Design and Performance of the Electron Synchrotron
for the 1 GeV Synchrotron Radiation Source at SORTEC

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Abstract

Present status of the 1 GeV electron synchrotron at Tsukuba Research Laboratory of SORTEC Corporation is reported. Injection and extraction energies are respectively 40 MeV and 1 GeV. At present, the 1 GeV acceleration is successful and the maximum accelerated current at 1 GeV has been attained 50 mA.

Introduction

The synchrotron radiation source facility of SORTEC is composed of a 40 MeV linac, a low energy beam transport line (LBT line), the 1 GeV electron synchrotron, a high energy beam transport line (HBT line) and a SOR-ring. In this paper, design and performance of the 1 GeV electron synchrotron and the HBT line are reported.

The assembly of the synchrotron was started in January 1989 and was completed at the end of March 1989. The beam test of the synchrotron was started from August and the acceleration at 1 GeV was successful on 16 September 1989. The accelerated beam is extracted at 1 GeV with a fast extraction system and is injected into the SOR-ring through the HBT line. An injection system of the SOR-ring is designed as a full energy injection.

General Description

The construction of the synchrotron radiation source facility at Tsukuba Research Laboratory of the SORTEC Corporation started in December 1987 and had been completed in March 1989. The beam test of the synchrotron started at the beginning of August and the beam acceleration with the synchrotron was successful on 16 September. Finally on 28 September 1989, the beam injection and accumulation into the SOR-ring had been successful. Layout of the 1 GeV electron synchrotron and the HBT line is shown in Fig. 1. The injection system is composed of a septum magnet and four bump magnets, and an extraction one is composed of a fast kicker magnet and a septum magnet. Principal design parameters of the synchrotron are listed up in Table 1. The injector of the synchrotron is the 40 MeV linac. Extracted beam properties of the linac[1] is below.

Beam Energy	40	MeV
Beam Current	60 ∿ 80	mA
Available Pulse Width	1.7	μS
Energy Spread (FWHM)	±0.67	%
Emittance	$\bar{0}$.7	πmm.mrad
Beam Size	±1.5	mm

Table 1 Principal Design Parameters
of the 1 GeV Electron Synchrotron

Extraction Energy	1	GeV
Injection Energy	40	MeV
Circumference	43.19	m
Radius of Curvature	3.03	m
Superperiodicity	6	
Lattice Structure	FBDBFO	
Beam Current	30	mA
Repetition Rate	1.25	Hz
Batatron Tune Value (ν_x/ν_y)	2.25/1.25	
Maximum Field of Dipole Magnet	1.1	T
Maximum Gradient of Quadrupole Magnet	4.8	T/m
Accelerating Frequency	118	MHz
Harmonic Number	17	
Maximum RF Voltage	60	kV
Vacuum Pressure	$<1 \times 10^{-6}$	Torr
	(with beam)	

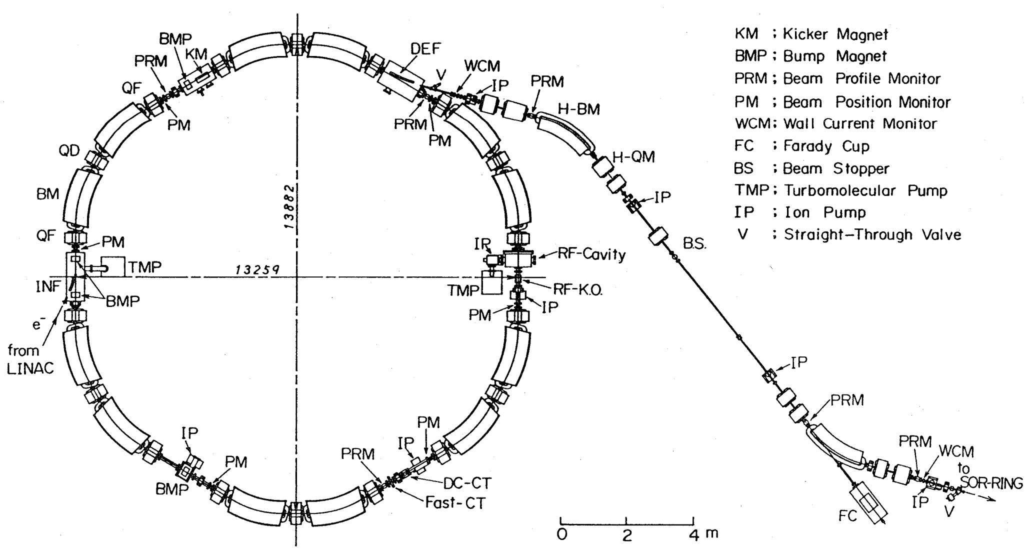

Fig. 1 Layout of the 1 GeV Electron Synchrotron at SORTEC

Magnetic System and Operation Mode

Lattice structure of the synchrotron is shown in Fig. 2. This lattice is designed on FBDBFO structure with 12 dipole magnets and 18 quadrupole magnets. The superperiodicity of this ring is 6. The dipole magnets and the quadrupole magnets are respectively excited up to the maximum currents of 1300A and 585A. The excited voltage and current patterns of magnets are shown in Fig. 3. The rising time of currents and the periodicity of the acceleration is designed to be 400 msec and 1.25 Hz. The main coils are excited by a 12 phase controlled thyristor rectifier backed up with MOSFETs choppers. Only a dipole magnet supply is equipped with a forcing circuit for the improvement of its rising time. All power supplies satisfy the stability requirement of the current 1×10^{-4} in all range.

So as to suppress the eddy current effect, dipole and quadrupole magnets are made of stacked laminated steel. Dipole magnets are desinged to be H-type, 260 mm in pole width and 55 mm in gap length. As the result of a field measurement, the field uniformity ($\Delta B/B$) was less than 2×10^{-4} within ±45 mm.

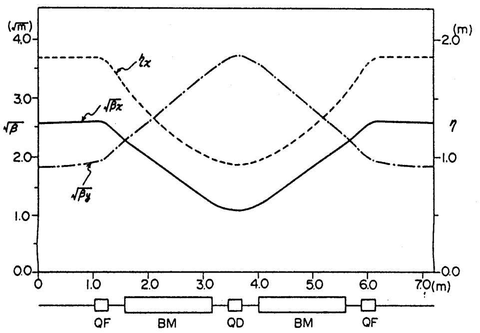

Fig. 2 Beta and Despersion Function of the 1 GeV Electron Synchrotron

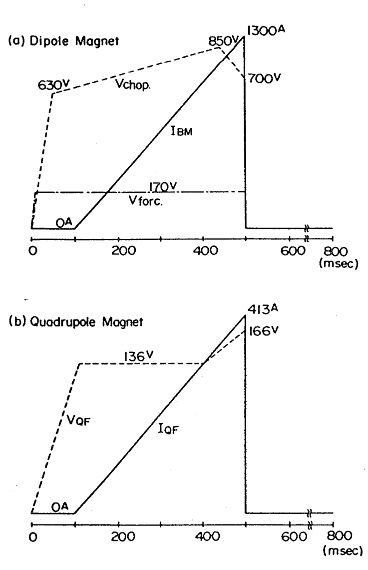

Fig. 3 Current and Voltage Patterns of Magnets

RF Acceleration System

Principal design parameters of an rf acceleration system are shown in Table 2. The rf cavity is re-entrant type and is made of all copper. Design values of Q-value and effective shunt impedance are 9400 and 0.785 MΩ which are half values of a calculation with the program code SUPERFISH. As a result of a low power test, the Q-valve and the effective shunt impedance were respectively 15200 and 1.28 MΩ. The maximum power of the rf acceleration system is designed to be 10 kW. Figure 4 shows a block diagram of an rf power supply. A cavity voltage Vc is kept to be constant by a feedback loop.

Table 2 Principal Design Parameters of the RF Acceleration System

Acceleration Frequency	118	MHz
Q-Value	9400	
Effective Shunt Impedance	0.785	MΩ
Maximum RF Voltage	60	kV
Coupling Coefficient	1.2	
RF Power	5	kW

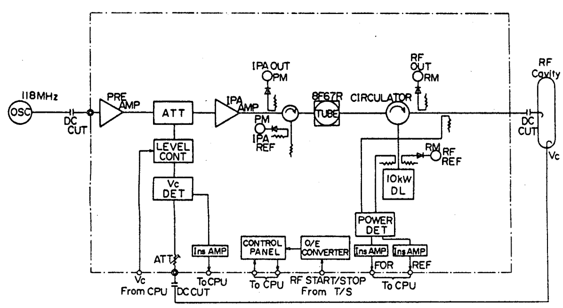

Fig. 4 Block Diagram of the RF Power Supply

Monitor System

The 1 GeV electron synchrotron is equipped with the monitor system which consists of 3 beam profile monitors, 6 beam position monitors, a fast current transformer, a beam dc current transformer and a tune monitor.

The beam profile monitor is composed of a 99.5% aluminum oxide with chromium oxide and a TV monitor. With a remote control system, the beam profile and the beam position can be monitored on the TV set. The beam position monitor is the electrostatic type with 4 disk electrodes. With six beam position monitors installed in six long straight sections, closed orbit distortion (COD) is measured. The fast current transformer is used to measure multi-turn injections because of its time response of 50 nsec. On the other hand, the beam dc-current transformer is used to measure the accelerated current. Its sensitivity and time response are ±0.2 mA and 0.3 msec. The tune monitor is composed of rf knock-out electrodes and a pick-up monitor which is the same type of the beam position monitor. The input power and the frequency range in rf knock-out electrodes are respectively 150 W and 300 kHz - 12 MHz. One synchrotron radiation (SR) port is installed at a long straight section for monitoring synchrotron light during the beam acceleration.

Vacuum System

The vacuum pressure better than 1 x 10^{-6} torr is required for the long beam life time which depends on the multiple scattering between electrons and residual gass. A long bellows duct shown in Fig. 5 with the same cross section from end to end is installed in two dipole and three quadrupole sections. The long bellows duct is made of 316 stainless steel and are 5403 mm in length and 0.3 mm in thickness. The inner cross section of the bellows duct is 126 mm x 41 mm race track.

The vaccum System of the synchrotron is composed of two 330 1/sec turbomolecular pump sets, seven 230 1/sec ion pumps and one 400 1/sec ion pump at the rf-cavity. At present, the average vacuum pressure of the synchrotron with beam is better than 1 x 10^{-7} torr.

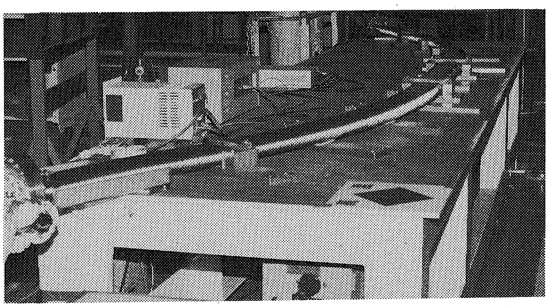

Fig. 5 Beam Duct at Dipole and Quadrupole Magnet Section

High Energy Beam Transport Line

The total length of a high energy beam transport line (HBT line) is 22 m. As shown in Fig. 1, the main components of the HBT line are 2 dipole magnets, 9 quadrupole magnets, 5 steering magnets, 3 beam profile monitors, 2 wall current monitors, a farady cup, a beam stopper, 2 straight-through values and four 120 1/sec ion pumps. The HBT line is operated in dc mode. With the farady cup, 1 GeV Cherenkov light in water was measured.

Performance

As an injection into the synchrotron, the multi-turn injection is adopted. The design value of multi-turns is seven times. The average accelerated current at 1 GeV is 35 mA and the maximum one is 50 mA. The current wave form during the 1 GeV acceleration is shown in Fig. 6.

Present operation point (ν_x, ν_y) is (2.27,1.40), but the 1 GeV acceleration was also confirmed at another operation point (2.22,1.17). These operation points were measured with rf knock-out electrodes and a pick-up monitor.

Figure 7 shows closed orbit distortion (COD) during the acceleration without excited steering magnets. The maximum value of the horizontal and vertical CODs are respectively 5.5 mm and 4.2 mm. These CODs are smaller than estimated ones. That is because both manufacturing error and alignment error of magnets were small. After COD correction with steering magnets, COD becomes less than 3 mm.

Figure 8 shows synchrotron light from the synchrotron through the SR port. Efficiency of the extracted beam with the fast extraction system is 30 - 40% of the accelerated one. Efficiency of the injected beam of the SOR-ring is 12% of the accelerated beam of the synchrotron. The maximum injected current of the SOR-ring during one cycle is 5 mA. This value will be increased by the beam adjustment in future.

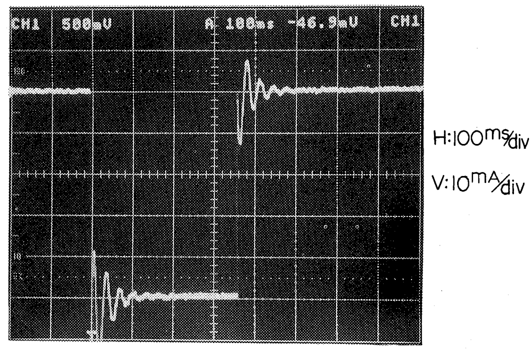

Fig. 6 Current Wave Form during the Acceleration

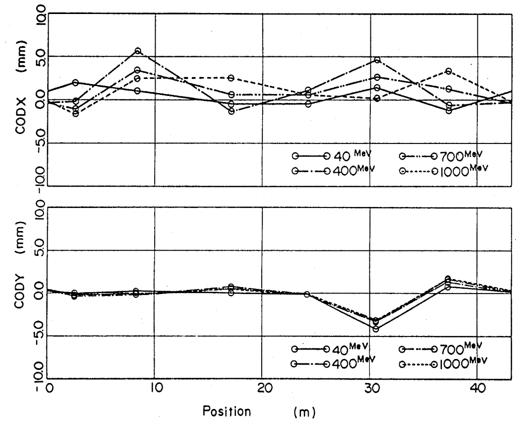

Fig. 7 COD during the Acceleration

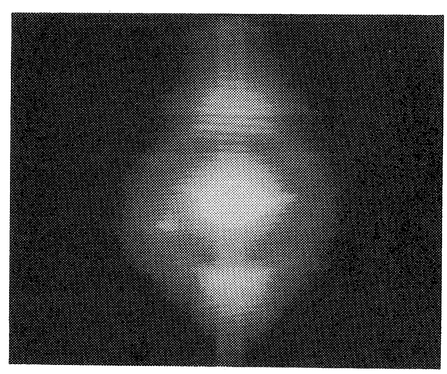

Fig. 8 Synchrotron Light from the 1 GeV Electron Synchrotron

Reference

1) S. Nakamura et al., Proc. of the 14th Linear Accelerator Meeting in Japan (1989) P15.