DESIGN STUDY OF RF SECTION AND CAVITIES FOR CEPC 650 MHz KLYSTRON

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Abstract

An 800 kW CW klystron operating at 650 MHz is developed for CEPC at Institute of High Energy Physics in China. The conceptual design has been finished and the main parameters are presented in this paper. A 1D large signal disk model code, AJDISK, has been used to design and optimize klystron RF section parameters. In addition, the RF cavities have been designed using SUPERFISH, HFSS and CST.

INTRODUCTION

Recently the future plan of Circular Electron Positron Collider (CEPC) is proposed at Institute of High Energy Physics (IHEP) in China [1]. In this project, 192 sets of 800 kW CW klystron with a frequency of 650 MHz are used [2]. The operational efficiency of a klystron greatly determines the running cost of CEPC, so the high efficiency klystron is regarded as the key technology to be developed. Up to now, the main sections of the klystron for CEPC have been designed. The gun design [3] and the collector design [4] are presented in this conference. The design for the RF interaction region including cavity design is presented in this paper.

How to improve the efficiency of the klystron is a hot subject in the field of the klystron research. After decades of developments, the theory and technology of the high efficiency klystron have made great progress. Some classical techniques such as using a low perveance, harmonic bunching [5] and a multi-beam klystron [6] have been used in commercial klystrons. Recent progresses such as adiabatically bunching [7], the BAC theory [8], the congregated bunch theory [9] and the depressed collector method [10], are very perspective nowadays.

For the CEPC klystron development, due to the lack of R&D experience of a high efficiency CW klystron, the efficiency goal is just set to be larger than 65-70% at first stage using a second harmonic cavity. In fact, even in this approach, there was an example to obtain 75% efficiency [11]. Our goal is more than 80% for the ultimate objective; therefore we have a strategy to develop step by step to obtain the experience. The first klystron prototype will use this mature approach to ensure the feasibility of design.

KLYSTRON MAIN PARAMETERS CONSIDERATION

The klystron efficiency depends largely on the quality of electron bunching. The high fundamental beam current and the low velocity spread are prerequisite for obtaining the high efficiency. To get a good electron bunching, the space charge forces must be reduced. The klystron beam perveance is normally used as the measure of space charge forces. The lower the perveance is, the weaker the space charge force is, and the higher the efficiency is. Since there is an upper limit to the gun voltage due to the electric field break down, we need to make a trade-off between the efficiency and the operating voltage for a single-beam klystron design. According to the Thales empirical relation, an efficiency of 68% can be expected with a perveance of 0.65 $\mu A/V^{3/2}$ [12].

Table 1: CEPC Klystron Main Design Parameters

Parameters	**Value**
Operating frequency	650 MHz
Beam Voltage	81.5 kV
Beam Current	15.1 A
Beam Perveance	0.65 $\mu A/V^{3/2}$
Efficiency at rated Output Power	⩾65%
Saturation Gain	⩾45 dB
Output power	800 kW
1 dB Bandwidth	±0.5 MHz
Brillouin Magnetic 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
Beam Fill Factor	0.65

The normalized beam radius can influence the coupling coefficient between the beam and the cavity field. For a high efficiency klystrons design, this value can be chosen from 0.4 to 0.6. In the case of a given normalized beam radius, the larger the fill factor is, the higher the efficiency is. In order to reduce the electron interception especially in CW klystron, this fill factor can be selected between 0.6 and 0.8. The focusing magnetic field is generally chosen to be 2-3 times of the Brillouin magnetic field to

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get the rigid beam. The number of cavities is determined by the gain and the bandwidth. The main design parameters for the CEPC klystron are listed in Table 1.

RF SECTION DESIGN AND OPTIMIZATION

The RF section plays an important role in the klystron performance like the gain, the bandwidth and the overall efficiency. The CEPC klystron consists of five fundamental cavities and a second harmonic cavity. To get maximum efficiency, all fundamental cavities have been tuned to frequencies which are higher than the operating frequency. The third cavity is a second harmonic cavity, tuned to slightly below the second harmonic frequency, which can reduce the bunch core charge density to bunch more electrons so as to produce the high fundamental RF current. The fourth and fifth cavities have great influence on the klystron efficiency, which are tuned to outside the band pass at the high frequency side. When the drift tube and beam size are fixed, the coupling coefficient is almost determined by the cavity gap length. For the bunching section cavity, a relatively large gap length is desired to have a high gain and a wide bandwidth since the cavity has a large R/Q. But for an output cavity, a small gap length can improve the conversion efficiency due to the high coupling coefficient.

AJDISK is a 1D large signal klystron simulator developed at SLAC [13]. Its primary use is to run fast large signal design simulations prior to running more accurate and time consuming 2D and 3D simulations. With the aid of AJDISK, the lengths of the drift sections between the six cavities and the cavity characteristic parameters such as frequency, R/Q and coupling coefficients are optimized to obtain a maximal efficiency. All initial input parameters for AJDISK can be calculated using small signal formulas. The results of AJDISK indicate that efficiency of more than 74.5% and the gain of 48 dB can be achieved. The AJDISK simulation results are shown in Figure 1. The bandwidth response and the transfer curve are shown in Figure 2 and Figure 3 respectively. In order to avoid possible oscillations, particular attention was paid not to produce the reflected electrons in the output cavity. Since the 1D simulation does not consider the effect of the focusing magnetic field, the 2D and 3D simulations should be carried out to validate these results as soon as possible.

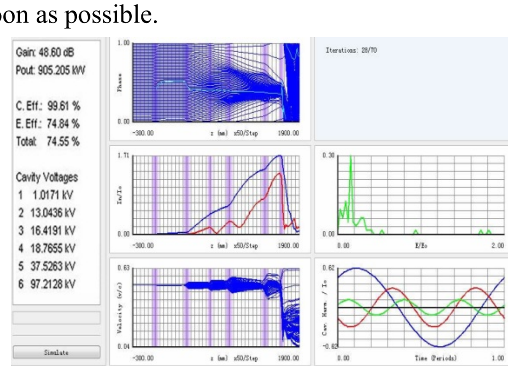

Figure 1: AJDISK simulation results.

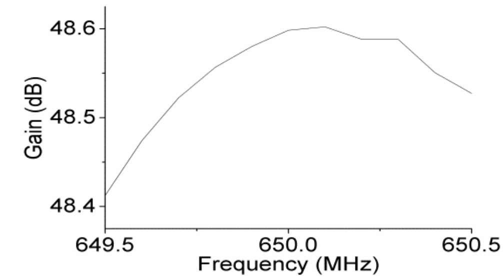

Figure 2: Bandwidth response.

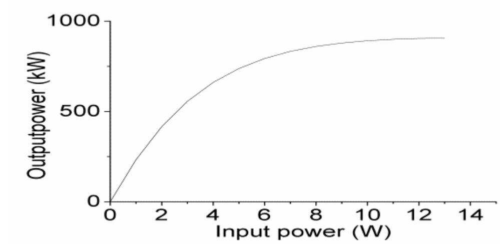

Figure 3: Transfer curve.

CAVITY DESIGN

The cylindrical re-entrant cavities with the knife edge nose cone are used in RF section of our klystron, which are designed to operate in the TM_{010} mode. The gap and the drift tube dimensions have been determined in RF section design. The shape and size of the nose cone are determined by considering the characteristic impedance R/Q, the maximum surface electric field and the water cooling capability. The diameter and height are decided finally to get the desired resonant frequency and the maximum characteristic impedance. The oxygen free high conductivity (OFHC) copper materials will be used for fabrication of the cavities because of the low ohmic losses and the high thermal conductivity. When designing the cavity, following considerations are taken into account:

1. Electric breakdown must be avoided by limiting the peak surface electric field, especially in the output cavity design.

2. High order modes must be suppressed, especially the TM0mn mode by keeping these mode frequencies away from the high order harmonic frequency.

3. Multipacting effect must be suppressed by cutting groove in nose cone (castellated tips) [14]

With the aid of electromagnetic simulation tools such as SUPERFISH [15], CST Microwave Studio [16] and High Frequency Structure Simulator (HFSS)[17], all cavities have been optimised to meet the RF section requirement. The SUPERFISH was used for the initial optimisation of the cavity geometry due to its fast simulation speed. Then the optimized dimensions are taken as the input for CST and HFSS to calculate the frequency and R/Q. The simulation results of the fourth cavity are shown in Table 2 using the different simulation tools: they are good agreements.

Table 2: Comparison of Results with Different Tools

Parameters	SUPERFISH	CST	HFSS
f (MHz)	670.26	670.11	670.2
R/Q	152.86	152.89	152.85

The electromagnetic field distribution of the TM_{010} mode from CST is shown in Figure 4 and Figure 5. To suppress the high order mode, the radius and the height of the cavity vary at the same time to keep the frequency of the TM_{010} mode constant, whereas all other resonant mode frequencies especially TM_{0mn} vary away from high order harmonic frequencies, as shown in Table 3. The relation between the radius and height of one of cavities is shown in Figure 6.

Table 3: High Order Mode Frequency

Mode	Frequency (MHz)
TM_{011}	979.47
TM_{012}	1892.92
TM_{020}	2312.79
TM_{021}	2414.34

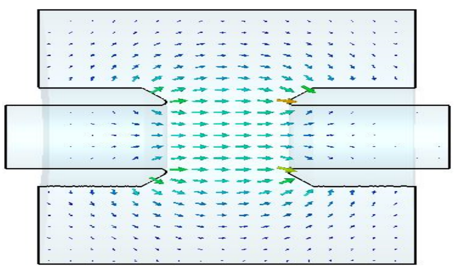

Figure 4: Electric field pattern of TM_{010}.

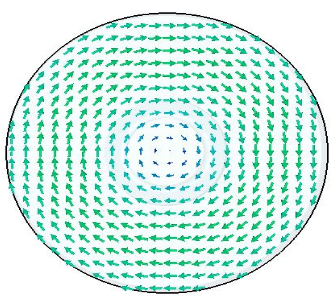

Figure 5: Magnetic field pattern of TM_{010}.

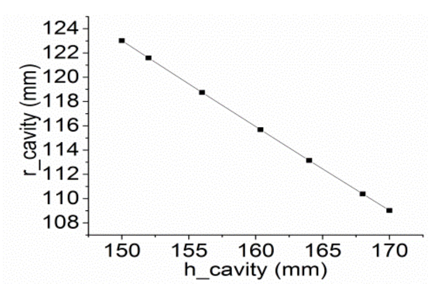

Figure 6: The relation between the radius and the height.

CONCLUSION

The preliminary design of RF section for an 800 kW CW klystron operating at 650 MHz has been completed using AJDISK code. The validation and optimization of design parameters of complete RF section using 2D and 3D codes are in process. The results of different CAD tools for cavity design give good agreements. The coupling loop design for input and output cavity and cavity multipacting effect analysis will continue in future.

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