PRESENT PERFORMANCE AND COMMISSIONING DETAILS OF RIBF ACCELERATOR COMPLEX

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Abstract

Construction of an accelerator complex of RIKEN RI Beam Factory (RIBF) project have been completed in November 2006 and commissioning of RIBF accelerator complex started just after it. We succeeded in the first beam acceleration of RIBF on December 28th, which was a 345-MeV/nucleon aluminum beam, and also succeeded in the first uranium beam acceleration with the energy of 345 MeV/nucleon on March 23rd, 2007. In this report, the performance of the RIBF accelerator complex is presented, which includes transmission efficiencies of all the accelerators and the beam transport system, isochronous fields and radial beam patterns of all the RIBF cyclotrons obtained in the commissioning phase, stability of the accelerators and so on. We also summarize briefly what we have done in order to obtain better performance in the commissioning phase.

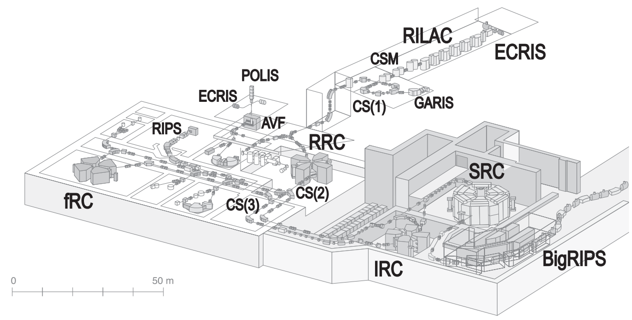

Figure 1: Layout of RIBF.

INTRODUCTION

Radioactive Isotope Beam Factory project [1] has been proceeding at RIKEN Nishina Center since 1997. All elements extending to uranium are accelerated over 345 MeV/nucleon and provided to the fragment separator BigRIPS [2] in order to produce the world's most intense radioactive nuclear beams. The RIBF opens up new possibilities of investigations for nucleosynthesis in the cosmos, reaction process of the exotic nuclei, and unified understanding of the nuclear structure. The layout of RIBF is described in Fig. 1. Three new cyclotrons was constructed for the accelerator complex, and beam commissioning of the new cyclotrons was performed in the 2006 fiscal year. In this report, our progress on beam commissioning and the present performance of RIBF accelerator complex is outlined. More particular prehistory is described in Ref. [3].

BEAM COMMISSIONING

The beam commissioning of RIBF was started at June 2006. At first, the beam commissioning of fRC [4], which is the first booster among the new cyclotrons, was performed in the intervals of experiment at the existing facility. The construction of other equipments at RIBF was also performed in parallel with the commissioning. Figure 2 indicates the schedule of the construction and study from April to December in 2006. The first uranium beam with energy of 50 MeV/nucleon was successfully extracted from the fRC on September 29th, 2006 [5]. The beam study of fRC was performed at total seven times from June to November in 2006 in order to improve the beam quality of emittance and the transmission efficiency. After the completion of the beam line to IRC [6], beam commissioning for the IRC was started on November 21st. The first beam of ^{84}Kr^{31+} was extracted on November 25th, only 110 minutes were required from the injection to the extraction of IRC. The beam study for the world's first superconducting ring cyclotron SRC [7] was hard work and the first beam extraction was accomplished at 16:00 of December 28th. The beam was ^{27}Al^{10+} with energy of 345 MeV/nucleon. After the various modification, the first RI beam production of BigRIPS was achieved by the fragmentation of 345 MeV/nucleon ^{84}Kr beam on March 15th, 2007. The first ^{238}U^{86+} beam with energy of 345 MeV/nucleon was successfully extracted from the SRC on March 23rd, and the whole of middle-range objective was attained. After passing the facility inspection, the beam become possible to utilize the experiment at April 2007. The first experiment at the RIBF was carried out using 345 MeV/nucleon of ^{238}U beam from mid-May to early in June, and a new isotope ^{125}Pd was discovered [8].

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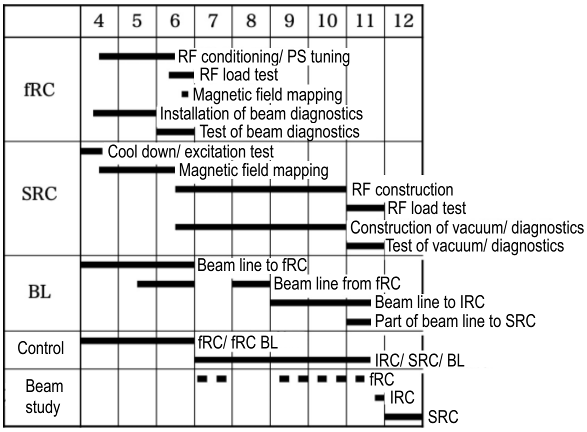

Figure 2: Schedule of the construction and study.

PRESENT PERFORMANCE

Isochronism Of Cyclotron

The accurate isochronism is the significant condition to make the cyclotron available. Figure 3 describes the periodic arrival time of cyclic beam in each cyclotron as a function of the position along the radius vector. Signals were detected by the pairs of phase pickups which is radially mounted on the orbital region of cyclotron, and analyzed by a lock-in amplifier (SR844). The result indicates that the isochronous condition of the magnetic field is attained to the acceptable level. Since the beam intensity was too low to obtain the precious data set with high signal to noise ratio, the isochronous condition of the SRC was not good as the others. If the beam intensity increases in future, the isochronous condition of SRC will be fulfilled as same level as the ones of fRC and IRC.

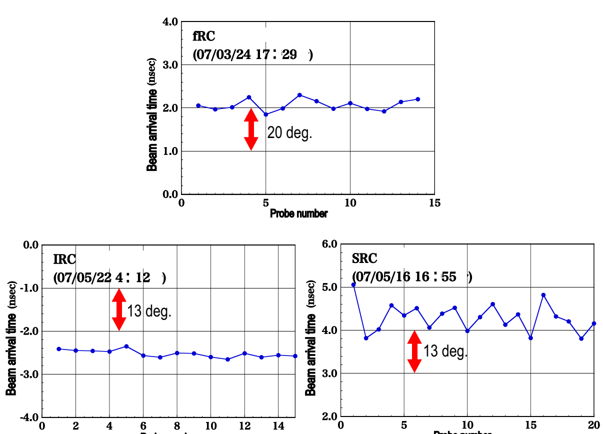

Figure 3: Isochronous condition of new cyclotrons.

Transmission Efficiency

The beam intensity and transmission efficiency at the key position of accelerator complex on June 29th, 2007 are shown in Fig 4. The beam was ^{238}U. The numerical value in the figure is intensity in the unit of nA, and the value in parentheses is transmission from the ion source to the key position. These values may include the 100 % error because these values are based on the data of faraday cups which are not normalized. The result of RRC transmission exceeds 100 % due to the error. For the acceleration of ^{238}U, two charge strippers are applied at the downstream of RRC and fRC. The transmission value in the figure excepts the efficiency of charge exchange reaction. The transmission efficiency of the accelerator complex is 4 % in the present day. Only the transmission of RRC and fRC is acceptable. The cause of low transmission is under vigorous investigation, which is outlined in the following section. The total efficiency of charge exchange was evaluated to be 5 % by the measurement of charge distribution. The efficiency for the whole transmission of RIBF including the charge exchange was found to be 0.2 % for ^{238}U beam.

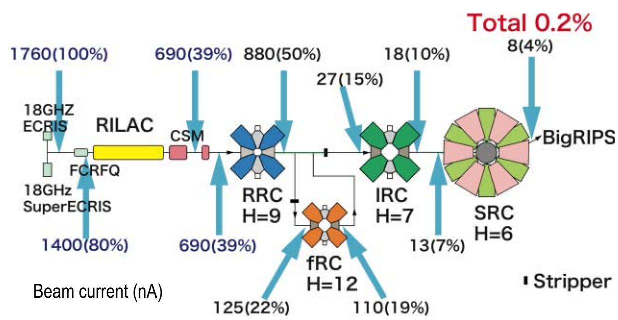

Figure 4: Beam intensity and transmission efficiency.

Long-Term Stability

The long-term stability of the accelerator is crucial to influence the availability of facility. The RIBF is accelerator complex consisting of the RIKEN Linear Accelerator (RILAC) including the RFQ, six cavities of linear accelerator, injection buncher, and re-buncher; four ring cyclotrons; three re-bunchers; and two charge strippers. The stability of the RIBF depends on lifetime of the charge stripper, stability of the isochronous condition, and availability of the RF system. The lifetime of the charge stripper located at the downstream of fRC is long enough to keep one carbon sheet (14 mg/cm^2) during the commissioning, whereas the stripper at the downstream of RRC is available only 12 hours. The exchange of the stripper is required at semidaily because of the meaningful decrease of beam intensity [9]. The magnetic field of RRC and fRC is constantly monitored by the NMR probe. After the one week operation of the magnet, the field of fRC varies 1.2 ppm per hour, which requires the adjustment for every three hours, because the variance of 5 ppm is not allowable for the cyclotron. The magnetic-field monitoring for IRC and SRC is future plan.

The stability of RF system for the part of RILAC was observed by the vector voltmeter. It was confirmed that the stability satisfied the specification. The constantly monitoring for other RF system is the order of business in future. The system of beam phase monitor [10] is under construction for the RIBF, which uses the phase pickup and lock-in amplifier. The beam phase at four position between the RILAC and fRC is presently available. Figure 5 shows the result of phase measurement for ^{238}U beam performed at the downstream of RILAC on June 21th, 2007. The drastic transition in the figure is due to the operation. The fluctuation of 1 nsec is arisen and that is not satisfy the requisite stability of 0.2 nsec and less. The immediate elucidation and counterplan is necessary.

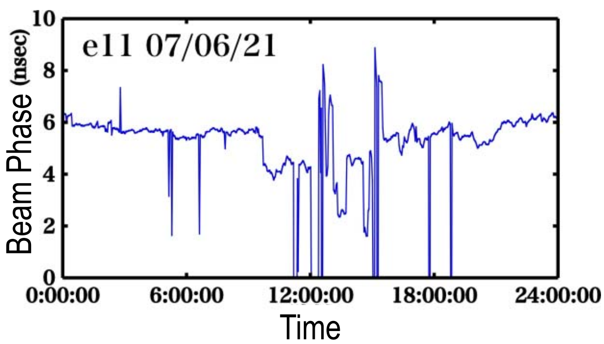

Figure 5: Stability of RILAC beam.

Beam Quality

The energy and longitudinal structure of the beam can be measured by plastic scintillators located at the downstream of each accelerator [11]. The longitudinal distribution of ^{238}U beam just after the IRC is shown in Fig. 6 for example. In the case of ^{238}U beam, the RILAC and RRC are operated with the RF frequency of 18.25 MHz and the RF frequency of IRC is 36.5 MHz with harmonics of 7. Although the beam ought to extract from the IRC with 18.25 MHz, the distinct peak can be seen between the 18.25 MHz peaks in the figure. This peak corresponds to the beam accelerated one turn over than the regular turn number. It was also found that the beam accelerated two turns over than the regular one was mixed in the 18.25 MHz peak. The fact indicates that the longitudinal spread of the beam, which is evaluated to be 50 degrees, is much larger than the one of 25 degrees accepted by the IRC. The flat-top resonator was not used in this case. This is the major cause for the IRC and SRC not to realize the high transmission efficiency. It is possible that the uniformity of the charge stripper is insufficient and the operation of fRC is inadequate. More precise investigation will be performed after autumn in this year. The upgrade of the beam diagnostic system and the various modification for the equipment are now in progress in order to improve the beam intensity and the transmission efficiency.

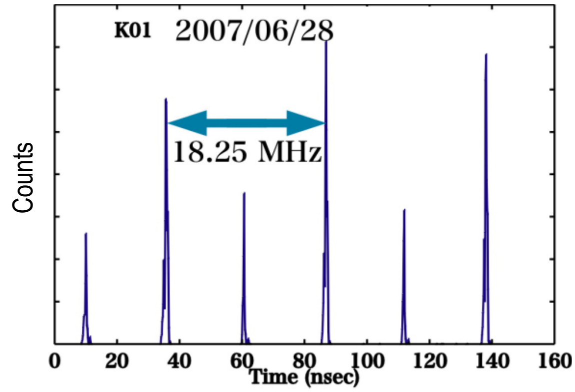

Figure 6: Longitudinal beam structure at downstream of IRC.

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