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DESIGN AND DEVELOPMENT OF COATED CHAMBER FOR IN-AIR INSERTION DEVICES

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Abstract

The insertion devices (ID) is an important guarantee for further improving the performance of the light source and meeting the needs of different users. For in-air ID (undulator, wiggler, etc.), the magnetic structure is in the air, and there is a vacuum chamber in the middle of the magnetic structure to ensure the normal movement of the beam. In order to increase the magnetic field strength, the magnetic gap is generally relatively small. Factors such as small space, high precision, and low conductance all pose challenges to the design and processing of vacuum chamber. This paper introduces the development process of the vacuum chamber prototype of the coating type ID. Taking the application of the prototype in the HEPS project as an example, the simultaneous analysis and vacuum pressure distribution calculation are carried out, and the NEG coating scheme is proposed as an more economical means to obtain ultra-high vacuum. And the prototype NEG coating progress is introduced.

INTRODUCTION

The HEPS is a 6 GeV, green field light source, with the aim of generating X-ray synchrotron radiations with brightness of higher than 1×10^{22} ph/(s·mm^2·mrad^2· ‰BW) and photon energy of up to 300 keV at the designed beam current of 200 mA [1–5]. The ID is one of the important light-emitting components of the synchrotron radiations light source and meeting the application needs of different users [6, 7]. The main types of ID include in-air undulators/wiggler, in-vacuum undulators/wiggler, and polarization adjustable undulators. In-air IDs are usually used in applications where the photon energy is relatively low and the peak field strength is required for a line station that is not particularly high. The vacuum chamber is an important part of the ID, and its successful development is crucial. In order to obtain a vacuum chamber that meets the engineering needs, we carried out the vacuum chamber design, prototype development, NEG coating.

COATED CHAMBER FOR IN-AIR ID

Design Requirements and Layout

According to the layout of the linear section in the HEPS storage ring, specific requirements are proposed for the dimensions of the vacuum chamber along the Z-axis. This includes a distance of 5754 mm between BPMs at odd-numbered ends, which encompasses: 2 gate valves, 2 RF bellows, 2 transition vacuum chambers, and 2 front feeder coils with ID and their respective vacuum chambers. The experimental line stations necessitate a magnetic structure length of 5 m for these ID. Considering welding, installation space, and flange thickness requirements for the vacuum chambers, it is imperative that their Z-direction length exceeds 5 m.The layout of the 5 m in-air undulator (IAU) linear section is shown in Fig. 1.

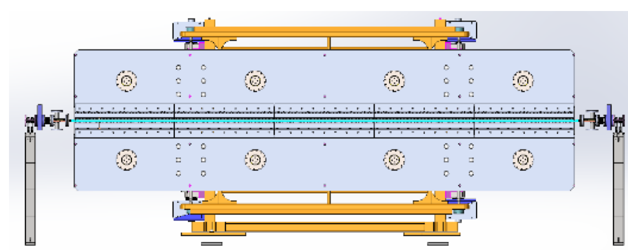

Figure 1: Layout of IAU.

According to the needs of the IAU, the parameters of the vacuum chamber can be proposed, as shown in Table 1.

Table 1: Parameters Vacuum Chamber

Parameter	Value
ID minimum gap in Y direction	11.0 mm
Straightness of vacuum chamber	±0.2 mm
Roughness of the inner surface	<Ra 0.8 µm
Thickness of vacuum chamber	9.3(±0.2) mm
Beam channel aperture size in Y direction	7.3(+0.05/-0.3) mm
Flatness of vacuum chamber	0.2 mm
Length of flange to flange	5376 mm
Cooling water velocity	<3 m/s
Static vacuum pressure	6.65×10^{-8} Pa
Dynamic vacuum pressure	1.33×10^{-7} Pa

Material Selection

Due to the characteristics of the undulator magnets, a vacuum chamber with narrow cross section (7.3 mm × 22 mm) and 5376 mm length is proposed. To achieve the necessary cross section geometry, mechanical strength, and vacuum

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requirements, comparing the material properties of 6063-T5 and 6061-T6, 6061-T6 has higher strength and good corrosion resistance; 6063-T5 has better thermal conductivity, electrical conductivity, and extrusion performance. Therefore, after research and communication with the manufacturer, a custom 6063-T5 extruded aluminum profile was selected for the chamber prototype.

Synchrotron Radiation Power and Thermal Analysis

Aiming a safe performance for the chamber in accelerator environment under ultra-high vacuum, structural and thermal analysis were done using the software Ansys Mechanical.

After the synchronous light enters the vacuum chamber, it starts to hit the side wall of the vacuum chamber at 160 mm and continues to the outlet of the vacuum chamber, with a total power of about 391.7 W and cooling water on both sides. The support mode adopts a unilateral support mode, and a steel plate is installed on one side of the vacuum chamber to support the aluminum vacuum chamber. The steel plate is fixed on the slider and can slide along the Z direction; The support under the guide rail can adjust the height, pitch, etc.

Thermal simulation analysis of aluminum vacuum chamber was carried out. At the entrance of the vacuum chamber, the synchronous light power is large, and then the power gradually decreases with the increase of distance. The entrance is about 1 W/mm^2 and the exit is about 0.1 W/mm^2. The temperature is about 41.6 °C, which meets the requirements of use as shown in Fig. 2.

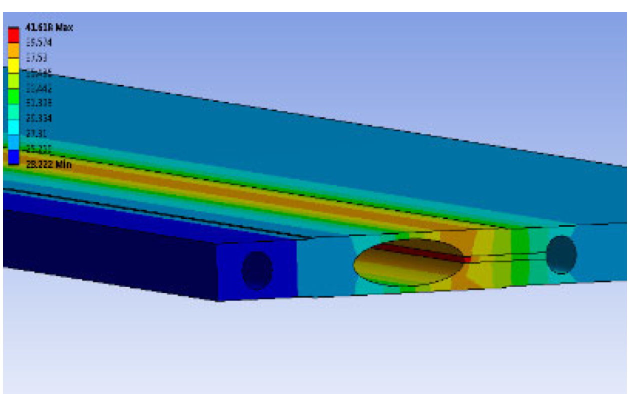

Figure 2: Thermal analysis of vacuum chamber.

The thermal-structural coupling analysis of the vacuum chamber was carried out. The stress of the coated vacuum chamber was 17.7 MPa, and the maximum displacement was 0.28 mm, which meet the usage requirement as shown in Fig. 3.

Pressure Distribution

Molflow software was used to calculate the pressure distribution. The outgassing data of 5 × 10^{-12} mbar·L/(s·cm^2) was selected. The dynamic gas output of the vacuum chamber by synchronous light was about 3.1 × 10^{-7} mbar·L/s, the

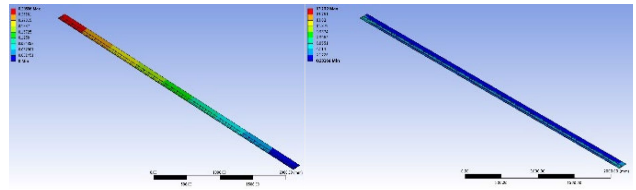

Figure 3: Structural analysis results.

suction adhesion coefficient of NEG film was 0.005, and the vacuum degree was about 5.8 × 10^{-8} Pa. The calculation results are shown in Fig. 4:

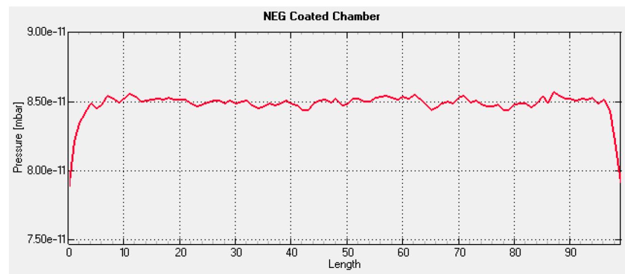

Figure 4: Vacuum pressure distribution.

PROTOTYPE MANUFACTURING

Aluminum tube is thermally extruded. The connection ports of cooling water channels and support plate are machined by numerical control machine tool. S.S.-Al transition plate are fabricated through explosion bonding in a domestic company. Ultrasonic flaw detection is used before the flange will be machined. Leak detection is carried out after the flange has been machined.

At the same time, the baking deformation measurement experiment is carried out, the stainless steel yoke plate is installed on the side of the vacuum chamber, and the yoke plate is fixed on the platform, and the aluminum vacuum chamber is in the suspended state. A plurality of heating plates (aluminum shell with heating wire inside) are uniformly distributed on the upper surface of the vacuum chamber, and a temperature sensor is placed next to it for temperature control, and the outside is covered with aluminum foil for heat preservation; Make a dial indicator in the middle position of the vacuum chamber and on the upper and lower surfaces of the elliptical hole to record the deformation data of the vacuum chamber. The test data show that the atmospheric pressure has no effect on the deformation of vacuum chamber after vacuuming. The main deformation is caused by thermal expansion at high temperature. However, the theoretical thickness of 9.3 mm and the expansion of 100 °C should be about 0.02 mm, which is much different from the actual result. After cooling from 180 °C to normal temperature, the deformation of the vacuum chamber is basically restored, and the shrinkage is 0.04 mm, which meets the needs of engineering use.The prototypes of aluminum vacuum chamber with a length of 5376 mm have been fabricated and tested, which meet the engineering requirements.

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NEG COATING

The NEG coating scheme is proposed as an more economical means to obtain ultra-high vacuum.The prototype was coated aiming a film thickness of 1 µm. The cathode made from intertwisted 0.5 mm diameter Ti, Zr, V wires was submitted to a linear power density of 30 W/m, a magnetic field of 650 G and a vacuum pressure of 10 Pa. Cathode centering is critical for NEG coating of ID chamber. After NEG activation, the pressure was validated trough a measurement bench and the value of 3×10^{-8} Pa was achieved, as illustrated by Fig. 5. When the two angle valves of the two ion pump ports are closed, the vacuum is maintained only by the NEG film, and the vacuum degree can be maintained at 8×10^{-8} Pa. This shows that the NEG film coated on the inner wall of the in-air ID vacuum chamber has good performance.

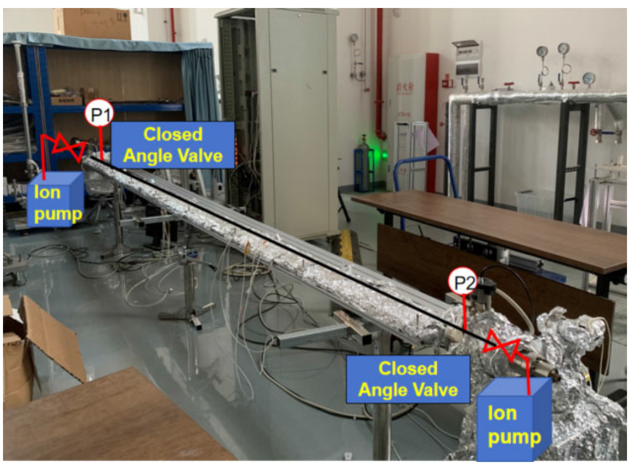

Figure 5: Ultimate pressure measurement bench.

CONCLUSION

The development process of the vacuum chamber prototype of the coating type ID was introduced. Taking the application of the prototype in the HEPS project as an example, the simultaneous light analysis and vacuum pressure distribution calculation were carried out. The prototypes of aluminum vacuum chamber with a length of 5376 mm have been fabricated and tested, which meet the engineering requirements. The NEG coating scheme is proposed and coated to obtain ultra-high vacuum. The vacuum is maintained only by the NEG film, and the vacuum degree can be maintained at 8×10^{-8} Pa. This shows that the NEG film coated on the inner wall of the insert vacuum chamber has good performance.

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