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APS-Upgrade Storage Ring RF Noise Reduction for Beam Stability

AUTHORS

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Abstract

The new Advanced Photon Source Upgrade (APS-U) storage ring is now operating and x-ray beamlines are coming back on-line. Targeted suppression of 60-Hz-harmonic-related rf amplitude and phase noise from megawatt-class klystrons has played a role in achieving orbit stability at the micron level and reducing beam energy fluctuations.

1. INTRODUCTION

The dominant source of rf amplitude and phase noise in the APS storage ring is the 60-Hz-harmonic additive noise of the megawatt-class klystrons caused by their high-voltage power supplies as depicted in Fig.1. Targeted suppression of the 60-Hz-harmonics is achieved via n parallel bank filters each with a dedicated filter $C_n(s)$.

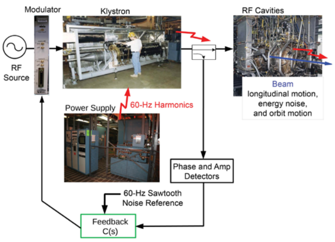

Figure 1: *Depiction of rf system with 60-Hz-harmonic noise propagation and suppression with feedback filters $C_n(s)$.*

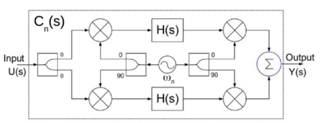

Figure 2: *Block diagram of Controller, $C_n(s)$, at the n^{th} 60-Hz-harmonic frequency ω_n and baseband filter $H(s)$.*

- $C_n(s)$ in Fig. 2 is the familiar symmetric I/Q feedback controller with baseband filter $H(s)$ used in LLRF applications

$$C_n(s) = \frac{Y(s)}{U(s)} = \frac{1}{2}\{H(s-i\omega_n) + H(s+i\omega_n)\} \quad (1)$$

- $H(s) = \frac{1}{s}$ when using an integrator at baseband.

$$C_n(s) = \frac{1}{2}\left\{\frac{1}{(s-i\omega_n)} + \frac{1}{(s+i\omega_n)}\right\} = \frac{s}{s^2+\omega_n^2} \quad (2)$$

- This is the familiar shifting of a baseband pole at zero to the reference frequency ω_n using a local oscillator at ω_n.
- This is used to create a zero and notch at ω_n in the noise rejection transfer function $R_n(s)$.

$$R_n(s) = \frac{1}{1+C_n(s)} = \frac{s^2+\omega_n^2}{s^2+s+\omega_n^2} \quad (3)$$

- Classic LLRF feedback working at 60-Hz "carriers" (Fig.3)
- ω_n references are derived with narrowband filtering of a 60-Hz line-synchronous sawtooth generator. (Fig.4)
- A Hilbert Transform filter is used to derive quadrature references of the "local-oscillator" at ω_n.
- The sampling clock is free-running. Synchronous detection occurs since both signal and reference are sampled.
- The phase rotator achieves a stable phase-margin near ω_n. This is done in the presence of existing noise. In open-loop an in-phase drive term is applied. The rotator is adjusted such that the existing quadrature-component is unchanged while the existing in-phase-component is decreased.
- A parallel bank of 8 independent harmonics is provided.

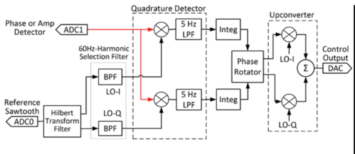

Figure 3: *Implementation Block Diagram.*

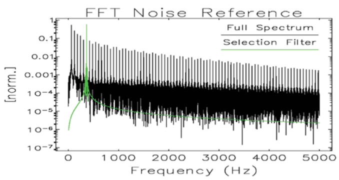

Figure 4: *FFT of sawtooth generator and scaled output of an example ω_n narrowband selection filter at 360Hz.*

2. RF Noise Suppression Results

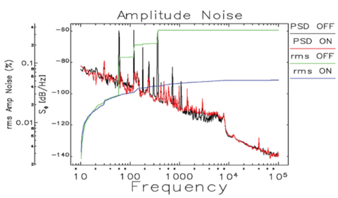

Figure 5: *8-cavity-sum amp. noise w & w/o suppression.*

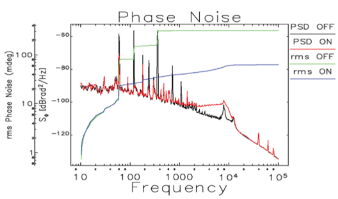

Figure 6: *8-cavity-sum phase noise w & w/o suppression.*

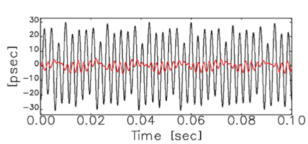

Figure 7: *Beam jitter w & w/o RF Noise Suppression.*

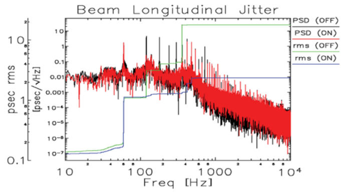

Figure 8: *Beam jitter PSD w & w/o RF Noise Suppression.*

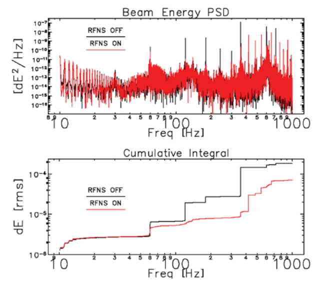

Figure 9: *Beam energy fluctuations PSD (top) and Cumulative Integral (bottom) w & w/o RF Noise Suppression.*

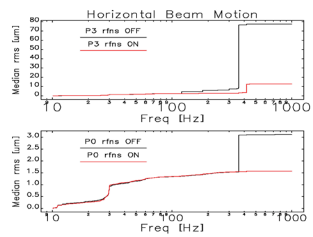

Figure 10: *Median horizontal beam motion at the P3 (top) and P0 (bottom) BPMs.*

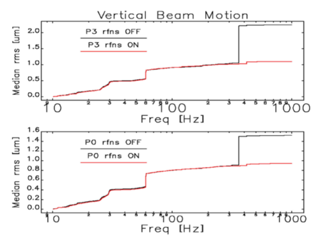

Figure 11: *Median vertical beam motion at the P3 (top) and P0 (bottom) BPMs.*

3. CONCLUSION

The noise suppression system has reduced some rf noise disturbances to the beam. Suppression of additional 60-Hz-harmonics is desired especially to avoid the synchrotron tune.