PRESENT STATUS OF THE 1GEV SYNCHROTRON RADIATION SOURCE AT SORTEC

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Abstract

The design, construction and the initial beam operation of the 1GeV synchrotron radiation source facility at SORTEC have been completed successfully.

The facility consists of a 40MeV electron linac (pre-injector), a 40MeV to 1GeV booster synchrotron and a 1GeV storage ring. Since the major purpose of SORTEC Corporation is to study application technologies of synchrotron radiation, major parameters of the storage ring are optimized for the production of soft x rays around 1 nm which meet the lithography requirements.

The construction of the synchrotron radiation facility has been completed in the end of March 1989 at Tsukuba Research Laboratory of SORTEC. Initial beam operation has been started in the end of July 1989 after four months of tests without beam. The first beam was stored in the storage ring at the design energy on September 28, 1989. In the end of October, the stored beam current of 200mA, which is our design goal, has been successfully achieved with the beam lifetime of over 4 hours only 1 month after the first beam storage. At present, the beam lifetime reached 10 hours.

This paper gives a summary of the characteristics of the facility and describes the remarkable progress during the initial beam operation.

Introduction

Synchrotron radiation is expected to offer remarkable possibilities for many fields of science and technologies. In recent years, there are worldwide interests in the field of industrial applications especially of x ray lithography[1]-[3]. Since the major purpose of SORTEC is to study the application technologies of synchrotron radiation, the facility is optimized for the production of soft x rays around 1nm which meet the lithography requirements[4].

1GeV synchrotron radiation source facility

As shown in Fig.1, the facility consists of a 40MeV electron linac, a 40MeV to 1GeV booster synchrotron and a 1GeV storage ring. Though, in general, industries would prefer that synchrotron radiation source be as compact as possible in the future lithography system, we determined to adopt a steady accelerator system for our facility making use of proven technologies such as full energy injection scheme and normal conducting magnet system in order to attain a stable light source and to provide sufficient intensity of synchrotron radiation as soon as possible.

Table 1 shows major design parameters of our facility together with the achieved values as of October 31,1989. The fact that the beam energy, beam current and lifetime all reached design goals successfully only a month after the first beam storage, indicates the validity of our choice described above.

As to spectral characteristics and the intensity of radiation, the electron energy and the dipole field of the storage ring have been selected to generate synchrotron radiation of nearly 1.5nm critical wave-length (0.65nm peak wavelength) and the stored beam current of 200mA has been chosen. Spectrum and spatial distribution of synchrotron radiation are shown in Fig.2. The average power density within 1mrad vertical angle is $40\mathrm{mW}/\text{Å}/\mathrm{mrad}^2$ at wavelength of 1nm.

The views of the accelerators are shown in Fig.3 The linac and the booster synchrotron are placed in the injector room. The power supplies for synchrotron magnets are placed in another room as shown in Fig.1. In case of the storage ring, the whole power supplies are placed in the storage ring as shown in Fig.3. The accelerators are placed in the basement except for the computer control system. The design details for the synchrotron and the storage ring are described in refs.[5] and [6], respectively.

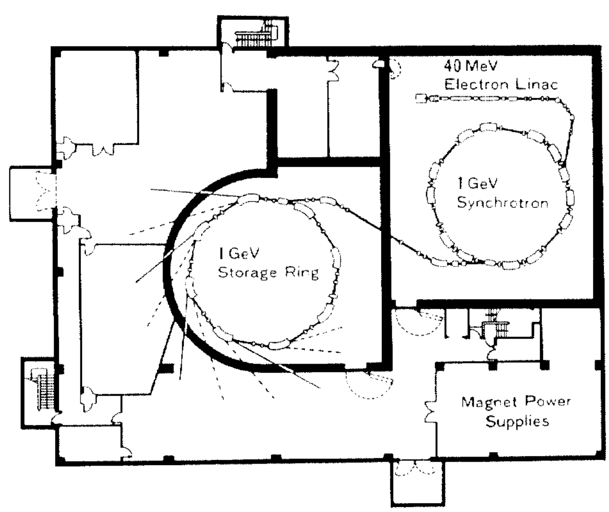

Fig.1 The layout of SORTEC 1GeV synchrotron radiation source facility

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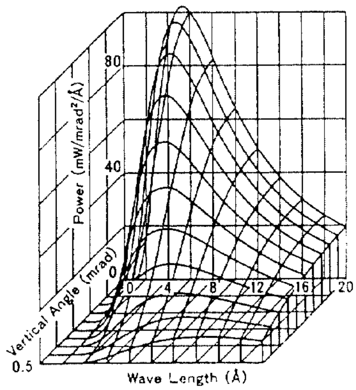
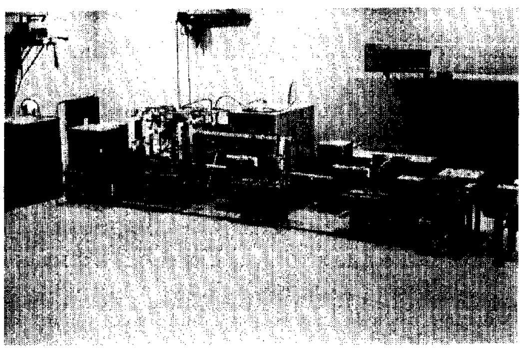


Fig.2 Spectrum and it's spatial distribution



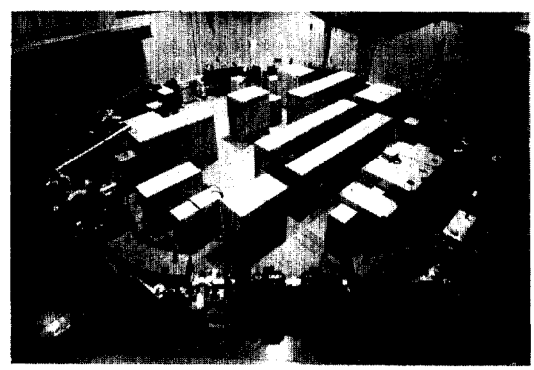
(a) Electron linac

Table 1 : Major parameters of 1GeV synchrotron radiation facility with achieved values as of Oct.31, 1989

	Designed	Achieved
Storage Ring		
Energy	1GeV	1GeV
Dipole Field	1.2T	1.2T
Bending Radius	2.78m	-
Critical Wavelength	15.5Å	-
Peak Wavelength	6.5Å	-
Beam Current	200mA	200mA
Beam lifetime	4hr	4hr
Circumference	45.7m	-
Synchrotron(Booster)		
Injenction Energy	40MeV	40MeV
Maximum Energy	1GeV	1GeV
Dipole Field (maximum)	1.1T	1.1T
Beam Current	30mA	30mA
Circumference	43.2m	-
Linac(Pre-Injector)		
Energy	40MeV	40MeV
Beam Current*	> 30mA	60 ~ 80mA
Energy spread	< ±1.5%	±0.67%
Emittance	< 3.8π mm·mrad	0.7π mm·mrad

* Useful beam current which satisfies values of energy spread and beam emittance

(b) Booster synchrotron



(c) Storage ring (SR ring)

Fig.3 Overview of the synchrotron radiation facility

Initial beam operation and it's results[7]

The initial beam operation of our facility has been started on July 26, 1989. At first, the optics of the beam ejected from the electron linac was surveyed and adjusted so that the beam can be guided along the design orbit of the low energy beam transport line. Also in this transport line, beam current, energy spread and beam emittance were measured.

The output beam quality from the linac satisfied the requirement as a pre-injector as shown in Table 1.

The beam characteristic from the linac and configuration of the beam transport line are reported in detail in ref.[8].

At the beginning of August 1989, beam test of the synchrotron has been started. The beam is injected into the septum magnet and is stacked by multi-turn-injection and energy is ramped from 40MeV to 1GeV in 400ms. Though the injection cycle is designed to be repeated every 800ms, the cycle was repeated every 3.2s during the initial beam operation.

At the middle of September 1989, the beam acceleration to the top energy was succeeded after several beam tests such as the adjustment of betatron tunes and tracking of magnetic fields between dipoles and quadrupoles during the acceleration.

Synchrotron radiation was also observed through a SR beam monitor of the synchrotron during the acceleration.

Average accelerated beam current of 30mA, which corresponds to the design current has been obtained in the early stage of the initial beam operation. The more details about the performance of the synchrotron are reported in ref.[9].

The beam injection into the storage ring and single turn test began on September 27,1989 making use of screen monitors.

The beam current of 3.5mA has been stored at the design energy on the next day. Synchrotron radiation was also observed through SR beam monitors. The first stored beam lasted 2 hours until the beam was stopped by intension. The substantial time required for the beam tuning for the attainment of the first beam storage was 9 hours.

After 2 weeks of beam cleaning by the maximum beam current of around 60mA, the beam lifetime reached 3 hours at 50mA and 2 hours at 80mA.

The stored beam current of 200mA which is our design goal has been achieved on October 23,1989. Also the beam lifetime of 4 hours at 200mA has been achieved at the end of October.

In Fig.4, the improvement of the pressure in the vacuum chamber and the beam lifetime at the end of November 1989, are shown. The beam lifetime has increased to 8 hours at the beam current of 200mA. Corresponding vacuum pressure is 1×10^{-9}Torr. The improvement of the beam lifetime day by day is also shown in Fig.5 which represents the decay rate of the beam current[10].

In parallel with the beam cleaning, the tuning of the beam was carried out such as adjustment of betatron tunes, COD corrections, detuning of the RF cavity and ion clearing, etc.. The more details about the storage ring are reported in ref.[11].

In reference[12], the performance of the vacuum system of the storage ring is described.

Current status

From the beginning of this year(1990), the installation of four beam lines was started and was completed at the end of March 1990. The user operation has been started at the beginning of this May.

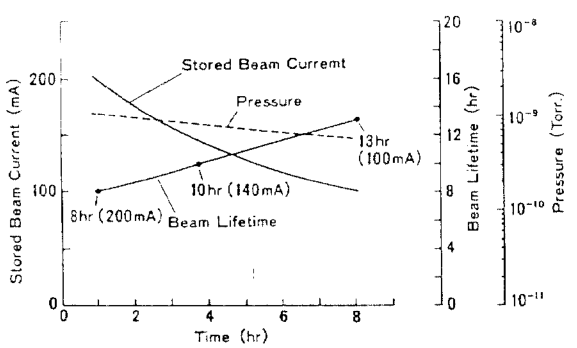


Fig.4 Stored beam current, beam lifetime and vacuum pressure obtained at the end of Nov. 1989

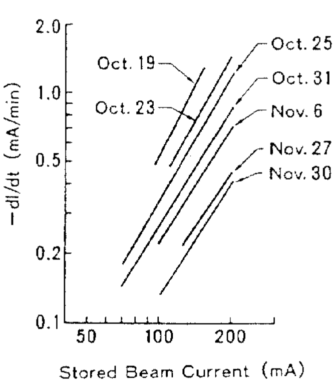


Fig.5 The improvement of the beam lifetime (Decay late plot)

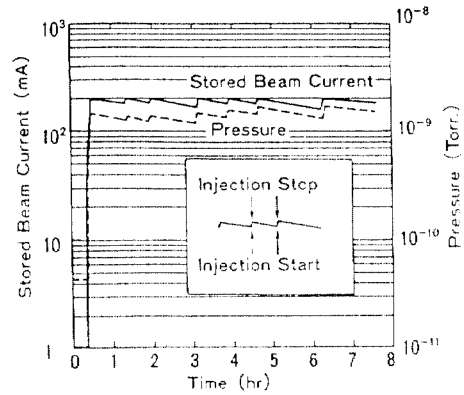


Fig.6 Result of the beam refill operation

Though the facility was not fully operated during the installation of beam lines, the beam lifetime has increased to 10 hours.

Fig.6 shows one of the results from the beam refill operation. As shown in this figure, there are no unstable behavior of the stored beam at the moment of the beam injection. In this example, the refill was manually operated, however, automatic operation can be easily utilized for the fine control of the stored beam current.

The general description of the control system is described in ref.[13].

As to the beam stacking efficiency, the minimum time required for the storage of 200mA beam is only 1 minute up to now. This is faster than our estimation in the design stage.

Since the beam tuning and machine conditioning are in progress, the improvement of the performance can be expected hereafter with more precise measurements of the beam behavior.

In parallel with the regular operation, the machine studies will be continued to achieve the beam current of over 500mA.

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