NUMATRON PROJECT

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Abstract

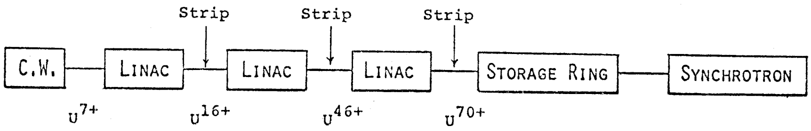
In the last few years, heavier ions and higher energy are called for in several fields of researches and applications, especially among nuclear physicists in Japan. Responding to such demands, a study group has been organized at the Institute for Nuclear Study, University of Tokyo, in order to promote basic studies for the construction of a high-energy heavy-ion facility named NUMATRON, which should provide heavy ions up to uranium in an energy range of 100 ∿ 1000 MeV per nucleon. In this talking, the outline for the design study of the accelerator is described.

§ 1. General

The NUMATRON is designed to provide heavy ions up to uranium in an energy range of 100 ∿ 1000 MeV per nucleon. Such capability can not be achieved by a single stage machine, considering the present technology of heavy ion source and cost performance. It should be necessary to investigate and accelerator complex including charge stripping stages between acceleration stages, while the final stage is exclusively synchrotron.

Important problems to be studied on the design of such a multistage accelerator are how to share acceleration stages, at what energies to install strippers and how to get an expected ion beam intensity. Besides, a very wide frequency range of RF acceleration and a necessary ultrahigh vacuum in the synchrotron are also the problems to be studied carefully through preparatory experiments. On the other hand, developement of heavy ion source should be endeavored after higher charge state and higher intensity, although already achieved data are referred at the present design stage.

The proposed machine complex here consists of a Cockroft-Walton generator, Wideröe linacs, Alvarez linacs and a synchrotron with a storage ring of almost the same structure and radius, as shown in Fig. 1. The values of T/A and β are common for all ions except for the values at the synchrotron stage, and the other values indicate the case of uranium as a typical extreme case.



q/A	0.029	0.067	0.193	0.294		
T/A	15 keV	300 keV	1.6 MeV	10 MeV		670 MeV
β	0.006	0.026	0.059	0.146		0.813
	500 keV	10.9 m	15.5m	32.1 m	R = 29.4 m	R = 33.6 m

Fig. 1. The Structure of the proposed machine and some parameters for the case of uranium.

§ 2. Injector linacs

The injector system is designed to accelerate heavy ions up to the energy of 10 MeV per nucleon.

The number of charge stripping stages is three and these positions are of 0.3, 1.6 and 10 MeV per nucleon. The final stage is used depending on a required energy, while the use of the other two stages is chosen according to ε (= q/A) of ions before each stripping stage, as illustrated in Fig. 2.

1) No stripper mode between linacs ($\varepsilon \geq 0.193$, $Z \lesssim 18$)
Ions are accelerated without passing through the strippers of the 1st and 2nd stages.

2) No 1st stripper mode between linacs ($0.193 > \varepsilon \geq 0.067$, $18 \lesssim Z \lesssim 27$)
Ions are accelerated through only the stripper of the 2nd stage.

3) Normal mode ($0.067 > \varepsilon \geq 0.029$, $27 \lesssim Z \lesssim 92$)
Ions must pass through the strippers of the 1st and 2nd stages.

Some ions can be accelerated in two of these modes. In these cases, the choice of mode depends on the required intensity. Typical beam intensities in each mode of stripping using data of conventional PIG ion sources are shown in Fig. 2. These low energy beams at each stage can also be provided for many researches and applications.

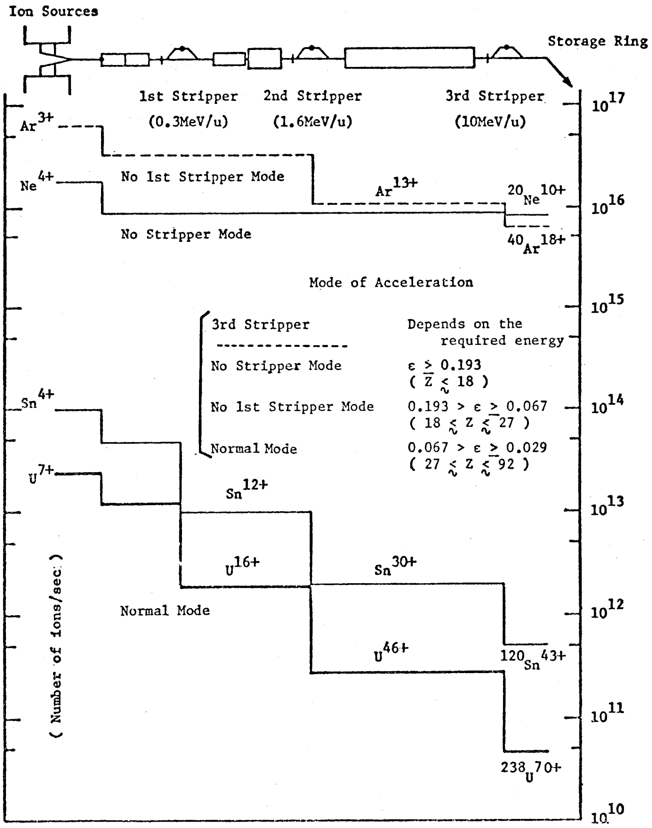


Fig. 2

Typical beam transmission

§ 3. Storage Ring

In order to obtain an expected high-intensity beam, a storage ring is inserted between injector linac and synchrotron. This ring has almost the same structure and radius as those of the synchrotron, and is installed in the same tunnel as illustrated in Fig. 3.

An RF stacking method combined with a multiturn injection method is applied to the ring. As compared with a single-turn injection directly to the synchrotron, the intensity increase is estimated at 640 times.

§ 4. Synchrotron

The injection energy from the storage ring is 10 MeV per nucleon. The maximum energies are 670 and 1470 MeV per nucleon for uranium and lighter ions than argon, respectively. For these cases, the maximum field of the dipole and the maximum field gradient of the quadrupole magnets are 15.5 kG and 1.19 kG/cm, respectively. It will be possible that the maximum energy for uranium is raised up to 850 MeV per nucleon by the excitations of 18 kG and 1.38 kG/cm, respectively.

The main parameters of every stage are given in Table 1. Fig. 4 shows the total layout of the machine complex.

§ 5. Various Acceleration Modes of the Two-Ring Synchrotron

The proposed machine has two rings as the final stage. One of the operation modes is described above. The other various operation modes can also be discussed. These are illustrated in Fig. 5. For each mode, designed energy, intensity and duty factor are described in the figure. The choice of the mode will depend on the preparatory works for the stacking technique, RF system and ultrahigh vacuum system. Developements of heavy ion source will play an important role for the choice.

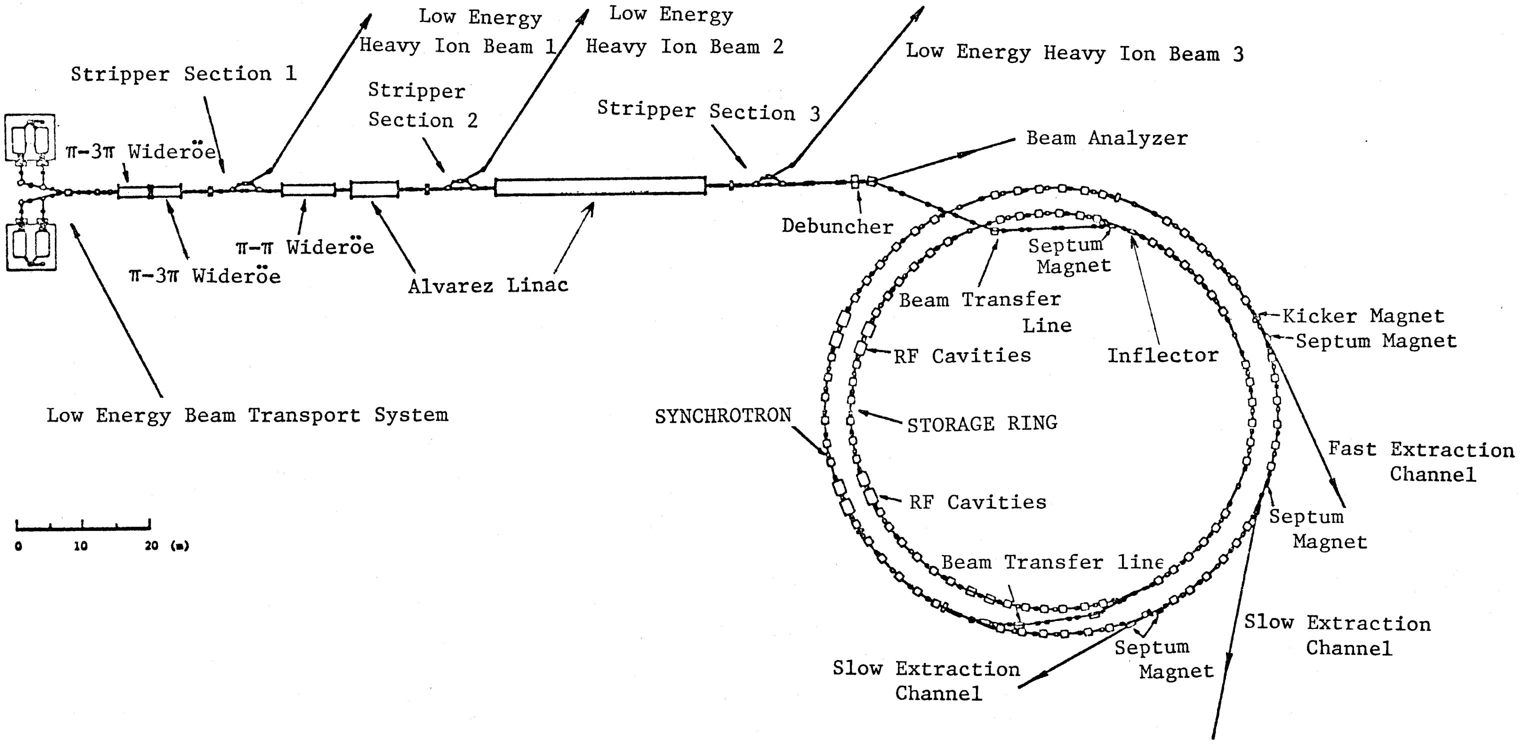
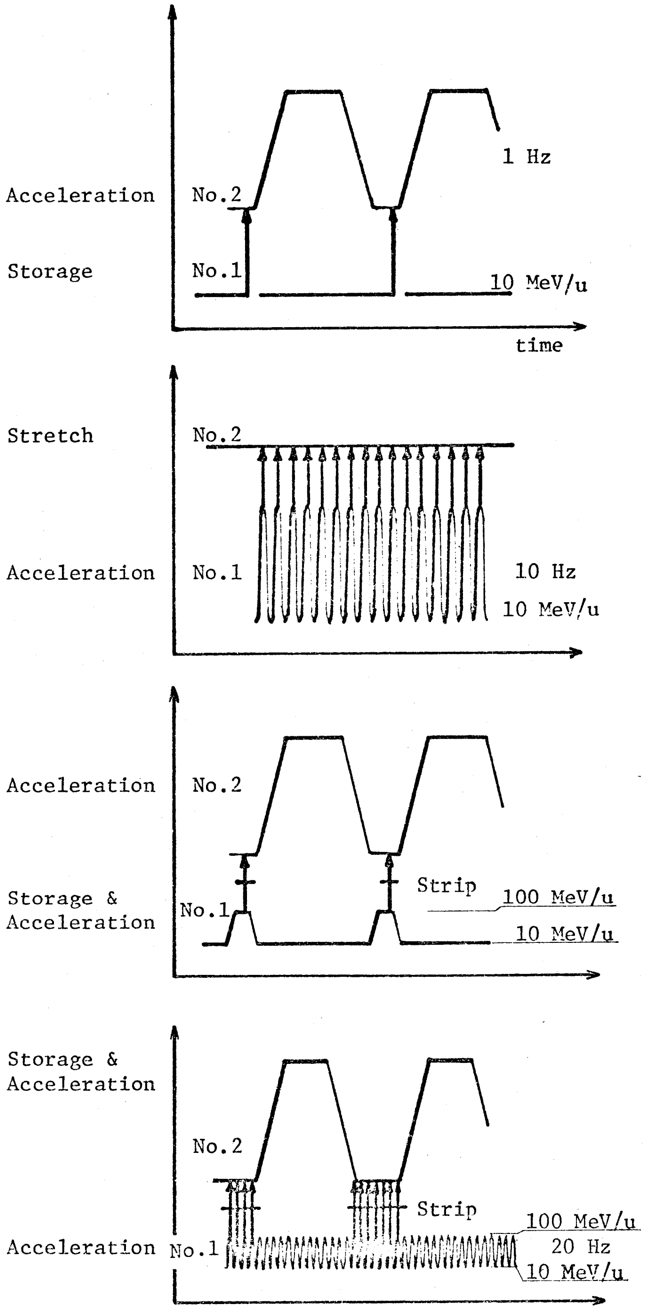


Fig. 3. Layout of NUMATRON



T/A(U^{70+}) = 700 MeV
Intensity = 1×10^{9} pps
Duty Factor = 40 %

T/A(U^{70+}) = 700 MeV
Intensity = 1×10^{8} pps
Duty Factor = 100 %
Vacuum easy

T/A(U^{90+}) = 1000 MeV
Intensity = 3×10^{8} pps
Duty Factor = 40 %

T/A(U^{90+}) = 1000 MeV
Intensity = 1×10^{7} pps
Duty Factor = 30 %
Vacuum easy

Fig. 4. Operation Modes of Two-ring Acclerator

Table 1 Numatron Parameters

A。 Particle, Energy and Intensity

Particle	Energy (GeV/u)	Intensity(pps)
U	< 0.7	$\sim 10^{9}$
Xe	< 0.9	$\sim 10^{11}$*
Kr	< 1.0	$\sim 10^{11}$*
Ar	< 1.3	$\sim 10^{11}$*
Ne	< 1.5	$\sim 10^{11}$*

* Space Charge Limit

B. Injector

	T/A(MeV)	Freq.(MHz)	β(v/c)	ε(q/A)
Cockcroft-Walton (500 kV)	0.0147	—	0.006	0.029(U^{7+})
Wideröe (π-3π)	0.146	25	0.018	—
Wideröe (π-3π)	0.305	25	0.026	—
Stripping(Gas)	—	—	—	0.067(U^{16+})
Wideröe (π)	1.10	25	0.048	—
Alvarez	1.60	100	0.059	—
Stripping (Solid)	—	—	—	0.193(U^{46+})
Alvarez	10.0	100	0.146	—
Stripping (Solid)	—	—	—	0.29 (U^{70+})

C。 Storage Ring

Beam Energy/Nucleon	10 MeV
Lattice Structure	Similar to Synchrotron
Repetition Rate of Stacking	160 Hz
Max. RF Voltage of Stacking Cavity	5 kV
Momentum Spread of Stacked Beam(Δp/p)	± 0.02
Vacuum Pressure	1×10^{-10} Torr

D。 Synchrotron (Separated Function Type)

Guiding Field (B_{max})		15.5 kG
Quadrupole Field $(dB/dr)_{max}$		1.19 kG/cm
Repetition Rate		1 Hz
Magnetic Radius		9.55 m
Average Radius		33.6 m
Circumference		211.2 m
Number (Length) of Normal Periods		24 (6.6 m)
Number (Length) of Periods Including Long Straight Section		8 (6.6 m)
Structure of Normal Periods		FODO
Useful Aperture	radial	16 cm
	vertical	4 cm
Number of Betatron Oscillations		6.25
Phase Advance per Normal Period		70°
Amplitude Function	max	11.21 m
	min	2.90 m
Space Charge Limit (Number of Particles/sec)		3×10^{10} p/sec (U)
		8×10^{10} p/sec(Ar)
Vacuum Pressure		1×10^{-9} Torr