RECENT EXPERIMENTAL STUDY OF FAST ION INSTABILITY IN ATF DAMPING RING

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Abstract

A series of experiments have been conducted to study the fast ion instability (FII) in KEK-ATF damping ring in 2007. The first trial was to trigger the FII when the ion pumps were switched off in some locations of the ring. There was no clear beam size blow-up in that case even when vacuum pressure was raised by one order of magnitude. For the second trial, the new gas inlet system has been set up for the first time to elevate the vacuum pressure to up to more than two orders of magnitude. Different gas pressures and fill patterns were used to trigger this instability. The beam profile has been measured for various configurations. We did observe a beam size blow-up for multi-bunch operation.

INTRODUCTION

Fast ion instability is one of the highest priority R&D issues for the damping rings of the International Linear Collider (ILC) in the Technical Design Phase [1]. Ions coming from collisions between beam particles and residual gas molecules couple to the motion of the beam and lead to a beam size blow-up and emittance growth. In general, two kinds of ion effect can affect the machine's performance. One is called ion trapping in which the ions are turn by turn trapped by the beam potential. This effect can be cured by a sufficient number of empty RF buckets, which allow the ions to clear. This remedy has been applied in several existing machines. Another kind of ion effect is a transient effect, the so-called fast ion instability in which case the ions come from a single passage of the bunch train [2, 3]. For high intensity and low emittance storage rings, for example, the ILC electron damping ring, the ions produced by single passage of the beam can accumulate and lead to adverse effects to the machine's performance.

The recent experimental studies of fast ion instability in the KEK ATF damping ring [4] are presented in this paper. Our motivation is to see in what beam conditions and vacuum pressures can trigger such kind of instability.

FII EXPERIMENTS

For the first trial, the ion pumps were turned off in several locations around the damping ring as shown in Fig. 1 and resulting vacuum pressures were summarized in Table 1. They are raised by one order of magnitude.

After proper tuning (including dispersion correction and coupling correction), a single bunch has been injected into the damping ring. The sizes of the electron beam and of the beta function at the laser wire location were measured. The vertical emittance can be estimated to be about 14 pm for zero current operation.

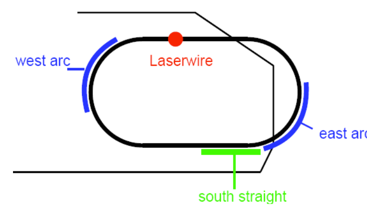

Figure 1: Location of switched ion pumps and of laserwire.

Table 1: Vacuum Pressure in the Measurement

ion pump status	5 mA	10 mA	20 mA
normal operation	4.6E-7 Pa	5.9E-7 Pa	1.0E-6 Pa
south straights off	2.0E-6 Pa	2.7E-6 Pa	5.5E-6 Pa
both arcs & south straight off	3.4E-6 Pa	5.2E-6 Pa	

For multi-bunch operation, the beam size of each bunch was measured in the laser wire scan. A beam size blowup was not apparent even at high beam intensity. Fig. 2 shows the measured vertical beam size for multi bunch operation at 20mA/20 bunches. Using the measured beam size data, the vertical emittance was calculated and is shown in Fig. 3. It can be seen that the vertical emittance does not change significantly in this case. Compared to the data taken in 2004, we speculate that this is due to the bigger vertical emittance.

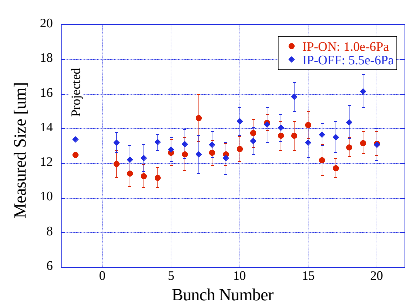

Figure 2: Measured size of multi-bunch at 20mA/20 bunches.

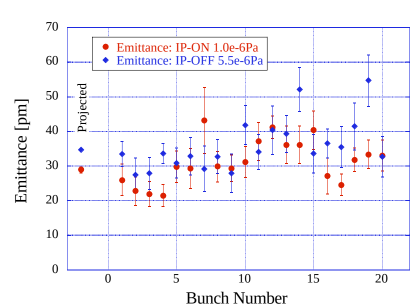

Figure.3: Emittance of multi-bunch at 20mA/20 bunches.

In order to study FII in more detail, a new gas inlet system has been installed in the ring. Fig. 4 shows the location of this system in the ring. It is a south straight section in the ring, ten metres long between QM10R.2 and QM16R. The gas density distribution can be estimated by monitoring the vacuum pressure.

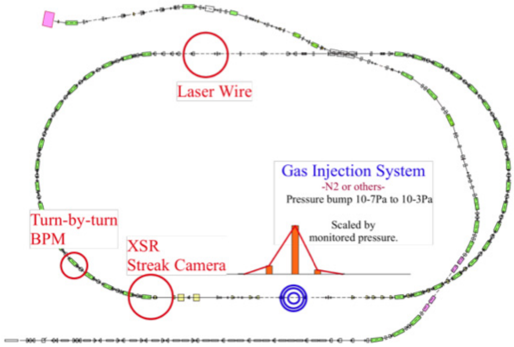

Figure 4: Layout of devices for the fast ion study.

Schematics of the gas inlet system and a close-up view of the gas flow controller are shown in Figures 5 and 6, respectively. Nitrogen gas can be leaked into the vacuum chamber to elevate the vacuum pressure. The fine leak valve is manually adjusted to set the maximum leak amount of Nitrogen gas and the gas-flow control valve is controlled remotely from the ATF control room to vary the leak rate up to maximum. In order to keep the near RF cavities to operate safely, the pressure excursions must be limited. Our first test is to increase the pressure by a factor 100. Cold-Cathode Gauges (CCGs) along the beam line are employed to measure the gas pressures in the elevated pressure regions. Since this region occupies about 10% of the entire ring (13/130=0.1) two orders of magnitude local pressure increase correspond to about a factor 10 larger pressure for the entire ring.

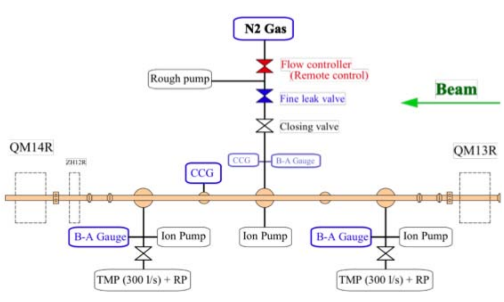

Figure 5: Schematics of gas inlet system.

Table 2 lists the machine and beam parameters during the experiments. In nominal operation of the machine, a single bunch is injected from the S-band linac. After 200 ms, all injection oscillations are fully damped. The ring can also run in multi-bunch operation mode, with up to three equally spaced bunch trains, each containing 1~20 bunches, spaced by 2.8 ns.

Table 2: Beam Parameters in the Experiment

Beam energy [GeV]	1.28
Circumference [m]	138.6
Harmonic number	330
Bunch spacing [ns]	2.8
Number of bunches	1~20
Single bunch intensity [nC]	2.0
Multibunch intensity [nC]	22.4
Bunch length [mm]	5~8
Momentum compaction	2.14E-3
Energy spread	0.06%
Vert. damping time [ms]	30
Hor. betatron tune	15.204
Vert. betatron tune	8.462
Synchrotron tune	0.0045
Horizontal emittance [m rad]	1.5E-9
Vertical emittance [m rad]	50E-12
Vacuum pressure [Pa]	1.0E-6~9.0E-4

After setup of the gas inlet system, the gas flow controller has been checked for effectiveness. Fig. 7 shows the measured results in different CCGs. It can be seen that the vacuum pressure changes with respect to the gas flow controller setting and shows almost a linear dependence. Pressure adjustments are thus straightforward.

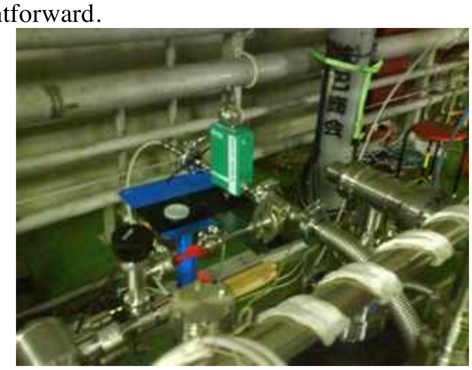

Fig. 6: Gas flow controller.

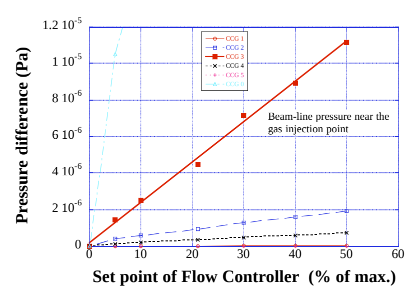

Figure 7: Vacuum pressure near the gas inlet system.

EXPERIMENTAL RESULTS

In 2007 most users run the machine in single bunch mode. For the FII study, we want to store multiple bunches in the ring. It took a few hours to tune the machine for multi-bunch operation (activating the energy compensation RF system to cure the beam loading on multi-bunch beam, match the phase of RF and have all bunches ride in right phase).

In our experiment, the beam profile was observed with the X-Ray Synchrotron Radiation Monitor (XSR). The observations from the XSR monitor show that for the same vacuum condition, the measured beam profile increases as a function of the number of trains. For the three-train case, the beam size shows a sudden blow-up, which does not occur for one train. Fig. 8 shows some sample measurements from the XSR monitor, in which the dark region denotes the measured beam profile. Table 3 lists the beam parameters in the experiments.

For a fixed number of trains we did not see much change in beam profile when changing the number of bunches from 1 to 15.

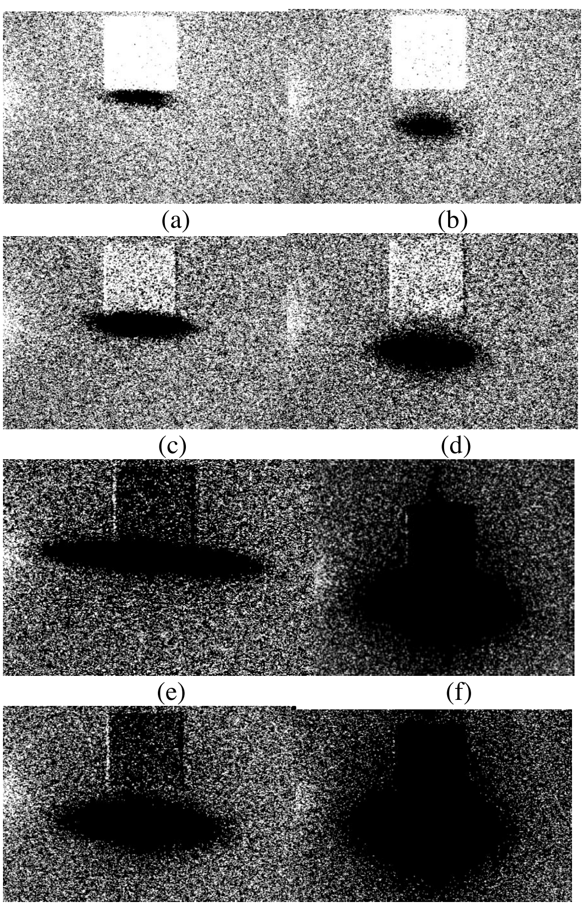

Figure 8: Beam profile from the XSR in various fill parameters.

Table 3: Beam Fill Parameters in the Experiment

figure	pressure [pa]	pulse intensity	# of bunch	# of train
a	2.92E-5	0.30E10	1	1
b	9.15E-4	0.39E10	1	2
c	2.98E-5	2.20E10	5	1
d	9.27E-4	2.39E10	5	2
e	1.87E-4	5.30E10	15	1
f	9.40E-4	5.90E10	15	2
g	9.27E-4	11.10E10	15	1
h	9.27E-4	11.10E10	15	2

The average beam profile can be estimated from the data of the XSR monitor. In nominal operation, the beam size is about 12 μm as deduced from the XSR monitor. Assuming an average beta function of 4 m we estimate a beam emittance of about 51 pm.

In order to compare between single and multi bunch operation, the streak camera was used to look at the beam oscillation for different bunches. We observe a strong oscillation for the trailing bunches as shown in Fig. 9.

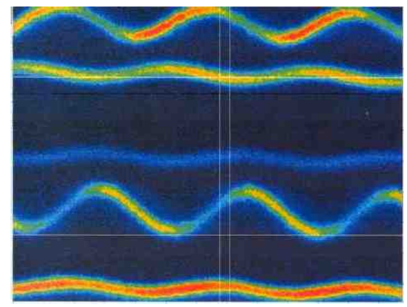

Figure 9:Bunch oscillation measured by the streak camera. Longitudinal bunch images are plotted in vertical and scanned over 200 μs in horizontal. The lines correspond to the bunches #5, #15, #1, #3 and #12.

SUMMARY

No clear beam size blow-up is seen when the ion pumps were turned off. When the gas inlet system was introduced, the ion effects were greatly enhanced. A sudden beam profile blow-up was observed for multi-bunch operation when then vacuum pressure is increased beyond nominal operation. If we increase the number of trains, the beam profile also increases significantly. Further studies of this instability are planned. The machine will have to be tuned to a low emittance (<10pm). We will optimize the machine to multi-bunch mode operation. The beam size and emittance can be measured through laser wire and the XSR. In addition, other diagnostics such as streak camera, turn by turn BPM can be used to monitor the beam property in the ring.

ACKNOWLEDGEMENT

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