PRESENT STATUS OF THE RCNP CYCLOTRON COMPLEX

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Abstract

In recent years, high-quality beams in momentum spread have been strongly required and successfully obtained in a RCNP cyclotron complex. Intense beams have also been required. Present status of the RCNP cyclotron complex is described in this report.

1. INTRODUCTION

The Research Center for Nuclear Physics (RCNP) in Osaka University has a cyclotron complex, which consists of a large-sized ring cyclotron (K=400) and an injector AVF cyclotron (K=140). Beams are used mainly for nuclear physics research. Various kinds of ions were accelerated to different energies. Table 1 shows a summary of the beam usage of the cyclotron from 1999 to 2002. Mainly light-ion beams, such as proton, deuteron and helium beams, were required. More than 80 % of the machine times were carried out for the light ions in the past few fiscal years.

Table 1: A summary of the beam usage of the RCNP cyclotron complex

	1999	2000	2001	2002
H	1295.2hrs	989hrs	1846.8hrs	1050.1hrs
pol H	952.5	2038	879.7	1108
D	0	0	42.3	131.3
pol D	374.8	573.2	84.3	108
H_2	0	0	0	60
^{3}He	262.7	611.7	1338.8	1304.5
^{4}He	967.8	698.7	647	1189.3
^{6}Li	0	0	0	84.5
^{7}Li	295.8	152	180	244.1
^{11}B	21.7	0	312	0
^{12}C	93.3	0	0	0
^{14}N	251.3	118	0	0
^{16}O	0	35	0	0
^{18}O	282.2	0	0	0
Total	4797.3	5215.5	5331	5279.8

In the period shown here, ^{12}C, ^{16}O and H_2 molecular ions were accelerated to 480 *MeV*, 1120 *MeV* and 140 *MeV*, respectively, by the Ring cyclotron for the first time. Charge states for ^{12}C and ^{16}O ions extracted from the NEOMAFIOS ECR ion source[1] were 4 and 6, respectively. After acceleration by the injector AVF cyclotron, both ions were stripped to bare charge state. The target intensity for the ^{12}C, ^{16}O and H_2 molecular ions were 24 *nA*, 190 *nA* and 20 *nA*, respectively.

For 786 *MeV* 11B6+ beam, the obtained beam intensity much increased in the April of 2003, because the vacuum level in the NEOMAFIOS ECR ion source became better. Now 30 *nA* of the beam current can be obtained at the target.

For further update detail, see the relevant pages of http://www.rcnp.osaka-u.ac.jp.

Table 2: A summary of the performance of the RCNP cyclotron complex

	1999	2000	2001	2002
Beam time	4797.3hrs	5215.5hrs	5331hrs	5279.8hrs
Maintenance and set up	1695.8	1625.2	1367.8	1395.3
Scheduled shutdown	2023.5	1791	1843	1921
Unscheduled shutdown	267.3	128.3	218.2	163.8
Total	8784	8760	8760	8760

A summary of the performance of the RCNP cyclotron complex is given in table 2. During the last four fiscal years, unscheduled shutdown periods were always less than 270 hours, which were only less than 5 % of the beam times.

2. HIGH-QUALITY BEAM

High-quality beams are strongly required in the RCNP for light ions, such as proton, deuteron, helium-3 and helium-4. Figures 1, 2 and 3 show the observed energy spread in each machine time for a proton beam, a helium-3 beam and a helium-4 beam, respectively, as a function of the period. Different energies are required for both ions, especially in the last four fiscal years. For deuteron beam, we have no enough data comparable.

All lines in these figures seem to decrease, which means that cyclotron operation is still made progress in. Filled symbols represent the best energy spreads. All of the best results were obtained between 2000 and 2003. Without 210 *MeV* helium-4 beam, The best values of the ratios of the energy spread to the beam energy ($\Delta E / E$) in FWHM were achieved as less than 3x10-4. It should be noted that the reproducibility of the energy spread is quite well.

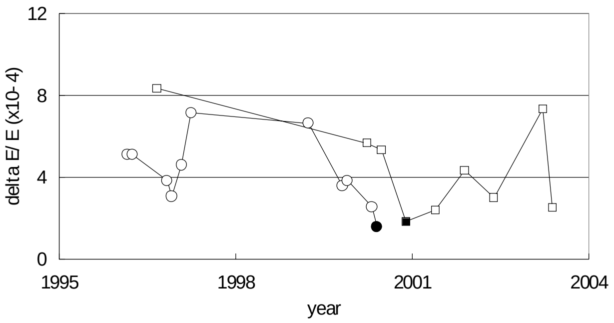

Fig.1 : Observed energy spreads in each machine time for 392 *MeV* proton beam(circle) and for 300 *MeV* proton beam(square). Filled symbols represent the best results.

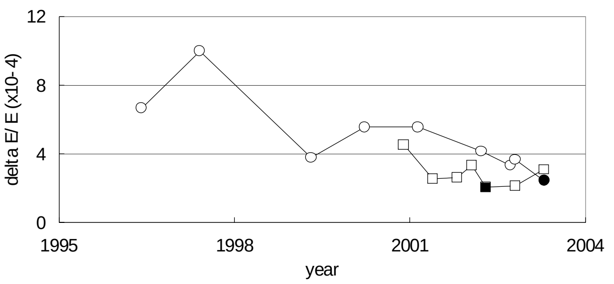

Fig.2 : Observed energy spreads in each machine time for 450 *MeV* 3He beam(circle) and for 420 *MeV* 3He beam(square) . Filled symbols represent the best results.

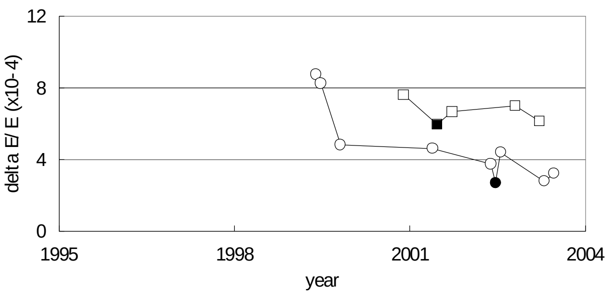

Fig.3: Observed energy spreads in each machine time for 400 *MeV* ^{4}He beam(circle) and for 210 *MeV* ^{4}He beam(square) . Filled symbols represent the best results.

A new beam line which accomplish both lateral and angular dispersion matching with the Grand Raiden spectrometer[2] in the RCNP was constructed[3]. In the dispersive mode, the energy distribution of the beam itself can be principally cancelled out. Energy resolutions of ΔE = 13.0±0.3 *keV* and ΔE = 16.7±0.3 *keV* in FWHM were achieved for 295 *MeV* and 392 *MeV* protons[3], respectively, i.e., $\Delta E/E \sim 4 \times 10^{-5}$.

Even in the dispersive mode, an energy resolution of the beam itself is much important practically. The lateral size of the beam on a target point is approximately proportioned to the momentum spread of the beam itself, which means that a high-quality beam is still experimentally expected.

3. INTENSE BEAM

Intense beams have also been required. It should be noted that a beam current is limited to less than 1100 *nA* by means of radiation control of the Ring cyclotron.

Table 3: Typical beam current at a target

	Energy(*MeV*)	Current(*nA*)
proton	100	330
	150	1000
	200	1000
	250	720
	300	700
	392	690
^{4}He	210	440

Typical beam intensity at a target is shown in table 3. A few hundreds of *nA* beams were obtained. Especially for 150 *MeV* and 200 *MeV* proton beams, beam intensities are just below the radiation control limitation of the Ring cyclotron. We also have ~ 5 μA limitation by means of radiation control of the AVF cyclotron. Therefore, transfer efficiencies through the Ring cyclotron are very important to obtain intense beams in the RCNP.

4. QUASI-SINGLE TURN EXTRACTION FROM THE AVF CYCLOTRON

In order to realize high-quality beams, single component beam is required. Therefore, single-turn extraction from a cyclotron is desirable. In the RCNP cyclotron complex, single-turn extraction from the Ring cyclotron is carried out. However, single-turn extraction from the AVF cyclotron was not realized for a normal operation.

Using a phase defining slit located in the central region of the AVF cyclotron, a single or two turns extraction was already achieved[4]. Recently, practical method to obtain quasi-single-turn-extraction beam with finite intensities have been found out mainly by the operators.

Detailed technique was described elsewhere[5]. It should be noted that the suitable magnetic field for quasi-single-turn-extraction needs to be searched by adjusting the main coil current by 0.02 *A*, i.e., the magnetic field is searched on the order of 10-5.

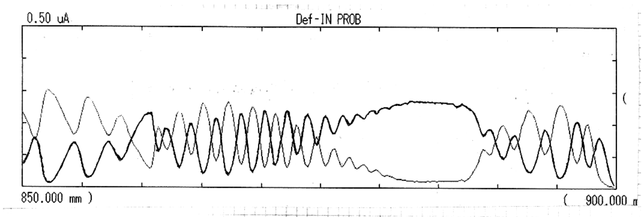

Fig.4 : ^{3}He beam current as a function of a position of the beam probe of the AVF cyclotron

Figure 4 shows observed herium-3 beam current as a function of a position of the beam probe. Extraction energy from the AVF cyclotron was 93 *MeV*. The right side of the figure corresponds to an extraction point. Not well, but separated peaks were observed, which means that quasi-single-turn extraction is realized.

5. R & D

Past a few years, we have stressed an importance of cooling systems for the RCNP cyclotron complex to obtain high-quality beam[6]-[9]. Here, other improvements in the last four years were very briefly described.

One-turn-coil systems were installed both to the AVF cyclotron and to the Ring cyclotron to correct the main coil currents. As a result, the magnetic fields both of the AVF cyclotron and of the Ring cyclotron can be controlled on the order of 10^{-7}.

A newly phase probes for the AVF cyclotron were also installed. Comparing the old ones, noise levels became quite small and we can get signals from a few *nA* of the beam.

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