CONSTRUCTION OF NEW INJECTOR LINAC AT RIBF

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Abstract

A new injector linac called RILAC2 has been constructed in order to enable the independent operation of the RIBF experiments and super-heavy element synthesis. Construction of the RILAC2 started at the end of FY2008. The RFQ linac and three DTL tanks were installed in the AVF-cyclotron vault and the excitation of rated voltage have succeeded. Two rebunchers are in fabrication and alignments of LEBT and HEBT are performed now. We plan to start the beam commissioning in December 2010.

INTRODUCTION

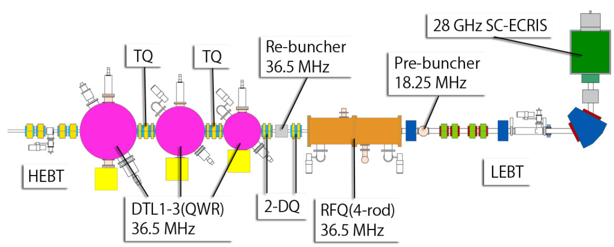

Figure 1: Schematic-layout view of the RILAC2.

A new additional injector linac called RILAC2 has been constructed at the RIKEN Nishina Center for performing independent RIBF [1] experiments and super-heavy-element synthesis [2]. As shown in Fig. 1, RILAC2 consists of a 28-GHz superconducting ECR ion source (SC-ECRIS) [3], a low-energy beam transport (LEBT) [4] with a pre-buncher, a four-rod RFQ linac, three drift-tube linac tanks (DTL1-3), a rebuncher between the RFQ and DTL1, a high-energy beam transport (HEBT) from the DTL3 to the RIKEN Ring Cyclotron (RRC) [5], and strong quadrupole magnets between the acceleration cavities for transverse focusing. Another rebuncher is located at the HEBT to focus the longitudinal phase spread at the injection of RRC by a combination of the rebuncher and an existing rebuncher. Very heavy ions with mass-to-charge ratio (m/q) of 7, such as $^{136}Xe^{20+}$ and $^{238}U^{35+}$, are accelerated up to an energy of 680 keV/u in the cw mode and injected into the RRC without charge stripping. The rf resonators excluding the pre-buncher are operated at a fixed rf frequency of 36.5 MHz, whereas the pre-buncher is operated at 18.25 MHz. The basic design of the RILAC2 was finished in 2006 [6] and the construction has started since the budget was approved at the end of FY2008. We decided to relocate the SC-ECRIS, which was originally fabricated for the existing linac called RILAC and tested in the RILAC, to a new room for the ion source of RILAC2. Other equipments for the RILAC2 are placed in the existing AVF-cyclotron vault. This article mainly presents the details for the construction of linac part.

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CONSTRUCTION OF RF CAVITIES

RFQ Linac

To save construction cost, we decided to recycle a four-rod RFQ linac which was originally developed by Nissin Electric Co., Ltd. in 1993 [7] for ion implantation. In November 2007, the RFQ system was transferred to RIKEN through the courtesy of Kyoto University. The RFQ linac can accelerate heavy ions with an m/q of 16 up to 84 keV/u in the cw mode with an rf frequency of 33.3 MHz. The maximum rf input power was designed to be 50 kW(cw). If the RFQ resonator is so modified to have a resonant frequency of 36.5 MHz, ions with an m/q of 7 can be accelerated to 100 keV/u for RILAC2 without changing the vane electrodes. The intervane voltage required for RILAC2 is 42 kV, which is less than the originally designed value of 55 kV. The basic parameters corresponding to the RFQ linac after the conversion are listed in Table 1; the parameter values were obtained by scaling the original values.

For modification of the resonant frequency, we inserted a block tuner into the gaps between the posts supporting the vane electrodes. The size of the block tuner was optimized by 3D electromagnetic calculations using the computer code Microwave Studio 2009 (MWS) and rf measurements using cold-model test pieces made of aluminum. The rf power required to excite the intervane voltage of 42 kV was evaluated to be 17.5 kW by taking into account 80% derating of the shunt impedance (63 kΩ) determined by the MWS calculation.

The heat load distribution was also evaluated by MWS calculations to decide the cooling conditions. The Maximum current density in the block was 32 A/cm, which was very small. The total heat load estimated for the five blocks was approximately 2.1 kW. The size of the cooling

Table 1: Basic parameters corresponding to RFQ linac.

Frequency (MHz)	36.5
Duty (%)	100
m/q ratio	7
Input energy (keV/u)	3.28
Output energy (keV/u)	100.3
Input emittance (mm·mrad)	200π
Vane length (cm)	225.6
Intervane voltage (kV)	42.0
Mean aperture (r_0:mm)	8.0
Max. modulation (m)	2.35
Focusing strength (B)	6.785
Final synchronous phase (deg.)	-29.6
Unloaded Q	4500 (MWS)
Shunt impedance (kΩ)	63 (MWS)
Required rf power (kW)	17.5 (80%-Q)

water channel was so chosen that the flow rate of water was approximately 16 L/min; at this flow rate, the water temperature increases only by 2 °C. The cooling capacity was found to be sufficiently high if the value of the shunt impedance degraded to 70%.

The block tuner was made of oxygen-free copper; three types of blocks were required by the mounting position. Intricate cutting was carried out on the block in order to reduce the weight of block to half the original value. The blocks were mounted on a base with an rf contact provided by coil springs. The water channels in the blocks were connected in series by copper pipes. Figure 2 shows the internal structure of the RFQ linac after mounting the block tuner and water pipe.

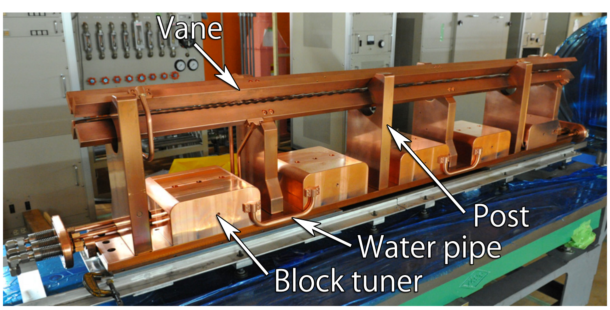

Figure 2: Internal structure of RFQ after mounting the block tuner.

Figure 3 shows the present aspect in the AVF vault. A low-power test was performed to evaluate the rf characteristics, and the resonant frequency was found to be changed to 36.5 MHz successfully. Vacuum level reached 8×10^{-6} Pa with the cooling-water flow. After the electric-wire and water-pipe connection, high power test was performed in August 2010, and the excitation with rated voltage of 42 kV has been achieved successfully.

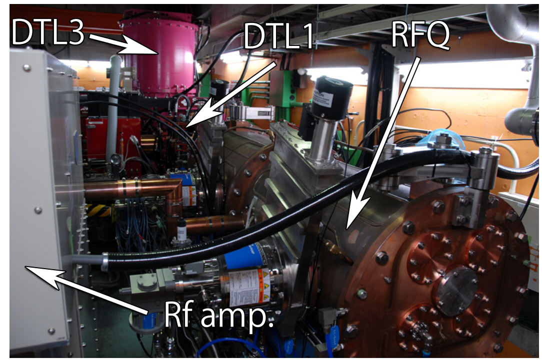

Figure 3: RILAC2 located in the AVF vault. DTLs can be seen behind the RFQ.

Drift-tube Linac

The structure of DTLs is based on a quarter-wavelength coaxial-cavity resonator. Table 2 shows the design parameters of DTLs. The cavity dimensions were determined by MWS calculations to optimize the rf characteristics. Figure 4 shows a DTL1 model used in the MWS calculation. The distribution of rf-power dissipation in the cavity was also evaluated by the MWS calculations to determine the amount of cooling required.

Table 2: Design parameters of three DTL tanks.

	DTL1	DTL2	DTL3
Frequency (MHz)	36.5	36.5	36.5
Duty (%)	100	100	100
m/q ratio	7	7	7
Input energy (keV/u)	100	220	450
Output energy (keV/u)	220	450	680
Cavity diameter (m)	0.8	1.1	1.3
Cavity height (m)	1.32	1.43	1.89
Gap number	10	10	8
Gap length (mm)	20	50	65
Gap voltage (kV)	110	210	260
Drift-tube aperture (mm)	17.5	17.5	17.5
Peak surface field (MV/m)	8.9	9.4	9.7
Synchronous phase (deg.)	-25	-25	-25
Max. power of amp. (kW)	25	40	40

In order to reduce the construction cost and the space occupied by the equipments, a direct coupling scheme was adopted for the rf amplifier. A plate electrode of a 4CW50000E vacuum tube was directly connected to the capacitive coupler, which was mounted on the cavity. The load impedance of the vacuum tube can be adjusted by changing the position of the coupler electrode. When the coupler and vacuum tube were mounted on the cavity, the resonant frequency decreased because of their series/parallel capacitance. Thus, we had to set the target frequency of the cavity such that this decrease in the resonant frequency was compensated. The decrease in the resonant

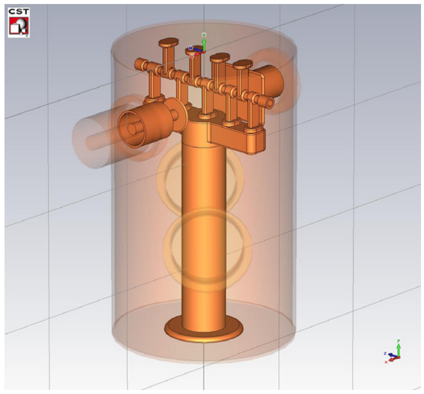

Figure 4: A DTL1 model used in the MWS calculation; the model includes a tuner and coupler.

frequency was estimated by comparing the result of MWS calculations with the measurement results obtained using the DTL3 with a 50-Ω coupler. Since the DTL3 was obtained by modifying a decelerator resonator that was developed for a Charge-State-Multiplier system [8], we were able to use it for the comparison. For example, the cavity length of DTL1 was determined to actualize the target frequency of 36.725 MHz. The coupler was designed such that the load impedance could be adjusted to approximately $1000 + j0\ \Omega$ with using vacuum tube. The default position and radius of the coupler electrode were determined by the MWS calculation using a frequency-domain solver.

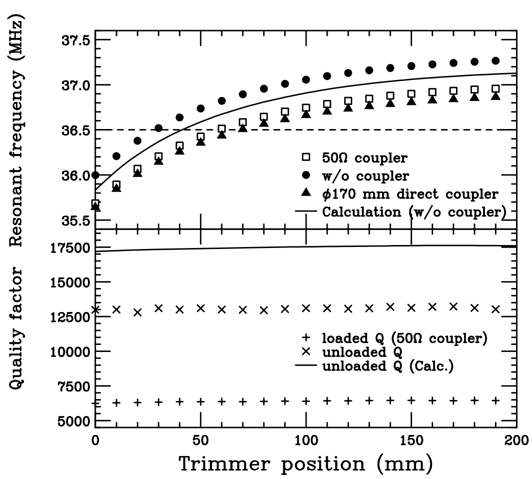

Figure 5: Frequency response of DTL1 as a function of trimmer position.

The results of the low-power test measurements for the DTL1 carried out using a network analyzer are indicated in Fig. 5. The frequency response as a function of trimmer position is plotted in the upper panel of Fig. 5. The lower panel presents the quality factors. As shown in the figure, an operation frequency of 36.5 MHz was achieved at the trimmer position of 68 mm by using a ϕ 170 mm direct coupler for the DTL1, that is consistent with the estimation by MWS calculation. The load impedance can be adjusted from 600 to 1300 Ω for the DTL1 by moving the coupler electrode over a distance of 40-mm. The electric-field distribution along the beam axis was measured using a ϕ 12 mm TiO_2 bead by the perturbation method. The shunt impedance was evaluated from the integral of the result, and the required rf power was determined. The rf characteristics of DTLs are listed in Table 3.

Table 3: Measured rf characteristics of DTLs.

	DTL1	DTL2	DTL3
Unloaded Q	13000	20350	22500
Shunt impedance (MΩ)	0.94	1.65	1.72
Effect. shunt imp. (MΩ/m)	135	176	102
Required rf power (kW)	6.5	13.4	19.6

A high-power test was performed with a load impedance setting of 700-1000 Ω depending on the tank. After one day of conditioning, the rated voltages were successfully achieved for every tank. Further conditioning and re-tunes to improve the long-term stability are performed now.

Rebuncher

The structures of rebunchers are also based on the quarter-wavelength cavity resonator with four gaps. The total required voltage of the rebuncher between the RFQ and DTL1 is 100 kV, which is driven by a 1 kW transistor amplifier. The cavity is now in fabrication and it will be installed in November 2010. For the rebuncher in HEBT, total 200 kV is required and a 3 kW transistor amplifier is used. It is now in mechanical design and will be installed in January 2011. Low-level circuits, power amplifiers, and control systems are ready.

OUTLOOK

The 28-GHz SC-ECRIS has been installed and cooled. Beam test will be performed before long. The LEBT and HEBT have been installed in the AVF vault and being aligned to the beam line now. Beam diagnosis and control system are also in preparation. We plan to start the beam commissioning of RILAC2 in December 2010.

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