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DEVELOPMENT AND OPERATION OF VACUUM SYSTEM FOR RAPID CYCLING SYNCHROTRON TO TARGET BEAM TRANSFER LINE OF CHINA SPALLATION NEUTRON SOURCE*

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Abstract

China Spallation Neutron Source (CSNS) is a major scientific project during the China's National Eleventh Five-Year Plan. It consists of a negative hydrogen ion linear accelerator, a rapid cycling synchrotron (RCS), a linac to RCS beam transfer line (LRBT), an RCS to target beam transfer line (RTBT), and a target station. As an important part of CSNS, the RTBT connects the rapid cycling synchrotron and the target window. This paper described the design requirements, technical solutions, and operating conditions of the vacuum system for the CSNS RCS to target beam transfer line. In addition, the fast valve protection system and its verification results were also expounded. The CSNS has been in operation for over three years, during this period, the beam power has been gradually improved from 10 kW to 100 kW, and the vacuum system for RTBT has been operating stably.

INTRODUCTION

China Spallation Neutron Source (CSNS) is one of the national basic scientific projects in china and allows a proton beam with an energy of 1.6 GeV to smash into a solid metal target at a frequency of 25 Hz to produce neutrons. It can be used for research in physics, chemistry, biology and material science, and is a research platform for multidisciplinary applications. The equipment mainly consists of a negative hydrogen ion linear accelerator, a proton Rapid Cycling Synchrotron (RCS), two RTBTs, a target station, three neutron spectrometers, as well as the corresponding supporting facilities and civil works [1]. RTBT is an important part of CSNS, which connects the rapid cycling synchrotron and the target window, and its main task is to transmit the high-power proton beam from RCS to the target station.

Based on the general requirements of accelerator vacuum system and combined with the actual situation of CSNS, RTBT vacuum system must meet the following points [2]: 1. Meet the vacuum requirements for accelerator operation; 2. Reliable, as the accelerator needs to run for a long time; 3. Radiation resistant, working in radiation environment; 4. Easy to assemble and disassemble, reducing the staff exposure period to irradiation; 5. Be capable of quickly restoring the vacuum; 6. Reliable inter-lock protection function to prevent accident expansion.

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DESIGN OF VACUUM SYSTEM

The physical parameters of RTBT are shown in Table 1 [3]. The dynamic vacuum degree of RTBT is required to be higher than 1×10^{-5} Pa, its front end is connected to RCS (vacuum degree 1×10^{-6} Pa), and the terminal is connected to spallation target station and beam dump (RTDUMP) through Proton Beam Window (PBW). The RTBT is about 145 m long, with a total design volume of 2100 L and a total surface area of 58 m^2.

Table 1: Physical Parameters of RTBT

General parameters	100 kW	500 kW	Units
Kinetic energy of beam	1.6	-	GeV
Length	144.3	-	m
Height	1.405	-	m
Average beam power	100	500	kW
Size of beam spot on target H×V	120×40	160×60	mm^2

Section of the RTBT

One all-metal pneumatic gate valve is arranged every 30 to 40 m in the RTBT, which is divided into five sections, as shown in Fig. 1, which are Section I, Section II, Section III, Section IV and RTDUMP section respectively, in each of which, two all-metal angle valves are set as roughing valve and inflatable valve. The sections are independent of each other, which makes it possible that it is only necessary to destroy the vacuum in the corresponding section for repair and restore it individually. Each section is equipped with a cold cathode gauge (CCG), and Section IV is equipped with a residual gas analyzer to monitor the status of the vacuum system.

Vacuum Acquisition

The dynamic vacuum of RTBT is required to be higher than 1×10^{-5} Pa, and the Sputter Ion Pump (SIP) has good pumping speed in this range, which not only has high pumping speed for inert gas, no oil and no noise, but also has the characteristics of positive correlation between ion flow and vacuum degree in the pump, which can assist in monitoring the vacuum of the system, help to quickly determine the leakage point in case of vacuum leakage, and therefore, ion pump is selected as the main pump of RTBT vacuum system.

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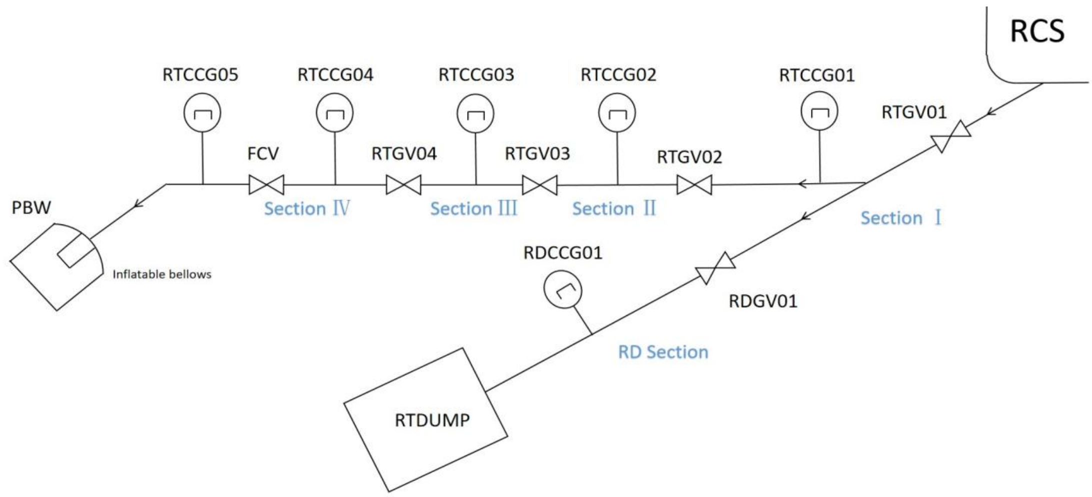

Figure 1: Section of the RTBT (RT: abbreviation of RTBT; GV: gate valve; FCV: fast closing valve).

The area 24 m in front of the proton beam window in Section IV is a highly radioactive area, which is inaccessible to workers. No vacuum acquisition equipment and measuring equipment can be installed inside the shielding wall, outside of which a 400 L/s ion pump and a 1000 L/s turbomolecular pump are used to maintain the vacuum and a 200 L/s ion pump is installed every 6 meters in other sections, assuming that the material outgassing rate is 1.33×10-11 Pa·m3/s·cm2, the RTBT pressure distribution curve is obtained by using the program developed by European Organization for Nuclear Research (CERN), and get the average pressure of 8×10-6 Pa, meeting the design requirements, as shown in Fig. 2.

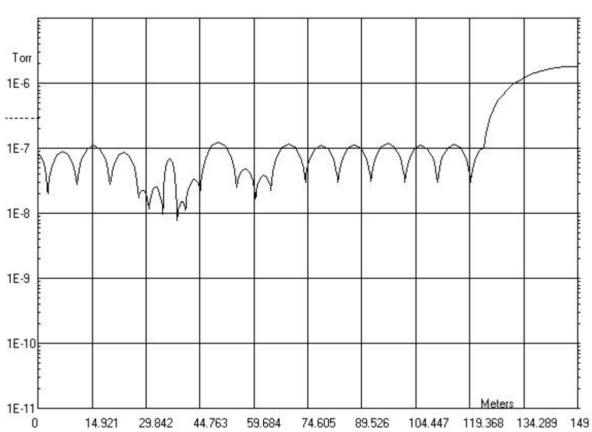

Figure 2: Pressure profile of the RTBT.

MECHANICAL DESIGN

The vacuum chamber is the basic part of the accelerator, which should meet the requirements of vacuum and beam dynamics at the same time. The clear area of RTBT quadrupole magnet beam is round, so the cross section of vacuum box in RTBT linear area is round, with an inner diameter of 168 mm; The beam path in the deflection magnet is arc, and the clear area is ellipse, so the vacuum box in the deflection area is rectangular or irregular. The vacuum box in the magnet is made of 316 L stainless steel with lower permeability, and the other vacuum boxes are made of 304 stainless steel. The strength of rectangular or irregular vacuum chamber is lower than that of circular vacuum box, and thus checked.

Due to the large radiation of CSNS, it is necessary to complete the replacement and maintenance of damaged parts in a short time after the equipment in the tunnel has problems. As shown in Fig. 3, quick release flanges and chains are used for the connection between RTBT vacuum chambers and pump ports, and the sputter ion pump bracket is mobile. The support has casters and the chain has only two bolts (as shown in Fig. 4), which can reduce a large amount of installation, disassembly and transportation time, and minimize the working time of maintenance personnel in the radiation environment.

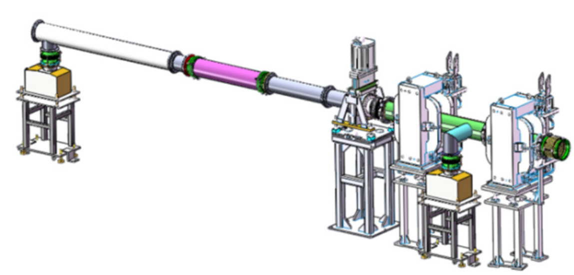

Figure 3: Partial assembly diagram of the RTBT.

Figure 4: Various specifications of quick release chains for the RTBT.

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VACUUM INTER-LOCK PROTECTION SYSTEM

RTBT vacuum protection system consists of common valve interlock protection system and fast valve protection system, which are independent of each other.

Common Valve Interlock Protection System

The gate valve interlock protection system is controlled by Programmable Logic Controller (PLC), which is composed of valve, vacuum gauge and PLC. The vacuum controller can be set with the alarm value of vacuum exceeding limit and will generate the vacuum alarm signal when it detects the vacuum exceeding limit. The PLC input module receives the vacuum alarm signal and valve status signal from the vacuum gauge controller, and the output module outputs the switch action signal to the vacuum valve. When the vacuum alarm signal on both sides of the valve is 0, the valve will close automatically to protect the vacuum system. The alarm value of the vacuum gauge should be set higher than the actual pressure by a certain amount, so as to avoid frequent closing of the gate valve. Table 2 shows the alarm values of each vacuum gauge that RTBT can operate stably.

Table 2: Alarm Value of Vacuum Exceeding Limit for RTBT Vacuum Gauges

No.	RTC CG01	RTC CG02	RTC CG03	RTC CG04	RDC CG01
value $\times 10^{-5}$ Pa	1	1	1	5	1

Fast Closing Valve Protection System

A proton beam window and inflatable bellows are installed at the end of the RTBT. The inflatable bellows are filled with high-pressure air to expand and make the end face contact with a smooth plane to form a seal. In order to avoid damaging the vacuum by exposure to air due to air source failure or other reasons, a DN200 fast closing valve is installed 24 meters away from the proton beam window, and capable of being closed within 40 ms to protect the front-end vacuum system in case of accident.

The fast closing valve is located in Section IV of RTBT, and equipped with a cold cathode gauge as a sensor, which is installed outside the shielding wall, as shown in Fig. 5. In order to ensure that the fast valve has enough response time in the event of an accident, a distance of about 4 meters is left between the fast valve and the sensor, so that the fast valve can be closed before the air flow reaches.

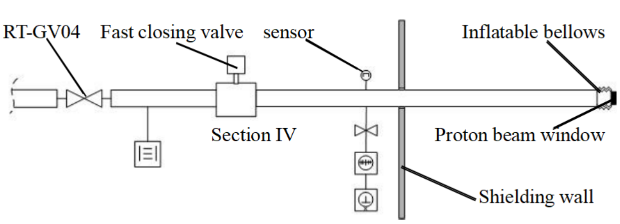

Figure 5: Schematic diagram of fast closing valve system.

OPERATION

The RTBT vacuum system was installed in June 2017 and has been in stable operation for nearly 4 years. The vacuum degree at each section is better than the design index and meets the requirements of accelerated operation. Table 3 shows the pressure of each section of RTBT at the beam power of 100 kW.

Table 3: Pressure of RTBT at 100 kW

Sections	I	II	III	IV	RD
Pressure $\times 10^{-7}$ Pa	2.0	1.5	2.5	160	1.7

Figure 6 shows the response curve of the fast valve and the relevant vacuum gauge in Section IV when it is subjected to an unexpected airborne impact:

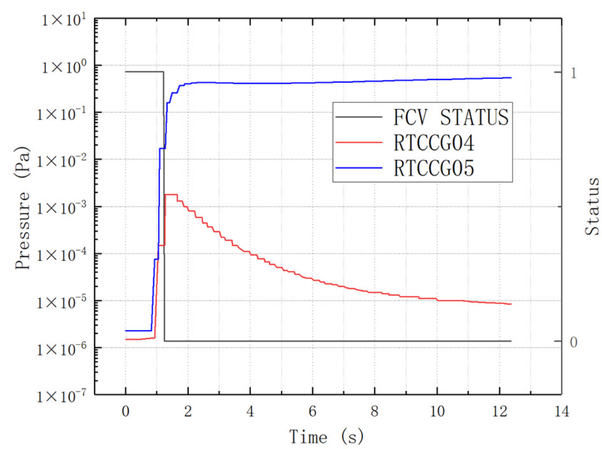

Figure 6: Response curve of the fast closing valve and the relevant vacuum gauge in Section IV when it is subjected to an unexpected airborne impact.

The curve shows that the fast valve can be closed in time to protect the vacuum system in case of unexpected impact and meet the design requirements.

CONCLUSION

After nearly four years of operation, the RTBT vacuum system is proved to be stable and reliable, and achieves the expected effect. The layout of the vacuum pump is reasonable, and the FCV can also effectively protect the vacuum system.

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