STATUS REPORT ON THE JAERI AVF CYCLOTRON SYSTEM

Y. Nakamura, T. Nara, T. Agematsu, I. Ishibori, H. Tamura, S. Kurashima, W. Yokota, S. Okumura, M. Fukuda, K. Akaiwa*, To. Yoshida*, S. Ishiro*, A. Matsumura*, Y. Arakawa*, Tsu. Yoshida*, S. Kanou*, A Ihara* and K. Takano*

Japan Atomic Energy Research Institute,
* Ion Beam Irradiation Service, Co. Ltd.
1233 Watanuki, Takasaki, Gunma 370-1292, Japan

Abstract

The AVF cyclotron system at JAERI Takasaki has been smoothly operated without serious troubles since the first beam extraction in March, 1991. A yearly operation time is about 3200 hours on an average for recent eight years.

In last two years, we performed some improvements and developments as followings: stabilization of the cyclotron beam by addition on an exclusive cooling system, designing and investigation of the flat-top system using fifth-harmonic RF, reconstruction of the rotary shutter for radiation shielding and reinforcement of the magnetic channel and its power supply.

Furthermore, the renewal of main circulation pump for cooling system, replacement of shunt resistor in the power supplies and re-alignment of the several magnets along the trunk beam transport line were also carried out.

1 INTRODUCTION

The AVF cyclotron system [1],[2] was introduced to promote various researches of many fields at the Takasaki site of Japan Atomic Energy Research Institute (JAERI). The cyclotron system can accelerate plenty of ion species from hydrogen to gold at TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) facility. Especially, the cyclotron system has been utilized mainly for material science such as semiconductor devices, seeds and plants, organic and inorganic functional materials, and so on for about 10 years.

2 PRESENT STATUS

2.1 Operation

A cumulative operation time of the cyclotron amounted to 31009 hours at the end of August in 2001. In FY 2000, the rate summed up heavy ions and cocktail ion of M/Q=5 occupied about 70 % of yearly operation time, on the other hand, the rate of light ions consisting of proton and deuteron was 28 %. A yearly operation time is kept constantly more than 3000 hours for past several years in spite of the executions of many reconstructions, improvements and repairs.

A beam time for users has been allotted in consideration of various demands from them as conscientiously as possible so far. Therefore, the frequency of the change of particle, energy and beam course increases certainly year by year as shown in Fig. 1. According as the number of ion species increases, the allotted beam time for users gradually decreases while the time for scheduled beam tuning including the beam course change increases considerably. This means that the utilization efficiency of the cyclotron system is lowering.

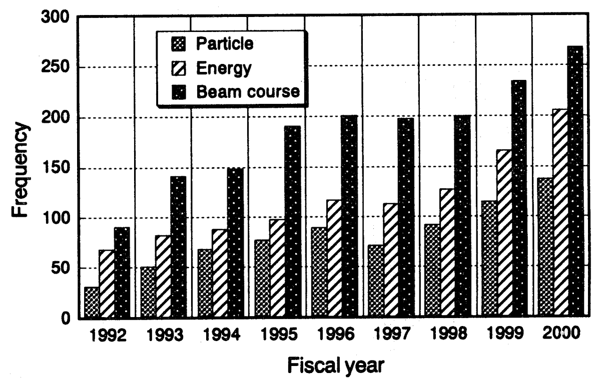

Figure 1: Frequency of the change of particle, energy and beam course.

2.2 Improvement

It had been pointed out from operational experience of beam transport that the beam trajectory just behind the cyclotron was shifted upward. As a measurement result, several magnets along the trunk beam transport line had sunk below maximum about 3 mm as illustrated in Fig. 2. These magnets were aligned again in original positions within the precision of 0.2 mm.

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 fabrication of the reduced-size MC was also needed. The output current of the power supply for this MC was

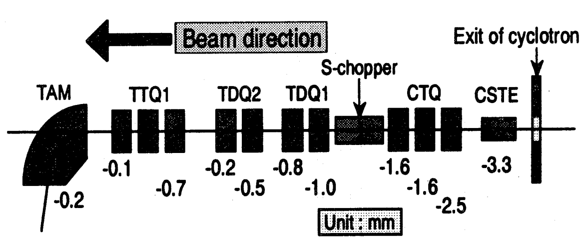

Figure 2: Sinkage of several magnets along the trunk beam transport line.

reinforced up to 1430 A from 1300 A to guarantee the same performance as the old MC.

Five controllers for TMP's installed in the switching magnet room on the first floor were moved to the cyclotron pit room on the basement where the radiation level is lower, because they had to be sometimes repaired so far owing to accumulated radiation damage.

A rotary shutter (RS) for one of beam lines embedded in the shielding wall through the HB course was renewed since significant air leakage through the driving shaft had been observed whenever it was operated. This RS was operated most frequently among nine RS's in the cyclotron facility. The number of operations already exceeded 3500 before the renewal.

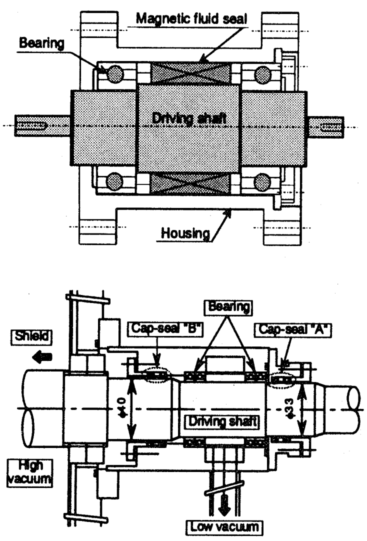

Figure 3: Sectional view of the vacuum seal part around the new driving shaft (upper) and the old (lower).

Some improvements were performed for the new RS [3] as follows: 1) the alteration of vacuum seal structure from double O-rings (Cap-seal "A" and "B") to magnetic fluid seal as shown in Fig. 3, 2) the modification of driving mechanism from a pneumatic rotary actuator to an electric stepping motor, 3) the reconstruction to the polyethylene shield covered with stainless steel plate to diminish the outgassing in the vacuum.

The control system constituting of personal computers for cyclotron was renewed completely in March, 1999 [4]. A pair of liquid crystal displays were further installed on each control console to always monitor the operating condition.

In order to improve the uniformity of beam fluence of the scanner, the phase control of triangular scanning wave was added on three beam scanners so that the scanning pitch on the target plane became to be narrower. A new scanning frequency of 0.25 Hz was also added on the scanner equipped with LD course.

2.3 Maintenance and Repair

Four mechanical-seal pumps with electric motors for the circulation of cooling water were renewed preventively. The manufacturing period for these pumps is more than three months as they are usually begun to make after the order from a customer. They had been operated for about 35000 hours since the installation in 1990. In addition, the control mode for cooling tower on the building roof was also modified to the continuous operation using an inverter from the intermittent ON-OFF motion.

Serious water leakage from the MC occurred at the "Vebeo" fitting for both introductions of coil current and cooling water. The Vebeo fitting contacted directly with neighbor one because the shrinkable tube covering the fitting suffered from deep damage by heating for a long-term operation. Therefore, the localized meltdown was caused by rare-shortening of this metal fitting where the large coil current was flowed.

We altered the fitting type from Vebeo to "Swagelok" on account of mechanical property and contact condition. Then, we examined the difference of surface temperature between stainless steel and brass fitting. A measurement result of saturated temperature is shown in Fig. 4. Since the surface temperature on the shrinkable plastic tube was restrained below 70 ℃ with maximum coil current of 1430 A, finally we chose the Swagelok fitting made of brass.

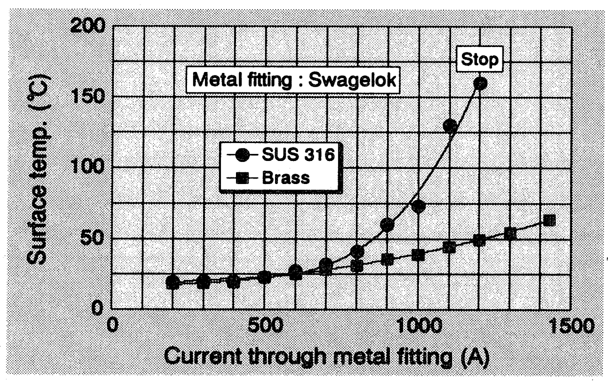

Figure 4: Comparison of surface temperature between stainless steel and brass fitting.

The vacuum chamber of the OCTOPUS was filled fully with cooling water for serious leakage. The OCTOPUS was disassembled completely for internal cleaning, polishing and replacement of gaskets. The HYPERNANOGAN was operated for the experiments for about two weeks instead of the OCTOPUS.

Many shunt resistors in the power supplies were replaced with new type made of "Zeranin" or "Manganin" due to the deterioration of electrical property and the possibility of internal corrosion.

As one of the preventive countermeasures, a great amount of plastic (nylon) tubes used for cooling water and compressed air was replaced with new ones along the beam lines. Total length of theirs was about 520 m and the number of replaced tubes was 720.

3 DEVELOPMENT

3.1 Cocktail Beam and Scaling Acceleration

Two kinds of $^{58}Ni^{15+}$ and $^{82}Kr^{20+}$ ion were newly added on the previous series of cocktail beam of M/Q=4.

It is considerably difficult to separate clearly a single species from several cocktail ions when the difference of the M/Q ratios between an objective ion species and the others is less than proper M/Q resolution of the cyclotron (about $3x10^{-4}$). However, we find out that the reduction of dee voltage is very effective to eliminate impurities in combination with slight shift of RF frequency [5].

The series of $^{20}Ne^{8+}$ 350 MeV, $^{20}Ne^{7+}$ 270 MeV and $^{20}Ne^{6+}$ 200 MeV beam was developed for the purpose of quick change of the ion species using a "scaling method". Actually, the magnetic field generated by twelve pairs of trimming coils was adjusted mainly on condition that the main coil current was maintained constantly.

3.2 Others

We have found out that the instability of cyclotron beam comes from the slight reduction of magnetic field in the accelerating gap because of temperature rise of the cyclotron body by large amount of heat transferred from the main coils. The comprehensive measures for the beam stabilization were carried out in March, 2000 [6]. As a result, the stabilization of the cyclotron beam was improved within 10 % decreasing by means of continuous operation of an exclusive cooling system [7].

A flat-top (FT) acceleration system for the JAERI AVF cyclotron has being designed to minimize the energy spread for the micro beam formation. The fifth harmonics of the main RF frequency will be used to construct the FT system. We investigate carefully the structure, characteristics and power consumption for the FT system using a MAFIA code [8].

All of the ion species accelerated by JAERI AVF cyclotron so far is summarized in Table 1.

REFERENCES

[1] Y. Nakamura, T. Nara, T. Agematsu, *et al.*, Proc. 16th Int. Conf. Cyclo. Their Applic., East Lansing, MI, USA (2001)

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

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

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

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

[6] Y. Nakamura, S. Okumura, M. Sano, *et al.*, JAERI-Review 2000-024 (2000)

[7] S. Okumura, S. Kurashima, T. Ishimoto, *et al.*, in this proceedings

[8] S. Kurashima, M. Fukuda, Y. Nakamura, *et al.*, Proc. 16th Int. Conf. Cyclo. Their Applic., East Lansing, MI, USA (2001)

Table 1: List of ion species accelerated by JAERI AVF cyclotron. The symbol of "T_{ext}" in the table is defined by a ratio of the beam current at first Faraday cup just behind the cyclotron to that at 900 mm of the cyclotron radius. The "T_{all}" is a ratio of the beam current extracted from the cyclotron to that injected into.

Ion species	Energy (MeV)	Beam (eμA)	T_{ext} (%)	T_{all} (%)
H^+	10	12	80	27
	20	7	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	31
	35	40	59	13
	50	20	49	7.2
$^4He^{2+}$	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	2.0	M/Q=4	
$^{12}C^{5+}$	220	1.0	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	1.0	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
$^{20}Ne^{6+}$	200	0.80	Scaling	10
$^{20}Ne^{7+}$	260	0.33	70	19
$^{20}Ne^{7+}$	270	0.28	Scaling	14
$^{20}Ne^{8+}$	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	3.0	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	2.0	61	11
$^{56}Fe^{11+}$	200	1.4	M/Q=5	16
$^{56}Fe^{15+}$	400	0.59	66	28
$^{58}Ni^{15+}$	388	0.012	M/Q=4	
$^{82}Kr^{20+}$	488	10^6 cps	M/Q=4	
$^{84}Kr^{17+}$	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	0.023	49	3
M/Q = 2, 4 and 5 : Cocktail beams				