Research Facility Development Division
Instrumentation Development Group
Rare RI-ring Team

1. Abstract

The aim of Rare-RI Ring (R3) is to measure the masses of short-lived unstable nuclei far from the beta-stability line. In particular, a high-precision mass measurement for nuclei located around the *r*-process pass (rare-RI) is required in nucleosynthesis point of view. Through the commissioning experiments by 2017, we confirmed the high ability of R3 as a storage ring capable of handling one event, and demonstrated that it is possible to perform the time-of-flight Isochronous Mass Spectrometry (IMS) in shorter than 1 millisecond. In 2018, we performed mass measurement experiments for the first time. In 2020, the kicker system was modified to flatten the magnetic field distribution, and the performance study using unstable nuclei was successfully conducted. In this fiscal year, we performed mass measurement experiments using the upgraded kicker system. The preliminary results of the experiment dispelled concerns about the results of the previous experiment that the injection angle might greatly affected the accuracy of the mass determination. On the other hand, through the experiments of this fiscal year, a problem was found in the kicker power supply. We are currently taking measures to the problem.

2. Major Research Subjects

(1) Further improvement of experimental efficiency and mass measurement precision
(2) Precision mass measurement for rarely produced isotopes related to *r*-process

3. Summary of Research Activity

In the commissioning experiments up to 2017, we confirmed the unique performances of R3 and demonstrated the time-of-flight isochronous mass measurement method. The ring structure of R3 was designed with a similar concept of a separate-sector ring cyclotron. It consists of six sectors and straight sections, and each sector consists of four rectangular bending magnets. Two magnets at both ends of each sector are additionally equipped with ten trim coils to form a precise isochronous field. We have realized in forming the precise isochronous field of less than 5 ppm with wide momentum range of $\Delta p/p = \pm 0.5\%$. Another performance required for R3 is to efficiently seize hold of an opportunity of the mass measurement for rare-RIs produced unpredictably. It was realized by constructing the Isotope-Selectable Self-trigger Injection (ISSI) scheme which pre-identified rare-RI itself triggers the injection kicker magnets. Key device was a fast response kicker system that has been successfully developed. Full activation of the kicker magnetic field can be completed within the flight time of the rare-RI from an originating point (F3 focal point in BigRIPS) of the trigger signal to the kicker position in R3.

Since R3 accumulates, in principle, only one event, we fabricated high-sensitive beam diagnostic devices in the ring. One of them is a cavity type of Schottky pick-up installed in a straight section of R3. The Schottky pick-up successfully monitored a single $^{78}Kr^{36+}$ ion circulation with the measurement time of less than 10 milliseconds in the first commissioning experiment. We also confirmed that it is useful for fine tuning of the isochronous field. Another is a timing monitor called E-MCP, which detects secondary electrons emitted from thin carbon foil placed on the circulation orbit. The thickness of the foil is 60 μg/cm^2. This timing monitor is working well to observe first several tens turns for injected event.

We performed mass measurement in the third commissioning experiment by using unstable nuclei which masses are well-known. The masses of ^{79}As, ^{77}Ga, ^{76}Zn, and ^{75}Cu relative to ^{78}Ge were deduced with the accuracy of several ppm. In addition, we have improved the extraction efficiency to 2% by considering the matching condition between the emittance of injection events and the acceptance of R3 in the fourth commissioning experiment. This extraction efficiency was sufficient to conduct the accepted two proposals: mass measurements of Ni isotopes and Sn region.

In November 2018, we conducted the first experiment using R3 to measure the masses for ^{74,76}Ni in 4 days. After that, we also measured the masses for ^{122}Rh, ^{123,124}Pd, and ^{125}Ag in 4.5 days. These nuclei were successfully extracted from R3 with the efficiency of 1–2%. However, unexpected deviation from the evaluated values of literature remained in the masses obtained by detailed analysis. This was thought to be due to the following two reasons. One is that due to the kicker field distribution is not flattened, the injection angle is different between the reference and target nucleus, and therefore the relative value of TOF is incorrect. The other is that the absolute value of beta or magnetic rigidity determined for each extracted event is incorrect.

In 2020, we modified the kicker system to flatten the magnetic field distribution as well as to dispel the concerns of the results of first experiment. As a result of performance study using unstable nuclei, we succeeded in forming the kicker field with 100 ns flat-top for injection and long flat-top of 350 ns or more for extraction. The experimental efficiency had been improved by a factor of two or more than previous condition because all nuclides can be extracted at once thanks to the long flat-top.

Using this upgraded kicker system, we measured the mass for ^{74}Ni again in April 2021. Although the kicker field distribution was flattened, the results of masses were the same as those of the first experiment. In other words, concerns about the effects of differences in injection angles have been dispelled. As a subsequent analysis, it was clarified that the reason is the second concern described above. The final mass values will be determined soon. On the other hand, the ceramic capacitor of the kicker power supply broken several times due to insulation breakdown. We are currently working on measures to prevent insulation breakdown of ceramic capacitors, since this problem defects reliable mass measurement experiments.

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List of Publications & Presentations

Publications

[Review Article]

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