The Tohoku University Storage Ring, Stretcher-Booster Ring Project

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Abstract

The Tohoku University Storage Ring, Stretcher-Booster Ring Project is proposed. The existing linac will be improved by adding two more klystrons, adopting new designed accelerating structures, and using a recirculation system. Its maximum output energy is 1 GeV.

1.5 GeV storage ring will be built, and a lot of beam lines from bending magnets and various insertion devices are utilized. Injection to the ring is done at full energy.

Electron beams from the linac are accelerated in the booster ring up to 1.5 GeV and injected into the storage ring. This ring has another features, a pulse stretcher ring which delivers continuous beam to nuclear experiments, and a storage ring for the internal target experiment.

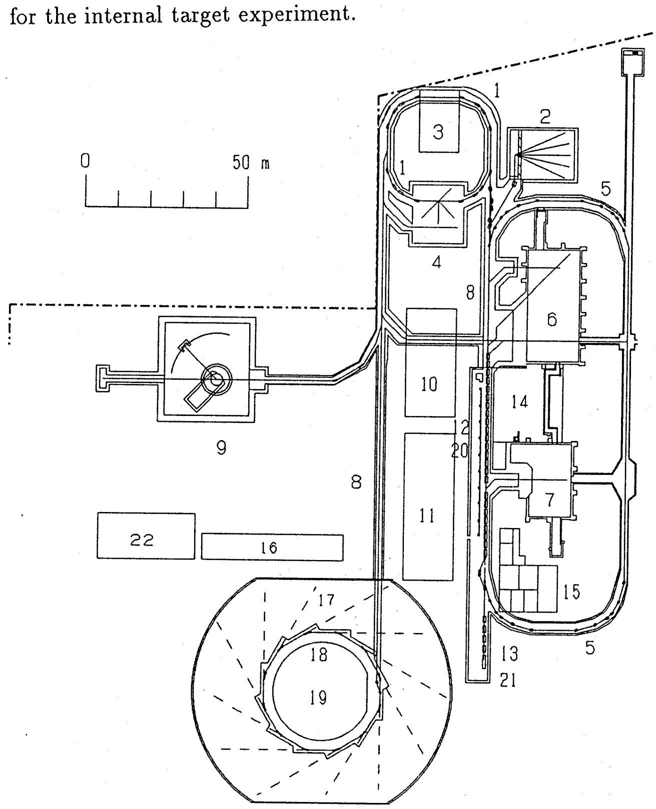

Fig. 1. General layout of the Tohoku University Storage Ring, Stretcher-Booster Ring Project. 1 : Stretcher-Booster Ring. 2 : Neutron Scattering Facility. 3 : Power supply room for electromagnets. 4 : Internal Target Experimental hall. 5 : Recirculator. 6 : Second Experimental hall. 7 : First Experimental hall. 8 : Beam Transport System. 9 : Third Experimental hall. 10 : First Utility Building. 11 : Control Building. 12 : Main Linac. 13 : Injector linac. 14 : Second Utility Building. 15 : Radio Isotope Laboratory. 16 : Labolatory. 17 : Synchrotron Radiation Experimental Hall. 18 : Storage Ring. 19 : Third Utility Building. 20 : Klystron Gallery for Main Linac. 21 : Klystron Gallery for Injector Linac. 22 : Central Laboratory.

Introduction

Intermediate energy, high current electron linacs have played an important role in the study of nuclear physics in 1960s and 1970s. Since the end of 70s, high duty cycle electron beam has been required in order to execute more precise coincidence experiments. Our laboratory proposed a 1 GeV $100\mu A$ electron linac and a pulse stretcher ring (STR) in 1978.[1] Next year, we started construction of a prototype pulse stretcher ring to study technical problems and completed it in 1981.[2,3] The energy of a proposed linac had been raised up to 1.5 GeV[4,5] and 2.2 GeV.[6]

Thereafter, we were obliged to reduce the proposal so that we should cut down the cost of project.[7] We will reconstruct our existing linac from 300 MeV to 550 MeV and achieve 1 GeV using a recirculator. STR has quite similar structure to the storage ring for synchrotron radiation research. Naturally, we gave two functions to the ring, pulse stretcher and storage ring. The energy of stretcher ring should be limitted within 1 GeV, that is the energy of injector linac. On the contrary, in the case of storage ring operation, the stored electron energy may be raised higher after injection. The ring would be operated at 1.5 GeV in storage ring mode.

In that proposal, it is inconvenient for us that we can not use this ring as a pulse stretcher ring (dynamic beam) and a storage ring (static beam) simultaneously. So, we propose new improved plan, the Storage Ring, Stretcher-Booster Ring Project. Fig.1 shows a general layout of the Tohoku University Storage Ring, Stretcher-Booster Ring facility.

Table 1
Electron Linac Parameters

Accelerating structure	(Traveling wave)
RF frequency	2856 MHz
Quasi-constant gradient	$2\pi/3$ mode
Shunt impedance	73 $M\Omega/m$
Effective length	2.0 m
Number of structures	29
(main acceleration	24)
(injector	4)
(energy compression system	1)
Number of klystrons	7
Typical operation	
Pulse repetition rate	300 pps
Energy gain (@ 100 mA peak)	20 MeV/structure
RF input	4.5 MW/structure
Klystron	
Peak power	30 MW
Average power	36 kW
RF pulse duration	3.0 μsec
Electron beam with (without)	recirculation.
Energy	1.0 (0.53) GeV
Peak current	100 mA
Beam pulse width	1.0 (2.0) μsec
Average current	30 (60) μA
Energy spread with ECS	0.1 %

Electron Linac

New linac consists of a 70 Mev injector linac, a 480 MeV main linac and a recirculator. Table 1 shows main parameters of the new linac system. Main linac has six klystron sockets, five ones of them are exising, and each klystron feeds four accelerating structures. All of the old accelerating structues will be replaced by the 2 meters long, newly designed ones. The energy gain per one klystron is 80 MeV at 100 mA beam loading, then the maximum energy gain for main linac is 480 MeV. This energy may be doubled using a recirculator up to 960 MeV. We can get total maximum energy, 1030 MeV, including injector energy.

The accelerating structure is a quasi-constant gradient, $2\pi/3$ mode, traveling wave, modified SLAC disk-loaded structure in which the outer wall of the cells are curved. The shunt impedance of the optimized structure is expected to be 73 $M\Omega/m$.

The path length of main linac and a recirculator is 300 meters. The recirculated beam required for energies above 550 MeV is fixed in pulse length. This pulse length, using head-to-tail recirculation, is just 1 μ sec. The single pass beam for energies below 550 MeV is variable in pulse length from 0.1 μ sec to 2 μ sec.

The circulator should be achromatic and isochronous as a whole, and a phase control system is installed to keep correct phase relation between recirculated bunches and acceleration RF fields.

Between the linac and the stretcher-booster ring, an energy compressing system (ECS), which consists of four magnets chicane and an energy compensation accelerating structure, is installed. This system adjusts the energy and energy spread of the beam suitably for the stretcher operation of the ring.

The linac is operated at 300 pulse per sec, then the average beam current is 30/60 μA with/without a recirculation system.

Table 2
Stretcher-Booster Ring Parameters

Circumference	115.256 m
(average radius	18.343 m)
Straight section for internal target	5.23 m
Bending magnet	16
bending radius	4 m
edge angle	11.25°
Quadrupole magnet	44
Sexstupole magnet	16
(Booster-internal target mode)	
Injection energy	1 GeV
Extraction and stored energy	1.5 GeV
Betatron frequency ν_x/ν_y	5.25/5.175
RF frequency	476 MHz
Harmonic number	183
Klystron	100 $kW \times 1$
Stored current	400 mA
Beam loading	44.8 kW @1.5 GeV
Emittance	403 $nm \cdot rad$
Energy spread	0.064 % @1.5 GeV
Damping time	5.15 $msec$ @1.5 GeV
Extraction	fast (booster mode)
Repetition frequency	max 0.2 pps
Dilatation factor	0.0469
(Stretcher mode)	
Energy	max 1 GeV
Repetition frequency	300 pps
Duty factor	90 %
RF frequency	2856 MHz
Harmonic number	1098
Klystron	50 $kW \times 1$
***monochromatic extraction**	
Betatron frequency ν_x/ν_y	5.46/5.20
Injection	two-turn injection
Extraction	half-integer resonance
Extracted current	20 μA
Energy spread	0.014 %
***achromatic extraction**	
Betatron frequency ν_x/ν_y	5.325/5.20
Injection	two-turn injection
Extraction	third-integer resonance
Extracted current	30 μA
Emittance	0.06 $mm \cdot mr$
Energy spread	0.1 %

Stretcher-Booster Ring

The stretcher-booster ring has been designed to have three functions. The first function is a booster synchrotron which boosts electron beam from energies below 1 GeV to 1.5 GeV for injection into the storage ring. Booster-mode operation works twice a day around thirty minutes each.

The second is a pulse stretcher ring which stores electrons from the linac temporarily then delivers them gradually as a continuous beam to the nuclear physics experiments.

The last is a storage ring which accelerates and stored electrons at desired energies below 1.5 GeV for internal target experiments. The life time of the beam is expected few minutes, therefore the cycle should be repeated regularly.

This ring has two RF systems, 2856 MHz for stretcher-mode and 476 MHz for booster-mode and storage-mode. Parameters of the ring are given in Table 2. Details are described by Tamae et al.[8] in this proceedings.

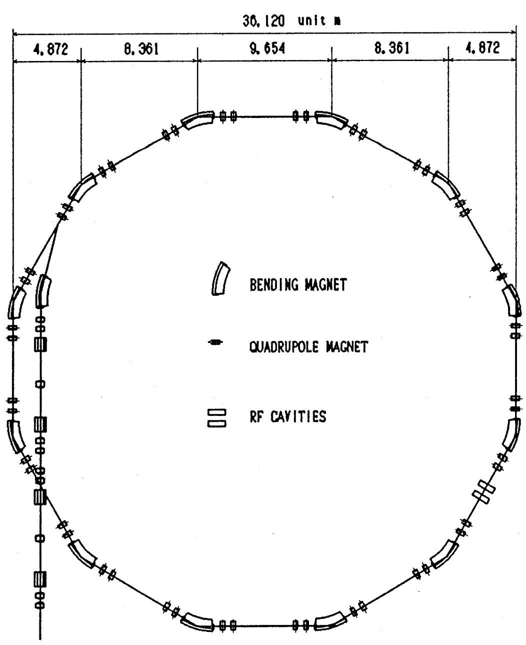

Fig. 2. Layout of the 1.5 GeV Storage Ring. It consists of 12 dipoles, 48 quadrupoles and 36 sextupoles.

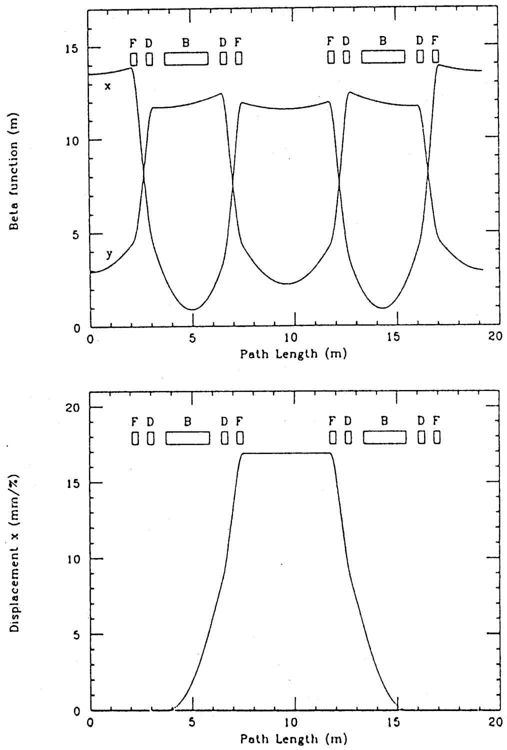

Fig. 3. Betatron and dispersion functions of sixth part of the Storage Ring.

Storage Ring

Intermediate energy electron storage ring dedicated to synchrotron radiation studies has been designed. A circumference is 115.26 m and as large as the stretcher-booster ring. The storage ring lattice has an EDBA (Extended Double Bend Achromat) structure with six superperiods and the shape is a equilateral dodecagon like a clockface as shown in Fig. 2. Fig. 3 shows betatron and dispersion functions of sixth part of the ring. The ring has twelve 4.21 meter long free spaces, one for injection, one for RF cavities and others are for various insertion devices. The frequency of the RF system is chosen to be 476 MHz same as that of stretcher-booster ring. The system is composed of two cavities and powered by a 100 kW klystron. Maximum operation energy is 1.5 GeV and stored beam current is expected to be 400 mA. DC operation of storage ring guarantees good injection efficiency and a distinct advantage of the use of a linac-booster combination as beam injector is that the booster synchrotron also serves as a damping ring. The design parameters of the storage ring lattice are listed in Table 3. Dynamic aperture, calculated by a code PATRICIA, is large enaugh as $120\sigma_x$ by $170\sigma_y$.

Level of the storage ring is higher than level of the linac and the stretcher-booster ring by 6 m. Electron beam transport line from the booster ring goes across under the storage ring and electron beam is injected into the ring from inside so that electron beam transfer line should not interfare with photon beam lines.

Combination of a linac, a stretcher-booster ring and a storage ring should be the best choice for synchrotron radiation and nuclear physics experiments.

In conclusion the author wishes to express his gratitude to all members of Working Group for the Tohoku University Storage Ring, Stretcher-Booster Ring Project.

Table 3
Storage Ring Parameters

Electron energy	1.5 GeV
Circumference	115.256 m
(average radius	18.343 m)
Straight section	
whole/for insertion device	9.654/4.5 m
Number of bending magnets	12
bending radius	4 m
field strength	1.251 T
Quadrupole magnet	48
Sextupole magnet	36
Injection energy	1.5 GeV
Injection Method	one turn injection
Injection repetition rate	max 0.2 pps
RF frequency	476 MHz
Harmonic number	183
Klystron	100 $kW \times 1$
Storage current	400 mA
Betatron frequency	
ν_x/ν_y	5.39/3.72
Beam size (bending)	
σ_x/σ_y	0.299/0.705 mm
Beam size (straight)	
σ_x/σ_y	1.064/0.349 mm
Beam divergence (bending)	
H/V	0.357/0.059 $mrad$
Beam divergence (straight)	
H/V	0.079/0.120 $mrad$
Emittance	83.5 $nm \cdot rad$
Momentum compaction factor	0.0098
Energy spread	0.064 %
Bunch length (2σ)	19.1 mm (127 $psec$)
Revolution frequency	2.601 MHz (time 384 $nsec$)
Beam life time	12 $hours$

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