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FAST ION INSTABILITY AT CESR-TA*

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Abstract

Fast Ion Instability can lead to deterioration of an electron beam (increasing emittance and instability of a train of bunches) in storage rings and linacs. We study this at the Cornell Electron Storage Ring Test Accelerator using a 2.1 GeV low emittance beam. As the source of ions is residual gas, our measurements are conducted at various pressures, including nominal vacuum as well as injected gas (Ar, Kr). We measure turn-by-turn vertical bunch size and position, as well as the multi-bunch power spectrum. A detailed simulation is then used to compare theory with observations.

INTRODUCTION

The residual gas in the accelerator vacuum system can be ionized by a circulating electron beam. The positively charged ions are trapped in the potential well of the electron bunch train. The transverse motion of the lead bunch in the train will be transferred to the ions and then from the ions to the next bunch in the train. In this way, the motion of the bunches near the head of the train is coupled to the bunches near the tail. The resulting instability limits the total charge in each bunch and the number of bunches in the train. It is observed in linear accelerators as well as electron storage rings. In a storage ring, having a long charge-free gap at the end of the train prevents multi-turn ion trapping. However, this cannot prevent ions from accumulating during a single passage of the bunch train, a phenomenon referred to as fast ion instability (FII [1]).

In 2008, the Cornell Electron Storage Ring (CESR) was reconfigured as a Test Accelerator (CESR-TA [2]) to study electron and positron beam dynamics. Such studies provide insight into phenomena that are likely to limit the performance of next-generation colliders and storage rings (e.g., intra-beam scattering, electron cloud growth, and FII). FII has been qualitatively observed at many accelerator facilities, either by injecting gas, or by turning off vacuum pumps, or by reducing the beam emittance to increase the trapping potential under nominal vacuum. However, the instrumentation available at CESR-TA makes it possible to measure effects of FII on the beam at a per-bunch level rather than the beam as a whole. The CESR Beam Position Monitor (CBPM [3]) system is capable of measuring bunch-by-bunch, turn-by-turn horizontal and vertical beam motion with a resolution of ~ 10 µm. The X-ray beam size monitor (xBSM [4]) is able to measure bunch-by-bunch, turn-by-turn vertical beam size at the 10–100 µm range.

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MEASUREMENTS

The results discussed in this report correspond to a subset of the data taken during the Dec. 2013 run of CESR-TA. We were able to establish two pressures of Kr (~10 and 20 nTorr) and three pressures of Ar (~6, 9, and 13 nTorr) in about a 10 m portion of the CESR ring (circumference = 768 m). The pressures mentioned are gauge pressures, and to get the true pressure we need to divide by 1.29 for Ar and 1.94 for Kr. Our measurements are with a 30 bunch train with 0.75 mA/bunch and 14 ns bunch spacing. For each pressure, we measured 4k turns of CBPM data, 1k turns of xBSM data, as well as the power spectrum of the train. Each of these measurements was done with and without the multi-bunch vertical feedback so we could make sure that the instability could be successfully eliminated with a fast feedback.

BPM Data

Figure 1 shows the vertical motion of each bunch (the band depicts the RMS amplitude) as a function of bunch number, with bunch 1 denoting the head of the train. The lightly shaded regions show the motion when the vertical feedback system is turned off, and the filled regions show the motion with the feedback turned on. As the pressure of the injected gas is increased, the amplitude of the motion becomes larger for the tail of the train, and the train is less stable. When the feedback is turned on, the motion is damped to a small RMS amplitude independent of pressure.

Besides looking at the RMS amplitude of bunch motion, we can also do a FFT of the bunch motion, thereby extracting the oscillation frequencies (e.g., betatron motion, synchrotron motion, etc). Figure 2 shows the amplitude of the vertical betatron tune for each bunch (which is correlated with the strength of beam-ion coupling), which grows along the train from head to tail. We notice that as the pressure is increased, the growth in the amplitude along the train becomes stronger, consistent with our expectations since the ion density increases linearly with gas pressure.

XBSM Data

Figure 3 shows the vertical beam size of each bunch as measured by the xBSM (the band depicts the statistical uncertainty of the measurement) as a function of bunch number. The lightly shaded regions show the beam size when the vertical feedback system is turned off, and the filled regions show the beam size with the feedback turned on. As the pressure of the injected gas is increased, the beam size growth becomes stronger, and the measurements for the later half of the train become more uncertain (due to large beam motion as well as large beam size oscillations). When the feedback is turned on, the beam size is reduced to about the same value (~ 20 µm) regardless of pressure.

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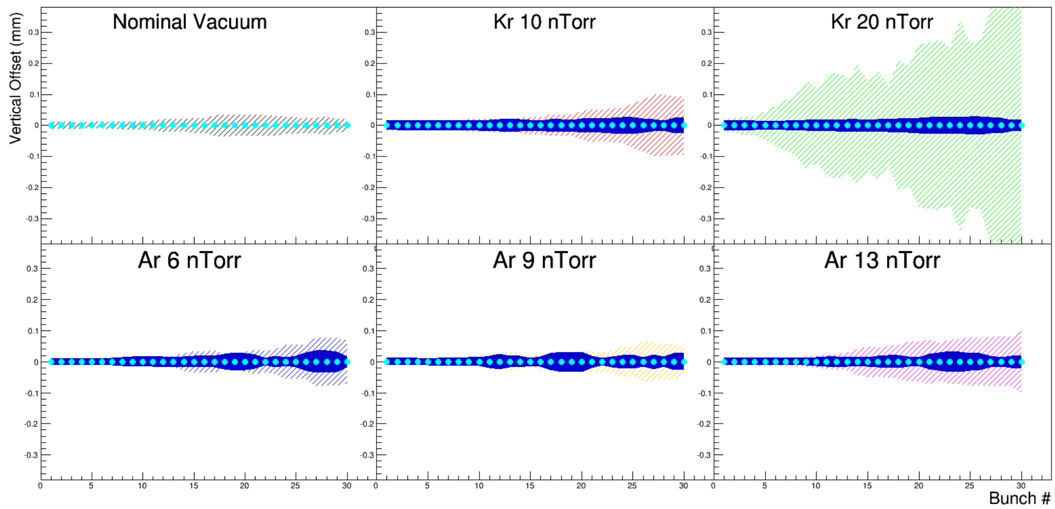

Figure 1: Vertical bunch motion as a function of bunch number at different vacuum pressures (lightly shaded = vertical feedback off, filled = feedback on). The nominal vacuum data with vertical feedback turned on was not recorded.

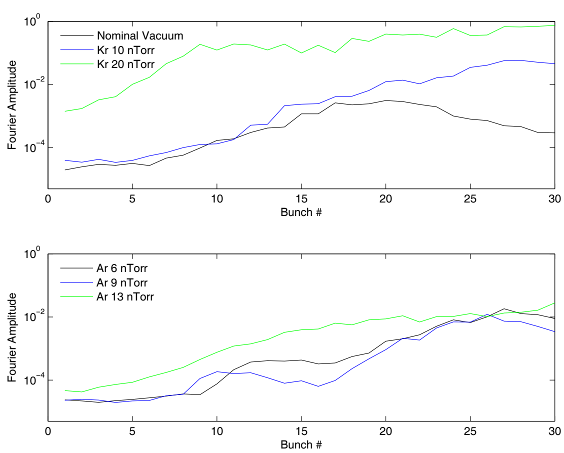

Figure 2: Amplitude of vertical tune (obtained from FFT of vertical bunch motion) as a function of bunch number at different vacuum pressures.

Train Spectrum Data

Besides the per-bunch measurements already mentioned, we also record the power spectrum of the train as a whole using the signal from a single BPM as input. Since the bunch spacing is 14 ns, this corresponds to a frequency range of 72 MHz. Figure 4 shows the vertical lower sidebands off the revolution harmonics. We notice that as the pressure increases, so does the amplitude of the vertical lower side-bands. Since the only known multi-bunch instability that is affected by increasing vacuum pressure is FII, we can infer that the observed sidebands are a consequence of beam-ion coupling.

SIMULATION

We have adapted the FASTION simulation code [5], developed at CERN to study FII at the CLIC linac, to create a detailed simulation of the effects we anticipate at CESR-TA. The simulation tracks electron macroparticles along the ring, creating ion macroparticles at fixed points in the ring where the beam and residual gas atoms interact with each other. Our update to the code allows the use of 6x6 matrices for beam tracking in order to include synchrotron motion. It also allows for the pressure to vary along the ring, so as to mirror our experiment (where we only increase the pressure in a small portion of the ring). We also added an RF kick, chromatic damping, and radiation damping. Finally, we include the capability to apply vertical feedback.

The simulation plots correspond to the beam behavior for the last 1k turns of a 25k turn simulation (we do not track for more turns in the interest of computation time). Since the damping time of the CESR ring is larger (about 50k turns), the beam has not reached equilibrium. However, we can see if the predicted dependence on pressure agrees with our observations. Figure 5 shows sample simulation results for nominal vacuum (defined as 0.5 nTorr each of Ar and CO) and 10 nTorr Ar injected at a single beam-ion interaction point. The location and extent of the pressure bump used in simulation is consistent with our experiment. The ionization cross section of Ar and CO are assumed to be 1.5 and 2 MBarn, as used elsewhere [5]. Assuming a larger cross section would create a greater number of ions, increasing the instability. We see that the beam is less stable with injected gas, and that the RMS amplitude of beam motion and the growth in beam size are similar to data. Moreover, under nominal vacuum, the beam size growth first appears near bunch 10, whereas with 10 nTorr Ar, it starts around bunch 7. Similarly, in data, beam size growth starts around bunch 10 and around bunch 7 for nominal vacuum and the largest Ar pressure, respectively.

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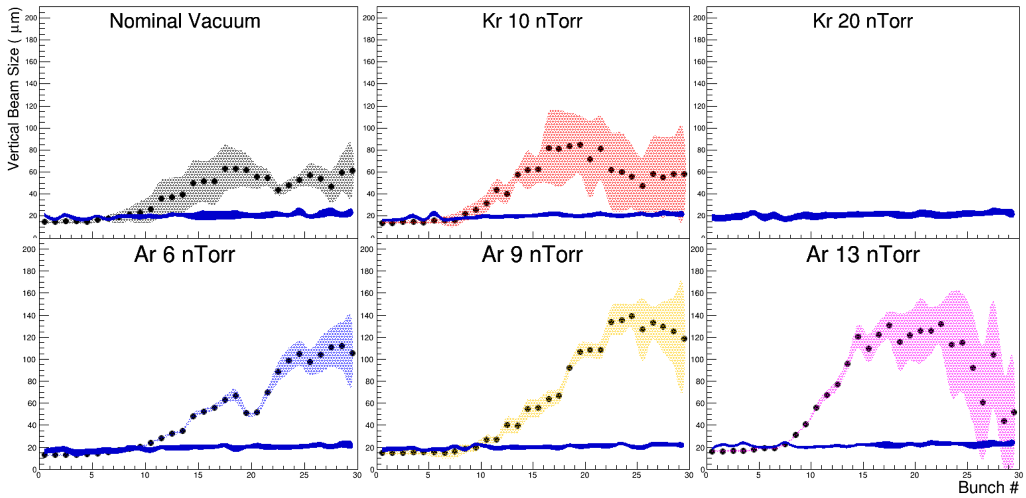

Figure 3: Vertical bunch size as a function of bunch number at different vacuum pressures (lightly shaded = vertical feedback off, filled = feedback on). The 20 nTorr Kr data with vertical feedback turned off was not recorded.

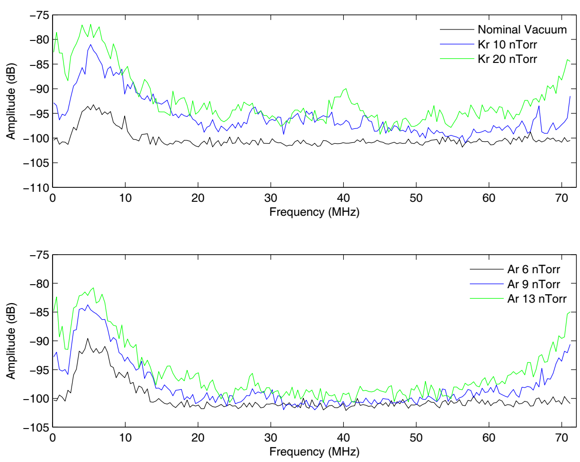

Figure 4: Vertical lower sideband spectra at different vacuum pressures.

CONCLUSIONS AND FUTURE WORK

We reported here the first measurements of FII at CESR-TA. The observed increase in beam motion and beam size along the train is correlated with pressure, and the location (along the train) and magnitude of the instability agree well with simulation. With vertical feedback, the emittance growth due to FII is eliminated, in both measurement and simulation. During April 2014, we extended our fast ion measurements, looking at the effects of (i) varying bunch current, (ii) larger bunch spacing (16 ns and 28 ns), (iii) larger beam emittance, and (iv) having two or three mini-trains instead of a single train. The initial results look very promising, and consistent with our expectations based on theory and simulation. After a more detailed analysis is complete, we plan on doing further experiments in Dec. 2014 provided that there is adequate funding.

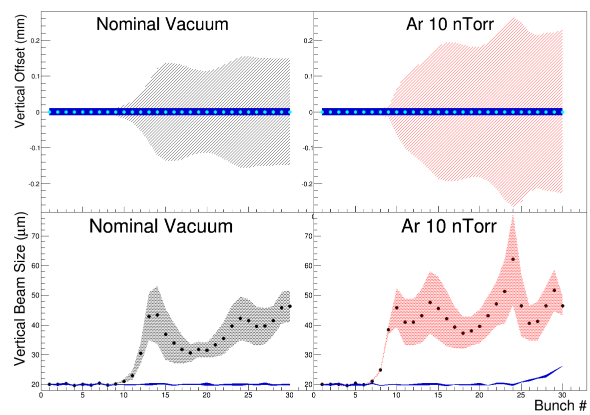

Figure 5: Sample simulation results. Top: vertical bunch motion as a function of bunch number at different vacuum pressures (lightly shaded = vertical feedback off, filled = feedback on). Bottom: vertical bunch size as a function of bunch number at different vacuum pressures (lightly shaded = vertical feedback off, filled = feedback on).

REFERENCES

[1] T. O. Raubenheimer and F. Zimmermann, Phys. Rev. E **52**, 5487 (1995).

[2] M. A. Palmer et al., *The CESR Test Accelerator Electron Cloud Research Program: Phase I Report*, Technical Report CLNS-12-2084, LEPP, Ithaca, NY (2013).

[3] M. A. Palmer et al., *CESR Beam Position Monitor System Upgrade for CesrTA and CHESS Operations*, IPAC'10, Kyoto, Japan, 1191 (2010).

[4] J. P. Alexander et al., Nucl. Instrum. Methods Phys. Res. A **748**, 96 (2014).

[5] A. Oeftiger and G. Rumolo, *Fast Beam-ion Instabilities in CLIC Main Linac Vacuum Specifications*, CERN-OPEN-2011-050 (2011).