STATUS REPORT ON THE INS SF CYCLOTRON

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ABSTRACT

10-year-long period of time has lapsed since the 1st extracted beam was achieved with our SF cyclotron. Presently this cyclotron accelerates ions ranging from a proton to a Xe element. The energy of proton has now been attained up to 45 MeV. By the development of a heavy-ion source, many heavy-ion beams have been drastically increased, and the ion source has been proved to be remarkably trouble-free. The improvement of beam transport allows the beam handling time to be shortened and has brought about the betterment of beam transport efficiency. This paper describes these developments and the performance of the cyclotron.

INTRODUCTION

The SF cyclotron was achieved with the 1st extracted beam in the spring of 1974.[1] In the end of 1976, experiments of nuclear phyisics were started. The total running hours of the cyclotron has already reached 23,850 hours. At present the cyclotron is now in good conditions. The working ratio of the cyclotron, that is, the beam-on time ratio to the scheduled machine time is 80%. The principal purpose of the SF cyclotron is for nuclear physics study. The cyclotron has also been put to practical use for studies of solid state physics and biomedical application.

For this one year and a half, the number of ion species newly accelerated has greatly increased from 22 to 83 by adopting a new heavy-ion source. Following are examples of such elements: Be, F, Na, Mg, Aℓ, Si, S, Cℓ, K, Ca, Ti, Fe, Cu and Xe. Furthermore, we have been being exerted endeavors to improve beam transport method with the aid of a micro-computer. As a result of that, the time required for transport of a beam reaching its target can be shortened to the smaller value of 1/3∿1/5 in comparison with the time measured by the conventional method. Also, the following consequences have ensued with this method: the beam loss in the beam transport is very small; the beam intensity as weak as 5nA is adequate enough to make transport; recurrence of the parameters in the transport system is excellent.

The short pulsed beam of H, He and C ions (pulse width 1ms, repetition frequency 33Hz) is accelerated with the use of a light-ion source.

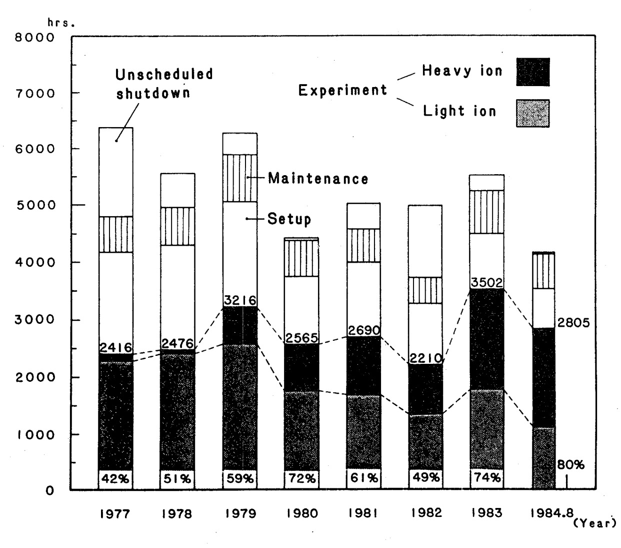

Fig. 1 Time distribution of the SF cyclotron between 1977 and August 1983

OPERATION

The usage of the machine time of the cyclotron between 1977 and August 1984 is shown in Fig. 1 for the sake of comparison. As has been deduced from the Figure, utilization of heavy-ions has been increased since 1979. In recent years, the ratio of such experiments of the heavy-ions in the total machine time reaches 50% and kinds of heavy-ion have been diversified. In the Fig. 1, numbers of the percent denote the ratio of the beam-on time to the scheduled machine time. It has been made clear that since 1983 the working ratio is being raised again. Fig. 2 shows the numbers of newly established beams for 10 years. As revealed in this Figure, the drastic increase of the beams since 1983 due to the employment of the new heavy-ion source is noticed.

Numbers of available beams which the SF cyclotron has accelerated is listed in Table 1. The several kinds of acceleration using the 5th, 7th and 9th harmonics have been realized, which enables the beam to extend to lower energies and also to obtain a heavier ion than Ar ions.

RF SYSTEM

Since the RF system was converted from the self-excited oscillator to MOPA system,[2] improvements have been conducted in order to mainly obtain better operational performance up to present. Operation of the RF system is performed with 68kV as its maximum of dee voltage. Frequency range is covered from 7.32 MHz to 22.5 MHz. However the operation in the frequency range of more than 20 MHz is avoided, since the ion source and its driving device are heated in the said range.

The phase between a grid and a plate in the oscillating tube (RCA4648) is controlled so that the 180° phase can be maintained. However, this phase signal has been modulated as ±2.5° at 40 Hz. It is found that the noise was caused since the vibration of the rotary pump attached to the resonator was transmitted to the

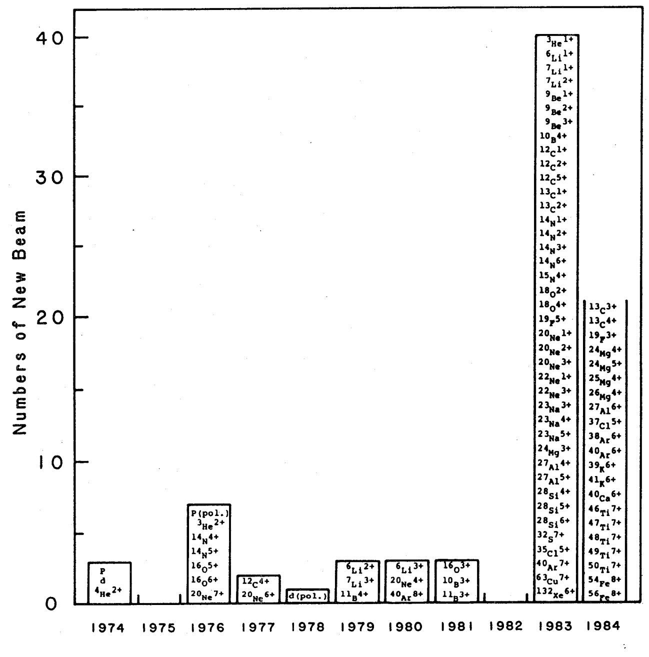

Fig. 2 Newly accelerated beams in the SF cyclotron

dee. As the phase meter, such a one that can take accurate measurement during the pulse operation of the RF has been made.

LIGHT-ION SOURCE

The proton beam with the highest energy of 45 MeV has been finally extracted. It is explained that there are several factors involved in the achievement. The improvements on the second electrode attained in 1981 and on the first electrode succeeded in 1982 resulted in less dark current in the deflector, which allows the electrodes to supply higher deflecting voltage. Furthermore, the improvement in the center region makes the first half turn with a smaller orbit. In consequence, a more stable acceleration can be maintained with lower dee voltage.

A pulsed beam of $^{12}C^{4+}$ (76 MeV) was extracted using a combination of the light-ion source and the arc power supply for the heavy-ion source. As the conditions for the pulse arc (pulse width 0.4ms, repetition rate 30ms), 6A arc current and 1,200V arc voltage were most suitable. Under conditions, pulsed beam current of 3.3μA was obtained. The pulsed beam intensity is not proportional to the duty factor under the condition of the pulse width of less than 1ms, and it reaches its optimum value under the condition of 0.3ms. CO_2 gas flow rate is 0.2cc/min, while 1cc/min in case of a heavy-ion source. The beam thus obtained was injected into TARN. The lifetime of the filament during the experiment was 13 hours.

HEAVY-ION SOURCE

The arc power supply has been improved and it provides much more stable operation. Further improvements have been continuously made on the internal heavy-ion source.[3] The arc-heated cathode PIG type source was designed based on the one that was developed at Texas A & M cyclotron.[4] The structure is shown in Fig. 3. In contrast to the old model, this new source can be utilized for both gaseous and metallic ions. The present model has already been used for more than 3,400 hours since the operation utilizing this source started in 1983, and proved to be very trouble-free and the handling is much simplified.

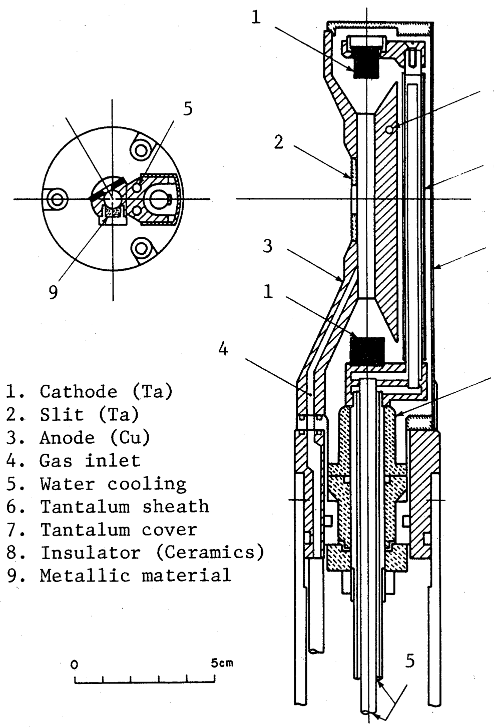

Fig. 3 Cross section of the internal arc-heated cathode PIG source

The $^{20}Ne^{6+}$ ion is one of those ions with which acceleration is hard to provide, because it is liable to be invaded by ghost ions. Prior to providing the ion with acceleration, we found the following procedure: primarily the $^{13}C^{4+}$ ion which is similar to the $^{20}Ne^{6+}$ ion in the charge to mass ratio is accelerated using the natural CO_2 gas. Thus accelerated parameters will be obtained. After that, the $^{20}Ne^{6+}$ ion can be accelerated very easily by slightly strengthening the magnetic field and just changing the gas into Ne. Recently the extracted beam intensity of $^{20}Ne^{6+}$ is 4μA.

Table 1 INS SF cyclotron beam list

Ion	H	Energy (MeV)	Ext.Beam Current (eμA)
P	1	45	10
P(pol.)	1	35	0.05
d	1	33	10
d(pol.)	1	33	0.08
$^{3}He^{1+}$	1	21	7
$^{3}He^{2+}$	1	90	10
$^{4}He^{2+}$	1	67	10
$^{6}Li^{1+}$	3	10	1.0
$^{6}Li^{2+}$	1	40	4.5
$^{6}Li^{3+}$	1	73	1.0
$^{7}Li^{1+}$	3	9	1.0
$^{7}Li^{2+}$	3	32	1.0
$^{7}Li^{3+}$	1	85	0.3
$^{9}Be^{1+}$	3	7	0.04
$^{9}Be^{2+}$	3	26	0.05
$^{9}Be^{3+}$	1	59	0.02
$^{10}B^{3+}$	1	58	(4.3)
$^{10}B^{4+}$	1	106	0.05
$^{11}B^{3+}$	3	46	3.0
$^{11}B^{4+}$	1	81	(0.001)
$^{12}C^{1+}$	5	5	0.5
$^{12}C^{2+}$	3	20	5.0
$^{12}C^{4+}$	1	85	5.1
$^{12}C^{5+}$	1	123	0.025

Ion	H	Energy (MeV)	Ext.Beam Current (eμA)
$^{13}C^{1+}$	5	5	0.005
$^{13}C^{2+}$	3	18	0.1
$^{13}C^{3+}$	3	41	0.02
$^{13}C^{4+}$	1	76	1.0
$^{14}N^{1+}$	5	4	0.3
$^{14}N^{2+}$	3	17	3.0
$^{14}N^{3+}$	3	38	10.0
$^{14}N^{4+}$	3	70	5.5
$^{14}N^{5+}$	1	115	3.0
$^{14}N^{6+}$	1	142	0.006
$^{15}N^{4+}$	3	61	0.013
$^{16}O^{3+}$	3	33	3.6
$^{16}O^{5+}$	1	105	1.5
$^{16}O^{6+}$	1	150	0.07
$^{18}O^{2+}$	3	13	0.014
$^{18}O^{4+}$	3	52	0.001
$^{19}F^{3+}$	3	18	0.05
$^{19}F^{5+}$	3	64	1.1
$^{20}Ne^{1+}$	7	3	0.07
$^{20}Ne^{2+}$	5	12	0.8
$^{20}Ne^{3+}$	3	27	3.0
$^{20}Ne^{4+}$	3	52	1.7
$^{20}Ne^{6+}$	3	116	4.0
$^{20}Ne^{7+}$	1	150	0.01

Ion	H	Energy (MeV)	Ext.Beam Current (eμA)
$^{22}Ne^{1+}$	9	3	0.002
$^{22}Ne^{3+}$	3	23	0.15
$^{23}Na^{3+}$	3	23	0.5
$^{23}Na^{4+}$	3	41	0.1
$^{23}Na^{5+}$	3	65	0.02
$^{24}Mg^{3+}$	3	22	0.14
$^{24}Mg^{4+}$	3	39	0.05
$^{24}Mg^{5+}$	3	61	0.12
$^{25}Mg^{4+}$	3	24	0.0008
$^{26}Mg^{4+}$	3	25	0.001
$^{27}Al^{4+}$	3	35	0.035
$^{27}Al^{5+}$	3	55	0.01
$^{27}Al^{6+}$	3	79	0.001
$^{28}Si^{4+}$	3	34	0.5
$^{28}Si^{5+}$	3	52	0.05
$^{28}Si^{6+}$	3	76	0.007
$^{32}S^{7+}$	3	90	0.05
$^{35}Cl^{5+}$	3	42	0.2
$^{37}Cl^{5+}$	3	35	0.002
$^{38}Ar^{6+}$	3	36	0.0001
$^{40}Ar^{6+}$	3	38	0.07
$^{40}Ar^{7+}$	3	80	0.06
$^{40}Ar^{8+}$	3	104	0.02

Ion	H	Energy (MeV)	Ext.Beam Current (eμA)
$^{39}K^{6+}$	3	37	0.03
$^{41}K^{6+}$	3	39	0.001
$^{40}Ca^{6+}$	3	38	0.008
$^{46}Ti^{7+}$	3	44	0.0001
$^{47}Ti^{7+}$	3	45	0.0001
$^{48}Ti^{7+}$	3	46	0.003
$^{49}Ti^{7+}$	3	47	0.0005
$^{50}Ti^{7+}$	3	48	0.0001
$^{54}Fe^{8+}$	3	52	0.00002
$^{56}Fe^{8+}$	3	53	0.003
$^{63}Cu^{7+}$	5	46	0.005
$^{132}Xe^{6+}$	9	16	0.0002

H ; Harmonic number

( ) ; Acceleration with the old heavy-ion source

$E_{max.} = 68 \cdot q^2/A$ (MeV)

A state of the accelerated Ti^{7+} ions by a back bombardment method[5] is shown in Fig. 4. By changing the magnetic field, Ti's isotope or Ar, Ne and N ions are clearly identified by installing Hall probe (Siemens SBV 601-S1) into the magnet.

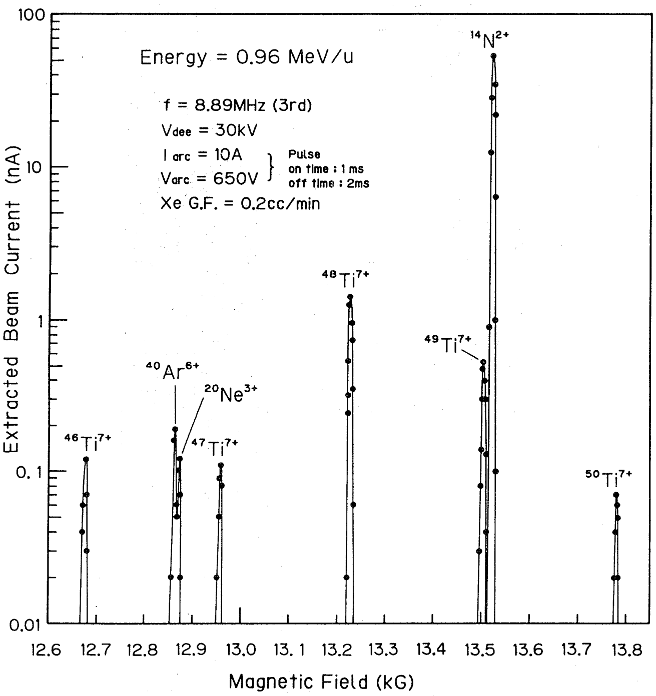

Fig. 4 Acceleration of the Ti's isotope by using back bombardment method with Xe gas discharge

BEAM TRANSPORT

By adopting the beam alignment method[6] developed by UNILAC GSI, the extracted beam of the cyclotron was able to be injected so that it could be aligned with the axis of the transport system.[7] Fig. 5 shows the measuring system referred to as above. A micro-computer together with CAMAC has been installed to make on-line measurement of the beam profile. We developed a subroutine (in the assembler language) for fast data-taking using an ADC (12 bits) module. Much shorter acquisition time, a few percent of the one using a commercial subroutine, is achieved.

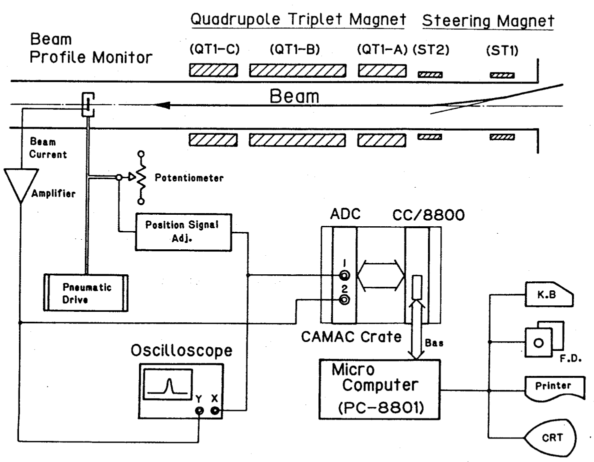

Fig. 5 On-line beam profile measurement system

The beam profile measurement determines the phase space parameters (α, β, γ and ε) at the entrance to the quadrupole magnets[8]. An example of the phase space diagram measured for the 65 MeV α beam is shown in Fig. 6.

Fig. 7 shows an example of optical calculation worked out for the beam transport by employing this phase space parameters. The comparison between the above-mentioned example of the calculation and the outcome of the beam transport actually conducted has brought about a sufficient result. The new system proves to be very powerful for the beam transport: much efficient transmission with good quality beams is obtained.

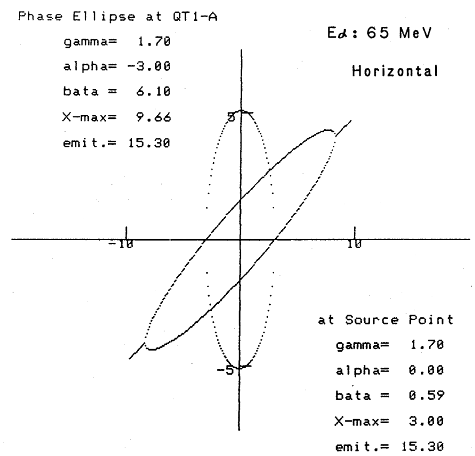

Fig. 6 Phase-space diagram obtained with 65 MeV α beam at the entrance of the first set of quadrupole magnet (QT1-A)

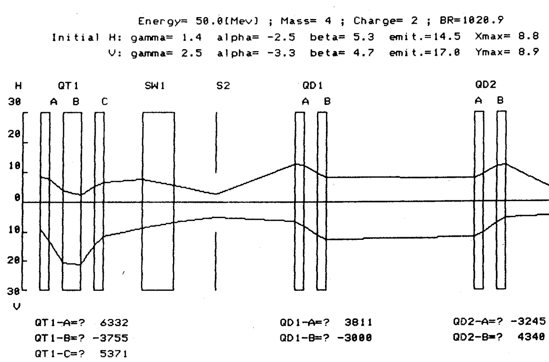

Fig. 7 Beam envelope display for the experiment course 1-1

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