THE DESIGN OF A 5MEV ACCELERATOR BASED ON MULTIPACTOR ELECTRON GUN

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Abstract

The Multipactor Electron Gun (MEG) can produce high current self-bunching electron beams. In this paper, the design of an S-band accelerator based on MEG and the result of low power test are presented. The mechanical structure was designed with ability of replacing secondary electron emitters. Pd-Ba alloy and Pt are used as the secondary electron emitters of the MEG. The distance between electrodes and the resonant frequency of the MEG can be adjusted separately by step motors. The parameters of the accelerator tube were optimized by using numerical simulation with the design output energy of 5MeV and an average current of 100mA.

INTRODUCTION

Multipactor electron gun is a new kind of cold cathode microwave electron gun. It has the advantages of short duration, high current electron beams, simple structure and long lifetime. Therefore it is very suitable for small industrial and medical accelerator or high power microwave generation. F. M. Mako designed Micro-Pulse Electron Gun (MPG) in 1993 [1]. The MPG (S-band) reached a high macro-pulse current density of 10A/cm^2 [2, 3]. The Accelerator Lab of Tsinghua University has been doing research work on MEG since 1999. The research work includes Theoretical Analysis, simulation [4], design, manufacture, cold test and high power experiments and multipactor material et.al [5]. With CVD diamond cathode, a macro-pulse current density of 1.2 A / cm^2 was reached [6]. This paper presents our work on the design of an S-band accelerator based on MEG and the result of preliminary experiments.

PRINCIPLES

We choose a standing wave accelerating tube works on S-band, 2.998GHz, and its output energy can reach 6MeV. For typical acceleration tube, the electron source is thermionic cathode electron gun, which uses a high voltage to pull the electron out with energy about more than 10KeV. MEG is a resonator in front of the accelerator cavity chains, and parts of the microwave power feed into MPG through coupling holes. The electron beam is produced, amplified and then bunched simultaneously in the cathode-grid gap. When the current in the cavity reaches a steady level by space charge and beam loading effect, the outgoing electron beams will be the saturation emission current. Finally the emission current comes into the accelerating cavity and is accelerated.

The structure of the MEG accelerator is shown in Figure 1, it contains several parts: 1) adjusting device controlling the axis position of cathode and tuner. It uses two linear step motors and metal bellows to archive a minimal step of 3.2μm and vacuum sealing; 2) MEG resonate cavity with a microwave probe and replaceable grid, connected to the accelerating tube through flange; 3) accelerating tube, combined with resonate cavities, waveguide window, water cooling and Ti window.

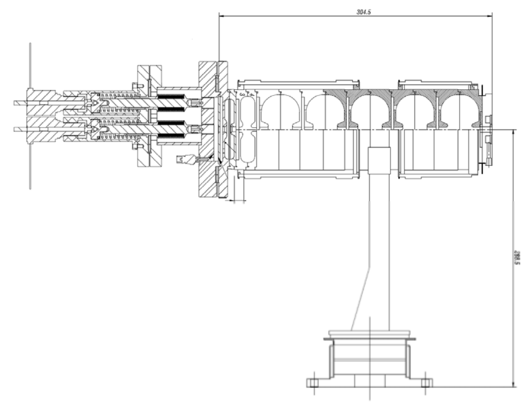

Figure 1: Structure of the MPG accelerator.

MEG PARAMETER DESIGN

A self-developed simulate software, SEEG, is used to simulate the electron emission behavior of MEG [4]. SEEG is a MEG beam dynamics simulating code , which can provide beam current destiny, beam energy and emittance under given conditions. Relativistic effect, RF field effect and space charge effect are considered. The secondary electron emission (SEE) model used in the program is that: SEE yield δ has a relation with primary electron energy E_i, $\delta = \delta_{max} (w \bullet e^{1-w})^k$. δ_{max} is the maximal value of SEE yield and $w = E_i / E_{max}$, E_{max} is the relevant primary electron energy, k = 0.62 while w < 1, and k = 0.25 while w > 1. The injection angle is ignored and all SE come out vertically. The SEE velocity and emittance delay can be defined as constant.

Table 1: Parameter of the MEG

Parameter	Design Value
Cathode-grid distance	d=0.25cm
Frequency	f=2.998GHz
RF voltage amplitude	V_{rf}=3.7kV
Material	Pd-Ba / Pt
Transparency of grid	TT=0.15
Radius of cathode	$R_{cathode}$=5mm

Platinum and Pd-Ba alloy are used as the emitting material. The maximal value of SEE yield of Pt is

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δ_{max}=1.8, and δ_{max}=2.6 for Pd-Ba alloy. The lifetimes of two kinds of materials are relatively stable. The average output electron energy and current destiny during a RF cycle are simulated with different cathode-grid distances *d*. Figure 2 shows the output current destiny of Pd-Ba during a RF cycle.

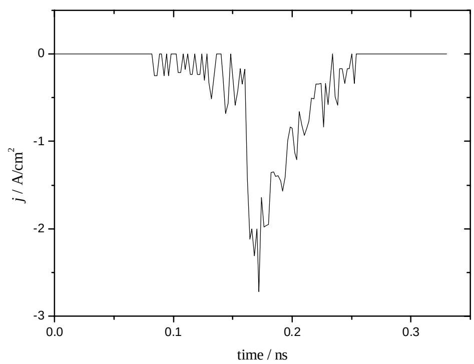

Figure 2: Output current destiny of a RF cycle.

The result shows that during the microwave phase of 180 degree to 270 degree, there is an output electron beam, with maximal electron energy about 3KeV and current destiny of 280mA/cm^2.

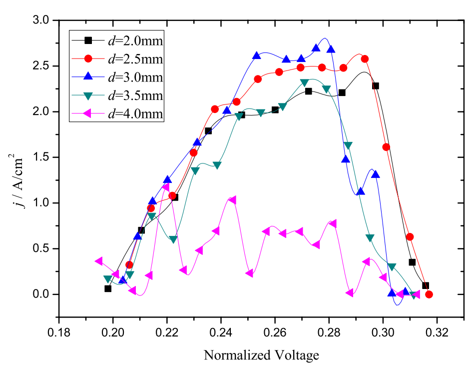

Figure 3: Maximal current destiny with different cathode-grid distance.

By changing the cathode-grid distances, the effect of different RF voltages on the emittance current is simulated. Figure 3 shows the maximal current destiny J_{out} of Pd-Ba alloy with different cathode-grid distances. The abscissa is normalized RF voltage

$$\alpha = \frac{eV_{rf}}{m_0(\omega d)^2}.$$

The radius of the cathode is 5mm, the transparency of the grid is 15% and the current destiny takes the average of last 5 cycles with a total cycle number of 25.

With the distance range of 2.0mm~3.5mm, certain RF voltage can produce a saturation emission current.

ACCELERATOR DESIGN

The parameter of accelerate tube is designed by a numerical optimal code. The longitudinal and transverse dynamics can be calculated with given cavity frequency, Q, coupling factor, shunt impedance and cavity length [7]. As multipactor effect can not be simulated in this software, we consider MPG cavity as a part of the accelerator cavity, the single secondary electron comes out with very low energy, less then 10eV, and is accelerated by RF field through the grid. To approve this, we compared the SEEG output electron energy during a RF cycle and the AccDesign output, the result shows that they are in good agreement. So we use AccDesign to simulate the whole process. The accelerating tube consists of 2-cell buncher and 5-cell accelerating section, excited by a 2MW magnetron. The cathode-grid distance is 2.5mm, the cathode radius is 5mm, the emission current is 200mA, and after accelerating, the beam energy is 5MeV with current of 78mA.

In order to adjust the cathode-grid distance online, an adjusting structure is designed. And a tuner must be used to eliminate the frequency drift due to the changed cathode-grid distance.

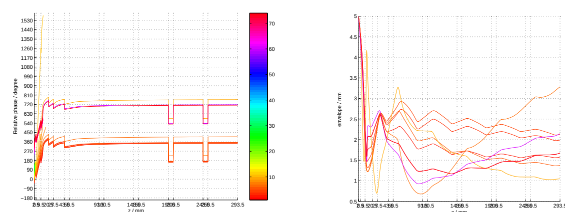

Figure 4: Relative phase and beam envelope.

The MEG cavity is a cylindrical structure with a fixed grid and a moveable cathode in the axis. The tuner is placed at the edge of cavity where the magnetic field has the largest value. The mechanical structures of cathode and tuner are nearly the same, but cathode has emission material in front of it.

On the symmetrical point of tuner, there is a microwave probe to measure the electric field intensity.

COLD TESTS

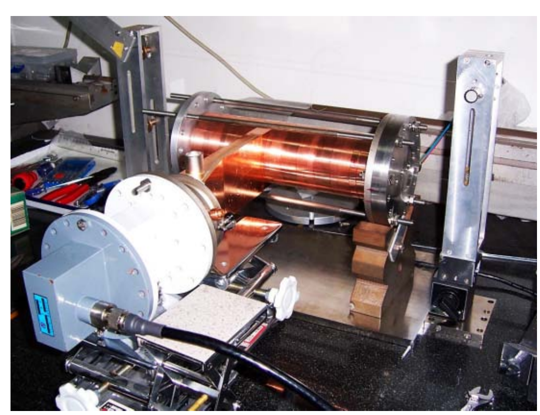

Figure 5: Photograph of the accelerator.

Figure 5 shows a photograph of the accelerator in field distribution measurement, the adjusting structure is not installed yet.

The field distribution is measured by a HP8720B network analyzer and the result is shown in Figure 6.

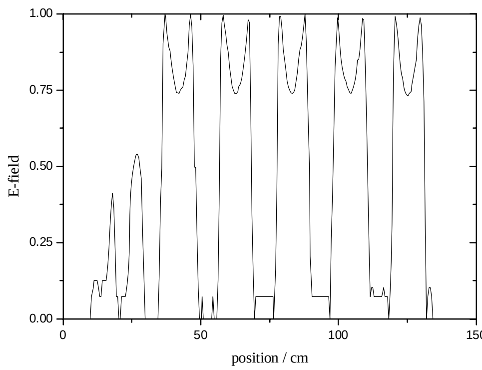

Figure 6: Normalized field distribution.

With the cathode-grid distance set to 2.5mm, the SWR is 1.6 and Figure 7 shows the smith chart.

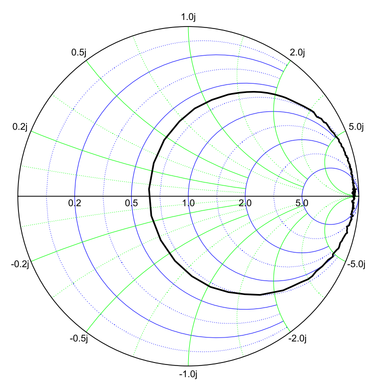

Figure 7: Smith chart.

CONCLUSIONS

An S-band accelerator based on MEG has been designed, manufactured and preliminary tested in the Accelerator Lab of Tsinghua University. Pt and Pd-Ba alloy are used as SE emitters. It has the ability to produce 5MeV, 100mA beam current with a compact structure and online adjusting component. The accelerator can be used for high power experiments of the SE emitters.

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