Deployment of digital LLRF in the RRC

K. Yamada,[*1] K. Suda,[*1] K. Yadomi,[*2] S. Ishikawa,[*2] R. Koyama,[*2] and N. Sakamoto[*1]

The RIKEN Ring Cyclotron (RRC) has provided beams not only for the RIBF injection but also directly for various experiments such as biological irradiation, RI production, and industrial applications. For high-intensity beams to be stably accelerated in the RRC, particularly in the RIBF with multi-stage acceleration, as high an rf voltage as possible should be generated with a high degree of stability. The RRC has two sets of rf systems with frequency-variable resonators,[1)] which were upgraded through FY2017.[2)] These enhancements have increased the acceleration voltage in the low-frequency range of the RRC, and the stability has reached a level satisfactory for voltage fluctuations of less than 0.1% and phase fluctuations of less than 0.1 degree. However, the analog feedback circuit conventionally used determines time constants and feedback gain parameters by circuit elements, making it difficult to optimize the feedback parameters by changing them each time for various frequencies during each operation. Occasionally, rf voltage fluctuated owing to a drop in the commercial receiving voltage, which affected the increased beam loss in the later stage accelerators. Therefore, we decided to apply digital low-level rf (LLRF) circuits, whose parameters can be adjusted remotely, to the RIBF cyclotrons one at a time, and first installed them in the RRC.

The modification work was conducted from late July to early September 2024. As shown in Fig. 1, the old analog LLRF, old PLC, and wiring were all removed from the existing control panel and a new digital LLRF and new PLC were installed and wiring connected. The digital LLRF introduced for this work is equivalent to the one developed in SRILAC and successfully introduced in the RILAC injector.[3)] The circuit integrates automatic gain control, phase-lock loop, and phase difference detection for automatic tuning in one body. In the new control system, the PLC was updated from the Mitsubishi Electric MELSEC Q series to the iQ-R series, and the program was completely rewitten based on the RILAC injector. This deployment enabled us to adjust the all setting parameters such as the feedback parameters and thresholds remotely for each frequency for each operation.

Figure 2 presents one-day trend graphs depicting the rf voltage and phase stability of the RRC operated with the digital LLRF. The new system is operating properly, and the rf stability satisfies the requied performance. However, the 28.1 MHz operation still exhibits poor stability owing to suboptimal adjustment of feedback parameters, and optimization of the parameters is a future research challenge. As the next step, we plan to replace the analog LLRF of the RILAC no.6 with an equivalent digital LLRF by March 2025. Additionally, the digital LLRF will be deployed in the fRC to further improve the acceleration voltage and phase stability.

Fig. 1. Rf control system for the RRC resonator no.1 before (a), during (b), and after modification (c). Same for no.2 system.

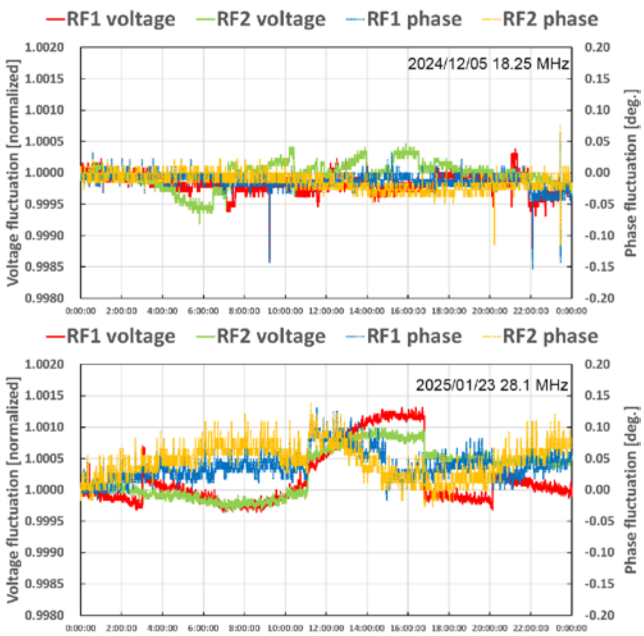

Fig. 2. Trend graph for rf voltage and phase of the RRC operated with two frequencies of 18.25 MHz (upper panel) and 28.1 MHz (lower panel). The areas in which the values change abruptly are those whose voltage or phase settings have been changed by the operator.

*1 RIKEN Nishina Center
*2 SHI Accelerator Service Ltd.

DOI:10.34448/RIKEN.APR.58-236

References

1) T. Fujisawa *et al.*, Nucl. Instrum. Methods Phys. Res. A **292**, 1 (1990).
2) K. Yamada *et al.*, Proc. of CYCLOTRONS2022, 6 (2022).
3) K. Yamada *et al.*, RIKEN Accel. Prog. Rep. **56**, 68 (2023).