Design and construction of drift tube linac cavities for RIKEN RI Beam Factory†

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A recent intensity upgrade for uranium and xenon beams at the RIKEN RI Beam Factory required the construction of a new injector linac, RILAC2. The acceleration system consists of three drift tube linac cavities (DTL1, DTL2, and DTL3) that operate at $f_0 = 36.5$ MHz in CW mode. The cavity structure is based on a quarter-wavelength resonator, since its size is the smallest in this frequency range among the available cavity structures. The DTL3 was built by modifying the decelerating cavity of the Charge State Multiplier (CSM)[1–3]. Because specifications for the DTL3 were similar to those for the CSM, the design was performed carefully, comparing our simulation with the actual cavity to check the validity of the design procedure. Finally, the DTL3 was built by removing a movable shorting plate and relocating the drift tubes. The other two cavities were newly constructed.

The most significant characteristic of the design is the adoption of the direct coupling method for amplifiers connected to the cavity. The amplifier using a tetrode 4CW50,000E (Eimac) is directly connected to the cavity with a capacitive coupler. Load resistance for the tetrode, or an input impedance, was assumed to be $Z_0 = 700\ \Omega$ in the design. Direct coupling reduces the number of parts, such as the stub and output capacitor, thereby reducing size and construction cost. However, as the resonant frequency of the cavity changes significantly because of the capacitance of the tetrode, the cavity design cannot be independent of the amplifier design.

The design procedure we used comprises the following two steps. We first design the cavity itself without the coupler. We then design the combined cavity and amplifier system, determining the coupling capacitance and size of the cavity. It is helpful to evaluate load impedance of the tetrode using the lumped circuit model, but modeling the coupler as a lumped element neglects some effects; namely, the coupler occupies a certain volume inside the cavity, so capacitance between the outer conductor and the coupler is non-negligible, making it difficult to estimate the resonant frequency shift due to the coupler. Because of this frequency shift, geometric parameters such as cavity height must be carefully determined. we design the The cavity without a coupler was designed first using CST Microwave Studio 2009 (MWS)[4]. We optimized the shape of parts constituting the resonator, such as gaps between the drift tubes, stem geometry, and the inner diameters of the coaxial section, using the eigenmode solver of the MWS to obtain a high parallel shunt impedance considering height and radius limitations. We also calculated RF power loss distributions to determine the flow rate of cooling water for each part. When determining the frequency of the resonator, it is crucial to consider the effect of the coupler; attaching the coupler to the cavity can result in a frequency shift as large as −300 kHz. The target frequency f_0 of the cavity determined by considering the coupler effect can be realized by adjusting the cavity height. The measured frequency shift against a cavity height of DTL3 was approximately 18 kHz/mm. We must determine the cavity height within an accuracy of ±4 mm to realize a frequency within ±73 kHz around f_0.

RF simulations of the cavity including the coupler were performed next. The calculated frequency shift due to the coupler was −290 kHz. Further frequency shifts due to the tetrode were estimated with the aid of the frequency domain solver. The load impedance of the tetrode $Z'(f)$ was roughly estimated by adding a lumped capacitance of tetrode C_p in parallel as $1/Z'(f) = 1/Z(f) + j2\pi f C_p$. $Z'(f)$ takes a real value of 750 Ω, which was close to Z_0. The frequency shift due to the tetrode was estimated to be −19 kHz.

The cavity height of the DTL3 was finally determined by taking these frequency shifts into account. The calculated shift with the tetrode and coupler was −309 kHz, and the measured frequency shift was −288 kHz. The estimation agreed well with the measurement. We also estimated the coupling strength using the frequency domain solver. Input impedance was calculated with various diameters of the coupling disk. Combining the result with the frequency dependence of the impedance $Z'(f)$, we concluded that a plate disk with a diameter of approximately 130 mm would be suited to obtain the desirable load resistance of 700 Ω at f_0. Based on these estimations, the diameter of the coupling disk was adjusted by making iterative measurements with the real structure of the cavity, so that the desirable load resistance was successfully obtained.

References
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