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Present Status of RF Gun for Highly Brilliant Electron Beam Production in Kyoto University

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Abstract

An S-band RF gun having 4.5 side-coupled cavities with a thermionic cathode was set up in the beam line, and its fundamental characteristics have been measured, such as beam current, the beam sizes and the voltage standing-wave ratio (VSWR) of the RF gun.

The beam current was found to be nearly proportional to the input RF power (up to 3.5 MW). Also, the transverse profile was found to be nearly cylindrically symmetric and the beam size was found to decrease together with increase of the input RF power. This is because the higher the electron beam gets energy from the RF power, the interaction time with space charge effects becomes smaller, eventually the beam receives less transverse momentum.

The time evolution of the reflected RF power was also measured and compared with the analytical solution of the equivalent resonant circuit, and the agreements were seen.

1. Introduction

A beam with extremely low emittance is required for further improvements of FELs, in particular, for FELs of shorter wavelengths, and of narrower bandwidths. As is well known, RF guns have the advantages over conventional electrostatic guns on such as (1) more rapid acceleration in excess of 100 MV/m, resulting in appreciable reduction of emittance growth due to space charge effects, (2) very compact structure in producing high current, low emittance beam, and (3) pre-bunched beam and longitudinal phase-space lending itself to magnetic compression.

To search for the innovative methods for the reduction of the beam emittance, firstly we developed a 2-D code with full Maxwell equations with space charge effects taken into account self-consistently to precisely evaluate RF gun performance characteristics [1-4]. Also for experiment we prepared an S-band RF gun having 4.5 side-coupled cavities with a thermionic cathode, and its fundamental characteristics have been measured, such as the beam current, the beam sizes, and the voltage standing-wave ratio (VSWR) of the RF gun. Also we are planing to measure energy spectrum and emittance, and to compare them with the simulation results for code verification. Then with the verified code, we can design the optimal gun configuration and operation scheme.

In this paper the measurements of the fundamental characteristics of the RF gun are presented such as the beam current and the beam size. The comparison of the analysis result with the experimental result on time evolution of the reflected RF power is also presented.

2.Experimental Setup

An S-band RF gun was developed by AET Associates Inc., having 4.5 side-coupled cavities with a thermionic cathode as is schematically shown in Fig.1. It is designed to provide about 4 MeV electron beam with 5 MW RF input. A water cooling circuit is included to keep the temperature of the gun body constant. During the experiment the temperature was set 30 ℃, and this temperature can be maintained within ± 0.5 ℃.

Fig.2 shows the beam measurement system. The beam tube diameter is 20mm. Two beam current transformers are installed. The beam profile is monitored with two sets of a Desmarquest screen and a CCD camera.

The RF power supply system consists of a 23.8 MW modulator and a 10 MW klystron.

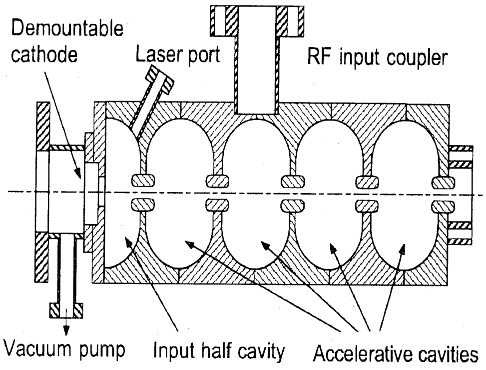


Fig.1 Schematic of an S-band 4.5-cavity RF gun.

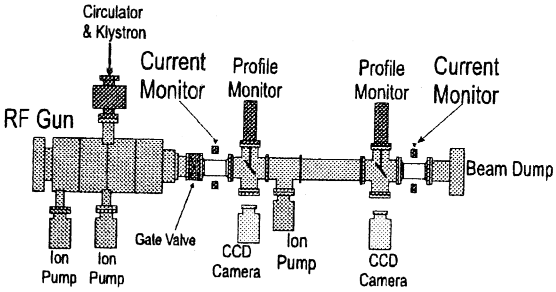


Fig.2 The beam measurement system.

3.Analysis of the Time Evolution of the Reflected RF Power

In order to study the time evolution of the electric field in the accelerating cavities, eventually to study that of the beam energy we studied the equivalent circuit of the RF gun and compared the analytical result with the experimental result.

3.1 Equivalent Resonant Circuit of RF Gun

As is well known an RF gun is equivalently represented as Fig.3 (a) [5] with the cavity parameters such as the admittance G, the inductance L, the capacitance C and the coupling constant β. β equals VSWR at complete resonance, so it can be measured experimentally and in our case it is 3.55.

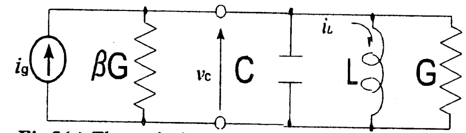


Fig.3(a) The equivalent resonant circuit of RF gun, RF gun, RF power supply and dummy load.

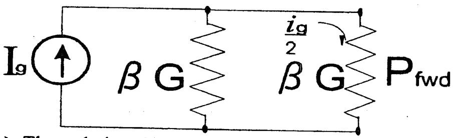


Fig.3(b) The relation between I_g and P_0 in the power supply in the matched measurement system.

Those parameters can be calculated from the following equations (3.1).

$$\omega_0^2 = \frac{1}{LC}, \quad Q_0 = RC\omega_0, \quad R_{sh} = \sqrt{\frac{L}{C}} = \frac{R}{Q_0} \qquad (3.1)$$

where ω_0 is the resonance angular frequency, Q_0 is the Q-value and R_{sh} is the shunt-impedance. They can be measured and in our case $\omega_0 = 2\pi \times 2857.7\,\mathrm{MHz}$, $Q_0 \approx 19000$ [6] and $R_{sh} \approx 24.75$ $\mathrm{M\Omega}$. And the pulsed RF power P_{fwd} is represented as a DC power supply i_g as is shown in Fig.3(b). When i_g is supplied from $t = 0$ to $t = t_0$,it is represented as

$$\mathrm{Im}[i_g(t)] = \mathrm{Im}[I_g e^{j\omega t} u(t) - I_g e^{j\omega(t-t_0)} u(t-t_0)] \qquad (3.2)$$

where ω is the angular frequency of the RF and $u(t)$ is Heaviside function. Besides with I_g which is defined as (3.2) P_0 is represented as (3.4) (Fg.3 (b)).

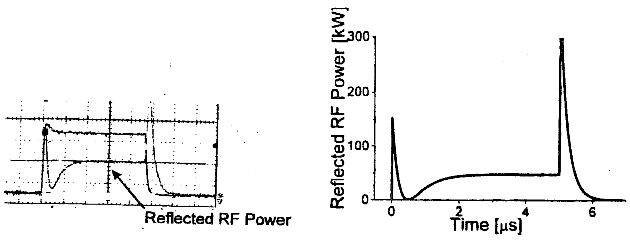
$$P_0 = \frac{1}{2}\frac{1}{\beta G}\left(\frac{I_g}{2}\right)^2, \quad P_{fwd}(t) = P_0\{u(t) - u(t-t_0)\} \qquad (3.4)$$

Finally we obtain

$$I_g = \sqrt{8\beta G P_0} \qquad (3.5)$$

3.2 Comparison between the analysis and the measurement

Then Fig.4 shows the time evolutions of both calculated and measured reflected RF power at the resonant angular frequency. Their results showed agreement. Besides we will take the time constant of this circuit into consideration, much more agreement will be seen.



Experimental results Calculated results

Fig.4 The time evolution of both calculated and measured reflected RF power. $\omega = 2\pi \times 2857.7\,\mathrm{MHz}$

4.Beam Measurement

4.1 Beam Profile

The transverse beam size was measured at the profile monitor with a CCD camera and an image capture board on a personal computer. As is shown in Fig.5(a),(b) the transverse profile was found to be nearly cylindrically symmetric, and the beam size, defined as FWHM of Gaussian fitted profile, was found to decrease together with increase of the input RF power. It would be one of the reasons that the higher the electron beam gets energy from the RF power, the interaction time with space charge effects becomes smaller, eventually the beam receives less transverse momentum. It would be another reason that the RF gun was designed to focus the electron beam. So the focusing force is proportional to the input RF power.

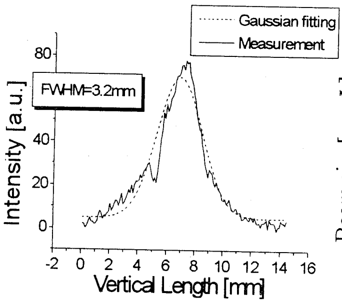


Fig.5(a) Beam size measurement

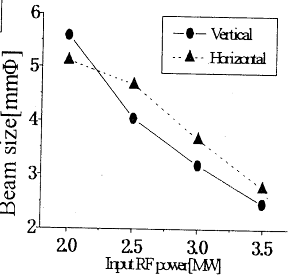


Fig.5(b) Vertical and horizontal beam size versus the input RF power.

4.2 Beam Current

The beam current was measured with a beam current transformer. Fig.6 shows that the beam current was found to be nearly proportional to the input RF power up to 3.5 MW.

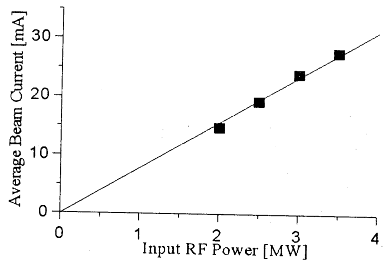


Fig.6 Average beam current versus the input RF power.

5.Conculusion

Measured results of the time evolution of the reflected RF power agree with the analytical results of the equivalent resonant circuit. The beam current was found to be nearly proportional to the input RF power. The transverse profile was found to be nearly cylindrical symmetric. The beam size was found to decrease together with increase of the input RF power.

Acknowledgement

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