Present Status of SORTEC 1-GeV 500 mA SR Source Facility

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Abstract

At the SORTEC 1-GeV synchrotron radiation (SR) source facility for the study of SR lithography, upgrading of the stored beam current to over 500 mA has been successfully achieved. Although details of reconstruction work and results of operation tests for the upgrading, and upgraded performance of the storage ring (SR ring) has been presented, the upgraded performance of the SR ring is discussed further in terms of high current, long lifetime, current control, radiation safety and update operating statistics at SORTEC SR facility in this paper. The recent vacuum trouble is also briefly shown.

I. INTRODUCTION

The SORTEC SR facility which was constructed mainly for SR lithography development has been successfully operated since October 1989 without serious failures. However, a maximum stored beam current(hereafter current) of 500 mA with beam lifetime (hereafter lifetime) of 20 h is needed for the SR ring to achieve high throughput requirement for SR lithography [1]. Upgrading of the SR ring to 500 mA to achieve this requirement was scheduled and preliminary machine studies to solve technical problems were carried out [2][3].

The reconstruction work for the upgrading was completed successfully on schedule, and the maximum lifetime reached 25 h at 500 mA. Details of reconstruction work and operation tests were presented in ref.4 and 5.

In this paper the upgraded performance of the SR ring is discussed further in terms of high current, long lifetime, current control, radiation safety and update operating statistics at SORTEC SR facility. The recent vacuum trouble and beam operations without baking after the trouble are also briefly shown.

II. UPGRADED PERFORMANCE OF SR RING

A. Summary of test operation [4]

The required current of 500 mA is achieved with the lifetime of 10 h only 12 days after the restart of beam operation on July 2, 1992 mainly owing to the memory effects of beam duct cleaned by a beam dose over a long period.

Since August 5, 1992 the storage ring has been started again to provide SR first at a current of 200 mA for users. Subsequently the lifetime was extended steadily according to the increase of integral dose. The maximum lifetime reached 25 h at 500 mA in February 1993.

Table 1 summarizes the designed and achieved performance. Figure 1 represents a typical daily operation. Lifetime in this example is 24 h with 500 mA at 1 GeV. A nominal current of 500 mA is stored within 10 min. New beams are refilled in one or two-minute doses to recover the beam reduction of about 15 % only once or twice a day. Owing to a result of the upgrading of the current to 500 mA from 200 mA, synchronous radiation power was increased by two and a half times. The power density per horizontal angle of 1 mrad ranging from 0 to 2 nm was 1470 mW /mrad.

Table 1. Main parameters of SR facility at SORTEC.

		Designed	Achieved
Storage Ring			
Energy	Get	1	1
Dipole Field	T	1.2	1.2
Critical Wavelength	nm	1.55	–
X-Ray Power	kW	15.9	15.9
Beam Current	mA	500	500*
Beam Lifetime	h	>4	>22**
Natural Emittance	mm·mrad	0.51	–
Circumference	m	45.7	–
Synchrotron (Injector)			
Injection Energy	MeV	40	40
Maximum Energy	GeV	1	1
Beam Current	mA	30	50
Circumference	m	43.2	–
Linac (Pre-Injector)			
Energy	MeV	40	40
Beam Current	mA	>30	60~80
Energy Spread	%	<±1.5	±0.67
Emittance	π mm·mrad	<3.8	0.7

* max. 512 mA
** max. 25 h (80h at 200mA)

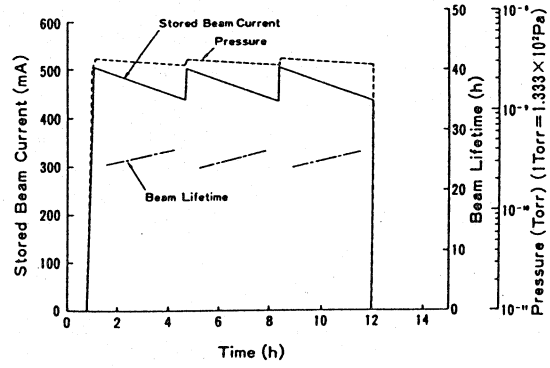

Figure 1. Typical daily operation.

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B. Upgraded performance [5]

1) High stored beam current

·*RF accelerating system* The RF-generator-produced power was increased to 28 kW. The calculated value of the power agrees well with measured values of up to 500 mA, and attained 22 kW at 500 mA. This shows that the current of 600 mA can be stored at 28 kW [5].

·*Cooling of the ceramic ducts and bending ducts* The temperature rise due to the increase of current was the primary problem and was solved as follows. The temperature rise of the ceramic duct facing a bump magnet was reduced to one-half by forced ventilation using a fan, as shown in Figure 2. The temperature rise around the SR port of a bending duct was also suppressed by adding local water-cooling pipes.

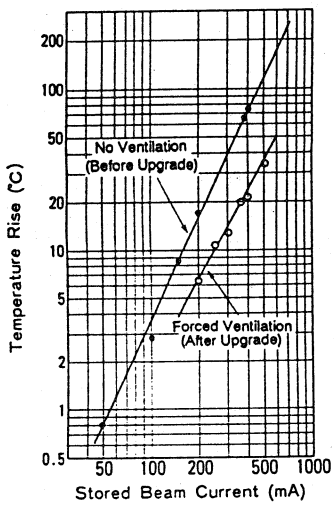

Figure 2. Temperature rise of the ceramic duct facing a bump magnet.

2) Long beam lifetime

·*RF accelerating system* The cavity voltage was increased from 90 kV to 100 kV to improve the Touscheck lifetime [6].

·*Vacuum system* The pumping speed was increased by 2000 l/s against the higher-photo desorption gas under increased current. NEG (Non Evaporable Getter) pumps were newly added to remove H_2 at downstream of each straight section where the pressure is relatively higher than that in each bending section. The normalized pressure $\Delta P/I$ was almost flat before upgrading, but again began to decrease sharply after upgrading. The lifetime exceeded 70 h at 200 mA, which had been the maximum value before upgrading, and reached 80 h only after 8 months.

·*Effect due to trapped ion* The stripe-type ion clearing electrode, was newly installed in each chamber of the NEG pump. One clearing electrode was newly installed at the one straight section not previously equipped with an electrode. The voltage of power source was changed to -1500 V from -500 V. The lifetime was improved with voltage less than a value which was almost proportional to current. For example the lifetime was improved to 22 h from 9 h at 500 mA by applying the voltage of -1100V.

3) Beam current control.

As shown in II.*A*, based the merits of full energy the nominal current of 500 mA is stored within 10 min. Based on not only the merits of the injection but stable long lifetime, the current can be kept constant at 500 mA within ± 2% by refilling beams every 30 min, as shown in Figure 3. This operation is effective for X-ray lithography.

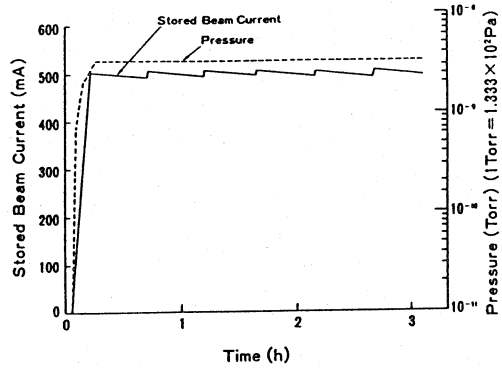

Figure 3. Constant control of the stored beam current.

4) Radiation safety

The amount of radiation measured by TLD (thermoluminescence dosimeter) at SORTEC SR facility is shown as the weekly dose equivalent in μ Sv/week (value of background is subtracted) in Figure 4. The amount of radiation before upgrading was shown in ref.7. The regular measuring points were increased twice to 24 points in according with upgrading to a 500 mA ring. Even after upgrading, outside the concrete shields, radiation generated in operation of the SR source facility is of the same level as that of the background and far lower level as compared with the 1 mSv/week limited by law. It depends heavily on high injecting efficiency and effective radiation shields at the SORTEC SR source facility.

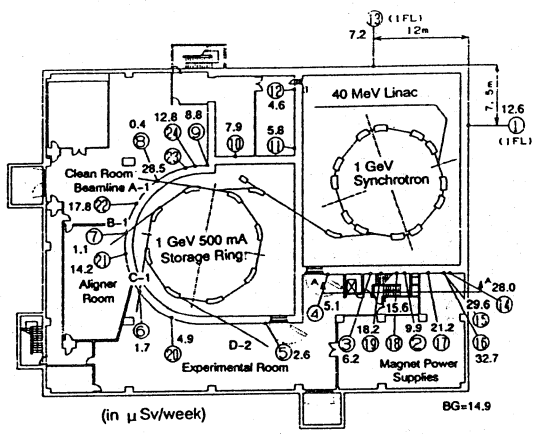

Figure 4. Amount of radiation measured by TLD at SORTEC SR facility.

III. OPERATING STATISTICS

The total monthly integrated current of the SR ring from April 1992 to May 1993 is shown in Figure 5. This period is divided into two. One is "before upgrade" which is from April 1991 to April 1992. The other is "after upgrade" which is from July 1992 to March 1993. In May and June 1992, the SR source was shut for reconstruction work. In April and May 1993, irregular operation occurred

because of vacuum trouble. The integrated current has been gradually increasing, corresponding to the increase of demand for operation at 500 mA from users and some extension of operating time for them, and recorded 66.5 A·h. The average "before upgrade" and the average "after upgrade" of the total monthly integrated current were 29.7 A·h and 45.6 A·h (53% increase) respectively.

The total monthly operating time of the SR ring and electric power consumption of the SR facility in the same term as mentioned above are shown in Figure 6. The "before upgrade" and the "after upgrade" values of the average total monthly operating time of the SR ring were 156 h and 189 h (21% increase), respectively. The average "before upgrade" and the average "after upgrade" of the total monthly electric power consumption of the SR facility were 372 MWh and 392 MWh (6% increase), respectively.

The total monthly electric power consumption of SR facility is not affected very much, in spite of the increase of the total monthly operation time and the total monthly integrated current due to upgrading, because 200 ~ 250 MWh (about 60 % of total electric power consumption) is consumed even if the SR ring is shut down.

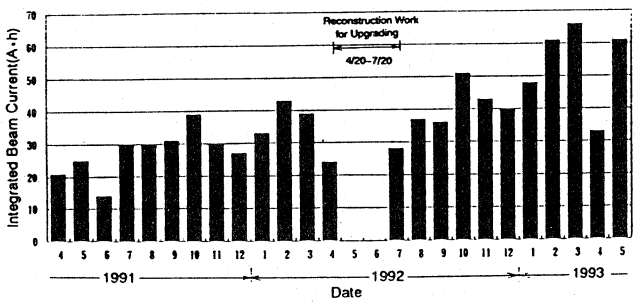

Figure 5. Total monthly integrated current of SR ring.

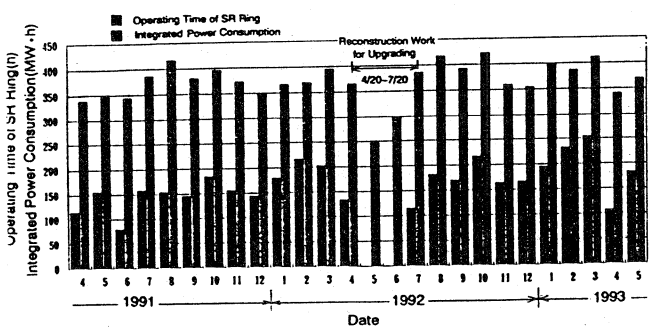

Figure 6. Total monthly operating time of SR ring and power consumption of SR facility.

IV. VACUUM TROUBLE AND RECOVERY

On April 2, unfortunately, vacuum trouble was caused by corrosion in the part of the metal brazed to the ceramic joint on the high-voltage feedthrough of the sputter ion pump installed at the straight section (S-8). Beam operations were performed for 50 days from April 14 to June 3 without baking in the vacuum duct. Figure 7 shows the improvement of lifetime after April 14 as a function of time-integrated beam current in comparison with the data from first beam operation in 1989 and upgraded beam operation to 500 mA after July 2, 1992. After 102 A·h of integrated current, The lifetime reached 10 h at 500 mA ($i \cdot \tau$ =5.0 A·h) at less than 2 weeks after 20 A·h of integrated current. To recover the lifetime faster, the vacuum components in a duct were baked again for 48 h at 150 ± 10 ℃ during the term of annual periodical inspections of the SR source facility in June as scheduled. The beam operation will resume early in July, and it is expected that the lifetime will recover fast like at the reconstruction work last year.

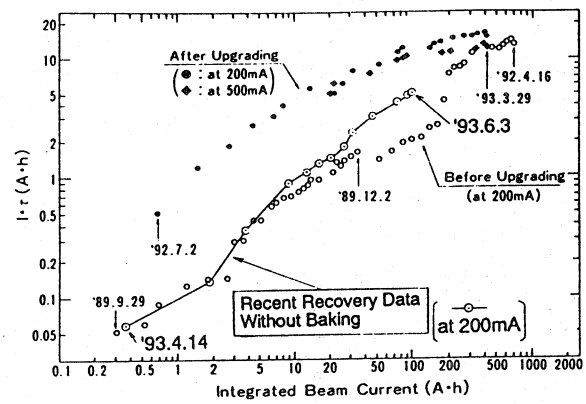

Figure 7. Improvement of beam lifetime as function of integrated beam current.

V. CONCLUSIONS

As a result of the success of upgrading to 500 mA with over 20 h, the SORTEC 1-GeV SR source has attained top levels for current, lifetime and X-ray power as a SR source dedicated to industrial use. To attain more reliable operation hereafter, more careful and more frequent inspections of the SR source are needed, considering the vacuum trouble just overcome.

VI. ACKNOWLEDGEMENT

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