

COLD MODEL CAVITY FOR 20-K CRYOCOOLED C-BAND PHOTOCATHODE RF GUN*

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Abstract

Following the results of the previous pillbox type cryo-cooled 2.6-cell C-band photocathode RF gun test cavity with an input coupler, a new cold model has been designed. In the new cavity, the corners of the pillbox cells have been modified to be rounded off in an optimum shape. The design of the input coupler has also been modified to improve the VSWR characteristics and the conversion efficiency from TE₁₀ to TM₀₁ mode. The cavity has been completed at KEK by ultraprecise machining and diffusion bonding techniques. The properties of the new model measured at room temperature have been in agreement with the design specifications based on the CST-Studio simulation.

INTRODUCTION

Development of a cryo-cooled 2.6-cell C-band photocathode RF electron gun has been advanced at Nihon University in collaboration with KEK [1]. In the previous model equipped with an input coupler, the frequency separation between the TM₀₁ π and the TM₀₁ π/2 modes in the pillbox type 2.6-cell cavity was only approximately 20 MHz as a result of the design consideration to achieve a high shunt impedance at 20 K. In order to expand the separation to more than 40 MHz, while avoiding a serious decrease in the shunt impedance, the original design of the pillbox structure has been modified to have a larger beam-hole radius and round-offs at the cylinder corners of each cell as shown in Fig. 1. The RF input coupler has also been improved from the previous design; the dimensions of the

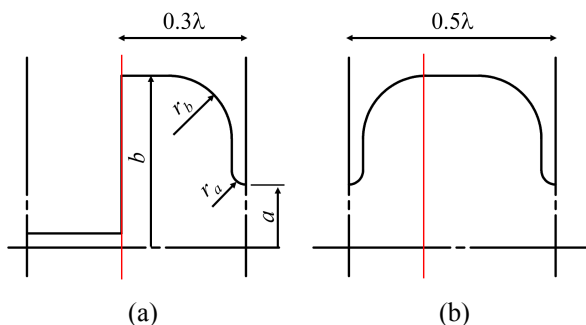


Figure 1: The parameters in the Superfish simulations of the π-mode accelerating cells with round-offs at the corners of the cylinder. (a): 0.6-cell structure, (b): full-cell structure.

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coupler have been optimized for low VSWR at the input port and high conversion efficiency from the rectangular TE₁₀ to the circular TM₀₁ mode [2].

The design simulations and the result of the room temperature measurements of the new cold model cavity are discussed in the following sections.

MODIFICATION OF THE CAVITY STRUCTURE

The behaviors of the shunt impedance, the unloaded *Q*-value and the mode separation between the TM₀₁ π/2 and the TM₀₁ π modes were calculated in advance with Superfish for a variety of combinations of the cell dimensions indicated in Fig. 1 [3, 4], where λ is the free space wavelength at 5712 MHz. The vertical solid red lines in Fig.1 show the borders between the cavity segments in diffusion bonding. As a cold model the left side of the 0.6-cell structure has a hole of 3.6 mm in diameter for bead-pull measurements on the center axis.

Adjusting the cylinder radius *b* to fix the π mode resonant frequency to 5712 MHz, each property was evaluated as a function of the beam hole radius *a* in the disk, the round-off radius *r_a* of the beam hole, and the round-off radius *r_b* at the cylinder corner, with the disk thickness being equivalent to twice the *r_a* value. As a result of the Superfish simulations the dimensions adopted in the new cavity design have been *a* = 8.0 mm, *r_a* = 1.8 mm, and *r_b* = 8.0 mm, respectively for every cell. The properties of the 2.6-cell cavity expected from the simulation are listed in Table 1, where a room-temperature surface resistance was assumed in the calculation. The separation from the TM₀₁ π/2 mode has been expanded to 46 MHz, while the shunt impedance has not been reduced as compared to the previous pillbox cavity.

Table 1: Properties of New 2.6-cell Cavity by the Superfish Simulation

π-mode resonant frequency	5712 MHz
Unloaded <i>Q</i> -value	13000*
Shunt impedance	113* MΩ/m
Separation from π/2 mode	46 MHz

* Estimated from the surface resistance at room temperature.

CST-STUDIO SIMULATIONS

Based on the dimensions of the accelerating cells determined by the Superfish calculations, the fundamental design of the accelerating structure was completed. Then there were two conditions that should be satisfied in the

final RF structure; the coupling coefficient between the 2.6-cell accelerating structure and the circular waveguide of the input coupler should be adjusted to approximately 20, and the TM_{01} mode resonances excited in the circular waveguide should be separated from the π -mode accelerating frequency. In order to satisfy these conditions, detailed design calculations were performed with CST-studio [5] in two steps as follows. A copper surface resistance of $3.541 \times 10^{-3} \Omega$ at 20 K and 5712 MHz has been assumed in the simulations.

Simulations for the Coupling Adjustment

In the new model the input coupler has been designed independently of the 2.6-cell structure. The VSWR of the coupler has been adjusted to 1.01 with the conversion efficiency of 99.6 % from the rectangular TE_{10} to the circular TM_{01} mode, which means that the coupler is approximately regarded as a single waveguide [2]. In this case the coupling coefficient between the circular waveguide and the 2.6-cell structure can be considered equivalent to the apparent coupling coefficient measured at the input port of the rectangular waveguide.

In the first step, simulations were performed to adjust the coupling between the 2.6-cell accelerating structure and the circular waveguide as shown in Fig. 2. The right side end of the waveguide in Fig. 2 was set as the RF input port. The VSWR and the resonant frequency were adjusted by the dimensions of the cylinder radius in the last full cell and the radius and thickness of the coupling iris. An example of the deduced reflection spectrum $|S_{11}|$ at the input port

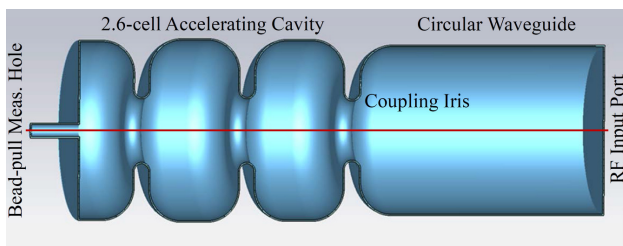


Figure 2: Cutaway view of the simulation model for the adjustment of the coupling between the 2.6-cell cavity and the circular waveguide.

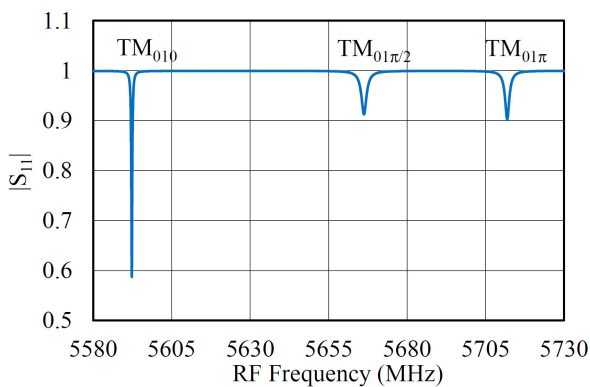


Figure 3: The behavior of the reflection coefficient at the input port of the circular waveguide.

is shown in Fig. 3, where the separation between the $\pi/2$ and the π modes is approximately 46 MHz in agreement with the Superfish simulation, the lowest VSWR of the π mode being 19.7 at 5712 MHz.

Simulations of the Entire Structure

In the second step, simulations of the entire structure were performed using the optimized 2.6-cell cavity dimensions in the first step. Figure 4 shows the full inner surface of the structure in the model of the simulation. The result showed little change in the resonant frequency and the VSWR of the TM_{01} π mode from the simulation in the first step. This confirms that the coupler can be regarded as a single waveguide at around the accelerating frequency.

As shown in Fig. 5, however, additional resonances are found in the $|S_{11}|$ spectrum of the simulation of the entire structure. From the field distribution on the center axis, these resonances were identified as the TM_{01} modes excited in the circular waveguide.

The additional modes were separated from the accelerating mode by modifying the radius and the length of the circular waveguide. Due to the need of these modifications, iterations of the above two steps and the calculation of the coupler were made several times before the final dimensions were determined. The length of the circular wave was determined by another condition that the distance between

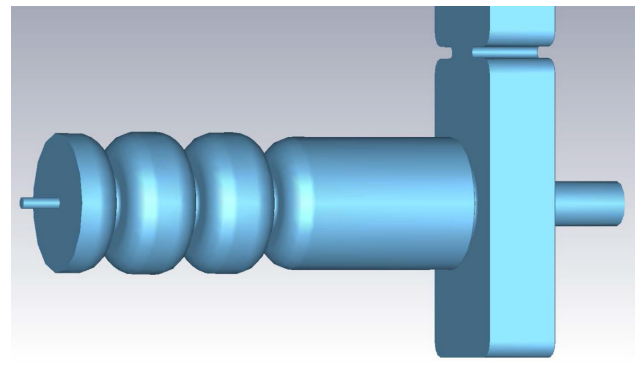


Figure 4: The simulation model of the entire structure of the RF gun cavity.

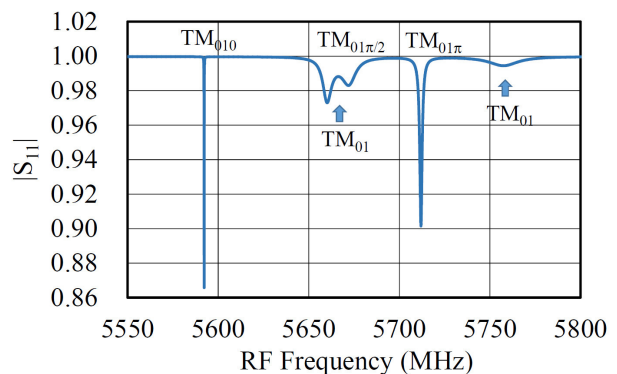


Figure 5: The reflection coefficients at the input port of the rectangular waveguide in the simulation of the entire structure.

the midpoints of the last full cell and the rectangular waveguide was chosen to be 1.73λ so that the energy gain of the electron bunch in the rectangular waveguide can be canceled. The $|S_{11}|$ spectrum in Fig. 5 is the result of the simulation after the iteration. The properties of the RF gun cavity expected from the CST-Studio simulation are listed in Table 2.

Table 2: Properties of New 2.6-cell Cavity at 23.5 °C and 20 K by the CST-Studio Simulation

Cavity temperature	23.5 °C	20 K
Resonant frequency	5692.79	5712.02 MHz
Unloaded Q	13310	73029
Loaded Q	2945	3597
Coupling coefficient	3.52	19.30

CAVITY MEASUREMENTS AT ROOM TEMPERATURE

The cross sectional drawing for machining of the RF gun cavity is shown in Fig. 6. The cavity was completed at KEK with ultraprecise machining and diffusion bonding techniques. Each accelerating cell has tuners at the cylinder wall every 90° around the cavity axis. The thin off-axis hole in the left-side end plate is for a pickup antenna. Figure 7 shows the photograph of the completed cavity.

The properties of the cavity have been measured at room temperature using a network analyzer E5071C (Agilent Technologies). The network calibration has been carried

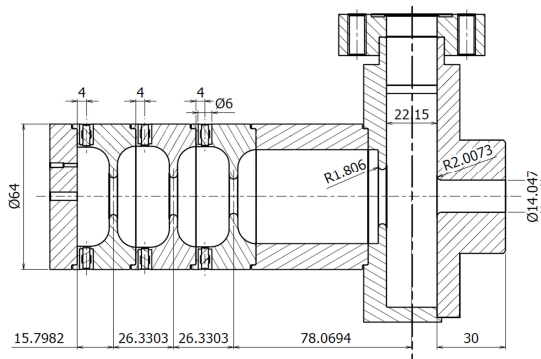


Figure 6: Cross sectional drawing of the cavity. The dimensions indicated are those at 23.5 °C.

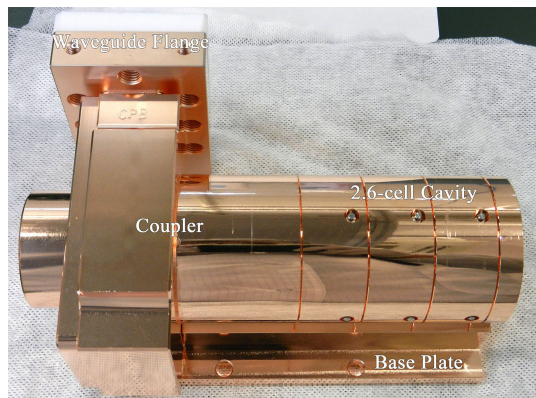


Figure 7: Photograph of the cold model cavity.

out at the waveguide flange. The $|S_{11}|$ spectra measured at a wide frequency range and around the π mode resonance are shown in Figs. 8 (a) and 8 (b). The resonant frequency at 23.5 °C in vacuum and the other properties are in good agreement with the CST-Studio simulation as compared in Table 3. The shunt impedance of 113 M Ω /m has been deduced from the bead-pull measurement of the electric field on the cavity axis, which is also in good agreement with the result of the Superfish simulation.

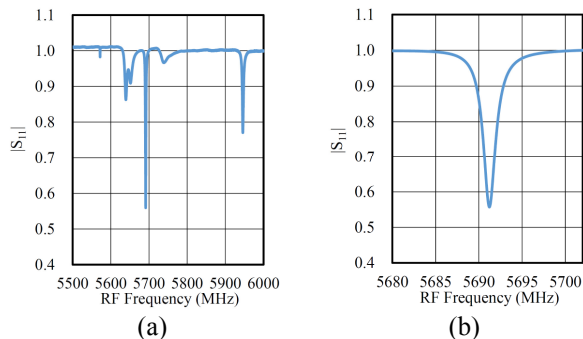


Figure 8: $|S_{11}|$ spectra measured at (a) a wide range, and (b) around the π mode resonance.

Table 3: Comparison of the RF Properties Between the Measurement and the CST-Studio Simulation at 23.5 °C

	Measurement	Simulation
Resonant frequency	5692.84	5692.79 MHz
Unloaded Q	13200	13310
Loaded Q	2920	2945
Coupling coefficient	3.52	3.52

CONCLUSIONS

Based on the simulations by Superfish and CST-Studio, a new cold model of a C-band cryocooled photocathode RF gun has been fabricated. The RF properties measured at room temperature have been in good agreement with the simulations. A low-temperature test with the RF through a low thermal flux waveguide is under consideration.

REFERENCES

- [1] T. Tanaka *et al.*, “Basic design of a 20K C-band 2.6-cell photocathode RF gun”, in *Proc. 5th Int. Particle Accelerator Conf. (IPAC’14)*, Dresden, Germany, Jun. 2014, paper MOPRI030, pp. 658-660.
- [2] K. Takatsuka *et al.*, “Optimization of C-band RF input coupler as a mode converter for 20-K cryocooled photocathode RF gun”, presented at the 7th Int. Particle Accelerator Conf. (IPAC’16), Busan, Korea, May 2016, paper WEPMY038, this conference.
- [3] J. H. Billen and L. M. Young, LA-UR-96-1834 (2006), Los Alamos National Laboratory; http://laacg.lanl.gov/laacg/services/download_sf.phtml
- [4] K. Nakao *et al.*, “Simulation of electromagnetic field for 20K cooled photocathode RF gun”, in *Proc. 12th Annual Meeting of Particle Accelerator Society of Japan*, Tsuruga, Japan, Aug. 2015, paper WEP057, pp. 596-599.
- [5] CST Studio Suite™, CST AG, Germany, <http://www.cst.com>