Designment of alignment support for high energy photon source (HEPS) storage ring vacuum tubes*

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Abstract

The storage ring of high energy photon source (HEPS) has about 1536 vacuum tubes, which need different supports to align them to the desired position and keep their stability. According to the operational requirements of the storage ring vacuum tubes, this article introduces several types support structure of vacuum tubes. And finite element thermal-stress analysis was conducted on the vacuum tube and vacuum tube bracket. The result of the analysis provides a reliable theoretical basis for the design of the vacuum tubes support.

INTRODUCTION

High energy photon source is a light source with an emissivity close to or even reaching the diffraction limit of X-rays, characterized by high energy and extremely low emissivity [1-2]. The main function of the vacuum tube installed in the storage of HEPS is to maintain high vacuum requirements for efficient operation of the electron beam. There are approximately 58 types of storage ring vacuum tubes, with a total of 1536 pieces. Considering the compact layout of electromagnets, BPM and other equipment on the storage ring, the space left for the flanges at both ends of the vacuum tube is relatively small. The minimum theoretical gap between the vacuum tube and the electromagnet pole is 0.5mm, making it easy for the vacuum tube to come into contact with the electromagnet pole, which is not allowed. And vacuum tubes are mostly slender structures, which are prone to deformation during installation and normal working conditions. At the same time, in order to achieve a high degree of vacuum inside the vacuum tube, thermal baking [3-4] is required during use, resulting in significant thermal deformation. The above stringent usage conditions impose strict technical requirements on the vacuum tube alignment bracket. Three types of vacuum tube alignment brackets were designed to support the alignment of storage ring vacuum tubes, and finite element analysis software was used to simulate the thermal stress and deformation of the brackets and vacuum tubes.

REQUIREMENTS FOR VACUUM TUBES

The overall support system of the storage ring adopts a hybrid 7BA structure, with each support unit using a concrete base as the installation reference surface. Adjacent electromagnets, vacuum tubes, and various small equipment alignment brackets are supported by a shared girder, and the shared girder equipment is pre installed and aligned in place on the corresponding support unit[5-6]. Finally, the pre aligned unit is lifted as a whole to the storage ring tunnel for overall alignment installation. The common frame body, electromagnet, BPM, vacuum tube, etc. have high processing accuracy, and the alignment adjustment requirements of each equipment are relatively small.

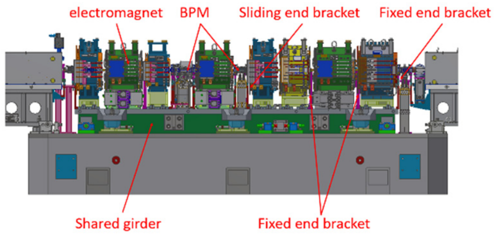

Figure 1: Equipment layout

The vacuum tube collimation bracket mainly realizes the collimation adjustment of the vacuum tube in the XY directions. The adjustment amount and collimation accuracy are shown in Table 1, where the X direction is the horizontal direction on the beam section, the Y direction is the vertical direction on the beam section, and the Z direction is the beam direction.

Table 1: Adjustment quantity and accuracy

Direction	Amount	Accuracy
X	±5mm	0.2mm
Y	±5mm	0.2mm
Z	Non	Non

The material of the vacuum tube is chromium zirconium copper or stainless steel. Vacuum tubes are mostly slender structures, with a maximum length of 1698mm and a minimum length of 200mm. Figure 2 shows the appearance of various vacuum tubes for storage rings. It can be seen from the figure that this type of structure is prone to deformation during alignment and normal use; How to ensure that the vacuum tube does not deform or that its deformation is within an acceptable range is the basic function that the vacuum tube alignment bracket needs to achieve.

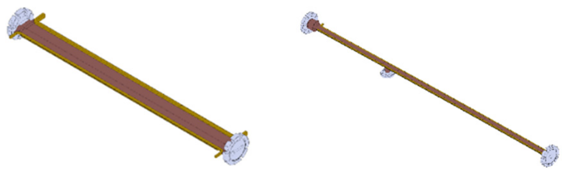

Figure 2: Structure of Vacuum Tube

High temperature baking will inevitably cause thermal deformation of the vacuum tube, and the vacuum tube alignment bracket needs to meet the following requirements; Firstly, ensure that the deformed vacuum tube does not interfere with the surrounding equipment. Secondly,

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the thermal stress does not exceed the yield strength of the material, and the position of the vacuum tube after returning to room temperature is within an acceptable range.

ALIGNMENT SUPPORT STRUCTURE

The vacuum tube bracket needs to achieve initial alignment support for the vacuum tube and ensure that its position changes within the required range after thermal baking and cooling; Considering the compact layout of the storage ring electromagnet and BPM, as well as the small space left for the vacuum tube bracket (the minimum longitudinal space is only 17mm), the design of the vacuum tube bracket is relatively difficult. Due to the aforementioned space constraints, the vacuum tube bracket adopts a narrow plate support structure. According to the different functions of the vacuum tube bracket, the designed vacuum tube bracket can be divided into fixed end vacuum tube bracket, sliding end vacuum tube bracket, and auxiliary support.

1. Fixed end vacuum tube bracket

The structure of the fixed end vacuum tube bracket is shown in Figure 3, which is connected to the vacuum tube flange by fastening bolts. The X-direction adjustment screw realizes the alignment adjustment of the vacuum tube in the X-direction. As the vacuum tube bracket is a narrow plate support structure with a maximum thickness of 15mm, a V-shaped groove guide structure is designed to prevent the vacuum tube bracket from tipping over during X-direction adjustment. The Y-direction adjustment mechanism consists of nuts and bolts, which can achieve the alignment adjustment of the vacuum tube in the Y-direction. The fixed end bracket enables alignment adjustment of the vacuum tube in two (XY) directions, with an adjustment amount of ± 5mm and an adjustment step size of 0.02mm; No fine adjustment is made in the Z direction. During the process of heating the vacuum tube to 200 ℃, the fixed end vacuum tube bracket maintains the flange of the vacuum tube at that end without displacement.

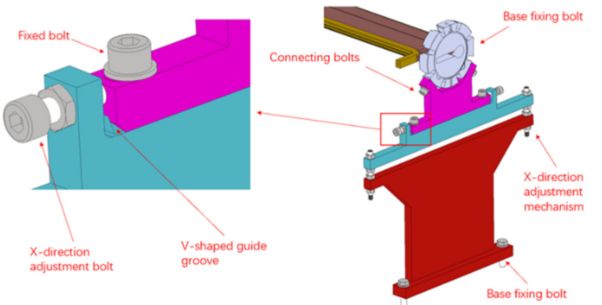

Figure 3: Fixed end vacuum tube bracket.

2 .Sliding end vacuum tube bracket

The sliding end bracket is also connected to the vacuum tube flange by screws, which can achieve alignment adjustment in the XY directions of the vacuum tube. The adjustment amount and step size are the same as those of the fixed end vacuum tube bracket. The difference is that a guide plate is added to the sliding end bracket, which is fixed to the bracket by screws. At the same time, the gap between the guide plate and the vacuum tube flange is ensured to be about 0.15mm according to the tolerance fit. During hot baking, the bolts connecting the vacuum tube flange and bracket need to be removed. The vacuum tube can be extended in the Z-direction along the beam direction, and the 0.15mm gap between the guide plate and the flange can ensure smooth sliding of the vacuum tube flange. When the vacuum tube returns to room temperature, this structure can ensure that the vacuum tube does not undergo significant displacement.

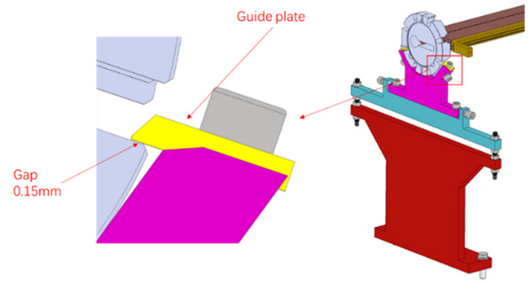

Figure 4: Sliding end vacuum tube bracket

3. Auxiliary support

Most vacuum tubes are slender structures, and when the vacuum tube bracket supports the flanges at both ends of the vacuum tube, the weight of the vacuum tube will cause the middle section of the vacuum tube to bend downward; The auxiliary support is located in the middle section of the vacuum tube, supporting the weight of the vacuum tube vertically in the Y direction to prevent the middle section of the vacuum tube from bending downwards. Its structure is shown in Figure 5, and the Y-axis adjustment screw achieves vertical adjustment of the bracket; The gap between the vacuum tube bracket and the vacuum tube tube body is 0.15mm, which ensures that it slides along the beam direction when heated and can limit the displacement of the vacuum tube body in the XY directions.

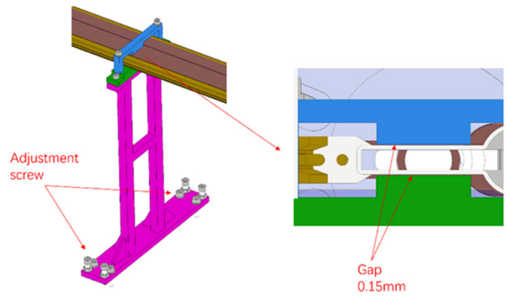

Figure 5: Auxiliary support

FINITE ELEMENT ANALYSIS

Considering that the minimum theoretical gap between the vacuum tube and the electromagnet is only 0.5mm, it is necessary to use finite element analysis to simulate the deformation of the vacuum tube under gravity, internal vacuuming, external atmospheric pressure, and thermal baking after it is installed on the bracket. There are various types of storage ring vacuum tubes, with a minimum of 18 vacuum tubes per section, ranging from VC01 to VC18. We have selected the VC10 vacuum tube for simulation calculation, with a length of 1697mm, which is close to the longest vacuum tube length. At the same time, the vacuum tube is composed of 5 sections with curvature and 2 sections of straight tube body spliced together, and its extension direction during thermal baking is somewhat complex. Simulation calculation of this vacuum tube can better verify the performance of the bracket.

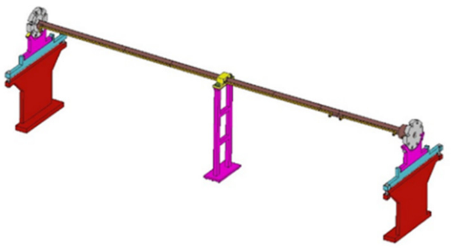

Figure 6: Auxiliary support

Draw simplified models of vacuum tube VC10, fixed end vacuum tube bracket, sliding end vacuum tube bracket, and auxiliary support using INVENTOR, as shown in Figure 6. Assemble the four devices as a whole and then convert them into. step format to import into finite element analysis software. The material properties of the vacuum tube and its bracket are shown in Table 2.

Table 2: Material properties

Structure	Bracket	Bracket
Material	304	C18150
Density /Kg·m^-3	7750	8900
Thermal expansion system/°C^-1	1.55E-05	1.75E-05
Young's modulus /Pa	1.28E+11	1.20E+11
Poisson's ratio	0.31	0.34
thermal conductivity /W· M^-1·°C^-1	17	20

Simulate the stress and deformation process of the vacuum tube and its bracket by loading loads such as gravity, vacuum, and thermal baking step by step. After fixing the bottom surface of the vacuum tube bracket, the first step is to load the gravity load onto the overall equipment. The second step is to load the atmospheric pressure load onto the outer wall of the vacuum tube. The third step is to load the thermal load into the heating tank. The thermal load is divided into four small steps of 50 °C, 100 °C, 150 °C, and 200 °C. The simulation results for each step are shown in Table 3.

Table 3: Deformation under different loads

Load step	1	2	3	4	5	6
Gravity	√	√	√	√	√	√
1 atm	×	√	√	√	√	√
50°C	×	×	√	×	×	×
100°C	×	×	×	√	×	×
150°C	×	×	×	×	√	×
200°C	×	×	×	×	×	√
(X)/mm	0.001	0.02	0.03	0.08	0.14	0.19
(Y)/mm	0.05	0.056	0.04	0.13	0.21	0.29
(Z)/mm	0.039	0.042	0.8	2.25	3.67	5.08

It can be analyzed that the deformation caused by gravity and vacuum is relatively small, while the deformation caused by thermal baking is relatively large. The three types of vacuum tube supports can meet the Z-direction elongation of the vacuum tube while ensuring small displacement in the XY direction.

POSITION MEASUREMENT BEFORE AND AFTER HOT BAKING

After the installation of the vacuum tube alignment is completed, it needs to be heated to 200 °C, kept warm for 48 hours for internal coating activation, and then cooled to the working temperature. In order to ensure that the position of the vacuum tube is within the allowable error range, the position after vacuum baking was measured; And compared with the position before baking, the measurement positions were the flanges at both ends of the vacuum tube. Figure 6 shows the measurement results of the vacuum tube before and after hot baking. The vast majority of vacuum box positions meet the alignment requirements. Some positions have significant deviations, but as a minor adjustment, it immediately meets the requirements.

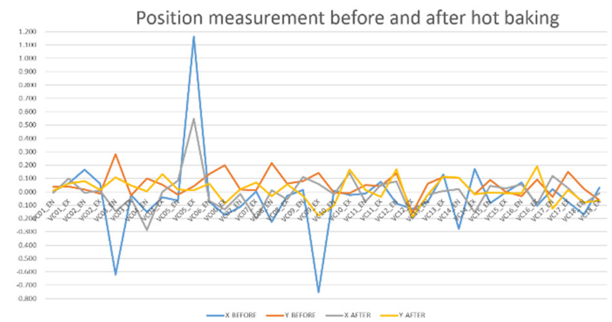

Figure 6: Position comparison before and after hot baking

CONCLUSION

The fixed end vacuum tube bracket, sliding end vacuum tube bracket, and auxiliary support structure described above can achieve the alignment requirements of the vacuum tubes. Through finite element analysis and simulation of the usage status of the vacuum tubes, three types supports meet the requirements for guiding and limiting the vacuum tubes under hot baking conditions. The position measurement results after hot baking show that the Supporting structure meets the requirements for use.

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