SUPERCONDUCTING LINAC FOR THE RARE ISOTOPE SCIENCE PROJECT

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Abstract

The RISP (Rare Isotope Science Project) accelerator has been planned to study heavy ion of nuclear, material and medical science at the Institute for Basic Science (IBS). It can deliver ions from proton to Uranium. The facility consists of three superconducting linacs of which superconducting cavities are independently phased. Requirement of the linac design is especially high for acceleration of multiple charge beams. In this paper, we present the RISP linac design, the superconducting cavity, and cryomodule.

INTRODUCTION

The RISP (Rare Isotope Science Project) accelerator has been planned to study heavy ion of nuclear, material and medical science at the Institute for Basic Science (IBS). It can deliver ions from proton to Uranium with a final beam energy, for an example, 200 MeV/u for Uranium and 600 MeV for proton, and with a beam current range from 8.3 pμA (Uranium) to 660 pμA (proton) [1, 2]. The facility consists of three superconducting linacs of which superconducting cavities are independently phased and operating at three different frequencies, namely 81.25, 162.5 and 325 MHz.

SUPERCONDUCTING LINAC

Lattice Design

The layout of the RISP accelerator is shown in Fig. 1. The Uranium ions produced in an electron cyclotron resonance ion source are preaccelerated to an energy of 500 keV/u by a radio frequency quadrupole and transported to the superconducting cavities by a medium energy beam transport. The driver linac is divided into three different sections: low energy superconducting linac (SCL1), charge stripper section and high energy superconducting linac (SCL2). Figure 2 shows a conceptual structure of SCL1 and SCL2. The SCL1 uses the two different families of superconducting resonators, i.e., quarter wave resonator (QWR) and half wave resonator (HWR). The SCL11 consists of 22 QWR's whose geometrical β is 0.047 and 22 doublets. The resonance frequency of QWR is 81.25 MHz. The cryomodule of the SCL11 hosts one superconducting cavity. The SCL12 consists of 123 HWR's whose geometrical β is 0.12 and 27 doublets. The resonance frequency of HWR is 162.5 MHz. This segment has the two families of cryomodules: one type of cryomodule hosts three superconducting cavities and the other hosts six superconducting cavities.

The SCL2 consists of the SCL21 and the SCL22, each consisting of geometric β 0.30, resonance frequency 325 MHz Single Spoke Resonators (SSR) and geometric β 0.53, resonance frequency 325 MHz SSR. Single Spoke Resonator type is chosen mainly because it can have a larger bore radius compared with the Half Wave Resonator type, which is very essential to reduce the uncontrolled beam loss in the high energy linac section. The number of cavities in the SCL21 and SCL22 is 84 and 144 respectively. The cryomodule of the SCL21 and SCL22 hosts 4 and 8 cavities respectively. The charge stripper section is located between SCL1 and SCL2. The charge stripper strips electrons from heavy ion beams to enhance the acceleration efficiency in the high energy linac section. The charge stripping section consists of four normal conducting quadrupole triplets and two room-temperature 45 degree bending magnets. The quadrupole magnets provide adequate transverse focusing and beam matching to the SCL2 and bending magnet provides the momentum dispersion for the charge selection. Figure 3 shows the energy gain from the cavities. Table 1 summarizes the beam energy of stable ions in the RISP superconducting driver linac.

The post accelerator (SCL3) is designed to accelerate the rare isotopes produced in the ISOL (Isotope Separation On-Line) system. The SCL3 is, in principle, a duplicate of the driver linac up to low energy linear accelerator. The accelerated rare isotope beams are reaccelerated in the SCL2. Hence, the RISP accelerator provides a large number of

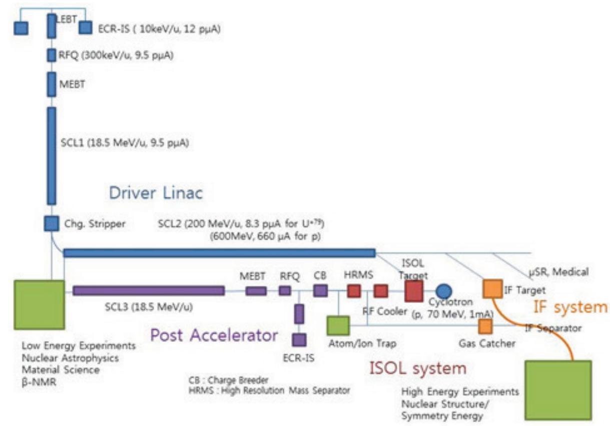

Figure 1: Layout of the RISP accelerator.

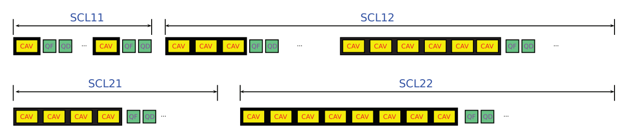

Figure 2: Layout of the SCL: SCL1 (top) and SCL2 (bottom).

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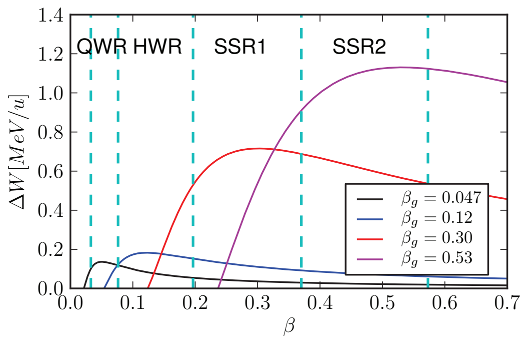

Figure 3: Plot of the energy gain from the RISP superconducting cavities.

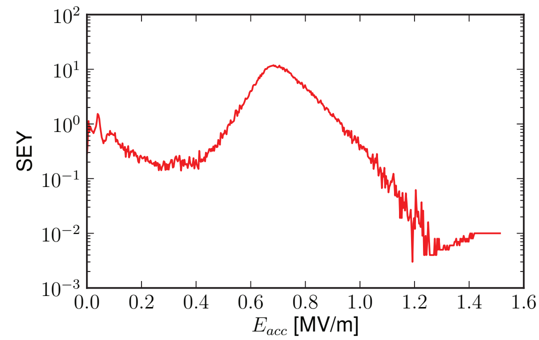

Figure 4: Plot of multipactor in QWR when Niobium is baked at 300°C.

Table 1: Beam Energy of Stable Ions in the Driver Linac

	Unit	SCL11	SCL12	SCL21	SCL22
Uranium	MeV/u	2.5	18.5	68	205
Proton	MeV/u	7.5	87.4	222	630
Oxygen	MeV/u	7.5	56.1	128	325
Xenon	MeV/u	3.1	22.4	86	250
Carbon	MeV/u	5.6	41.4	115	313

rare isotopes with high intensity and with various beam energies. Table 2 summarizes the beam energy of rare isotope ions in the RISP post-accelerator linac.

Superconducting Cavity

QWR is like a simple cylinder of 220mm diameter and 905mm length with a conical stem, donut-shaped drift tubes, and rounded upper/lower ends. The performance of cavity is estimated and optimized by using CST MWS code [3]. In the optimization, the fabrication cost, symmetry of transversal field around drift tubes, and minimization of peak fields are mainly concerned. The multipacting barriers of QWR are predicted by using CST PIC code with the secondary emission yield (SEY) of a 300°C baked Niobium as shown in Fig. 4. Several peaks are shown in the plot of multipacting factors of 4 RF periods. The most serious multipactor occurs around the upper end of QWR at 1/8 of the accelerating gradient (5.2MV/m). The detuning due to the tolerances of fabrication and the frequency sensitivities to mechanical deforming are estimated. The cavity is fabricated by electron beam welding of hydroformed 3 mm Niobium sheets, drift tube and 4 additional ports without bottom flange. Two ports in the lower end are added

Table 2: Beam Energy of Rare Isotope Ions in the Post-Accelerator Linac

	Unit	SCL31	SCL32	SCL21	SCL22
Sn-132	MeV/u	2.4	19.2	73	210
Xe-144	MeV/u	2.5	19.8	76	222
Ni-68	MeV/u	4.7	37.3	151	456

Table 3: Detuning and Frequency Sensitivities of QWR cavity

Frequency Shift	Value
Cavity length(upper)	-67kHz/mm
Cavity length(lower)	+1.3kHz/mm
Chemical etching(nose)	+20kH/mm
Chemical etching(others)	-8.6kHz/mm
External pressure	-4.6Hz/mbar
Cool down(293K to 2K)	+200kHz
Lorentz force	-1.7Hz/(MV/m)^2

for RF power and pickup coupling. The other two ports are installed for evacuation and high pressure rinsing. The predicted detunings and sensitivities of the bare cavity are shown in the Table 3.

The electromagnetic design of the HWR was done by tuning the geometrical parameters of the cavity to optimize the figures of merits. The ratio of the outer to inner radius of the cavity was determined to roughly minimize the peak field values. Secondly, the electric field region (near the beam port) was optimized with the various factors. The donut shape of beam tube was introduced to ensure symmetric quadrupole fields. A flat surface was included in the beam port cup to tune the frequency by elastic deformation of the beam port. The blending radius of the surfaces in the beam ports and tube were determined to further improve time transit factor. For easier and cheaper manufacturing of the cavity, the neck region (joining the center conductor to the beam tube) was realized by a very short straight section. Finally the magnetic field region (near the short plates) was optimized by tapering the center conductor to further reduce the B_{peak}. Also, the center conductor was joined to the short plates through a straight section. The error analysis shows that the the margin of the errors (a few mm) that allow the change in the accelerating field by 1% is much bigger than controllable machining error.

For particle beams passing through the cavity to get maximum energy gain, the acceleration gradient should be maximized while decreasing the peak electric and magnetic fields. We have performed simulations on electromagnetic

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Table 4: Superconducting Cavity Parameters

Parameter	Unit	QWR	HWR	SSR1	SSR2
Frequency	MHz	81.25	162.5	325	325
β_g		0.047	0.12	0.30	0.53
$L_{eff} = \beta_g \lambda$	m	0.173	0.221	0.277	0.470
Q	10^9	2.1	5	8	10
QR_s	Ω	21	50	80	108
R/Q	Ω	468	314	248	304
E_{acc}	MV/m	5.2	5.0	6.1	7.5
E_{peak}/E_{acc}		5.8	6.0	4.9	4.2
B_{peak}/E_{acc}	mT/(MV/m)	9.8	7.6	6.6	8.6

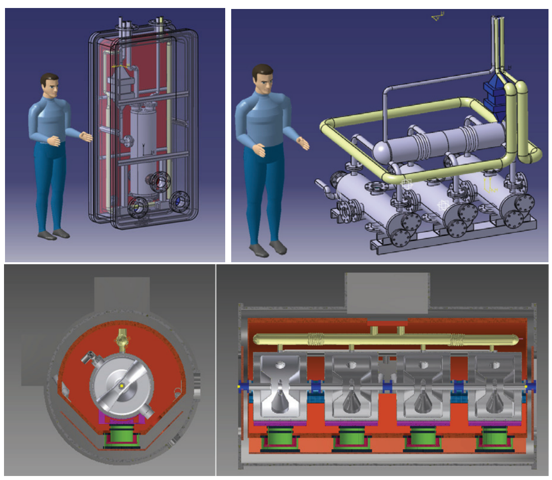

Figure 5: 3D model of cryomodules: (top left) cryomodule for QWR, (top right) cryomodule for HWR, and (bottom) cryomodule for SSR.

analysis with changing the design parameters of the single spoke resonator. It is not possible to design the cavity with simultaneously optimizing the figure-of-merit characteristics. Therefore, we determined the design parameters sensitive to the resonant frequency. The peak electric and magnetic fields were selected for minimizing the field emission in the cavity surface and maintaining the superconducting properties. Finally, the remaining design parameters were determined to maximize the R/Q and V_{acc}. Table 4 summarizes the parameters of four different superconducting cavities for the RISP superconducting linac.

Cryomodule

The linac has five types of cryomodules for four different kinds of cavities. The main roles of the cryomodules are maintaining operating condition of superconducting cavities and alignment of the cavities along the beam line. High level of vacuum and thermal insulation are required for the cryomodule to maintain the operating temperature of superconducting cavities. The cryomodules including QWR and HWR cavities are box-type while those including SSR1 and SSR2 cavities are cylindrical as shown in Fig. 5. The QWR is vertically installed while the HWRs are horizontally installed in the cryomodule. The main components of the cryomodule are dressed cavities and two phase pipe, power couplers to supply RF power to the cavities, tuners to control the operation of the cavities, and support systems to fix the cavities along the beam line. Since the operating temperature of the superconducting cavities are 2 K, 70 K thermal shield which is cooled by cold helium gas and 70 K and 4.5 K thermal intercepts are installed to minimize the thermal load. The cold mass including cavity string, coupler and tuner is installed on the strong-back and then inserted into the vacuum vessel with thermal shield and MLI. The design of the cryomodule components has been conducted based on the thermal and structural concerns. The thermal design starts from the estimation of the thermal loads that determine the required size of the components such as two phase pipes and other cryogenic pipes. Three levels of cryogenic flow are necessary such as 2 K, 4.5 K and 70K. The schematic of the flow circulation system in the cryomodule is shown in Fig. 6.

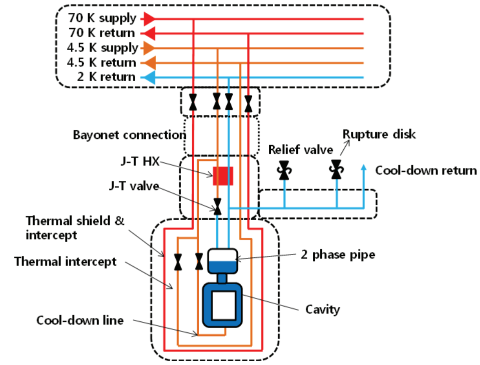

Figure 6: Flow circulation system for the SCL11 cryomodule.

SUMMARY

The RISP low and high energy linacs have been presented. In the design, the focusing in the superconducting linacs is provided by normal conducting quadrupole doublets. Four cavities, such as QWR, HWR, SSR1 and SSR2, are used to accelerate the beam in the linac. The parameters of the cavities are optimized. The box-shaped and cylindrical cryomodules are designed for hosting cavities.

ACKNOWLEDGMENTS

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