Conceptual design of SC linac for RIBF-upgrade plan

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An upgrade plan for the RIKEN RI-Beam Factory is under discussion, with the objective of significantly increasing the uranium beam intensity. Difficulty in the present acceleration scheme mainly stems from the two-stage charge stripping located at 11 and 50 MeV/u, respectively, which yields a maximum total stripping efficiency of 5%. In the upgrade plan, the fixed-frequency Ring Cyclotron will be replaced by a new cyclotron[1)] that will be designed to accept U^{35+} ions without charge stripping at 11 MeV/u, and the RIKEN ring cyclotron will be replaced by a new linac, mainly consisting of superconducting (SC) cavities, to improve the transmission of the high current beam. To evaluate the feasibility of the new linac, we started a design study of the SC linac in fiscal year 2013[2)].

A layout plan of the new linac is shown in Fig. 1. The present injector, RILAC2, will be used at the low-energy end. We will add a short room-temperature (RT) section to RILAC2, which will boost the beam energy from 0.68 to 1.4 MeV/u. The main part is the succeeding SC section working in the energy range from 1.4 to 11 MeV/u.

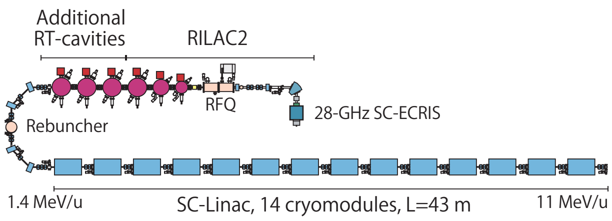

Fig. 1. Layout plan of new linac injector.

The beam energy at the border of the RT and SC sections was chosen so that the SC section could be covered by a single structure of a quater-wavelength resonator (QWR) with two acceleration gaps. Because a broad range of velocity had to be covered, the gap length and cavity diameter of the SC section were optimized to minimize the number of QWRs in the section. The energy gain of each gap was calculated based on hard-edge approximation. The gap voltage was assumed to be 800 kV, and the synchronous phase was chosen to be -25°. After several iterations, we determined a length $d = 160$ mm, which is the length between the gap centers, and a total cavity number of 56. The gap length was decided to be 60 mm.

The modular configuration of the SC section was optimized based on first-order approximation for the transverse and longitudinal motions. Some configurations were checked to determine whether a semi-periodic envelope could be obtained with moderate-strength focusing elements, while keeping the longitudinal acceptance large enough to capture the output beam from the RT section. Finally, we chose a configuration that consists of 14 cryomodules, each of which contains four QWRs operating at 73 MHz, and a RT quadrupole doublet placed in each space between the cryomodules. Quadrupoles with an aperture diameter of 50 mm and a field gradient of less than 20 T/m would be easier for us to make and operate compared to the SC solenoid.

The SC QWRs were designed using CST Microwave Studio 2013. The RF surface resistance is assumed to be 25 nΩ on the safe side, where the BCS resistance is negligibly small. The curently used parameters of the SC section are listed in Table 1. The definition of the effective length for the determination of E_{acc} is selected to be $\beta_{geom}\lambda$.

Table 1. Design parameters of the SC section.

Frequency [MHz]	73
Duty [%]	100
Mass-to-charge ratio (m/q)	~7
Input energy [MeV/u]	1.4
Output energy [MeV/u]	11.0
Number of cavities	56
Number of cryomodules	14
Number of quadrupole magnets	28
Total length [m]	43
Cavity inner diameter [mm]	ϕ300
Cavity height [mm]	1103
Gap length g [mm]	60
Gap voltage V_{gap} [kV]	800
β_{geom} of cavity	0.078
Beam aperture a [mm]	ϕ40
Synchronous phase ϕ_s for β_{geom} [°]	-25
Operating temperature T [K]	4.5
$G = Q_0 \times R_s$ [Ω]	22.6
R_a/Q_0 [Ω]	718
$R_s = R_{BCS} + R_{res}$ [nΩ]	25
Q_0	9.0×10^8
Shunt impedance R_a [Ω]	6.5×10^{11}
Rf power loss P [W]	4.0
E_{acc} [MV/m]	4.5
E_{peak}/E_{acc}	6.0
B_{peak}/E_{acc} [mT/(MV/m)]	9.5

Further study is under way on the SC QWR, including the mechanical considerations, tuner design, and coupler design. We are also going to start thermal and mechanical studies of cryostats based on the initial design shown above.

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References

1) J. Ohnishi *et al.*: Proc. of Cyclotrons2013, MOPPT022 (2014).
2) K. Yamada *et al.*: Proc. of SRF2013, MOP021, 137 (2014).