ION INSTABILITY OBSERVED IN PLS REVOLVER IN-VACUUM UNDULATOR*

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Abstract

Revolver In-Vacuum X-ray Undulator which was designed and fabricated at Spring-8 is under commissioning at PLS. This planar undulator whose permanent magnet array structure is a revolving type with 90-degree step provides 4 different undulator wavelengths of 10, 15, 20, and 24 mm. The minimum gap of the undulator is 5 mm. It was observed that the trailing part of a long bunch-train was scraped off due to ion instability when the undulator gap was closed down below 6.4 mm. At that time the vacuum pressure in the undulator, which is estimated to be several times lower than that at the undulator gap, increased from 1.4×10^{-10} (gap 20 mm) to 7.9×10^{-10} Torr (gap 6 mm) at the stored beam current of 100 mA. This high vacuum pressure causes fast beam-ion instability: trailing part of a long bunch-train oscillates vertically. It was also confirmed that adjusting the orbit along the undulator has improved the situation appreciably. The ion instability measured with a pico-second streak camera and a one-turn BPM as well as the result of orbit adjustment will be described in this paper.

INTRODUCTION

The in-vacuum undulator has become popular in the 3-rd generation light sources because it provides a possibility of hard x-ray experiments in a medium-scale SR facilities. Many SR facilities such as SLS, ESRF, KEK, SSRL, SPring-8, NSLS, ALS, and PLS are using in-vacuum undulators [1, 2, 3].

The stray synchrotron radiation should be blocked by appropriately located photon stops in the storage ring to keep the vacuum good because the outgassing from the chamber surface irradiated by stray synchrotron radiation is very huge. But the continuous irradiation of small amount of stray synchrotron radiation can make the chamber surface clean. Under the certain circumstances such as misguided or badly set orbit, the chamber already cleaned before does not cast an outgassing problem.

In the out-vacuum undulator the inner surface of the vacuum chamber is likely to be continuously cleaned by stray synchrotron radiation so that the surface is very clean and is not weak to beam wake and/or stray synchrotron radiation. But, the permanent magnet array of in-vacuum undulator which is covered with copper plate is exposed to electron beam and stray synchrotron radiation. The cleaning by stray synchrotron radiation is only effective when the gap is closed down enough to see the radiation. Thus, the surface condition is not good because the cleaning is intermittent depending on the position of the magnet array. That is why the inner surface of the in-vacuum undulator is weak to stray synchrotron radiation.

In PLS (Pohang Light Source) there are six insertion devices in the ring: two out-vacuum undulators, two out-vacuum wigglers, and one in-vacuum undulator. The in-vacuum undulator is a revolver undulator (Revolver In-Vacuum X-ray UNdulator) designed and fabricated at Spring-8 [4]. The concept of a revolver undulator is to mount a number of magnet arrays with different period lengths on a rotary beam, which enables users to select an appropriate one among them for their experiments. The permanent magnet array structure of the revolver undulator is a revolving type with 90-degree step, which provides 4 different undulator wavelengths of 10, 15, 20, and 24 mm. The available radiation wavelengths are four times the conventional in-vacuum undulator. Figure 1 shows the magnet array structure. The magnet material is Nd2Fe14B. The minimum gap of the revolver is 5 mm and its magnet length is 1.2 meter.

We observed ion instability when the gap of the revolver was closed down below 6.4 mm. The instability was caused by vacuum degradation in the revolver. It was also found that adjusting the orbit along the revolver has improved the situation appreciably.

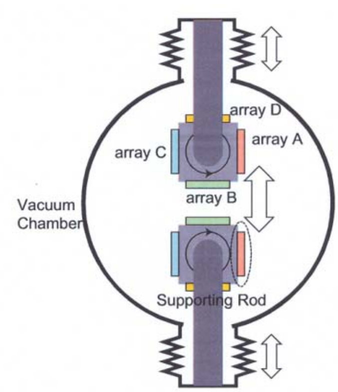

Figure 1: Permanent magnet array structure of the in-vacuum revolver (RIVXUN).

ION INSTABILITY

When the gap size was above 7mm, there was no instability and no lifetime change at the beam current of 165 mA. However, below 6.4mm, transverse ion instability appeared and then beam loss occurred. At that time the re-

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volver vacuum pressure increased by 10 times as the gap was changed from 20mm to 6mm. However, the average vacuum pressure of other places in the ring remained at 5.0×10^{-10} Torr.

A pico-second streak camera image reveals that this ion instability is fast beam ion instability (FBII) as shown in Fig. 2 which is generated by a localized population of ions in high vacuum region [5, 6]. High vacuum pressure in the revolver gave rise to this instability: trailing part of a long bunch train oscillates vertically.

Figure 3 shows the bunch train signal after the ion instability was generated. The bunch current profile was uniform before the ion instability. Due to ion instability the trailing part of a long bunch train was scraped to a triangular shape, which means the effective beam sizes must be linearly growing along the bunch train as FBII grows [7]. The physical aperture of the storage ring reduced to the revolver gap size.

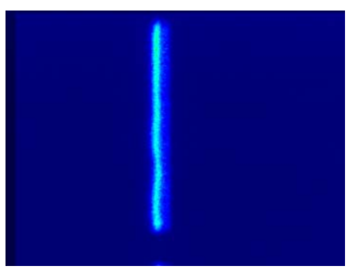

Figure 2: A pico-second streak camera image. Horizontal axis represents the beam motion in the vertical direction. The full extent of vertical axis is $1\mu s$.

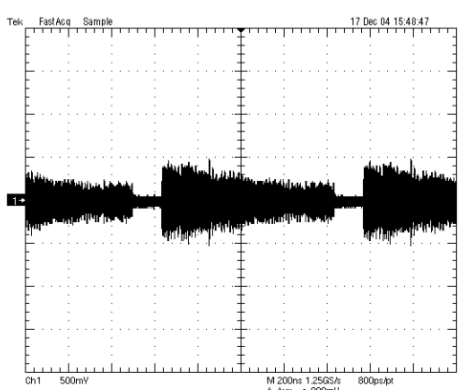

Figure 3: Bunch train signal after the ion instability was generated. The horizontal time division is 200ns. The ring revolution time is 0.936 μs. The unfilled part is ion-clearing gap.

Figure 4 shows the measured vacuum pressure in the revolver as a function of the gap size. Surprisingly, the vacuum pressure increased by one-order of magnitude as the gap was closed down to 5 mm. The measured point is not close to the revolver gap. The vacuum pressure near the gap is estimated to be several times higher than the measured one. Thus the vacuum pressure at the revolver gap of 5 mm is higher than 5×10^{-9} Torr.

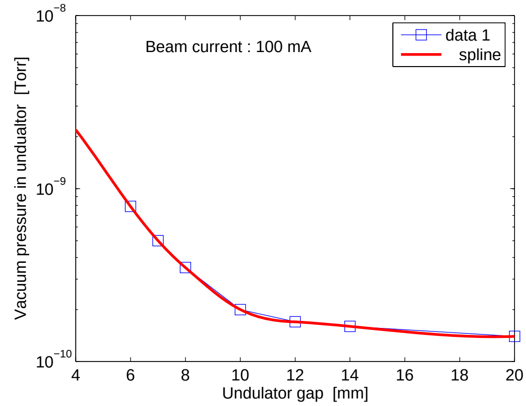

Figure 4: The vacuum pressure in the revolver as a function of the revlover gap.

Figure 5 shows the horizontal and vertical beam oscillations obtained by a turn-by-turn digital BPM when the gap was set at 6 mm. There was no movement in the horizontal direction but a very large blow-up in the vertical direction as high as 700 μm in peak to peak. The digital BPM data in the figure is an average value of all bunches for each turn. Thus, the oscillation amplitude of the tail must be much bigger than 700 μm. Growth and damping of coupled bunch instability is clearly seen in the figure. The growth time of the instability is about 2 ms. The transverse damping time of PLS storage ring is 8 ms.

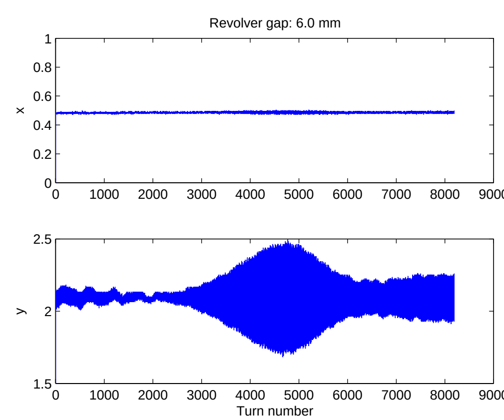

Figure 5: The horizontal (x) and vertical (y) beam oscillation obtained by a turn-by-turn digital BPM when the gap was set at 6 mm. The unit of vertical axis is mm and one turn in horizontal axis corresponds to 0.936 μs.

SUPPRESSION OF ION INSTABILITY

In order to suppress the ion instability the orbit adjustment was performed for the orbit around the upstream dipole magnet and around the revolver. Stray synchrotron radiation from the upstream dipole magnet may strike the inner structure of the revolver. The in-vacuum undulator system was baked to reach UHV levels. The temperature for the bakeout is about 200 ^oC for the vacuum chamber and 125 ^oC for the magnet arrays. Even though the bakeout is properly done, if the stray synchrotron radiation hits the inner structures of the revolver the vacuum condition is getting worse.

Figure 6 depicts the lattice around the revolver and the upstream dipole magnet. At first we adjusted the orbit around the upstream dipole magnet (BM3), BPM 10-8 and 10-9, by using two corrector magnets, CM4 and CM5. The orbit adjustment around the upstream dipole magnet reduced the vacuum pressure in the revolver to certain level, but not enough to suppress the ion instability. And a fixed photon mask with a vertical aperture of 8 mm was installed in front of the revolver, but no improvement.

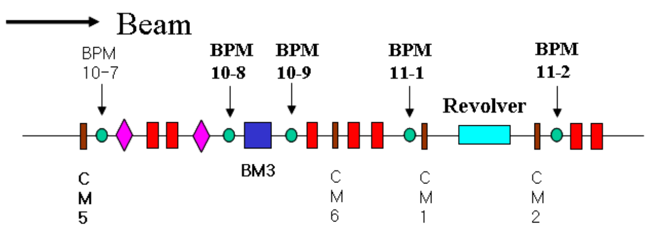

Figure 6: Lattice around the revolver and the upstream dipole magnet. CM represents the corrector magnet and the red color box the quad.

Secondly, we adjusted the orbit around the revolver monitoring the BPM 11-1 and 11-2. We used three corrector magnets (CM6, CM1, and CM2) for that. Figure 7 shows the vertical beam position change around the revolver and the resultant change of the revolver vacuum. Keeping the vertical beam position at the BPM 11-2, downstream of the revolver, the vertical position of BPM 11-1 was adjusted. By reducing the vertical position offset between BPM 11-1 and 11-2 below 100 μm, which corresponds to the divergence angle of 15 μrad, the vacuum pressure remarkably reduced and therefore the instability was completely suppressed.

Ion instability did not appear even at the gap of 5 mm, therefore, beam loss did not occur. Beam lifetime decreased by 5 hours from 21 hours at the beam current of 165mA as the gap was changed from 20 mm to 5 mm, which was due to the reduced physical aperture at the revolver.

Stray synchrotron radiation from the upstream dipole was found to be not serious. Other sources looks dominant: stray synchrotron radiation from the revolver itself, or the heat deposit in the flexible input / output transitions, or resistive wall impedance in the permanent magnet array.

In order to reduce the resistive wall impedance the permanent magnet array is covered with a 50μm-thick Cu sheet coated with 50μm-thick Ni. It is more likely that the heat deposit in the flexible input / output transitions rather than the resistive impedance in the magnet array would be a heat source.

However, as shown in Fig. 7, as soon as the orbit was changed, the vacuum pressure abruptly dropped. It means that the time constant of vacuum pressure change is very short. Generally, the gas outgassing from the surface of vacuum chamber by heat is very slow until the thermal equilibrium reaches. On the contrary, photo-desorption of gas molecules is fast because the molecules in the surface interact with photons directly. Form this remark, we can conclude that the dominant source of vacuum degradation would be the stray photons from the revolver itself.

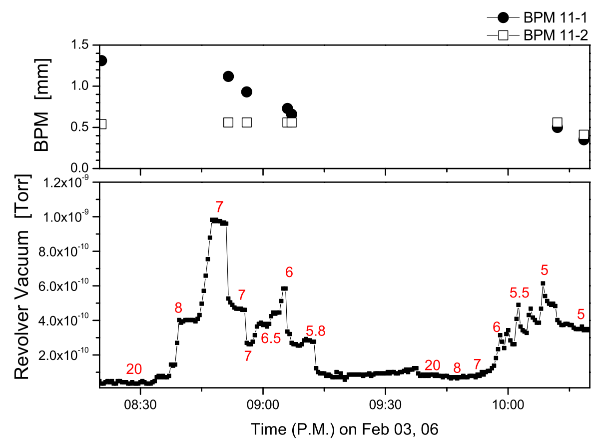

Figure 7: Upper figure: vertical beam position change around the revolver; lower figure: the resultant change of the revolver vacuum. The red-colored numbers in the lower figure denote the gap size.

SUMMARY

The observed ion instability during the gap change was caused by vacuum degradation in the in-vacuum revolver. Orbit optimization around the revolver undulator improved the vacuum condition so that the ion instability disappeared. The stray synchrotron radiation from the revolver itself would be more serious than that of the upstream dipole.

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