COMMON MODE NOISE ON THE MAIN TEVATRON BUS AND ASSOCIATED BEAM EMITTANCE GROWTH

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Abstract

Overlap of betatron tune frequencies with the power supply noise spectrum can cause transverse beam emittance growth in a storage ring. We have studied this effect for tunes near the integer, where the betatron frequency is low. By injecting noise onto the main power supply bus, it was determined that common mode noise was the dominant source of emittance growth. A noise suppression feed-back loop was then used to reduce the noise and the emittance growth. These experiments are described as are investigations of the common mode propagation along the Tevatron bus and measurements of the fields generated by common mode excitation of isolated Tevatron magnets.

Introduction

The main power supply bus for the Tevatron powers 774 dipole magnets and 180 quadrupole magnets connected in series about the entire storage ring. Measurements of the common mode noise spectrum of this power supply shows that the noise decays exponentially with frequency as shown in Fig. 1.

The frequency of betatron oscillations is a product of the fractional part of the tune and the revolution frequency of the beam. The Tevatron normally operates at a revolution frequency of 49 KHz and at a tune close to 19.42, which implies a betatron frequency of 20 KHz. Previous Tevatron studies found that the common mode noise had no significant effect on the beam at this betatron frequency.[1]

Recent investigations of alternate working points have emphasized regions of tune space near the integer. When operating at a tune of 19.05, the betatron frequency is about 2.4 KHz. The level of common mode noise at this betatron frequency was found to have a significant effect on the emittance growth rate of a stored proton beam.

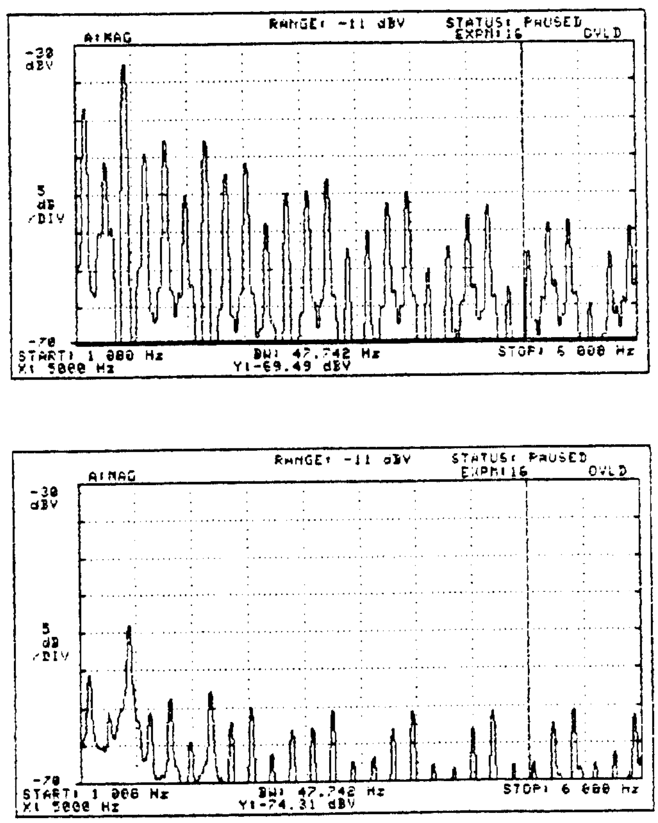

Figure 1: Tevatron main bus power supply noise spectrum with the noise suppression circuit off (top plot) and on (bottom plot). Vertical scale is 5 dB/div. Frequency bandwidth is 47.7 Hz. Frequency ranges from 1 KHz to 6 KHz.

Emittance Growth Model

The normalized transverse proton emittance growth rate, $d\epsilon/dt$, (95% definition) in the presence of tune spread, $\Delta\nu$, is given by

$$\frac{d\epsilon}{dt} = \frac{4\sqrt{3}\pi {f_0}^2(\beta\gamma)\Delta\nu}{\beta_L} x^2(t) \qquad (1)$$

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where f_0 is the proton revolution frequency, β is the betatron amplitude function at the point of observation and $x(t)$ is the time dependant rms envelope of the beam.

$$x(t) = x(0)\ \exp(-t/\tau) \qquad (2)$$

A decay time of τ represents a $1/e$ amplitude decay of a coherent beam with initial amplitude $x(0)$.

Emittance Growth due to Common Mode Noise

Experimental measurements are discussed below which quantify how common mode noise in the Tevatron main power supply bus contributes to transverse beam emittance growth for near integer tune proton stores.

Injecting Noise

Different levels of common mode noise were injected onto the main power supply bus in order to examine the relationship between the common mode noise and transverse beam emittance growth. A noise generator connected to an audio amplifier was used as the noise source. Emittance growth rates were measured for injected noise levels up to 3 mV. The experimental results for two proton stores at tunes of 19.07 and 19.10 show that the emittance growth rate of the stored beam grew linearly as the square of the power supply noise.

Noise Suppression

In an effort to reduce the beam emittance growth rate, a negative feedback circuit was designed and built to lower the noise level on the main power supply bus. A diagram of this circuit is shown in Fig. 2. The circuit reduced the common mode noise in the Tevatron power supply by approximately 10 to 15 dBV near 2.8 kHz. One would expect a correspondingly tenfold decrease in the emittance growth rate due to this noise reduction.

During a proton beam store operating at a tune of 19.05, emittance measurements were taken with the circuit first connected and then disconnected as shown in Fig. 3. The horizontal and vertical emittance growth rates with the circuit disconnected were 19 $\pi mm - mr/hr$ and 20 $\pi mm - mr/hr$, respectively. With the feedback connected, the emittance growth rates were decreased by a factor of two. This improvement in the growth rate was less than expected, indicating that another source of emittance growth must be dominant at this level.

It is not completely understood why the emittance growth rates are reduced by equal amounts in the two planes. The most probable answer is that the skew quadrupole circuits were not precisely adjusted to reduce the width of the $\nu_x = \nu_y$ coupling resonance and motion in the two planes was strongly coupled.

Common Mode Propagation

In order to understand the mechanism of an increased emittance growth due to common mode noise, the fields generated

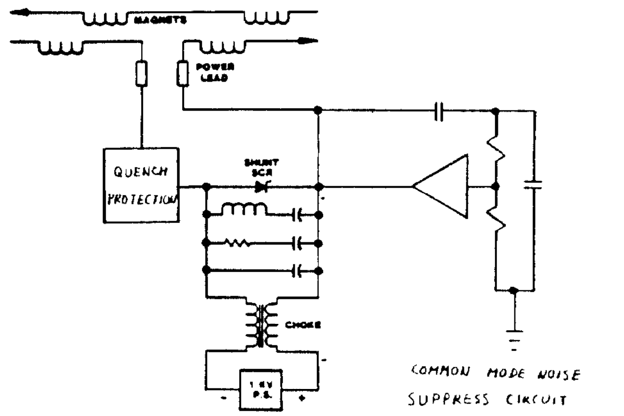

Figure 2: Diagram of the noise suppression feedback circuit. The circuit is outlined by the dashed line. The power leads are connected to the main power supply. A passive filter was also used as shown.

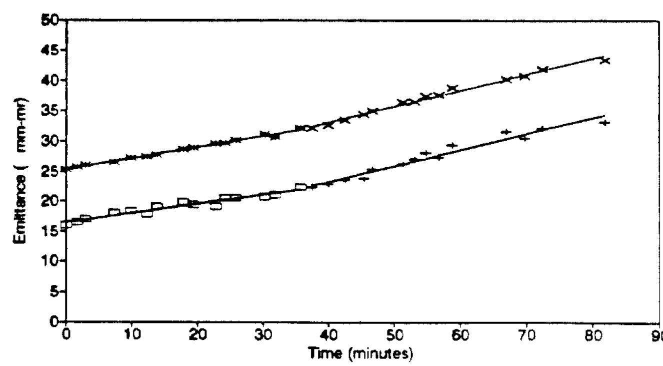

Figure 3: Emittance measurements over time for a near integer tune store with the noise suppression circuit connected from 0 to 37 minutes and then disconnected. The upper curve is a measurement of the vertical emittance and the lower is the horizontal emittance.

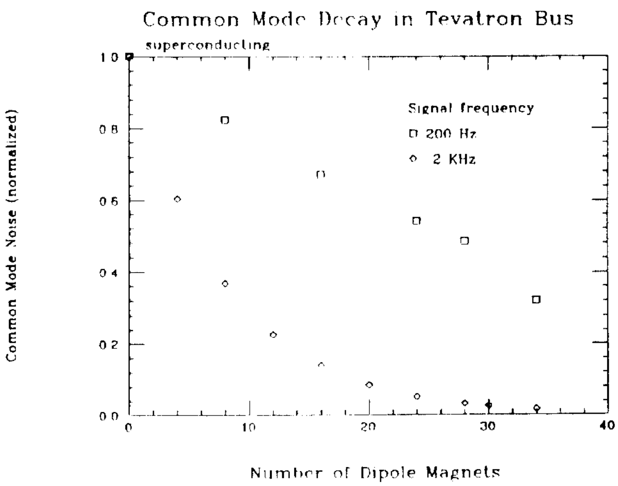

Figure 4: Noise propagation in the chain of magnets in the Tevatron. Measurements for a signal frequency of 200 Hz and 2 KHz are shown.

in an isolated Tevatron dipole test magnet were measured. A magnetic probe was used to determine that the common mode noise produces a fluctuation of the dipole components of the magnetic field in the center of the magnet. The dipole magnetic field was found to increase linearly as a function of the level of common mode excitation with a slope of 3.1 G/V.

The common mode ripple starts at the main power supply and decays through the series of magnets connected in the Tevatron much like a damped transmission line. An emittance growth rate of 0.058 $\pi mm - mr/hr$ per magnet is calculated using the emittance model discussed above and using the measured value of 50 mV for the common mode ripple in the Tevatron for a frequency close to 2 kHz.

Measurements of noise propagation as a function of frequency is shown in Fig. 4. This data fits an exponential curve with a decay constant of 8.2, thus the total number of magnets contributing to the common mode noise effect is calculated to be 17. One can thus estimate the emittance growth rate due to common mode ripple to be approximately 17 $\pi mm - mr/hr$ (0.058×17^2), in agreement with the measured values of Fig. 3.

Conclusions

Common mode noise was the dominant source of emittance growth for stores with tunes near integer values. A noise suppression circuit reduced the emittance growth rate by one half. Since the growth rate was predicted to be reduced by a factor of ten, other sources of emittance growth must be present.

The mechanism for the emittance growth due to the common mode noise was found to be a fluctuating dipole field in the Tevatron dipole magnets. The excitation factor for the common-mode induced dipole field was measured for a Tevatron magnet.

Transmission of the common mode noise along the magnet bus was measured. At the frequencies corresponding to the integer tune studies the effective number of magnets contributing to the emittance growth was 17. The emittance growth rate predicted by the measured bus noise, effective number of dipoles, and excitation factor is in agreement with the measured rates.

References

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[2] R.P. Johnson and P. Zhang, "A New Tevatron Collider Working Point Near the Integer", Proceedings of the 1989 IEEE Particle Accelerator Conference, Vol.II, p. 806.

[3] P. Zhang, C. Ankenbrandt, D. Finley, G.Goderre, R.P. Johnson, and D. Siergiej, "Prospects for Tunes near the Integer at the Fermilab pbar-p Collider", these proceedings.