PRACTICAL DESIGN OF RESONANCE FREQUENCY TUNING SYSTEM FOR COAXIAL RF CAVITY FOR THERMIONIC TRIODE RF GUN

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Abstract

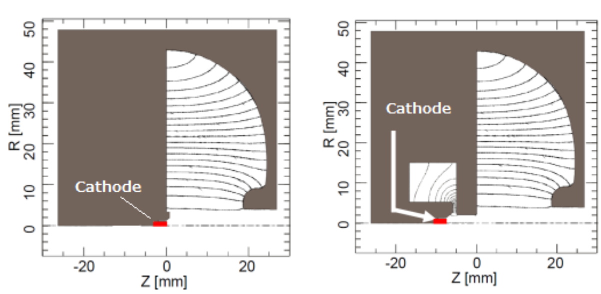
A prototype of coaxial rf cavity for thermionic triode rf gun has been fabricated and tested at low power.

The low power test reveals the dependency of cavity resonance frequency on cavity and cathode temperature. Another critical point for resonance frequency is the cavity length. Inaccuracies in machining or simulation of cavity length cause errors in resonance frequency of manufactured cavity. In order to compensate for undesired resonance changes a tuning mechanism has been installed for the prototype of coaxial rf cavity.

In this paper we present the capability of the stub tuning system and propose a modified coaxial rf cavity design.

INTRODUCTION

A FEL (free electron laser) facility require low emittance and high peak current electron beams[1]. Thermionic rf electron guns are often used for generation of high quality electron beams, which are used for generation of FEL. The conventional thermionic rf guns suffer from electron back- bombardment effect, which causes large energy spread of generated electron beams[2]. In order to mitigate the amount of back streaming electrons our group has developed a new triode type thermionic rf gun[3-4]. The triode design consist of an additional coaxial rf cavity with a thermionic cathode on its inner rode. This cavity can be integrated into the main body of a rf gun[3].



(a) Conventional (b) Triode type

Figure 1: Electric field distribution in cross section of conventional and triode coaxial rf cavity.

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Figure 1 shows the comparison between the 1st cell of thermionic rf gun body in conventional and triode type design in cross section. The triode thermionic rf gun has an additional coaxial rf cavity, later referred as triode cavity. This cavity is supplied by an electric field which is independent from that of the first cell of the gun body. By adjusting the phase and amplitude of the electric field in the triode cavity the extraction of thermionic electrons from the cathode can be synchronized with the accelerating rf phase of 1st cell of the main accelerating cavity. By this means the amount of back streaming electrons can be reduced and as the consequence the energy spread of electron beam mitigated[3].

The efficiency of the triode approach shall be proved for the KU-FEL(Kyoto University Free Electron Laser) facility[5]. The facility uses 4.5 cell thermionic rf gun[3] for electron beam generation. This rf gun is intended to be modified to triode type in order to mitigate the back-bombardment effect[6]. A corresponded prototype of triode cavity for thermionic rf gun has been fabricated.

The resonance frequency of triode cavity must correspond to that of the main accelerating cavities of the gun. The test of fabricated triode cavity prototype reveals the resonance deviation of 462 MHz from expected value[4]. For reasons of refinement of resonance frequency we have implemented a stub based frequency tuning system. This mechanism allows the frequency tuning up to 102 MHz at the present experimental setup. Further frequency tuning can be achieved by changing of triode cavity length.

FREQUENCY TUNING SYSTEM

Figure 2 shows a schematic cross-sectional view of the triode cavity and the fabricated prototype with cavity length of L=19.2 mm.

A thermionic cathode is set on the inner rod of the coaxial cavity. The cathode is heated in order to ensure emission of electrons. Since the cavity length L is sensitive to the temperature, the resonance frequency is changed according to cathode heating conditions.

Figure 3 shows the measured correlation of cavity resonance frequency and cathode temperature. The increase in temperature causes resonance shift of max. 10 MHz towards lower frequency at operational conditions (1290 K-1570 K). In order to correct for temperature rise

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and other possible frequency distorting mechanisms, a stub tuning system is used.

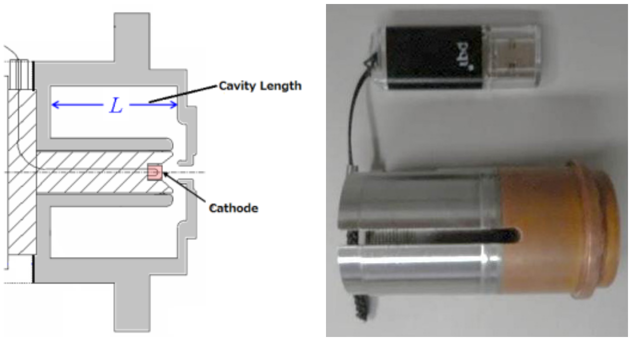

Figure 2: Schematic cross-section of the triode cavity and side view of fabricated prototype.

The frequency tuning is achieved by insertion of two symmetrical copper stubs of different length into the cavity. Figure 4 demonstrates the symmetrical alignment of the stubs.

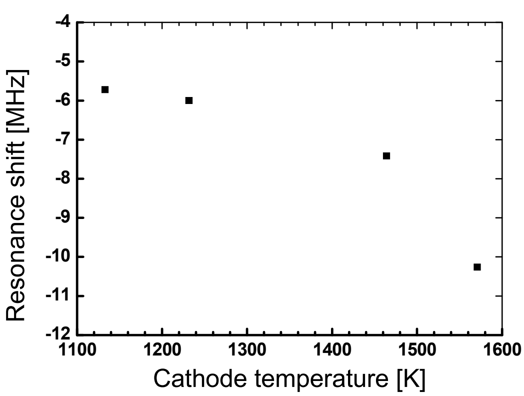

Figure 3: Dependency of resonance frequency on cavity temperature.

The stubs have the diameter of 4 mm. The frequency tuning is done by proper choice of the stub length. We use two copper stabs simultaneously, as shown in Fig. 4.

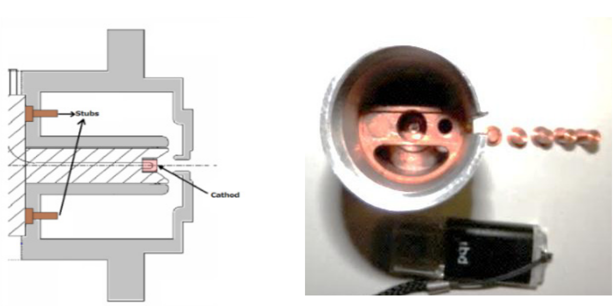

Figure 4: Stub tuning system of the coaxial triode cavity.

LOW POWER TEST

The triode cavity was tested with 1 mW input power without air evacuation and without heating the cathode. The ratio of inputted and reflected power was measured by spectrum analyser (.Agilent, N9320B.) with stubs of different length: 0mm (no tuning), 4 mm, 6 mm, 8 mm, 10 mm, where both stubs had the same length.

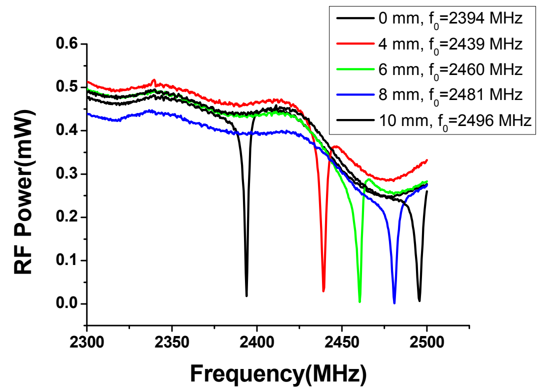

Figure 5: Measured dependency of resonance frequency on stub length.

The test results reveal linear dependency of the resonance frequency shift on the stub length, as shown in Fig. 5. Each enlargement of stub length by 2 millimetres changes the resonance for about 20 MHz. towards higher frequency. It corresponds to range of approximately.100 MHz achieved by usage of 10 mm long stubs. The limitation is set by the cavity length of current 19.2 mm.

The tuning steps might be shortened by using the combination of two stubs of different length.

Figure 6 shows the tuning by using two stubs of different length. The first stub is 10 mm long, and the second was successively changed to 0, 4, 6 and 8 mm. In Fig. 6 these combinations are denoted as 10/0mm, 10/4mm, 10/6mm and 10/8mm.

In order to compare the combined and same length stub tuning methods, the effective stub length is calculated. The effective stub length is defined as l= v-(v-x)/2, where "v" is the length of the first stub (v=10) and "x" is the length of the second stub. The correlation of the effective stub length and the resonance shift is within the error bars the same in case of two stubs with same and with combined length, see Fig. 7. Table 1 shows the fitting equation for both cases.

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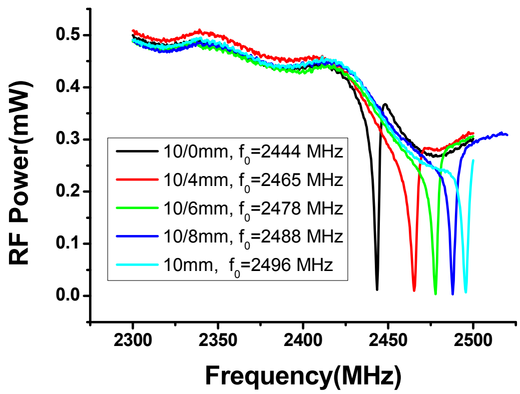

Figure 6: Resonance tuning by combination of stubs with different length.

The heating of cathode causes the resonance shift to lower frequency for about 10 MHz, thus it can be recovered by using two 1 mm long stubs.

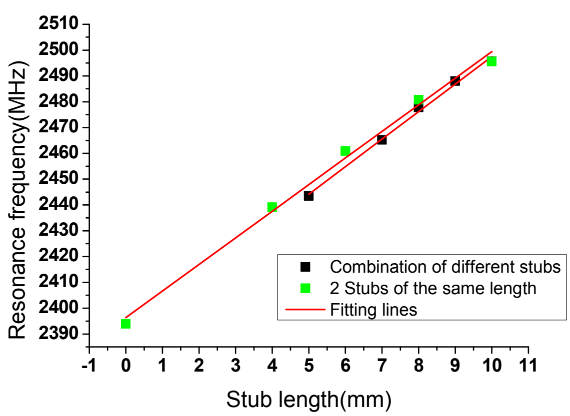

Figure 7: Variation of stubs with different length as compared with stubs of same length.

Table 1 : Fitting Equation of Resonance Shift

y=a+bx	a	b
Same length stubs	2396±3	10.3±0.4
Different length stubs	2391±3	10.6±0.4

NEW DESIGN OF THE TRIODE CAVITY

The prototype cavity was designed for resonance frequency of 2856 MHz corresponding to the operational frequency of KU-FEL thermionic rf gun[5]. However, the measured value has deviation of 462 MHz. Such deviation can`t be tuned by stub system, since 462 MHz frequency shift requires stub with length extending the cavity length.

The reason for the deviation is the mistake in definition of cavity length "L`" used for calculation. The calculation is referred to the middle of the cathode mount plate, see Fig. 7. It was mistaken as the cavity length "L". As the result the cavity length was fabricated L`-L=4 mm longer as intended [7].

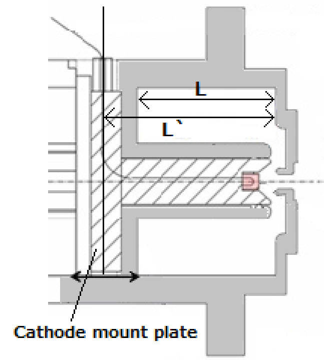

Figure 8: Cavity length determination.

For frequency adjustment new design of triode cavity is required. Especially the cavity length has to be defined new in order to match the resonance of the main accelerating cavities (2856MHz). The calculated values are shown in the Table 2. The calculation assumes the measured resonance frequency at 2439 MHz for L=19.20 mm, however the measurement of stub tuning for 0 mm stubs show the resonance frequency at 2394 MHz, see Fig. 5. This discrepancy of 45 MHz relies on the mechanical distortions by installing the stub tuning mechanism. Nevertheless this distortion doesn`t affect the linearity of correlation between resonance frequency and stub length, as demonstrated in Fig. 7.

Another important aspect for the new cavity is the accessibility to the inner side, which would allow the controlling of the cavity condition after operation. In order to ensure such ability the cavity is designed as consisting of two separated parts, which are connected to each other by screwing. The copper rings serve for prevention of discharge on connecting edges during the gun operation. Figure 9 (a) and (b) shows the electric field distribution in cross section of the triode cavity for the prototype and for the new designed cavity, respectively. The new design doesn't cause significant changes in electric field distribution.

Table 2 : Calculation of Cavity Length

	prototype	new design
Cavity length, *L*	19.20 mm	14.59 mm
Frequency	2439 MHz	2858 – 2862 MHz

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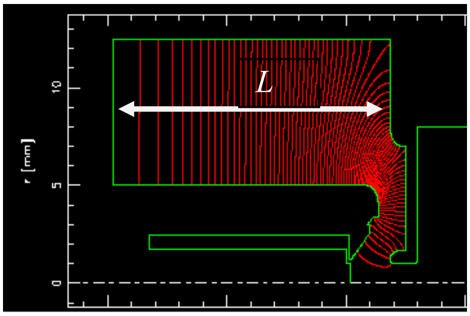
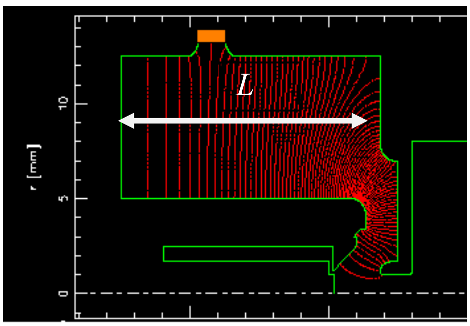


(a) Simulation of ele. Field distribution in cross section of cavity according to old design



(b) Simulation of ele. Field distribution in cross section of cavity according to new design

Figure 9 : Simulated electric field distribution in cross section of triode cavity.

SUMMARY AND FUTURE WORK

A frequency tuning stub based system was tested for the triode electron gun cavity. The stub tuning revealed linear correlation between resonance shift and stub length. The 10mm long stubs can shift the resonance for 102 MHz towards higher frequency.

This system is sufficient for correcting for resonance changes due to variation of experimental conditions, i.e. beam loading effect, which shifts resonance towards lower frequency.

A new triode cavity design has been proposed. In order to correct the deviation in resonance of 462 MHz as measured for fabricated prototype, the cavity length has to be changed to 14.59 mm according to calculations.

As the next step a newly designed triode cavity has to be fabricated and tested for application in the KU-FEL as an electron beam source.

REFERENCES

[1] C. Travier, “Rf guns: bright injectors for FEL”, Nuclear Instruments and Methods in Physics Research, A304 (1991) 285-296 285, North-Holland.

[2] T. Kii et al. “Experiment and analysis on back-bombardment effect in thermionic RF gun”, Nuclear Instruments and Methods in Physics Research A 475 (2001), 588–592.

[3] K. Masuda et al., “Design and study of RF triode structure for the KU-FEL thermionic RF gun”, Proceedings of FEL 2006, BESSY, Berlin, Germany.

[4] K.Masuda et al. ,”Development of a thermionic triode RF gun”, Proceedings of FEL 2009, Liverpool, UK.

[5] T. Kii et al.,“Status of the MIR FEL facility in Kyoto University”,Proceedings of IPAC’10, Kyoto, Japan.

[6] M. Bakr etal., “Numerical simulation for the back bombardement effect on thermionic cathode at KU-FEL RF gun”, Proceedings of the 7th Annual Meeting of Particle Accelerator Society of Japan, August 4-6, 2010, Himeji, Japan.

[7] M. Takasaki et al., “Cold testing of a coaxial RF cavity for thermionic triode RF gun”, Proceedings of FEL 2010, Malmö, Sweden.

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