STUDY ON BEAM VACUUM LEAK DETECTION METHOD FOR HEPS STORAGE RING

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Introduction

As a major national science and technology infrastructure, the High Energy Photon Source (HEPS) imposes extremely high requirements on the vacuum level and c leanliness of its beam vacuum system. Such strict vacuum environment presents unprecedented challenges to the manufacturing, installation, connection and leak detect ion processes of all system components. Any tiny leak or material outgassing may deteriorate the vacuum level, thereby affecting the beam lifetime and the performanc e of the light source.

The vacuum leak detection strategies and practices adopted in the HEPS storage ring vacuum system during installation, commissioning and operation phases provi de a solid guarantee for the system to meet standards and operate stably.

HEPS Vacuum Equipment Layout

HEPS is composed of 48 standard cells: straight sections and bending sections.

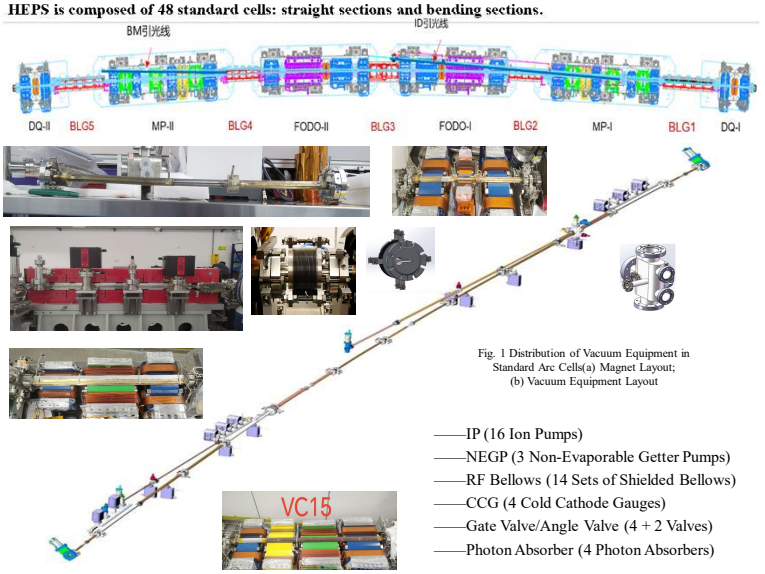

Fig. 1 Distribution of Vacuum Equipment in Standard Arc Cells(a) Magnet Layout; (b) Vacuum Equipment Layout

——IP (16 Ion Pumps)
——NEGP (3 Non-Evaporable Getter Pumps)
——RF Bellows (14 Sets of Shielded Bellows)
——CCG (4 Cold Cathode Gauges)
——Gate Valve/Angle Valve (4 + 2 Valves)
——Photon Absorber (4 Photon Absorbers)

Calculation of Storage Ring Pressure Distribution

1.Stainless steel vacuum chambers VC02, VC04, VC14 and VC17: Gas is mainly pumped by ion pumps and getter pumps.
2.Chromium-zirconium-copper vacuum chambers: The inner surface is coated with a getter film (accounting for approximately 70% of the total length).
3.Through calculation, it is found that the positions coated with the getter film provide a lower pressure.
4.Causes of pressure increase in the vacuum system:
① Thermal outgassing of vacuum materials;
② Photon desorption mainly caused by synchrotron radiation light striking the inner surface of the vacuum chamber.

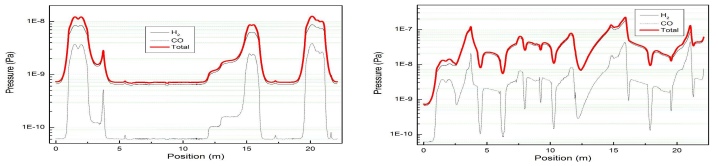

Fig. 2. Static/Dynamic Pressure Distribution Diagram of the Storage Ring Standard Arc Cell

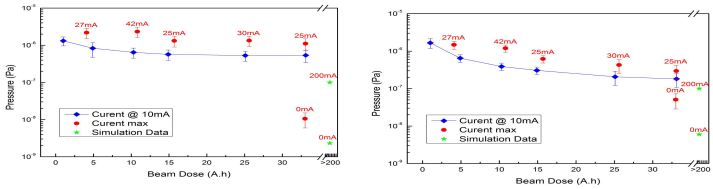

Fig. 3 Curve of the Relationship Between Beamline Vacuum Level and Beam Current

Leak Detection Schemes and Equipment

1. Leak Detection During Installation

The system is in a high-vacuum state during this phase. A helium mass spectrometer leak detector is mainly used for leak detection. The leak detector is connected via a metal bellows to the installed and to-be-tested section of the vacuum system. Helium gas is sprayed on suspected leak locations; if a leak exists, the helium gas will enter the leak detector and be detected. This method features high sensitivity and can accurately locate the position of leaks. The leak detection process is shown in the figure.

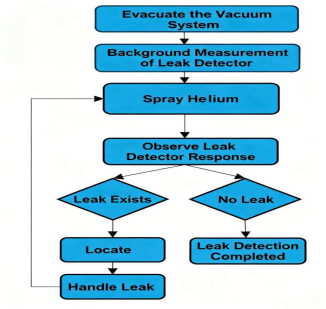

Fig. 4 Process flow chart of helium mass spectrometer leak detection

2. Leak Detection After Baking of the Vacuum System

The system is in a high-vacuum state. A quadrupole mass spectrometer installed on the system is used for leak detection.

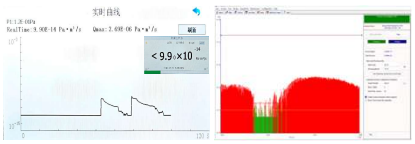

Fig. 5 Main interface of the leak detector

Meanwhile, by monitoring the full spectrum or the partial pressure of specific mass numbers, the quadrupole mass spectrometer can accurately identify key gases such as H_2, He, H_2O, N_2, O_2, and CO_2, which is used for residual gas analysis.

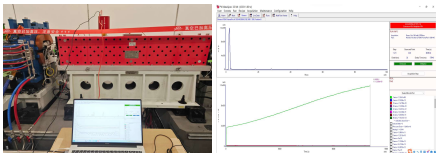

Fig. 6 Gas composition measurement by quadrupole mass spectrometer

Installation and Leak Detection

During the installation and commissioning of the HEPS storage ring, various types of leak points were encountered. Below, combined with typical cases, the characteristics and solutions of various leaks are analyzed.

1.Seal Gasket Installation Issues

Improper installation of seal gaskets at flange joints is the most common cause of leaks in vacuum systems. In the early stage of HEPS vacuum system installation, flange joints often exhibited leaks of varying degrees. Most of these leaks could be resolved by further tightening the flange bolts, while a small number of joints required seal gasket replacement.

2.Outgassing from Material Surfaces

Outgassing through micro-pores on material surfaces is a relatively concealed type of leak in vacuum systems. During the HEPS project, surface outgassing was detected at one stainless steel adapter. The leak detector showed that the leak rate increased slowly over time, typically reaching the maximum leak rate within 2–5 minutes.

Treating outgassing:

For minor outgassing that does not affect the ultra-high vacuum, the temporary method of brushing vacuum sealant is adopted.

For areas with significant outgassing, the vacuum components need to be replaced during system maintenance.

Tab.1 Leak Types and Treatment Solutions for the HEPS Vacuum System

Leak Type	Leak Detector Response Characteristics	Location Method and Process	Solution
Improper Seal Gasket Installation	Rapid response after helium spraying, slow leak rate decrease.	Spray helium on flange connections, with obvious response.	Retighten bolts; if leak rate meets standards, pass; if ineffective, replace the seal gasket.
Material Surface Outgassing	Slow increase in the leak detector’ s background leak rate.	Use the alcohol coating method for auxiliary judgment.	Temporarily seal with vacuum glue and replace later.
Ion Pump High-Voltage Head Leak	Slow leak rate increase; rapid leak detector response when helium is sprayed on the high-voltage head.	Power off the ion pump, remove the high-voltage head, and spray helium.	Replace the ion pump.
Ion Pump Shell Leak	Obvious leak rate increase when helium is sprayed near the ion pump.	Remove the ion pump shell and accurately locate the leak point.	Replace the ion pump if it does not affect system operation.
Weld Defect	Slow leak rate increase about 3-5 minutes after helium spraying.	Perform hood leak detection on the weld.	Repair the weld by welding

Conclusions

Through the practice of leak detection and gas analysis throughout the entire process of the HEPS storage ring vacuum system, from installation to operation, the following conclusions can be drawn:

1.Effectiveness of Leak Detection Strategy: The phased leak detection strategy, which combines a helium mass spectrometer leak detector and a quadrupole mass spectrometer (QMS), has proven to be efficient and reliable. The characteristics and disposal plans summarized for six types of typical leak points hold significant reference value for leak detection work in similar large-scale vacuum engineering projects.

2.System Performance Meets Standards: The adopted leak detection and quality control methods have successfully ensured that the HEPS storage ring vacuum system achieves and maintains the extremely high vacuum level and cleanliness required by the design, laying a solid foundation for the successful commissioning and operation of HEPS.

In the future, we will continue to use the Quadrupole Mass Spectrometer (QMS) for long-term monitoring of gas composition changes in the vacuum system, conduct in-depth research on gas load patterns under different operating modes, and provide continuous data support for the performance optimization and reliable operation of HEPS.

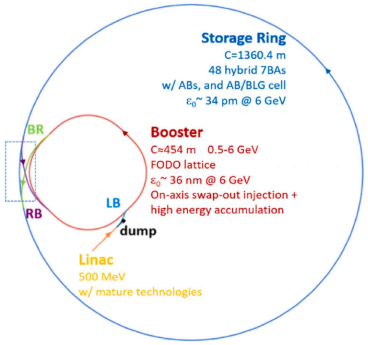

Fig. 7 Schematic Diagram of HEPS Project Layout

References： Dong H Y， He P， Li Q et al. Vacuum system of the HEPS storage ring[J]. Vacuum，2025，62(2)：1-11.