VHF GUN RESEARCH AT SINAP

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Abstract

The R&D work on the high power THz based on energy recovery linac (ERL) has been carried out in Shanghai Institute of Applied Physics (SINAP). One of the key components for the ERL is the high brightness electron source. The low frequency gun technology has been adopted, by comparing with the SRF gun and DC gun. In this paper, the design and cold test of a 250 MHz gun will be presented.

INTRODUCTION

A number of projects in energy recovery linacs (ERL) and linac-based free electron lasers (FEL) are proposed and commissioned [1-8]. These facilities require injection of 100 pC - 1 nC electron bunches at repetition rates from kHz to hundreds of MHz and with the normalized emittance from 0.1 mm*mrad - 10 mm*mrad.

In the ERL, the electron source dominates the emittance and beam current of the whole facilities. Several type of electron sources are proposed and developed in the past few decades [10-13], which could be classified by different accelerating technologies into direct current (DC) guns, normal conducting radio-frequency (NCRF) guns, superconducting radio-frequency (SCRF) guns and hybrid (DC+SCRF) guns. In the application for various ERL facilities, the different type of the electron source has its own progressive and conservative aspects. And there are challenges and limitations for these techniques.

Recently, on the basis of ERL-based FEL oscillator, a THz source with kilowatts average power is proposed in Shanghai, China [9]. In order to achieve an average output power of 1 kW, the average beam current and the beam energy is expected to be 20 mA. To cover the band of 0.5~10 THz, two FEL oscillators are supposed. It is 2~10 THz FEL oscillator with 20 MeV electron beam and 0.5~2 THz with 10 MeV electron beam, respectively. The layout of the THz source is shown in Figure 1.

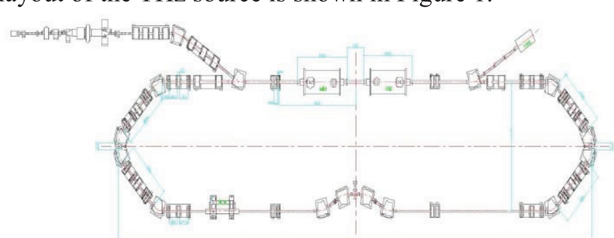

Figure 1: Schematic layout of Shanghai THz source.

The energy of the electron beam extracted from a 500 kV electron source is boosted up to 2 MeV at the injector, and accelerated up to 20 MeV by two 5-cell SRF modules in the energy recovery ring and transported through the THz oscillator. The return electron bunch passes the SRF module again with a decelerating phase for energy-recovery, and then dumped.

By compromising with the accelerating technologies, the photocathode technologies, the beam parameters and the cost, we adopted the NCRF gun design with a low frequency of 250 MHz which is the sub-harmonic of the main frequency of the energy recovery ring. The detail information of the RF and mechanical design, and the cold test results will be shown.

THE RF DESIGN OF THE GUN CAVITY

The re-entrance shape is used in the RF design of the gun cavity. With the larger nose compared to the normal accelerating cavity design, one can get a smaller accelerating gap and higher transit-factor in hence, which is very important to reduce the non-linear emittance growth during the acceleration in the beam dynamics view. In the re-entrance cavity, the electric field concentrates around the beam axis, while the magnetic field concentrates near the outside diameter. This means that one can do the beam dynamics and the RF parameter optimization separately. The beam dynamics study has shown that the accelerating gap should be 4 cm, and this parameter is fixed in the following RF optimization.

The baseline of the RF design is shown in Figure 2. All dimensions except for the G (for the gap dimension), are parameterized during the RF optimization. We have used the 2-D simulation code SUPERFISH [14] to calculate the RF parameters of the gun cavity. During the parametric scan, a short python code has been written to generate the input file for the simulation code, tune the cavity to the right frequency by changing 'R' (for radius of the cavity), and collected the main RF parameters.

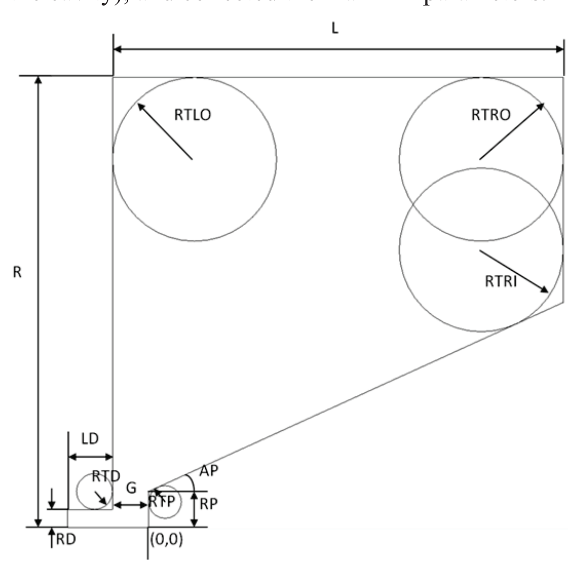

Figure 2: Parameterized dimensions of the gun cavity.

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The result of the parametric scan has shown that all the dimensions could be classified into 2 sets. Rtli, rtlo, and rtro have very limited effect on the RF parameters, while rp, rtp, ap and l have great impact on these parameters (shown in Figure 3).

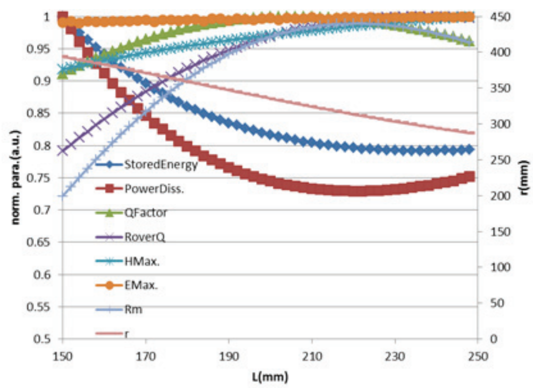

Figure 3: RF parameters of the cavity vs dimension of l.

To operate the cavity at high power, the multipacting should be well suppressed. The multipacting will happen at the condition that the secondary electron yielding factor is great than 1. The material, local shape of the structure and RF power (electric and magnetic field) are the key factors. The structure is the only thing could be optimized. We have used the 2-D simulation code MultiPac [15] to study the multipacting in the gun cavity with parametric scan.

We found that the multipacting moved along the inner surface of the cavity and could not be well suppressed when we changed the dimensions except for l. In the scan result of l, we found the strong relation between the multipacting enhancement factor and the cavity length (shown in Figure 4).

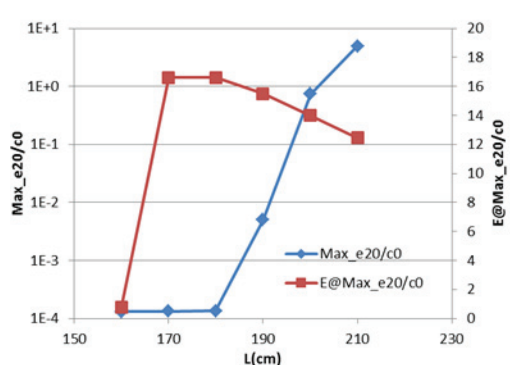

Figure 4: Multipacting enhancement factor vs l.

Firstly, we choose the cavity length of 190 cm for well suppressed multipacting and this cause about 6% increase on the RF power consumption. The effects of other dimensions (rp, rtp, ap) on the impedance, peak electric field and maximum current density are opposite, so the compromised and optimized dimensions are shown in Table 1 and the related RF parameters are shown in Table 2.

Table 1: Optimized dimensions of the gun cavity

Parameters	Values	Units
rp	15	mm
rtp	25	mm
ap	30	deg
g	40	mm
l	190	mm
r	347.222	mm

Table 2: Main RF parameters of gun cavity

Parameters	Values	Units
Frequency	249.82655	MHz
Q	28827.1	
r/Q	176.786	Ohm
Emax/E0	3.0793	
Hmax/E0	0.0013	A/m/V

THE MECHANICAL AND VACUUM DESIGN OF THE VHF GUN

We adopted some ideal from the VHF gun of LBNL [13] during the design. The main difference is that we design a stainless steel vacuum vessel to put the whole copper cavity into (shown in Figure 5). This design removes the atmosphere pressure on the tuning plate and could reduce the tuning force and deformation after evacuation. This design uses additional fixture system for the copper cavity and leads to more interface between water and vacuum, which is much complicate and difficult in manufacture. We have to make a proto-type to check the process of the manufacture.

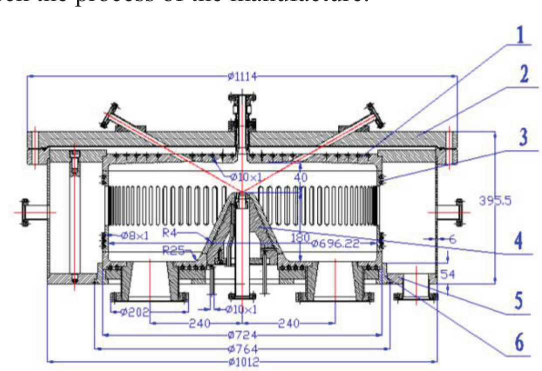

Figure 5: Mechanical design of the gun cavity proto-type.

The thermal and structural analysis has been done to find out the water cooling effect and deformation caused by pressure and thermal stress. The current density from the SUPERFISH code has been converted to the power consumption distribution and import to the ANSYS code. In the analysis, the gap voltage is assumed to be 750 kV and the total RF power is 110 kW. With the cooling water, the maximum temperature is about 85 ºC at the

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centre of the pole surface, while the temperature increase of this circuit is about 50 ºC (shown in Figure 6). The thermal stress dominates the deformation of the structure and the accelerating gap changes about 0.15 mm.

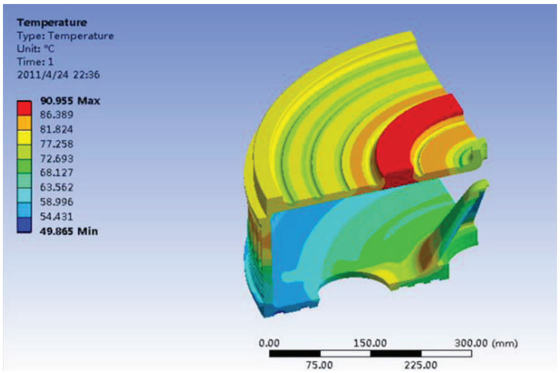

Figure 6: Temperature distribution in the gun cavity.

The maximum hydrogen pumping speed with all NEG pump installed is about 9600 l/s and this pumping speed is reduce to 3900 l/s by the pumping slots. The estimated vacuum pressure could be down to 10^{-9} Pa.

THE COLD TEST

The gun cavity proto-type has been manufactured and integrated in SANHAO vacuum instruments Co. Ltd. The photo of the testing area is shown in Figure 7.

Figure 7: Gun cavity proto-type in test area.

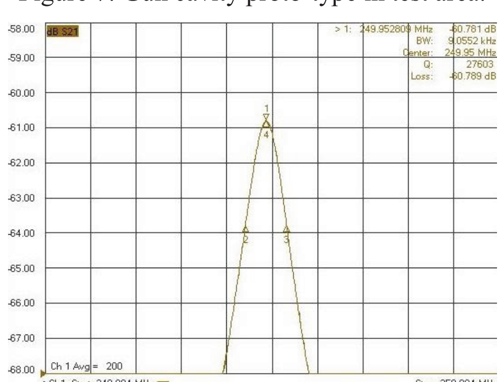

Figure 8: RF measurement of the gun cavity proto-type.

There have been one 1000 l/s ion pump and eight 400 l/s NEG pump installed to the cavity and the vacuum pressure is about $5*10^{-9}$ Torr with low temperature baking. Two pick-ups have been installed to the cavity and the S21 has been measured. The frequency is 249.95 MHz and the Q value is about 27000 shown in Figure 8.

CONCLUSION

The RF parameters and basic dimension of the VHF gun have been optimized and the mechanical and vacuum design and analysis have been done. A proto-type has been made and the measured RF parameters are close to the design value.

We also find some problem during the manufacturing and the design is under updating now. A new gun for the high power test and beam test will be ready in the next year.

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