Performance of SORTEC 1-GeV Synchrotron Radiation Source Facility and Future Plan

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Abstract

The SORTEC 1-GeV synchrotron radiation (SR) source facility[1] started to provide internal users with an SR in April 1990. Since then, regular operation has been stably maintained without serious accidents for two years. The performance of the ring was improved and the beam lifetime with the beam current of 200mA reached over 60 hours. Moreover, making the best use of the full energy injection system, the automatic operation for a constant level control of the stored beam current was confirmed.

In parallel with the regular operation, machine studies are continued for the forthcoming upgrading of the beam current to 500mA. The upgrading is scheduled to start in April 1992.

1 INTRODUCTION

Recently, compact SR sources have been developed as a source for X-ray lithography in producing next-generation ULSIs. Most of these SR sources[2] adopt superconducting magnets or a synchrotron storage system to make the system as compact as possible.

On the other hand, at SORTEC Corporation, a full energy injection system and normal conducting magnets are adopted to attain a stable SR source and to provide sufficient intensity of the SR as soon as possible. The SR source consists of a 40-MeV electron linac (pre-injector), a 40-MeV to 1-GeV booster synchrotron (injector) and a 1-GeV storage ring. The characteristics of the SORTEC SR source are short injection time, long beam lifetime, stable beam refilling and reliable operation without serious accidents. These characteristics are very important for an industrial SR source. At present, through 4 beamlines[3], the storage ring provides internal users with a stable SR.

2 PERFORMANCE OF THE SR SOURCE

2.1 A Regular Operating Pattern

A typical daily operating pattern for users is shown in Fig. 1. It takes only two or three minutes to accumulate the beam current of 200mA at first injection. This is not only because the accelerated beam current by the booster synchrotron is large (>50mA) but also because the total transfer efficiency of a beam transport line combined with injection into the storage ring is high (20-25%). The repetition rate of the injection system is 0.31Hz (max: 1.25Hz). As shown in Fig. 1, refilling of a new beam is done twice a day and is also stable. It takes within one minute to increase the stored beam current from 180mA to 200mA by refilling a new beam. Table 1 summarizes the principal parameters of the SR source including the achieved values and the planned values of the upgrading.

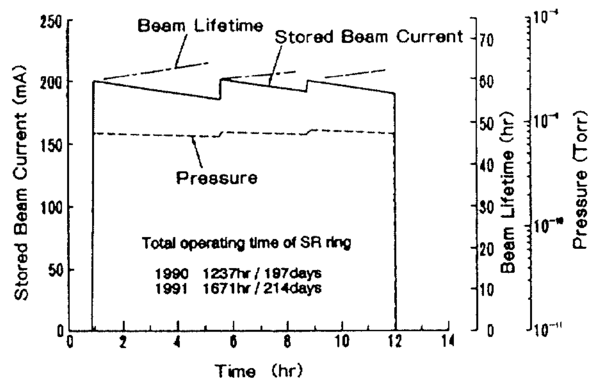

Fig. 1 Typical daily operating pattern

Table 1 Principal parameters of SR facility at SORTEC

	Achieved	Planned
Storage Ring		
Energy	1 GeV	1 GeV
Dipole	1.2 T	*
Critical Wave-length	15.5 Å	*
Radiation Power	6.37 kW	15.93 kW
Beam Current	200 mA	500 mA
Beam Lifetime	>60 hr	>20 hr
Natural Emittance	0.51 mm · mrad	*
Circumference	45.7 m	*
Synchrotron(Injector)		
Injection Energy	40 MeV	40 MeV
Maximum Energy	1 GeV	*
Beam Current	50 mA	*
Circumference	43.2 m	*
Linac(Pre-Injector)		
Energy	40 MeV	*
Beam Current	60~80 mA	*
Energy Spread	±0.67 %	*
Emittance	0.7π mm · mrad	*

2.2 An Estimation of Vacuum Condition

The current pressure profile for the 1/4 sector of the storage ring is shown in Fig.2[4]. This profile is estimated from measured results by cold cathode gauges. Photo cleaning effect in the bending section is higher than that in the straight one. As the result of the residual gas analysis with Q-mass sensor, H_2 molecules amount to over 90% of the residual ones. Present beam lifetime of over 60 hours is dominated by the multiple scattering of electrons on residual gas molecules.

On the other hand, to suppress the influence of trapped ions[4], eight ion clearing electrodes are installed in each straight section. In Fig.3, beam induced potential, togerther with the ion clearing field, and beam size ($\pi \cdot \sigma x \cdot \sigma y$) are shown. An operating condition at storage mode is slightly changed from that at injection mode. At the storage mode, we make a beam round ($\sigma x, \sigma y$=1mm) by using the difference resonance line. This condition results that the minimum positions of the beam induced potential coincide with positions of clearing electrodes.

2.3 A Drift of Beam Position

Figure 4 shows a drift of beam position, which was measured by a SR monitor, during a daily operation. The drift at an initial stage was caused by the temperature change of magnet core because of short warming-up time. After the sufficient warming-up time, the drift of beam position was kept within 100μm in spite of several beam refillings, which was found to be harmless for X-ray lithograpy.

2.4 A Flat Top Operation of The Stored Current

In the lithography process, an SR source with constant intensity is desirable from the viewpoint of simplicity in controlling the whole lithography system, as well as maintaining high throughput. As for the SR source, the beam current inevitably decreases with time during storage. We have tried to control automatically the stored beam current at an almost constant level. The measured result of the stored beam current is shown in Fig.5. Almost flat top operation of the stored beam current can be achieved within 1%

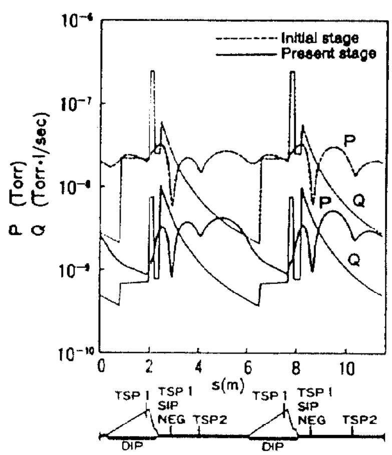

Fig.2 Pressure and gas yield profile for 1/4 sector of vacuum ducts

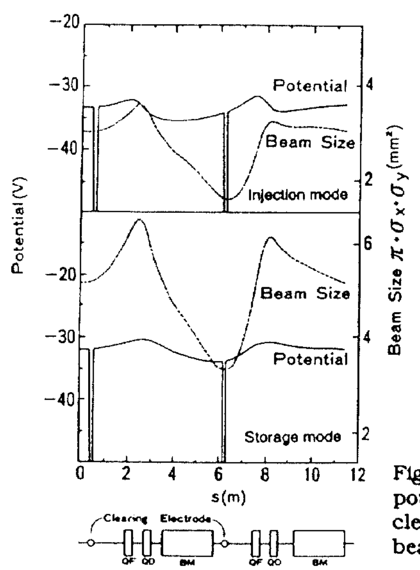

Fig.3 Beam induced potential, applied ion clearing field and beam size($\pi \cdot \sigma x \cdot \sigma y$)

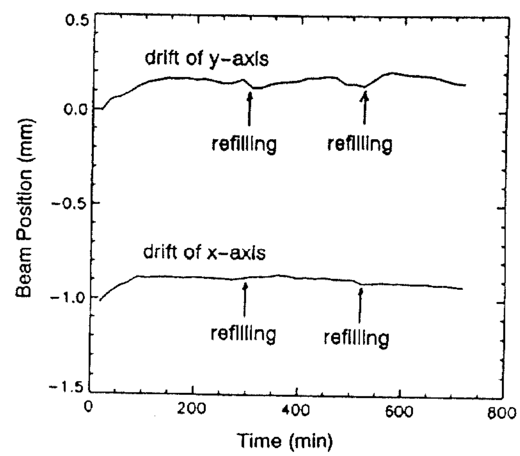

Fig.4 Drift of beam position during daily operation

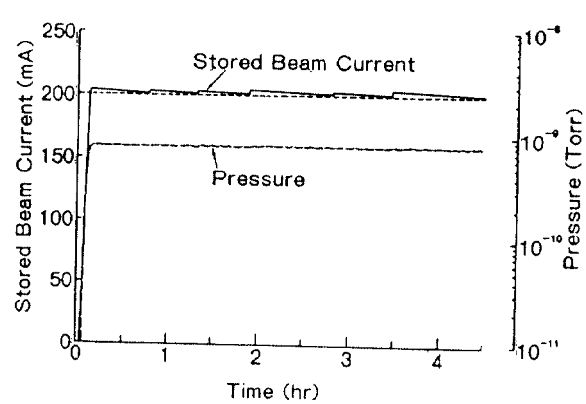

Fig.5 Flat top operation of the stored beam current

fluctuation by the automatic injection of the beam. According to the long beam lifetime, the interval of beam refilling is about 40 minutes and also refilling time is within 5 seconds, which implies that dead time of the exposure for beam refilling is negligibly short.

3 THE UPGRADING OF THE STORAGE RING

The upgrading of the storage ring is scheduled from April through July in 1992[5]. After this upgrading, the radiation power will increase to 15.9 kW at the stored beam current of 500mA as shown in Table 1. For this improvement, the capacity of power supply for an RF cavity will be increased from 14 kW to 28 kW by replacing the main power tube RS2012CJ with RS2058CJ (Siemens). The RF coupler will be also modified along with RF power supply.

In addition to the modification of RF system, the pumping speed of the storage ring will be increased against the higher photo desorption gas. The NEG module (SAES WP-1250,ST707) will be added to remove H_2 at the downstream of the each straight section where the pressure is relatively high as shown in Fig.2. The structure of the NEG pump is shown in Fig.6. This chamber has an ion clearing electrode which is expected to clear trapped ions effectively for the wide operating region. As the basic test, the pumping speed of the NEG module for H_2 in the high vacuum region was measured. The NEG module was confirmed to have sufficient pumping speed around the 10^{-10} Torr region, as shown in Fig.7. After the improvement of the vacuum system, the beam lifetime with 500mA is expected to reach 20 hours.

The other primary problems under higher current are high temperature rise at bending ducts and ceramics ducts. Through machine studies, these problems are turned out solvable by the reinforcement of local cooling systems.

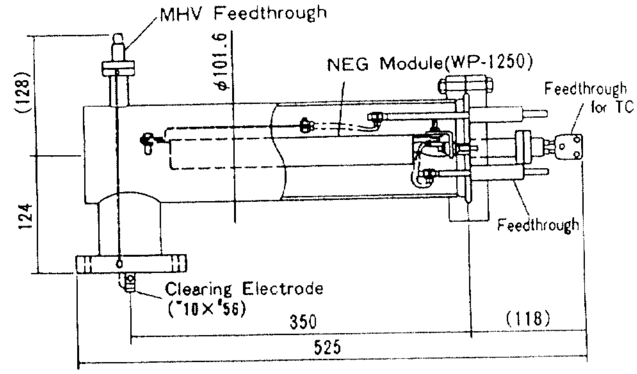

Fig.6 Structure of additional NEG pump

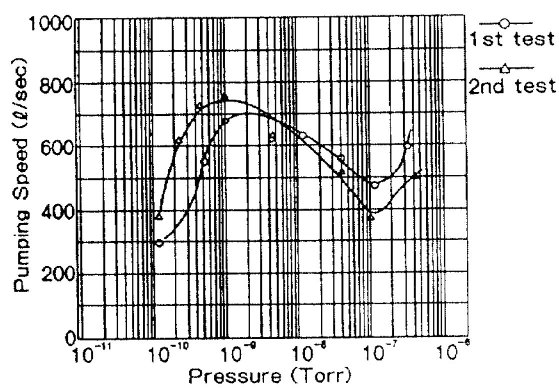

Fig.7 Measured pumping speed of NEG module for H_2

4 SUMMARY

The SORTEC SR source facility was successfully developed in 1989, and regular operation for X-ray lithography experiments was started in April 1990. Since then, the SR source has been operated stably, efficiently and flexibly without serious accidents. These operational features are key factors of an industrial SR source for X-ray lithography. At present, beam lifetime with 200mA has reached over 60 hours. The automatic operation for a constant level control of the stored beam current within 1% fluctuation is also confirmed. In parallel with the regular operation, machine studies are continued for the upgrading of the storage ring. This upgrading of the beam current to 500mA is scheduled to start in April 1992.

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