CONSTRUCTION AND BEAM EXPERIMENTS OF A 1 GEV SYNCHROTRON AT MITSUBISHI

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Abstract

A 1GeV electron synchrotron has been constructed at the Mitsubishi Electric Corporation, and accelerated a beam of 60mA. The synchrotron is designed to act as a storage ring as well as an injector to a compact storage ring. A beam of 20mA has been stored in this ring at 1GeV.

Introduction

A high-energy electron beam facility is under commission at the Mitsubishi Electric Corporation[1].

Basic research for industrial applications is planned with this facility. The applications include synchrotron radiation (SR) for lithography and material analysis, generation and measurement of positrons, and free electron lasers.

This facility consists of a 20MeV linac, a 1GeV booster synchrotron, and a 0.8GeV storage ring with superconducting bending magnets[2]. The linac and synchrotron have been constructed, and the storage ring is under construction.

The principal function of the synchrotron is to provide the accelerated electron beam (0.8GeV) to the storage ring. The second function is to store the beam and use it as an SR source. Other application is utilization of high energy electrons themselves. For these applications, the maximum energy is determined to be 1GeV higher than the injection energy of the storage ring.

The first beam injection into the synchrotron was done in March 1991, and a beam was accelerated to 1GeV after 2 days. An accelerated beam has been also stored in the synchrotron at 1GeV successfully.

In this paper we describe the design and beam experiments of the synchrotron.

Design and construction

A schematic drawing and photograph of the synchrotron are shown in Fig.1 and 2, respectively. A 20MeV linac is used as an injector. It was built in the Communication Equipment Works of the Mitsubishi Electric Corporation. The main parameters of the linac are shown in Table 1.

Lattice

The lattice type is FODO with F and D adjacent, as shown in Fig. 1. The bending magnets (BM) are of a sector type. In order to install sextupole magnets (SM) in every other straight section, the quadrupole magnets (QM) have to be located away

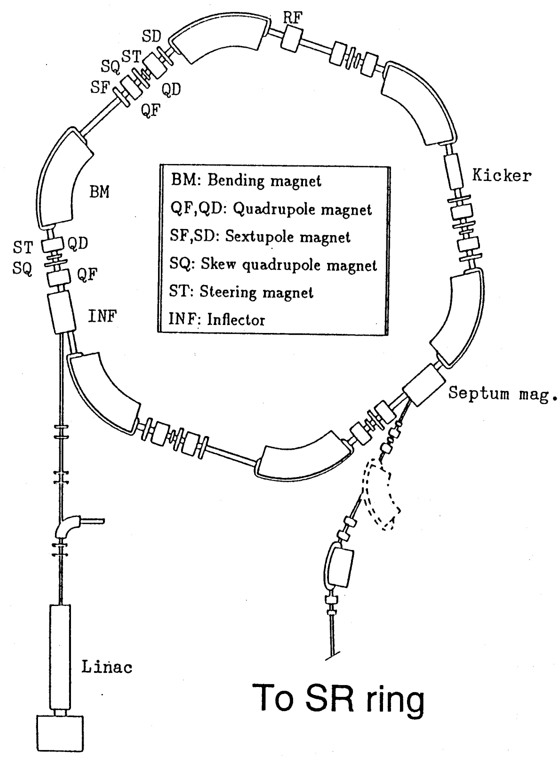

Figure 1: Schematic drawing of the synchrotron.

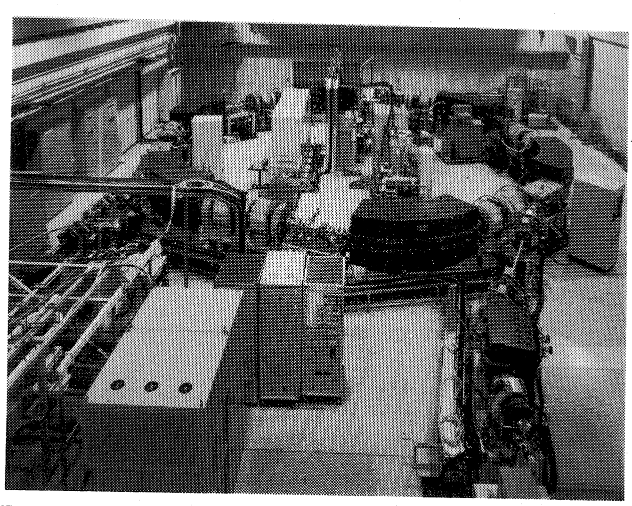

Figure 2: Photograph of the synchrotron. The linac is placed on the left down.

Table 1: Main parameters of the linac

Energy	$20MeV$
Current	$100mA$
Pulse width	$2.5\mu sec$
Repetition	$3Hz$
Energy spread	$\pm0.6\%$
Emittance	$1.3\pi mm \cdot mrad$
Tube length	$1.6m$
Acceleration Frequency	$2.856GHz$

Table 2: Main parameters of the synchrotron

Energy	E	1	GeV
Current	I_b	200	mA
Harmonic number	h	15	
Circumference	C	34.59	m
Bending field	B	1.5	T
No. Bends	n_B	6	
Bending radius	ρ	2.22	m
Repetition		2	Hz
Radiation loss	U_0	40	$keV/turn$
Acceleration frequency	f_{RF}	130	MHz
RF Voltage	V_{RF}	100	kV
Coupling factor	κ	0.1	

from the BM. Hence, a superperiod requires two straight sections resulting in a lattice structure of three superperiods.

The main parameters are shown in Table 2, and the lattice parameters are summarized in Table 3.

Magnets

The BM, QM, and SM are operated with a repetition rate of 2Hz and the coil currents of a trapezoidal waveform which has flat top and bottom of 10ms. These magnets, therefore, are made of laminated cores with silicon steel plates of 0.35mm thickness. The BM has a gap length of $\pm25mm$, and the QM has a bore radius of $65mm$ and a pole length of 296mm.

Vertical-steering magnets (ST) and skew quadrupole magnets (SQ) are installed between the QMs. In order to steer the beam horizontally, the trim coils of the bending magnets (BMT) are excited.

Injection and extraction

The linac beam is injected through an electrostatic inflector with the aid of three magnetic perturbators with a pulse width of $4\mu s$. With these devices, eight turns of electrons are captured in a ring acceptance.

The accelerated beam is extracted by a septum magnet (deflector) with the aid of a kicker magnet. For this small synchrotron with a turning time of $115ns$, it is a requirement that the kicker is excited in a short risetime of $40ns$. This fast rise has been achieved by use of a double-ended Blumlein circuit[3].

RF system

The parameters of the RF system are shown in Table 4. The

Table 3: Lattice parameters of the synchrotron

Tune	ν_x	2.23	
	ν_y	1.21	
Strength of quads	K_f	2.39	m^{-2}
	K_d	2.12	m^{-2}
Emittance	ϵ_{x0}	0.405	$\pi mm \cdot mrad$
Energy dispersion	σ_E	0.053	%
Momentum compaction	α_p	0.146	
Beam size	σ_{xmax}	1.73	mm
	σ_{xmin}	0.86	mm
	σ_{ymax}	0.60	mm
	σ_{ymin}	0.32	mm
Bunch length	σ_z	76.9	mm
Natural chromaticity	ξ_x	-1.63	
	ξ_y	-2.34	
Damping time	τ_x	9.08	$msec$
Quantum lifetime	τ_Q	203	hr

Table 4: Parameters of RF cavity

Cavity inner radius	600	mm
Drift-tube radius	160	mm
Cavity length	350	mm
Acceleration gap	12.2	mm
Q (measurement)	13000	
Shunt impedance	0.93	$M\Omega$
Maximum field	11	kV/mm
Coupling coefficient	1.80	
Phase angle	$0 \sim -51$	deg
Output power	20	kW

system is operated with both cw and pulse. For the pulse operation, CAMAC memory modules provide a required RF pattern synchronized with output currents of magnet power supplies.

The cavity is made of copper except for flanges so as to make the cooling effectively. The resonant frequency can be changed by $\pm500kHz$ using a plunger.

Vacuum

A pumping system is installed such that a pressure of $10^{-9}Torr$ is maintained when the beam is stored, and a pressure of $10^{-7}Torr$ is maintained for the acceleration mode.

A vacuum pressure is $2\times10^{-7} \sim 5\times10^{-9}Torr$ with the present system for the acceleration mode.

While bellows chambers are currently used for acceleration experiments, flat thin chambers mechanically strengthened with rib structures will be substituted for future storage.

Control System

The beam signals are recorded by computers via CAMAC, GPIB, and RS-232C interfaces. These interfaces are connected to local personal computers and a host computer. All computers are networked using Ethernet.

Two console computers independently work as man-machine interfaces. One can operate the accelerator from the main console, from local stations in the control room, or on-site.

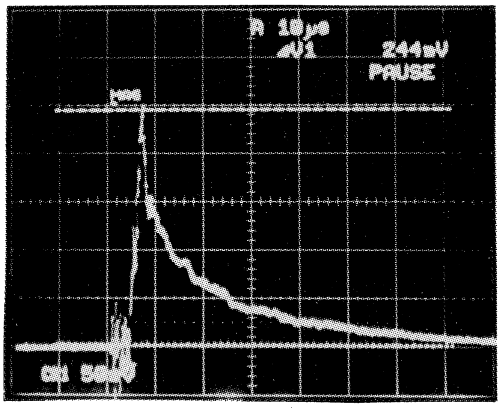

Figure 3: Beam signal at multiturn injection. The used CT has a sensitivity of 4A/V and a decay time constant of $40\mu s$. $10\mu s$/div, 50mV/div.

Beam experiments

Injection and Acceleration

Figure 3 is a beam signal at multiturn injection. The monitor is a CT with a sensitivity of 4A/V and a decay constant of $40\mu s$. A beam intensity of around 400mA is usually obtained just after injection.

A beam signal during acceleration measured with a DCCT is shown in Fig. 4 together with a coil current of BM which is equivalent to beam energy. The DCCT has a rising time of around 10ms. A beam is accelerated and then decelerated without beam loss from 30ms after injection. The maximum intensity of an accelerated beam is 60mA.

The details of injection and extraction which has already done successfully is presented in another paper contributed to this conference[4].

Beam Storage at 1GeV

Figure 5 is a decay signal of a beam stored after acceleration to 1GeV. A life time is about 15min at $I = 5 \sim 10$mA and 25min at $I < 5$mA. A vacuum pressure when this experiment was done was $5 \times 10^{-7} \sim 5 \times 10^{-9} Torr$. The maximum intensity of a stored beam is limited to around 20mA because of a temparature rise of the bellows vacuum chambers.

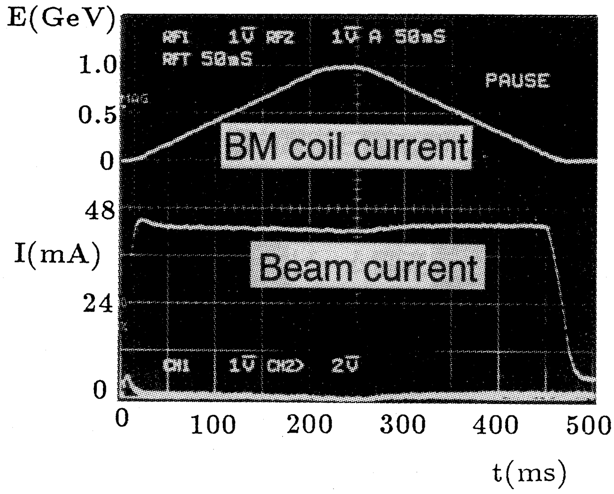

Figure 4: Beam signal during acceleration measured with DCCT which has a rising time of around 10ms.

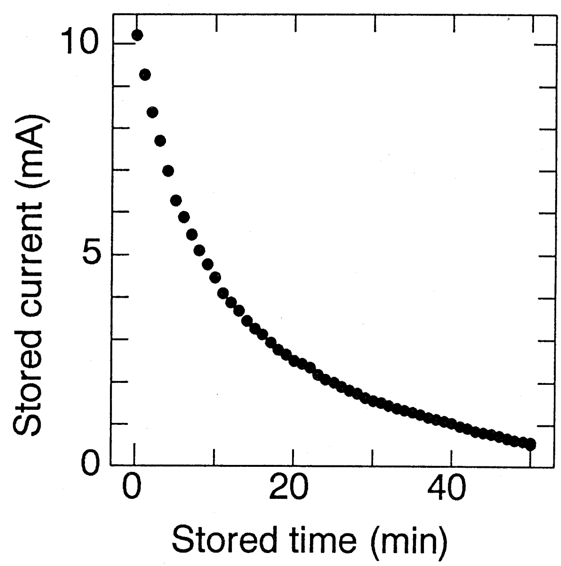

Figure 5: Decay signals of beams stored after acceleration to 1GeV.

Summary

The 1GeV electron synchrotron with a 20MeV linac injector has been constructed and accelerated a beam successfully. The maximum current of an accelerated beam is 60mA. An accelerated beam can be stored in this ring at 1GeV. An accelerated beam of about 20mA was stored at 1GeV with the lifetime of about 15min. This machine will be used as an injector of a compact storage ring and for industrial applications using high energy electrons.

References

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