Thermal Structural Analysis and Test of the New Electron Gun for BEPCⅡ Linac*

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Abstract The Beijing Electron Positron Collider Upgrade Project (BEPCⅡ) requires its injector linac to upgrade the beam energy and current. Hence the high emission current and low emittance electron gun must be newly designed and fabricated to meet the requirement of high positron beam current. This paper describes the temperature field distribution in the gun and the gun deformation caused by this distribution which is performed by using ANSYS. According to the real complex structure and the energy conversion inside the electron gun, we took conduction as the main energy conversion form after deep consideration and then got the temperature field. The coincidence between the temperature field and the structural deformation is also described. In this paper, the beam optics simulated by EGUN before and after structure deformation is discussed, and the valuable results have been obtained. The test results and simulation results are analyzed and compared.

Key words electron gun, thermal-structure, analysis, test

1 Introduction

The Beijing Electron Positron Collider Upgrade Project (BEPCⅡ) requires the injector linac to increase the beam energy from 1.30GeV—1.55GeV to 1.89GeV, and to increase the positron beam current from 3mA to 37mA[1]. Hence the high emission current and low emittance electron gun must be newly designed and constructed to meet the requirement of high positron beam current. According to the BEPCⅡ design request, the new gun provides narrow-pulse single bunch and two-bunch beam for the BEPCⅡ linac, and also 2.5μs broad pulse single bunch for the slow positron high current test facility. The cathode assembly for the new gun is an EIMAC Y796 and it is a conventional three-electrode thermal electron gun. Under the narrow pulse working condition, the emission current density can be up to roughly 10A/cm^2. Moreover, the work temperature of the cathode is about 1000℃. Under that high temperature, the cathode suffering nonlinear deformation makes the gun beam optics different from its cold conditions. In order to determine the "hot" dimensions of electrodes and supporting structures, a thermal-structural analysis is carried out by ANSYS[2] code. Firstly, the deformations of electrodes are simulated and those asymmetry deformations described. Secondly, the electrodes' sizes are compared before and after deformations, and the beam optics are determined by EGUN[3] code. Finally, the beam optics simulation results before and after deformations are compared with the test results. It provides reliable data for the design of the electron gun. This paper describes the BEPCⅡ new gun temperature field distribution and the gun deformation caused by its temperature. According to the complex structure and

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the energy conversion inside the electron gun, we took conduction as the energy conversion form and got the temperature field. The coincidence between the temperature field and the structural distortion is also described. In this paper, the beam optic simulation using EGUN before and after the structural deformation is also discussed, and the valuable results are obtained. The test results and simulation results are also analyzed and compared.

2 Electron gun thermal structural analysis

To better understand the thermal deformation influence on the beam optics characteristics, at first, the temperature field and its influence on the deformations of electrodes are simulated by ANSYS, and then, an asymmetry variation at different sites are described. In the thermal structure analysis of the electron gun, we have calculated the thermal deformations of cathode, focusing electrode and the supporting structure when the cathode is heated up to 1000℃. The cathode material is mainly tungsten (and a little barium for barium-tungsten cathode). Both the focusing electrode and the supporting structure consist of stainless steel parts. The heat radiation should be mainly downstream direction (the direction of beam propagation) and does not affect the thermal deformation of the cathode structure[4]. Therefore, we have tried simple 2D modeling that only includes the conduction as heat exchange form. In this simulation, the analyzing unit is of the thermal structure coupled type, while the finite element is of two dimensional flat solid types. Fig. 1 is the side view of the axial section of electrodes and supporting structures.

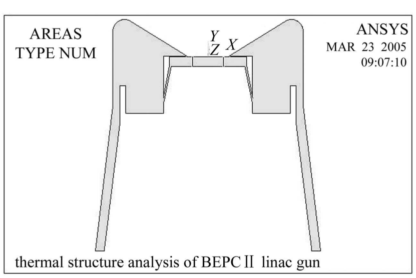

Fig. 1. Side view of the axial section of electrodes and supporting structures.

After geometry modeling, and defining material parameter of electrodes (just as Young's modulus, POISSON ratio, thermal expansion coefficient and thermal conductivity), we calculated the loading temperature on the boundary and the gun temperature field distribution. Taking the cathode surface temperature as 1000℃, the end of the electrode supporting structure has a normal temperature of 30℃. The temperature field distribution of electrodes and supporting structures are shown in Fig. 2.

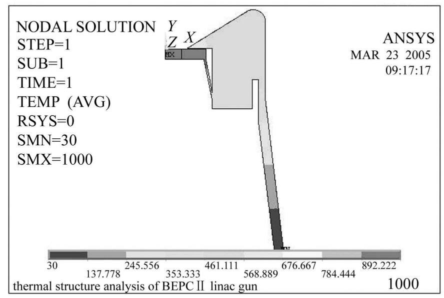

Fig. 2. The temperature field distributions of electrodes and supporting structures.

The structure analysis is processed after thermal analysis. To convert the analysis unit type from thermal to structural, the elements' degrees of freedom (DOF) are defined and the displacement restriction on the structure's boundary is loaded. The end displacement of electrode support is set to be zero (fixed together with the ceramics cylinder) and the structural analysis is performed after loading the thermal analysis results. The thermal deformed shape overlaid with the original one is shown in Fig. 3 and Fig. 4. In these figures, the direction of x and y show the radial direction of R and axial direction of z, respectively.

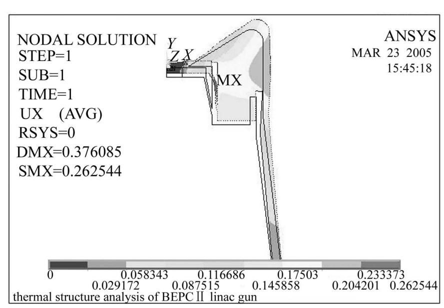

Fig. 3. Calculation of X direction before and after thermal deformation.

From the above figures, we can see that the mechanical shape of electrodes and the supporting structures are greatly changed under high temperature conditions. It is found that the cathode structure is expanded by about 2mm axially and about 0.5mm radially. These are quite a large amount that would cause perveance to vary more than 10%. Because the end of electrode supporting structure fixed by the ceramic cylinder, the thermal deformation of Y direction makes all structures expand to anode. The deformations of different positions are shown in Fig. 3 and Fig. 4.

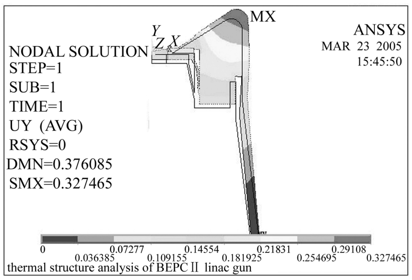

Fig. 4. Calculation of Y direction before and after thermal deformation.

After ANSYS simulation, the thermal expansion characteristics of electrodes and supporting structures are summarized and the expansion sizes at different sites are provided. It gives a great help in designing and upgrading the electron gun.

3 Simulation and analysis of electron gun beam optics

According to the simulation results of ANSYS code, the cathode and electrode under high temperature are nonlinearly expanded and deformed. Then the beam profile is obviously changed. Therefore, the beam optics sizes before and after deformation must be analyzed and compared. In order to determine the so called “cold dimension” of the electron gun, which is important for fabrication, we have utilized EGUN code to simulate the beam optics before and after deformation. The calculated beam current and pervence are 11.7A, 0.2μP before deformation and 14.8A, 0.25μP after deformation, respectively, when DC high voltage is 150kV. The beam current and pervence are greatly increased when the cathode and focusing electrode extend to the anode. Fig. 5 and Fig. 6 show the beam optics characteristics before and after deformation, respectively.

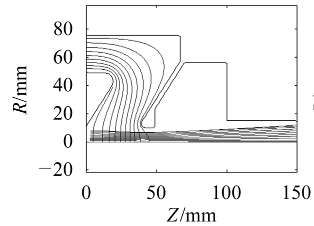

Fig. 5. The beam optics characteristics before deformation.

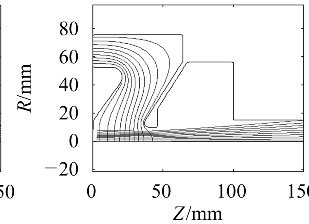

Fig. 6. The beam optics characteristics after deformation.

From the above calculation and simulation, the thermal deformations have a great influence over the beam optics. The smaller the space between cathode and anode, the larger the beam current and pervence. Therefore, while designing the electron gun, the thermal working conditions need to be considered and the thermal structure analysis provides a theoretical guidance for the design and fabrication of the electron gun.

4 Analysis of electron gun test results

After theoretical analysis, the simulation results and the test results are compared. The electron gun is a complete system. Besides the gun itself, it also includes facilities of related power supplies, vacuum, control system, etc. As part of the whole system, those systems also relate directly to the whole electron gun’s performances. After assembling Y796 cathode-grid assembly, the pulser, the power supplies, the vacuum system and the control system are also connected to the whole electron gun system. Pulsed high voltage power supply is used for the gun test.

To obtain the gun test results, the variations between beam current and high voltage are concluded under normal condition of cathode-grid assembly and bias[5]. The cathode filament works at 6.03V and 5.50A. The high voltage varies from 60kV to 150kV. The pulser output voltage is 460V and the grid bias is −100V. Fig. 7 shows the beam current vs. high voltage for the test and simulation results before and after deformations.

From Fig. 7, we can see that there is a little difference between the test results and the calculation results. The beam current difference is up to 2A or even to 3A between the test result and the calculation result before thermal deformation, and 1A difference after thermal deformation. Especially, they are basically consistent when the high voltage is 130kV. From all the facts mentioned above, we can see that the thermal deformations have a crucial influence on the electron gun beam optics characteristics. Those influences need to be seriously considered when designing the electron gun.

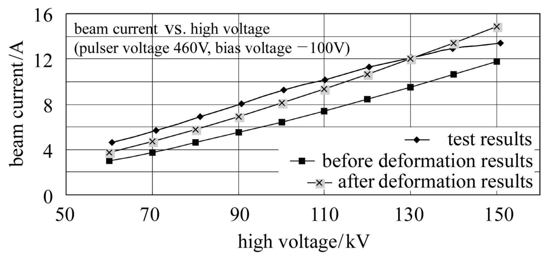

Fig. 7.　Emission beam current vs high voltage of gun.

5　Conclusion

A comparison of the analysis with the test results on the new gun of BEPCⅡ Linac provides a good help for the gun design and improvement. Considering the deformation of electrodes and supporting structures on high temperature, the thermal deformations have a great influence on the gun beam optics. Under the same high voltage, simulation results after thermal deformation are much close to the test results. Moreover, because of different materials between cathode and focus electrode, nonlinear expansion may occur at the intersection part of cathode and focusing electrode, which may bring bad effect on the beam quality, such as emittance growth and beam current instability. From the above mentioned calculations and analyses, the thermal deformations have a crucial influence on the electron gun beam optics characteristics. Those influences need to be seriously considered when designing the electron gun.

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BEPCⅡ 新电子枪热结构分析与测试*

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摘要　北京正负电子对撞机重大改造工程(BEPCⅡ)要求其直线注入器提供更高的能量和流强, 为此必须设计大电流和小发射度的新电子枪, 以提高正电子的产额. 利用ANSYS对BEPCⅡ 新电子枪的温度场分布及结构的热变形进行了模拟分析. 对于电子枪复杂的内部结构形态以及能量转换方式, 分析了传导传热方式对温度场的影响. 在此基础上进行了温度场与结构变形的耦合分析, 利用EGUN对电子枪形变前后束流光学特性进行模拟分析, 并对模拟结果与试验测试结果进行了分析比较.

关键词　电子枪　热–结构　分析　测试

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