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TECHNICAL DESIGN OF NORMAL CONDUCTING RE-BUNCHER IN THE MEBT FOR RARE ISOTOPE SCIENCE PROJECT

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Abstract

The front-end system of RISP heavy-ion accelerator (RAON) consists of an electron cyclotron resonance(ECR) ion source, a low energy beam transport (LEBT) line, a radio frequency quadrupole(RFQ) accelerator and a medium energy beam transport (MEBT) line. The MEBT system, which consists of quadrupole magnets, three normal-conducting re-bunchers and several diagnostic devices, is installed between the RFQ accelerator and the superconducting linac (SCL). The three normal-conducting re-bunchers are used to minimize the growths of the longitudinal emittance and to manipulate the particle distribution on longitudinal phase space for beam transportation in SCL. Several combination of the number of cavities was examined, and the quarter wave resonator(QWR) type re-buncher was chosen for MEBT line in RAON. The QWR cavity has a frequency of 81.25 MHz, a maximum electric field of 2.53 MV/m on the cavity surface with an electric field of 1 MV/m on the beam axis, a geometric beta factor of 0.032 and an effective length of 24 cm. In this presentation, I will present the results of baseline design for electro-magnetic field analysis and mechanical design for stress analysis, thermal stress analysis and cooling channel.

INTRODUCTION

The main goal of the Rare Isotope Science Project is to construct a high-power heavy-ion accelerator which is based on the superconducting linear accelerator (SCL). The accelerator is a key research facility allowing groundbreaking investigations into numerous facets of basic science, such as nuclear physics, astrophysics, atomic physics, life science, medicine, and material science [1, 2]. The machine named as a RAON (Rare isotope Accelerator Of Newness) will provide ion beams from proton to uranium with a beam power of 400 kW. The target beam current and energy of the uranium beam are 8.3 pμA and 200 MeV/u, respectively. The MEBT system, which consists of the eight quadrupole magnets, three re-buncher, and several devices for beam diagnosis, is located between the RFQ and the SCL to match the optical parameters in the transverse plane and to remove of the unaccelerated ion beams from the RFQ. It also measure the beam quality during operation. The schematic layout of RAON is shown in Fig. 1.

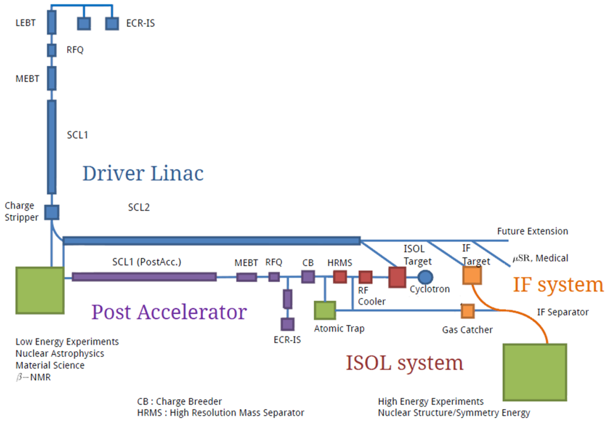

Figure 1: Schematic layout of the RAON accelerator.

OPTICS DESIGN FOR MEDIUM ENERGY BEAM TRANSPORT

In the MEBT system, three quarter wave resonators (QWRs) type re-bunchers with the frequency of 81.25-MHz and the geometric beta of 0.032 and eight room-temperature quadrupole magnets were chosen for tuning the beam on longitudinal and transverse direction at the entrance of SCL. Several beam diagnostic devices such as stripline beam position monitors, current monitors and a bunch length monitor are installed to measure the beam parameter and beam collimators and steering magnets are also installed to remove the halo and to correct the trajectory in the MEBT line. Figure 2 shows the beam line for medium energy beam transport system.

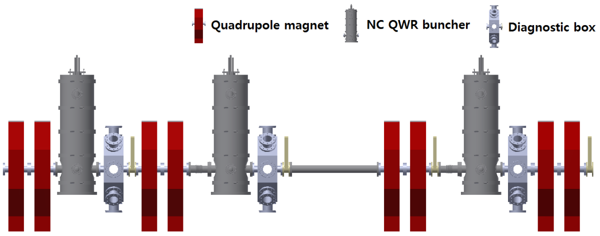

Figure 2: Layout of the MEBT line in RAON.

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ELECTRO-MAGNETIC DESIGN FOR A NORMAL-CONDUCTING QWR REBUNCHER

Two gap normal conducting 81.25 MHz resonators were chosen to provide enough electrical field with a low geometric beta for longitudinal matching of the 500 keV/u beams from the RFQ into the SCL. In order to decide the dimensions of re-buncher, the beam parameters was required at the exit of the RFQ accelerator. It is listed in Table 1.

Table 1: Major Beam Parameters for Re-Buncher at the Exit of RFQ Accelerator [3]

Beam parameter	Value
Reference Particle	$^{238}U^{+33}$, $^{238}U^{+34}$
Charge state	33, 34
Kinetic Energy [MeV/u]	0.5
Repetition rate [MHz]	81.25
RMS buncher length [deg]	5.74
RMS energy spread [%]	0.57

The distance between the center of the gap of QWR type re-buncher is 9 cm and is consistent with the velocity of the ion beam (β = 0.032). Based on the result of multi-particle tracking simulation, the requirement of the peak electric field on the beam axis is about 2.6 MV/m to match and control the longitudinal beam parameter from RFQ accelerator [4]. The bore radius of designed cavity is 5cm to minimize the uncontrolled beam loss inside the cavity. It was mainly limited by the shunt impedance of the cavity for high acceleration by the field. The electromagnetic design of the cavity field was performed using code CST-MWS [5]. The drawing of the designed QWR re-buncher and transverse and longitudinal components of the electric fields on beam-axis are shown in Fig. 3 and Fig. 4, respectively.

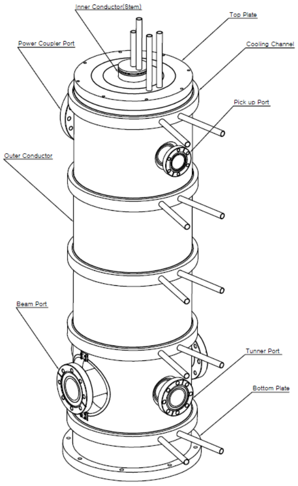

Figure 3: Drawing of the designed re-buncher.

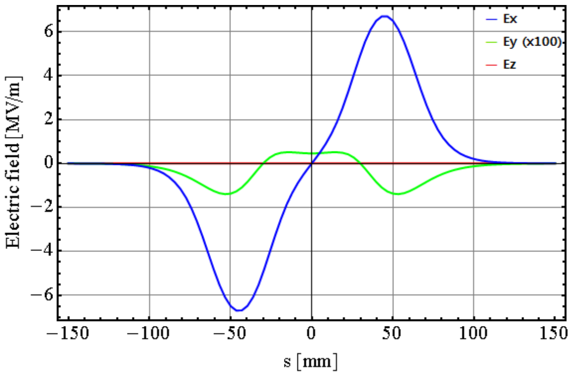

Figure 4: The electric field of the designed re-buncher.

The power loss of the designed re-buncher was estimated to be 1.4 kW for 1 MV/m of electric field on the beam axis. Then the power loss for the nominal operation is about 10 kW. The high pressure water cooling system is required to maintain the temperature of the cavity. As in most accelerators, high pressure water system is well used which is based on the media as the absorbing heat generated by a multitude of accelerator components for a few kW power. The main design parameters of the resonator are listed in Table 2.

Table 2: Parameters of the Designed Normal Conducting QWR Re-Buncher

Parameter	Value	Unit
Frequency	81.25	MHz
Geometric beta(=v/c)	0.032	
Chamber radius	2.5	cm
Gap	90	mm
Q factor	8124	
R_{eff}	3.9	MΩ
R_{eff}/Q	482.3	
Effective voltage	74	kV
Power loss	1.4	kW
E_{peak} on axis	1	MV/m

One of the critical issue to design the normal conducting re-buncher is the effect of multipacting inside of the cavity because it can cause the damage on the surface and external heat of cavity. The estimation of the effect of multipacting in the design cavity was performed using code CST-PS. Based on the electromagnetic field calculated by using code CST-MWS, the secondary emission yield (SEY) as a function of the effective acceleration field inside the designed re-buncher was estimated.

As shown in Figure 5, the SEY value was larger than 3.2 for the effective acceleration field of 50 $\sim$ 60 kV/m of and it was reduced less than 1 when the acceleration field was over the 160 kV/m. In our case, the minimum effective acceleration field for nominal operation of the re-buncher is 320 kV/m. Even through the operation acceleration field is higher than the criteria for the effect of multipacting, the

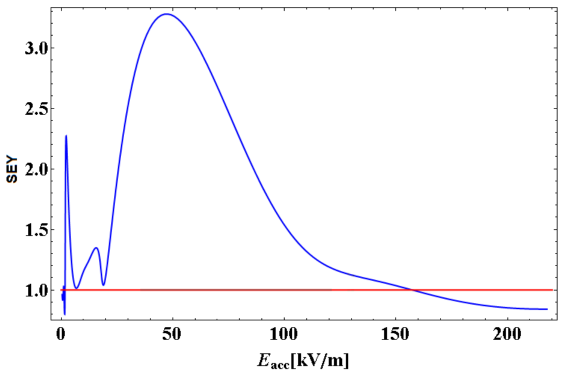

Figure 5: Simulation result of the multipacting effect as a function of the acceleration field of the re-buncher.

careful attention was required to protect the damage of cavity by multipacting effect in the beam operation.

MECHANICAL DESIGN FOR A NORMAL-CONDUCTING QWR REBUNCHER

The wall of the re-buncher received the pressure due to the pressure difference between outside(atmospheric pressure) and inside(vacuum) of the designed cavity. It gives the deformation of the cavity wall, which causes the shift of resonant frequency. And the stem and wall parts of the re-buncher was also dilated due to the thermal expansion of the structure by power of 15 kW. Temperature (left) and total deformation (right) of the designed re-buncher under the heat of 15 kW and 1 atm pressure were estimated that are shown in Fig. 6.

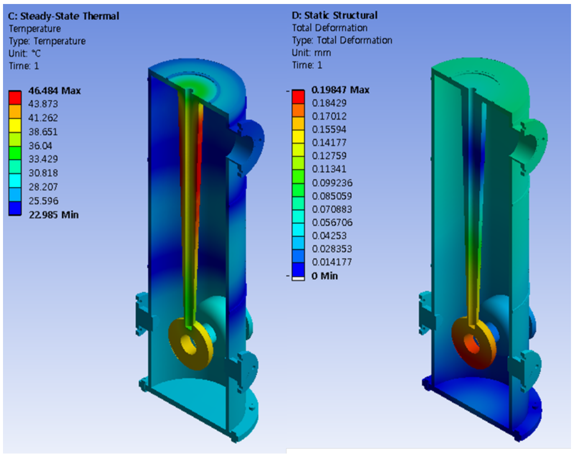

Figure 6: The temperature distribution(left) and total displacement(right) of the designed re-buncher.

The analysis shows that the maximumtemperature and total deformation were occurred on the inner conductor of the re-buncher and it are to be 46 °C and 0.2 mm under 1 atm differential pressure and heat of 15 kW, respectively. The frequency shift due to the deformation is 34 kHz and it is tunable by using a tuner. A slug tuner is used to bring the frequency of the resonator close to the master frequency and stabilize it there.

The tuner was installed in the perpendicular plane of the beam port which has a high electric field to decrease the resonant frequency. Diameter of the tuner port was decided as 40 mm to achieve the enough tuning range. The tuner sensitivity and total tuning range of the designed cavity using two tuners are 20 kHz/mm and 436 kHz within tuner depth of 20 mm. The resonant frequency as a function of the tuner depth is shown in Fig. 7.

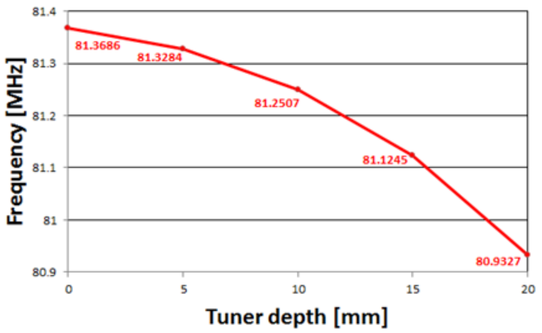

Figure 7: The resonant frequency as a function of the tuner depth.

CONCLUSION

The QWR type re-buncher, which has a frequency of 81.25 MHz and a geometric beta factor of 0.032, was designed for manipulating the longitudinal distribution in MEBT line. The criteria for the effect of the multipacting, which causes the degradation of the performance of the designed re-buncher, was investigated. The effect of the atomic pressure and thermal expansion were also estimated to determine the tuning range of the tuner. Based on this, the diameter and depth of the slug tuner was decided and it was installed in the perpendicular plane of the beam port which has a high electric field to decrease the resonant frequency to compensate the effect of the deformation due to the thermal expansion and atomic pressure.

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