S-RING PROJECT AT NIRS

K. Noda, M. Kanazawa, T. Murakami, M. Muramatsu, E. Takada, S. Yamada, NIRS, Chiba, Japan
S. Shibuya, K. Ohtomo, SHI, Tokyo, Japan
T. Fujimoto, H. Fujiwara, H. Izumiya, H. Ogawa, AEC, Chiba, Japan
T. Furukawa, Graduate School, Chiba University, Chiba, Japan
E. Syresin, JINR, Dubna, Russia

Abstract

The small ring (S-ring) has been designed and constructed for the following purposes: (1) Development of key-technologies for a compact heavy-ion synchrotron for a cancer therapy, (2) Study of the radical behaviour in a living body, (3) Biophysics experiments with high LET beam for the estimation of the radiation risk in space and (4) Booster ring for the HIMAC synchrotron. The S-ring, having the circumference of less than 25 m, will provide heavy-ions ranging from proton to Xe, and cool ions down to improve a beam quality in both longitudinal and transverse directions. The paper describes the design and the R&D.

1 INTRODUCTION

The cancer therapy has been successfully carried out for more than 1100 patients with the HIMAC accelerator complex at NIRS (National Institute of Radiological Sciences), since June 1994 [1]. As a next step, the S-ring project [2], combined with the HIMAC injector [3], has been started since April 2001. Design considerations based on the purposes are as follows:

(1) A fast cycling synchrotron, having an operation cycle of 3–10 Hz, is one of candidates for a compact heavy-ion synchrotron for the cancer therapy, because it can easily deliver a high-intensity beam and make the energy variable at every operation cycle. The S-ring employs a fast extraction method that is one of characteristics of a fast cycling synchrotron.

(2) It is highly desirable to investigate the track structure in a time-resolved manner, because it is speculated that the behavior of the radicals, which rapidly decreases in the radiation track, essentially defines the OER [4]. A short bunched beam, thus, having a bunch width of less than a few tens ns, has been strongly required. In the S-ring, for this purpose, an electron beam cooling will be combined with the bunch rotation method.

(3) In order to obtain high LET beams for biophysics experiments, the S-ring decelerate the beam energy to 1 MeV/n from 6 MeV/n of the injection energy.

(4) In the S-ring as a booster ring for the HIMAC synchrotron, the maximum energy is to be 24 MeV/n for a charge-to-mass of 1/2, which is determined by the maximum magnetic rigidity of 1.42 Tm in the injection-beam line.

The design parameters are summarized at Table 1, and a layout of the S-ring is shown in Fig. 1. In this paper, the design and the R&D for the S-ring are described.

Table 1: Design parameters of the S-ring

Injection energy [MeV/u]	6
Extraction energy for q/A=1/2 [MeV/u]	1-28
Acceptable charge to mass ratio	1-1/4
Circumferences [m]	23.7
Magnetic rigidity [T.m]	0.13-1.54
Bending radius [m]	1.1
Bending angle [deg]	90
Number of quadrupoles	10
Length of EC solenoid [m]	0.9
Nominal tune (Hori. / Vert.)	2.21/1.35
Natural chromaticity (Hori. / Vert.)	-2.08/-5.62
Momentum compaction factor	0.106

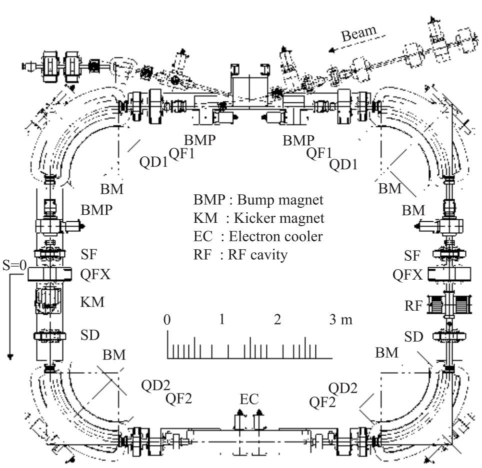

Fig. 1: A layout of the S-ring.

2BASIC DESIGN

2.1 Lattice design

A lattice for the S-ring has been designed including estimations of a COD and a dynamic aperture [5]. For an electron cooler to obtain a high-quality beam, dispersion-free sections are prepared through a double-bend achromatic structure. For efficient the injection and extraction, further, large values of the horizontal beta-function are required at both the injection and extraction positions. For efficient cooling, on the other hand, a beta-function in the cooling section should be relatively small. Thus the S-ring employs a superperiodicity of 1 as well as that of 2. The S-ring has four 90-degree bending magnets, having a bending radius of 1.1 m and the edge angle of 22.5 degree in both the entrance and the exit of the magnet. Two pairs of the long-straight sections, 4.8 m and 3.6 m are prepared. One of the long-straight sections is used for the injection and extraction systems, and the other is for the electron cooler. The S-ring has five kinds of the quadrupole magnets, called QFX, QF1, QD1, QF2, QD2. Each QFX is placed at the center of the shorter long-straight section to obtain the dispersion-free section. In the superperiodicity of 1, the five kinds of Q-magnets are independently operated, while QF1/QD1 and QF2/QD2 are operated with same parameter in that of 2. The lattice functions are shown in Fig. 2.

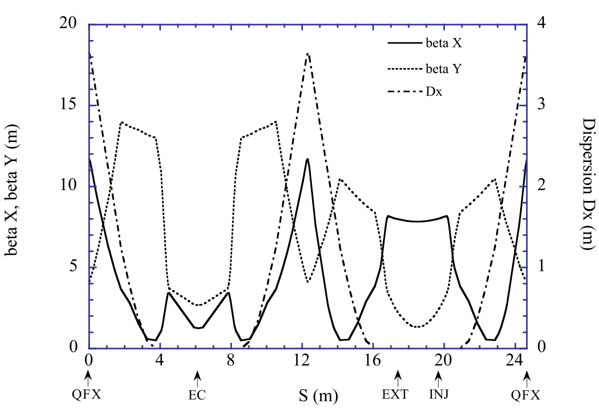

Fig. 2: Lattice functions of the S-ring in the superperiodicity of 1.

2.2 Injection and extraction system

Using a common septum magnet and four common bump magnets for the injection and extraction systems, both the systems are placed at the same long-straight section in order to save the space. Further, an inflector for the injection and the deflector for the extraction are located symmetrically in the center of the long straight section.

The multiturn-injection method is applied in order to obtain high intensity. Assuming a constant collapsing rate of the bump orbit and the septum thickness of 0.3 mm in the electrostatic inflector, a filling factor through the multiturn injection is optimised at around 90% in the acceptance of 200π mm·mrad. The fast-extraction method is adopted in order to realize the variable energy at every operation cycle. A magnetic deflector with the septum thickness of 4.5 mm and a fast kicker are prepared for the extraction. In order to extract a beam with a horizontal emittance of 30 π mm·mrad beyond the effective septum thickness of 10 mm, the fast kicker is designed and manufactured to be a length of 0.25 m and a maximum field of 0.025 T with a rise time of 80 ns.

2.3 RF system

An RF frequency should sweep from 0.5 to 6 MHz for deceleration as well as acceleration. Assuming a dB/dt of 1.8 T/s corresponding to an operation cycle of 1 Hz and a dilution factor of 2, an RF voltage is required at 950 V for a beam with a charge-to-mass ratio of 1/2. Further, the RF system will provide a short bunched beam through the bunch rotation technique with longitudinally cooled beam having a momentum spread of 10^{-4} order. Combining the third-harmonics component with the fundamental one, in this case, a filamentation in the longitudinal phase space will be considerably reduced. In addition, raising the RF voltage rapidly, a bunch width will be sufficiently reduced after a quarter period of the synchrotron oscillation, which is estimated at around 10 ns at FWHM. For these purposes, an un-tuned RF cavity is very useful, because of a broad band in the frequency and a low Q characteristic [6].

2.4 Electron cooler

An Electron cooler will be installed in the S-ring to obtain high-quality beam such as a short bunched beam and high intensity beams through the cool-stacking method. Thus an electron cooler for the S-ring has been designed [6]. The S-ring cooler is similar with HIMAC cooler [7]. However, the characteristics of the S-ring cooler [8], which are different from the HIMAC one, are mainly as follows: (a) a relatively short cooling section of 0.9 m, but a ratio of the cooling length to the circumference (3.6%) is considerably larger than that in other cooler rings, (b) an adiabatic-expansion factor of 6 in the magnetic field of 0.05 T in the cooling section, (c) a low horizontal and vertical beta functions in the cooler of $\beta x/\beta y$ = 1.16/1.95 m.

3 R&D FOR KEY THECHNOLOGIES

3.1 Bending magnet

In order to simplify manufacturing bending magnet, only the pole is mechanically cut along with the edge angle after laminating silicon-steels. It should be verified that an eddy-current effect due to an electrical short between laminations does not disturb its magnetic field. Thus using search coils carried out the measurement on tracking between the excitation current and the field strength in a model magnet. Figure 3 shows the measurement result. Considering a power-supply stability of around 10^{-3}, the field follows sufficiently with the excitation current in the dB/dt of less than 3 T/s. Increasing the dB/dT up to 5.9 T/s, however, the tracking accuracy was deteriorated to around 0.5%.

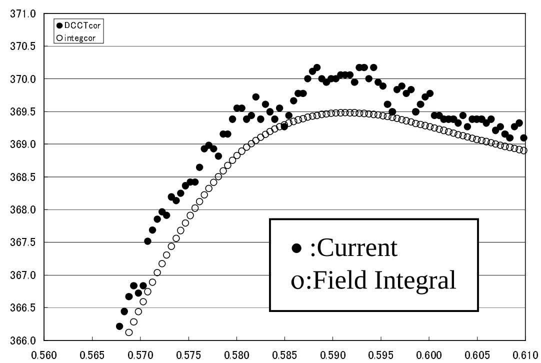

Fig. 3: Tracking between the excitation current and the field strength in dB/dt = 3.0 T/s just before a flat top. The open and closed circles indicate the integral field and the excitation current, respectively.

3.2 Un-tuned RF cavity

An un-tuned RF cavity, having the length of 350 mm along beam path and the diameter of 780 mm, was constructed for R&D. The cavity is a re-entrant cavity filled with magnetic core made of the magnetic alloy rather than push-pull λ/4. As a result of the low-level test, a 1:9 transformer in an input circuit for impedance matching was adopted in order to minimize the power reflection. As a result of a high-power test in the case of 6 cores is shown in Fig. 4, the gap voltage is obtained more than 1500 V in the input power of 780 W, and the shunt impedance ranges from around 500 to 600 Ω for the frequency region from 0.6 to 4 MHz. The obtained voltage satisfies the requirement for the acceleration and the short bunched beam [10].

3.3 Power supply

As a power supply for main magnets, the advanced current-source-type self-commutated converter (ACSC) has been developed [11]. The ACSC system has a capacitor in the bridge arm, which softens considerably the turn-off phenomena, compared with the conventional one. A hybrid filter was developed, further, to improve considerably a power-supply performance [12]. This filter consists of a switch and resister that work as a variable resister. The switch operates at the frequency of several kHz and the duty ratio can be controlled. The hybrid filter was tested by using a power supply of the sextupole magnets for the HIMAC synchrotron. Consequently, it was verified that both the current ripple in a DC operation and the tracking error in a pattern operation were suppressed to 20%.

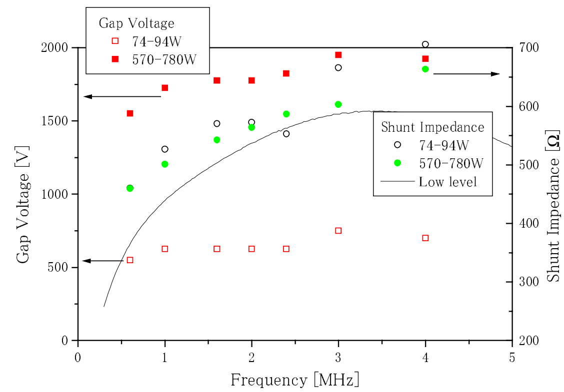

Fig.4: Gap Voltage and Shunt impedance in 6 cores. Squares and circles indicate the gap voltage and the shunt impedance, respectively. The solid line indicates the result from the low-level test on the shunt impedance.

4 SUMMARY

The S-ring project has been founded since 2001 as a five-years project at NIRS in order to develop key-technologies for a compact heavy-ion synchrotron. The S-ring will provide high-quality and high-intensity beams, not only for medical application, but also for biophysics, radiation chemistry and atomic physics.

REFERENCES

[1] E. Takada *et al.*, "Present Status of HIMAC", Proc. 13th SAST, Osaka, 2001, pp.187-189.
[2] K. Noda *et al.*, "The small ring project in HIMAC", Reports of the 1st workshop on the small ring for heavy ions, HIMAC-017, NIRS, 1997 (in Japanese).
[3] Y. Sato *et al.*, "Status of the HIMAC Injector", Proc. 20th Int'l. LINAC Conf., Monterey, 2000, pp.654-656.
[4] G. E. Adams, Rad. Res. 104, S-40-S-46, (1985).
[5] S. Shibuya *et al.*, "Lattice Design of The NIRS Small Ring for Heavy Ions", Proc. 6th EPAC, Stockholm, 1998, pp.547-549.
[6] C. Ohmori *et al.*, "A Wide-band RF Cavity for JHF Synchrotrons", Proc. PAC97, Vancouver, 1997, pp.2995-2997.
[7] K. Noda *et al.*, "Electron cooler for medical and other application at HIMAC", Nucl. Instrum. Meth A 441 (2000) 159-166.
[8] S. Shibuya, et al., in these proceedings (WEPLE085).
[9] K. Noda *et al.*, "Commissioning of Electron Cooler for Medical and Other Application at HIMAC", Proc. 7th EPAC, Vienna, 2000, pp.2548-2550.
[10] K. Ohtomo *et al.*, "Simulation of Short Bunched and Accelerated Beam by An Un-tuned Cavity", Proc. 7th EPAC, Vienna, 2000, pp.1540-1542.
[11] E. Ikawa and K. Noda, "Development on Advanced Current-Source-Type Self-Commutated Converter for Accelerator Electromagnets", Proc. 13th SAST., Osaka, 2001, pp.60-62.
[12] E. Ikawa, *et al.*, "Development on Hydrid Filter for High-Precision Power Source to Accelerator Electromagnets", Proc. 13th SAST., Osaka, 2001, pp.286-288.