DRIFT TUBE LINAC CAVITIES WITH SPACE-SAVING AMPLIFIER COUPLING OF NEW INJECTOR FOR RIKEN RI-BEAM FACTORY

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Abstract

Drift Tube Linac cavities for the new injector RILAC2 for RIKEN RI-Beam Factory were designed and constructed. The structure of the cavities was based on the quarter-wavelength resonator. A direct coupling scheme was adopted for the RF amplifier in order to save the construction cost and space for the equipments. A capacitive coupler was designed to match the input impedance to $\sim$ 700 Ω, which corresponds to the optimum output impedance of a tetrode. Design of the cavities and couplers will be described in detail.

NEW INJECTOR LINAC FOR RIBF

A schematic view of the new injector RILAC2 for RIKEN RI-Beam Factory [1] is shown in (Fig. 1). The injector is designed to accelerate very heavy ions such as $^{238}U^{35+}$ and $^{136}Xe^{20+}$ up to 680 keV/u for the injection to the RIKEN Ring Cyclotron. The injector consists of the 28 GHz superconducting ECR ion source [2, 3], a low energy beam transport line [4] including a pre-buncher, an RFQ linac based on the four-rod structure, a rebuncher, three drift tube linac (DTL) cavities, and a high energy beam transport line. Details of RILAC2 are described in Ref. [5].

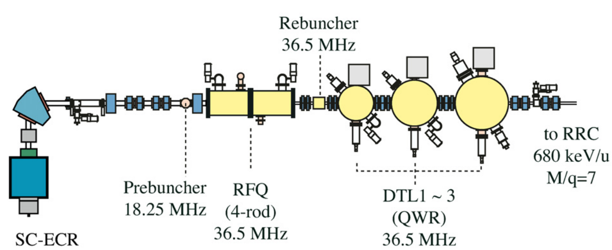

Figure 1: Schematic view of the new injector RILAC2.

DRIFT TUBE LINAC

The structure of DTL is based on the quarter-wavelength resonator. The inner diameter ranges from 0.8 to 1.3 m. The DTL cavities are designed to be operated at a fixed RF frequency of 36.5 MHz. The design parameters are shown in Table 1. The first two cavities (DTL1 and DTL2) are newly constructed, and the decelerator cavity developed for Charge-State-Multiplier system [6] (CSM-D1) is modified for the last cavity, DTL3. For the purpose to minimize an final RF amplifier and to save the construction cost, we adopted direct coupling scheme of the amplifier to the cavity. At first, the design and modification of DTL3 was performed.

Table 1: Design parameters of DTL cavities.

Resonator	DTL1	DTL2	DTL3
Frequency (MHz)	36.5	36.5	36.5
Duty(%)	100	100	100
Mass-to-charge ratio	7	7	7
Input energy (keV/u)	100	220	450
Output energy (keV/u)	220	450	680
Diameter (m)	0.8	1.1	1.3
Height (m)	1.320	1.429	1.890
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)	8.2	9.4	9.7
Synchronous phase (deg.)	-25	-25	-25
Input power (100% Q: kW)	5.1	13.4	15.4
Power amp. (Max: kW)	25	40	40

DTL3

A schematic view of DTL3 is shown in Fig. 2. The DTL3 has eleven drift tubes, non-50 Ω capacitive coupler, and trimmer (fine frequency tuner). The modification of CSM-D1 to DTL3 was performed as follows. Firstly, the original drift tubes and stems were replaced with those designed for DTL3. The CSM-D1 is frequency variable from 36 to 76.4 MHz through a movable shorting plate. In order to install the modified cavity in the AVF hall, it was necessary to reduce the cavity height, removing the shorting plate as well as its drive mechanism, cutting the inner and outer cylinder, and attaching a new fixed top plate with a flange which supports inner cylinder.

Secondly, a cavity height was determined considering a decreases in resonant frequency of the cavity due to a direct coupled amplifier. A coupling condition of this direct coupler were determined at the same time. For the purpose to estimate a coupling condition, measurements using a 50 Ω-coupler, originally attached to CSM-D1, were performed (Fig.3). The length of the coaxial line is 1700 mm. Two sizes of coupler plate (ϕ 115 and 210 mm) were used to measure resonant frequencies and impedances. In a case of a coupler plate of ϕ 115, an input impedance was matched to 50 Ω at a coupler position of 456.2 mm from the center of the cavity. When a coupler plate of ϕ 210 is

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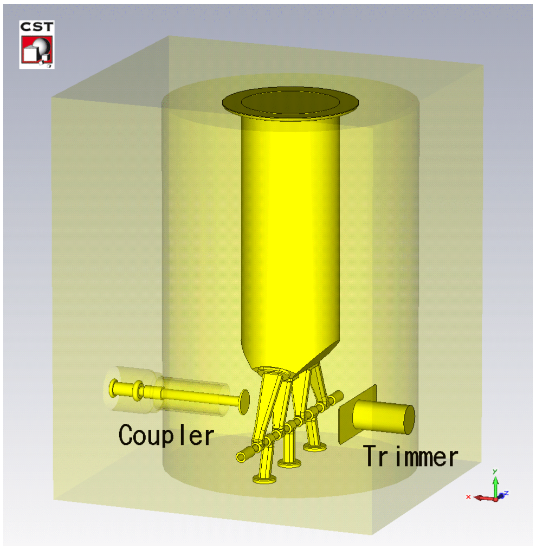

Figure 2: Schematic view of DTL3. It has eleven drift tubes, non-50 Ω capacitive coupler, and trimmer.

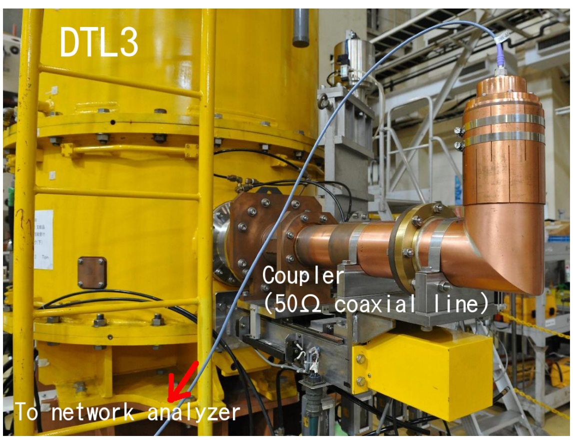

Figure 3: DTL3 with a 50 Ω coupler for the measurement of coupling conditions.

used, no matching condition for 50 Ω within a stroke of coupler.

A coupling condition for direct coupler was estimated by transforming the measured data to the case of a shorter 50 Ω coaxial line (529.8 mm) using f-matrix calculations, which matches a geometry of a direct coupler. From the operating analysis of the tetrode 4CW50000E, used in a final power amplifier, the optimum output impedance was estimated to be 700 Ω. According to the estimation, an impedance will be matched to 700 Ω at a coupler position of $\sim$ 300 mm, and the amount of decrease in frequency is -175 kHz $\sim$ -275 kHz (average -225 kHz).

On the other hand, the flange below the top plate increases a frequency by $+125$ kHz from the calculation of the Eigenmode solver of the CST Microwave Studio (MWS). Therefore, the target frequency was set to be 36.6 MHz ($= 36.5 + 0.225 - 0.125$). From the measured frequency changing a height of the shorting plate (Fig. 4), a cavity height was determined to be 1.890 m. The required cooling powers for each part of the cavity were determined according to thermal distributions from MWS calculation, on the condition of the maximum output of the amplifier.

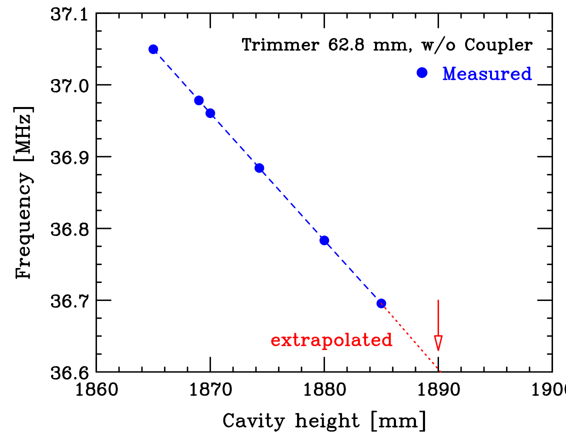

Figure 4: Resonant frequency of DTL3 measured by changing a height of the shorting plate.

The electric field distribution was measured by a perturbation method using a titanium oxide bead of ϕ 16 mm. The result is shown in Fig. 5. The deduced shunt impedance is 1.72 MΩ, which is 80% of the calculation by MWS. An average gap voltage 260 kV can be obtained when an input power of 19.6 kW is fed.

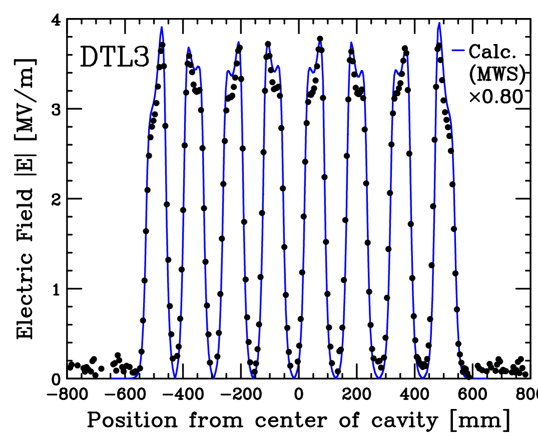

Figure 5: Electric field distribution of DTL3. The data are plotted as solid circles. A calculation result by MWS is shown as a solid line.

Then, a design of a capacitive coupler was performed. It consists of a non-50 Ω coaxial cylinder and a plate at the end of the inner cylinder. A position of the inner cylinder is manually adjustable within ± 20 mm to tune input impedance. In order to keep tolerance for input impedance tuning by changing the diameter of the plate, a coupler position was set to be 250 mm (50 mm shorter than determined above). This is because the maximum diameter of a coupler plate was limited to be less than 213 mm due to the inner size of flange. The diameter of a coupler plate was estimated by scaling to be less than 192 mm. On the other hand, calculations of MWS Frequency Domain solver predicted a diameter to be $\sim$ 130 mm. The actual diameter was determined through measurements to be to 135 mm. The MWS prediction was found to be fairly accurate. The frequency of the cavity was decreased by 288 kHz, which is close to the above prediction (Fig. 6).

A high power test was successfully performed to achieve the desired gap voltage in December 2009.

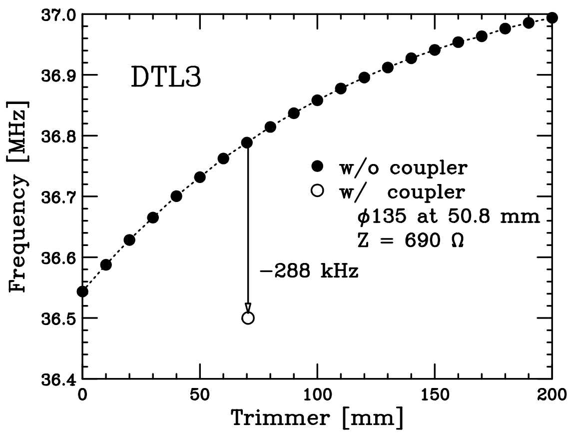

Figure 6: Resonant frequency of DTL3. The measured values without and with coupler are shown as closed and open circles, respectively. The decrease in frequency was 228 kHz.

DTL1 and 2

Based on the experience on DTL3, a design of DTL1 and 2 was performed only by MWS calculation. DTL1 and 2 have similar structures. Figure 7 shows a schematic view of DTL2. A length of stems was changed from 200 mm (original) to 150 mm in order to improve a deviation of gap voltages (Fig. 8). The deviations were improved from 8.6% to 6.4% for DTL1, and 6.4% to 4.6% for DTL2, respectively.

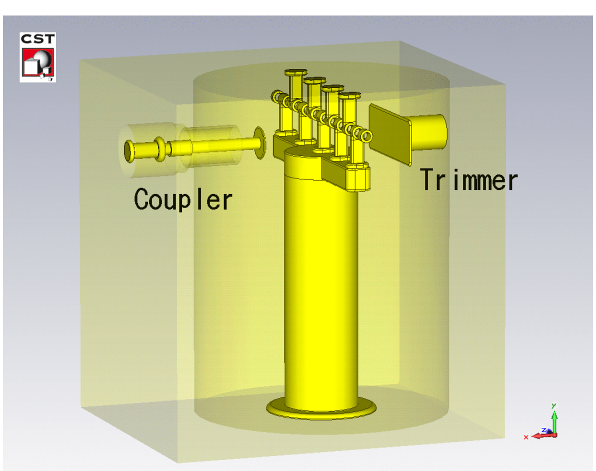

Figure 7: Schematic view of DTL2. It has nine drift tubes, non-50 Ω capacitive coupler, and trimmer.

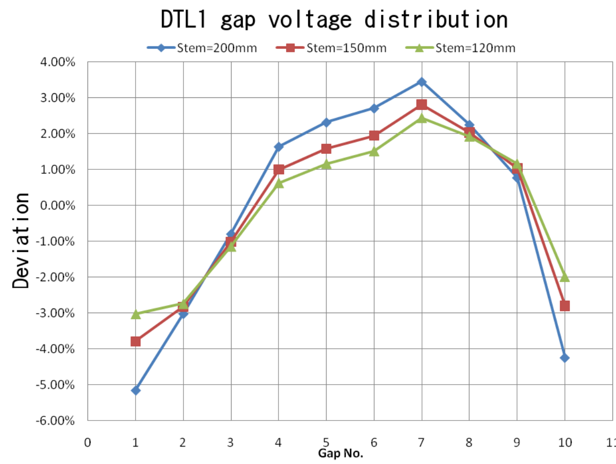

Figure 8: Gap voltage distribution of DTL1.

The cavity heights were determined, in a similar way of DTL3, taking into account a decrease in frequency. A target frequency was set to 36.725 MHz for both cavities, and the heights were determined to be 1.320 and 1.429 m for DTL1 and 2, respectively.

The couplers were designed as follows. At first, the coupler position where an impedance is matched to 50 Ω was determined for each cavity by calculating external Q-factor [7] and comparing it with unloaded Q. In this calculation, a coupler plate of ϕ 115 was used. Then, after a case of DTL3, these positions were scaled for a coupling of 700 Ω. The determination of the coupler diameters was performed in the same manner as DTL3.

High power tests of DTL1 and DTL2 were successfully performed in January 2010.

Perspective

All the DTL cavities were installed in the AVF hall in February 2010. A beam commissioning is scheduled in November 2010.

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