STATUS OF KEK-PF STORAGE RING

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INTRODUCTION

The 2.5 GeV electron storage ring constructed at the Photon Factory, KEK, is the dedicated machine for the research work with synchrotron radiation. The principal parameters of the storage ring are listed in Table 1. The storage ring is essentially a X-ray ring, however, one third of users are coming from the fields of VUV region. Although the 3 GeV operation of the ring was succeeded on June 1983, the ring has been operated at the nominal energy of 2.5 GeV, because of the lack of the RF power. This means that in the normal operation the critical wavelength of synchrotron radiation is 2.98 Å. The superconducting vertical wiggler has been operating normally in the user's time since February 1984. The aimed field strength is 6 T, however, the wiggler is now operating at 4.5 T, because above 4.5 T there observed some beam instability. This field strength give the critical wavelength of 0.64 Å, which makes possible to do research works using hard X-ray of about 0.2 Å. The permanent magnet undulator which has 60 periods had come into operation since February 1983. This supplies synchrotron radiation with the high brightness in the wavelength region from 7 Å to 400 Å. The brightness is higher by about two orders than that of synchrotron radiation coming from the bending magnet.

Table 1. Principal parameters of the storage ring

Energy	2.5 GeV max. achieved 3.0 GeV
Stored current	150 mA max. achieved 250 mA
Mean radius	29.77 m
Radius of curvature	8.66 m
Critical wavelength	2.98 Å (0.5 Å at 6 T wiggler)
Emittance	horizontal $5.4\pi \times 10^{-7}$ m.rad.
	vertical $6.5\pi \times 10^{-8}$ m.rad.
RF frequency	500.105 MHz
Harmonic number	312
No. of cavity	4
Radiation loss	399 keV/rev.(510 keV with wiggler)
Straight section	2 long 5 m
	8 medium 3.5 ∿ 3.75 mm
Insertion devices	vertical wiggler 4.5 T (aimed 6 T)
	60 period undulator k=1.78 ∿ 0.1
SR channel	SR Exp. 8, beam diagnosis 1
Vacuum pressure	3×10^{-11} torr no beam
	4×10^{-10} torr at current of 100 mA
Beam lifetime	15 hr at I=150 mA. 30 hr at 100 mA
Injection energy	2.5 GeV
Injection rate	1 Hz
Injection time	1.5 ∿ 10 minutes

OPERATION

The scheduled operation of the storage ring started on June 1982 (run 2), and the run 8 was ended on July 1984. Except for the run 2, which was used mainly for machine tuning up, the storage ring was routinely operated at 2.5 GeV in multi-bunch mode. So far the stored current record was 250 mA, the initial stored current was limited to 150 mA because of the heating problem of the vacuum chamber. In a normal operation week, the storage ring is operated from Tuesday morning 9 o'clock through Saturday morning. During 96 hours operation, 64 hours are dedicated to user's experiments, 24 hours are used for the accelerator study and 8 hours for machine tuning up. From FY 1983, the storage ring accumulates the beam at the very beginning of the Linac study time, so that users can make experiment during this eight hours study. This is the reason why the operated user time has become beyond two third of the total operating time, though the first week of every run was used only for machine tuning.

The beam time statistics from April 1982 to July 1984 is shown in Table 2. As for the effective time during which users can use synchrotron radiation, that is, the time except the time needed for injection, machine failures and other miscellaneous times, the ratio in the total operated user time is exceeded 90%. The percentage of machine failure is less than 3%, and the percentage of injection time is also less than 6%. In short, the storage ring has operated quite efficiently and stably.

Table 2. Beam time statistics

Fiscal year		1982	1983	1984*	total
Ring operation time	hr	1298	2047	811	4156
Integrated current	A•hr	58	157	67	282
User's time**					
scheduled	hr		1336	384	
operated	hr	661	1357	423	2441
effective time	hr	594	1241	381	
time for injection	hr		66	33	
machine failure	hr	67	31	3	
miscellaneous	hr		19	6	
integrated current	A•hr	40	123	39	202
average current	mA	68	99	101	
number of injection		233	261	67	
ave. injection interval	hr	2.6	4.8	5.7	
Wiggler operation					
operated time	hr		115	175	
average current	mA		103	92	
ave. injection interval	hr		3.3	5.3	

* till July 27
** including wiggler operation

Concerning with the injection time, the rate of injection is 1 Hz and the beam storing rate is ranging from 0.1 mA/sec to 2 mA/sec depending on the matching between Linac (2.5 GeV) and the storage ring. So the accumulating time is very short, say, a few minutes. However, some beam instability was observed during injection and it took long time to accumulate beams of 150 mA. In FY 1983, the average injection time was 15 minutes including the reconfirmation of the radiation safety. Although the study on beam instabilities had progressed through FY 1983, the average injection time in FY 1984 becomes much longer and is about 20 minutes. The reason is that the wiggler has been operated in an amount of 45% in the total time and it takes about 20 minutes to operate the wiggler, because the vertical wiggler operation consists of following complicated procedure; scraping beams, reducing the current of the superconducting coils, moving up the wiggler magnet, injecting beams, moving down the wiggler and exciting coils.

IMPROVEMENT OF VACUUM PRESSURE AND BEAM LIFETIME

As illustrated in Fig. 1, the weekly average of stored current has grown up by and by, though the initial current is still limited to 150 mA, and now the average becomes to about 100 mA inspite of the wiggler operation. The average time interval between injections also became longer, and on December 1983, the injection took place once every eight hours. Both facts mainly attributes to improvement in the beam lifetime, which means also that the vacuum pressure has

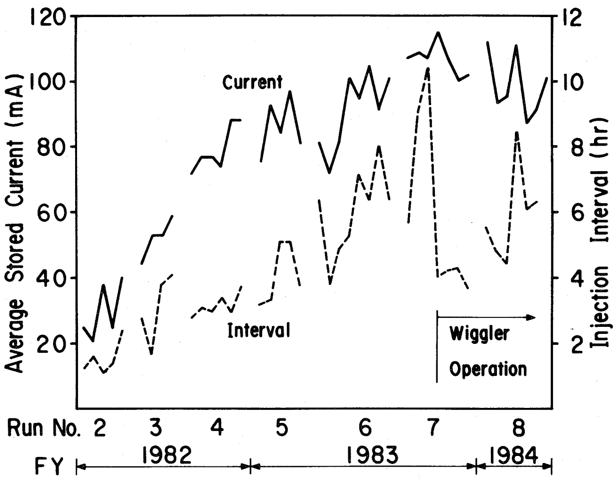

Fig. 1 Progress of the weekly average of stored current and of time interval between injections. Initial current is limited to 150 mA.

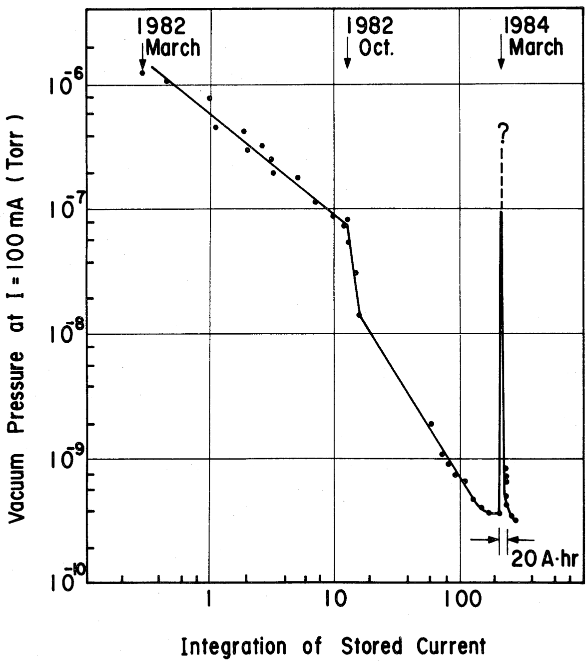

Fig. 2 Improvement of the vacuum pressure as a function of the time integration of stored current. October 1982, argon discharge cleaning was done, Ti-getter pumps were added and distributed ion pumps started in operation. March 1984, N_2 gases leaked into the vacuum chamber.

been improved through the operation as can be seen in Fig. 2. At the end of the run 8, the beam lifetime was 15 hours at the current of 150 mA and 30 hours at 80 mA. Figure 3 the best example of the beam decay recorder. The initial current was 152 mA and 19 hours after injection, the stored current still remained 67 mA and the beam lifetime was 46 hours at this point.

DETERIORATION OF BEAM LIFETIME

Two types of the beam lifetime deterioration were observed. The first type is closely connected to the vacuum pressure as is seen in Fig. 3. This phenomena had been never observed before the partial fill operation has started. The partial fill operation means

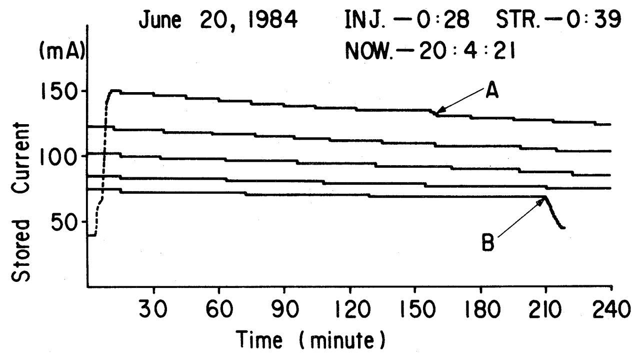

Fig. 3 The best example of the beam decay recorder. A and B show lifetime deteriorations.

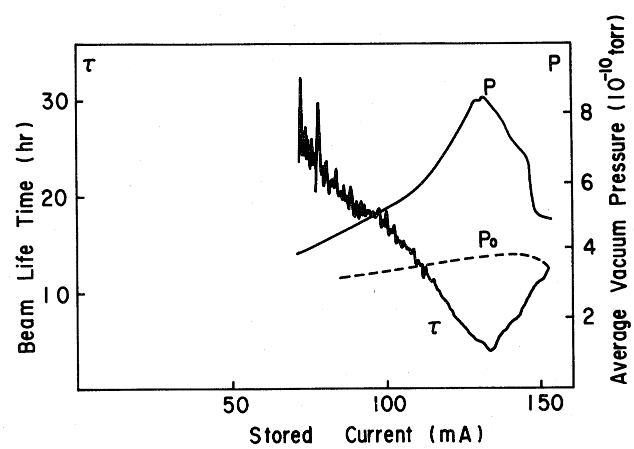

Fig. 4 An example of the beam lifetime deterioration connected to the rise of vacuum pressure. P_o is the vacuum pressure in the normal case.

that about one third of RF buckets (total 312) remains empty and other RF buckets are filled with electrons nonuniformly. In this operation mode, wake fields which are generated by electron bunches in the cavities or cavity like chambers are stronger than that in the uniform fill operation. In fact, this operation gives a wrong vacuum pressure near the gate valves which have no RF shield and have Viton gaskets inside valves. The rises of vacuum pressure near the gate valves are not so high to shorten the beam lifetime. On the contrary, the vacuum pressure near the cavities is gradually raised up to shorten the beam lifetime as shown in Fig. 3. In a extreme case, the vacuum pressure is raised up to 10^{-7} torr region. (P in Fig. 3 is the averaged value around the ring). It seems that wake fields in a cavity may be related to this phenomena, because it occurs more frequently when the filling shape of RF buckets is more sharp. Sometimes this phenomena occurs repeatedly for every injection. In such a case, we stop to store beams for two hours, then the storage ring again works well. These facts suggest that wake fields may heat some part of the cavity and make digassing, however, the problem is not yet solved.

The second type of deterioration has perfectly no relation to the vacuum pressure and occurs quite rapidly. Two examples are seen in Fig. 3, A and B. In the case of A, the beam lifetime which was 700 minutes suddenly became 60 minutes and 3 minutes after the lifetime recovered. In the case of B, the lifetime changed from 2800 minutes to 40 minutes and did not recover. The vacuum pressure was continuously measured, but there were no change at A and B. Statistics of the deterioration shows that the time interval between deteriorations has a poisson's like distribution and the average interval was 29 hours and the peak

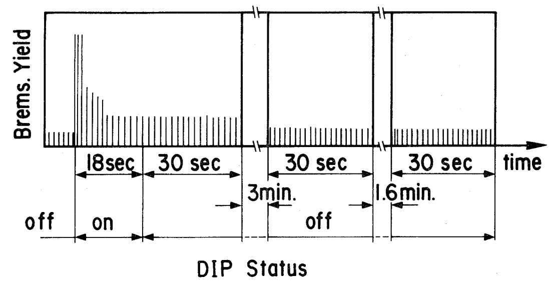

Fig. 5 Bremsstrahlung generated by collisions between electron beams and residual gases. A distributed ion pump (DIP) not operating for a day is switched on, then, a burst of yield was observed.

is located at 5 hours.

The origin of deterioration is considered as the heavy ion trapping. Heavy atoms, such as argon, are emitted from the vacuum chamber or ion pumps, ionized by collision with electrons and are trapped into electron beams. To demonstrate this assumption, bremsstrahlungs generated by collision between electron beams and residual gasses are measured. The counter telescope aimed the beam orbit in the bending magnet B-20. The distributed ion pump (DIP), which is installed in B-20 and did not operate for a day, was switched on (SW-on), then a burst of the bremsstrahlung yield was observed as shown in Fig. 5. The yield at the burst reached 7 times higher than that before SW-on and then decreased like step functions. After 18 sec, DIP was SW-off, still the yield remained twice of that before SW-on. Another experience was that a DIP was repeated SW-on and SW-off, then the lifetime fell to a few minutes. This fact can not be explained by heavy ion trapping. A new theory is that a fine particle of some material falls into beams, irradiated by synchrotron radiation, emitting many photoelectrons to be charged heavily and is trapped by beams. But we have no method to testify the theory.

STUDY ON STORAGE RING

The study on the storage ring itself is helpful to supply more stable and powerful synchrotron radiation for users. Accordingly, in a normal operation week, twelve hours are used for this study.

Tune diagram survey: On the tune diagram, except betatron resonance lines and their satellites, many lines or islands on which the beam lifetime is short are observed. Specially in the wiggler operation, the pattern of these lines or islands is complicated and seems to depends on field strength of the wiggler. So extensive survey must be necessary to rise up the field strength of the wiggler.

Coupled bunch instabilities: A longitudinal instability which is excited by the higher order mode resonance of cavity, 758 MHz, was observed. Also two horizontal instabilities (830 MHz, 1070 MHz) were observed and were cured by lowered the temperature of cavity cooling water. The longitudinal instability gives no beam loss but accompanies the horizontal beam density modulation with the frequency of about 200 Hz, which sometimes makes the beam lifetime short. There are two RF stations in the ring and the suitable phase change between two RF stations can cure this modulation, but the phase control is not so easy. Another method of the cure is to modulate the RF power with the synchrotron frequency, but this enlarges the beam size both in horizontal and longitudinal direction.

Two beams instability: This instability is caused by so-called ion trapping and induces the pulsation of beam density in the vertical direction. The partial fill operation, already mentioned, can eliminates the pulsation fairly well. Another method of the cure is that RF fields with the frequency of about 1.3 MHz are applied to the beam. The mechanisms of these cures is not clearly understood.

Head-tail instability: This instability was observed in the partial fill operation and more clearly in the single bunch operation. This instability was cured by operating the sextupole magnets which corrects chromaticities of both horizontal and vertical direction to zero or slightly positive value.

In the machine study, RF knock out electrodes measuring the betatron tune, the spectrum analizer measuring the frequency of a oscillation which is the origin of a beam instability, the television camera measuring the beam profile, the photodiode array measuring the electron density distribution, the counter telescope measuring bremsstrahlung, that is, measuring the local vacuum pressure at the electron beam, undulator lights measuring the brightness of synchrotron radiation, these were used as powerful apparatus, and now a streak camera is introduced as a useful tool.

FUTURE IMPROVEMENT

Realignment of quadrupole magnets: The construction of a large building for TRISTAN was finished, but it gave a mis-alignment of Q-magnets and, inevitably, gave a closed orbit distortion of order of 4 mm. This distortion was corrected by using steering magnets, however, it will become difficult to give the correct light axis to every beam channel when the number of channels will increase. Accordingly, the realignment of Q-magnets must be done when the ground is settled stably.

Increase of cooling system for vacuum chamber: The present cooling system limits the stored current to 150 mA, so that about fifty light absorbers cooled with water will be inserted into the vacuum chamber.

All metal gate valve: The present gate valves have Viton gaskets. In the single bunch operation, strong wake fields heat viton gaskets and give a wrong vacuum pressure, which limits the stored current less than 20 mA. So these valves will be changed by all metal gate valves with RF shields.

Water cooling system for cavities: Coupled bunch instabilities are very sensitive to the temperature of cavities. A new water cooling system will finely control the temperature of each cavity independently.

Higher order mode damper: To cure coupled bunch instabilities, higher order mode dampers will be inserted into each cavity. Now, two damping antennas were built, and the test with RF power of 60 kW is progressing.

Octupole magnet: For instabilities, the origin of which is not known, octupole magnets are useful to make Landau damping.

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