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DESIGN PROGRESS OF HIGH EFFICIENCY KLYSTRON FOR CEPC LINAC *

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Abstract

The injector linear accelerator (LINAC) for the CEPC requires a higher efficiency klystron with 80 MW output power than S band 65 MW pulsed klystron currently operating in LINAC of BEPCII to reduce energy consumption and cost. The efficiency is expected to improve from the currently observed 42% to more than 55% and output power will be improved from 65MW to more than 80 MW with same operation voltage. In this paper, BAC bunching method is applied for klystron efficiency improvement. The optimization of the gun and solenoid parameters is completed with 2-D code DGUN and then 3-D code CST. The preliminary design of the cavity parameters is also completed in 1-D disk model based AJDISK code and then further checked by 2-D code EMSYS. Finally, new klystron prototype will be fabricated in Chinese company after design parameters are determined.

INTRODUCTION

After the discovery of the Higgs particle at Large Hadron Collider (LHC) in 2012, a 240 GeV Circular Electron Positron Collider (CEPC) was proposed at institute of high energy physics (IHEP), China [1]. The design of CEPC RF source system includes CW klystron for CEPC collider and pulsed klystron for CEPC LINAC. In order to reduce the energy consumption and cost, the main goal of the klystron design is efficiency improvement. Several methods have been proposed to increase the efficiency of a klystron. These methods can be divided into two main categories: The first kind is a multi-beam klystron (MBK) which has several low perveance beam-lets because lower perveance usually corresponding to higher efficiency [2]. Each beamlet carries a small amount of current, but the total current can be large. The other kind focuses on novel bunching mechanisms. Based on this idea, the core oscillation method [3], bunching-alignment-collection (BAC) [4], and core stabilization method (CSM) [5] are proposed.

The RF power source system of CEPC LINAC includes 75 sets of pulsed klystron operating at a frequency of 2860 MHz. The power of these klystron are excepted to be 80MW so that the gradient of the accelerating structure will be 22 MV/m as shown in Fig. 1 [1]. Based on the existing S band 65 MW klystron currently applied in the BEPCII LINAC injector, the BAC method will be adopted to increase the klystron efficiency from 42% to 55% to meet the CEPC power requirement. Table 1 compares the parameters of the klystron operating in BEPCII and the proposed BAC-based klystron. The output power will be improved from 65 MW to 80 MW with the same beam power.

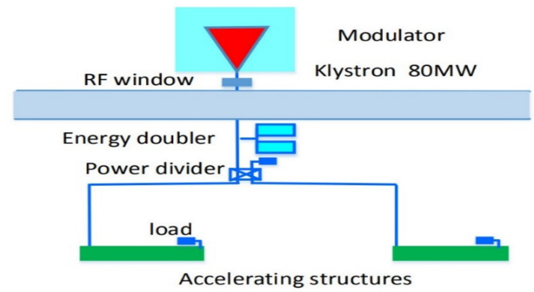

Figure 1: Accelerating structure of CEPC LINAC.

Table 1: Klystron Parameters

Parameters	Original	BAC-based
Operating frequency	2856 MHz	2856 MHz
Output power	65 MW	80 MW
RF pulsed width	4 μs	4 μs
Beam voltage	350 kV	350 kV
Beam current	414 A	414 A
Beam perveance	2.0 μP	2.0 μP
Efficiency	42%	55%

BAC METHOD

The BAC method consists of 3 stages: traditional bunching, alignment velocity spread of electrons and collecting outside electrons [6]. Compared with COM bunching mechanism, BAC method can shorten the length of klystron besides improving efficiency. The present BEPCII S band 6 5MW klystron has 6 cavities in its interaction section. In order to apply BAC method, we insert 4 additional cavities including 2 second harmonic cavities between the 4th and 5th cavity of the original klystron. Various codes, such as AJDISK [7], EMSYS, MAGIC, KLYC and CST, can be used for klystron dynamic simulation. The 1-D code AJDISK is suitable for the preliminary optimization of the interaction section parameters. Based on AJDISK, a 1-D automatic optimization code via NSGA-II was developed at IHEP. With this code, the length of the drift tube between the cavities and the cavity characteristic parameters such as frequency, R/Q and coupling coefficient are optimized to obtain a maximal efficiency. And then these parameters are further checked by 2-D code EMSYS combined with the parameters of gun and solenoid.

Figure 2 shows the 1-D AJDISK simulation result of the original klystron and the proposed BAC-based klystron. With the help of the four new cavities, the process of the electron core oscillation and the process of collecting 'particle-outsiders' is accelerated. Therefore, compared with

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the original klystron, more outside particles are collected by the interaction section of the BAC klystron at the output cavity. The 1-D efficiency is improved from original 49% to 64%.

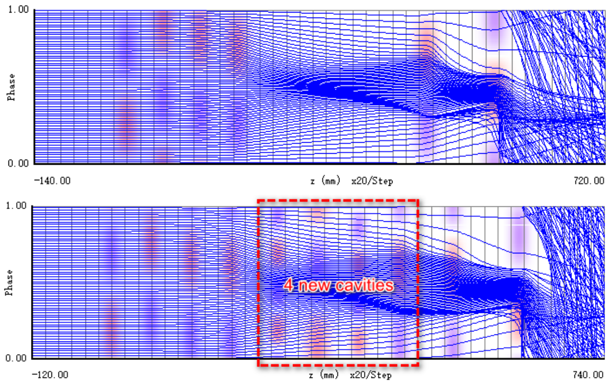

Figure 2: 1-D simulation result in AJDISK.

GUN AND SOLENOID

The prototype of the electron gun for the new BAC-based klystron is optimized from that of the original one. Table 2 compares the parameters of the previous gun and the new one. While keeping the parameters like beam voltage and beam current same, the radius of the drift tube is decreased from 15.986 mm to 12.3mm to cut off the second harmonic wave. With the same fill factor 70%, the radius of the beam should be 8.65 mm. Figure 3 shows the electric filed on z axis around one of the second harmonic cavities with 12.3 mm drift tube radius. That means it will be safe if the distance between each cavity is more than 40 mm.

Table 2: Comparison of the Gun Parameters

Parameters	**Original**	**BAC-based**
Beam voltage	350 kV	350 kV
Beam current	414 A	414 A
Beam perveance	2.0 µP	2.0 µP
Drift tube radius	15.986 mm	12.3 mm
Beam radius	9.45 mm	8.65 mm

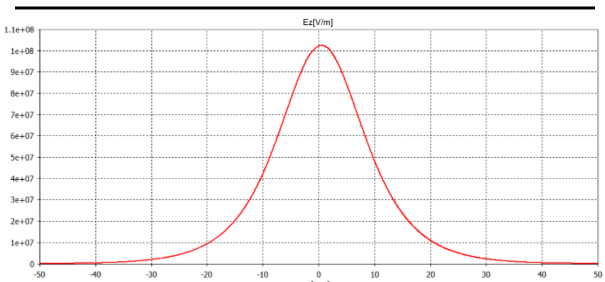

Figure 3: The electric field on z axis around a second harmonic cavity.

The solenoid of BAC-based klystron are also re-designed based on the original one. Because we have extended the length of the interaction section to achieve a higher efficiency, it is necessary to have a longer magnet that also has a stronger field at the output cavity to suppress the stronger space-charge effect [8]. The value of the magnetic field is firstly simulated by 2-D code POISSON SUPERFISH [9] and then input to 2-D code DGUN for beam optics simulation. Figure 4 compares the magnetic field value of the BAC-based klystron and that of the original one. The result is also checked by 3-D code CST. Figure 5 and Table 3 shows the comparison of beam optics simulation result in DGUN and CST. The maximum of the beam radius is below 8.65 mm, and the beam ripple is less than 5%.

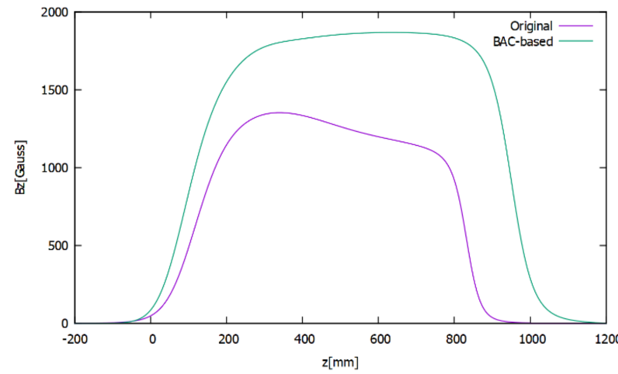

Figure 4: Comparison of the magnetic field on z axis.

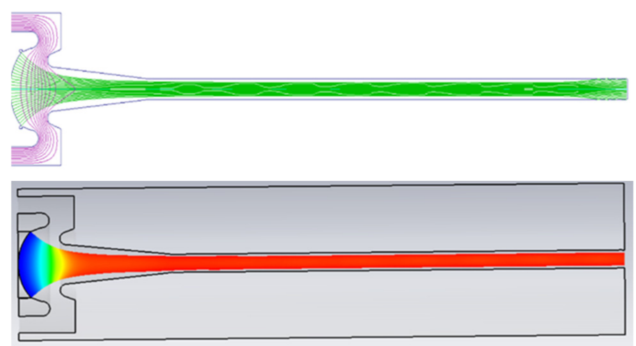

Figure 5: Beam optic simulation result in DGUN and CST.

Table 3: Beam Optic Parameter in DGUN and CST

Parameters	**DGUN**	**CST**
Beam perveance	1.978 µP	1.997 µP
Beam maximum radius	8.54 mm	8.64 mm
Beam minimum radius	7.93 mm	8.02 mm
Beam ripple	3.7%	3.6%

2-D DYNAMIC SIMULATION

Because of the limitation of 1-D code, we have to check the parameters obtained from AJDISK with 2-D code and even 3-D code. With beam optic parameter from DGUN, the dynamic simulation of interaction section is firstly done in the 2-D code EMSYS. Figure 6 shows the comparison of the simulation result of the original klystron and the new BAC-based klystron. As is shown in these two situations, more electrons are bunched at the output cavity of BAC-based klystron than that of the original one. The 2-D efficiency simulation result increase from original 45% to 54%, 10% lower than 1-D simulation result. From our experience, however, the efficiency simulation result in EMSYS is usually 5% lower than that in AJDISK. To solve this problem, we have tried to adjust the mesh density in EMSYS, but there was no obvious change in the result. The

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optimization work is still ongoing now, and there are also some other possible problems we need to find out in further study.

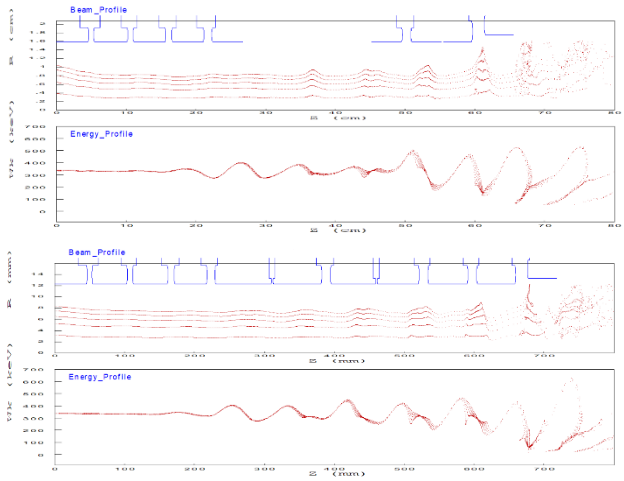

Figure 6: Beam and energy profile simulated by EMSYS

SUMMARY AND OUTLOOK

For the design of the CEPC LINAC klystron, we try to apply the novel bunching mechanism known as BAC method to the current BEPCII LINAC klystron. Now, the gun and the solenoid are well optimized according to the new requirement. The efficiency result simulated by 1-D code AJDISK is shown 64% while the 2-D simulation result in 2-D code EMSYS is 54% which is 5% lower than our expectation. The optimization work will be continued in the future. And then we will check the dynamic simulation result in 3-D code CST. Besides, the cooling system and the output window should also be re-designed due to the increase of the magnetic field and the output power. We hope the fabrication of the first prototype of CEPC LINAC klystron will start in Chinese company as soon as possible.

REFERENCES

[1] CEPC Conceptual Design Report, IHEP, Beijing, China, Rep. IHEP-CEPC-DR-2018-01, 2018.

[2] A. Larionov *et al.,* "Design of Multi-Beam Klystron in X Band", in *Proc. 27th Linear Accelerator Meeting*, Kyoto, Japan, 2002.

[3] A. Yu. Baikov, C. Marrelli, I. Syratchev, "Toward high power klystrons with RF power conversion efficiencies on the order of 90%", *IEEE. Trans. Elec. Dev.,* vol. 62, no. 10, pp. 3406-3412, Oct. 2015.

[4] R. V. Egorov, I. A. Guzilov, "BAC-klystron: a new generation of klystrons in vacuum electronics", *Moscow University Physics Bulletin*, Vol. 74, No. 1, pp 38-42, 2019.

[5] G. Burt *et al.,* "Particle-in-cell simulation of a core stabilization method klystron", in *Proc. IEEE International Vacuum Electronics Conference. (IVEC 2017)*, London, UK, April, 2017.

[6] I. A. Guzilov, "BAC method of increasing the efficiency in klystrons", in *Proc. 10th Int. Vacuum Elec. Sources Conf. (IVESC '14)*, Saint Petersburg, Russia, July 2014.

[7] A. J. Jensen *et al.*, "Developing sheet beam klystron simulation capability in AJDISK", *IEEE Trans. Elec. Dev.*, vol. 61, no. 6, pp. 1666-1671, June 2014.

[8] F. Qiu, S. Fukuda, S. Matsumoto, T. Matsumoto, T. Miura, and T. Natsui, "Design Study of a High Efficiency Klystron for SuperKEKB Linac", in *Proc. LINAC'18,* Beijing, China, Sep. 2018, pp. 901-904. doi:10.18429/JACoW-LINAC2018-THPO096

[9] K. Halbach, R. F. Holsinger, "SUPERFISH –A computer Program for Evaluation of RF cavities with Cylindrical Symmetry", *Particle Accelerators*, vol. 7, pp. 213-222, 1976.