CEPC 650 MHz KLYSTRON DEVELOPMENT*

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Abstract

The beam power of the CEPC collider is about 100MW, so an efficiency of an amplifier is very important for cost of project implementation. A high power klystron is the more attractive as an RF source because of its potentiality for a higher efficiency than a solid state amplifier and a much stable operation than an IOT. There is a renewed interest worldwide to improve efficiency of klystron. For CEPC klystron an output power is not so high, and the operation voltage can be a safe value. Advantage for a single beam: reliable, low phase noise, some perspective technology can be used to improve efficiency. The accelerating frequency is 650 MHz, the output power is a maximum power of 800 kW, and efficiency goal is about 80%. In this paper, the specifications and developments of 650 MHz CW klystron, including a design, a beam tester and a future high efficiency consideration are summarized.

INTRODUCTION

Accelerators used for experiments in high-energy physics require very high power RF sources to provide the energy needed to accelerate the particles. Most popular RF source for the accelerator is a klystron, which has advantages to operate at a high power with a reasonable high efficiency; saving the power loss and cost. As the CEPC (Circular Electron and Positron Collider) collider the beam power is about 100 MW, a high efficiency RF source is very important since the electric power is directly related to the operation cost due to the large numbers of RF source [1]. The high power klystron is the more attractive as RF source because of its potentiality for a higher efficiency than a solid state amplifier and more stable operation than an IOT.

The CEPC SRF (Super-conducting RF) system consists of 384 RF stations per beam. Each RF station includes a 5-cell 650 MHz accelerating superconducting cavity. In addition to the energy losses due to radiation in dipoles, damping wigglers, and undulators, the RF power transmitter must provide for the HOM losses excited by the beam. A minimum transmitter power of 280 kW is required to meet the sum of the radiated, HOM, and reflected power demands. With one klystron for two cavities, the specified saturation power of the klystron should be in the range from 600 to 700 kW. This takes into an account to operate a klystron in a linear operation region, and losses of a circulator and a waveguide. The choice of one klystron for two cavities is justified technically by better control of microphonic noise and minimum perturbation in the case of a klystron trip.

Table1 shows the RF power requirements for the CEPC collider SRF system. The CEPC collider RF power source configuration is shown in Figure 1.

Table 1: CEPC Collider SRF System Parameters

Frequency	MHz	650
Cavity type	5-cell	5-Cell
Cavity No.		384
Kly. No.		192
Kly. power	kW	800

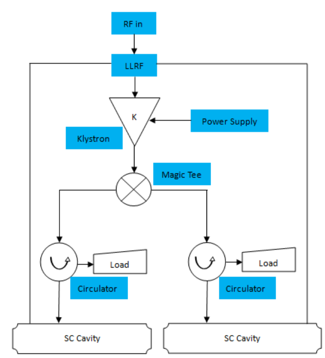

Figure 1: RF power source configuration.

DEVELOPMENT STRATEGY

Considering the klystron operation lifetime and power redundancy, each cavity will be individually powered with a CW klystron amplifier capable of delivering more than 400 kW. A single 800 kW klystron amplifier will drive two of the main ring cavities through a magic tee and two rated circulators and loads.

The klystron, with gun and collector, would be about 4 m in length and could be manufactured in industry by a partnership between IHEP and an industrial company. Computer simulation tools are used to design the klystron including the electron gun, electromagnet, cavities and RF output structure.

In order to fulfil this program, there may have following problems. IHEP have not experienced to manufacture the high power, UHF klystrons. There is not the big fur-

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nace infrastructure in China also. Design and simulation are not enough and matured, therefore we need to step up one by one. In order to save the money and time, demountable structure is available way. The first step is set up beam test stand to verify gun and collector design, and then to connect cavities part for classical klystron prototype, then finally to change classical cavities to high efficiency part to check final development. The klystron development strategy is shown in Figure 2.

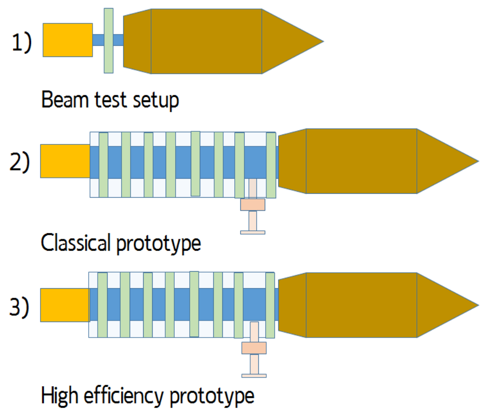

Figure 2: Klystron development strategy.

DESIGN CONSIDERATION

The increase in efficiency of RF power generation for CEPC is considered a high priority issue. The vast majority of the existing commercial high-power pulsed klystrons operate in the electronic efficiency range between 40% and 55%. Only a few continuous wave and multi-beam klystrons available on the market are capable of operating with 65% efficiency or above. A new method to achieve 90% RF power conversion efficiency in a klystron amplifier is presented in A. Y. Baikov's paper [2].

Table 2: CEPC Klystron Key Design Parameters

Frequency(MHz)	650	650
Output Power(kW)	800	800
Beam Voltage(kV)	80	70
Beam Current(A)	16	15
Efficiency	65	80

Considering the recent high efficiency approach, our goal of the efficiency is set to be 80%, and the strategy described in the previous section is the first step. Multi-beam approach may be a future task. The design parameters for CEPC 650 MHz klystron are shown in Table 2.

Electron Gun

Though the future tube employs a diode gun, at first an electron gun with a modulating anode (MA) is designed using DGUN software [3]. The uniform beam trajectories, with a beam perveance of 0.64 $\mu A/V^{3/2}$ are designed. We employed a Ba-dispenser cathode of radius 35 mm with Φ10 hole at the centre and obtained a current density on cathode less than 0.45 A/cm^2. The beam trajectories were also simulated over whole tube length with a magnetic field of 207 Gauss. More simulation results are presented in this conference [4]. The design parameters of CEPC klystron gun are shown in Table 3. Simulation results using DGUN code are shown in Figure3. Left shows beam trajectory and maximum electric field on electrodes. Right shows the current density on cathode.

Table 3: CEPC Klystron Gun Parameters

Cathode voltage.	kV	-81.5
MA voltage.	kV	-47.5
Beam waste diameter	mm	34.4
Beam/Gun perveance.	$\mu A/V^{3/2}$	0.64/1.45
Avg. cathode density.	A/cm^2	0.45
Cathode uniformity		1.24

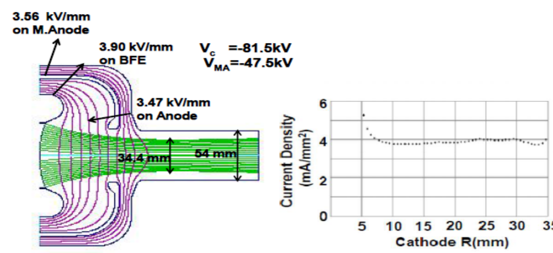

Figure 3: DGUN simulation results.

RF Interaction and Cavities

Computer simulation tools for klystron cavities design have become a great necessity in many laboratories around the world. To achieve much higher conversion efficiency, the RF interaction and cavities design for klystron are strongly studied. This activity has started recently, integrating the earlier proposed concepts of the congregated bunch and regularized bunching [5].

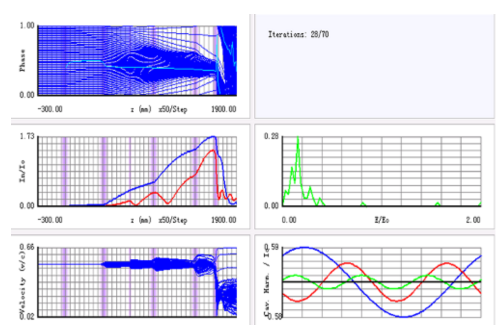

Figure 4: AJDISK simulation results.

In our case, at first, the classical approach of cavity layout was chosen. In fact, there was an example in the past to have a 75% in this approach [6]. The RF interaction and cavity design is described and an optimized result of 74% using AJDISK [7] is reported in this conference [8]. Figure 4 shows AJDISK code simulation result.

Collector

The capability of collector beam dissipation is an issue, and if whole beam power is dissipated without RF drive, it should be reached up to 1.2MW. While if the dissipated power is limited in the case of RF on, it is less than 400 kW. At first, a former case with pure water cooling was considered. Then the collector has sizes 203 cm in diameter and 45.7 cm long, and has cooling channels in its body. Figure 5 shows profile of collector.

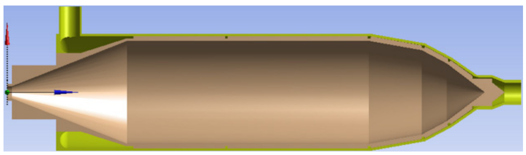

Figure 5: Collector profile.

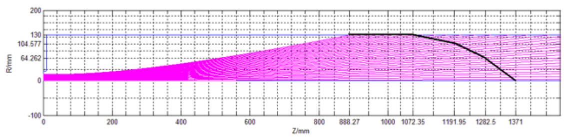

Figure 6: Electron beam trajectory.

Simulation of the beam dynamics in electron guns was also made by DGUN and EGUN codes [9]. Figure 6 shows the result of collector simulation for CEPC klystron. Collector thermal analysis is show in Figure 7. More details about collector design are presented in this conference [10].

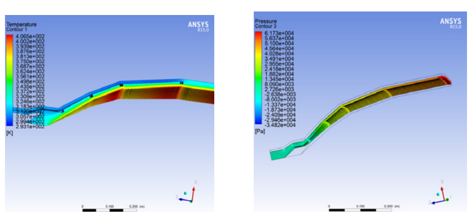

Figure 7: Collector thermal analysis.

Output Window

Coaxial output window is now designed as one of the important issues for developing the high power klystrons. For designing windows, an average power capability and multi-pactoring analysis for fundamental and harmonic frequency are important issues. The electromagnetic simulation of an output window was carried out using CST Microwave Studio Code [11]. We have optimized the return loss and a loss not only at the desired frequency but also in the entire range of desired bandwidths. Figure 8 shows the reflection coefficient in the desired frequency range.

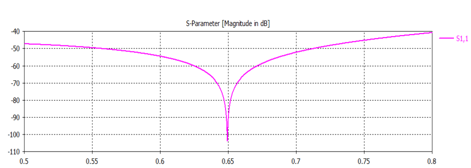

Figure 8: The reflection coefficient.

The more thermal and mechanical analysis will be done in the near future and cooling system design is also included.

BEAM TESTER AND FUTURE PLAN

Considering the manufacturing restriction and empirical training, we have a plan to start from beam test stand including gun and collector and then add the interaction region between gun and collector. The beam test stand includes gun, collector and focusing magnets to verify design of gun and collector. Figure 9 shows simulation results of beam tester using DGUN code.

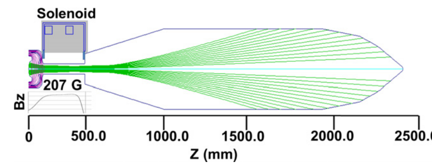

Figure 9: Simulation results of beam tester.

The design for gun and collector will be completed at the end of this month and mechanical design for beam tester is in progress. And its fabrication is about to begin in a few months. The design of window for classical and high efficiency klystron is also under way. Design of output window is also in progress and we have planning to build high power test stand together ADS RF power source facility.

The whole length of CEPC klystron layout is reached up to about 4.5 m and current limitation for the baking furnace, different size of the collector is also considered. For such a big and high efficiency klystron development to succeed, both international and domestic cooperation is necessary.

CONCLUSION

The design of 650MHz klystron for CEPC project has been summarized. The gun, cavities, collector and output window are designed to meet the specifications and capacities of specific infrastructures. The beam tester will be built and the test stand is also prepared in the near future. We also plan to train domestic industries in the component fabrication and processing.

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