STATUS REPORT ON JAERI-AVF CYCLOTRON SYSTEM

Y. Nakamura, T. Nara, T. Agematsu, I. Ishibori, S. Kurashima, M. Fukuda, S. Okumura, W. Yokota, K. Yoshida, N. Miyawaki and K. Arakawa, JAERI, Takasaki, Japan

Abstract

The AVF cyclotron system at JAERI Takasaki has been smoothly operated for 13 years since 1991. The system continues to deliver various ion species with very frequent alterations of operational conditions. In order to provide a heavy ion beam with energy spread of 0.02 % required for microbeam production, we have developed a flat-top acceleration system, an additional buncher driven by a saw-tooth wave, and improved the configuration of the cyclotron central region. An old gradient corrector of passive type was replaced by a new one with an active coil inside to obtain complete matching between the trunk beam line and a beam trajectory in the extraction region. A compact ECR ion source with a set of movable permanent magnet has been designed to produce mainly light ions, which will replace the existing multi-cusp ion source.

1 INTRODUCTION

The first beam from the JAERI AVF cyclotron was extracted successfully in March, 1991. This cyclotron system was introduced first in the world as an exclusive machine for the research mainly in materials science and bio-technology. The cyclotron system covers the highest energy range in TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) facility including three electrostatic accelerators and is operated under frequent alteration of the operational condition.

2 PRESENT STATUS

The cyclotron system [1]-[3] continues to operate smoothly without any serious troubles. Yearly operation time for last three years was 3362 h on the average. Since 1993 when the operation went into steady state, the yearly operation time always exceeds 3000 hours as shown in Fig. 1 although various reconstruction, improvement, renewal, maintenance, repair and so on have been done.

Alteration frequencies, such as acceleration harmonics, particle, energy and beam course, increase gradually year by year. Especially, the yearly number of beam course changes has rapidly attained up to 369. As the result, the utilization efficiency for cyclotron system, which is defined as the ratio of total allotment time to experimental one for users, has decreased to 0.73 in 2003, whereas 0.85 in 1996.

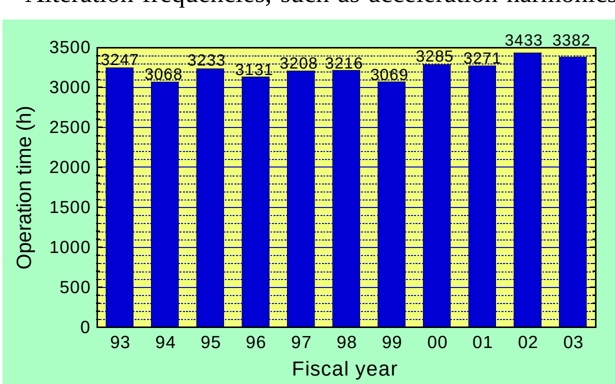

Figure 1 : The transition of the operation time for past eleven years.

3 SEVERAL IMPROVEMENTS

3.1 Central Region

With a view to certain producing the microbeam, the central region of the cyclotron were modified to improve the excellent space controllability and high device reliability for the beam [4]. Based on the detail analysis of beam phase selection, the beam exit of the third harmonic inflector was circled by about 180 degrees in comparison with the original position. In the case of first and second harmonics, the exit positions of the beam from the inflector electrode were shifted slightly.

The position and shape of two sets of the defining phase slit were also designed carefully. Furthermore, the inflector electrode and its shield cover were separated completely as shown in Fig. 2. The modified common shield cover was mounted at an upper earth plate of the cyclotron centre.

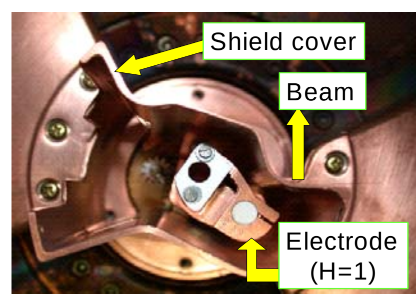

Figure 2 : New inflector electrode for harmonics H=1 and shield cover (view from bottom).

3.2 Flat-top Acceleration System

The cyclotron tuning for microbeam formation has being continued energetically under operation of the flat-top system [4]. Clear turn separation at a few outermost orbits in the cyclotron was observed using the deflector probe equipped with thin molybdenum sheet. And the single-turn extraction was also achieved for 260 MeV $^{20}Ne^{7+}$ by the flat-top acceleration system.

3.3 Active Gradient Corrector

In order to realize the complete matching between trunk beam line and the extraction orbit, a new gradient corrector with bending function was fabricated after the design using three-dimensional analytical code (TOSCA) and the orbit calculation. An appearance of the gradient corrector before the installation in the cyclotron is shown in Fig. 3. After the installation, the exciting current of the steering magnet just behind the cyclotron became rather smaller and the efficient beam transport to the trunk beam line was also attained easily.

Figure 3 : An appearance of the new gradient corrector before installation.

3.4 Compact ECR Ion Source

A new compact ECR ion source using permanent magnets has being developed [5]. The shape of the magnet made of NdFeB was designed using TOSCA code. As shown in Fig. 4, it is the principal characteristics that six pieces of the magnet can be moved independently up to 50 mm in the radial direction.

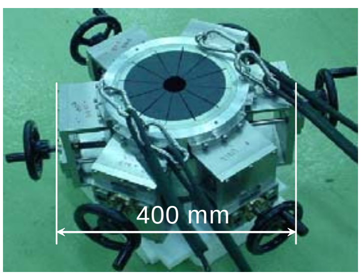

Figure 4 : An outline of permanent magnet structure.

In the preliminary operation, 300 nA of Ar^{6+} and 30 nA of Ar^{9+} were produced with only 10 W RF power at 14 GHz.

4 MAINTENANCE AND REPAIRS

Annual maintenance including some improvement of the cyclotron system is scheduled for 4-5 weeks in summer. Furthermore, the routine maintenance of power supplies for 1 week in fall, some reconstruction and improvement for 2-3 weeks in March have been also implemented.

Half of troubles are concerned with the vacuum events including the water leakage in vacuum. Typical events experienced for recent three years are described as the followings.

4.1 Sinkage at Trunk Beam Transport Line

It had been observed that the beam trajectory just after the cyclotron was shifted upward. As a result of measurement, several magnets along the trunk beam transport line had sunk below about 3 mm at maximum as illustrated in Fig. 5, caused by the gradual sinking of the floor. These magnets were aligned again in original positions with the precision of 0.2 mm. The condition of beam transportation was improved.

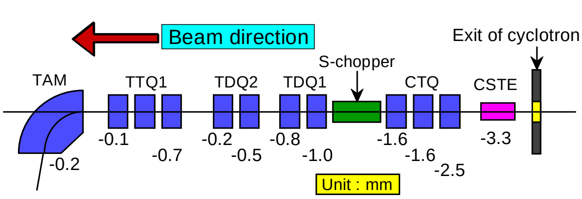

Figure 5 : The measurement data at several magnets along the trunk beam transport line. Numbers below the magnets show the vertical displacement of the sinkage.

4.2 Air Leakage at Magnetic Channel

An air leakage was caused at the stainless shield case of the magnetic channel (MC). A small penetrating hall through the case was formed during the cyclotron tuning by bombardment of the intense beam of 70 MeV H^{+} as illustrated in Fig. 6. Normal high vacuum condition in the cyclotron chamber became worse due to the air leakage. This MC was replaced with a spare MC. Two months later, this small hall was repaired carefully at Takasaki site by the TIG welding. And the soundness of the MC was also confirmed by the measurements of magnetic field and resistance of the molded coils.

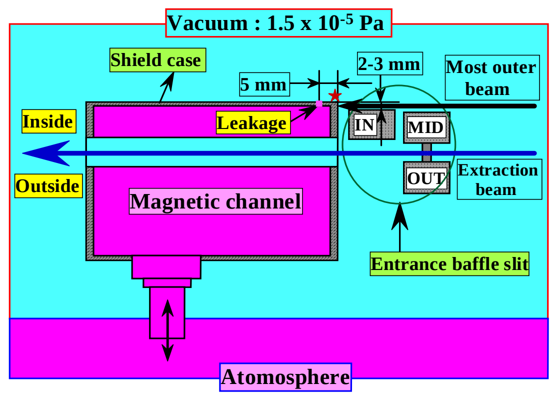

Figure 6 : Prediction of beam bombardment at the MC case. The entrance baffle slit "IN" had been placed outside by 2-3 mm from the designed position.

4.3 Breakdown of TMP

As well as similar trouble experienced once in 1994, the TMP vane was broken completely as seen in Fig.7 and the hair crack occurred at the conjunction part to the beam diagnostic chamber. Therefore, some measures for avoidance from serious vibration were performed later. The damaged TMP (600 L/s) and the chamber were also replaced by new ones.

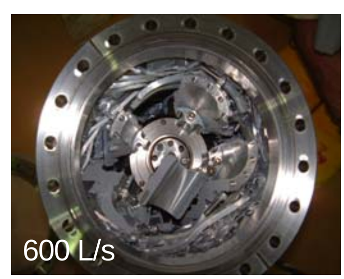

Figure 7 : Breakdown of TMP rotating vane.

4.4 Radiation Damage of Sequencer

During the irradiation with several μA beam of 100 MeV $^{4}He^{2+}$, three gate valves were shut and the indication of some vacuum gauges disappeared suddenly in an irradiation room. The cause of this trouble was the malfunction of the sequencer which governs to the sequence and information for vacuum control. The control program had to be rewritten finally based on the ladder circuit on the chart. It was presumed that the soft error (single event effect) was induced in the sequencer by the exposure of intense neutrons and gamma rays.

5 BEAM DEVELOPMENT

Sixty-five kinds of ion beams have been provided by the JAERI AVF cyclotron so far as summarized in Table 1. Both efficiencies of "Text" and "Tall" in many kinds of ion species were also improved by the fine tuning mainly in routine operation.

The series of $^{4}He^{+}$ (25 MeV), $^{12}C^{3+}$(75), $^{16}O^{4+}$(100), $^{22}Ne^{6+}$(165), $^{40}Ar^{10+}$(250), $^{58}Ni^{15+}$(390) and $^{82}Kr^{20+}$(490) is available as the cocktail beam with M/Q=4. Three kinds of isotope ions were selected intentionally to avoid the contamination of impurity ions although the ratios of M/Q are rather far from 4 and their intensities are also lower.

For the main purpose of the microbeam formation, the intensity of 260 MeV $^{20}Ne^{7+}$ beam was increased drastically to 9.8 μA from 0.33 μA using the "HYPERNANOGAN" instead of the "OCTOPUS".

Both $^{4}He^{2+}$ ions of 75 MeV and 80 MeV with harmonic number (H) of 2 were newly developed for efficient utilization and excess radioactivation on the experiment of radioisotope production, in place of 100 MeV $^{4}He^{2+}$ ion with H=1. The intensities of both ion beams were successfully achieved about 6 μA.

6 OTHERS

The information of an accumulated dose around the JAERI AVF Cyclotron is significant for the damage control of various electronic components. We put many alanine and thermo-luminescence dosimeters to estimate the accumulated dose [6]. The highest absorbed dose of 1000 Gy in silicon was recorded at the beam diagnostic station where the beam extracted from the cyclotron was frequently stopped for tuning and waiting. The dose on the shielding wall surrounding the cyclotron vault amounts to several Gy. Actually, only a few electronic components were suffered through the radiation damage because the majority of electronic devices had been installed at suitable places under lower dose rate.

The cyclotron facility in TIARA is equipped with many kinds of auxiliary safety devices such as entrance doors, rotary shutters and so on. These devices are required especially so as to always maintain their reliability and durability. We have accumulated so far the number of operations [7] since the installation in 1991 for the plans of maintenance and overhaul. The number of operations for the doors and rotary shutters are added up 100-500 and 100-450 times for a year on an average, respectively.

REFERENCES

[1] Y. Nakamura, T. Nara, *et al.*, Proc. 4th Workshop Accelerator Operation (WAO), Hayama and Tsukuba, Japan (2003) pp. 8-13

[2] Y. Nakamura, T. Nara, *et al.*, Proc. 14th Sympo. Accel. Sci. Technol., Tsukuba, Japan (2003) pp. 678-780

[3] Y. Nakamura, T. Nara, *et al.*, TIARA Annual Report 2002 (2003) pp. 312-314

[4] S. Kurashima, M. Fukuda, *et al.*, this conference

[5] K. Yoshida, T. Nara, *et al.*, Proc. 1st Annual Meeting Particle. Accel. Society Japan., Narashino, Japan (2004) pp. 392-393

[6] Y. Nakamura and T. Kojima, TIARA Annual Report 2002 (2003) pp. 317-319

[7] Y. Nakamura and Y. Arakawa, TIARA Annual Report 2001 (2002) pp. 303-304

Table 1 : Ion species accelerated by the JAERI AVF cyclotron. The symbol of "Text" is defined by a ratio of the beam current at the Faraday cup just after the cyclotron to that at a radius of 900 mm in the cyclotron. The "Tall" is a ratio of the beam current extracted from the cyclotron to that injected into.

Ion species	Energy (MeV)	Intensity (eμA)	Text (%)	Tall (%)	Ion species	Energy (MeV)	Intensity (eμA)	Text (%)	Tall (%)	Ion species	Energy (MeV)	Intensity (eμA)	Text (%)	Tall (%)
H^{+}	10	12	80	27	$^{4}He^{2+}$	80	6	65	9.2	$^{36}Ar^{8+}$	195	2.5	73	13
	20	11.5	89	25		100	10	32	10	$^{36}Ar^{10+}$	195	0.1	43	1.2
	30	6.2	78	22		108	1.6	M/Q=2		$^{36}Ar^{18+}$	970	10^{5} cps	M/Q=2	
	45	30	79	14	$^{12}C^{3+}$	75	2	M/Q=4		$^{40}Ar^{8+}$	150	2.4	M/Q=5	6.2
	50	5	64	14	$^{12}C^{5+}$	220	0.25	77	22		175	3	73	15
	55	5	63	14	$^{12}C^{6+}$	320	0.037	M/Q=2		$^{40}Ar^{10+}$	250	0.2	M/Q=4	
	60	5	68	22	$^{14}N^{3+}$	67	4	43	10	$^{40}Ar^{11+}$	330	0.7	86	22
	65	7	78	12	$^{15}N^{3+}$	56	0.70	M/Q=5	5.0	$^{40}Ar^{13+}$	460	0.045	76	24
	70	5	42	12	$^{16}O^{4+}$	100	5	M/Q=4	22	$^{40}Ca^{9+}$	200	2	61	11
	80	4.4	72	13	$^{16}O^{5+}$	100	4	34	21	$^{56}Fe^{11+}$	210	1.4	M/Q=5	16
	90	10	48	7.7	$^{16}O^{6+}$	160	1.9	58	21	$^{56}Fe^{15+}$	400	0.59	66	28
D^{+}	10	11	29	3.7	$^{16}O^{7+}$	225	1	82	13	$^{58}Ni^{15+}$	390	0.012	M/Q=4	
	20	5.6	80	16		335	0.1	41	6	$^{82}Kr^{20+}$	490	10^{7} cps	M/Q=4	
	25	15	88	31	$^{16}O^{8+}$	430	0.0045	M/Q=2		$^{84}Kr^{17+}$	320	0.08	M/Q=5	5.0
	35	40	76	23	$^{20}Ne^{4+}$	75	1.5	M/Q=5	6.6	$^{84}Kr^{18+}$	400	0.04	60	2
	41	3.4	80	16	$^{20}Ne^{5+}$	125	0.01	M/Q=4		$^{84}Kr^{20+}$	520	0.06	75	22
	50	20	49	9.7	$^{20}Ne^{6+}$	120	1.6	53	18	$^{84}Kr^{21+}$	525	0.0032	M/Q=4	
$^{3}He^{2+}$	60	8.2	68	18	$^{20}Ne^{6+}$	200	0.8	Scaling	10	$^{102}Ru^{18+}$	320	0.013	50	3.9
$^{4}He^{+}$	25	3.6	M/Q=4	13	$^{20}Ne^{7+}$	260	9.8	70	22	$^{129}Xe^{23+}$	450	0.2	72	14
$^{4}He^{2+}$	20	5.5	69	12		270	0.28	Scaling	14	$^{197}Au^{31+}$	500	0.038	49	3.8
	30	10	42	10	$^{20}Ne^{8+}$	350	1.5	63	26					
	50	20	86	22	$^{20}Ne^{10+}$	540	10^{5} cps	M/Q=2		M/Q = 2, 4 and 5 : a series of cocktail beams				
	75	6	81	7.5	$^{22}Ne^{6+}$	165	0.007	M/Q=4		Woven pattern : modified data on previous table				