THE ULTRA-HIGH VACUUM PROTOTYPE OF HIRFL-CSR

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Abstract

The average static pressure for the ultra-high vacuum system of HIRFL-CSR will obtain 3×10^{-9} Pa. To achieve this goal, a lot of research and experiments have been done. As a result, the first prototype of the vacuum system has been finished. The pressure near the pump and at the end of the chamber (about 4m away from the pump) were 9×10^{-10} Pa and 3.6×10^{-9} Pa respectively. This paper mainly describes the process of the design, manufacture and test on the prototype. We focused on chamber structure design, the machining technology, calculating and the testing for the main pumps, and designing for the bake-out system.. The further development of the project on the vacuum system is also mentioned in the paper.

1 INTRODUCTION

The static pressure of the ultra-high vacuum system [1] of HIRFL-CSR should obtain 3×10^{-9} Pa, which is difficult to be reached for a large system based on Chinese vacuum manufactories. It is very necessary for us to trial-manufacture some prototypes in order to accumulating experiences. A small cell of the main ring (CSRm) is chosen as the first prototype (figure 1). It includes one CSRm dipole chamber, one pumping chamber, one sputter ion pump (360l/s), one titanium sublimation pump (2000l/s), a set of turbo molecular pump, two gauges and a quadrupole mass spectrometer (mass range 1~100).

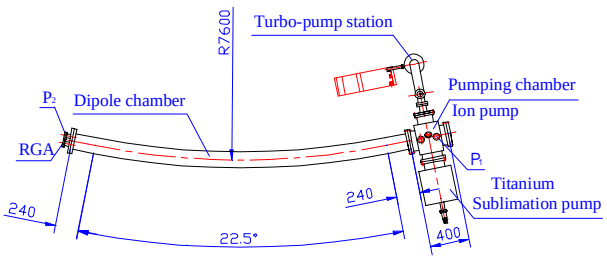

Figure.1: The first UHV prototype of HIRFL-CSR

We were going to find solutions for following questions in terms of the test results:

1) To determine the structure of the dipole chambers according to the studying on the shape, the welding technology and the deformation detecting;

2) To test the moving distance and direction of the chamber's size during bake-out process, to check whether the chamber's size can move back to the original position or not after the bakings;

3) To test the outgassing rate of the chamber materials, to verify the feasibility of the material surface treatment procedure;

4) To verify the rationality and the reliability of the pumping system;

5) To calculate and test the pumping speed of the pumps, select pump type (for ion pump) and determine the design parameters (for titanium sublimation pump);

6) To verify the vacuum equipment used in the prototype were satisfied with the UHV environment;

7) To test the properties of the trial-produced bake-out elements.

2 THE DESCRIPTION ON THE ELEMENTS USED IN THE PROTOTYPE

2.1 The dipole chamber

The dipole chamber has a curve length of 3.5m with a radius of 7.6m and an angle of 22.5°. Rectangular cross-section of 152×60 mm is required. Stainless steel 304L plate was chosen to make the chamber and the flange material is stainless steel 304 (forged, second vacuum smelted). The up and under plates are arc with a large radius of 7.6m , which were cut out under water with a numerical control cutter. The precision of the plates sizes were ensured in this way. It is difficult to weld the thin wall plates (3mm) with long welding lines. The deformation of the chamber was limited by using the necessary models and fixtures during the welding process. The inner surface of the chamber was electrolytic-polished in order to obtain an ideal surface with a roughness of 0.8μm.

After welding, the chamber (without flanges) was put into the vacuum furnace at a pressure of 5×10^{-4} Pa and a temperature of 950°C for 1 h. At the end of the firing process, the temperature was reduced quickly (about 8 min.) from 900°C to 600°C by filling pure N_2 into the furnace to prevent segregation of carbon at the material surface.

2.2 The pumping chamber

The pumping chamber is a multi-manifold vacuum vessel, which is used to connected with the sputter ion pump (SIP), titanium sublimation pump (TSP), turbo-molecular pump (TMP) and measuring elements. The stainless steel 304 was used for both chamber and flanges. The inner surface of the chamber was electrolytic-polished. After welding, it was degassed in a vacuum furnace (with flanges) at a pressure of 10^{-4} Pa and

a temperature of 500°C for 24 h.

2.3 The titanium sublimation pump

According to the design parameters, a pumping speed of 2000 l/s should be reached for the pump. In an ultra-high vacuum environment, the pumping speed of the TSP depends mainly on the sticking factor σ and the surface area A. namely: $S \approx \sigma AK$.

Here K is the flow factor ($K = 3.64\sqrt{T/M}$ $l/cm^2.s$).

σ was 0.2 for N_2 and 0.07 for H_2 respectively[3]; K_{N2} is 11.9; K_{H2} is 44.6; the internal surface of the pump chamber A is 4482cm^2, therefore, the intrinsic pumping speeds of 10667 l/s and 13993 l/s were calculated for Sp_{N2} and Sp_{H2} separately.

The effective pumping speeds (S) were limited by the gas conductance (U) from the chamber into the pump. The calculated results showed that the effective pumping speeds for N_2 was 1921 l/s and for H_2 was 2001 l/s.

The regulated power supply with a large adjustable current (to 50A) and a low-voltage AC power (a maximum of 6V) was equipped with the pump. The three argon-free titanium wires produced by VACOM Company (USA) were installed as the filaments sublimation cartridge. A baffle was arranged above the cartridge to prevent the vacuum chamber from depositing of the titanium molecules.

2.4 The sputter ion pump

As one of the main pumps of the system, an ultimate pressure of 10^{-10} Pa was required for the SIP. The greatest pumping speed was kept in 10^{-7} Pa range, and in 10^{-8} Pa range the 65% of the nominal pumping speed was still kept. The several pumps from different companies were tested and the results as follows: the ultimate pressure of the pumps from ULVAC Company (Japan), Shanghai Vacuum Pump Factory (China) and Varian Company (USA) were 7×10^{-10} Pa, 2×10^{-9} Pa and 6×10^{-9} Pa respectively. The pumping speeds of the three pumps for N_2 were showed in figure 2. Comparing with the ultimate pressure, the pumping speed, the stability and the reliability of the pumps, finally, the ULVAC's pump was chosen.

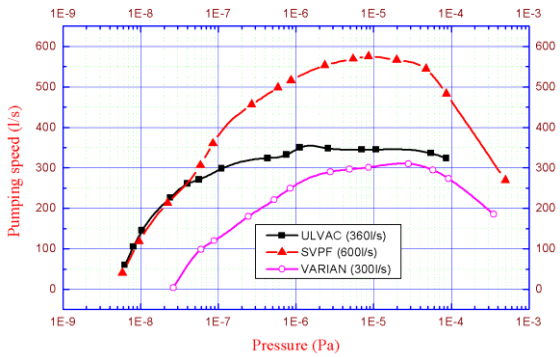

Figure 2: The pumping speed curves of the ion pumps

2.5 The other vacuum elements:

The rough-pump station consisted of a Varian's TMP with pumping speed of 550 l/s and an Alctel's dry pump with pumping speed of 5 l/s. The vacuum gauge IM 520 with IE 414 and IE 514 sensors produced by Leybold Company were adopt as the measuring equipment. The QMA 422 quadrupole mass spectrometer produced by Balzers was used to test and analyze the residual gases in the system.

3 INSTALLATION AND TEST OF THE PROTOTYPE

3.1 The first cycle of the installation and test (the TSP wasn't installed)

The prototype was assembled in our ultra-high vacuum laboratory in July, 2000. It was pumped-down by the oil-free TMP station and leak detected by Varian's leak detector (979) with high sensitivity of 1×10^{-9} Pa.l/s. After the leaks were eliminated, all the elements of the system were baked-out by winding with heaters and insulations to 300°C for 40 h. The temperature was controlled by several thermocouples and the rate of temperature change is 30°C/h. During the bake-out process, the SIP, the gauges and the mass spectrometer's filaments were degassed for many times. At the end of the bake-out, the SIP had been turned on. When the pressure of the system had approached the pressure of the TMP, the valve connected the rough pump station and the system was closed. The device was pumped by the SIP only. 48 h later, the pressure of the pump chamber (P_1) and the end of the dipole chamber (P_2) were 1.1×10^{-8} Pa and 1.7×10^{-8} Pa respectively.

According to the formulas: $P_L - P_0 = qA / 2U$ and $P_0 = Q / S$ [3], the outgassing rate of the chamber materials can be estimated.

In the formulas, P_L, P_0 indicates P_2 and P_1 (Pa), q is the outgassing rate of the chamber walls (Pa.l/s.cm^2), A the internal surface area of the chambers (cm^2), Q the gas load ((if the leak rate was ignored, Q is the outgassing of the chamber walls (Pa.l/s)), U the gas conductance (l/s), S is the effective pumping speed of the ion pump (l/s).

The result of the calculation was: 48 h after the bake-out stopped, $q \approx (2\sim8)\times10^{-11}$ Pa.l/s.cm^2.

The partial pressure proportion of the main residual gases showed in QMS 422 were follows: before bake-out, the pick value of the H_2O is very high, occupied about 75%, CO 10%; after bake-out, the pick of H_2 is highest, 80% at a pressure of 10^{-8} Pa, CO 10% and H_2O only 1%.

In this cycle, another two tests were done:

1) Before the system was exhausted, a dial gauge was putted in the middle of the dipole chamber's up plate in order to measure the deformation when the chamber was pumped down. During the exhausting process, the reading

of the dial gauge was 0.5 mm. Using Ansis program, the mechanical analyses showed that the maximum stress of the chamber was at four corners. The value of the stress was about 30 N/mm^2. It was safe to compare with the yield stress of 110 N/mm^2 of stainless steel 304 at 300°C.

2) Before the system was baked-out, two plumbs were separately hanged in the ends of the pump chamber and the dipole chamber. When the chambers were heated, the length of the chambers was increased. The maximum length increase was 17 mm when the temperature reached 300°C. The chamber returned to the original position when the temperature reduced to 20°C. The vacuum chamber didn't become deformed due to expend with heat and contract with cold.

3.2 The second cycle of the installation and test (the TSP was installed)

Same schedule were carried out for the system to pump-down, leak-detect and bake-out. During the bake-out process, the three filaments were degassed alternatively for a long time (several h for each). The degassing current was 30A. When the pressure of the system was reached to 1×10^{-7} Pa, one of the filaments was ignited with a current of 48A (corresponding a voltage of 5V) for 1 min. 8 h later, P_1 displayed 1×10^{-8} Pa (if using the SIP only, 48 h was needed for the same pressure). Then the filament was ignited 1 min. again, the pressure reduced rapidly. P_1 displayed 5×10^{-9} Pa in 0.5 h and 1.5×10^{-9} Pa in 12 h. In the following days, P_1 was kept in $1.1\sim1.7\times10^{-9}$ Pa and P_2 was kept in $3.8\sim5.5\times10^{-9}$ Pa. The residue gas analysis show that H_2 was the dominant gas (about 90%). The rest gases were mainly CO. The content of argon was very exiguous, only several ppm.

The system pressure was $(1\sim2)\times10^{-8}$ Pa if the SIP was only used. According to the pumping speed curve of ULVAC's ion pump, the pumping speed in $(1\sim2)\times10^{-8}$ Pa range was about 200 l/s. If the pressure of $(1\sim2)\times10^{-9}$ Pa was required, the effective pumping speed should be more than 2000 l/s. From the experiment result (P_1= $(1\sim2)\times10^{-9}$ Pa), the pumping speed of the TSP should be more than 2000 l/s in $10^{-8}\sim10^{-9}$ Pa range. The calculation value was verified. However, the exact value of the pumping speed of the pump will be tested when the test dome are built up.

The prototype was tested for many cycles subsequently. The bake-out temperatures were modulated between 220°C~300°C. The results were almost the same if the back-out time was kept longer. For example, when the temperature was 220°C, the bake-out time had to be lasted to more than 80 h. Reducing the bake-out temperature is very profitable for the project budget, because the cost of the magnet elements machining and running is in direct proportion to the fourth power of the magnet gaps. If the heat insulation thickness can be reduced in a lower bake-out temperature, the magnet gaps can be reduced as well.

4 THE INITIAL PROGRESS OF THE BACK-OUT SYSTEM RESEARCH

The armor heaters with 2 mm in diameter were used in the dipole chamber because of the strait space of the magnet gap. For the same reason, the thickness of the insulation for dipole chamber was less than 3 mm. A kind of insulation material with the thermal conductivity of 0. 027 W/m.K (in 300°C) was trial-produced in an insulation material institute in China. It was successfully used in the dipole chamber to keep the outside temperature of the insulation lower than 80°C while the chamber temperature was 300°C. For other chambers the baking jackets with heaters and insulation together were trial-made by the same institute and been tested. The result was satisfied.

.Now, the further improvement on the bake-out elements and the design for the control system are underway.

5 CONCLUSION

The first prototype has obtained anticipated results: The structure of the dipole chamber is reasonable; the outgassing rate of the material is $\leq 10^{-11}$ Pa.l/s.cm^2, which means the material surface treatment method is advisable; the disposition of the main pumps is rational and reliable; the pumping speed of the TSP is accordant with the design value; the vacuum equipment used in the prototype are satisfied with the UHV requirements; the progress has been obtained in the bake-out system design and trial-product. Now, the design for 1/10 CSRm UHV prototype has been finished and it is being manufactured, which include dipole chamber, quadrupole chamber, pumping and diagnostic elements chambers and large bellows. The installation and the test for the prototype will be finished in end of the year 2001. At the same time, the design for CSRm inject beam line, one of the subsystems of the project, has been finished and it is being manufactured as well. The beam line will be installed in site in October 2001.

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REFERENCES

[1] X.T.Yang, "The ultra-high vacuum system of HIRFL –CSR", "Vacuum" 61(2001) 55-60.

[2] D.A.Da, "Vacuum design manual", The national defense industry publishing company, 1995. [in Chinese].