THE DESIGN AND STRUCTURE OF THE ULTRA-HIGH VACUUM SYSTEM OF HIRFL-CSR

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Abstract

To minimize the beam loss due to charge exchange of very heavy ions with the residual gas molecules, ultra-high vacuum of 6×10^{-9} Pa is required for the HIRFL-CSR facility, which is the lowest pressure in a large vacuum system in China up to now. The total length of the system is about 450 meters and the total inner surface is about 263 square meters. More than 500 standard vacuum components are needed and more than 400 different chambers have to be manufactured. A lot of researches have been down to try to find out the experiences to obtain the required pressure. In this article the following contents are described: the layout of the system; the structure of main vacuum chambers; the treatment metherd to reduce the outgassing rate of the chamber wall surfaces; vacuum equipment; pressure distribution and the progress of the system.

1 THE LAYOUT OF THE SYSTEM

The total length of the HIRFL-CSR vacuum system is 450 m and the total inner surface is about 263 m^2 (not including the equipment inside the vacuum system). The four subsystems (CSRm, CSRe, SSC-CSRm beam line and CSRm-CSRe beam line) all have different dipole and quadrupole chambers. The Electron Coolers, RF cavities, internal targets, injection and extraction elements such as kickers, bumpers and septa are installed in the straight sections of the two rings. Various beam diagnostic elements are mounted in the appropriate chambers.

The vacuum equipment layout is shown in Fig.1. More than 500 standard vacuum components are needed for the whole system and more than 400 different chambers have to be manufactured. The gate valves divide CSRm into 5 sections, CSRe into 4 sections, SSC-CSRm beam line into 2 sections and CSRm-CSRe beam line into 4 sections. For each section there are two or three pump-down stations where movable turbo pumps can be mounted.

Fast closing valves are installed in the injection and extraction lines to prevent the two rings from possible vacuum breakdown. A pressure measurement device is installed in each vacuum section. Bellows allow for adjustment of the different chambers and avoid damage by the increase of chamber length during the bake-out process.

The rings will be equipped with permanent heater jackets and thermocouples. In the two transfer lines

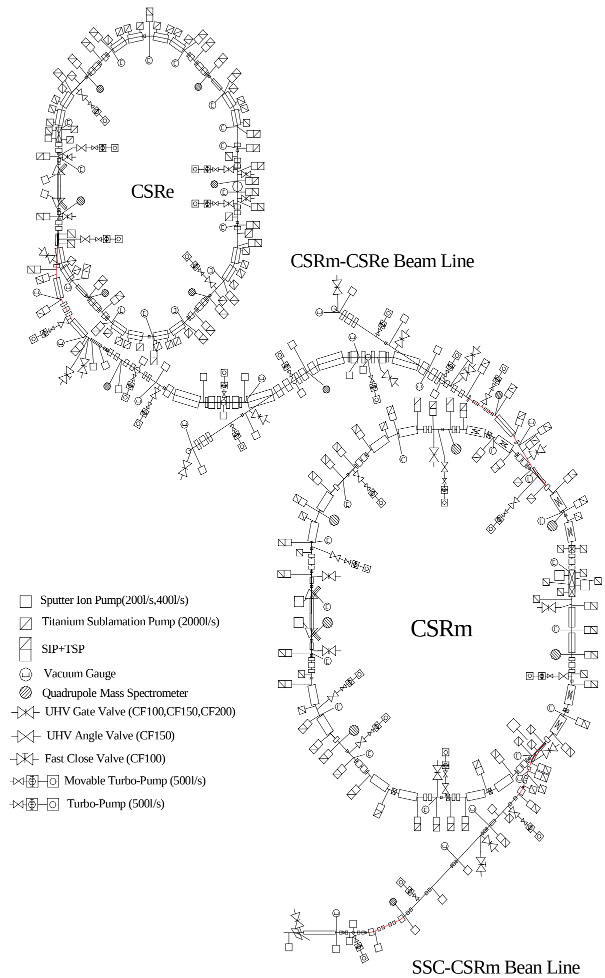

Figure 1: The vacuum equipment layout of HIRFL-CSR

which have a lower degree of vacuum of 10^{-7} Pa are only baked-out on the last sector before and after the two rings. Near the rings, there are large pumps installed to reduce the pressure from 10^{-7} Pa to 10^{-9} Pa.

2 THE VACUUM CHAMBERS

There are 16 dipole chambers and 16 quadrupole chambers in each ring. The CSRm dipole chambers have a curve length of 3.5 m with a radius of 7.6 m and an angle of 22.5°. The CSRe dipole chambers have a curve length of 2.9 m with a radius of 6 m and the same angle. The low permeability stainless steel of 316L is used to make these chambers. Rectangular cross-sections of 156×60 mm and 234×70 mm are required for CSRm and

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CSRe respectively. An octagonal cross-section is chosen for the quadrupole chambers according to the magnet gaps.

The other chambers (beam diagnostic chambers and pumping chambers) are made of stainless steel 304L with wall thickness of 2 to 3mm. Bellows are welded to some chambers for adjustment and for bake-out. Specially designed supports are needed because of the changes in chamber length during the bake-out process.

For chambers where the diameter is less than 250 mm, Conflat flanges are used. For larger diameter vessels, rotatable DESY type flanges are used. Both are manufactured from stainless steel, type 316LN.

All metal seals are adopted throughout the vacuum system. Oxygen-free copper gaskets and copper wires are used for the two types of flanges. Screws and nuts are made of stainless steel. The screws are silver plated to avoid sticking during the bake-out process. All materials inside the vacuum chambers have to be chosen for low outgassing rate and for being able to withstand temperatures of 300°C.

3 REDUCE THE OUTGASSING RATE

In an ultra-high vacuum system, the gas load is mainly thermal outgassing of the chamber materials. Hence, the pretreatment of the materials is critical for obtaining minimum outgassing rate in order to obtain a low pressure. The pretreatment includes 1) degassing the materials in a vacuum furnace. Copper gaskets can be fired in the furnace at a pressure of 10^{-4} Pa and a temperature of 450°C for 6 hours. The stainless steel materials are fired for 1 hour per mm wall thickness at a pressure of 10^{-4} Pa and a temperature of 950°C. At the end of the firing process the temperature should be reduced quickly (in about 15 minutes) from 900°C to 600°C to prevent segregation of carbon at the surfaces. A vacuum furnace with an operating pressure of $p \leq 10^{-4}$ Pa, with a diameter of 800mm and a length of 3000 mm has been finished in Lanzhou for this process. 2) cleaning the materials and chambers in terms of ultra-high vacuum cleaning procedure. 3) *in-situ* bake-out. The chambers and the vacuum components inside are designed to be bakeable *in-situ* to 300°C. The dipole and quadrupole chambers are baked by coaxial heaters with a diameter of 2~3 mm. The tight space of the magnet gaps limits the thickness of the insulation to less than 5 mm. Microtherm, a special insulation is used for these chambers to avoid thermal lost and protect the magnet coils from damage. The other chambers are heated by heating tapes, insulated by glass fibre. Thermocouples are used for each heater circuit to control the temperature during bake-out so that temperature differences do not exceed 10°C.

4 VACUUM EQUIPMENT

4.1 *Main pumps*

The two rings are pumped by titanium sublimation pumps and sputter ion pumps. Sputter ion pumps with pumping speeds of 200~400 l/s remove non getterable gases such as methane and argon. The ultimate pressure of the pumps is lower than 1×10^{-9} Pa. The pumping speed in this pressure range should be more than 30% of nominal pumping speed.

Titanium sublimation pumps have a high capacity for hydrogen at very low pressure, where the residual gas is mainly H_2 (90%). Three filaments made of titanium -molybdenum wire (85% Ti, 15% Mo, Ar-free) are mounted on holders in the pump bodies, which are made of 3O4L stainless steel. Each pump has an inner surface area of about 5000cm^2 of sublimated titanium and a pumping speed of approximately 2000l/s for active gases.

4.2 *Pump-down stations*

Each pump-down station consists of a ceramic ball bearings turbo-pump of 500l/s and an oil-free roughing pump of 20m^3/h. Pump-down stations are used to pump the system down to 10^{-5} Pa, to extract the gases during the bake-out process and to detect leaks in the system.

4.3 *Vacuum measurement*

The pressure is monitored by combination tubes consisting of a Pirani gauge with either a Bayard-Alpert gauge or an extractor gauge. The Pirani gauge covers the pressure from atmosphere to 10^{-2} Pa, and the extractor gauge measures down to 10^{-10} Pa. The ion pump currents can also indicate pressure down to 10^{-7} Pa.

Mass spectrometers are installed in every section to analyze the residual gases in the system.

4.4 *Vacuum valves*

The valves in the two rings are bakeable to 300°C. All metal gate valves of 200mm diameter in bore are used as insulation valves for the sectors of both CSRm and CSRe. Because of the high price, the number of valves is reduced to a minimum. All metal gate valves of 150mm diameter in bore are used to connect the main system and the pump-down stations. Small all metal angle valves are used to vent the system with dry nitrogen to protect the walls from contamination with water and dust when the system is opened.

The sector valves are controlled by gauges and ion pump currents to protect the system from pressure breakdowns. Fast closing valves with a closing time of 20 ms are mounted between the beam lines and the rings to protect the ultra-high vacuum from possible failures in the beam lines and experimental areas.

5 PRESSURE DISTRIBUTION

The gas-load in CSRm is 1.53×10^{-4} Pa.l/s and the effective pumping speed for each main pump station is about 1000 l/s. According to the equation: $S = Q / P$, 51 main pump stations are needed for CSRm. The distance between two pumps is about 3m. Similarly, 57 main pump stations are needed for CSRe, which has a gas-load of 1.71×10^{-4} Pa.l/s. The distance between two pumps is about 2.2 m. The degree of vacuum in the beam lines is not so high, so the distance between two pumps is about 6~8 m.

The calculation shows that the pressure distribution curve along the system with uniform gas-load (mainly thermal stimulated outgassing of the vacuum materials) should be a series of parabolas. The highest pressure between two pumps is at the middle.

The vacuum elements in four quadrants of CSRm and CSRe are almost symmetrical arranged. Figure 2 shows the pressure distribution in one quarter of CSRm.

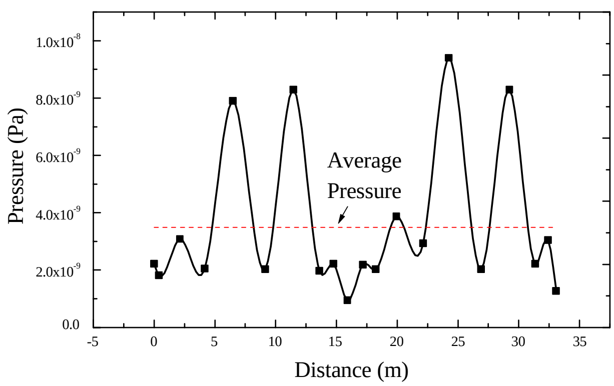

Figure 2: The pressure distribution in one quarter of CSRm

6 THE PROGRESS OF THE SYSTEM

The HIRFL-CSR project is to be finished in 2004. Now everything is under way and on schedule. In vacuum system, a CSRm dipole chamber cell as the first ultra-high vacuum prototype has been finished and tested. The pressures in the pump chamber and the end of the dipole chamber (4 m away from the pump) were 9×10^{-10} Pa and 3.6×10^{-9} Pa respectively. The out gassing rate of the chamber material walls was $2\sim8\times10^{-11}$ Pa.l/s.cm^2. The design for larger CSRm prototype has been finished and is being manufactured in Lanzhou. At the same time, the vacuum chambers of SSC-CSRm beam line are being making in Beijing. They will be finished in end of July this year when the pumps and valves needed in the subsystems will be sent to Lanzhou from different foreign companies.