NUMATRON PROJECT

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1. Introduction

In recent years, interests in high-energy heavy-ions have been growing up not only in the field of nuclear physics but also in the fields of atomic physics, solid-state physics, medical biology, fusion power generation engineering and many other sciences and applications. In Japan, an accelerator complex has been proposed at INS, University of Tokyo, which is named NUMATRON.

The energy-mass capability of the NUMATRON is shown in Fig. 1, together with those of other machines in the world in operation, under construction or in planning stage. All the accelerators higher than 200 MeV/u consist of a linac and synchrotron complex similar to the layout of Fig. 2. The main difficulties expected in the construction of this type of heavy-ion machine may be achievements of ultra-high vacuum in the synchrotron ring ($\sim 10^{-11}$ torr), of a large sweep range of the frequency for RF acceleration ($\times 6$), and of hood devices for beam control by detecting a very low beam current.

In order to investigate these probelms, we have carried out several preparatory works. One of the most important achievements is the construction of a 10 m diameter accumulation ring which is called at TARN. The typical results so far obtained are described in other papers of this symposium. Based on the experimences of the TARN project, the design details of the machine complex were determined. In this paper, the characteristics of the NUMATRON Project is described briefly.

2. General design of NUMATRON

The proposed accelerator consists of Cockcroft-Walton generators, three Wideröe linacs, two Alvarez linacs and two synchrotrons as shown in Fig. 2.

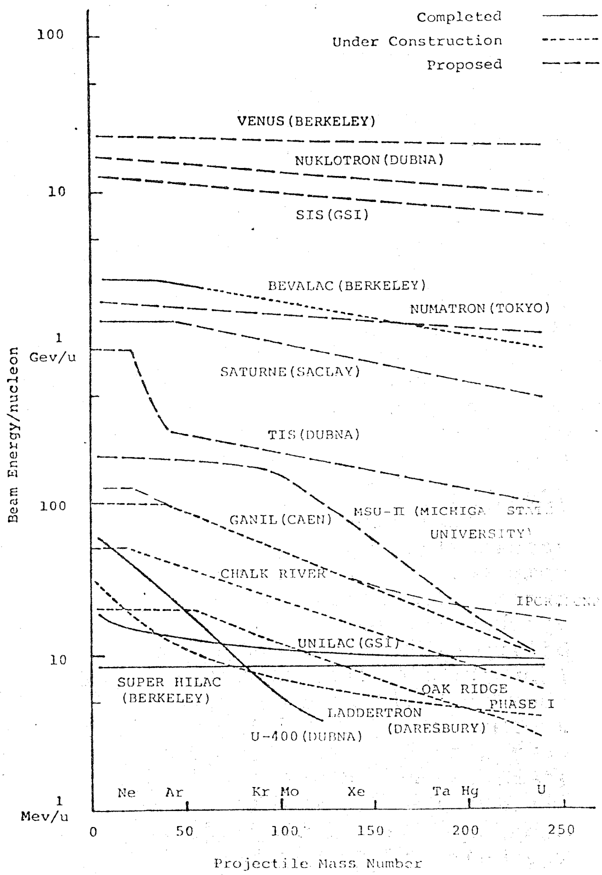

Fig. 1 Energy mass capabilities of heavy ion accelerators in the world

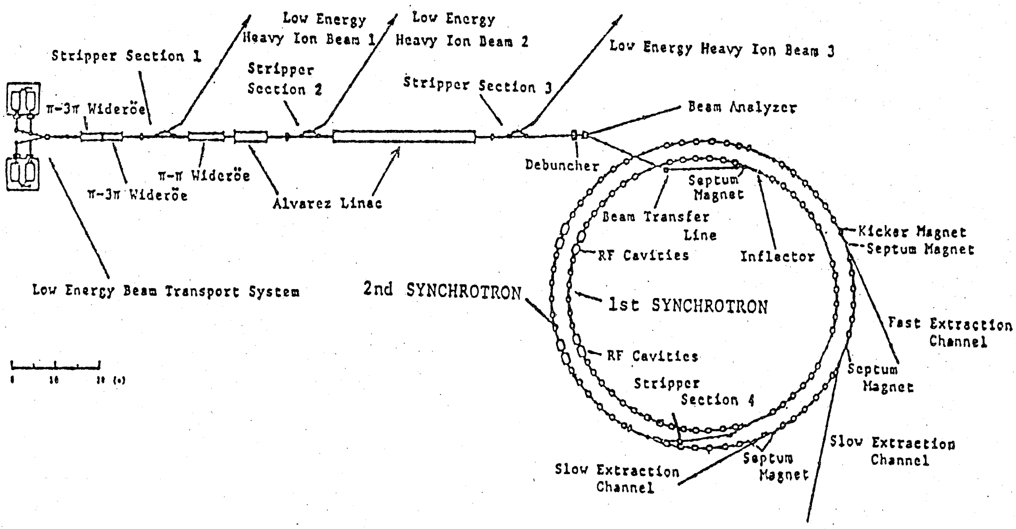

Fig. 2 Layout of MUNATRON

(Injector)

Two identical preaccelerators are arranged symmetrically in order to be operated in parallel. Each preaccelerator has a 500 kV high voltage generator and two ion source terminals. The acceleration voltage is adjustable in a wide range so that ions of various charge-to-mass ratios can be accelerated to a constant energy. After passing through the buncher section, ions are injected into a row of three Wideröe linacs of a resonant frequency of 25 MHz. The first and the second are operated in π-3π mode and the third in π-π mode. The last Wideröe linac is followed by an Alvarez linac with a resonant frequency of 100 MHz at the enrgy of 0.9 MeV/u. Two stripper sections with achromatic charge analyzing systems are installed at the specific energies of 0.3 and 1.6 MeV/u in order to obtain an efficient acceleration. The injector linac parameters are shown in Fig. 3.

(Synchrotron)

Final stage of the accelerator complex is composed of two synchrotrons. The first synchrotron has a capability of beam accumulation for obtaining heavy ions of high intensity. A combination of multi-turn injection and RF stacking methods is applied to the injection scheme to the first ring. The beam is accelerated up to the energy of 250 MeV/u and is extracted by a one turn ejection

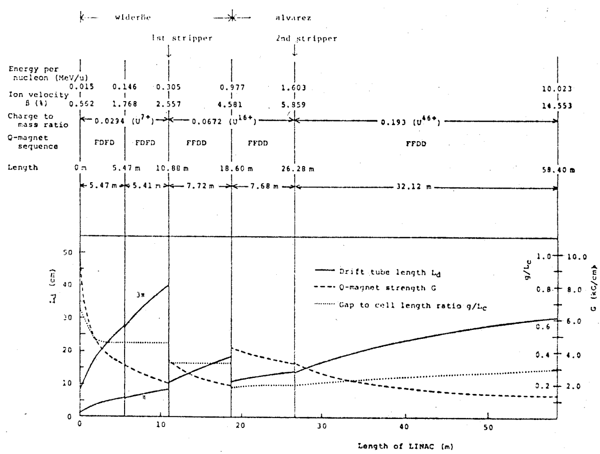

Fig. 3 Parameters in injector linac

method. After passing through the final stripper section in the beam transport line between the first and the second synchrotrons, ions are completely stripped and injected into the second ring, where uranium ion is accelerated up to the maximum energy of 1270 MeV/u. A transition energy of the second synchrotron is 4.33 GeV and any ions are not accelerated through the transition energy. The operation scheme of the linac and two synchrotrons is illustrated in Fig. 4. Lattice structure of one superperiod of the rings is shown in Fig. 5.

The RF systems in the rings are of two types, one of which is for RF stacking and the other is to accelerate the beams to the extraction energies. The former is similar to that of the TARN.

RF system for the beam acceleration is designed so that sweep range of frequency in the first ring is 1.65 ∿ 6.97 MHz and in the second ring it is 3.0 ∿ 11.2 MHz for the various operation energies of the first and second synchrotrons. At the present design the magnetic fields of two synchrotrons vary linearly with time, $\dot{B}$ = 47.0 kG.s, and then the required RF peak voltage is around 20 kV for the synchronous phase angle of 30°. On the other hand, the enrgy spread of the accumulated beam in the first ring is 200 keV for the RF stacked number of 50, and the required peak RF voltage is determined so that the separatrix well cover the energy spread of the beam, namely 80 kV.

The required vacuum in the first ring is 2×10^{-11} torr for a survival rate of 90 % after an injection period of 1 sec, whereas in the second ring, the pressure of 1×10^{-9} torr suffices the above survival rate because of its high energy operation. The output intensity of uranium is typically estimated at 10^9 particles per second, whereas for the ions lighter than $Z \simeq 20$, it may be 10^{11} particles per second, which is limited by space charge effects.

At the present proposal, one fast ejection channel and two slow ejection channels are provided to answer the various needs for high energy heavy ion beams as shown in Fig. 2. Even at the final stage of the acceleration, the beam size is rather large and it is important that the ejection

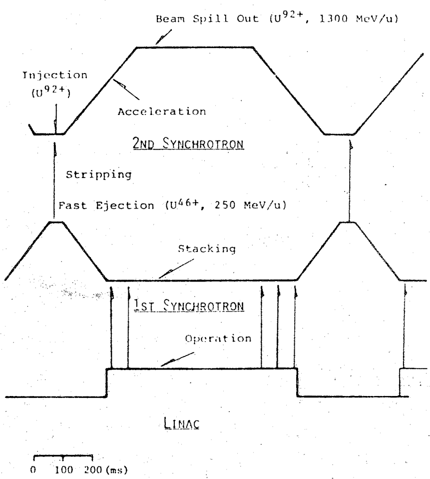

Fig. 4 Operation scheme of linac and two synchrotrons

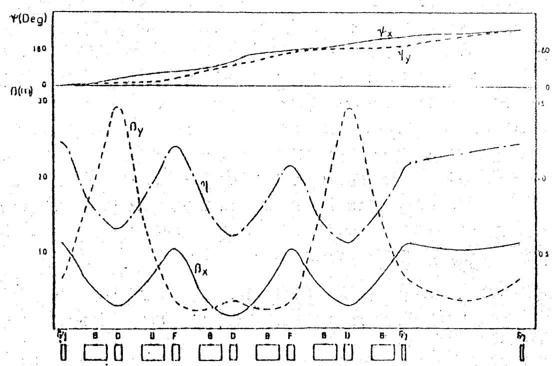

Fig. 5. Lattice structure of the synchrotron

system is safe for the beam blow up. From this point of view, we adopt the third integer resonance, although in this extraction mode the arrangements of nonlinear magnets will affect the emittance, spill time and the size of stable region.

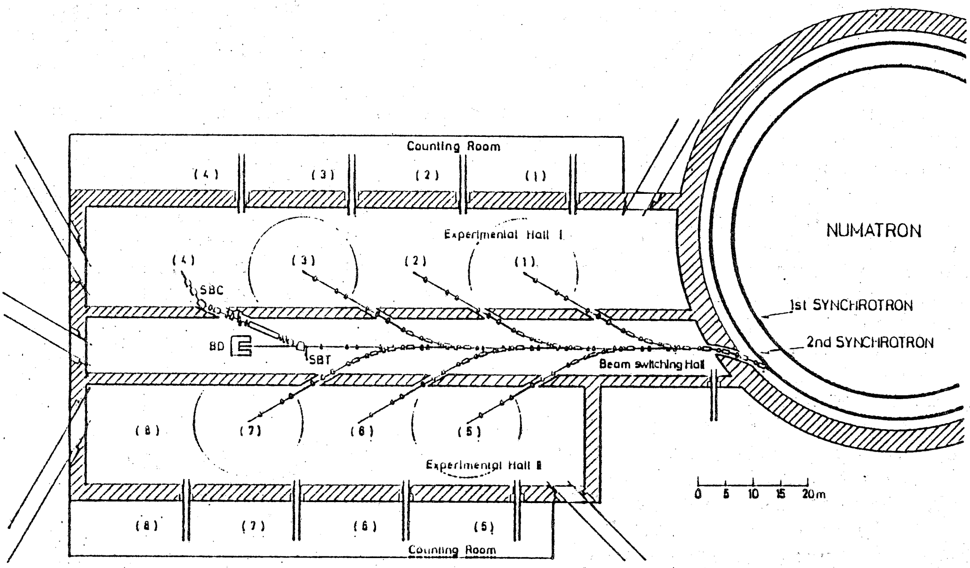

Fig. 6 Experimental hall and beam line

(Beam line)

The most important characteristics of the facility are to change the energy and the accelerated ion very easily, and also the beam course. To achieve such an operation, we are planning a beam transport system as shown in Fig. 6.

The special feature of the system is that all the magnets of beam lines are identical to those of the second ring and are connected in series to the power supply of the ring. The course change is performed by using non-contactor switch during zero excitation period of the magnets.

Structure of the bending secions is similar to one of 2 cells of the ring shown in Fig.5. Preliminary calculations of the orbit analysis for the matching (π) secions and the final focusing sections are shown in Figs. 7 and 8.

The beam shape control on target is achieved by moving axially some of the quadrupole magnets in the individual focusing section.

Using such a system, any ion beam can be provided to any target area and at any moment, according to beam acceleration and delivery program.

(Parameters of the accelerator complex)

The main parameters of the accelerator complex are given in Table 1.

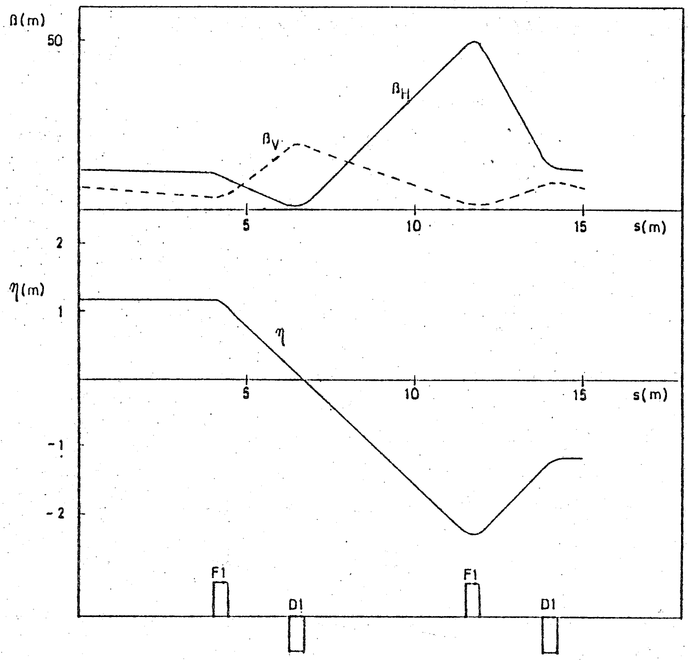

Fig. 7 Orbit Analysis for Matching (π) Section:
F1: $Q_F(G=G_F)$ D1: $Q_D(G=-G_F)$

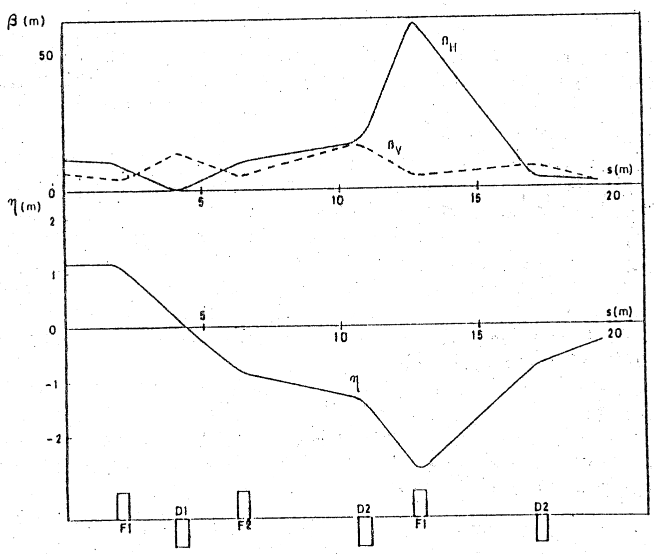

Fig. 8 Orbit Analysis for Focusing Secton:
F1: $Q_F(G=G_F)$ F2: $Q_F(G=-G_D)$ D1: $Q_D(G=-G_F)$ D2: $Q_D(G=G_D)$

Table 1 Numatron Parameters

A. Particle, Energy and Intensity

Particle	Max. Energy (GeV/u)	Intensity (pps)
U^{92+}	1.27	$\sim 10^9$
Kr^{36+}	1.47	$\sim 10^{11*}$
Ne^{10+}	1.81	$\sim 10^{11*}$

*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	—	—	—	0.067(U^{16+})
Wideröe (π)	0.90	25	0.048	—
Alvarez	1.60	100	0.059	—
Stripping	—	—	—	0.193(U^{46+})
Alvarez	10.0	100	0.146	—

C. 1st Synchrotron

Injection Energy		10 MeV/u
Maximum Energy		250 MeV/u
Repetition Rate of RF Stacking		100
Momentum Spread of Stacked Beam		± 0.7 %
Useful Aperture	radial	18 cm
	vertical	5 cm
Vacuum		2×10^{-11} torr
Space Charge Limit		2.9×10^{11} (U^{46+})
Number of Particles/sec		6.2×10^{11} (Ar^{13+})

D. 2nd Synchrotron

Guide Field (B_{max})		18.0 kG
Quadrupole Field $(dB/dr)_{max}$		1.38 kG/cm
Repetition Rate		1 Hz
Magnetic Radius		9.55 m
Average Radius		33.6 m
Circumference		211.2 m
Number of Normal Periods		24
Number of Long Straight Sections		8
Focusing Structure		FODO
Useful Aperture	radial	9 cm
	vertical	3.5 cm
Number of Betatron Oscillations		6.25
Phase Advance per Normal Period		70°
Vacuum		1×10^{-9} torr