EXPERIMENTAL CHARACTERIZATION OF THE "FIRST PULSE" E-P INSTABILITY AT THE LANL PSR*

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Abstract

A puzzling aspect of the e-p instability at PSR is the "1st Pulse" instability phenomenon. It shows up on the first beam pulse after a beam-off period of a few minutes or more. This pulse has a significantly lower instability threshold than beam pulses at regular repetition rate with a much shorter time separation. While the standard PSR operation for the Lujan Center spallation neutron source is unaffected by this phenomenon, it does interfere with some high intensity, single pulse experiments using PSR beam to another external beam area (WNR). We summarize the present experimental data characterizing this phenomenon as compared with the typical e-p instability observed at higher repetition rates and suggest some possible explanations.

INTRODUCTION

The transverse e-p instability has been observed at PSR since the ring commissioning in 1985-6. While not completely understood, it has been reasonably well characterized experimentally and is adequately controlled for present intensities at 20 Hz by the combination of sufficient RF buncher voltage, inductive inserts and beam scrubbing. One aspect of e-p, the aptly named 1st pulse instability, still interferes with certain modes of the PSR to WNR (Weapons Neutron Research Facility) operation. It has been observed at the LANL PSR for several years [1] and has received particular attention since the Direct H^- Injection upgrade of 1998. It occurs after the PSR beam has been off for several minutes or more and the full intensity beam (stable at a regular repetition rate) is turned on at full intensity. We observe that the 1st pulse is unstable while subsequent ones with a regular repetition rate of 1 or so Hz are stable, hence the name "1st Pulse Instability". The minimum wait time for the instability varies with the conditioning of the ring. It has been as low as 1.5 minutes shortly after startup from a several month shutdown and gradually increases with beam operating time to 30 minutes or more, presumably from some type of beam scrubbing effect.

One of the key differences between the 1st pulse instability and the instability on the subsequent pulses (or pulses with much smaller wait times typical of operation at a uniform repetition rate) is the difference in instability threshold curves as illustrated in Figure 1 below (data of 6/22/02). For example, at 4 μC of stored charge the threshold for no-wait is ~8 kV, but for the 1st pulse after a 5 minute wait it is 18 kV, a factor 2.2 higher.

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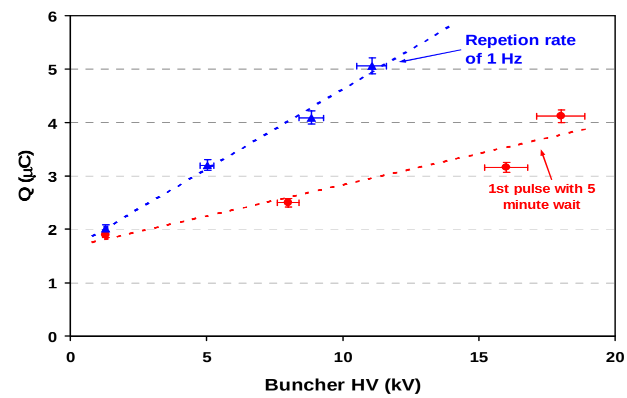

Figure 1. Instability threshold curves are plotted for the 1st pulse with a 5 minute wait (red circles) and those with a repetition rate of ~ 1Hz (blue triangles).

The 1st pulse instability is important to us for two reasons: First, it has an adverse impact on PSR to WNR beam delivery. For some experiments in the WNR external proton beam area, long wait times up to several hours are needed to make adjustments to the experimental set up and then they use just one high intensity pulse. Control of stability on the 1st pulse can require more buncher voltage than presently available. If the pulse is unstable there is considerable loss of beam intensity and an increased emittance which can compromise the experimental objectives. Secondly, the 1st pulse instability adds yet another dimension to the multidimensional parameter space for e-p at PSR and could add to the overall understanding of the instability.

EXPERIMENTAL RESULTS

The goals of various beam studies on this phenomenon over the past several years have been to characterize the 1st pulse instability and identify the accelerator/beam parameters/conditions that change during the wait time. Diagnostic signals for the unstable 1st pulse compared with subsequent pulses of the same intensity but much shorter wait are discussed in the next section. As for possible causes, we found no significant and reproducible changes in the beam injected into PSR after a several minute wait. Another possible cause is an increase in the electron cloud intensity during the wait time from changes in the secondary emission yield (SEY) during the wait time. In this regard, we did observe a significant change in electron emission from the stripper foil as a function of wait time as well as an increase in the trailing edge multipactor signal on an electron detector down stream of the foil. These are discussed in a later section.

Two examples of diagnostic signals for the 1st pulse (unstable) and subsequent pulses

The experimental signatures for two examples representative of the 1st pulse instability for an 8.3 μC/beam set up (6/23/02) using the standard, full-emittance beam are shown in Figures 2 and 3. These were taken within 45 minutes of one another for the wait times shown on the graphs using a buncher voltage of 15 kV where the no wait threshold was 12.3 kV. The 1st pulse was unstable and the subsequent pulse injected 1 second later (~no wait) is shown for comparison in both cases.

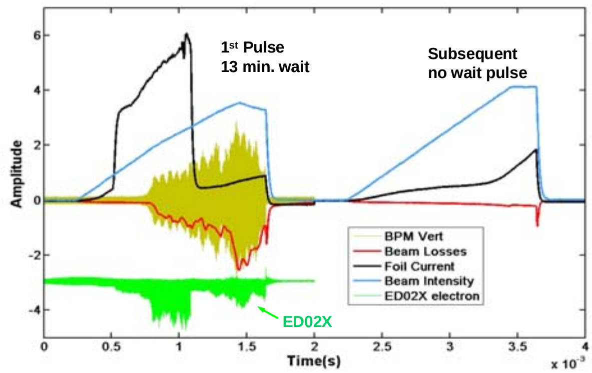

Figure 2. Diagnostic signals for a wait time of 13 minutes compared with subsequent pulse with no wait time. The electron signal, (ED02X) is offset vertically for clarity.

For the no wait pulse the beam intensity signal shows accumulation ramp and a flat top during the 200 us store after the end of injection. This foil current is consistent with an SEY of 1-1.5% and ~10% foil hits/turn in the plateau region. Thermionic emission starts to add appreciable current near the end of accumulation and in the store. The spike in beam losses occurs at extraction.

On the 1st pulse we see a large increase in foil current 10-20% of the way into accumulation followed by a rapid drop 60% of the way through accumulation. The unstable coherent motion starts about 30% of the way through accumulation as do the beam losses. In this example, about 20% of the beam was lost. There is a surge in the electron signal (ED02X located downstream of the stripper foil), which also includes the change in the beam-induce multipactor gain as the beam intensity increases. The abrupt drop in electrons at the same time as the drop in foil current indicates that the foil emission on the 1st pulse is providing the dominant source of seed electrons for trailing edge multipactor at this location. There was no significant vertical beam position monitor signal (BPM) for the stable subsequent pulses.

Figure 3 shows the signals for the second example taken 45 minutes earlier for a 10 minute wait. It is significantly different than the first example. The instability occurs later at the end of accumulation and is much more violent than in the previous example. We see less foil current in the first part of the accumulation but it goes off scale at the time of the instability. The influence of foil emission on the electron detector signal is not as distinctive as in the previous example.

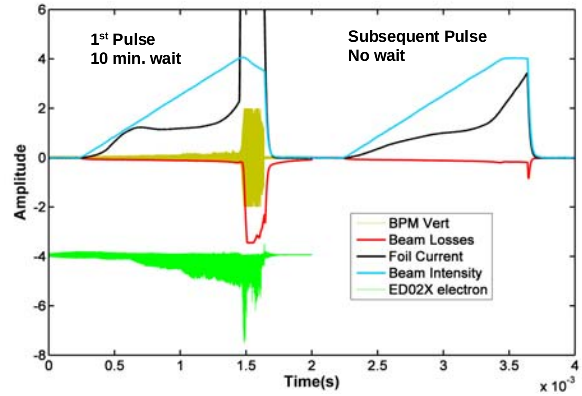

Figure 3. Diagnostic signals for a wait time of 10 minutes compared with subsequent pulse with no wait time.

Results of a spectral analysis of the BPM signal of Figure 3 are shown in Figures 4 and 5. The turn-by-turn power spectral density (PSD) is computed as square of digital fft amplitude and its contour plot is shown in Figure 4 as a function of turn number and mode number ($\omega/\omega_{rev} + Q_y$). To obtain a single parameter for the growth time we sum the over the modes 50-120 as shown in the plot of Figure 5. The measured exponential growth time for power was 4.4 μs or 8.8 μs for the amplitude and is a factor 5 shorter than that measured for the first example. Such growth rates are well beyond the control capability of the prototype damping system tested in 2005 [2].

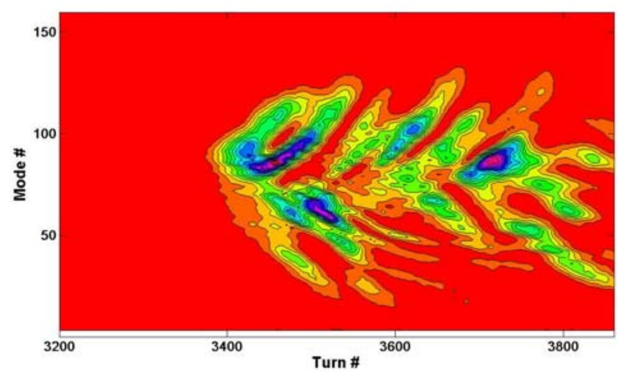

Figure 4. Contour plot of the power spectral density (PSD) as a function of turn number and mode number.

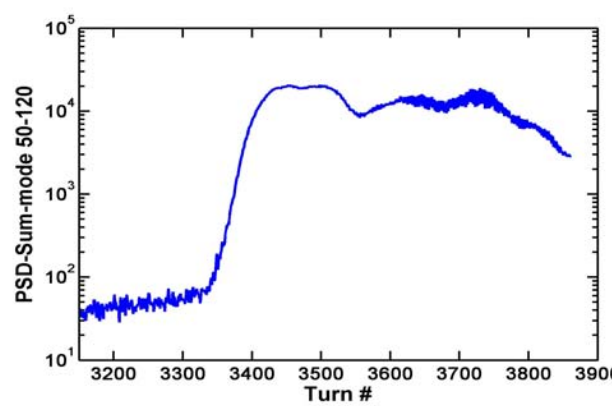

Figure 5. Log plot of the sum of the PSD over modes 50 to 120 used to obtain an average growth time.

Other observations

Additional observations of the first pulse instability over the past few years include:

- Growth times at threshold for the instability are generally shorter than for the standard no-wait beam and have greater variability.
- In 2002 tests, the minimum wait time for the 1st pulse instability gradually increased with time (over several weeks of beam operations) from 90 seconds to over 20 minutes. During this time the ring vacuum also improved by about a factor of 5.
- The 1st pulse instability has re-occurred after several long shutdowns (3-5 months each) for annual maintenance especially when portions of the ring were up to air and has diminished after a few weeks of beam operations, presumably due to some sort beam conditioning/beam scrubbing.
- PSR operators have found that a low intensity (down a factor of ~50) precursor shortly before full intensity pulse prevented the 1st pulse instability in 2002. The intensity of precursor needed has increased over the last few years.

Foil current data

Some foil current signals were obtained for various wait times during PSR to WNR beam operations in 2005. Foil currents in the region of 200-300 μs after the start of injection are linear in the beam current as shown in the expanded view of the first 400 μs of accumulation Figure 6. The slopes of the curves in this region are a good measure of the rate of change of foil emission with respect to beam intensity and are plotted as a function of wait time in Figure 7 (Carbon Foil 2005).

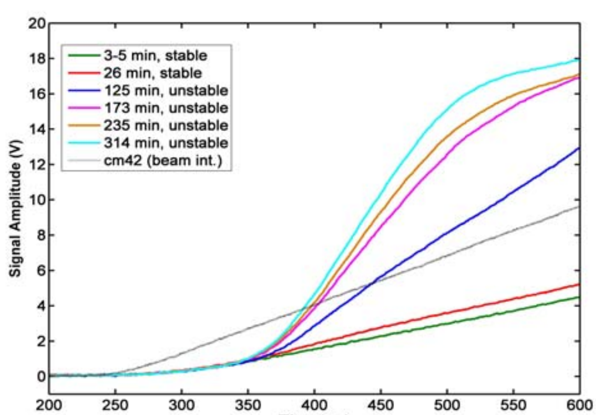

Figure 6. Foil current signals as a function time for the first 400 μs of injection (200 μs offset on the time axis).

Additional foil current data for both carbon and diamond foils was collected during startup of 2006 operations and the foil current growth rates are also plotted in Figure 7. While the foil current for the diamond foil is significantly less during normal 20 Hz operation, the improvement disappears with a long wait time (~100 minutes). The large increase in foil emission current with wait time was unexpected and the underlying surface science not well understood by us. However, large increases in SEY have been observed with low energy electrons in transmission through polycrystalline diamond foils terminated with a hydrogenated layer [3], [4]. Similar behavior is plausible for carbon foils.

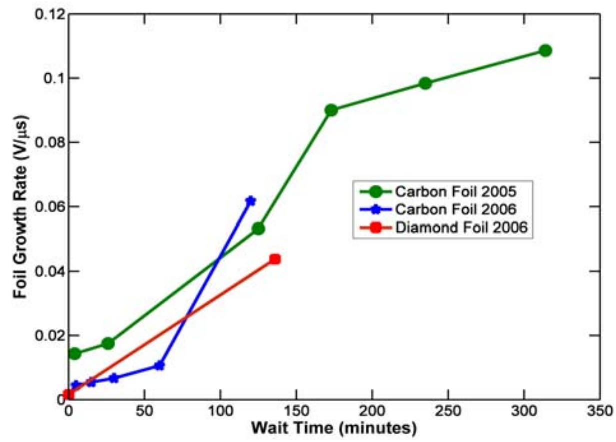

Figure 7. Foil signal growth rate plotted as a function of wait time.

CONCLUSIONS

The 1st pulse instability is a recurring phenomenon especially for the intense, small emittance, single-pulse beams for the external proton beam area at WNR. A totally satisfactory physics explanation has not yet been demonstrated but the large increase in foil emission current for long wait times could produce a sufficiently higher electron cloud density (in the foil region) to drive the 1st pulse unstable. Suppression of foil emission by strong electric bias fields could be a convincing test of this hypothesis. The increase in foil emission may be due to adsorption of H_2O during the wait time.

The impact on beam operations could be mitigated by a very reproducible and rapid switching of a low duty factor beam from a low-duty beam dump to the WNR transport with enough precision to place beam on target with the previously tuned spot size and centroid. This option will be tested in the near future.

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