Numerical Simulation and Experimental Research of Flow Resistance Characteristics of East Lower Tungsten Divertor Module

Kun Tian\textsuperscript{1,2}, Lei Li\textsuperscript{*}, Damao Yao\textsuperscript{1,2}, Le Han\textsuperscript{1}, Tiejun Xu\textsuperscript{1}, Qing Zhuang\textsuperscript{1,2} and Lei Yang\textsuperscript{1}

\textsuperscript{1} Hefei Institutes of Physical Science, Chinese Academy of Sciences, Hefei 230031, China
\textsuperscript{2} University of Science and Technology of China, Hefei 230026, China
Email: lilei@ipp.ac.cn

Abstract. During long-pulse plasma operation with high power in tokamak, excessive heat load on divertor may lead to material melting or erosion of the first wall material, which enhances impurity radiation and degrades plasma performance. As an important component of the first wall, divertor cooling system is important for the high power and stable operation of the device. The Experimental Advanced Superconducting Tokamak (EAST) is committed to achieving more than 400 s long-pulse H-mode operations, which is equipped with a first wall of full metal. The 10 MW/m\textsuperscript{2} heat load on divertor means a big challenge for the continuous operation of the system, but the current divertor cannot meet the conditions, so it needs to be upgraded. In order to check whether the cooling water system of the new divertor in EAST can meet the requirements, a fluid test was built to measure the flow rate and flow drop of the divertor. The results show that the difference between the test results and the results of ANSYS-based simulation is 9\%, and the maximum difference between the results of the comparison of two different model parts is 3\%. It is concluded that the cooling water system of the divertor in EAST can achieve the heat load and safety requirements.

Keywords: EAST; Divertor; Numerical simulation; Cooling system; Test

1. Introduction
The fusion nuclear reaction results in the release of large amounts of energy - typically a million times more energy than can be obtained by combining atoms chemically. Tokamak is a plasma confinement device, which uses a combination of magnetic fields to confine hot plasma [1]. During long-pulse plasma operation with high power(10-20MW) in tokamak, excessive heat load on divertor may lead to material melting or erosion of the first wall material, which enhances impurity radiation and degrades plasma performance [2,3]. Numerous studies on the heat load of plasma facing components (PFCs) have been carried out in many fusion experimental devices around the world, including TRIAM-1M [4,5], JET [6-9], QUEST [10], ASDEX-U [11], Alcator C-Mod [12], DIII-D [13], KSTAR [14], Tore-Supra [15] and EAST [16].

The Experimental Advanced Superconducting Tokamak (EAST) set a new world record on May 28, 2021, successfully achieving a repeatable 101-second plasma operation at 120 million °C and 20-second plasma operation at 160 million °C, which is five times the original record of 20-second plasma operation at 100 million °C.

In EAST, divertor is an important part of the first wall components, not only to take the...
responsibility of pumping and removing impurities, but also to be equipped with a cooling water system (CWS) to solve the heat load problem. The CWS of divertor is important for the long-term stable operation of divertor and even the whole device, so it is essential to test whether divertor can meet the system requirements.

2. EAST Divertor

EAST is the first fully superconducting tokamak device in the world, with a large radius of 1.8 m, a small radius of 0.45 m, a maximum circulating magnetic field of 3.5 T, and a first-wall water cooling system. EAST divertor consists of IVT, OVT and dome. The structure of target is composed of heat sink, support and the first wall material. The shape and configuration of divertor aims at flexible operation of different elongation and triangularity of plasma.

EAST is committed to achieving more than 400 s long-pulse H-mode operations, which is equipped with a first wall of full metal. The 10 MW/m² heat load on divertor means a big challenge for the continuous operation of the system, but the current divertor cannot meet the conditions, so it needs to be upgraded. Given the requirement of cooling system, it can be concluded that maximum flow rate, allowable pressure drop and allowable temperature increase is 800 t/h, 2 MPa and 30 °C. However, according to the simulation analysis that has been done, the flow rate of 650 t/h can fully meet the heat load requirement, it will not be discussed here because this paper is not concerned with such analysis. Therefore, the design flow rate discussed below is 670 t/h. In order to verify whether the new lower divertor can meet the requirements, relevant ANSYS-based simulations and tests were carried out. EAST vacuum vessel is shown in figure 1.

![Figure 1. EAST vacuum vessel.](image)

3. Simulation Based on ANSYS

The divertor module has been modeled as shown in figure 2.
Figure 2. EAST lower divertor.

The simulation based on ANSYS is shown in figures 3-4.

Figure 3. Flow rate simulation (design flow rate 670 t/h).
As shown in the figures above, For CWS of the divertor, it corresponds to two perfectly symmetrical parts connected in series, with the connecting part on the inside by a collector.

In the simulation shown above, the total flow rate passed by the divertor is 14t/h which corresponds to the design flow rate of 670 t/h. From the above figure, it can be concluded that at this time pressure drop of the divertor is 1.67 MPa, in line with the requirements put forward by the cooling system.

4. Test
In order to measure the flow rate and pressure drop of the divertor (as shown in figure 5) under different working conditions, a fluid test is equipped, as shown in figure 6.

**Figure 4.** Pressure simulation (design flow rate 670 t/h).

**Figure 5.** Divertor module.
Figure 6. Test platform.

As shown in the figure above, the divertor is assembled on a closed water circuit driven by a pump. Considering the strong vibrations are generated during the test, the divertor needs to be fixed on a tooling. Two pressure gauges are separately set on the inlet and outlet pipes of the divertor to measure the pressure drop, and an ultrasonic flow gauge is set on the main pipe to measure the flow rate through the divertor. The test is conducted by adjusting the pump frequency to control the flow rate on the main pipe, and measuring the flow rate and the pressure drop on the divertor at different pump frequencies. The flow diagram is shown in figure 7.

Figure 7. Diagram of the test system.
5. Results and Summary
Two EAST lower divertor module are selected for the test. The test results are shown in figure 8. The data summary is shown in table 1.

![Figure 8. Test results.](image)

| Error between test and simulation | Maximum error between two divertors |
|----------------------------------|-------------------------------------|
| 9%                               | 3%                                  |

As shown in figure 8, the relationship between flow rate and pressure drop tends to be consistent for the two divertor modules, and the maximum error of 3% is still within the acceptable range considering the individual differences. To some extent, it also shows a high consistency between two divertors and a more even distribution of fluid on the system.

In terms of absolute data, at a flow rate of 14t/h (i.e., a total design flow rate of 670t/h), the pressure drop of the divertor is still less than 2MPa, which meets the system design requirements.

Error between test and simulation of 9% reflects the difference in actual performance between the real model and the ideal model, which means that EAST lower divertor still has room for optimization.

To sum up, EAST lower divertor has been upgraded. In order to understand the fluid state of EAST divertor, EAST lower divertor model is built and the associated simulation is also carried out. Test to match the simulation analysis is completed. According to the data on both sides, the pressure drop of divertor meets the design requirement. The above results lead to the conclusion that the divertor design proposed in the article provides a reliable guarantee for the effective operation of EAST.

The birth of new record on May 28, 2021 shows that the new lower divertor has performed its task outstandingly, and author hopes that EAST will perform better in the future.

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