OVERVIEW OF THE ACCELERATOR OPERATION AT CHINA SPALLATION NEUTRON SOURCE SINCE ITS OFFICIAL OPENING

Y. Yuan[†,1,2], J. Zeng[1,2], Y. An[1,2], Y. Chen[1,2], M. Liu[1,2], Y. Zhang[1,2]

[1]Institute of High Energy Physics Chines Academy Sciences, Beijing, China
[2]Spallation Neutron Source Science Center, Dongguan, China

Abstract

The China Spallation Neutron Source（CSNS） is the first large-scale pulsed spallation neutron source in China and the fourth of its kind in the world. It is a large multi-disciplinary user facility. The facility passed national acceptance and officially opened for operation in 2018. It has been in operation for seven years. During this period, the beam power has continually increased, and both the beam runtime and availability have gradually improved. In the 2023-2024 period, it achieved a maximum beam on target time of 5,433 hours and the highest beam availability of 97.4%, which are the best among similar international facilities. This article will comprehensively introduce the operational performance of the accelerator over the past seven years, including annual beam runtime, beam availability, and statistics on hardware system downtime. Additionally, it will briefly discuss some measures taken to enhance operational reliability.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is a large-scale, multidisciplinary experimental facility that generates neutrons by bombarding a target with a high-intensity proton beam. Phase I was designed for a beam–target power of 100 kW and includes three neutron spectrometers. The proton beam energy at the target is 1.6 GeV, and the pulse repetition rate is 25 Hz. After passing national acceptance in 2018, the facility was officially opened to external users. The schematic layout of the facility is shown in Fig. 1[1].

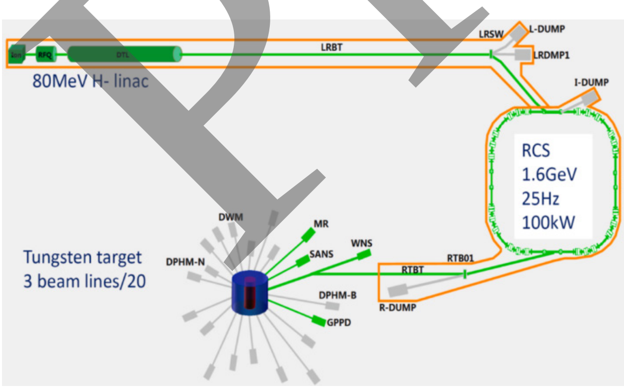

Figure 1: Schematic layout of CSNS.

† yuanyue@ihep.ac.cn

At acceptance the beam-on-target power was 25 kW; through machine studies and hardware upgrades it was raised to 100 kW in February 2020 and to 170 kW in October 2024, with stable operation thereafter. Figure 2 shows the operational progression of the accelerator's beam-on-target power.

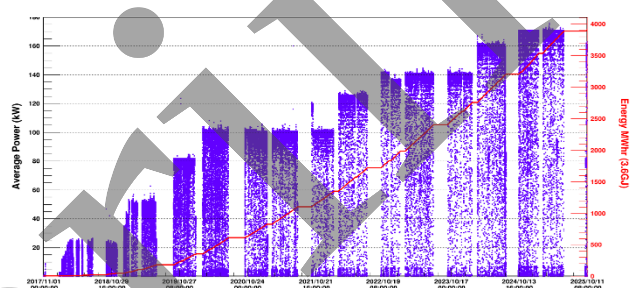

Figure 2: The operational progression of the accelerator's beam-on-target power.

Beam Delivery Time and Beam Availability

Since CSNS officially began operation in 2018, it has increased the proton beam power delivered to the target while gradually extending delivered beam time and improving beam availability. In the 2021–2022 operational year, delivered beam time first exceeded 5,000 hours and beam availability first exceeded 95%. In 2023–2024 the facility achieved its highest values to date—5,433 hours of delivered beam time and 97.4% availability. These operational metrics are also the highest among comparable facilities worldwide.

Beam availability is defined as delivered beam time divided by the sum of delivered beam time and fault-induced downtime, i.e. the scheduled (planned) beam time:

Availability = Delivered beam time / (Delivered beam time + Downtime).

In early 2024 CSNS formally began Phase II construction, requiring a balance between ongoing operation and upgrade works; together with an unexpected failure in the target station, this caused the summer maintenance shutdown in the 2024–2025 operational year to be roughly one month longer than usual, resulting in a noticeable reduction in delivered beam hours that year. Figure 3 summarizes the accelerator operating data from 2018 to 2025.

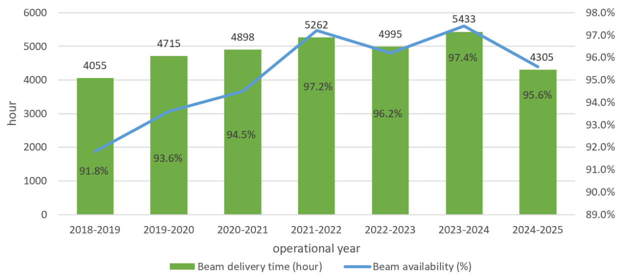

Figure 3: Delivered Beam Time and Beam Availability by Operational Year.

Accelerator Down Time of Different Systems

In the accelerator's fault and machine-time logging system, on-duty operators manually record each subsystem's downtime, while delivered beam time is automatically calculated in the backend from the duration of beam-on-target.

Fault records are divided into 11 systems, each with further device-level subcategories. These 11 systems comprise ten hardware subsystems and one 'Others' category. Figures 4 and 5 show the annual downtime statistics for each system over the operational years. The chart below shows annual statistics of fault-induced downtime by subsystem during user experiments. The largest contributors to downtime are high-power components such as Linac RF(LRF), ion source, Ring RF(RRF), warm cavities, pulsed power supplies. The front-end systems in the figure include the ion source and the RFQ. After commissioning a new RF ion source in 2021, ion-source-related failures decreased markedly.

The vacuum, magnet, beam-diagnostics, control, and radiation-protection systems have maintained relatively low failure rates. Downtime in other systems was mainly due to uncontrollable factors (e.g., lightning strikes, venting of vacuum lines), beam commissioning and tuning, and sporadic beam-loss interlocks whose precise causes remain unclear. Consequently, downtime in these other systems still constitutes a non-negligible share; it cannot be completely eliminated and can only be reduced as much as possible.

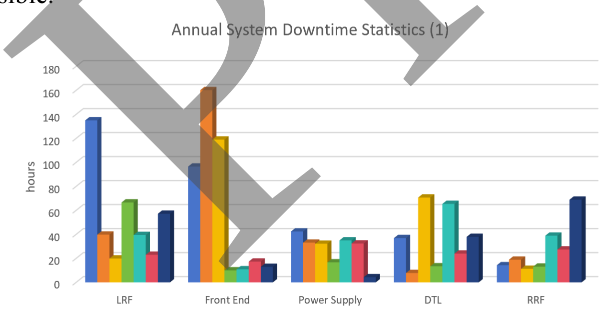

Figure 4: Annual downtime (hours) by system (a).

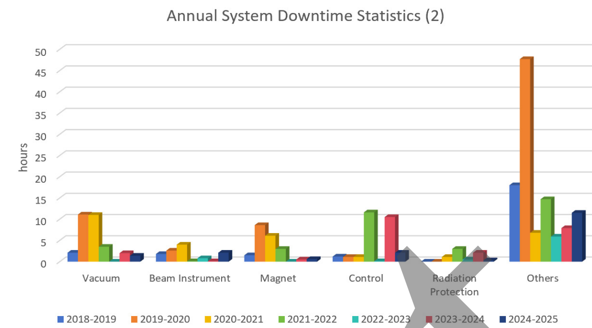

Figure 5: Annual downtime (hours) by system (b).

Reliability Assurance and Improvement

To improve accelerator operational reliability, we have undertaken numerous measures, including training and competency assessment of on-duty operators, hardware upgrades, software optimization, and the implementation of appropriate maintenance and inspection strategies.

Here I describe one hardware upgrade that significantly reduced beam-related downtime. The work was carried out mainly by the front-end team. It consisted of replacing the previous Penning-type surface H− ion source with an RF-driven ion source to improve operational stability and maintainability. The former Penning source required replacement and maintenance of the discharge (arc) chamber on average just over one month and consumed substantial amounts of cesium as a catalyst. Excess cesium tended to deposit on the extraction electrode, causing frequent electrode arcing and extraction-overcurrent events.

The RF ion source installed in 2021 greatly reduced front-end system downtime, achieving nearly fault-free stable operation for one operational year—totaling 7,200 hours—with availability exceeding 99.99%. Figure 6 shows the operational performance of the RF ion source during the 2021–2022 operational year [2]. The red trace represents the RF power of the ion source, while the blue trace shows the beam power delivered to the spallation target. The ion source exhibited consistently high reliability throughout machine studies and periods of beam delivery to the target.

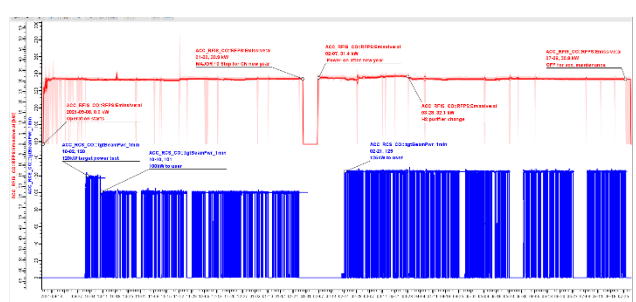

Figure 6: Operational performance of the RF ion source during the 2021–2022 operational year.

CONCLUSION

While continuously increasing beam power, the accelerator has maintained efficient and stable operation. In the 2023–2024 operational year, the metrics for delivered beam time and beam availability reached the best records among comparable facilities worldwide, at 5,433 hours and 97.4%, respectively. Following the commencement of Phase-II construction in 2024, the accelerator will strive to maintain a high level of user operation throughout the upgrade.

REFERENCES

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