CONSTRUCTION OF NEW INJECTOR LINAC FOR RI BEAM FACTORY AT RIKEN NISHINA CENTER

K. Yamada*, S. Arai, M. Fujimaki, T. Fujinawa, H. Fujisawa, N. Fukunishi, A. Goto, Y. Higurashi,
E. Ikezawa, O. Kamigaito, M. Kase, M. Komiyama, K. Kumagai, T. Maie, T. Nakagawa,
J. Ohnishi, H. Okuno, N. Sakamoto, Y. Sato, K. Suda, H. Watanabe, Y. Watanabe, Y. Yano, S. Yokouchi,
RIKEN Nishina Center, Wako, Saitama 351-0198, Japan

Abstract

A new injector 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. The SC-ECRIS and beam transport will be set on the RILAC2 in this summer, and beam commissioning will be performed in November 2010.

INTRODUCTION

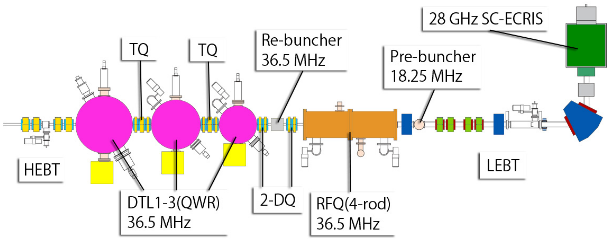

Figure 1: Schematic-layout view of the RILAC2.

A new additional linac injector called RILAC2 has been constructed at the RIKEN Nishina Center so that RIBF [1] experiments and synthesis of super-heavy element [2] can be carried out independently. As shown in Fig. 1, the RILAC2 consists of a 28-GHz superconducting ECR ion source (SC-ECRIS) [3], a low-energy beam transport (LEBT) [4] with a prebuncher, 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 that were placed between the rf resonators for the transverse focusing. Another rebuncher is required in 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 of the RILAC2 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 is placed in the existing AVF-cyclotron vault. This article mainly presents the details of the construction of linac part.

CONSTRUCTION OF RF CAVITIES

RFQ linac

In order to save the 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. Since the termination of its acceleration tests in the company, the RFQ linac has been maintained in the Advanced Research Center for Beam Science, Kyoto University for several years. In November 2007, the RFQ system was transferred to RIKEN through the courtesy of Kyoto University. The RFQ linac was able to accelerate heavy ions of $m/q = 16$ up to an energy of 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 modified so as to have a resonant frequency of 36.5 MHz, it becomes possible to accelerate ions of $m/q = 7$ to 100 keV/u and use for the RILAC2 without changing the vane electrodes. The basic properties of the RFQ linac after the conversion is listed in Table 1, that were obtained by scaling the original parameters.

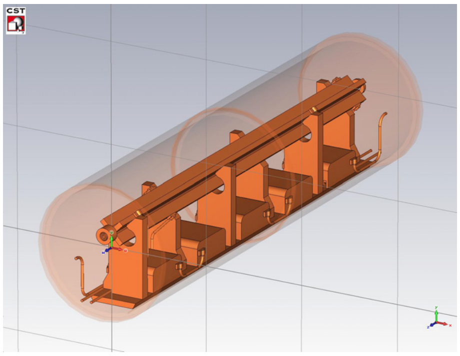

Figure 2: A RFQ model used in the MWS calculation.

For the modification of resonant frequency, we adopted to put a block tuner into every gap between the posts

---

* nari-yamada@riken.jp

Table 1: Basic properties of RFQ linac for the RILAC2.

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)

supporting the vane electrodes. The size of block was optimized by 3D electromagnetic calculation using the computer code Microwave Studio 2009 (MWS), and the rf measurement using cold-model test pieces made of aluminum. Figure 2 shows a RFQ model used in the MWS calculation. The block size was determined to be 240 mm×260 mm×114 mm. Required rf power to excite the intervane voltage of 42 kV was evaluated at 17.5 kW assuming 80% derating of the shunt impedance of 63 kΩ derived from the MWS calculation. The maximum output power 40 kW of final amplifier is enough to drive the modified RFQ resonator.

Heat load on the block was also evaluated by the MWS calculation to determine the amount of cooling required. Maximum current density on the block is 32 A/cm that is adequately small. The heat load added up the five blocks is about 2.1 kW for the rf input power of 17.5 kW. The size of cooling water channel for the block was decided so that the water flowed over 16 L/min, then the water temperature only rose at 2 °C. The cooling capacity is enough if the shunt impedance degrades furthermore.

The block was made of oxygen free copper and three types of block were prepared by the mounting position. Intricate cutting was applied to the block in order to reduce the weight of block in half. The blocks were mounted on a base with an rf contact of coil spring (bal seal). The water channel in each block were connected by copper pipes in series. Figure 3 describes the inner construct of RFQ linac after assembling the block and water pipe.

The low-power test and vacuum test were performed in April 2010 to conclude the result of modification. The resonant frequency successfully changed to 36.5 MHz and vacuum level reached 8×10^{-6} Pa with the cooling-water flow. A power amplifier, low-level circuits, and control system for the RFQ were installed and dummy-load test was performed in March 2010. The main body of the RFQ linac has been relocated in the AVF-cyclotron vault in May 2010 as shown in Fig. 4. Alignment, wire connection, and high power test will be performed in summer.

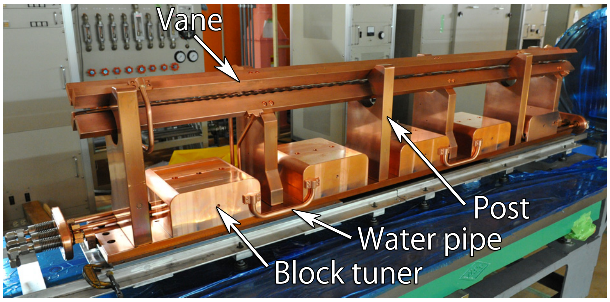

Figure 3: Inner construct of RFQ after modification.

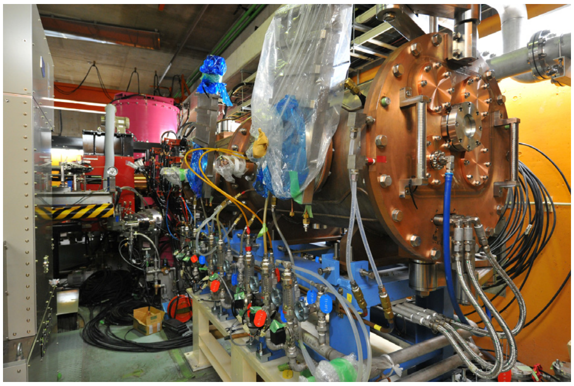

Figure 4: RFQ relocated in the AVF vault at 19 May, 2010. DTL can be seen behind the RFQ.

drift-tube linac

The structure of the DTL tanks is designed based on the quarter-wavelength coaxial-cavity resonator. In order to reduce the construction cost and the space occupied by the equipments, a direct coupling scheme was adopted for the rf amplifier and we modified a decelerator resonator developed for a Charge-State-Multiplier system [9] for the DTL3. Table 2 shows the main parameters of the DTL.

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 frequency was estimated by comparing the result of MWS calculation with the measurement results obtained using the DTL3 with a 50-Ω coupler. For example, the cavity length of the 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 $1000 + j0\ \Omega$ by using vacuum tube. The default position and radius of the coupler elec-

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

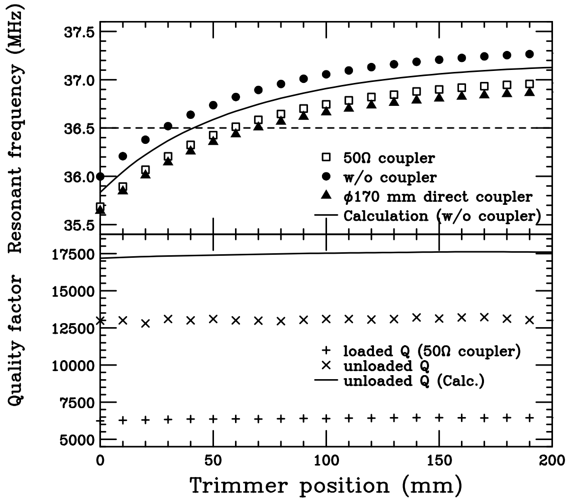

Figure 5: Frequency response of DTL1 as a function of trimmer position.

trode were determined by the MWS calculation using a frequency-domain solver. The length of the stem was optimized to reduce the asymmetry of the electric field distribution between the gaps. The distribution of rf-power dissipation in the cavity was also evaluated by the MWS calculation to determine the amount of cooling required.

Table 3: Measured rf characteristics of DTL.

	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

The construction of the DTL was completed in January 2010, and low-power and high-power tests were performed immediately. 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 results of 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 the DTL are listed in Table 3.

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 voltage was successfully achieved for every tank. The DTL were installed in the AVF-cyclotron vault in February 2010 and high-power test was performed again. Further conditioning and tests will be performed in summer.

Rebuncher

A cavity for the rebuncher between the RFQ and DTL1 is now in fabricating. The structure of the rebuncher is also based on the quarter-wavelength cavity resonator, which has four gaps. The total required voltage is 100 kV that is driven by a 1 kW transistor amplifier. The low-level circuit, power amplifier, and control system have already been ready. Another rebuncher in HEBT is now in design.

OUTLOOK

The SC-ECRIS will be moved to the new ion-source room in June 2010. The LEBT and HEBT will be installed in the AVF-cyclotron vault in this summer. Beam diagnosis and control system are also prepared in this summer. We plan to perform the beam commissioning of the RILAC2 in November 2010.

REFERENCES

[1] Y. Yano, Nucl. Instr. Meth. B 261 (2007) 1009.
[2] K. Morita et al., J. Phys. Soc. Jpn. 73 (2004) 2593.
[3] T. Nakagawa et al., Rev. Sci. Instrum. 79, 02A327 (2008).
[4] Y. Sato et al., Proc. of PASM6, FOBTA01, (2009) 801.
[5] Y. Yano, Proc. 13th Int. Cyclo. Conf., 102 (1992).
[6] O. Kamigaito et al., Proc. of PASJ3-LAM31, WP78, (2006) 502.
[7] H. Fujisawa, Nucl. Instrum. Meth. A 345 (1994) 23.
[8] H. Fujisawa et al., Proc. 7th Int. Symp. on Advanced Energy Research, Takasaki, Mar. 1996, p.436 (1996).
[9] O. Kamigaito et al., Rev. Sci. Instrum. 76, 013306 (2005).