A NOVEL STRUCTURE OF MULTI-PURPOSE RF GUN

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Abstract

RF guns have recently been very commonly used in high-energy research accelerators, as well as in various applications of accelerators such as FEL, because it offers significant advantages over the conventional techniques, which use electron guns and bunchers. In this paper, the novel structure of the RF gun, utilizing the $\pi/2$ mode, standing wave, on-axis coupled structure (OCS), is described. The new structure offers much higher group velocity and lower emittance over the structure that is commonly used. As a result, the new structure has a more stable operation for higher beam current without sacrificing beam emittance. Moreover, the structure offers unique characteristics in reduction of back bombardment for the application of thermionic cathodes in RF guns. The cavity structure and beam parameters were optimized by using EMSYS (2D) and MAFIA (3D). An overview of design detail and prototype structure, which can be used with either thermionic cathodes or photocathodes, will be presented.

1 INTRODUCTION

Since RF guns offer various advantages over the high voltage DC guns, many of today's electron injectors for physics accelerators and accelerators for FEL utilize this concept in order to obtain a higher brightness beam within a smaller space [1]. Although laser driven cathodes have been used in conjunction with RF gun, the complexity, the lifetime of cathode material, and cost have been the obstacles. Meanwhile, the RF Gun with the thermionic cathode offers a compact and low cost injector, but it suffers by pulse shortening due to electron "back-bombardment".

Here, we propose a new RF-Gun utilizes the $\pi/2$ mode, on axis coupled standing wave structure (OCS), that can offer highly stable, high current beam with lower emittance. The new structure can be used with both the photo cathode and thermionic cathode.

2 DESIGN CRITERIA AND CONCEPT

There are several very important criteria for designing RF guns, including:

2.1 The first accelerating cavity and the cathode for initial acceleration should be made electrically and mechanically as axis-symmetric as possible.

2.2 The accelerating field within the first cavity contains the least transverse components on an off-axis where the beam initially gains longitudinal momentum.

2.3 The amplitude and phase of accelerating field within the accelerating cavities should be stable with beam loading, frequency shift, and thermal instabilities.

2.4 Accelerating gradient must be as high as possible, but less than the RF breakdown and field emission threshold.

In order to satisfy these criteria, we have designed an S-Band RF Gun as shown in Fig. 1. The standing wave $\pi/2$ mode was chosen as the accelerating mode to satisfy criterion 2.3 [2]. The on-axis coupling structure (OCS) was used in order to satisfy criteria 2.1 and 2.2.

The selection of this mode and structure offers several other advantages, such as a) ease of machining the structure; b) ease of tuning; and c) flexibility of choosing the ratio of accelerating field in the first cell and the third cell.

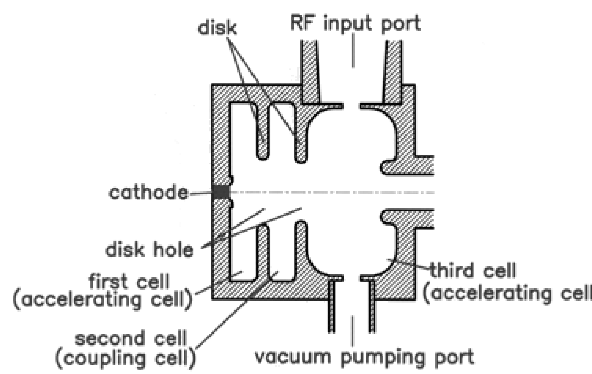

Fig. 1. Cross sectional view of OCS type RF gun

The RF input power will be fed to the third cell where a vacuum pump out-port is placed at the opposite side of the RF input-port in order to minimize the non-axis symmetry within the cavity as shown in Fig 1. A demountable cathode structure is designed by using a tungsten wire spring in the form of a toroid for RF contact. It employs an impregnated tungsten dispenser cathode for operation at around 1000^{o}C.

Fig. 2 shows an equivalent circuit for three cavity couple resonator models with the nearest neighbor coupling (k_{12} and k_{23}) and the second nearest neighbor coupling (k_{13}). Assuming Q is very high, one can obtain the relation of the couplings and the amplitude ratio of the first and third cavity as:

$$\frac{k_{12}}{k_{23}} = \frac{|X_3|}{|X_1|} = \alpha$$

for $\pi/2$ mode operation. This indicates that one can choose any α by changing the radii of the coupling disk holes.

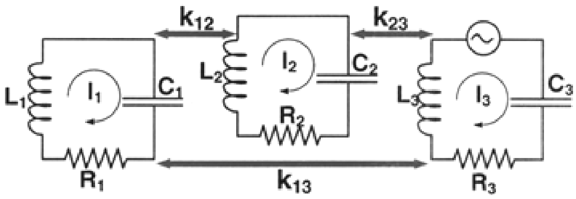

Fig. 2. Coupled resonator model for OCS type RF gun

3 NUMERICAL SIMULATION AND DESIGN OPTIMIZATION

The electromagnetic field profiles were computed using SUPERFISH and EMSYS. The beam dynamics were calculated by the 2D particle-in-cell (PIC) code EMSYS and 3D PIC Code (MAFIA).

Fig. 3 shows the relation of computed coupling coefficients, k_{12} and k_{23}, vs. disk hole radius in millimeters.

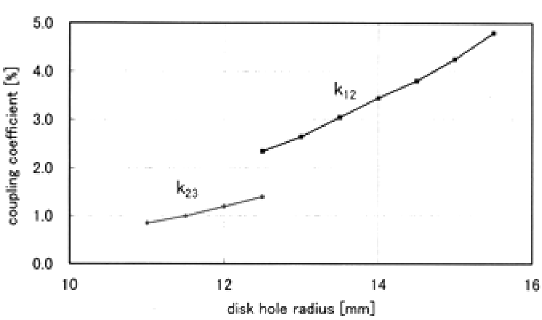

Fig. 3. Disk hole radii vs. coupling coefficients

Fig. 4 shows the dependence of output beam emittance and back bombardment power on coupling ratio α, assuming cathode diameter of 6mm and current density 16A/cm^2. In order to optimize the output beam energy spectrum, the length of the first cell and the second cell are varied along with α. A larger α offers lower back bombardment power, but aggravates the emittance of the beam, since the accelerating field on the cathode surface will be reduced. The optimum α will be around 2.5 and the normalized emittance is 12πmm·mrad. The average back bombardment power is about 1.1W, assuming the pulse width of 5μsec and a repetition rate of 10pps [3].

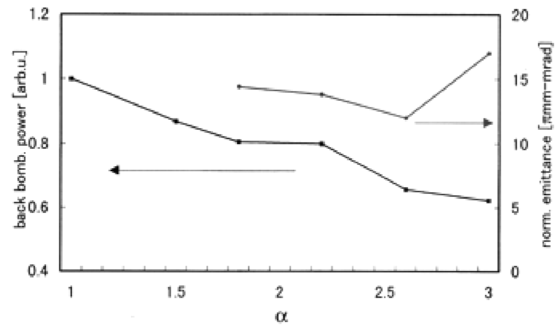

Fig. 4. Field balance (a) vs. beam emittance and back bombarding power

Fig. 5 shows the computed energy spectra of back bombarding beam for α=2.6 and for α=1.0. This figure clearly shows that the lower accelerating field within the shorter first cavity will generate much less electron back bombarding energy as 0.2MeV, compared to the back bombarding energy of higher accelerating field within the longer first cavity as 0.6MeV.

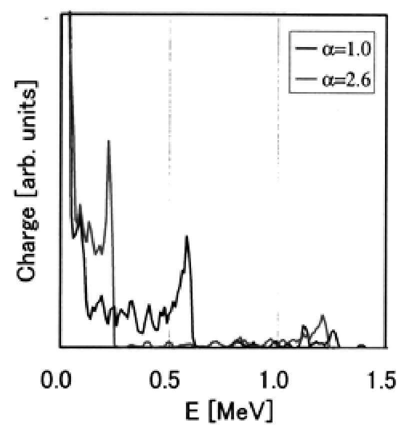

Fig. 5. Energy spectra of back bombarding beam

Fig 6 shows the radial distribution of back bombardment power density for α=2.6. The back bombardment power density is much higher in the center of the cathode due to the back bombarded higher energy electrons being focused by the radial RF field. This indicates that the back bombardment effect and pulse shortening will be completely eliminated by introduction of a hollow beam cathode with a Faraday cup of 2mm hole in the center of the cathode and a Faraday cup placed behind. Fig. 7 and Fig. 8 show an energy spectrum of output beam and energy spread as a function of time, respectively. The FWHM of the energy spectrum is about 25KeV and the charge contained during 10psec is about 0.17nC.

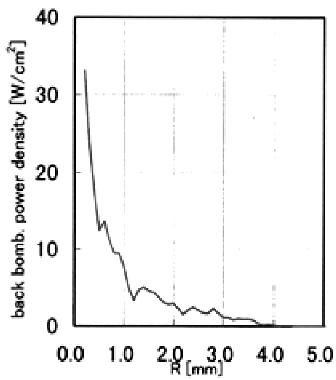

Fig. 6. Radial distribution of back bombarding power density

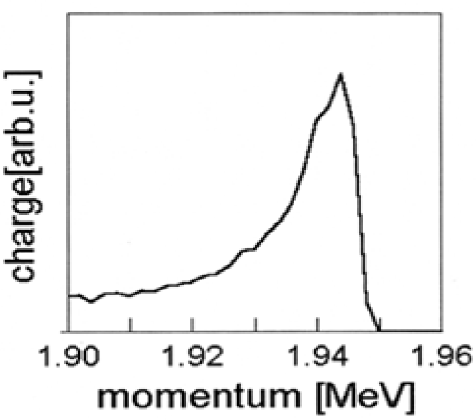

Fig. 7. Energy spectrum of output beam

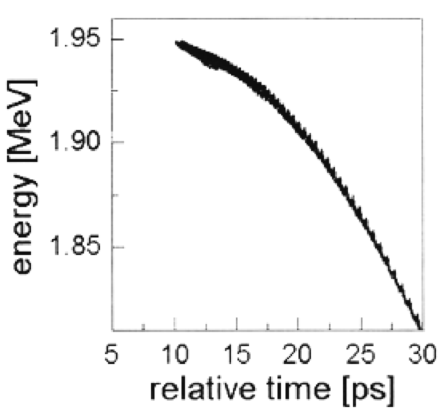

Fig. 8. Time dependence of energy of output beam

Table I summarized the optimized design parameters of the S-Band OCS RF gun. A prototype RF gun is under construction. The beam test will be expected to begin in early 1999.

Fig. 9 shows a comparison of experimental result of an axial field distribution and EMSYS computation.

Table I

Frequency:		2856MHz
Band Width:		103MHz
Peak Beam Energy:		1.9MeV
Peak RF Power:		5.0MW
β (Input Coupling):		3
Coupling Coefficients	k_{12}:	1.4%
	k_{23}:	3.6%
Peak Beam Current:		17A
Normalized RMS Emittance:		11πmm·mrad
Energy Spread (FWHM):		25KeV

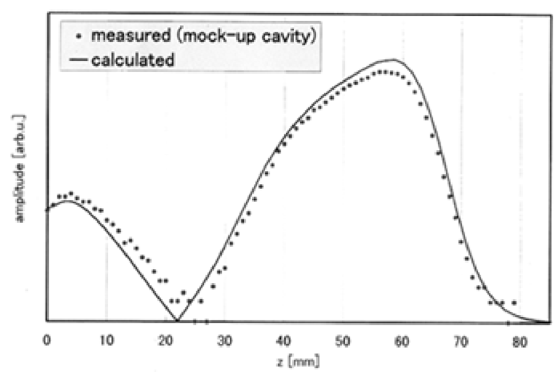

Fig. 9. Measured and calculated longitudinal field profile

4 CONCLUSION

The new on-axis coupled standing wave RF gun structure is presented. This structure offers numerous advantages over the RF guns, which are commonly used. It can be used with either the photocathode or thermionic cathode. Two prototype RF guns are under construction along with a hollow beam thermionic cathode with a beam dumper placed in the center of the cathode.

REFERENCE

[1] J.E. Clendenin, "RF Photo Injector," Linear Accelerator Conference Proceedings, 1996.

[2] E.A. Knapp, et al., "Standing Wave High Energy Linear Accelerator Structure," *Rev. Sci. Instr.* **39**, 979 (1968).

[3] E. Tanabe, et al., "A 2-MeV Microwave Thermionic Gun," Linear Accelerator Conference Proceedings, 106 (1989).