STATUS REPORT ON THE JAERI AVF CYCLOTRON SYSTEM

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Abstract

The AVF cyclotron system at JAERI Takasaki has been smoothly operated without serious troubles since the first beam extraction of 50 MeV $^4He^{2+}$ in March 1991. A yearly operation time is about 3200 hours on an average for past several years.

In the last three years, we performed some improvements and developments as follows: stabilization of the cyclotron beam, renewal of computers and basic programs for the control system, installation of a new ECR ion source and reconstruction of the rotary shutter.

Furthermore, two series of M/Q=4 and M/Q=2 cocktail beams have been developed continuously. Now we are modifying the RF cavities for the flat-top acceleration by superimposing the fifth-harmonic frequency on the fundamental one.

1 INTRODUCTION

The AVF cyclotron system [1,2] was introduced to promote various researches in many fields at the Takasaki site of Japan Atomic Energy Research Institute (JAERI). The cyclotron system can accelerate plenty of ion species covering the highest energy range in TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) facilities. Especially, the cyclotron system has been utilized mainly for materials science and biotechnology such as a radiation test of semiconductor devices, breeding of plants, development of organic and inorganic functional materials, and so on for about 10 years.

2 PRESENT STATUS

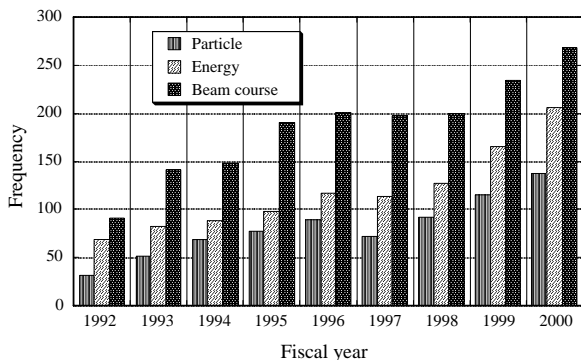A total operation time of the cyclotron amounted to 29800 hours at the end of April in 2001. Yearly operation time is kept constantly more than 3000 hours for the last several years in spite of the executions of many reconstructions, improvements and repairs.

The frequency of the change of the particle, energy and beam course is shown in Fig. 1. This frequency was corrected so as to add the condition of new beam development to the previous data. These quantities increase certainly year by year. As the number of ion species increases, contrarily the allotted beam time for users gradually decreases, while the time for scheduled beam tuning including the beam course change increases considerably. This fact means that the utilization efficiency of the cyclotron system is lowering slowly.

3 SEVERAL IMPROVEMENTS

3.1 Stabilization of Cyclotron Beam

We have found out that the instability of cyclotron beam came from the change of the magnetic field in the pole gap because of the temperature rise of the cyclotron magnet iron induced by large amount of heat conducted from the main coils [3]. Two measures for the better stabilization were introduced in March 2000. One is the insertion of the cooling jacket between the main coil stack and the upper/lower yokes. The other is the modification to an exclusive water-cooling system from the existing one for the trimming coils. Temperature control for the trimming coils is very efficient to suppress the drift of the magnetic field. The outline of the exclusive cooling system is shown in Fig. 2.

As a result, the decrease of the beam current was improved within 10 % by means of continuous operation of this cooling system [4].
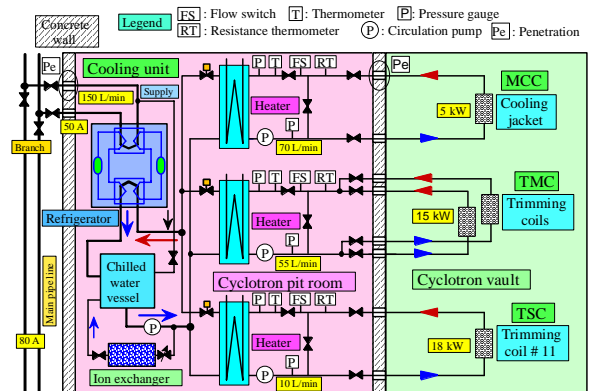

Figure 1: The frequency of the change of the particle, energy and beam course.

Figure 2: The outline of exclusive cooling system.

3.2 Renewal of Control Computers and Program

Increase of the load on the control system due to the addition of a new ion source, functional control program for the cyclotron fine tuning and so on, had been predicted in near future. In addition to these circumstances, it was becoming harder to get out-of-date spare components owing to the cessation of the manufacturing and company bankruptcy.

Some mini-computers were replaced with several personal computers [5]. Basic control programs were also rewritten completely. An example of the graphical display for several controllable devices on the CRT screen is shown in Fig. 3. Operators can assign up to 6 parameters at the same time for tuning objective devices.
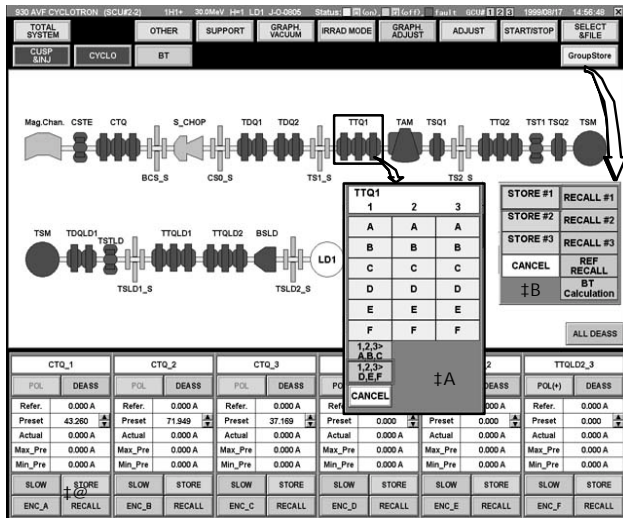

Figure 3: The graphical display for selecting and assigning the parameters for the beam transport group.

3.3 Installation of A New ECR Ion Source

A new ECR ion source, "HYPERNANOGAN" (HECR), was introduced to generate metallic ions mainly. The intensity of Ar^{13+} beams produced in the test operation was more than 5 times as high as the existing OCTOPUS. So far, the HECR have produced successfully some kinds of metallic ions such as iron, calcium and gold, which are accelerated by the cyclotron and provided to research experiments.

3.4 Reconstruction of Rotary Shutter

A rotary shutter (RS) for one of beam lines embedded into the shielding wall through the HB course was exchanged. This RS was operated most frequently among nine rotary shutters in the cyclotron facility. The number of operations had been counted up 3500 before the exchange. Serious air leakage through the driving shaft of the RS had been also observed whenever it was operated.

Some improvements were introduced in the new RS [6] as follows: 1) the alteration of vacuum seal structure from double O-rings ("cap-seal") to magnetic fluid seal as shown in Fig. 4, 2) the modification of driving mechanism from a pneumatic rotary actuator to an electric stepping
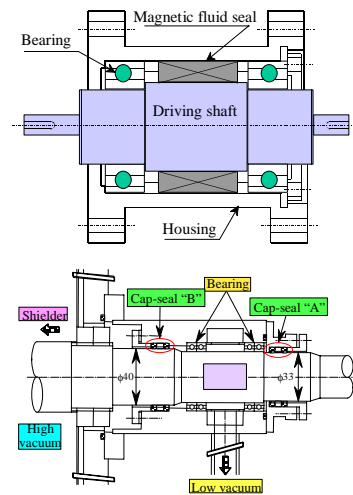

Figure 4: Sectional view of the part of the driving shaft. Upper: after the reconstruction. Lower: before the reconstruction.

motor, 3) the reconstruction to the polyethylene shielder covered with stainless steel plate to diminish the outgassing into the vacuum environment.

3.5 Exchange of Magnetic Channel and Its Probe

A tantalum head of the magnetic channel (MC) probe was replaced with graphite one to reduce the radioactivation. As this head became rather thick, the span of the MC needed to be reduced.

The output current of the power supply for this MC was reinforced up to 1430 A from 1300 A to maintain the same ability as the old MC.

3.6 Repairs and Maintenance

Four mechanical-seal pumps with motors for the circulation of cooling water were exchanged to new ones after about 35000 hours' cumulative operation time. Many shunt resistors in the power supplies were replaced with new types made of "Zeranin" or "Manganin".

The vacuum chamber of the OCTOPUS was filled with cooling water on account of serious leakage. The OCTOPUS was disassembled completely for cleaning, polishing and the replacement of gaskets to spares.

The water leakage originated from the metal fitting at the penetration part of the MC was repaired carefully. The cooling copper pipes spirally wound on the outer cylinder of the two RF resonators were also renewed because of the water leakage.

About 4000 push-button switches, which were assembled on the control panels of about 300 local controllers, were exchanged to reliable new types. The 317 cooling fans in a lot of power supplies and control racks were also replaced.

A great deal of plastic (nylon) tubes used for cooling water and compressed air were replaced with new ones along the beam lines. Total length of the tubes was about 520 m and the number of replaced tubes was 720.

4 BEAM DEVELOPMENT

Two series of cocktail beams of M/Q=4 and 2 have being developed. On the other hand, the cocktail beam of M/Q=5 has been already utilized for many users for five years [7].

Practical data for the extraction of single species in the case of M/Q=4 is summarized in Table 1. It is considerable difficult to extract the single species without impurity from several cocktail ion species when the difference of the M/Q ratios between objective ion species and the others is less than 4×10^{-3} because of the finite M/Q resolution of the cyclotron. However, we find out that the reduction of a dee voltage is very effective to choose single species by the combination with a slight frequency shift of the master oscillator [8].

Ion species	$\dfrac{V\left(\frac{M}{Q}\right)}{\frac{M}{Q}}$ (X10^{-4})	Energy (MeV)	LET in Silicon $\left(\frac{MeV}{\frac{mg}{cm^2}}\right)$	Impurity ratio with standard parameters	Impurity ratio less than 1X10^{-4}
^{4}He$^+$	6.5	25	0.2	-	Achieved
^{12}C^{3+}	3.2	75	1.8	O: 3X10^{-3}	Achieved
^{16}O^{4+}		100	3.0	C: 2X10^{-2} Ne: 3X10^{-2}	Achieved
^{20}Ne^{5+}	0.6	125	4.6	O: 4X10^0 Ar: 1X10^{-1} C: 1X10^{-2}	Achieved
^{36}Ar^{9+}	5.2 0.3	225	13	^{40}Ar: 3X10^1	Possible with highly enriched isotope gases
^{40}Ar^{10+}	1.2	250	13	^{36}Ar: 1X10^{-2}	
^{84}Kr^{21+}		525	36	Fe: 4X10^0 Cr: 6X10^{0*} Ar: 1X10^{3*}	Possible with ^{86}Kr^{22+} instead of ^{84}Kr^{21+}

* Coming from the plasma chamber wall of the ion source, and their M/Q differences for ^{84}Kr^{21+} are extremely small.

Table 1: Summary of M/Q=4 cocktail beams. Numbers in the column of the impurity ratio describe intermixture ratios of non-objective ions to an objective ion.

A fully stripped ion of 970 MeV ^{36}Ar^{18+}, which was the highest energy of the JAERI AVF cyclotron, was successfully accelerated.

Ion species accelerated by the JAERI AVF cyclotron so far are listed in Table 2. The "T$_{ext}$" described in Table 2 is defined by the ratio of a beam current at the exit to one at the entrance of the deflector channel, and "T$_{all}$" is the ratio of two beam currents injected into and extracted from the cyclotron.

5 OTHERS

We are going to minimize the beam energy spread with the addition of a couple of flat-top cavities for micro beam production. After the cavity model manufactured by RIKEN was transported to Tohoku University, it was mounted on the main cavity of the CYRIC 930 cyclotron, which has the same structure as the JAERI 930 cyclotron, since our cyclotron has no spare flange for installation of the cavity model. A cold model test for the flat-top acceleration was done elaborately in February, 2000.

Ion species	Energy (MeV)	Beam (emA)	T ext (%)	T all (%)
H$^+$	10	12	80	27
	20	5	77	23
	30	5	67	22
	45	30	79	14
	50	5	44	14
	55	5	63	14
	60	5	57	22
	65	7	62	12
	70	5	42	12
	80	3	47	13
	90	10	48	7.7
D$^+$	10	11	29	3.7
	20	5.6	80	16
	25	11	88	30
	35	40	59	13
	50	20	49	7.2
^{4}He^{2+}	20	5.5	69	12
	30	10	42	10
	50	20	62	22
	100	10	32	10
	108	1.6	M/Q=2	
^{12}C^{3+}	75	2	M/Q=4	
^{12}C^{5+}	220	0.25	77	22
^{12}C^{6+}	320	0.0025	M/Q=2	
^{14}N^{3+}	67	4	43	10
^{15}N^{3+}	56	0.70	M/Q=5	5.0
^{16}O^{4+}	100	5	M/Q=4	22
^{16}O^{5+}	100	4	34	21
^{16}O^{6+}	160	1.9	58	21
^{16}O^{7+}	225	1	82	13
^{16}O^{7+}	335	0.1	41	6
^{16}O^{8+}	430	0.0045	M/Q=2	
^{20}Ne^{4+}	75	1.5	M/Q=5	6.6
^{20}Ne^{5+}	125	0.01	M/Q=4	
^{20}Ne^{6+}	120	1.6	53	18
^{20}Ne^{7+}	260	0.33	70	19
^{20}Ne^{8+}	350	1.5	63	23
^{20}Ne^{10+}	540	10^5 cps	M/Q=2	
^{36}Ar^{8+}	195	2.5	73	13
^{36}Ar^{10+}	195	0.1	43	1.2
^{36}Ar^{18+}	970	10^5 cps	M/Q=2	
^{40}Ar^{8+}	150	2.4	M/Q=5	6.2
	175	3	73	15
^{40}Ar^{10+}	250	0.2	M/Q=4	
^{40}Ar^{11+}	330	0.7	86	22
^{40}Ar^{13+}	460	0.03	63	24
^{40}Ca^{9+}	200	2	61	11
^{56}Fe^{15+}	400	0.55	66	23
^{84}Kr^{17+}	320	0.08	M/Q=5	5.0
^{84}Kr^{18+}	400	0.04	60	2
^{84}Kr^{20+}	520	0.06	72	22
^{84}Kr^{21+}	525	0.0032	M/Q=4	
^{129}Xe^{23+}	450	0.2	72	11
^{197}Au^{31+}	500	0.022	49	3
M/Q = 2, 4 and 5 : Cocktail beams				

Table 2: The list of ion species accelerated by the JAERI AVF cyclotron.

Now, detail consideration and design are in progress [9]. In next March, our cyclotron will be equipped with a new flat-top system.

Furthermore, a superconducting AVF cyclotron, which has the Kb-value of 900 and Kf-value of 300, is being proposed and designed as next future plan [10].

6   REFERENCES

[1] H. Tamura, K. Arakawa, Y. Nakamura, et al., Proc. 12th Sympo. Accel. Sci. Technol., Wako, Japan (1999)

[2] Y. Nakamura, T. Nara, T. Agematsu, et al., JAERI-Review 2000-024 (2000)

[3] S. Okumura, K. Arakawa, M. Fukuda, et al., Proc. 12th Sympo. Accel. Sci. Technol., Wako, Japan (1999)

[4] S. Okumura, K. Arakawa, M. Fukuda, Y. Nakamura, et al., this conference

[5] T. Agematsu, K. Arakawa, S. Ishiro, et al., Proc. 12th Sympo. Accel. Sci. Technol., Wako, Japan (1999)

[6] I. Ishibori, Y. Nakamura, T. Torii, et al. JAERI-Review 2000-024 (2000)

[7] W. Yokota, M. Fukuda, S. Okumura, et al., Proc. 12th Sympo. Accel. Sci. Technol., Wako, Japan (1999)

[8] M. Fukuda, K. Arakawa, S. Okumura, et al., Proc. 1999 Particle Accel. Conf., Yew York, USA (1999)

[9] S. Kurashima, M. Fukuda, Y. Nakamura, et al., this conference

[10] M. Fukuda, K. Arakawa, W. Yokota, et al., this conference