

# COLD TEST OF THE COAXIAL CAVITY FOR THERMIONIC TRIODE TYPE RF GUN

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## Abstract

In this paper we present the results for cold test of a coaxial cavity, which is to be installed in an existing RF gun to consist what we call-triode type RF gun.

The triode type RF gun is supposed to drastically reduce the back-bombardment of electrons inherent in conventional thermionic RF guns.

The coaxial cavity design was done based on tests of a prototype cavity. The latter has revealed deviations in resonance frequency, from that of the existing RF gun main cavity, which makes application of the prototype impossible. The deviation is caused by errors in design and by change due to operational conditions, namely the temperatures of the thermionic cathode and cavity body.

In order to correct the resonance frequency the coaxial cavity was redesigned. Moreover the new design provides mechanisms for adjustment of the resonance frequency by means of a gasket and demountable stub system.

The cold test demonstrates that the new cavity matches the requirement for application to the triode RF gun.

## INTRODUCTION

The KU-FEL (Kyoto University Free Electron Laser) facility uses a 4.5 cell thermionic RF gun for the electron beam generation [1]. The advantage of a conventional thermionic RF gun as compared to photo-cathode RF gun is the simplicity of operation and lower costs. However, the thermionic RF gun in KU-FEL is affected by effect of electron back bombardment, which leads to degradation of the output laser beam properties [2].

In order to mitigate the electron back bombardment impact a new triode type RF gun was designed [3].

The triode type RF gun is a combination of a conventional thermionic RF gun e.g. the 4,5 cell RF gun in case of KU-FEL and an additional small coaxial cavity. Schematic drawing of such a gun is shown in Fig.1. The additional small coaxial cavity referred as “triode cavity” hereafter, acts as a pulsed gate electrode [4]. The control over phase and RF power of triode cavity allows us to synchronize the electron bunch injection and accelerating phase of main accelerating body of thermionic RF gun.

A triode cavity prototype for the thermionic RF gun, which is used in KU-FEL facility was fabricated and tested previously [5]. A new triode cavity was designed and fabricated based on test results of the prototype cavity [6].

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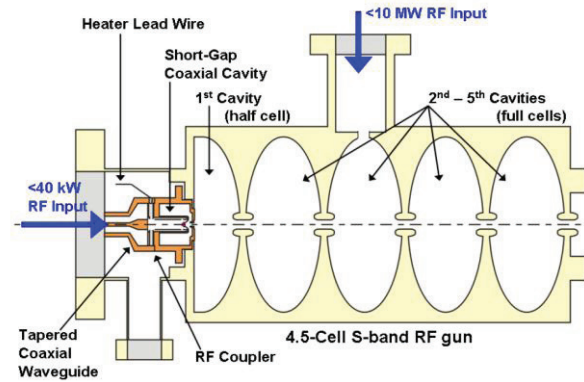


Figure 1: Schematic cross-section of the triode type thermionic RF gun.

## TRIODE CAVITY DESIGN

Figure 2 shows a schematic cross-sectional view of the triode cavity. The cavity consists of two separable parts, which are connected by screwing.

A thermionic cathode material is set on the inner rod of the triode cavity. For emission of electrons the cathode material is heated. The thermal expansion of cavity material might change the cavity length and the resonance frequency respectively. Desired resonance is given by the driving frequency of the KU-FEL, which is 2856 MHz.

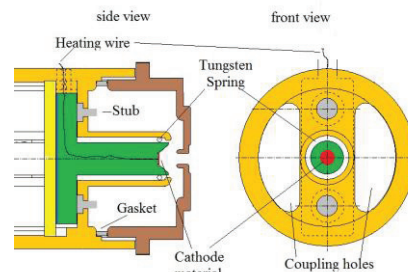


Figure 2: Resonance adjustment system of the triode cavity. The system consists of stub and gasket tuning mechanisms.

As results of cold testing, the resonance frequency is found to change by  $-60 \text{ kHz/K}$  as the cavity body

temperature changes. The triode cavity is supposed to be attached to the main body of thermionic RF gun, which has temperature of 60 deg.C. during operation. For that the triode cavity body is expected to have the same temperature.

Another important aspect for resonance frequency is the temperature of the cathode material, which should be heated for 1500-1700 K during for thermal electron emission. The frequency and current dependency on cathode material temperature will be studied in the future.

In order to correct for any possible resonance detuning effects, a frequency adjustment system inside of the triode cavity is used. The adjustment to higher frequencies is ensured by stub tuning system, to lower frequencies by gasket tuning.

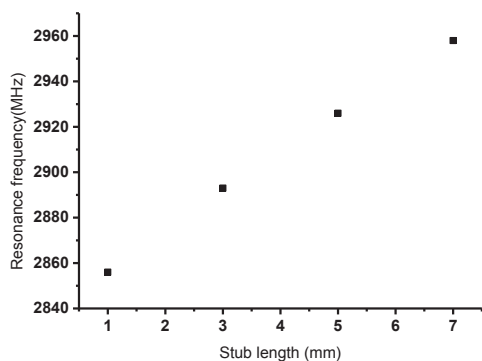


Figure 3: Dependency of resonance shift on stub length.

Figure 3 shows the measured resonance frequency adjusted by stubs of different length. According to this diagram the resonance can be increased by 15 MHz by extension of stub length by 1 mm. The prototype cavity had an adjustment gradient of 10 MHz/mm [6], which reflects the difference in geometry due to the gasket.

The triode cavity length is about 16 mm, which sets the limit for stub tuning by < 240 MHz. The stub length of 1 mm is enough to match the desired resonance frequency for newly fabricated cavity.

The variation of gasket thickness changes the drift length of the electron beam inside of the cavity. The frequency adjustment capability by gasket thickness as well as the influence on electron beam trajectory has been studied numerically (Kenta Mishima, unpublished) and will be experimentally tested in the future.

### COLD TEST

#### Low Power Test

The triode cavity was tested with 1 mW input power under vacuum conditions. For testing reasons a dummy plug is used without cathode material. Thus no

heating(cold test) and electron generation takes place. The ratio of inputted and reflected power was measured by spectrum analyser (Agilent, N9320B.).

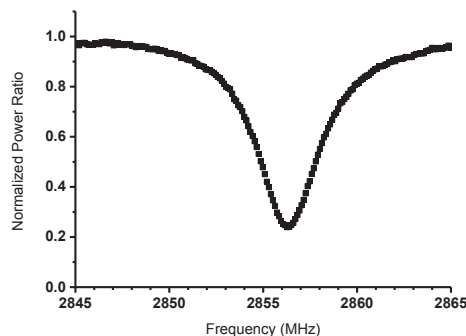


Figure 4: Resonance curve measured by low power test.

The resonance curve of the cavity with resonance at  $f_0 = 2856.4$  is shown in Fig. 4. The coupling constant  $\beta = 2.9 \pm 0.01$  and unloaded quality factor  $Q_0 = 2768.2 \pm 8$  are obtained by fitting with the equation of an equivalent circuit [7].

$$\frac{P_{ref}}{P_{in}} = 1 - \frac{4\beta}{(\beta + 1)^2 + Q_0^2 \left(\frac{f}{f_0} - \frac{f_0}{f}\right)^2}$$

Where  $P_{in}$  is the input power  $P_{ref}$  is the reflected power. The frequency is denoted by  $f$  and the resonance by  $f_0$ .

The resonance frequency corresponds to the desired value.

#### High Power Test

For the high power test klystron of KU-FEL facility was used as power source. The triode cavity was tested under vacuum conditions by pressure of  $p = 0.3$  mTorr. The RF frequency was varied by signal generator in order to record the resonance curve of the triode cavity.

The resonance curve obtained by high power test has maximum value at  $f_0 = 2856.3$  MHz. The input power on resonance is 263W. The fit of power ratio of input and reflected power is shown in the Fig. 6. The parameters obtained from the fit are  $\beta = 2.5 \pm 0.04$  and  $Q_0 = 2355.5 \pm 32$ .

### DISCUSSION

For the low and high power test dummy plug without cathode material is used. Thus the properties of triode cavity are studied without electron generation are studied. The  $\beta$  and  $Q_0$  values as obtained from low power and high power test are in agreement within 15% which is acceptable.

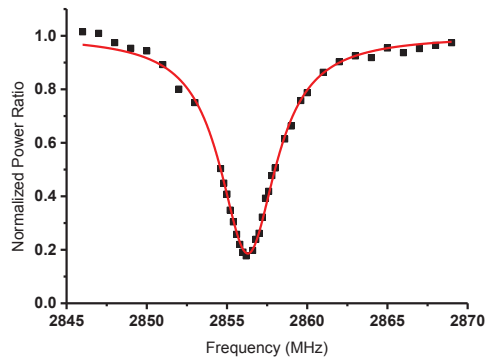


Figure 6: Normalized power ratio as obtained by high power test. Black dots are measured values fitted with red line curve.

The aim of the cavity test is to prove the triode cavity for the applicability to triode gun. An important requirement thereby is the triode cavity voltage, which was designed for 30kV [7].

Figure 7 shows the cavity voltage calculated from the equivalent circuit equation as function of frequency. The parameters for voltage calculation are taken from the low power test ( $\beta$ ,  $Q_0$ ) and from numerical eigenmode calculation ( $R/Q$ ). For the voltage calculation the results of high power test are used. The voltage on resonance is 8.3 kV, which is 28 % of required value. The change of  $\beta$ ,  $Q_0$  does not significantly affect the voltage. Important parameter is the input power. By input power of 2kW the cavity voltage of 30kV can be achieved. However, the triode cavity has limitation for input power caused by arcing. The maximal input by high power test is 263 W and vacuum conditions of 0.3 mTorr. The input power might be increased after conditioning process, which shall be done in the future.

### SUMMARY AND FUTURE WORK

A coaxial RF cavity for triode type thermionic RF gun was tested without heating up the cathode. The tests revealed that the resonance frequency corresponds to designed values and can be applied for the triode RF gun system.

The resonance frequency can be adjusted to  $< 240$  MHz by demountable stub tuning.

The triode cavity has power limitations due to discharge and requires conditioning. According to calculations the 30 kV of cavity voltage, as designed for triode gun system can be achieved by 2 kW input power. A higher input power can be applied after conditioning of the cavity and by better vacuum conditions ( $< 3 \times 10^{-3}$  Torr). As the next step generation of electron beam in a hot test will be studied.

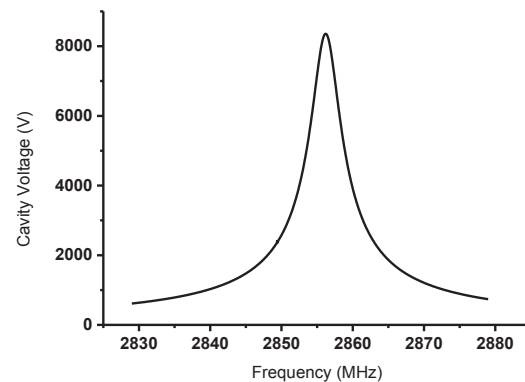


Figure 7: Cavity voltage as a function of frequency

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