TUNE MEASUREMENTS IN THE LOS ALAMOS PROTON STORAGE RING

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Abstract

At the Proton Storage Ring of the Los Alamos Neutron Science Center, the short (<1ms) store time and the long bunch (300ns) preclude use of many traditional techniques for measuring beam tunes. Presented here is a technique developed for use with coasting beam that takes advantage of the phase information in Fourier transforms of the transverse dipole oscillation of the beam when it is subjected to an external driving force.

INTRODUCTION

The Proton Storage Ring (PSR) at the Los Alamos Neutron Science Center (LANSCE) accumulates about 2000 300ns-long pulses from a linac to form a 5μC pulse that is immediately extracted to a neutron-production target. The short (<1ms) store time and the long bunch (300ns) preclude use of many traditional techniques for measuring beam tunes.

The tunes are typically measured during machine set-up by injecting off-axis a single 300ns-long pulse of beam from the linac; the position of this minipulse is measured at a single beam position monitor (BPM) during the first 30 turns around the ring, and a sinusoid is fit to the measurements. This technique is possible only during machine set-up because injection of additional minipulses interferes with the measurement of the first one; such a measurement cannot be performed near the end of an accumulation cycle for example. Another limitation arises from the fact that the production BPMs are tuned to the linac frequency of 201.25MHz; thus the BPMs respond to the micropulse structure of the beam from the linac; due to the energy spread of the linac beam, this microstructure disappears after about 30 turns around the ring.

For machine development measurements, a BPM with higher bandwidth is available. Signals from this BPM are recorded on a digital oscilloscope and uploaded to a computer for off-line analysis. The digitized signals can be manipulated to yield position information for the stored beam with no well-defined RF structure. This affords the ability to study beam instabilities, measure beam-transfer functions, etc.

DAMPING SYSTEM

A system to provide active damping of a transverse instability has been under development at the PSR [1]. This system employs the wide-band BPM described above to detect the beam dipole oscillations, various analog signal conditioning components, and a set of beam-deflecting electrodes to provide negative feedback; the system is illustrated in Figure 1.

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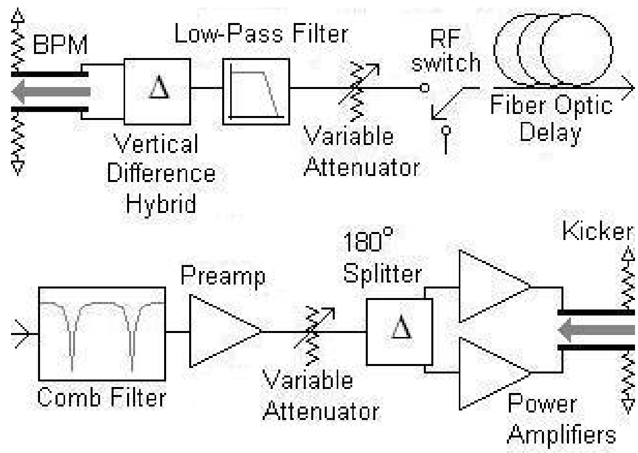

Figure 1: A block diagram of the damping system.

The RF switch allows rapid switching between the feedback signal and, for example, an RF signal generator for driving betatron sidebands during machine studies. For the work described here, the beam was driven with an RF signal generator only; the feedback signal was not applied.

MOTIVATION

A longitudinal slice of beam that is off-axis will undergo betatron oscillation as it orbits the ring, so on each turn the phase of the oscillation will advance by $2\pi \times (Q+q)$, where Q and q are the integer and fractional parts of the tune. A single BPM measures this phase advance modulo 2π, i.e. $2\pi\times q$. Similarly, a short deflecting electrode applying a deflecting signal at a frequency of $\Omega \times (n \pm q)$ (where Ω is the orbit frequency) will maintain a constant phase relative to each slice of the beam. Thus such a deflecting signal will resonantly drive transverse oscillation of the beam. These frequencies are the betatron sideband frequencies, with the plus and minus signs giving the upper- and lower-sidebands. For a small deflecting signal, the oscillation amplitude will saturate as natural passive damping forces prevent unbounded growth.

Figure 2a shows the result of driving coasting beam in the PSR at the lower sideband of mode 20, a frequency of 56.3 MHz, corresponding to Ω=2.8 MHz, n=20 and q=0.19 in the above formula. The signal grows monotonically as expected. In Figure 2b, where the beam was driven at the upper sideband frequency of mode n=20, the response of the beam grows and shrinks repeatedly. Investigating this response motivated the development of a way to precisely measure the tune of the beam as a function of time.

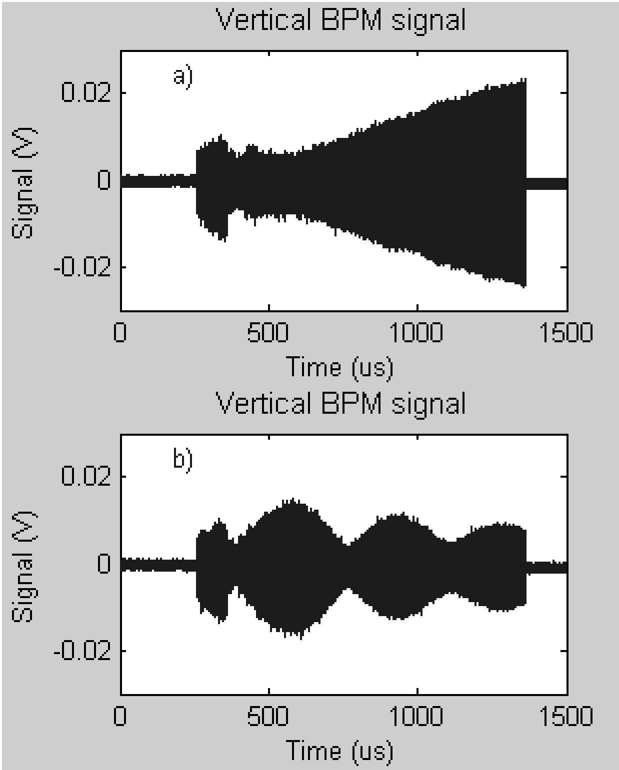

Figure 2: Signals from the wide-band BPM for coasting beam driven transversely at frequencies corresponding to the mode 20 lower sideband (a) and upper sideband (b). These signals are the difference signals from the top and bottom electrodes of the BPM, giving an indication of the vertical position of the beam. The drive was not present as the beam was accumulated during the first 100μs of the signal.

MEASURING THE COASTING BEAM TUNE

Figure 3 illustrates the tune measurement technique for a coasting beam. The signals from the BPM are digitized on an oscilloscope for about 5000 turns, then are sliced into turn-by-turn signals. The beam position oscillates at a frequency very near the betatron sideband drive frequency. On each turn the phase of the oscillation advances by $2\pi\times q$ as described above. This phase can be precisely determined by performing a digital Fourier transform of the data. The phase from the Fourier transform for a given slice of beam will be a linear function of turn number when the tune remains constant. The slope of the line provides a precise measure of the tune on a turn-by-turn basis. This measure is much more precise than fitting a sinusoid to many turns worth of data, and more precise than using the amplitudes of the Fourier transform, which also requires many turns' worth of data to get good precision.

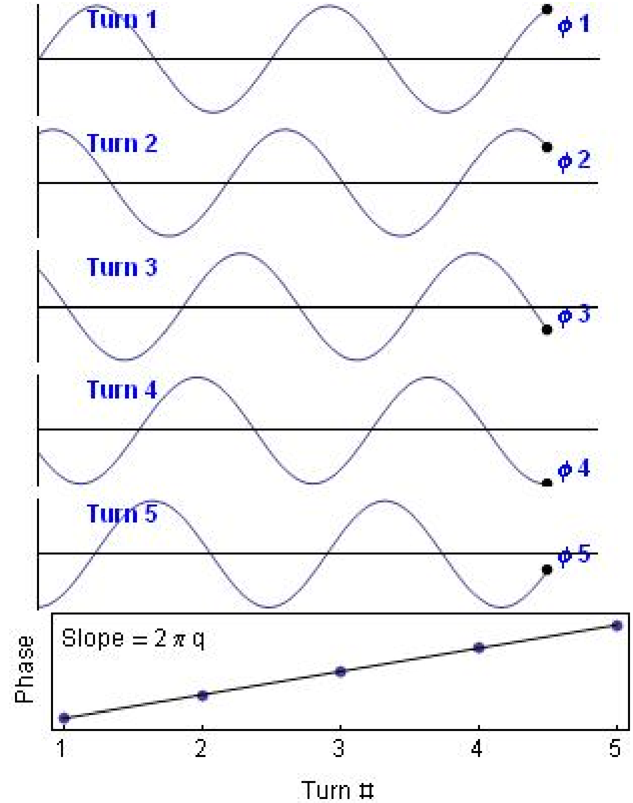

Figure 3: Illustration of the tune measurement technique. The first 5 plots show the transverse position of a slice of beam as it orbits the ring. The phase of its betatron oscillation is indicated after each turn. The bottom plot shows that the slope of the phase vs. turn gives the fractional part of the tune.

ANALYSIS OF BEAM RESPONSE

Figure 4 shows an example of tunes as determined using this method. The Fourier transforms of the data shown in Figure 2 were used, with the transform computed for a series 10-turn-long data samples. The frequency bins from the Fourier transform are therefore spaced by 1/10 of a mode, i.e. $\Delta f = \Omega \div 10$. With a drive frequency at the upper betatron sideband of mode 20, the data from the frequency bin corresponding to mode 20.2 is of interest, as the fractional tune $q \approx 0.19$ here, and this is the bin closest in frequency to the drive frequency. The difference in the phase of the Fourier transform turn-to-turn is plotted to show the slope, which is $2\pi\times q$.

Figure 4a shows the fractional tune with the drive frequency at the lower sideband of mode 20, corresponding to BPM signal in Figure 2a. The variation is quite small. Figure 4b is a similar plot for the drive at the upper sideband of mode 20, where the beam response grew and shrank as shown in Figure 2b. Here the tune varies by about 0.004 during the store. Discussion of this phenomenon is in the following section.

The noise present in the tune measurement is at a level of less than 10^{-4}. In order to achieve this resolution by looking at the amplitudes of the Fourier transform, the sample length would need to be 10^4 turns long, eliminating the possibility of observing variations on the time scales of interest here.

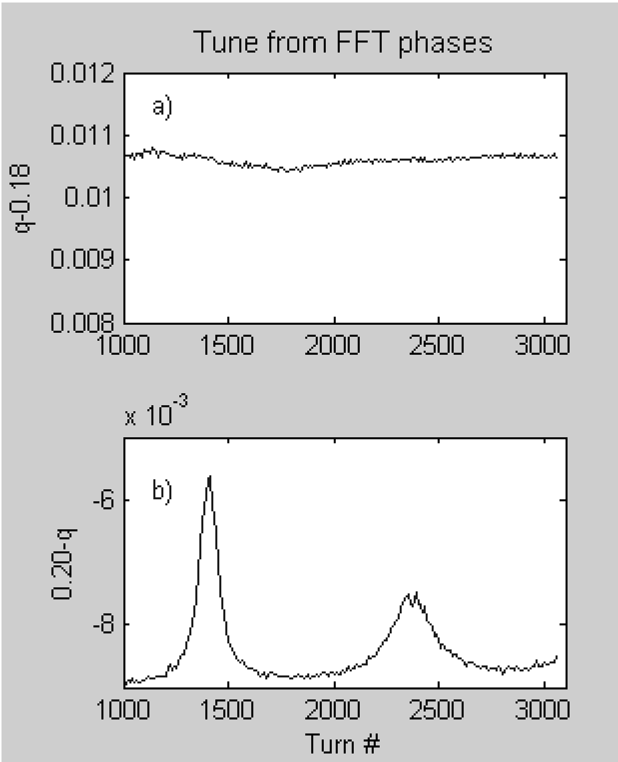

Figure 4: Tunes as determined from the slopes of the phases of Fourier transforms of the data shown in Figure 2. The final 2000 turns are shown. The vertical scales' ranges are the same to allow easy comparison of the magnitudes of variations.

DISCUSSION

The apparent variation of the betatron tune for a coasting beam is puzzling. It was first hypothesized to explain the growing and shrinking of the response of the beam to the transverse drive because near a betatron resonance the phase of the response of the beam varies rapidly with frequency as the frequency varies across the resonance, or as the resonant frequency varies. Thus a slight change in tune could change a driving force to a damping force and vice versa.

One mechanism for a variation in tune is the changing magnitude of the interaction of the beam with the beam pipe and magnet poles, which can change with the amplitude of the oscillation [2]. This seems somewhat unlikely though as the beam current is small here and this phenomenon is rarely seen in PSR data. No quantitative analysis of this hypothesis has been performed.

Another possibility is that the drive frequency varied during the store. Unfortunately the drive signal was not recorded, so analysis of this hypothesis is not possible.

CONCLUSION

A method of measuring the fractional betatron tune of a stored coasting beam, using the turn-to-turn progression of the phase of the Fourier transform of the beam position was shown. This method affords high precision and allows one to observe variation in the tune on short time scales.

REFERENCES

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[2] P. J. Bryant, K. Johnsen, "The Principles of Circular Accelerators and Storage Rings," Cambridge University Press, 1993.