Stainless Steel UHV Chamber for SSRF Storage Ring

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Stainless steel is adopted as the main material of the 3.5GeV electron storage ring UHV chamber for Shanghai Synchrotron Radiation Facility. The design of chambers is finished. The complex structure and high dimensional accuracy requirements are the features of these chambers. The finite element method is used to analyze the deformation under atmospheric pressure and the thermal situation under synchrotron radiation. The numerical control folding and the TIG welding are the main techniques in fabrication. The manufacture and test of three typical chamber prototypes were finished. Many problems on the structure design and fabrication technique were revealed and suitable solving methods were found. Based on the prototype manufacture, the necessary techniques for engineering construction have been prepared. One standard cell chamber has been successfully finished. The detail design, techniques and test results are presented in this paper.

1 Introduction

The Shanghai synchrotron radiation facility (SSRF)，a new third-generation light source, is being constructed in Shanghai. The vacuum system for storage ring has to provide the beam-on pressure of 1.3 10^{-7} Pa or less to gain the achievement of a beam lifetime of about 20 hours [1]. The UHV Chambers are the mainly components in the system. As the direct enclosure of the electron beam, the chambers have to meet the requirements of beam dynamics. At the same time they need to meet the requirements for SR extraction and the relations with other system such as magnet, girder and diagnoses. The complex structure and high dimensional accuracy requirements are the features of these chambers, which offer a challenge for the designer and manufacturer.

2 The material of the chambers

Aluminum alloy and stainless steel are wildly used as the materials of the storage ring vacuum chambers in third-generation light source. They all have excellent vacuum properties, machining capability and welding performance. Additionally, aluminum alloy has high thermal conductivity, no magnetic permeability. However, the complicated manufacturing process and bi-metal plate (used as the material of flanges) will result in higher costs. In china, the cost (in RMB) of the chamber will be 70000 Yuan/m if the aluminum alloy is used. We choose stainless steel 316LN as the material of the storage ring vacuum chamber and the cost of the chamber will be about 40,000 Yuan/m. So as to the storage chamber in standard cell, whose whole length is 300m, about 9,000,000 Yuan will be saved. The electrical conductivity of SS is low, which will result in low eddy current effect. When the global orbit is closed orbit, correction system will work at high frequency [2,3]. The SS has low magnetic permeability, and the Values of $\mu \leq 1.005$ can also be achieved even in the chamber welds and in the cold forming zones [4]. The thermal conductivity of stainless steel is very poor, so copper is used in bending chamber. However the residual radiation of SS is high, which should be alerted.

3 Structure design

According to the layout of lattice, there are 3 kinds of standard cells in SSRF, and the corresponding chambers are same or similar. There are 6 chambers in one cell, which are showed in fig.1. The first three chambers and the last two chambers are connected by flanges directly, and then connected with the forth chamber by RF bellows. The second and fifth chambers are bending chambers, and other four chambers are straight chambers. The electron channel has the same cross section in all vacuum chambers. The vacuum chambers for SLS storage ring are the main reference of the structure design of SSRF storage ring vacuum chambers. However there are many differences according to the features of SSRF and obtainable process in china.

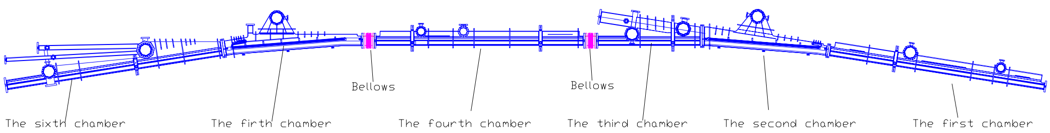

Fig.1. The chambers in one standard cell

Just as other 3rd generation synchrotron light source, the double-chamber structure is adopted. The vacuum chamber consists of an electron channel and an antechamber, and a slot. The slot connects the two other sections. The sizes of the chambers are mainly due to the requirement of physics, the angle of BMSR and IDSR, and the aperture of magnet. The beam-stay-clear is modeled as an ellipse 32mm high by 64mm wide. The vacuum chamber cross section is a 35 mm high by 68 mm wide octagon with a 13 or 15 mm tall slot and a 26 or 35 mm tall antechamber. The clearance between the beam chamber and the region required by physics system is 1.5mm， which accommodates manufacturing and alignment tolerances, as well as the deformation of the chamber due to vacuum loading. This slot offers effective RF isolation between the electron channel and the antechamber, and is used as the pumping channel and SR passage at the same time. The synchrotron radiation photons escape from electron channel and go into the antechamber through the slot. No SR is permitted to hit the SS wall. The minimum distances from the IDSR and BMSR to the wall of the chamber are 9mm in horizontal direction and 6.8mm in vertical direction. Discrete water-cooled absorbers located in the antechamber and slot region control the passage and angle of SR and intercept the photons that are not used. The huge gas load induced by SR photons, will be pumped by large TSP pumps, SIP+NEG pumps located over and below the absorbers. This kind of pumping structure avoids pump ports in the beam chamber, which may increase the impedance.

The body of straight chambers consists of symmetrical formed up and down plates, which are welded. Because the cost of electron beams welding is very high and difficult to be found in china, the TIG welding is adopted as the primary welding technology. We try to adopt inside welding, however the outside welding is inevitable taking the construct into account. In case of the outside welding, we try to reduce the remaining thickness which is not penetrated, and some samples are used to decide the welding current. Each straight chamber is equipped with one or two beam position monitors. The beam position monitor (BPM) stations are solid stainless steel blocks which contain the pick up electrodes. The vacuum chamber is fixed at each BPM-station with supports to the magnet girders to promise high position accuracy and high stability. In the bending chambers, a significant amount of the radiated power will be distributed on the walls of the slot between the electron channel and the antechamber, so a stainless steel body with inserted water cooled copper blocks to separate electron channel and antechamber. Taking into account the difficulty of forming and welding, an inner copper block is designed nearby the inner wall to form the octagon electron channel. The copper blocks are inserted through the entrance flange into the completed chamber and fixed with screws to the flanges at both ends of the chamber. For the fabrication of the vacuum chambers, it is important that the tolerances of the overall length and the angles of the flanges stay within small limits. Special tools and clamps will be helpful to reach the target. All chambers are equipped with CF seal flanges and RF springs are use to reduce the impedance.

4 The analysis for the chambers by finite element method

In many regions, the clearance between two magnets is very small, where the absorber can’t be set. That induces big width of the chambers, and the biggest width reaches 380mm. To withstand the outer atmospheric pressure and hold the chamber deformations at a certain level the chamber must be reinforced with inner and outside ribs. Finite element method is used to analyze the deformation and strength, and some deformation situations are shown in fig.2. The biggest deformation will be about 1mm in the slot region.

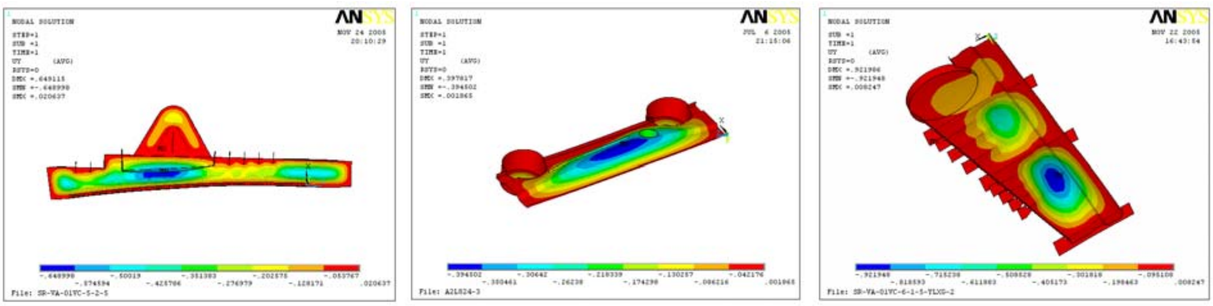

Fig.2. The deformations of the chambers due to vacuum loading

During commissioning, the BMSR and IDSR may drift and bomb the chambers continuously when the interlock system doesn't work. According to the calculation, the Current with 5mA in commissioning period is recommended.

During normal running, the interlock system must work in a certain time when the

BMSR and IDSR drift and bomb the chambers. Otherwise the following accidents may take place: (1) The temperature of the chambers is elevated rapidly, which will lead to plenty of desorption. (2) The cooling water in the bending chambers reaches the boiling point, which will cause the vibration of cooling tubes. (3) The chamber is melted. Result of analysis shows that the interlock system must work in 1.0s when the beam drift seriously.

5 Fabrications

Keeping the coherence of formed plates, reducing welding deformation and assembling well are the key technical difficulties for the chamber fabrication. Suitable and complete procedures for assembly, leak detection, and vacuum testing should be designed to avoid contamination and obtain good vacuum performance.

5.1 Folding

The bodies of straight chamber are mainly formed plates. The dimension precision and the coherence of the plates dominate the quality of the chambers. In the development of the chamber prototypes, the folding technical is used to form the plates. Special bending dies are designed and numeral control bending machine is used. However, the dimension precision can’t meet the requirements and the shapes of very plate have considerable difference, which affects the quality and costs much time to correct the shape. In the future, when the chambers are manufacture in mass, pressing die will be used.

5.2 Assembly and weld

The assembly and weld are finished in special platform. Different welding process is set to different kind of chamber. As to the straight chambers, a whole chamber consist of several sections of chamber body, BPM stations, SR tubes, pumping ports, flanges and ribs. The body of each section consists of two symmetrical plates. A rectangular groove with 1.5 mm× 1.5mm is machined in the edge of each plate . This kind of structure will decrease the input power during welding, which may decrease the area and degree of heat influence and also reduce the deformation of the chamber. In order to keep the welding quality steadily, this welding is finished by auto welding machine. Argon gas flows inside the chamber continuously during welding. When the flanges and BPM stations are welded to the body of the chamber, Inner support and outside clamp keep the end of he chamber body in right shape and size, so the flanges and BPM stations can match with chamber body very well, otherwise some step will be generated and impedance will be large, which will affect the impedance and planeness of the whole chamber. When welding the outside ribs, the power should be as small as possible, otherwise big welding deformation will be generated. When welding the SR tubes, special clamps must be used to keep the tubes in position. **A**s to the bending chamber, since the body of the chamber is welded by plain plates directly, the welding deformation is easier to taken place. So the welding process must be performed very carefully. The cooling tubes in the copper block are made of copper. It is difficult to weld them to the SS chamber directly, so SS transport tubes are brazed to the copper tubes, and then welding the transport tubes to the SS chamber by TIG. In the welding process, water flow inside of the copper tube to protect the brazing.

5.3 Cleaning

Since electron beam welding is not adopted, in order to reduce welding deformation, most of welding is not penetrated, so strict cleaning process must be adopted to get good vacuum performance. In the machining of BPM block, flanges and copper blocks, the lubricants must be water-soluble and don't contain the element Sulfur. After very component is finished, it must be seriously cleaned. Big cleaning trough with ultrasonic will be used to clean the chambers by immersion process. Because of the environmental pollution problems, the organic steam cleaning, the strong alkaline or acid cleaning techniques that have been used widely were forbidden and the cleaning with detergents is preferable to solvents for UHV applications [5,6]. The thermal desorption of stainless steel chambers without BPM buttons will be performed in a vacuum oven. In order to prevent the sealing edge of CF flanges being softened, the temperature will be 500℃..

6 The chamber prototypes

In order to decide feasibility of SS chambers in Chinese factories and to decide better process, three stainless chamber prototypes (two straight chambers and one bending chamber) are developed last year. Most dimension precisions meet the requirements. However, in the development of complex straight chamber, when we welded the upstream pumping tube with the chamber body, the edge of upstream chamber body inclined, so we had to truing the edge, which induced that the whole length of the chamber is 3mm shorter than specified size. To solve this problem, the process must be modified as follow: welding the pumping tube with the chamber body at first, and then cutting the edge of the chamber body to specified size. In the development of bending chamber, it's very difficult to place the copper slot blocks into the middle of upstream and downstream flanges, so we had to cut a 3mm length block form the copper slot block. When the copper slot blocks are putted in place, 3mm length blocks are used to fill the space. After test, the vacuum degree reaches 2×10^{-11}torr.

In the beginning of this year, six chambers in one standard cell have been developed. The size and vacuum performances are satisfied although there are still some shortages. More special tools and clamps will be used to guarantee the quality and ease the process. Now the chambers are assembling with other system to check the design and manufacture further. Some chamber prototypes are shown in fig.3.

Fig.3. Chamber prototypes

7 Conclusions

The complete process from design to manufacture of stainless steel UHV Chambers for SSRF storage ring has been performed. Many problems were exposed in the development of chamber prototypes and many effects have been taken to solve them. Many experiences have been accumulated in process. The necessary improvements on design and fabrication have been formed.

8 Acknowledgments

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Reference

[1] Lixin Yin, Dikui Jiang, Hanwen Du, et.al. Aluminum Alloy Vacuum Chambers for SSRF. 25th Advanced Beam Dynamics Workshop, Shanghai, September, 2001.

[2] M. Böge, M. Dehler, T. Schilcher, V. Schlott, R. Ursic, Fast Closed Orbit Control in the SLS Storage Ring, PAC'99, New York, April 1999.

[3]V.Avagyan, H.Gagiyan, S.Nagdalyan, et.al. Vacuum chamber design considerations for candle light source. Proceedings of Pairs, France.

[4] L.Schulz. Stainless Steel Vacuum Chambers. 25th Advanced Beam Dynamics Workshop, Shanghai, September, 2001.

[5] C. Benvenuti, G. Canil, P. Chiggiato, P. Collin, R. Cosso, J. Guérin, S. Ilie, D. Latorre, K.S. Neil "Surface cleaning efficiency for UHV applications", Vacuum 53 (1999) no.1-2, pp.317-20.

[6] R.J. Reid. Cleaning for Vacuum Service, CERN Accelerator School, Vacuum Technology, Snekersten, Denmark, June 1998.