ADVANCES IN LARGE-SCALE NON-EVAPORABLE GETTER COATING TECHNIQUES FOR THE HEFEI ADVANCED LIGHT FACILITY*

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Abstract

The Hefei Advanced Light Facility (HALF), currently under construction, is a fourth-generation synchrotron radiation source operating in the low-energy region (2.2 GeV) and based on diffraction-limited storage ring technology. The storage ring employs a modified hybrid 6BA lattice with a beam emittance of 86.3 pm·rad and consists of 20 achromat cells with a total circumference of approximately 480 meters. To meet the ultra-high vacuum environment of the storage ring, non-evaporable getter (NEG) films are applied to the inner surfaces of the vacuum chambers to provide distributed pumping capability and to reduce surface outgassing and photon-stimulated desorption. Large-scale NEG coating of the HALF storage ring vacuum chambers has been officially initiated. This paper presents an overview of the HALF storage ring vacuum system and provides a systematic description of the large-scale NEG coating system, including the equipment configuration and control system. In addition, a storage system for coated vacuum chambers is described to ensure film quality prior to installation, which provides technical support for subsequent assembly and commissioning.

INTRODUCTION

The Hefei Advanced Light Facility (HALF) is a fourth-generation synchrotron radiation source operating in the low-energy region and based on diffraction-limited storage ring (DLSR) technology. As illustrated in Fig. 1, the HALF project consists of a 192 m linear accelerator, a transport line with a length of 138.4 meters, and a storage ring with a circumference of 480 meters, with ten beamlines planned for construction in phase I. The storage ring comprises 20 achromat cells, and the total length of the straight sections is 5.3 m × 20 + 2.2 m × 20, accounting for approximately 31% of the ring circumference. HALF is designed to achieve one of the lowest beam emittances among fourth-generation synchrotron radiation storage rings operating in the low-energy region [1].

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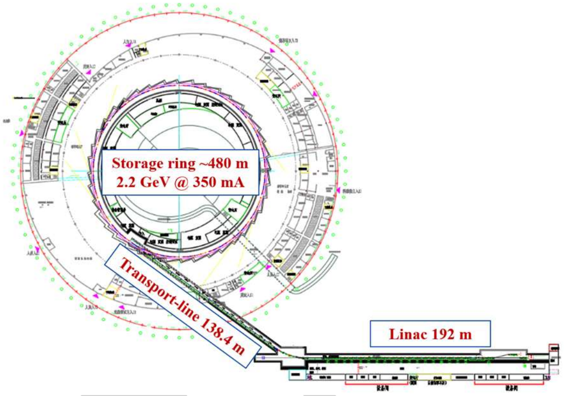

Figure 1: Schematic layout of the HALF.

STORAGE RING VACUUM SYSTEM

The vacuum layout of a standard achromat cell is shown in Fig. 2. In addition to the vacuum chambers, each cell consists of four gate valves, eleven beam position monitors (BPMs), four photon absorbers, four NEG pumps and one NEG strip, etc. Except for certain stainless-steel components, all remaining vacuum chambers (including Inconel structures) are fabricated from copper–zirconium alloy. This material exhibits high electrical conductivity and a low outgassing rate, which are beneficial for reducing impedance and improving vacuum performance [2]. The inner diameter of most beam pipes is 26 mm, with a wall thickness of 1 mm, the gap between the magnetic poles and the vacuum chamber is 1 mm (minimum 0.5 mm). The small aperture and the extremely compact magnet–chamber spacing impose stringent requirements on the design and fabrication of the vacuum system.

The vacuum system provides and maintains an ultra-high vacuum environment for the stable operation of high-intensity beams. The design specifications require a static vacuum better than 2×10^{-8} Pa and a dynamic vacuum better than 2×10^{-7} Pa for HALF. Due to the limited conductance of the small-aperture chambers and the compact spatial constraints, conventional lumped pumping schemes cannot satisfy the vacuum requirements of a diffraction-limited storage ring. Therefore, the Ti–Zr–V non-evaporable getter (NEG) coatings are deposited on the inner surfaces of the storage ring vacuum chambers to address the aforementioned challenges. The activated NEG coatings provide distributed pumping capability, improving the vacuum performance and reducing the pressure gradient along

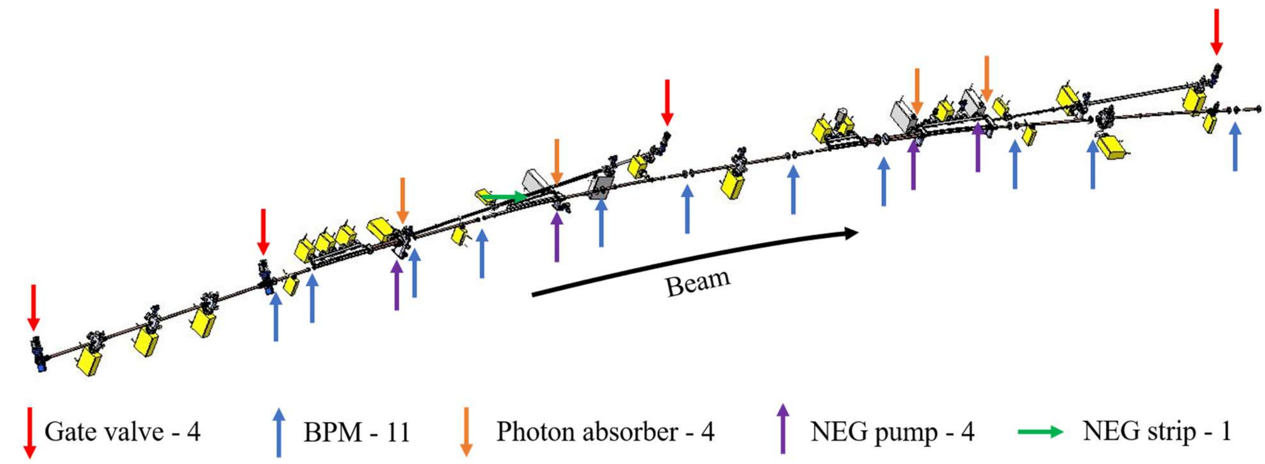

Figure 2: Vacuum layout of a standard achromat cell.

the beam pipes. Coated vacuum chambers account for approximately 81% of the total length of the storage ring. In addition, NEG strips are innovatively installed in certain special vacuum chambers to further enhance local pumping capacity. Ti-Zr-V NEG coatings also exhibit low thermal outgassing rates, reduced photon-stimulated desorption (PSD), electron-stimulated desorption (ESD), and low secondary electron yield (SEY), representing the most effective solutions for achieving ultra-high vacuum [3].

BATCH-COATING SYSTEM

Coating Equipment

The HALF project is currently progressing rapidly, and the vacuum system plays a crucial role in the storage ring, while the quality of the NEG thin films directly determines the vacuum performance. To ensure the timely and high-quality completion of the NEG thin films deposition, a batch coating unit was designed and implemented for the deposition of NEG thin films, capable of accommodating vacuum chambers with diverse sizes, geometries, and configurations. In addition, coating processes and vacuum performance tests were carried out on various types of vacuum chambers [4]. The results indicate that the NEG films satisfy the technical requirements of the storage ring vacuum system in terms of vacuum and pumping performance.

However, for the entire storage ring vacuum chambers, it is impractical to complete the coating of approximately 550 copper–zirconium alloy vacuum chambers within an 8-month schedule relying solely on a single four-station coating unit. Therefore, based on the original equipment design, the coating system was expanded to a larger scale including four independent batch coating units, as shown in Fig. 3. An independently operated configuration was adopted, in which the power supply, vacuum subsystem, gas control, and process control are fully decoupled among units. This configuration improves coating efficiency and enhances the stability and reliability of system operation.

Up to now, the large-scale NEG coating of the HALF storage ring vacuum chambers has been steadily progressing. A total of twenty-two copper–zirconium vacuum chambers with varying geometries have been successfully coated using the first batch coating unit and installed in the storage ring prototype section for validation. The results demonstrate excellent vacuum performance, confirming the feasibility and reliability of the batch coating system. At present, the remaining three coating units have also been commissioned, and the film sorption capacity deposited by all units exceeds 2.5×10^{-5} mbar·L/cm².

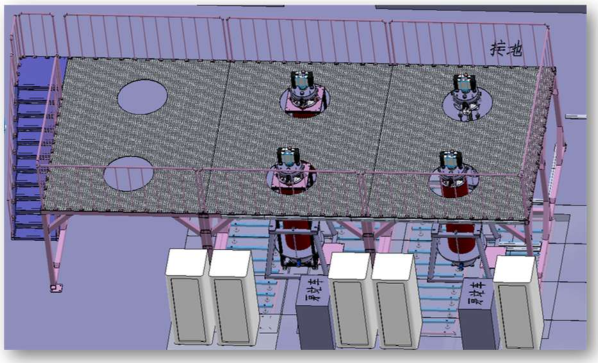

Figure 3: NEG batch-coating system.

Control System

In addition to the mechanical structure and basic support systems (e.g., water cooling and electrical supply), a fully automated control system has been developed for the batch coating system to enable centralized monitoring, remote control, and full-process data acquisition with traceability. The overall architecture of the system is shown in Fig. 4. The system adopts an industrial automation framework based on a Human–Machine Interface (HMI) and a Programmable Logic Controller (PLC). Through the integration of field devices, unified control and coordinated operation of the coating system components are achieved.

The HMI provides a graphical interface for operators, supporting equipment start–stop control, process parameter configuration, real-time status monitoring, and alarm management. The PLC serves as the core control unit and is responsible for input signal acquisition, logical processing, and actuator control. The controlled devices include vacuum gauges, ion pump power supplies, DC pulsed sputtering power supplies, and heating power supplies, etc. Based on this architecture, automated operation of the NEG coating system and real-time process data logging are realized, ensuring the stable implementation of the batch coating process.

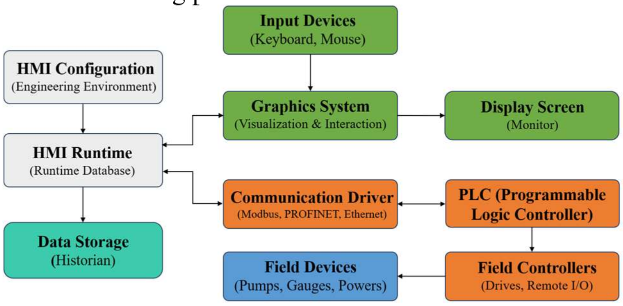

Figure 4: Logical architecture of the control system.

STORAGE SYSTEM

Following the completion of the coating process, it is imperative that the coated vacuum chambers are stored using appropriate methods prior to installation. The most common storage methods include neon, nitrogen, or vacuum storage. Based on experimental studies, high-purity nitrogen (99.9999%) was selected as the storage medium, and the corresponding results are reported in Ref. [5]. A dedicated storage system was designed and constructed, as shown in Fig. 5. The system primarily comprises a pumping unit, a gas inlet system, a main storage chamber, and associated auxiliary components. The storage procedure is as follows: first, the coated vacuum chambers and the storage chamber are connected and evacuated; subsequently, high-purity nitrogen at approximately 1.2 MPa is introduced into the coated vacuum chambers through high-cleanliness valves. The evacuation and nitrogen backfilling process ensures the effective preservation of the coated vacuum chambers.

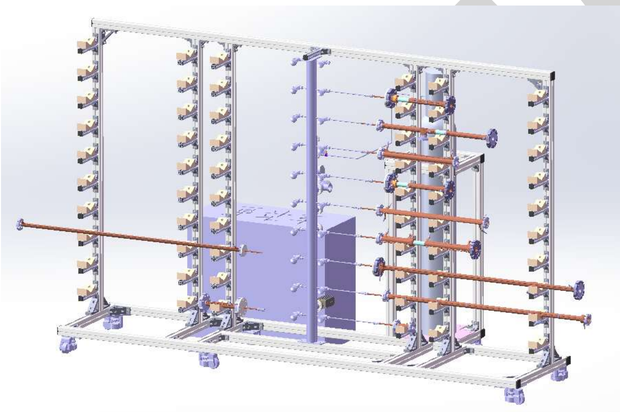

Figure 5: Storage system for coated vacuum chambers.

CONCLUSIONS

In this paper, the Hefei Advanced Light Facility (HALF) and its storage ring vacuum system have been presented. A self-developed batch NEG coating system has been commissioned, comprising four independently operating units integrated with an automated HMI–PLC control system. Large-scale coating has been implemented, demonstrating uniform film thickness, excellent pumping performance, and high operational reliability. In addition, a dedicated film storage system has been established to maintain the cleanliness and quality of the NEG films prior to installation. These advancements ensure that stable ultra-high vacuum conditions can be achieved in HALF storage ring vacuum system, while also providing a practical reference for the implementation and management of large-scale NEG coating systems.

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