RECENT EXPERIMENTAL EVIDENCE FOR THE LOS ALAMOS PROTON STORAGE RING BEAM INSTABILITY

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Abstract

The peak intensity of the PSR is limited by a fast transverse instability. In 1996 we started a project to upgrade the PSR to 200 µA at 30 Hz, which requires operation above the instability threshold achieved with our present rf system. We have, therefore, resumed our experimental program to understand and control the instability. In this paper we will present our latest data.

1 INTRODUCTION

A fast transverse instability has been observed [1] in the Los Alamos Proton Storage Ring (PSR) when the injected beam intensity reaches more than about 2 x 10^{13} protons per pulse. In the present operating intensity of the PSR (70 µA average @ 20 Hz), the instability is controlled by injecting with a notch or gap in the beam bunch greater than 90 ns and by applying sufficient rf buncher voltage (~7 kV with ramping). However, with our program to upgrade the PSR to 200 µA average at 30 Hz, we must improve our understanding of the cause and control of the instability to assure the success of the upgrade. Also, the neutron-scattering community is designing the next-generation accelerator-driven neutron spallation sources. These new machines may exhibit the same instability seen at PSR because they will have peak proton intensities greater than 10^{14} protons per pulse.

Experimental results indicate that electrons trapped within the proton beam most likely drive the PSR instability (e-p instability). In the e-p instability, coupled oscillations of low energy electrons and beam protons develop when electrons are trapped and oscillate in the potential well of the proton beam. In recent experiments we have measured the relative signal strength in the betatron sidebands, the effects of beam in the gap, the effects of clearing electrodes, and tune shift as a function of beam intensity. We have also explored operating at a higher vertical betatron tune.

The PSR is a fast-cycling high-current storage ring designed to accumulate beam over a macropulse (typically about 600 µs) from the Los Alamos Neutron Science Center (LANSCE) linac by multi-turn injection and to compress that beam into a short single-turn extracted pulse (~0.25 µs), which drives the short-pulse neutron spallation source. The beam storage time is typically less than 10 µs. Important parameters include a kinetic energy of 797 MeV, circumference of 90.1 m, revolution frequency of 2.8 MHz, and betatron tunes of $\nu_h \approx 3.17$ and $\nu_v \approx 2.14$.

2 BETATRON SIDEBANDS

We have measured the signal strength in the betatron sidebands by digitizing beam position monitor data and computing fast Fourier transforms. We used both a short stripline beam position monitor with peak sensitivity at about 400 MHz, and a capacitive beam position monitor with a frequency response up to about 100 MHz. The combination of these two pickups allows us to measure a broad range of frequencies. The usual method of viewing sidebands with a spectrum analyzer is not very useful at the PSR because the beam lifetime is only a few milliseconds due to beam loss incurred from the continual passage of the stored beam through the stripper foil. Beam conditions also vary slightly from pulse to pulse, so it is best to acquire all the data in a single pulse. We digitize the signals at 1 GS/s for up to 2 million samples, and analyze the data off line.

Our results show that at the onset of the instability the signal power grows in the lower (slow wave) sidebands, which is typical of many instabilities. As shown in Fig. 1, the power first appears at about 175 MHz, then begins to spread out to the lower sidebands at higher and lower frequencies. For the e-p instability, we expect [1] the signal power to appear at frequency

$$f = \frac{1}{2\pi}\sqrt{\frac{2Nr_e c^2(1-\eta_e)}{\pi b(a+b)R}}$$

where η_e is the neutralization factor, N is the number of protons, r_e is the classical electron radius, c is the speed of light, a and b are the elliptical beam dimensions, and R is the machine radius. At typical PSR parameters (doubling the average N to take into account the peak bunch density), f = 160 MHz.

One test of the e-p instability is to measure the frequency dependence of the signal power as a function of the beam intensity. It should scale as the square root of the number of protons in the ring. We have done this

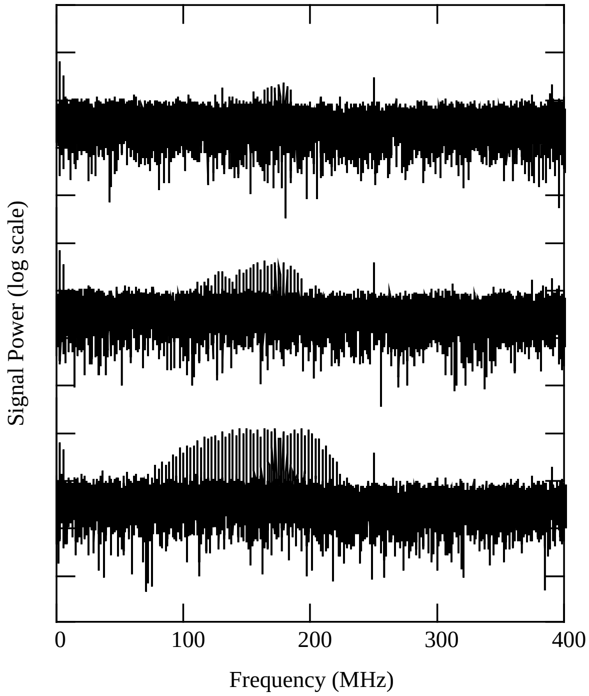

Fig. 1. Sideband power growing in time. The middle spectrum is 60 μs after the top spectrum, and the bottom is 160 μs after the top. All three spectra are from a single beam pulse.

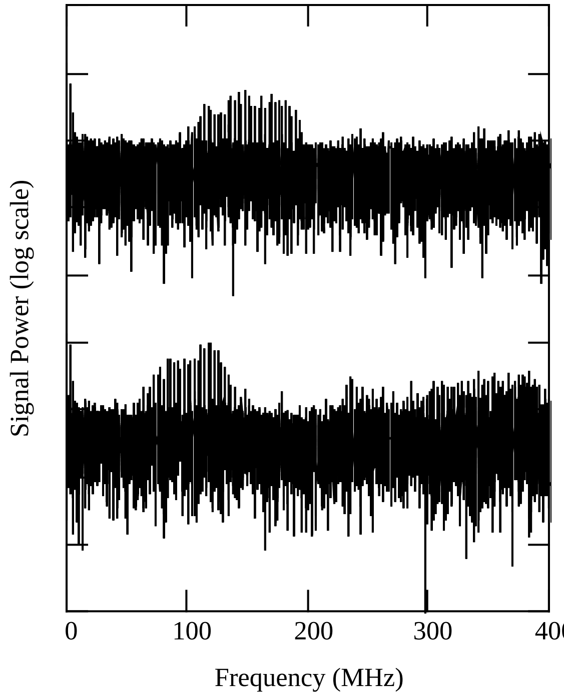

Fig. 2. The signal power at half intensity peaks at lower frequency. The intensity of the upper spectrum is twice that of the lower spectrum. The beam conditions are the same except for the beam intensity and the buncher voltage.

experiment, and we found that decreasing the number of protons by a factor of two (and lowering the buncher voltage to keep the beam unstable) shifts the signal power from about 150 MHz to about 100 MHz. This is almost exactly what one would expect (150 MHz / $\sqrt{2}$ = 106 MHz). Examples of the spectra for the two cases are shown in Fig. 2.

3 VERTICAL BETATRON TUNE

The vertical betatron tune setting is another "dial" that we have found to affect the instability threshold. There is a significant increase in the threshold when the tune is increased by an integer, (i.e., from ~2.14 to ~3.14). The mechanism for this effect might be Landau damping because of the increase in chromatic tune spread at higher tunes. Further evaluation is needed regarding the exploitation of a higher vertical tune. The impact of changes needed for higher-tune operation also needs more study. For example, it may require increased performance from the bump magnets that are part of the direct H^- injection upgrade, and it will change the Twiss parameters of the beam in the extraction line.

Recent tests of operating the PSR at the higher tune show an increase in the instability threshold of about 50%. The accumulation and storage beam losses are roughly twice the normal losses, and beam losses in the transport line to the spallation target are about the same as the normal losses. The higher accumulation and storage losses are consistent with model calculations, which show that the losses are primarily due to increased passages of the circulating beam through the stripper foil, due to the change in lattice parameters at the stripper foil location. We will be able to correct for the latter effect after our upgrade to direct H^- injection (in 1998).

4 BEAM IN THE GAP

Most models of the e-p instability require a mechanism for trapping electrons. In the PSR, if the gap between the head and the tail of the bunch is perfectly clear, then as the gap circulates around the circumference of the machine, any electrons in the beam pipe would self-repel and be lost to the beam pipe walls, thus clearing any electrons. However, if there is just a small amount of beam in the gap, electrons could be trapped.

We have recently conducted experiments designed to purposely inject beam into the gap and measure the effect on the instability threshold. Beam was injected into the gap by manipulating the chopper in the low energy transport area of the linac. By inhibiting the chopper that normally creates a 250-ns-on – 107-ns-off pattern for thousands of pulses, we injected beam for a full 357 ns for just a small number of pulses. We found that injecting beam into the gap significantly lowered

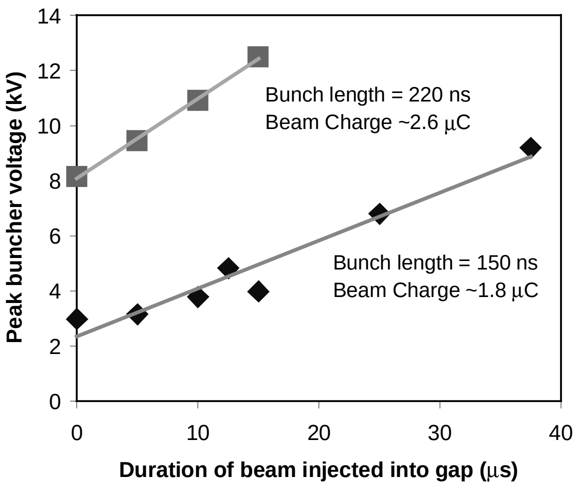

Fig. 3. The instability threshold is decreased (more buncher voltage is required) when beam is injected into the gap. The straight lines are linear fits to the data.

the instability threshold. Our data is shown in Fig. 3. We see from the figure a linear dependence between the threshold and the beam in the gap.

We also measured the beam in the gap by firing the extraction kickers early and extracting any beam that may be in the gap to a current transformer in the extraction line. Using this technique, we conclude that without purposely injecting beam in the gap there is about 15 mA in the gap by the end of the injection cycle for normal operating intensities.

5 CLEARING ELECTRODES

Clearing electrodes have been tried in PSR with limited success in raising the threshold for the PSR instability. During the 1996-97 extended maintenance period we installed small clearing electrodes in sections 1, 2, and 5 to add to previously-installed electrodes in sections 0, 3, and 4. By reconfiguring as clearing electrodes the extraction kicker electrodes in sections 7 and 8, we can bias electrodes of various sizes in 8 out of the 10 straight sections in PSR. Recent experiments using these electrodes have not shown a reproducible effect on the instability threshold.

It is difficult to estimate in detail how much the clearing electrodes suppress the number or density of electrons that are trapped (it is the trapped electrons that would cause the e-p instability – not the ones that are immediately lost), thus making it difficult to form an expectation for the effectiveness of the clearing electrodes. It can be argued that because we have not used clearing electrodes in all sections of the ring we may have missed a pocket that is effective in causing the instability. We plan to continue to study these and other measures for suppressing electron production and trapping. One promising avenue may be low secondary emission vacuum chamber coatings such as TiN.

6 COHERENT TUNE SHIFT

The simple application of the Laslett tune shift formula predicts a large (~0.1) tune shift for the PSR that could result in shifting the tune onto the integer resonance. This scenario has been proposed as a possible explanation of the PSR instability. To determine the importance of tune shift we have measured it as a function of beam intensity by kicking [2] the beam with short (~300 ns) pulses in the vertical plane, and counting the number of coherent betatron oscillations for several hundred microseconds. Our results are shown in Fig. 4.

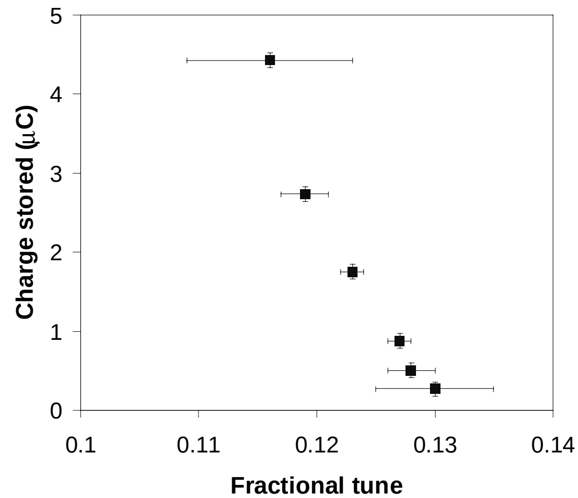

Fig. 4. Tune shift as a function of beam intensity.

We see that at our present operating intensity (3.5 μC), the tune shift is about 0.012. When we complete our upgrade to 200 μA at 30 Hz (6.67 μC), the tune shift will be about 0.023. The data shown in Fig. 4 is our first attempt at systematically measuring tune shifts. In future development periods, we hope to improve the accuracy of our measurements.

7 SUMMARY

Understanding and controlling the PSR beam instability has recently taken on new importance due to design considerations for our upgrade plans and for the next-generation neutron spallation sources. We have recently made a number of new measurements to characterize the instability. Our results add support to the hypothesis that we have an e-p instability. However, more work is needed to understand the electron-creation process and how to control it.

REFERENCES

[1] D. Neuffer et. al., Nucl. Inst. and Meth. A321 (1992) 1-12.
[2] T.W. Hardek and H.A. Thiessen, 1991 IEEE Part. Acc. Conf. (1991) 866.