ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWA015

RF INPUT COUPLER FOR 20 K COOLED C-BAND 2.6-CELL PHOTOCATHODE RF GUN*

T. Tanaka#, M. Inagaki, K. Nakao, K. Nogami, T. Sakai, LEBRA, Nihon University, Funabashi, Japan
T. Shintomi†, ARISH, Nihon University, Tokyo, Japan
M. Fukuda, T. Takatomi, J. Urakawa, M. Yoshida, KEK, Tsukuba, Japan
D. Satoh, Tokyo Institute of Technology, Tokyo, Japan

Abstract

Based on the low-power and low-temperature RF properties of the basic 2.6-cell cavity, a new cavity with the RF input coupler was fabricated in KEK. The coupler consists of a cylindrical waveguide and a mode converter from rectangular TE_{10} to cylindrical TM_{01} mode with both the elements having been located on the accelerating cavity central axis. The structure and the dimensions of the coupler have been designed using the 3-D simulation code CST Studio. The 2.6-cell structure has been modified from the previous test cavity. The RF properties of the cylindrical part of the cavity, measured without the mode converter before finishing, were in good agreement with the result of the CST Studio calculation. However, the behaviours of the $|S_{11}|$ and the field distributions in the completed cavity have to be investigated further because of possible non-axisymmetric field in the cylindrical waveguide.

INTRODUCTION

For the future use in the compact linac-driven X-ray source at KEK [1], a cryo-cooled C-band cavity for a photocathode RF gun has been under development. The RF properties measured on the basic 2.6-cell test cavity have shown that the π-mode accelerating frequency and the unloaded Q-value at around 20 K were well predicted from the room-temperature properties [2-4]. As the next stage of the development, a new cavity equipped with an input coupler has been designed. In the new design, a coaxial coupler which had originally been assumed was not employed because of possible difficulties in the cooling of the thin central electrode. Instead, a cylindrical coupler has been designed, which consists of a cylindrical waveguide and a mode converter that converts the rectangular TE_{10} mode to the cylindrical TM_{01} mode with both of them located on the accelerating cavity central axis. The basic design of the accelerating cells has not been greatly changed from that in the first test cavity. However, the design of the third disk located next to the coupling structure, has been changed so that it has the same shape as the other disks.

The cavity has been designed using the simulation codes SUPERFISH [5] and CST Studio [6]. SUPERFISH has been used primarily for the calculation of the resonant frequency of the cylindrical parts, while the 3-D code CST Studio has been necessary for the calculation of the RF properties of the whole structure including the coupler.

The low-power test cavity was fabricated in KEK with ultra-precision machining. The results of the design simulations and the RF property measurements at room temperature are presented in this paper.

DESIGN AND SIMULATIONS

Choice of Cylindrical Coupler

From the specification of the 20-K cryo-cooled photocathode RF gun cavity, the coupling coefficient of the RF input coupler has been required to be as large as about 20 [2]. The coupler was not included in the basic 2.6-cell test cavity, just the RF cutoff cylinder being reserved temporarily as a part of the outer wall of a coaxial coupler. For a high power operation of the cavity, an efficient heat removal structure is required of the thin inner electrode of the coaxial coupler, which seems difficult to realize in the C-band low-temperature cavity.

In order to avoid the heat removal problem with the coaxial coupler, a cylindrical coupler that was employed in an X-band photocathode RF gun [7] has been designed. The cylindrical coupler has the same advantage with a coaxial coupler that, though modifications are required in the method of the cavity cooling, it is possible to locate a focusing device such as a solenoid coil centered at any position on the cavity axis.

The cross-sectional view of the cavity for the low-power test is shown in Fig. 1. In the fabrication of the cavity, high purity 6N8 copper was used for the accelerating cells and the neighboring long portion of the cylindrical waveguide.

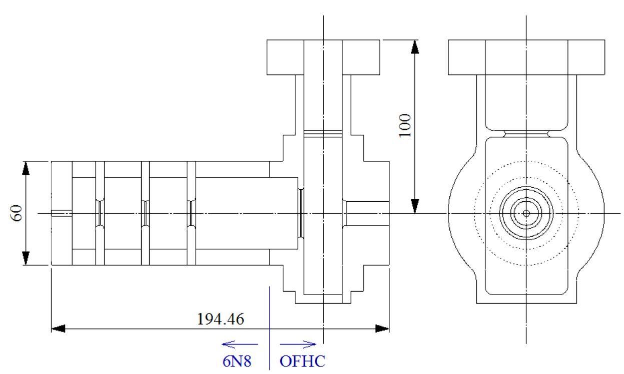

Figure 1: Cross-sectional view of the low power test cavity with the cylindrical input coupler. The hole in the left-side end plate is for the bead-pull measurement of the field.

*Work supported by the Photon and Quantum Basic Research Coordinated Development Program of the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT).
†Present affiliation: KEK, Tsukuba, Japan.
tanaka@lebra.nihon-u.ac.jp

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWA015

Considering the cost of purchasing a large block of 6N8 copper, however, the other cavity parts were made of the usual OFHC copper. The stainless-steel MO-type waveguide flange was coated with copper. The boundary between the two copper materials is indicated in Fig. 1, where the left side of the boundary is 6N8 and the right side is OFHC.

Cavity Materials

In the design calculation of the cavity, the surface resistance of 6N8 copper at 20 K has been calculated from the theory of the anomalous skin effect by assuming that the RRR of 6N8 copper is 3000, which is the same as the case in the previous simulations on the basic test cavity [4,8]. On the other hand, the normal room-temperature value has been used for the surface resistance of OFHC copper. Thanks to the low power loss compared to that in the accelerating cells, the employment of OFHC copper in place of 6N8 copper for the coupler has been expected to cause only a small difference. This has been confirmed by the comparison of the RF properties by the simulations with CST Studio.

Design of the Cylindrical Structure

The combination of the 2.6-cell pillbox structure and the cylindrical waveguide can be regarded as a cylindrical resonant cavity coupled to the rectangular waveguide through the circular iris. The cylindrical cavity structure has been designed with the SUPERFISH simulation separately from the rectangular part.

In the design calculation, the radius of the cylindrical waveguide was chosen to be the same as which in the second full-cell structure. The length of the cylindrical waveguide was chosen to be $1.25\lambda_0$, where λ_0 is the free space wavelength of the 5712 MHz RF.

The resultant cavity dimensions were used as the initial parameters in the simulation for the whole structure.

Design of the Mode Converter

In the calculation using CST Studio, the RF input boundary (S_{11} port) has been located near the position of the flange. The iris in the rectangular waveguide has been located at a height nearly $3/2\lambda_g$ from the bottom end plate in Fig. 1, where λ_g (= 62.937 mm) is the wavelength of the 5712MHz TE_{10} mode RF in the R48 waveguide.

The gap and the position of the rectangular iris, the radius of the circular iris, and the radius of the cylindrical waveguide were parameterized for the calculation of the RF transmission from the rectangular waveguide to the cylindrical waveguide. For the calculation of the transmission, the 2.6-cell cavity structure was replaced with the extended cylindrical waveguide so that the reflection coefficient of the traveling wave in the mode converter was estimated. By optimizing the above parameters with the CST Studio calculation, the VSWR was minimized to 1.03 at 5712MHz. The frequency at which the VSWR is minimized was dependent primarily on the radius of the cylindrical waveguide. Thus, the optimum radius obtained from the calculation has been assigned to the design value of the cylindrical waveguide.

Result of Design Simulation

Combining the results of the designs carried out separately for the cylindrical structure and the mode converter, the VSWR and the π-mode resonant frequency have been adjusted to the design specifications of the RF gun i.e., $\beta \sim 20$ and 5712 MHz, respectively by optimizing the radii of the second full-cell and the circular iris. Figure 2 shows the electric field distribution on the cavity axis, which has been obtained from the calculation using CST Studio. The resultant VSWR has been 19.85. The length of the cylindrical waveguide has been modified by -2.5 mm from 1.25 λ_0 in order to expand the separation between the TM_{01} π-mode and the TE_{112} mode frequencies.

The unloaded Q-value of approximately 64600 has been estimated from the analysis of the Smith chart. The simulation using the room-temperature surface resistance for the same configuration has resulted in the unloaded Q-value of 11500 and the VSWR of 3.61.

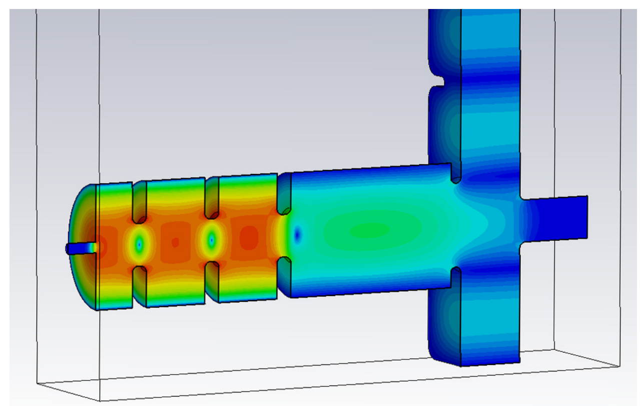

Figure 2: Example of the electric field distribution in the test cavity calculated using CST Studio. In the calculation shown here, the surface resistance for 6N8 copper at 20 K was assumed for all the surface.

LOW POWER MEASUREMENT AT ROOM TEMPERATURE

Based on the dimensions determined by the design calculations, the low power test cavity with the input coupler has been fabricated in KEK. The left-side parts made of 6N8 copper in Fig. 1 were assembled by diffusion bonding. However, the other parts made of OFHC copper were assembled by brazing due to difficulties in diffusion bonding of the complicated structure around the mode converter. These parts and the flange were finally assembled together by brazing. The results of the low power RF test at room temperature are described below.

Preliminary Test of the Cylindrical Structure

Before diffusion bonding, the RF properties of the 2.6-cell accelerating structure in combination with the cylindrical waveguide were measured. In the experiment a

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWA015

cylindrical waveguide with half the entire design length and a shorting plate were set in place of the waveguide for actual use. As seen in Table 1, the π-mode frequency of this configuration converted to 23.5 °C in vacuum is in agreement with the result of the CST Studio calculation rather than the SUPERFISH calculation.

Table 1: The π-mode Frequency of the Cavity Consisted of the 2.6 Cells and the Cylindrical Waveguide

Measurement	5692.38 MHz
SUPERFISH calculation	5693.08 MHz
CST Studio calculation	5692.46 MHz

Result of Field and $|S_{11}|$ Measurements

Figure 3 shows the experimental setup for the measurement of the RF field by the bead-pull method. The low power RF has been fed into the rectangular waveguide through the coaxial-to-waveguide mode converter. The result of the bead-pull measurement of the π-mode resonance is shown in Fig. 4 with closed circles. The solid curve in Fig. 4 is the electric field amplitude obtained by the CST Studio calculation, which is not consistent with the experimental result in the region of the cylindrical waveguide. The positive shift of the resonant frequency which is corresponding to the negative point seen in the cylindrical waveguide in Fig. 4 is due to the dominant non-

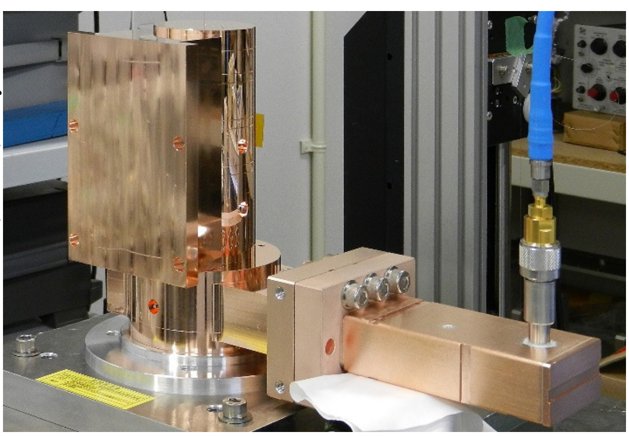

Figure 3: The test cavity mounted on the bead-pull measurement system.

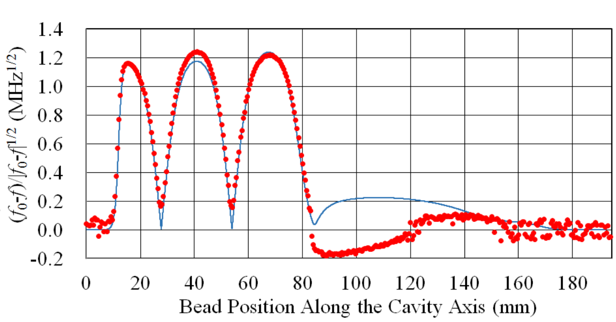

Figure 4: The result of the bead-pull measurement of the π-mode field. The solid curve is the electric field amplitude by the calculation using CST Studio.

axisymmetric magnetic field that was transmitted through the mode converter in the coupler.

The $|S_{11}|$ plot is shown in Fig. 5. The red curve shows the return loss and the TE_{112} mode resonance in the cylindrical waveguide, which has been obtained by detuning the 2.6-cell accelerating structure with insertion of a thin copper pipe from the left side in Fig. 1. The result suggests possibilities of problems attributed to the measurement method or the calibration of the measuring system. The above result has been based on the calibration of the network analyzer at the coaxial-to-waveguide converter input port. Measurement of $|S_{11}|$ with the system calibrated at the waveguide flange is being prepared for further investigation of the properties of the coupler.

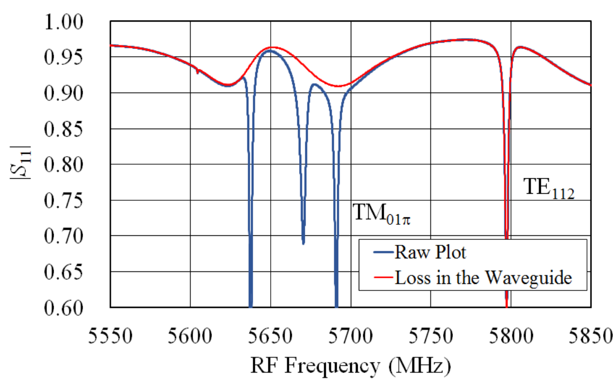

Figure 5: Plot of the $|S_{11}|$ distribution. The red curve shows the return loss and the TE_{112} mode resonance in the cylindrical waveguide, which was observed by detuning the 2.6-cell accelerating structure.

CONCLUSION

As the second phase of the development of a cryo-cooled photocathode RF gun, the low-power test cavity with the cylindrical RF input coupler was fabricated in KEK. The RF properties of the completed cavity have been measured at room temperature, which have suggested that the non-axisymmetric field was transmitted considerably into the cylindrical waveguide of the coupler. The return loss observed in the measurement of $|S_{11}|$ in a wide frequency range is under investigation in terms of the network analyzer system calibration. The RF properties at 20 K will be reported elsewhere.

REFERENCES

[1] M. Fukuda et al., NA-PAC13, Pasadena, USA (2013) p. 589; http://accelconf.web.cern.ch/AccelConf/PAC2013/papers/tupma01.pdf
[2] T. Tanaka et al., Proceedings of IPAC'14, Dresden, Germany (2014) p. 658; http://accelconf.web.cern.ch/AccelConf/IPAC2014/papers/mopri030.pdf
[3] T. Sakai et al., Proceedings of LINAC2014, Geneva, Switzerland (2014) p. 671; http://accelconf.web.cern.ch/AccelConf/LINAC2014/papers/tupp106.pdf
[4] T. Tanaka et al., WEPWA014, these proceedings, IPAC'15, Richmond, USA (2015).

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWA015

[5] 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
[6] CST Studio Suite™, CST AG, Germany, http://www.cst.com
[7] Y. Taniguchi et al., Proceeding of the 5th Annual Meeting of Particle Accelerator Society of Japan, Higashihiroshima, Japan (2008) p. 954; http://www.pasj.jp/web_publish/pasj5_lam33/contents/PDF/TP/TP115.pdf
[8] E. H. Reuter and E. H. Sondheimer, Proc. the Royal Society of London A, Mathematical and Physical Sciences 195, 1042 (1948) p. 336.