STRETCHER-BOOSTER RING OF THE PROPOSED FACILITY IN TOHOKU UNIVERSITY

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Abstract

The stretcher-booster ring of the proposed facility in Tohoku University plays three roles: a pulse stretcher , a booster ring for another storage ring, and a storage ring for internal target experiments. In each mode, the ring is operated in individual way as for beam extraction and RF acceleration.

Introduction

The stretcher-booster ring has been designed as a multi-purpose ring, which is operated in three modes. In the stretcher mode, a pulsed beam from a linac is converted into a continuous beam, which is supplied for coincidence experiments in Nuclear Physics. In the booster mode, the beam is accelerated up to 1.5 GeV in the ring and is transfered to a storage ring for synchrotron radiation. In the case of the storage mode, the stored beam in the stretcher-booster ring is used for internal target experiments, after being accelerated to experimental energies.

The beam is injected into the ring from the linac at 300 pps at maximum and is accelerated to the final energy in 5 sec.

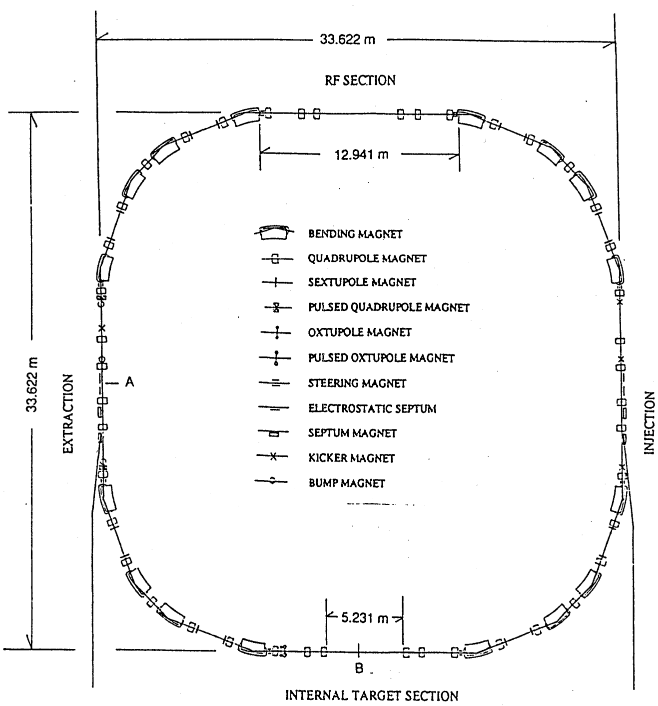

Fig.1 Structure of the stretcher-booster ring.

Structure of the Ring

Figure 1 shows the structure of the stretcher-booster ring. A circumference is 115.256 m. It has four 12.941 m long straight sections where the value of an off-energy function is zero. Two of them are used for injection and extraction, and other two sections, for internal target experiments and RF acceleration. Parameters of the ring is listed in Table 1.

The ring is constituted of 16 bending magnets with a bending radius of 4 m, 44 quadrupole magnets, 16 sextupole magnets, and devices for beam injection and extraction.

The lattice structure of the ring should be as symmetrical as possible. But the periodicity of the ring is restricted to 2 in

Table 1.
Parameters of the Stretcher-Booster Ring.

Circumference	115.256 m
Bending Magnet (Rectangular)	16
Bending radius	4.0 m
Length	1.571 m
Edge Angle	11.25°
Quadrupole Magnet	44
Sextupole Magnet	16
(Booster-Storage Mode)	
Energy	1.5 GeV (max)
Injection Energy	1.0 GeV
Tune	ν_x= 5.25 ν_y= 5.175
Stored Current	400 mA
Emittance	0.403 mm mr (1.5 GeV)
Energy Width	6.4 × 10^{-4}
Dumping Time	5.15 msec (1.5 GeV)
Extraction	Fast (Booster Mode)
Repetition	0.2 pps
Dilatation Factor	0.0469
(Stretcher Mode)	
Energy	1.0 GeV (max)
Repetition	300 pps
Duty Factor	90 %
*Monochromatic Extraction	
Tune	ν_x= 5.46 ν_y= 5.20
Injection	Two-turn injection
Extraction	Half-integer Resonance
Extraction Current	20 μA
Energy Width	0.01 %
*Achromatic Extraction	
Tune	ν_x= 5.325 ν_y= 5.20
Injection	Three-turn injection
Extraction	Third-integer Resonance
Emittance	0.06 mm mr
Extraction Current	30 μA
Energy Widtth	0.1 %

order that the ring can cope with the three operation mode. At the injection and extraction points, the betatron function in the horizontal direction should be somewhat large and flat. On the other hand, it should be small in the internal target and RF sections, and long free spaces are also needed there. The lattice has been designed so that these conditions can be satisfied. Figures 2 and 3 show the betatron functions and the off-energy function between A and B in Fig.1 in the booster-storage mode; they are almost identical with those in other two modes.

Stretcher Mode

The pulse-stretcher, accompanying a pulsed electron linac, converts a pulsed beam into an almost continuous current, as shown in Fig.4. The beam with a pulse length of about 1 μs is injected into th pulse-stretcher at 300 pps so that it fills two or three turns of the circumference of the ring. The stored beam is extracted continuously between injection times using resonance extraction methods. In the proposed facility, two resonance extraction methods are applied in different energy ranges.

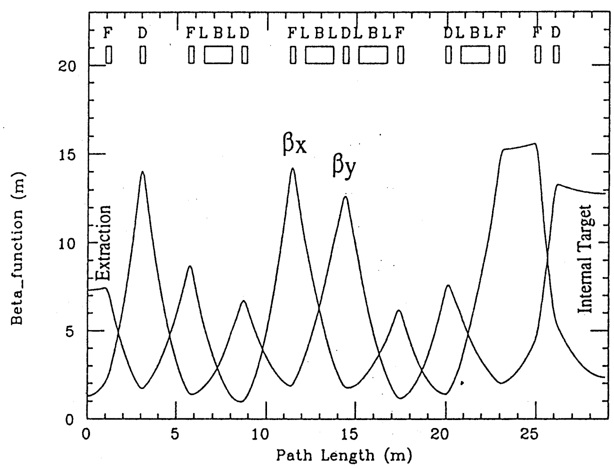

Fig.2 Betatron function of a quarter of the ring in the booster-storage mode.

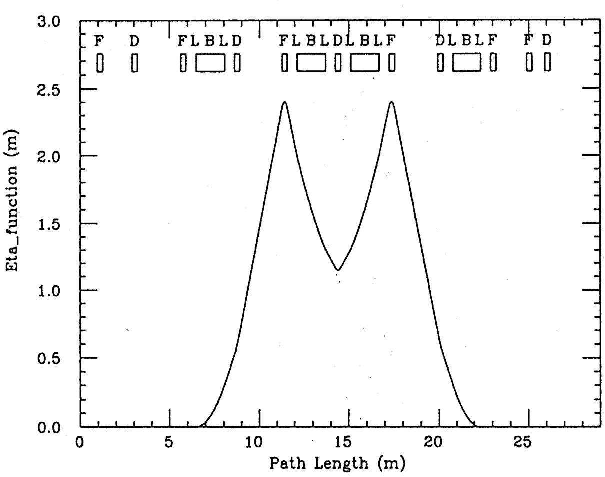

Fig.3 Off-energy function in the booster-storage mode.

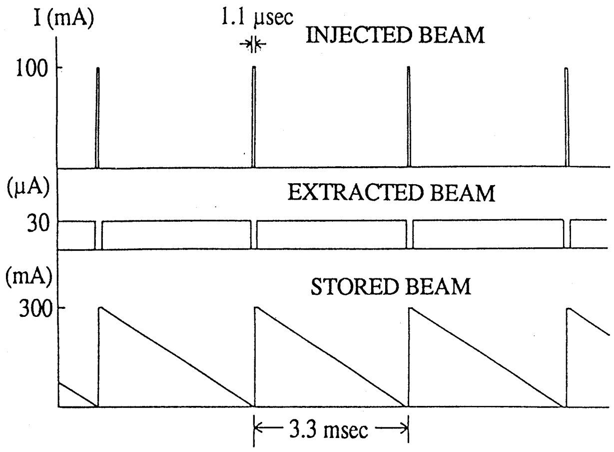

Fig.4 Conversion of the pulsed beam to a continuous beam and the intensity of the stored beam.

A monochromatic extraction without RF acceleration can be applied below 470 MeV. In this method, the energy spread of the injected beam is adjusted to be equal to the energy loss that occurs between two succesive injections. At an injection energy of 470 MeV, the energy loss corresponds to the energy acceptance of the ring, 2 %. Horizontal and vertical chromaticity have to be adjusted so that a resonance occurs at the lowest energy of the injected beam and no resonances occur at other energies. If a third-integer resonance were chosen, sextupole magnets used for chromaticity correction would interfer with one for inducing the resonance. A half-interger resonance, therefore, was chosen for the monochromatic extraction. In the half-integer resonance, an octupole magnet induces the resonance and sextupole magnets can adjust the chromaticity independently.

At higher energies than 470 MeV, a recirculator system is used, and the beam is accelerated two times by the linac. As the total length of the linac and recirculator is three times as long as the circumference of the strether-booster ring, the extraction method using a third-integer resonance is suitable, where three turns of the circumference are occupied with the injected beam. The energy loss is compensated by RF acceleration and an achromatic extraction method is used. No chromaticity correction is needed, because the energy spread is about 0.1 %. In such a condition, a third-integer resonance can be used for beam extraction with no problem.

Figures 5 and 6 show trajectories of a resonating electron in horizontal phase space at the electrostatic septum for the two extraction methods. In the case of the achromatic extraction, the phase space between 5 π and 10 π mm mr is occupied with electrons. Hatched area in Fig.6 gives the emittance of the extracted beam without any modulation. Four bump magnets in Fig.1 can reduce it to 0.06 π mm mr. Two-turn injection is applied for the half-integer extraction method, and three-turn injection, for the third-integer method, so that the beam trajectory of the injected beam can close.

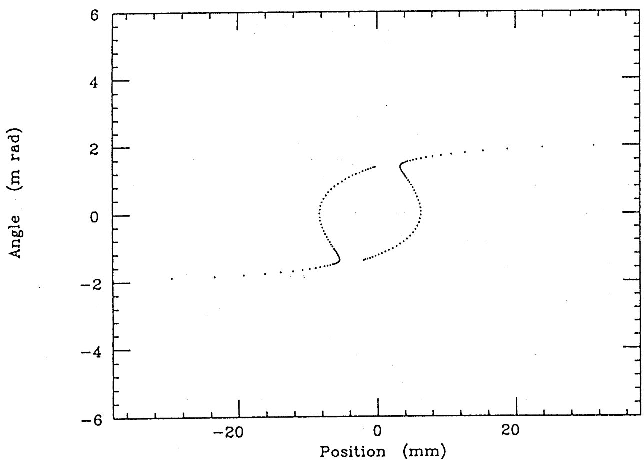

Fig.5 Trajectory of a resonating electron in horizontal phase space at the electrostatic septum in the half-integer resonance extraction.

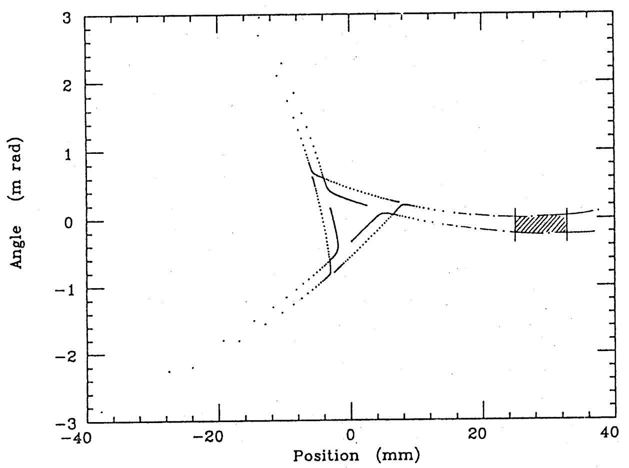

Fig.6 Trajectory of a resonating electron in the achromatic extraction mode. Emittance of the extracted beam is improved to 0.06 mm mr by bump magnets.

A current of the extracted beam is equal to the average current of the injected beam: 20 μA for two turn injection and 30 μA for three turn injection. A duty factor higher than 90 % is expected.

Booster-storage Mode

The highest energy of the electron accelerated by the linac is 1.0 GeV, whereas the storage ring for synchrotron radiation is usually operated at 1.5 GeV. The booster ring accelerates the beam from 1.0 GeV to 1.5 GeV. Beam injection into the storage ring at the operation energy is useful for keeping the ring stable.

In the storage mode of the stretcher-booster ring, the beam is stored in the ring and accelerated to the experimental energy. The stored beam is used for experiments in Nuclear Physics. The vacuum in the ring is under 1×10^{-8} Torr without internal targets. The lifetime of the beam exceeds 1 hour under the condition. But high density internal targets decreases it below 1 min; the injection frequency goes to several times per minute. Because injection with a repetition rate of 300 Hz is available below 1.0 GeV, thicker targets can be used for the internal target experiments. The beam size at the target position is about 1 mm and the dispersive angle is smaller than 0.5 mr.

RF System

Two types of RF system are installed in the stretcher-booster ring: 476 MHz system for the booster-storage mode and 2856 MHz system for the stretcher mode. Parameters of the RF system are shown in Table 2.

In the booster-storage mode, a frequency of 476 MHz is chosen, which is 1/6 of the linac frequency, because a high power source is needed in to accelerate the beam up to 1.5 GeV. Devices in this frequency are widely used at many facilities such as KEK and are available at a moderate price. A system of two nose-cone-type single cavities with a shunt impedance of 9 MHz is adopted, to which a klystron with an output of 100 kW supplies RF power.

In the stretcher mode, the frequency of the RF system in the ring is chosen to be identical with that of the linac, 2856 MHz, because high injection efficiency is essential. The stored current in this mode changes very fast, as shown in Fig.4. It jumps from zero to 300 mA within a beam injection period of 1.1 μsec, and goes to zero again after 3.3 msec. The fluctuating current changes the voltage and phase of acceleration field in the cavities with high shunt impedance. Because tuning the cavities at such a high speed is difficult, cavities with low impedance are chosen in this mode. A system of such cavities accompanying imput couplers with a large coupling constant (β= 15) can keep the acceleration field within small fluctuation.

Table 2. Parameters of the RF System

	Booster Mode	Stretcher Mode
Energy	1.5 GeV	1.0 GeV
Current	400 mA	300 mA
RF Frequency	476 MHz	2856 MHz
Harmonic Number	183	1098
Shunt Impedance	18 MΩ	1.2 MΩ
Over-voltage Factor	4.8	3.0
Acceleration Voltage	537 kV	66.3 kV
Quantum Lifetime	3 days	23.9 sec
Synchronous Phase	78°	70.5°
Synchrotron Frequency	56.9 kHz	58.8 kHz
Klystron Output	100 kW	50 kW
Wall Loss	16.0 kW	3.67 kW
Energy Loss due to Synchrotron Radiation	112 keV	22.1 keV
Number of Cavities	2	2
Revolution Frequency	2.601 MHz	2.601 MHz