Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 29-31, 2025

Current status of performance verification of the helium circulator of the Helium Cooling System in fusion reactors

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Keywords : Helium Cooling System, Helium circulator, PCHE economizer, PCEH cooler

1. Introduction

The blanket system in nuclear fusion reactors plays a crucial role in producing tritium, which is difficult to procure externally, thereby enabling self-sufficient fuel supply. For this purpose, the blanket must be maintained at high temperatures exceeding 500°C, while simultaneously removing several MW of thermal power to ensure system stability. The Helium Cooling System (HCS) is a key ancillary system designed to achieve these goals.[1] It performs three primary functions: (1) maintaining a high-temperature environment, (2) removing heat and transferring it to the heat sink, and (3) ensuring coolant integrity by transferring helium to the Coolant Purification System (CPS) for impurity removal.

Unlike a simple system operating under a single steady-state condition, the HCS must respond to a variety of operational scenarios, including plasma ignition, sustained operation, power transients, and maintenance phases. Therefore, both component-level performance verification and system-level scenario-based operational tests are essential. In this study, the Helium Supply System (HeSS) established at the Korea Atomic Energy Research Institute (KAERI) was utilized to evaluate the performance of key HCS components and to conduct operational scenario experiments under steady-state and transient conditions. The objective is to identify optimal operating conditions to secure long-term reliability of the HCS.

2. Test facility and methods

The HeSS is a scaled-down experimental facility of the HCS, consisting of a helium circulator (1.5 kg/s, design compression ratio 1.1, operating pressure 8 MPa), PCHE-type economizer, water cooler for heat sink, preheater, and control valves.[2]

The circulator has recently been structurally upgraded to operate stably at high rotational speeds up to 70,000 rpm, with significantly improved vibration stability. The PCHE economizer separates the high-temperature (500°C) and low-temperature (50°C) loops in an 8-shaped configuration. By optimizing the channel geometry and core size, the average pressure drop was reduced to 40–50 kPa, thereby decreasing the circulator load. An additional PCHE-type water cooler lowers the circulator inlet temperature to around 50°C, ensuring stable operation while rejecting heat to the external sink.

Three control valves in the HeSS are used for generating differential pressures during circulator performance tests and for adjusting bypass flows during operational scenario and transient experiments. The current series of tests focuses primarily on the upgraded circulator performance.

3. Performance Verification of the Circulator

The helium circulator must provide a maximum flow rate of 1.5 kg/s at 8 MPa while achieving the design compression ratio of 1.1. In addition, stable operation without excessive vibration must be maintained even at high rotational speeds of up to 70,000 rpm, and no performance degradation or structural defects should occur during long-term operation.

In early development, the previous circulator model could only achieve about 73% of the design performance, and instabilities were observed under high-pressure and high-speed conditions. Fluid-induced vibrations tend to increase with higher operating pressures and rotational speeds. To mitigate the root cause, identified as “seal instability,” a swirl brake was newly designed and manufactured, and installed on the compressor rotor. With this improvement, enhanced circulator stability was achieved.

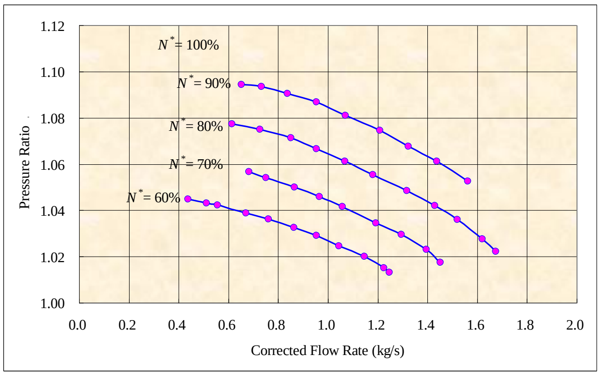

Fig. 1. Performance characteristics of the helium circulator (flow rate vs. pressure ratio)

Performance verification tests were conducted under rated operating conditions, namely 80 bar and 50°C. The tests were controlled by adjusting valve openings, beginning from the fully open position and gradually closing toward the surge region. Due to inverter instability at the highest speed, performance verification was carried out up to 90% of the rated speed (70,000 rpm). As shown in Fig. 1, stable aerodynamic performance was confirmed up to this condition. To achieve full verification at 100% rated speed, a new inverter capable of stable control under these conditions has been fabricated and installed. Additional tests are planned following the completion of circulator-inverter tuning.

3. Conclusions

This study presents the current status of performance verification of the key components of the HCS and ongoing operational scenario experiments. The upgraded helium circulator demonstrated stable compression ratios and low vibration characteristics at high-speed operation, and final performance verification under rated conditions is in progress. The PCHE economizer was designed and fabricated to achieve a low pressure drop (below 50 kPa). Further verification tests will be conducted to optimize operating conditions and enhance the long-term reliability of the HCS.

Future work will focus on extended durability tests and a broader range of operational scenario simulations, thereby establishing a reliable basis for high-performance HCS design applicable to nuclear fusion blankets.

ACKNOWLEDGMENTS

This work was supported by the R&D Program through the Korea institute of Fusion Energy (KFE) funded by the Ministry of Science and ICT of the Republic of Korea (KFE-IN2503)

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