THE VACUUM SYSTEM OF HIRFL*

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Abstract

The vacuum system of HIRFL is a large and complex system. Heavy Ion Research Facility in Lanzhou (HIRFL) consists of two ECR ion sources, a sector focus cyclotron (SFC), a separate sector cyclotron (SSC) and a multi-purpose cooling storage ring system which has a main ring (CSRm) and an experiment ring (CSRe). Several beam lines connect these accelerators together and transfer various heavy ion beams to more than 10 experiment terminals. According to the requirements of the ion acceleration and ion lifetime, the working pressure in each accelerator is different. SFC is nearly 50 years old. After upgrade, the working pressure in SFC is improved from 10^{-6}mbar to 10^{-8}mbar. The pressure in SSC which was built in 1980's reaches the same level. The cooling storage ring system with a length of 500m came into operation in 2007. The average pressures in CSRm and CSRe are 5×10^{-12}mbar and 8×10^{-12}mbar respectively. Different designs were adopt for vacuum system of dozens beam lines to meet specific requirement of each experiment terminal. For instance, some shockproof measures have to be taken for the heavy ion microbeam facility. A clean and large throughput differential pumping system was built for the Gas-filled Recoil Separator. Special pipes were used in the magnetic scanners mounted in the beam lines for heavy ion cancer therapy terminal.

VACUUM SYSTEM OF SFC

SFC with the energy constant of 69, is the injector of SSC and HIRFL-CSR. It was built in 1957. In the past 50 years, the vacuum system of SFC has been upgraded for three times. The working pressure was improved from ~10^{-6}mbar to 10^{-8}mbar. The vacuum chamber was redesigned to double-deck (Fig. 1) at last.

Figure 1: SFC double-deck vacuum chamber.

*Work supported partly by National Nature Science Foundation of China under the contract number of 10675152
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All components with large outgassing were put into the insulation chamber where the pressure is 10^{-1}mbar. Consequently, a pressure of 10^{-8}mbar can be obtained in the beam chamber by 2 cryo-pumps with total pumping speed of 40000 l/s.

After the upgrade of the vacuum system, 1.1 MeV/u $^{208}Pb^{27+}$ beam was accelerated to confirm the vacuum effect, which turned out that the upgrading of the SFC vacuum chamber was successful. SFC has delivered $^{208}Pb^{27+}$, $^{209}Bi^{31+}$, $^{238}U^{26+}$ beams in the past few years since the last upgrading of the SFC vacuum chamber.

VACUUM SYSTEM OF SSC

SSC with the energy constant of 450 began to operate in 1987. The vacuum chamber of SSC (Fig. 2), which is made of 316L stainless steel with a permeability of 1.01, has a volume of 100m^3. The magnet cores, RF cavities, injection and extraction components are inside the vacuum chamber with a large of gas load. 8 cryopumps with a pumping speed of 20000 l/s for each were installed in the chamber. Depending on the accelerated heavy ion species, 2~8 pumps were used to keep the pressure from 2×10^{-7}mbar to 5×10^{-8}mbar.

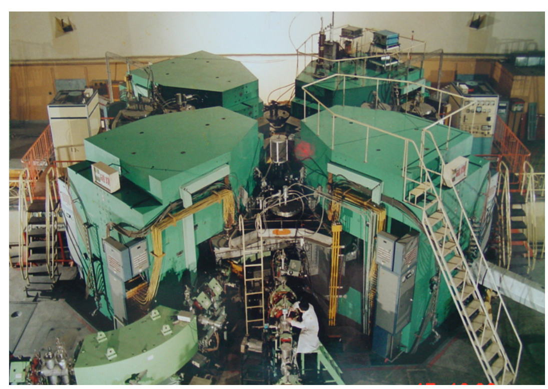

Figure 2: SSC (vacuum chamber is between the magnets).

VACUUM SYSTEM OF HIRFL-CSR

HIRFL-CSR [1], a new accelerator project just been completed is a multipurpose Cooling Storage Ring. To minimize the beam loss due to charge exchange of very heavy ions with the residual gas molecules, the working pressure of lower than 3×10^{-11} mbar is required, which is the lowest pressure in a large vacuum system in China up to now.

The total length of the HIRFL-CSR vacuum system is 500 m and the total inner surface is about 450m^2. All the four subsystems (CSRm, CSRe, CSRm injection beam line and CSRm-RIBLL2 beam line) have different dipole and quadrupole chambers. The Electron Coolers, RF cavities, internal targets, devices for beam injection and extraction, 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. 3. More than 500 standard vacuum components are needed for the whole system and more than 400 different chambers have been manufactured. The main pump for the system is the combination of titanium sublimation pumps and sputter ion pumps. Several metal gate valves divide CSRm into 5 sections, CSRe into 4 sections. For each section there are two or three pump-down stations where movable turbo pumps can be mounted.

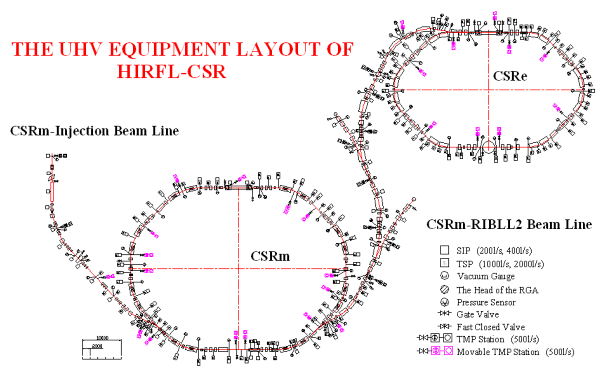

Figure 3: Vacuum equipment layout of HIRFL-CSR.

Fast closing valves are installed in the injection and extraction beam lines to prevent the two rings from possible vacuum breakdown. The pressure is monitored by IM520 gauges with IE514 sensors which cover the pressure range from 10^{-4}mbar to 10^{-12}mbar. The ion pump currents can also indicate pressure down to 10^{-9}mbar. Mass spectrometers are installed in every section to analyze the residual gases in the system and are used for leak-detecting after the system baked-out.

Stainless steel was chosen as the material for the vacuum chambers. To reduce the outgassing of the system, all chambers were degassed in a vacuum oven with the temperature of 950°C. The chambers in two rings are equipped with permanent heater jackets with the bake-out temperature of 250°C for 40h. The bake-out process is controlled by computers. The rate of temperature change is 30°C/h. Ni-Cr-Ni thermocouples are used for each heater circuit. The signals are sent to the control modules for switching the heaters on or off.

HIRFL-CSR project was completed in the end of 2007. The average pressures of 5×10^{-12} mbar and 8×10^{-12} mbar were obtained in CSRm [2] and CSRe respectively, which are better than the design target. During the accelerator commissioning [3] and operation period, the vacuum system keeps a very good and stable status.

VACUUM SYSTEM OF BEAM LINES FOR EXPERIMENT DEVICES

HIRFL has more than 10 experiment terminals which connected with the accelerators by beam transfer lines. The total length of the beam lines is about 250m. The pressure of 10^{-7}~10^{-8} mbar is low enough in most beam lines where ions pass through only once. The vacuum pipes in beam lines were made of stainless steel. Sputter ion pumps were used to keep the working pressure in most of the beam lines.

According to the specific purpose, special designs were adopted for some beam lines. Several examples are introduced below.

Vacuum System of Heavy Ion Microbeam Facility

The special requirement of the heavy ion microbeam facility is reducing the vibration and displacement of the vacuum pipes as small as possible. A welded bellows with a length of 200mm was installed above each turbo molecular pump (TMP, Fig. 4) in order that the vibration of the pipes is less than 2μm.

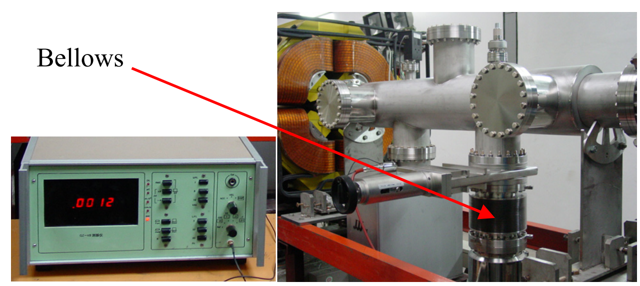

Figure 4: Shockproof measures were taken for TMP operation

Clean and Large Throughput Differential Pumping System

The Gas-filled Recoil Separator built in one experiment terminal of HIRFL requires He of 1mbar as a support medium. The working pressure in the beam line connected with the device is 10^{-7}~10^{-8}mbar. There are 7~8 orders of magnitude of pressure differential between them. The distance from the device to the beam line is only 2m long. The channels for the experimental particals is a coniform tube with diameters of 10mm and 30mm at each ends. Therefore, it is impossible to achieve the large pressure transition by extending the tube length or reducing the tube diametre like a capillary structure. In the other hand, the device is not far from the vacuum system of CSR, which has a working pressure of less than 10^{-11}mbar and must be protected from the contamination of any oil vapour.

The working pressure of the differential pumping system covers whole pressure ranges which including viscous flow, intermediate flow and molecular flow ranges. In the ranges of viscous flow and molecular flow, dry pump and trubo-molecular pump (TMP) can be used respectively to keep the system clean. However, they can not work well in the intermediate flow range (1mbar~10^{-3} mbar). Therefore, Roots pump unit is being used in the intermediate flow range for almost all differential pumping systems [4-5]. However, Roots pump unit has a large volume and has a big problem of back-streaming of pump oil. In our design [6], a special kind of Molecular/Booster pump (MBP) was adpped to replace the Roots pump unit. The new pumps can operate continuously in the intermediate flow range with large pumping throughput as that of Roots pump unit, and low contamination as that of normal TMP. As a result, a clean and large throughput differential pumping system with a small volume has been set up in our institute (Fig. 5).

Figure 5: The differential pumping system of the Gas-filled Recoil Separator (MBP were used in 1-2 stages).

Development of the Ultra-Thin Wall Stainless Steel Vacuum Pipe Inside the Scanning Magnets

The high frequency scanning magnets were used in the beam lines which connected with the heavy ion cancer therapy and material radiation experiment terminals of

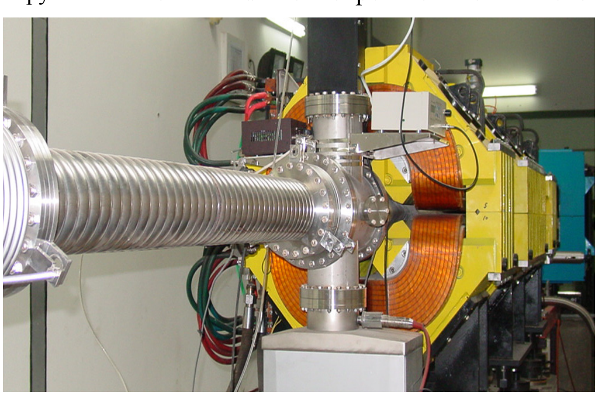

Figure 6: Arch shape stainless steel pipe with the wall thickness of 0.3mm was installed in the cancer therapy beam line.

HIRFL. In order to eliminate the eddy current, the best choice is using ceramic pipes inside the scanning magnets. If stainless steel pipes were used, the wall thickness of the pipes must be very thin (less than 0.3mm, for example). Considering security, the ultra-thin stainless steel pipes with the wall thickness of 3mm were developed. The pipes were punched into many arch sections on the basis of the principle of arch bridge (Fig. 6). Both the intensity and rigidity of the pipes meet the requirements and the eddy current can be ignored when the scanning magnets works.

SUMMARY AND OUTLOOK

The vacuum system of HIRFL was brief described. It consists of cyclotrons, cooling storage rings and beam lines. Now, the vacuum system of HIRFL works stably. We are going to renovate some old equipment every year and upgrade the vacuum system of SSC to provide a better vacuum condition for the heavy ion research facility. Because of the contamination of oil vapour and leaks occurred in some components inside the SSC vacuum chamber, which were very difficult to eliminate, at present the pressures in four vacuum gauges which were installed in different positions were 2~4×10^{-7}mbar with 6 cryopumps operating. It was a big problem to accelerate the heavier ions although the $^{209}Bi^{31+}$ beam was delivered recently. The upgrade for the SSC vacuum system will be an urgent task for us.

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