COLD TESTING OF A COAXIAL RF CAVITY FOR THERMIONIC TRIODE RF GUN

Masato Takasaki#, Kai Masuda, Keiichi Ishida, Naoki Kimura, Satoshi Ueda, Kyouhei Yoshida, Ryota Kinjo, Yong-Woon Choi, Mahmoud.A.Bakr, Taro Sonobe, Toshiteru Kii, Kazunobu Nagasaki, Hideaki Ohgaki
Institute of Advanced Energy, Kyoto University

Abstract

A triode RF gun has been developed with the aim of drastically reducing back-streaming electrons at the thermionic cathode. The thermionic triode RF gun features a new design for the RF coupler and a coaxial RF cavity where the length of the first cell is much shorter than the RF wavelength. In this work we construct a prototype coaxial RF cavity and perform a test in the absence of cathode heating and electron beam production (`cold test') to confirm the operation of this design. Experimental measurements include important quantities such as the coupling coefficient β and unloaded quality factor Q_0, as well as the bandwidth for which the cavity voltage $V_c > 30$ kV. Results show that although β and Q_0 are smaller than designed values, the new RF coupler demonstrates the desired resonance behavior with $V_c > 30$ kV achieved for a bandwidth 11.5 MHz.

INTRODUCTION

Until recently, we have used a 4.5 cell thermionic RF gun for the injector of the MIR-FEL facility (KU-FEL: Kyoto University Free Electron Laser) at the Institute of Advanced Energy, Kyoto University. Fig. 1(a) [1] shows that in this conventional design, electrons are extracted by the first cell acceleration phase containing the thermionic cathode. The simulation results of Fig. 2(a)[2] demonstrate an important drawback of this design called the back-bombardment effect, which is that some of the first-cell electrons return and strike the cathode due to the deceleration phase. This heats the cathode and increases the beam emission. Since RF power is constant, the macro-pulse duration becomes limited.

In order to reduce the back-bombardment, we have designed an RF gun that includes a coaxial RF cavity prior to the first cell, with the length of this cavity much shorter than the RF wavelength. The design is shown in Fig. 1(b) and is termed the `thermionic triode RF gun.'[3] From the simulation results of Fig. 2(b), here the back-bombardment should be reduced by more than 80% without loss of beam brightness. Space limitations in the FEL experiment also necessitate the use of a non-standard, previously un-proven design for the RF coupler. Here the RF is fed from behind the coaxial RF cavity, as will be presented in this paper.

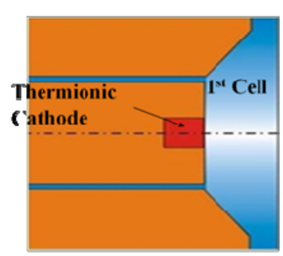
In this paper we perform a cold test on a newly constructed prototype of the RF cavity. For the MIR-FEL experiment the target resonance frequency is that of the accelerator tube, 2856 MHz. Rather than setting the input RF tuner to adjust the resonance frequency, here we seek to obtain a coupling coefficient β that maximizes the resonance bandwidth. Our primary aims are thus to confirm the operation of the RF coupler, and to obtain experimental values for the coupling coefficient β, the unloaded quality factor Q_0 and the bandwidth for which cavity voltage $V_c > 30$ kV.

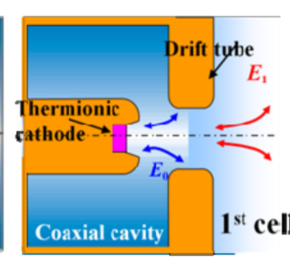
PRINCIPLES OF THE THERMIONIC TRIODE RF GUN

As shown in Fig. 1, the difference between the conventional and triode thermionic RF gun is in the vicinity of the thermionic cathode only.

In particular for the triode RF gun, the coaxial RF cavity induces an electric field E_0 that is independent of the first cell electric field E_1. By adjusting the phase and amplitude of E_0, electrons can be extracted by acceleration phase as in Fig. 2, with the back-bombardment effect decreased.

A cutoff between the first cell and the coaxial RF cavity is achieved by using a cylindrical aperture called the `drift tube', which contains a low electric field. Electrons extracted by E_0 attain tens of keV energies, pass bunched through the drift tube, and afterwards are accelerated to a few MeV in the acceleration tube.

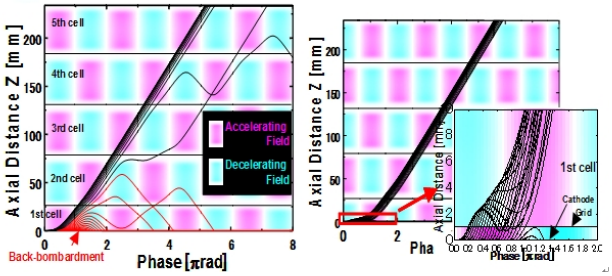




(a) (b)

Figure 1: Schematics of RF cavity structures in the vicinity of the thermionic cathode in (a) a conventional type, and (b) the triode-type RF gun.

tkskmst@iae.kyoto-u.ac.jp



(a) (b) (c)

Figure 2: Behavior of electrons vs phase shift in (a) a conventional type and (b) the triode type and (c) close up figure of the triode type RF gun.

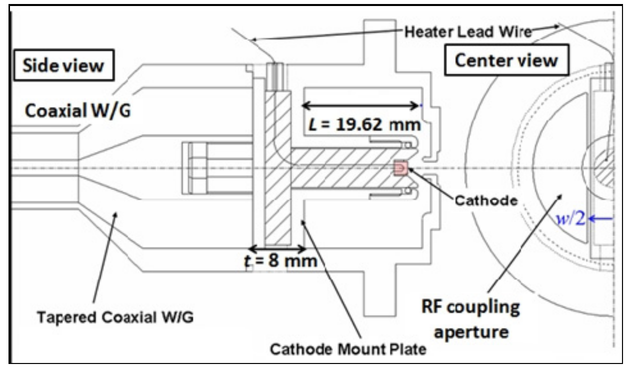
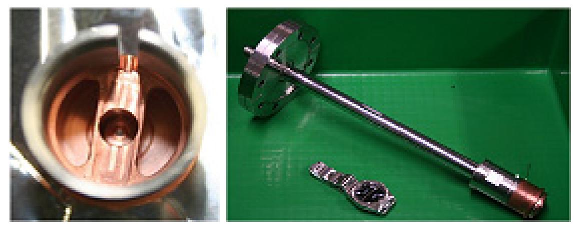


Figure 3: Cross sectional views of coaxial RF cavity with thermionic cathode.



(b)

Figure 4: (a) New type RF coupler and (b) triode RF gun.

DESIGN OF COAXIAL RF CAVITY

The thermionic triode RF gun uses a coaxial RF cavity with cross-sectional schematics shown in Fig. 3, and incorporates the new RF coupler shown in Fig. 4. We show the desired operation parameters in Table 1.

The coaxial RF cavity and coaxial wave-guide are concentric with the inner conductor supported by a cathode mount plate. This plate is also used as the feed through for the cathode heater lead wire. RF power is supplied through the coaxial waveguide from the left side of Fig. 3, passing a taper tube and the two half-moon-shaped apertures of the new RF coupler [4]. As the triode structure will be installed in the present 4.5 cell thermionic RF gun, we also require it to be compact. As a result, our design does not use a thermal modulation mechanism for adjusting resonance frequency, or a cooling mechanism for rejecting heat. Instead, it operates on the principle that it may achieve a cooling effect by touching the wall of the RF gun.

Our target of $\beta = 20$ determines the cavity length L and cathode mount plate thickness t in Fig. 3 through the use of a 3-dimensional analysis code (MW Studio). Here we determine input power of 40 kW which is the limit of coaxial cable capacity, with a cavity voltage $V_c = 30$ kV the typical working value arising from simulation [2].

Our input connector and coaxial waveguide is made from stainless steel, the coaxial RF cavity from free oxygen copper and the thermionic cathode from tungsten.

COLD TEST RESULTS AND DISCUSSION

Connecting a coaxial cable to the coaxial waveguide by using an input connector, we fed in RF power and measured the reflection ratio P_{ref}/P_{in} including both the coaxial RF cavity and the coaxial waveguide (Fig. 5, black data points). Here P_{ref}/P_{in} does not reach 1.0 even

Table 1: Desired parameters for triode RF gun

Resonance frequency [MHz]	2856
Unloaded quality factor (Q_0 value)	4000
Q value	200
Coupling coefficient β	20

outside of resonance frequency. This means that the coaxial RF cavity and waveguide exhibits some loss other than from the RF cavity. In order to determine the cause, we measured the reflection ratio with two half-moon–shaped apertures closed (Fig. 5, red data points), so as to exclude the contribution from the RF cavity. Here we were able to identify a loss in the waveguide section between input connector and cathode mount plate. We think this loss originates from resonance in the waveguide section possible because of high reflection at the input connector. We want to know the reflection ratio of the coaxial RF cavity only, and so we calculated the corrected reflection ratio (Fig. 6) by using

$$y_3 = (1 - y_1) + y_2 \qquad (1)$$

where y_1 is the reflection ratio of the waveguide section, y_2 is the reflection ratio for the combined coaxial cavity and waveguide sections, and y_3 is the corrected reflection ratio.

For the corrected reflection ratios, we apply a non-linear fit as shown in Fig. 6. From this we calculate the parameters of Table 2, including β and Q_0.

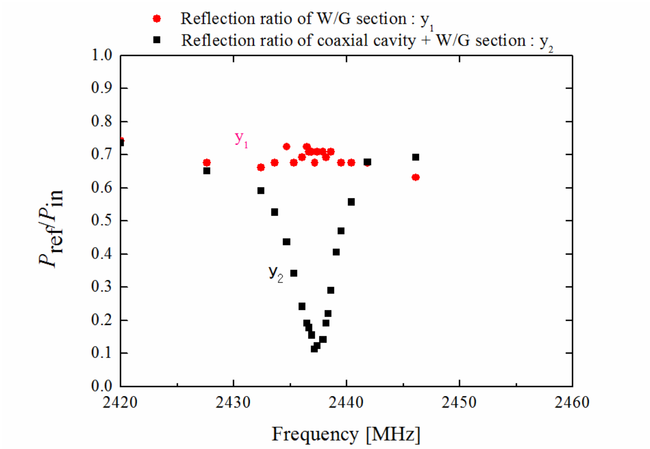


Figure 5: Ratio of output-to-input RF power for coaxial RF cavity & waveguide section.

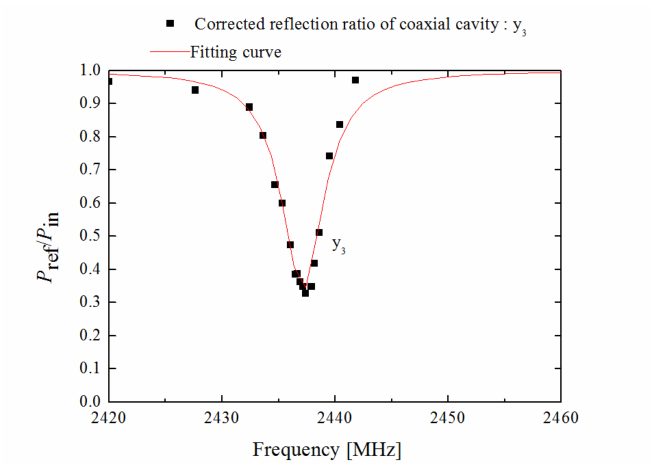


Figure 6: Corrected reflection power for coaxial RF cavity.

Table 2: Cold test results

Resonance frequency [MHz]	2437
Unloaded quality factor (Q_0 value)	2600
Q value	650
Coupling coefficient β	3

Using these parameters we used an analysis code (KUEMS) [5] to calculate the dependence of resonance frequency on cavity length in Fig. 3 assuming two-dimensional cylindrical symmetry. The experimental resonance frequency corresponds to an 'effective' cavity length L_{eff} = 23.2 mm, which is 3.63 mm longer than the designed cavity length. That is, in Fig. 3 the edge of the resonance mode is 3.63 mm left of the right hand side of the cathode mount plate. With t = 8mm, this point is near the center of cathode mount plate. The coaxial RF cavity is expected to induce a resonance mode that is similar to axially symmetric modes because the experimental frequency is close to simulation result value of L_{eff}. This shows that the new RF coupler and cavity design can work.

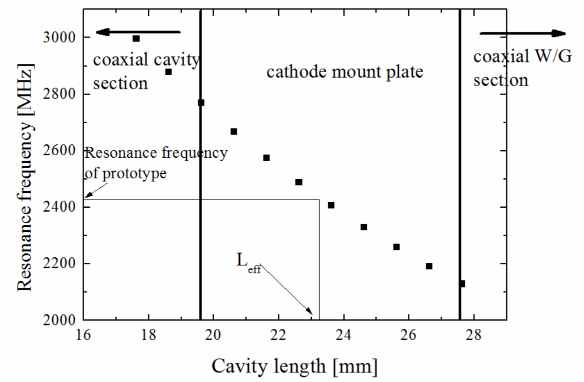


Figure 7: Cavity length vs. resonance frequency.

From the cold test results, we obtained an experimental value for Q that is larger than the designed value (650 versus 200 respectively). The values for Q_0 and β however were smaller. In fact the experimental β value is significantly smaller than designed one (3 versus 20 respectively), which we expect may also reduce another important parameter - the bandwidth for which the design can achieve V_c > 30 kV. In Fig. 8 we calculated the dependence of cavity voltage V_c on frequency in the presence of an electron beam, and using the cold test value of resonance frequency, Q_0 and β. Here we assume a constant input power of 40 kW and a beam loading as with particle simulations of typical operating conditions. For β = 3 the bandwidth is 10 MHz, about half of that calculated in the case where β = 20 as designed (22 MHz).

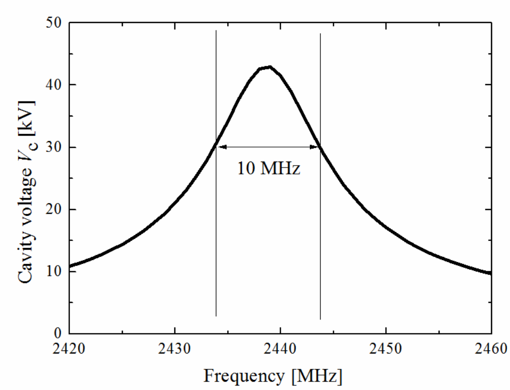


Figure 8: Frequency vs. cavity voltage.

FUTURE WORK

In cold tests we got smaller coupling coefficient β than designed value. If the edge of the resonance mode will shift by changing the cathode mount plate thickness t, the β is expected to change. That is, we will determine experimentally any dependence of the coupling coefficient β on the thickness of cathode mount plate t which may be applied to extend the bandwidth.

The resonance frequency of cold test results shifted about 400 MHz by comparison with desired value it cannot be supplied from klystron which is used to supply our accelerator tube. In order to adjust the resonance frequency, we will install small stubs (Fig. 9) and bore a hole at the cathode mount plate to insert these stubs.

We will also test whether the bandwidth is acceptable by measuring the change of resonance frequency under the experimental conditions of cathode heating, high input power, and electron beam production in the present prototype.

Following these, we will modify the design of the coaxial RF cavity, and construct a 2nd prototype with the desired resonance frequency of 2856 MHz by shifting the cathode mount plate position.

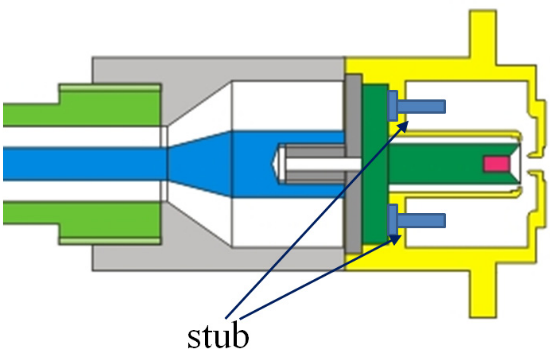


Figure 9: Example of stubs used to tune resonance.

CONCLUSION

We have constructed a prototype of the thermionic triode RF gun. We employed a non-standard RF coupler and a coaxial RF cavity whose coaxial waveguide is concentric with an inner conductor supported by the cathode mount plate. We confirmed that this prototype can work.

From the measured reflection ratio P_{ref}/P_{in} we also calculated the experimental parameters $Q_0 = 2600$ and $\beta = 3$.

In the cold test results, we found a resonance mode that is similar to axial symmetry with an edge located near the center of thickness of the cathode mount plate.

Using cold test result parameters and assuming beam loading as in a typical operating situation, we calculated the bandwidth for which $V_c > 30$ kV. Results show that the bandwidth is 10 MHz, which is equal to about half of the designed value.

We plan to modify the design of the coaxial RF cavity and 2nd prototype.

REFERENCE

[1] T. Shiiyama, et al., "A TRIODE-TYPE THERMIONIC RF GUN FOR DRASTIC REDUCTION OF BACK-STREAMING ELECTRONS", Proc of FEL 2007, Novosibirsk, Russia

[2] K. Masuda, et al., "PARTICLE SIMULATIONS OF A THERMIONIC RF GUN WITH GRIDDED TRIODE STRUCTURE FOR REDUCTION OF BACK-BOMBARDMENT", Proceedings of the 27th International Free Electron Laser Conference

[3] K. Kanno, et al., "Design of Back-bombardment-less Thermionic RF gun", Japanese Journal of Applied Physics Vol. 41 Suppl. 41-1 (2002) 62-64

[4] K. Masuda, et al., "DEVELOPMENT OF THERMINIC TRIODE RF GUN", Proceedings of FEL 2009, Liverpool, UK

[5] K. Masuda, et al., IEEE Trans. MTT, 46-8(1998)1180