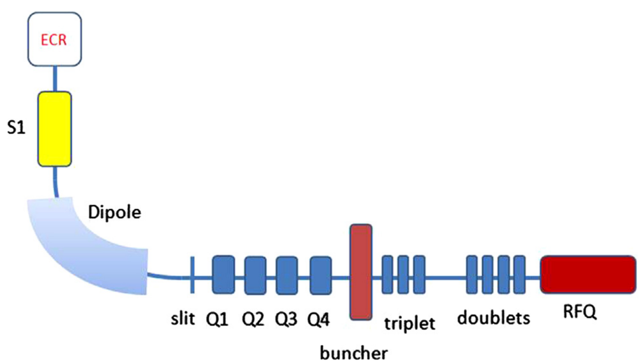


**Fig. 2.** Schematic layout of the LEBT lattice.

All ion species are assumed to have the same Twiss parameters at the exit of ECR with a divergence about 1° and beam radius 5 mm, which is a typical beam parameter extracted from the ECR ion source according to the experiment results of IMP. A normalized full uranium beam emittance of 0.9 pi-mm-mrad is used (normalized rms ~ 0.15 pi-mm-mard), and an intrinsic energy spread of 0.1% is included. The initial particle distribution is assumed as 4-D Water-Bag distribution in transverse hyperspace with a uniform distribution in longitudinal phase space. Fig. 3 shows the initial distribution used in the design and simulation. Fig. 4 shows the particles distribution after the bending magnet. It clearly shows that this slit with aperture about 1.5 cm could remove the unwanted charge state 33+ and 35+ safely. Because of the energy spread of different charge states, the longitudinal phase space will stretch to a large phase range. However, the particles of 33+ and 35+ charge states will get lost anyway. In this case, these particles will not affect the beam quality a lot. The most important result is that the charge state of interest is selected.

The simulation result of the whole LEBT with Track code is shown in Fig. 5. During this process, because of the nonlinearity of bending magnet and MHB field, there will be a little transverse emittance growth. Anyhow, this is still acceptable.

## 3. Bunching system

With a smaller longitudinal emittance, the design of the following superconducting linac will be much easier, because of a small longitudinal acceptance at the SC section. As a result, a scheme is promoted, to reduce the beam emittance, based on the use of an external MHB before the RFQ. A lower buncher frequency would result in a larger longitudinal output emittance [10]. With this method, not only the longitudinal emittance at the exit of RFQ is decreased significantly but also the length of RFQ can be

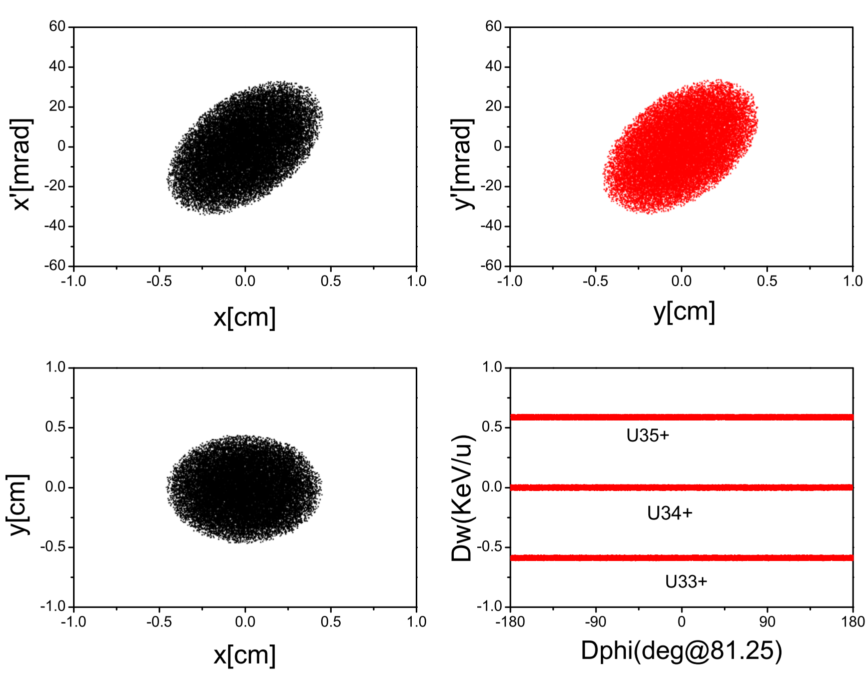


**Fig. 3.** Initial particle phase space distribution.