Activities of Accelerator and Beam Physics Research at Nuclear Science Research Facility, ICR, Kyoto University

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Abstract

An electron storage/stretcher ring, KSR has just been completed and beam commissioning will start soon. The compact proton synchrotron with combined-function lattice has been studied as a dedicated machine for proton cancer therapy. Possibility of 3-dimensional laser cooling with use of high symmetry ring like TARN II is studied. Based on these activities, an accelerator complex consisting of ion and electron storage rings and their booster synchrotron, is proposed to provide a unique facility for ion beam merging, 3-dimensional laser cooling and so on. In addition, a Disk-and-Washer type accelerator cavity has also been developed. Collaborations with NIRS and KEK are also going on.

1 Introduction

The activities of our accelerator and beam physics research group extend rather wide variety of fields such as synchrotron radiation, machine design of a unique feature, computer simulation of peculiar condition like crystalline state and so on. Recently, they are oriented to a somewhat common objective of accelerator complex as one of the facility for future plan at Kyoto University. In the present paper, the brief outline of our existing activities on accelerator and beam physics research is described in connection with the approach to the future plan.

2 Electron storage and stretcher ring, KSR

2.1 Commissioning of KSR

At Nuclear Science Research Facility, ICR, Kyoto University, an ion storage/ stretcher ring, KSR has been constructed since 1994. In Fig. 1, the layout of the KSR and its injector linac is shown. Recently the whole ring assembly of KSR has been completed as shown in Fig.2 except for the septum magnet,which is now under field measurement, and the steering magnet both for stretcher mode.

The average vacuum pressure of the ring is 5×10^{-8} Torr after baking to 170°C for normal parts and 120°C for berrows and parts made of Al during 100 hours and 90 hours. The beam life estimated for this vacuum pressure is ~40 s[1]. KSR is, at present, waiting for permission of operation and is expected that its first commissioning will be started at the time of this symposium. The details of the beam circulation test are to be reported from T. Shirai[2].

Fig.2 An overall view of completed KSR

2.1 Stretcher Mode of KSR

For the purpose of increasing the duty factor of the electron beam from the linac, the stretcher mode of KSR

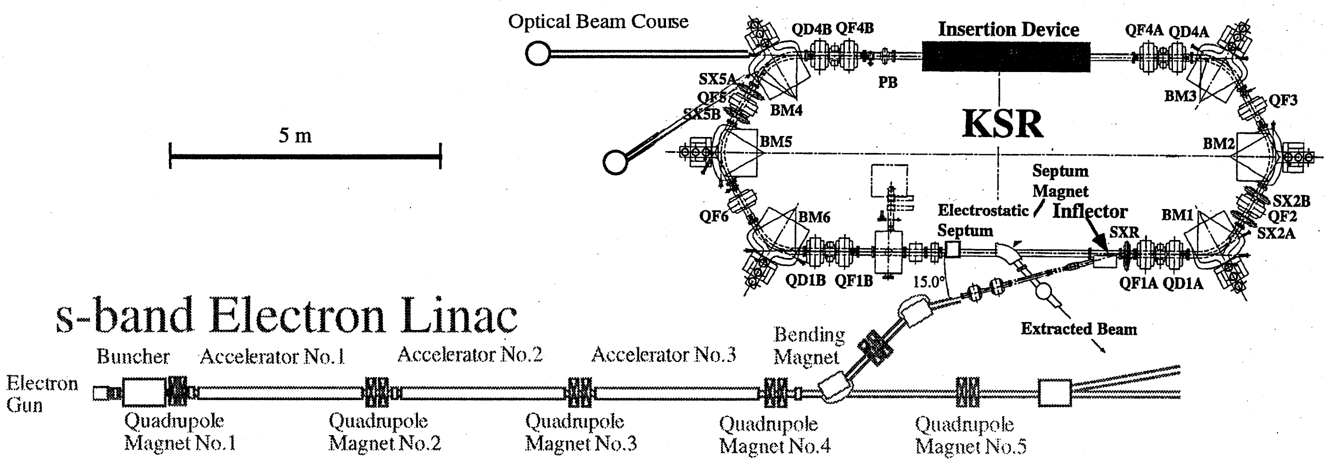


Fig.1 Layout of KSR and its injector linac

was proposed[3] and the slow beam extraction system with use of combination of the RF-knockout and the third order resonance has been constructed with Grant-in-Aid of Scientific Research from Ministry of Education, Science, Sports and Culture.

The extraction system consists of an electrostatic septum, a septum magnet, a sextupole magnet as the resonance exciter and the orbit-bump formation system. The last one is to be utilized to attain the aperture minimum at the entrance of the electrostatic septum just after the beam injection through the magnetic septum has been finished[4]. In Fig. 3, the electrostatic septum already installed into the KSR ring is shown. The commissioning of the stretcher mode is scheduled just after beam circulation test because the required vacuum for this mode is not so good compared with storage ring mode because beam circulating time is ~1 s.

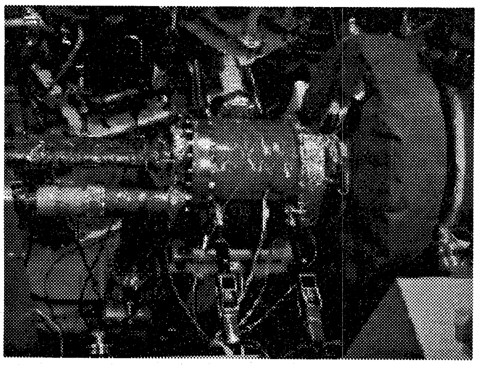


Fig. 3 The electrostatic septum installed into KSR.

3 Development of Combined-Function Synchotron

For the purpose of establishing a good reference design of a compact proton synchrotron dedicated for cancer therapy, we have been developing a combined function synchrotron[5]. As the RF accelerating cavity, we have developed an untuned cavity, which can cover the frequency range from 1 to 10 MHz without tuning and can produce the gap voltage higher than 1 kV with the applied power of 1,5 kW. In Fig. 4, a fabricated untuned cavity loaded with Ni-Zn ferrite for real application is shown[6].

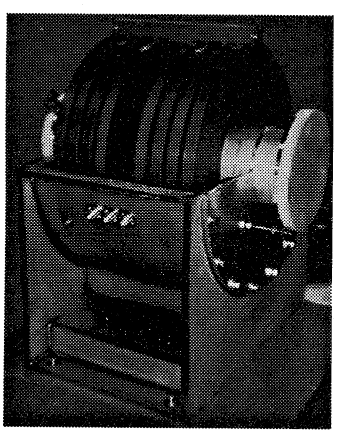


Fig.4 The untuned RF cavity.

As the synchrotron lattice, we have adopted a sixfold symmetric lattice with F/2-D-F/2 configuration for possible unification of magnet components. A model magnet with the full scale shown in Fig.5 is fabricated based on the 3-dimensional magnetic field calculation with use of the computer code TOSCA[7]. The magnetic field structure was investigated briefly at Hitachi works with use of a three dimensional Hall-probe and the basic characteristics are found to coincide with the calculation. The n-index which is derived by differentiating the magnetic field component in vertical direction with respect to the radial displacement. The measurement was found not precise enough for evaluation of n-value because of subtraction between measured values with similar sizes. We are now preparing for the more-precise field measurement[8].

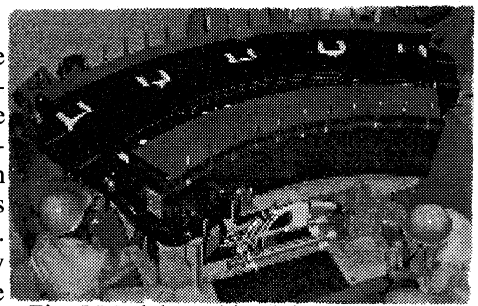


Fig. 5 Model combined-function magnet for a compact synchrotron.

It should be noted that the combined-function lattice has not only such merits as compactness in size and easiness of daily operation, but also a merit as slowly extracted beam is insensitive to the magnet ripple[9], which is considered to be very promising for irradiation with scanning.

4 Possibility of 3-dimensional Laser Cooling

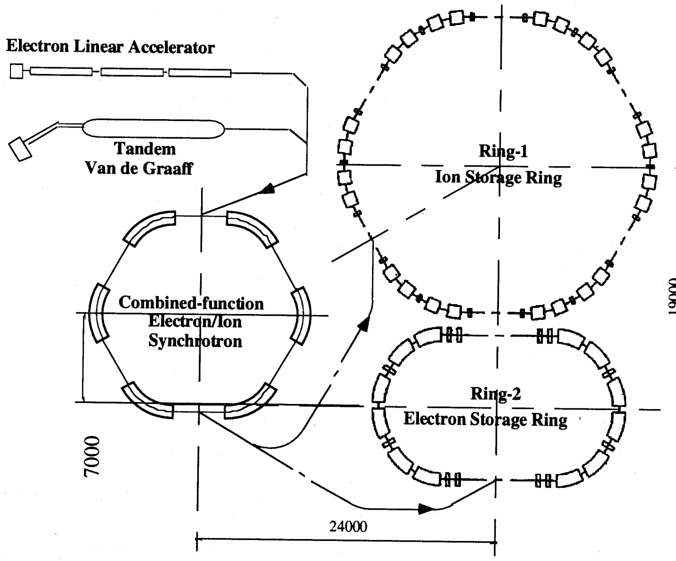
According to the simulation with use of molecular beam dynamics by T. Kihara et al.[10], it has been shown that the beam crystallisation is expected to be achieved if the ring lattice satisfies the 'so-called" maintenance condition[11] and the fast enough cooling force exists. In Table 1, the parameters assumed for their simulation are given for the case of TARN II. They assume the 3-dimensional laser cooling with synchro-betatron coupling.

With TSR at Max-Planck-Institute für Kernphysik, Heidelberg, transverse laser cooling has been demonstrated with schemes which utilize intra-beam scattering[12] or dispersive coupling[13]. The transverse cooling forcein these schemes, however, is not so strong, but the transverse equilibrium temperature is much higher compared with the longitudinal one. The transverse laser cooling proposed by H. Okamoto et al.[14] is considered to be important for investigation of possibility of crystalline beam.

Up to now, the longitudinal laser cooling has successfully been performed at two laboratories in the world, one of which is TSR and the other is ASTRID at Aarhus in Denmark. Both rings, however, do not satisfy the above maintenance codition. Three dimensional laser cooling with high symmetry ring staisfying maintenance condition is highly required[15].

Table 1 Parameters assumed for 3-dimensional laser cooling at TARN II [10]

Quantity	Value
Ring circumference, $2\pi R$	77.7 m
Betatron tunes (ν_x, ν_y)	(2.096, 2.104)
Dipole bending radius	4.01 m
Skew quadrupole strength	0.001 m^{-1}
Lattice superperiodicity	6
Transition energy γ_T	2.258
Ion species	$^{24}Mg^+$
Kinetic Energy	1 MeV
RF harmonic number	1000



Accelerator Complex Layout

Fig. 6 Layout of the Accelerator Complex.

5 Accelerator Complex as a Future Plan

In order to respond the above requirement, an accelerator complex consisting of ion and electron storage rings with their booster synchrotron is proposed[16]. In Fig. 6, the layout of the accelerator complex is shown. The combined-fuction synchrotron developed for dedicated machine for cancer therapy is to be utilized as the booster sychrotron for acceleration of both ion and electron beams. As the injector into the booster, the Tandem Van de Graaff with terminal voltage 8 MV and the disc-load type 100 MeV linear accelerator, both in operation at Kyoto University, are to be utilized for ion and electron acceleration, respectively. In Table 2, main beam parameters of the facility are given.

With this facility, the merging of ion beams, photo-ionization of highly ionized e-cooled ions with synchrotron radiation and Coulomb Explosion Imaging of Molecular and/or cluster beams with use of slow extracted beam will also become possible. In addition, the possibility of Laser cooling. with use of tunable free-electron laser might be a very challenging subject[17].

Table 2 Main Beam Parameters of the Accelerator Complex

Energy range	Ion(ε=1/2)	3~290 MeV/u
	Electron	100~1500 MeV
Beam intensity (current)	Ion(ε=1/2)	10^{10}~10^{12} ions
	Electron	100 mA
Reretition Rate		0.5 Hz

6 High Power Model of Disk-and-Washer Cavity

The design of the Disk-and-Washer type accelerating cavity which aims at electron acceleration in the β region of ~1 has almost been completed. It assumes s-band (2857 MHz) as the operating frequency and aims at the design goal of the accelerating field gradient of ~30 MV/m, which is almost twice of the existing disc-load type accelerating tube[18].

7 Collaboration with Other Institutions

At NIRS, a irradiation course with the secondary beam has been constructed. A beam enlargement system with use of scanning is now under construction utilizing the pencil beam of ^{11}C[19]. The really applied dose distribution will be measured with PET camera for ^{11}C irradiation.

A barrier bucket experiment at AGS in BNL has also been performed by collaboration with KEK Tanashi Branchi. The application of barrier bucket is found to be effective to reduce the space charge effect in the high intensity beam transfer from the booster to AGS[20].

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