DESIGN AND PERFORMANCE OF THE ELECTRON SYNCHROTRON FOR THE 1-GEV SYNCHROTRON RADIATION SOURCE AT SORTEC

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Abstract

Design and present status of the 1-GeV electron synchrotron at Tsukuba Research Laboratory of SORTEC Corporation are reported. The 1-GeV electron synchrotron is an injector of a 1-GeV storage ring. At present, the average accelerated current at 1GeV has attained the design value of 30mA.

Introduction

Synchrotron radiation (SR) has become key technologies in many fields of sience and industry. SORTEC Corporation was established in June 1986 to study the application technologies for SR such as X-ray lithography and material analysis etc. The 1-GeV SR source[1] is the cental facility of SORTEC Corporation.

The SR facility is composed of a 40-MeV linac[2] (pre-injector), a low energy beam transport line[3] (LBT line), the 1-GeV electron synchrotron (injector), a high energy beam transport line (HBT line) and the 1-GeV storage ring[4] (SR ring). Construction of buildings at Tsukuba Laboratory of SORTEC Corporation had been completed in September 1988. Consequently, the assembly of the SR facility was completed in March 1989. The commissioning of the synchrotron started in August and the beam acceleration to 1Gev was successful on September 16. On September 28, the first beam was successfully stored in the SR ring. The present lifetime with beam of 200mA is longer than 8 hours.

General Description

Figure 1 shows a layout of the 1-Gev electron synchrotron and the HBT line. Principal design parameters of the synchrotron are listed in Table 1. The quality of the extracted beam from the 40-MeV linac, energy spread and emittance, is ± 0.67 % and 0.7π mm · mrad at 80mA, respectively.

The lattice of the synchrotron is designed on FBDBFO structure with twelve dipole magnets and eighteen quadrupole magnets[5]. The lattice functions of the synchrotron are shown in Fig.2.

Dipole magnets are excited up to the maximum current of 1300A. A rising time of the current and a repitition rate of the acceleration is 400msec and 1.25Hz, respectively. Dipole and quadrupole magnets are excited by a twelve phases controlled thyristor rectifier backed up with MOSFETs choppers. Only a dipole magnet power supply is equipped with a forcing circuit for the improvement of its rising time. All power supplies satisfy the required current stability of 1×10^{-4} in all ranges.

An injection system of the synchrotron consists of a septum magnet (Inflector) and four bump magnets. An extraction one is composed of a fast kicker magnet and a septum magnet (Deflector). All of those pulse magnets are installed in vacuum chambers.

A shape of RF cavity[6] is re-entrant type and its accelerating frequency is 118MHz. A body of the RF cavity is made of OFHC copper.

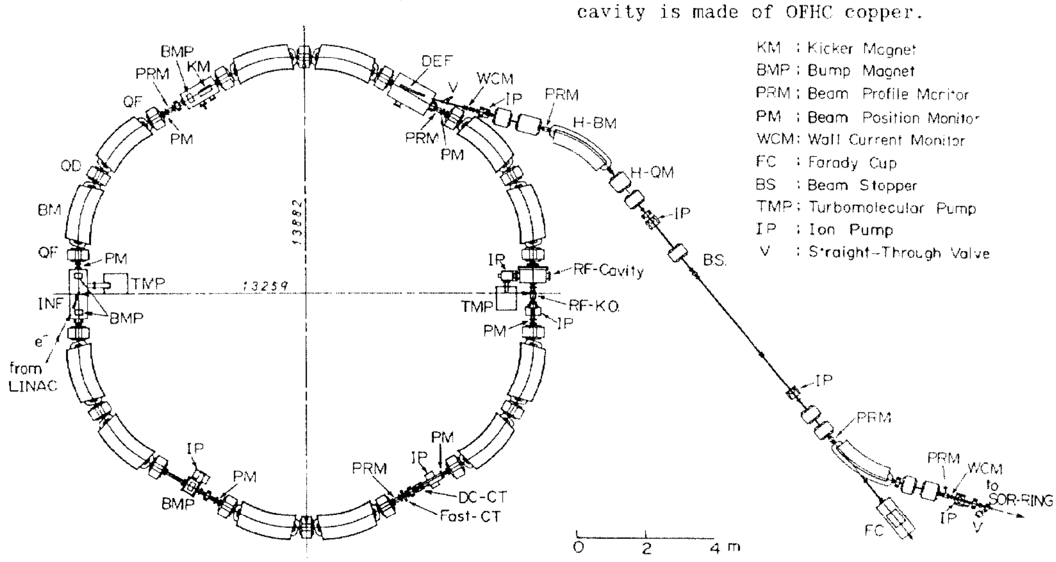

Fig. 1 Layout of the 1-GeV Electron Synchrotron at SORTEC

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Total length of the HBT line is about 22m. Thelattice of the HBT line is designed to make dispersion free at an injection point of the SR ring. Two wall current monitors and a Farady cup are installed in the HBT line as shown in Fig.1 and with those monitors the extraction efficiency from the synchrotron can be estimated.

Table 1 Principal Design Parameters of the 1-GeV Electron Synchrotron

Accelerating 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 ($\nu x/\nu y$)	2.25/1.25	
Maximum Field of Dipole Magnet	1.1	T
Maximum Field Gradient of Quadrupole Magnet	4.8	T/m
Accelerating Frequency	118	MHz
Harmonic Number	17	
Maximum RF Voltage	60	kV
Vacuum Pressure (with beam)	$<1\times10^{-6}$	Torr

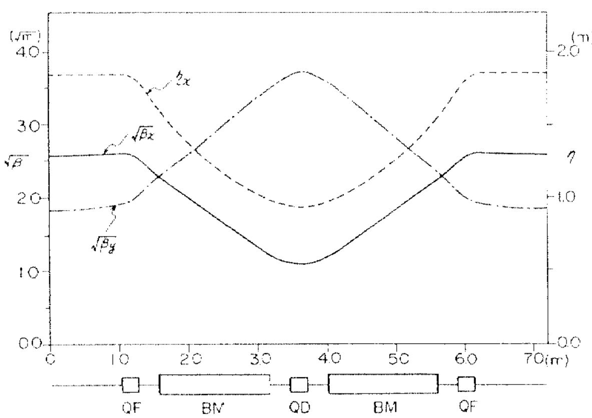

Fig. 2 Beta and Dispersion Functions of the 1-GeV Electron Synchrotron

Design and Magnetic Field Measurment of the Dipole Magnet

Principal design parameters of the dipole magnet are listed in Table 2. A shape of cross section with shims is designed by magnetic field analysis used finite element method so as to have a wide good field region. From the point of magnetic symmetry, H-type magnet is adopted.

A magnetic field measurement apparatus with a Holl probe had been developed. It could move on 4 axes (X,Y,Z, θ) and take mapping data of the magnetic field. The Holl prove was calibrated by a nuclear magnetic resonance method and its temperature was kept within 0.1 °C. An accuracy of this apparatus was 1×10^{-4}. A measured magnetic field is shown in Fig.3 which shows the result of the analysis agrees well with the measured one. From the measurement results of all dipole magnets, it has been confirmed that the magnetic field uniformity $\Delta B/B_c$ is better than 2×10^{-4} in the required field region.

Table 2 Principal Design Parameters of Dipole Magnet

Core Length	1540	mm
Gap Height	55	mm
Maximum Flux Density	1.1	T
Radius of Curvature	3.03	m
Bending Angle	30	deg.
Number of Magnets	12	
Good Field Region	± 45	mm
Field Uniformity	$<5\times10^{-4}$	
Material	t0.5 mm-Silicon Steel	
Shape	Rectangular, H-Type	

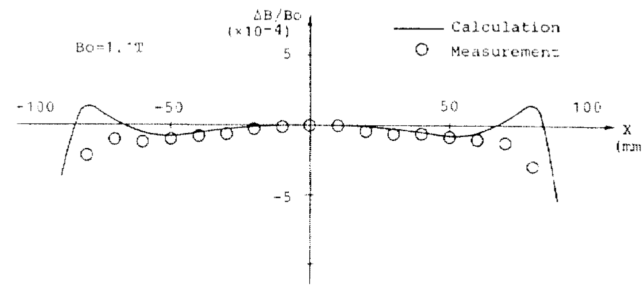

Fig. 3 Radial Magnetic Field Distribution of the Dipole Magnet

RF Acceleration System

Principal design parameters of RF acceleration system are listed in Table 3. Design values of a Q value and an effective shunt impedance R_{sh} ($P_c=V_c^2/R_{sh}$) are 9400 and 0.785M Ω which are half values of a calculation with the program code SUPERFISH. As a result of a low power test, the Q value and R_{sh} was 15200 and 1.28M Ω, respectively. Figure 4 shows a block diagram of a RF power supply. The cavity voltage V_c is kept to constant by a feedback loop.

Table 3 Principal Design Parameters of the RF Acceleration System

Acceleraing Frequency	118	MHz
Q Value	9400	
Effective Shunt Impedance	0.785	MΩ
Maximum RF Voltage	60	kV
Coupling Coefficient	1.2	
RF Power	10	kW

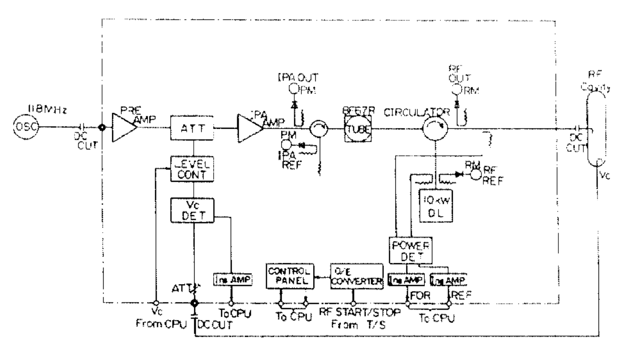

Fig. 4 Block Diagram of the RF Power Supply

Monitor and Vacuum System

The synchrotron is equipped with a monitor system which consists of three beam profile monitors, six beam position monitors, a fast current transformer (fast-CT), a beam DC current transformer (beam DC-CT) and a tune monitor.

The beam profile monitor is composed of an aluminum oxide plate and a TV monitor. The beam position monitor is an electrostatic type with four disk electrodes. With six beam position monitors installed in six long straight sections, the closed orbit distortion (COD) is measured. The fast-CT is used to measure multi-turn injection because of its fast response time of 50nsec. On the other hand, the beam DC-CT is used to measure an accelerated current. Its sensitivity and response time are ± 0.2mA and 0.3msec. 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. One synchrotron radiation port is also installed at a long straight section for monitoring the synchrotron light during the acceleration of the beam.

A vacuum pressure with beam is required better than 1×10^{-6} torr. A long bellows duct shown in Fig.5 with the same cross section from end to end is installed over two dipole and three quadrupole sections. The long bellows duct is made of 316 stainless steel and it is 5403mm in length and 0.3mm in thickness. The inner cross section of the bellows duct is 126mm × 41mm race track.

The vacuum system of the synchrotron is composed of two 330l/sec turbomolecular pump sets, seven 230l/sec ion pumps and a 400l/sec ion pump. At present, the average vacuum pressure of the synchrotron with beam is better than 1×10^{-7} torr.

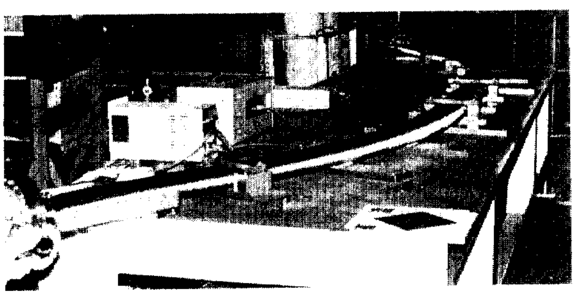

Fig. 5 Bellows Duct at a Dipole and Quadrupole Magnet Section

Performance

As an injection method into the synchrotron, the multi-turn injection process is adopted. Figure 6 which was observed by the fast-CT shows the status of the multi-turn injection. From this current wave form, the multi-turn injection turned out to be nine times. Figure 7 shows the other current wave form which was observed by the beam DC-CT during the 1-GeV acceleration. It shows that the beam was almost maintained during the acceleration because of a good tracking.

The maximum values of horizontal and vertical CODs without excited steering magnets is 5.5mm and 4.2mm, respectively. These CODs are smaller than the design values. That is because both manufacturing error and alignment error of magnets were small.

Figure 8 shows the current wave form observed by the wall current monitor in the HBT line. It shows that the number of bunches extracted from the synchrotron were fourteen. The reason why such many

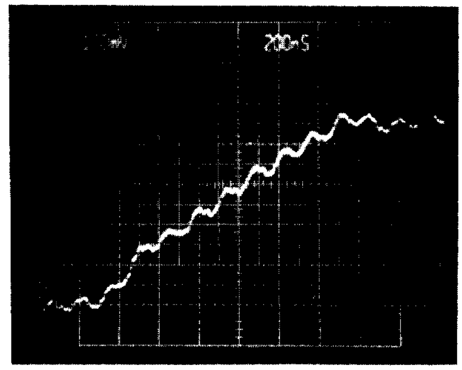

Fig. 6 Current Wave Form at the Multi-Turn Injection

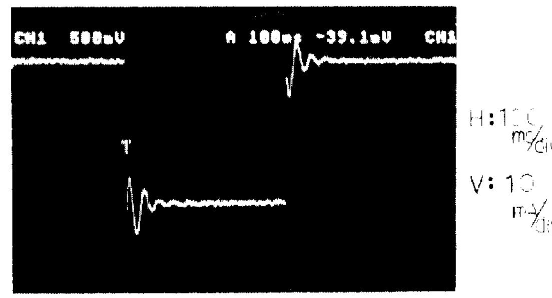

Fig. 7 Current Wave Form during the Acceleration

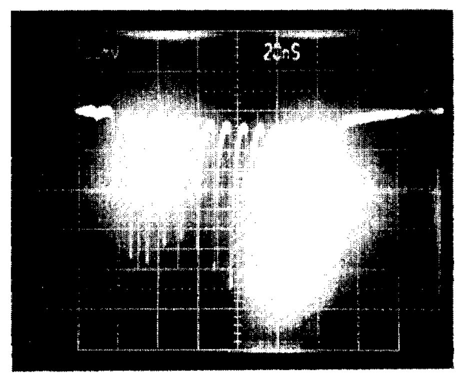

Fig. 8 Current Wave Form of the Extracted Beam

bunches were extracted from the synchrotron is now being studied. The extraction efficiency of the beam from the synchrotron with the fast extraction system is 30-40 % of the accelerated beam. The injection efficiency of the beam into the SR ring is 20-25 % of the accelerated beam. These efficiencies will be improved by the beam optimization in future.

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