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SUPPRESSION OF SECONDARY ELECTRON YIELD EFFECT IN THE 650 MHz/800 kW KLYSTRON FOR CEPC*

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Abstract

The Circular Electron Positron Collider (CEPC) is in pre-research, it will need more than two hundred 650 MHz/800 kW klystrons. The secondary electron yield (SEY) effect suppression is very important for the klystron working stable. The simulation uses an incident primary electron source and considers all the phases and power levels of the input microwave. Two methods are simulated for the SEY suppression. The groove cutting on the nose of cavities is much simple while the TiN coating can suppress better. The effect after groove cutting on nose is also simulated and the corresponding compensations are adopted. For simplifying the fabrication progress as well as some experience that can be referenced, the groove cutting method is adopted finally for the first klystron prototype, which is expected to be available in the summer of 2019.

INTRODUCTION

In July 2012 at the Large Hadron Collider, the Higgs particle was discovered, it is then a very important issue of the further research and measurement in Higgs for particle physics. For the Higgs' energy is much lower than expected, it is very possible for building a circular collider as a Higgs factory, the CEPC at 240 GeV centre of mass for Higgs studies is then proposed by Chinese scientists in September 2012 [1].

The design scheme of CEPC after further consideration and discussion is using a circumference of 100 km with double ring, the superconducting cavities are finally adopted and will be fed by 650 MHz/800 kW Continuous Wave (CW) klystrons, with a demand of more than two hundred. The pre-research of the first klystron prototype started in June 2017, and is expected to be available by the summer of 2019.

As all known, one of the main reasons why the klystron working unstable is the SEY effect [2-4], so the suppression is quite important. Two mainstream methods to suppress SEY are groove cutting and TiN coating, the former method is much simple while the latter one having better consequents.

Both two methods are simulated and compared, the nose groove cutting is finally adopted for the first klystron prototype for simplifying the fabrication process. The effect on microwave performances after groove cutting is also simulated and the corresponding compensations are considered.

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SIMULATION OF THE SEY EFFECT SUPPRESSION

The Method of Cutting Grooves on Nose

The klystron is designed to be working at 650 MHz and expected an output CW power of more than 800 kW. Six cavities including a second harmonic cavity are adopted to achieve a 45 dB Power Gain (PG), for a single cavity usually provides a PG around 10 dB, and the second harmonic cavity basically has no effect on the PG. The design parameter of the klystron is listed in Table 1.

Table 1: The Design Parameter of the 650 MHz/800 kW Klystron

Parameter	Value
Operating frequency	650 MHz
Beam voltage	81.5 kV
Beam current	15.1 A
Beam perveance	0.65 μA/V$^{3/2}$
Efficiency at rated output power	≥60 %
Saturation gain	≥45 dB
Output power	~800 kW
Brillouin field	106.7 Gauss
Reduced plasma wavelength	3.47 m
Number of cavities	6
Normalized drift tube radius	0.63
Normalized beam radius	0.41

By periodically cutting grooves in the circumferential direction on the nose of cavity, the SEY is significantly suppressed. There are 36 grooves on each nose, the width of the central angle of each groove and the interval between adjacent grooves are both 5 degrees. On the opposite side of nose, the center spacing of the corresponding grooves is also 5 degrees. The schematic diagram of the grooves on nose is shown in Fig. 1.

The simulation of the SEY is calculated in the Computer Simulation Technology (CST) particle studio. A surface electron source on the nose is defined with about 5000 particles. The parameter setting of the electron source is listed in Table 2. The particle tracking calculation is adopted, the electromagnetic field of the cavity is imported from the CST microwave studio for saving simulation time. The material of the cavity is chosen as SEE-copper from the CST material library.

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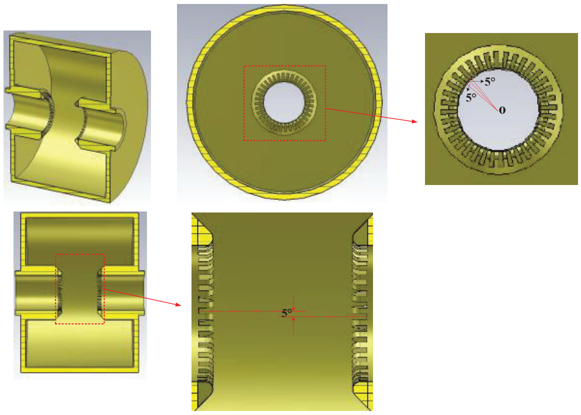

Figure 1: The schematic diagram of the grooves on nose.

Table 2: The Parameter Setting of the Surface Electron Source in CST Particle Studio

Parameter	Value
Type	Uniform distribution
Number of particles	>5000
Absolute current	0.1 A
Kinetic value	2 eV
Kinetic spread	200 %
Angle spread	45 degree

The simulated results of the SEY before and after groove cutting are shown in Fig. 2. The curves are based on the input (1st) cavity working at the modulation voltage 900 V and 800 V. The abscissa is the phase of the electromagnetic field at the nose while the ordinate is the SEY value. It can be seen that for a fixed modulation voltage value, the groove in the circumferential direction of the nose can effectively suppress the secondary electron multiplication effect.

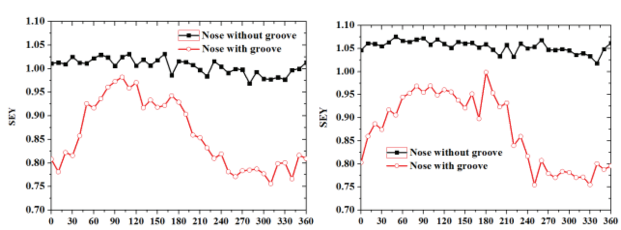

Figure 2: The SEY curve before and after groove cutting of the input cavity working at modulation voltage 900 V (right) and 800 V (left).

The grooves will be cut on the noses for all the six cavities of the klystron, however, the SEY of the cavity is only simulated for the input (1st) cavity, 2nd cavity and the output (6th) cavity. The maximal SEY (MSEY) and the average SEY (ASEY) curves are shown in Fig. 3 for the input cavity by modulation voltage from 50 V to 900 V. The ASEY is the averaged SEY values of the 360-degree-phase electromagnetic field (by 10-degree step). It is very clear that with the increase of the modulation voltage, the groove cutting can suppress both the MSEY and the ASEY.

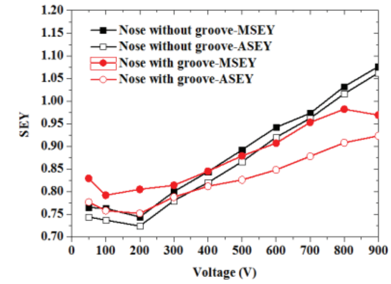

Figure 3: The SEY curve VS modulation voltage for the input cavity.

The Method of TiN Coating

The TiN coating method is also considered and simulated, the SEY curve of TiN material is converted into txt file and then imported into the CST particle studio. As we can see from Fig. 4 [5], For a given energy, the SEY value of the TiN material (purple curve) is much lower than copper OFHC (green curve), which results in the better suppression of the secondary electrons as shown in Fig. 5.

However, the groove cutting method is finally adopted for the first klystron prototype considering the simplicity of fabrication, though the TiN coating method has better effect.

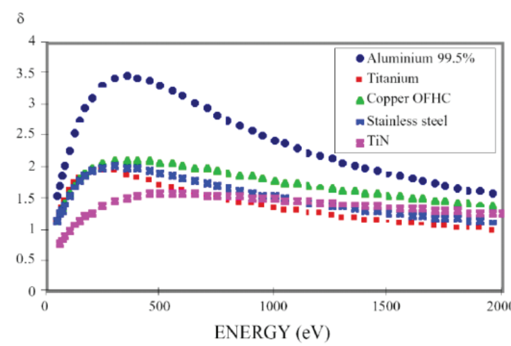

Figure 4: Typical SEY curves for various materials.

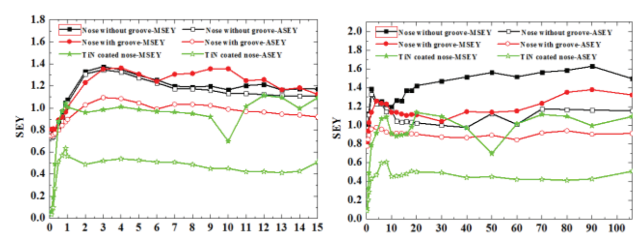

Figure 5: Compare of SEY for TiN coating, groove cutting and no suppression method adopted for the 2nd cavity (left) and the output cavity (right).

Influence of Groove Cutting on Cavity and Corresponding Compensations

As the maximal electrical field in the cavity is on the noses, the grooves should effect the microwave parameters of the cavity, which need to be simulated. The simulation results show that frequency is effected most while the quality factor as well as the R over Q almost the same after groove cutting.

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The frequency changes after groove cutting of the six cavities are listed in Table 3, the JDM, AKS and tetrahedral mesh are different simulation or meshing methods for mutual verification of simulation results. The frequencies increase by about 10 MHz for the 3rd cavity and 2 MHz for the rest cavities. The radius of the six cavities are then increased correspondingly for compensating the frequency changes.

Table 3: The Simulated Frequency Changes after Groove Cutting of Six Cavities

Cavity number	Frequency change (MHz)		
	JDM	**AKS**	**Tetrahedral mesh**
1	+1.93	+2.05	+1.7
2	+1.95	+2.04	+1.68
3	+11	+11.6	+9.7
4	+2.66	+2.8	+2.32
5	+2.41	+2.58	+2.15
6	+1.58	+2.2	+2.49

CONCLUSION

The SEY are considered and simulated in the CST particle studio for the first CEPC 650 MHz/800 kW klystron prototype. Both the groove cutting and TiN coating methods can significantly suppress the SEY value according to the simulation, and the former one is adopted considering the simplicity of fabrication. The influence of groove cutting on cavity is also simulated and the corresponding compensations are adopted for the guarantee of resonant frequency of the cavities.

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