A High Energy Electron Beam Facility for Industrial Research

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Abstract

A high-energy electron beam facility is under commission at the Mitsubishi Electric Corporation. This facility consists of a $20MeV$ linac and a $1GeV$ synchrotron. The synchrotron is designed to act as a storage ring as well as an injector to a compact storage ring.

1 Introduction

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

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.

The building containing this facility was completed at the end of 1989, and initial operation of the system has begun.

In this paper we describe the high-energy electron beam facility. The main subject is the design of the booster synchrotron.

2 Description of Facility

The configuration of the system is shown in figure 1[1]. It consists of a $20MeV$ linac, a $1GeV$ booster synchrotron, beam transport lines, and an $800MeV$ storage ring.

The linac, the synchrotron, and the beam transport lines have been installed and the electron beam is under commission.

2.1 Linac

The linac was built in the Communication Equipment Works of the Mitsubishi Electric Corporation. The main parameters of the linac are shown in table 1.

2.2 Storage Ring

An $0.8GeV$ storage ring of racetrack shape has been designed. This ring has a pair of superconducting bending

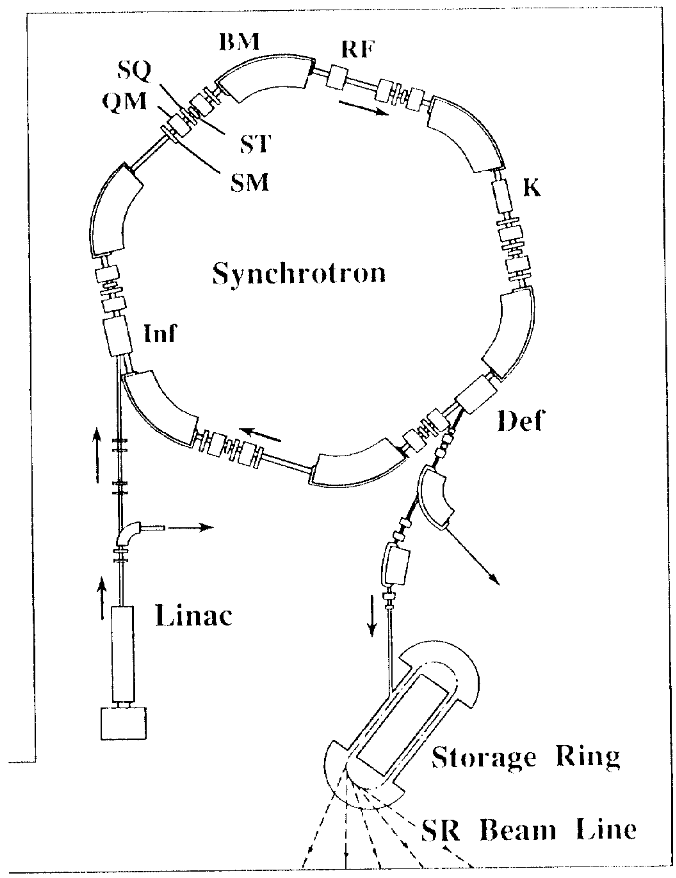

Figure 1: The high-energy electron beam facility and the synchrotron layout. BM: bending magnet, QM: quadrupole magnet, SM: sextupole magnet, ST: steering magnet, SQ: skew quadrupole magnet, RF: RF cavity, Inf: inflector, K: kicker, Def: Deflector

Table 1: Main parameters of the linac

Energy	$20MeV$
Current	$100mA$
Pulse width	$2.5\mu sec$
Repetition	$3Hz$
Energy spread	$\pm 0.5\%$
Emittance	$1.3\pi mm \cdot mrad$
Tube length	$1.6m$
Acceleration Frequency	$2.856GHz$

Table 2: Main parameters of the storage ring

Energy	$0.8GeV$
Current	$220mA$
Bending field	$4.5T$
Critical Wavelength	$0.7nm$

magnets with iron shields. The main parameters of the storage ring are shown in table 2.

The beam is mainly injected at the maximum energy ($0.8GeV$), while a beam injected at a lower energy may be accelerated as an option. The magnets and other components are currently being fabricated.

2.3 Synchrotron

The principal function of the booster 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.

The layout of the components are shown in figure 1, and the main parameters are shown in table 3.

2.3.1 Lattice

The lattice type is FODO. In order to install sextupole magnets (SM) in every other straight section, the quadrupole magnets (QM) have to be located away from the bending magnet (BM). Hence, a superperiod requires two straight sections resulting in a lattice structure of three sperperiods.

The lattice parameters are summarized in table 4.

2.3.2 Magnets

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

Table 5 summarizes the number, strength, and operational mode of each magnet.

Table 3: 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	

Table 4: 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	$\sigma_{x max}$	1.73	mm
	$\sigma_{x min}$	0.86	mm
	$\sigma_{y max}$	0.60	mm
	$\sigma_{y min}$	0.32	mm
Bunch length	σ_z	76.9	mm
Quantum lifetime	τ_Q	203	hr

Table 5: Magnet parameters of the synchrotron

	Number	Strength		Mode
BM	6	1.5	T	AC
QM	12	9.5	T/m	AC
SM	6	140	T/m^2	AC
ST	6	0.05	T	DC
SQ	6	1.7	T/m	DC
BMT	6	0.015	T	DC

Table 6: Synchrotron injection and extraction devices

Device	Beam energy	Deflection angle	Pulse width
Inflector	20 MeV	12 deg	DC
Perturbator	20 MeV	20 $mrad$	3 μs
Kicker	1 GeV	15 $mrad$	0.2 μs
Deflector	1 GeV	21.5 deg	3 ms

Table 7: Design parameters of RF cavity

Cavity inner radius	600	mm
Drift-tube radius	160	mm
Cavity length	350	mm
Acceleration gap	12.2	mm
Q	19700	
Shunt impedance	1.46	$M\Omega$
Maximum field	11	kV/mm
Coupling coefficient	1.80	
Phase angle	$0 \sim -51$	deg
Output power	20	kW

2.3.3 Injection and Extraction

The linac beam is injected through an electrostatic inflector with the aid of three magnetic perturbators. 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[2]. Table 6 summarizes these injection/extraction devices.

2.3.4 RF system

The design parameters (calculated) of the RF system are shown in table 7.

2.3.5 Vacuum

A pumping system is installed such that a pressure of $10^{-7}Pa$ is maintained when the beam is stored, and a pressure of $10^{-4}Pa$ is maintained 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.

2.3.6 Beam Monitors

The beam monitors installed in the synchrotron are as follows:

- two fast beam current monitors with risetimes of $0.1\mu sec$,
- a direct beam current monitor of one core type,
- a wall current monitor with a risetime of $5ns$,
- six beam-position monitors of $0.1mm$ spatial resolution,
- a betatron-frequency monitor with six knockout electrodes,
- an SR monitor installed in a thin flat chamber in a bending section,
- four screen-monitors,
- a beam scraper with four blades,
- eight gamma-ray monitors distributed around the chamber.

2.3.7 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.

3 Summary

The high-energy electron beam facility of Mitsubishi Electric Corporation consists of a $20MeV$ linac, a $1GeV$ synchrotron, and a superconducting storage ring. The lattice, magnets, injection/extraction, RF system, vacuum, beam monitors, controls of the $1GeV$ synchrotron are presented.

References

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