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# THE DESIGN AND COMMISSION OF VACUUM SYSTEM FOR CYCIAE-230 SUPERCONDUCTING CYCLOTRON

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*Abstract*

In this paper, the design, installation and commission of CYCIAE-230 superconducting cyclotron vacuum system are described. 8 sets of high compression ratio TMPs, which shielded by magnet material are used in combination with oil mechanical vacuum backing pumps and dry mechanical vacuum pumps. Another set of high compression ratio TMP is used to increase the central region degree. The pressure in the particle acceleration chamber is better than $2\times10^{-6}$ mbar in 48 hours.

## INTRODUCTION

CYCIAE-230, a superconducting cyclotron aims for proton therapy, is under design and construction at China Institute of Atomic Energy [1-3]. Vacuum system of CYCIAE-230 are studied for years. There are three technical difficulties of the CYCIAE-230 vacuum system, one is that 8 magnetic poles, 8 high frequency resonators, and 2 sets of striper targets and 2 sets of radial targets are installed in the accelerator vacuum chamber, which resulting in technical difficulties in many types of materials and large gases loads. Another is that CYCIAE-230 does not have a separate valley area for pumping, and can only be shared with RF vacuum vessel for exhaust. It means The more complex the high-frequency structure, the smaller conductance to pump. Third is that the residual magnetic field near the accelerator magnet is about 2000 Gs to 3000 Gs [4]. Many equipment, for example, molecular pumps, vacuum valves and other components will be damaged in such large residual magnetic fields. Therefore, these components need to be shielded from magnetic fields. To solve the above 3 technical problems of superconducting cyclotron CYCIAE-230 vacuum system, 8 sets of TMPs with magnet shields are installed on the valley of magnet poles, which also used as RF cavity [5], 1 set of TMP with magnet shields is installed on the central magnet pole to increase the vacuum degree of central region. The vacuum in the particle acceleration chamber is better than $5.6\times10^{-7}$ mbar in 48 hours without ion source. The detail design and commission of CYCIAE-230 vacuum system will be presented.

## CHALLENGES FOR VACUUM SYSTEM OF CYCIAE-230

Design of the vacuum system of CYCIAE-230 has gone through several listed and unlisted challenges:

- Shared with RF used the same cavity for exhaust.
- The strong residual magnetic for TMPs
- Inner Ion source.
- Thousands of internal welds in vacuum chamber

Meanwhile, technical requirements shall be met as the followings:

- Static pressure better than $2\times10^{-6}$ mbar
- Dynamic pressure better than $5\times10^{-5}$ mbar
- Clean, oil-free vacuum system
- Overall leakage rate less than $2\times10^{-11}$ mbar·l/s

## ACCELERATOR GAS LOAD IN ACCELERATION CHAMBER

The accelerator components in the superconducting cyclotron chamber include magnetic poles, high-frequency cavity, cryostat inner surface etc. The materials are accelerator iron, oxygen-free copper, stainless steel etc. The total volume is 10 m$^3$, and the outgassing area is about 200 m$^2$. CYCIAE-230 superconducting cyclotron is symmetric separated into two parts. The two halves and other seals on magnet yoke are sealed from the atmosphere using Viton O-rings with a hardness of 70 Shore, which cause more gas loading arising. The designing gas load of the ion source is less than 1 cm$^3$/min $H_2$. All sources of gas, such as the ion source gas inlet, leaks, permeation through gaskets and gas desorption is 210 mbar·l/s [6]. 2 sets of slim striper targets and 1 set of radial probes are also equipped with vacuum connector as shown in Figs. 1 and 2. The designation of vacuum devices and the cross-section of the inlet pipes have been dictated by their structure.

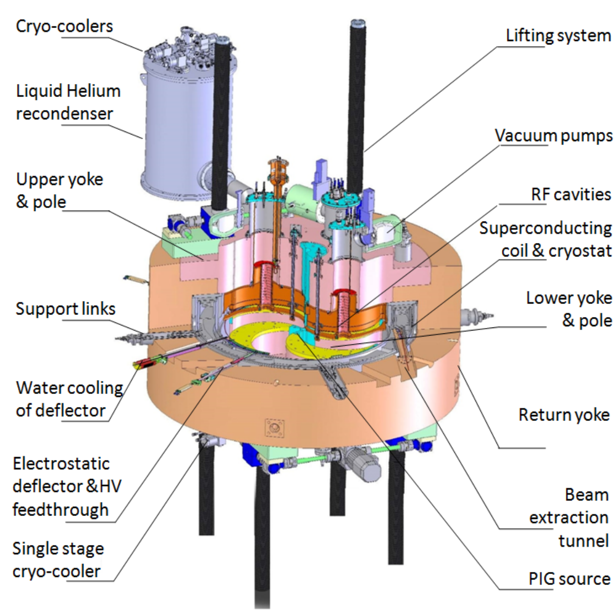


Figure 1: CYCIAE-230 cyclotron.

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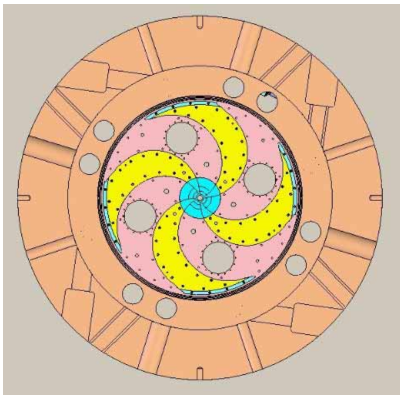

Figure 2: The median of CYCIAE-230 cyclotron.

## VACUUM SYSTEM DESIGN

Considering a leakage of 10 mbar·l/s and the permeation through gaskets are the most relevant gas sources for the final pressure, effective pumping speed of 2000 l/s is needed for the final pressure $2\times10^{-6}$ mbar. The conductance of the RF cavity the valley area is limited to only 1170 l/s, and the valley in which feed-in component stays, the conductance only is 540 l/s, the conductance of stem for the central region only 401 l/s, therefore the required pumping speed of 5000 l/s is calculated from the specified final pressure of $2\times10^{-6}$ mbar. The total installed pumping speed of 5000 l/s could be distributed optimally in the whole cyclotron with nine TMPs. 8 sets of TMPs with magnet shields are installed on the valley of magnet poles, which also used as RF cavity, 1 set of TMP with magnet shields is installed on the central magnet pole to increase the vacuum degree of central region. 3 sets of slim striper targets and 1 set of radial probes are also equipped with vacuum connector. The differential exhaust vacuum vessel is used to reduce the difference between the pressure in the target rod and the pressure in the accelerator chamber. 1 set of TMP with magnet shields and the cross-section pipe have been installed near the support of magnet yoke as shown in Fig. 3.

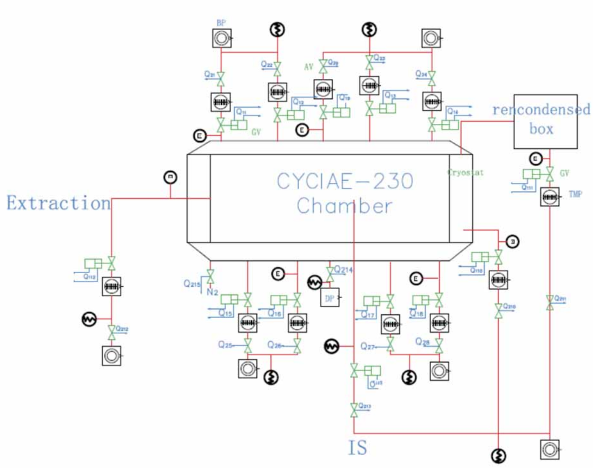


Figure 3: Schematic chart of CYCIAE-230.

Sets of TMPs installed on the cryostat always are used for insulation vacuum of the cyclotron magnet superconducting coils. The vacuum system diagram and the photo of the vacuum are shown as Figs. 3 and 4.

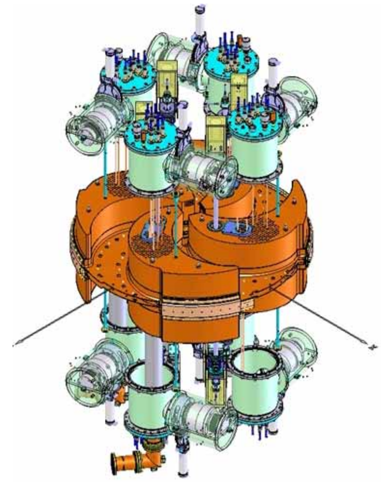

Figure 4: Nine TMPs used for CYCIAE-230 accelerator chamber.

## COMMISSION OF CYCIAE-230 VACUUM SYSTEM

All the parts of CYCIAE-230 superconducting cyclotron and vacuum system are tested while processing, ensuring that the leak rate of vacuum components and seals meet the design requirements. With this well-established concept, a rapid whole set leakage detect commissioning in one day is guaranteed.


Figure 5: Leakage detecting.

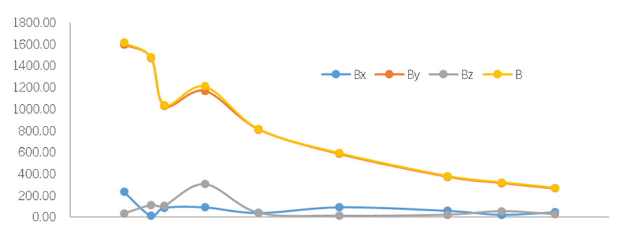


Figure 6: Residual magnetic of CYCIAE-230.

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Residual magnetic around CYCIAE-230 has been measured. Figure 6 shows that there is more than 1000 Gauss inevitably residual magnetic at the TMP installation ports [4], where the magnetic flux density reaches which is 20 times larger than the turbo pump's safe operation limit. This may further cause the malfunction of the turbo pumps. Shielding for TMPs are used as shown in Fig. 7 in order to guarantee secure operation.


Figure 7: Shield for TMPs.

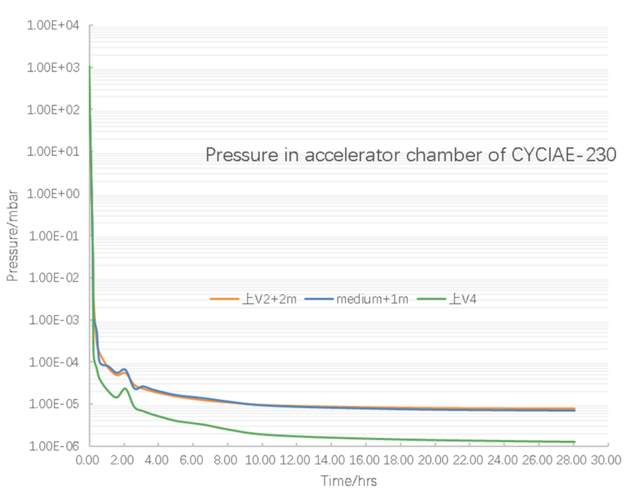


Figure 8: Pressure in accelerator chamber.

The Pressure in accelerator chamber shown in Fig 8, recorded on Mar 17th, 2020, shows that all requirements for the vacuum system have been achieved. The orange line in Fig. 7 means the measure gauge is 2 m from the flange. The blue line means the gauge is 1 m from the flange and the green one the measure gauge is fixed on the flange. So the further distance the worse pressure. Figure 9 shows pressure in accelerator chamber changes with RF power conditioning. Figure 10 shows dynamic pressure in CYCIAE-230 accelerator chamber changes with ion source and beam current recorded on May 19th, 2020.

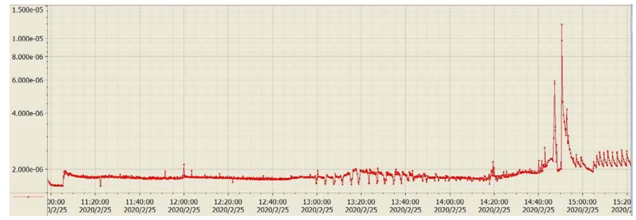

Figure 9: Pressure in accelerator chamber changes with RF power conditioning.

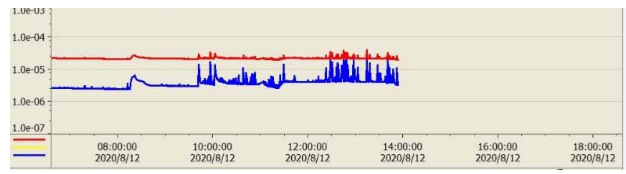

Figure 10: Dynamic pressure of CYCIAE-230 accelerator chamber.

After design, development and commission, CYCIAE-230 vacuum system has been successfully developed, static pressure is better than $5.6\times10^{-7}$ mbar, and the dynamic pressure is better than $5\times10^{-6}$ mbar, which is better than the design. And it has been in stable operation for more than two years.

## CONCLUSION

The challenges for the vacuum system of CYCIAE-230 are as follows: the first one is that the exhaust system and the strong RF system share same magnet valley area; Second strong residual magnetic has to be considered in the design, magnetic field shielding is designed to protect the vacuum equipment; 1 SCCM gas load for inner ion source also is the challenge for CYCIAE-230 vacuum system. 8 sets of TMPs (1600 l/s) with magnet shields are installed on the valley of magnet poles, which also used as RF cavity, 1 set of TMP (200 l/s) with magnet shields is installed on the central magnet pole to increase the pressure of central region. After design, development and commission, we have got $5.6\times10^{-7}$ mbar and $5\times10^{-6}$ mbar separately for static pressure and dynamic pressure. And it has been in stable operation for more than two years.

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