Feedback System Parameters for the PSR E-P Active Damping Experiment

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General Considerations

This note summarizes the feedback system parameters and damping estimates for the PSR e-p active damping experiment. Refer to [1] for a full description of the various terms and derivations of the various parameters. The basic results are summarized here. The damping rate (in inverse turns) is given by

$$\alpha = \frac{G}{2}\sin\psi \quad [\text{turns}^{-1}]$$

where G is the feedback gain, and ψ is the betatron phase advance between BPM and kicker (and may include the phase advance from multiple turns). The gain is a constant of proportionality relating the angular deflection provided by the kicker to the displacement recorded at the BPM:

$$\Delta x' = G\frac{x}{\sqrt{\beta_k \beta_p}}$$

where the beta-function values are those at the kicker and pickup. For optimal BPM to kicker betatron phase ($\sin\psi = 1$), the damping rate is

$$\alpha_{opt} = \frac{G}{2} = \frac{\sqrt{\beta_k \beta_p}}{2}\frac{\Delta x'}{x}.$$

The deflection of a beam having momentum *p* by parallel plates of length *l* separated by a distance *d* and held at equal and opposite potential $\pm V_L$ is

$$\theta_{DC} = \frac{2eV_L g_\perp l}{dcp\beta}$$

where $g_\perp$ is a geometry factor of order unity that accounts for the fact that a real kicker does not have plates of infinite extent.

A beam deflected by a stripline kicker includes terms due to both the electric and magnet fields (giving rise to the $1+\beta$ term) and also must include the transit-time effect which is important at high frequency. The angular deflection from a stripline kicker [1] is:

$$\theta_{SK} = \theta_{DC}(1+\beta)\frac{\sin\theta}{\theta}e^{-j\theta}$$

where

$$\theta = \frac{\omega l}{2c}\left(\frac{1+\beta}{\beta}\right).$$

At low-frequency the deflection from a stripline kicker is $\theta_{LF} = \theta_{DC}(1+\beta)$.

For a stripline kicker with each plate terminated in its characteristic impedance *Z*, and driven by a single amplifier with output power P_T, the voltage on each plate is determined from:

$$P_T = 2\frac{V_L^2}{2Z}.$$

The kicker can be described in terms of a transverse shunt impedance in analogy with RF cavities. For a stripline, the transverse shunt impedance is

$$R_\perp = 2Z_L\left(\frac{2g_\perp c\beta}{d\omega}\right)^2 \sin^2\theta$$

And the deflection is given by

$$\theta_{SK} = \frac{e}{cp\beta}\sqrt{2P_T R_\perp}.$$

Stripline Kicker Characteristics

The stripline kicker installed in PSR has an effective length of 0.46m and a plate separation of 0.10m. Each plate has a characteristic impedance of 50 Ohms. Due to the cylindrical geometry of the electrodes, the geometry factor is near unity. Assuming the stripline is driven by a single 400 W amplifier through a 180 degree hybrid to drive the plates differentially, the plate voltage is ±140 V. At PSR energy (800 MeV; cp = 1463 MeV; γ = 1.853; β=0.842) given these parameters, θ_{DC} = 1.05 μrad. The low-frequency deflection, θ_{LF} = 1.93 μrad. The transverse shunt impedance of this kicker is shown in Figure 1, and the deflection as a function of frequency for a few different amplifier powers is shown in Figure 2.

Damping Rate Estimation

To calculate the damping rate, we need to specify the values of the beta-functions at the pickup and kicker, and the displacement that corresponds to full output power of the amplifier. With a repositioning of the BPM in the PSR, the beta functions are β_k = 9.2m and β_p = 8m. The noise floor of the BPM and associated processing was estimated earlier to be about 0.3mm. To set the scale, taking full output power at 0.3mm displacement would give a damping rate at the low-frequency limit of 0.0276 turns^{-1} or a damping time of 36 turns. At higher frequency, the damping rate is reduced due to the transit time factor for the stripline kicker.

Figure 3 shows the damping time vs. frequency for a few different amplifier output powers assuming that the maximum output power is generated for a displacement of 1mm. These curves also assume that the frequency response of the rest of the system is flat, so that the only frequency dependence is through the transit time factor of the kicker. With a 400 W power amplifier, better than 200 turn damping time is achieved out to about 160 MHz.

References

[1] See presentations available at
http://www.sns.gov/APGroup/instability/instability.html

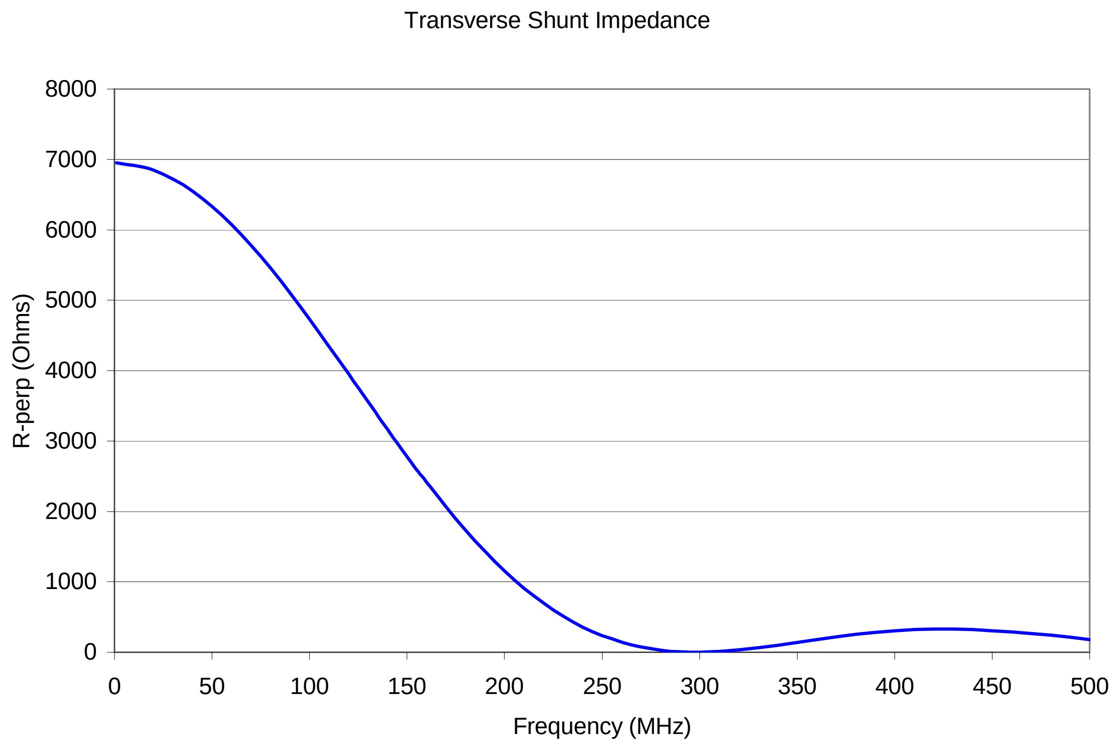

Figure 1: Transverse shunt impedance vs. frequency for the PSR stripline kicker.

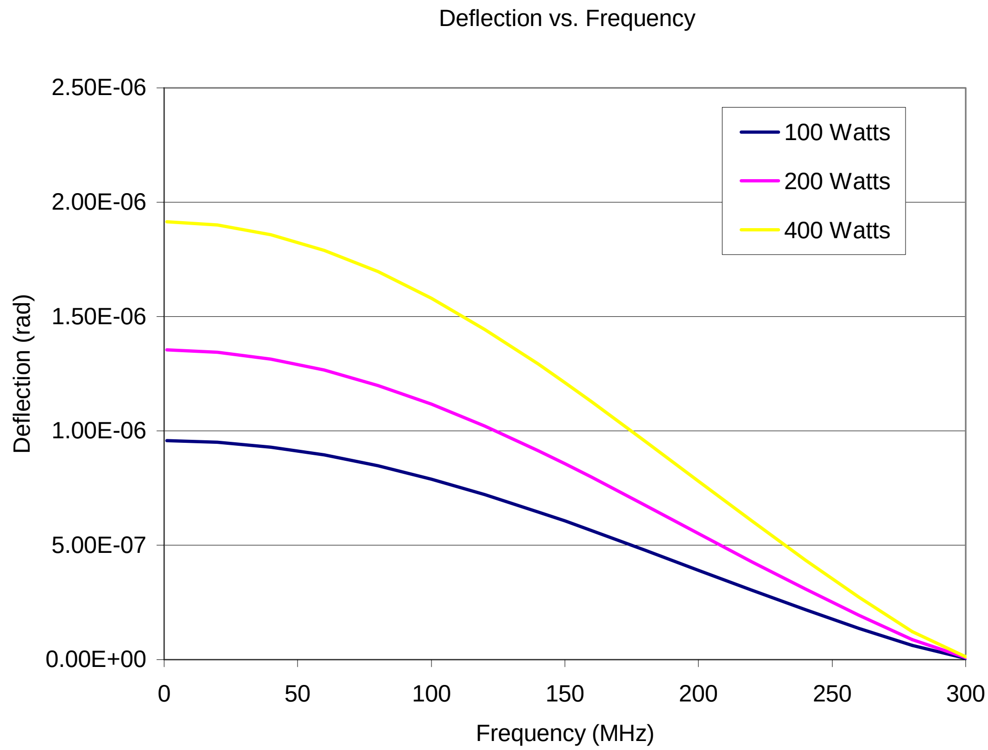

Figure 2: Deflection vs. frequency for the PSR stripline kicker.

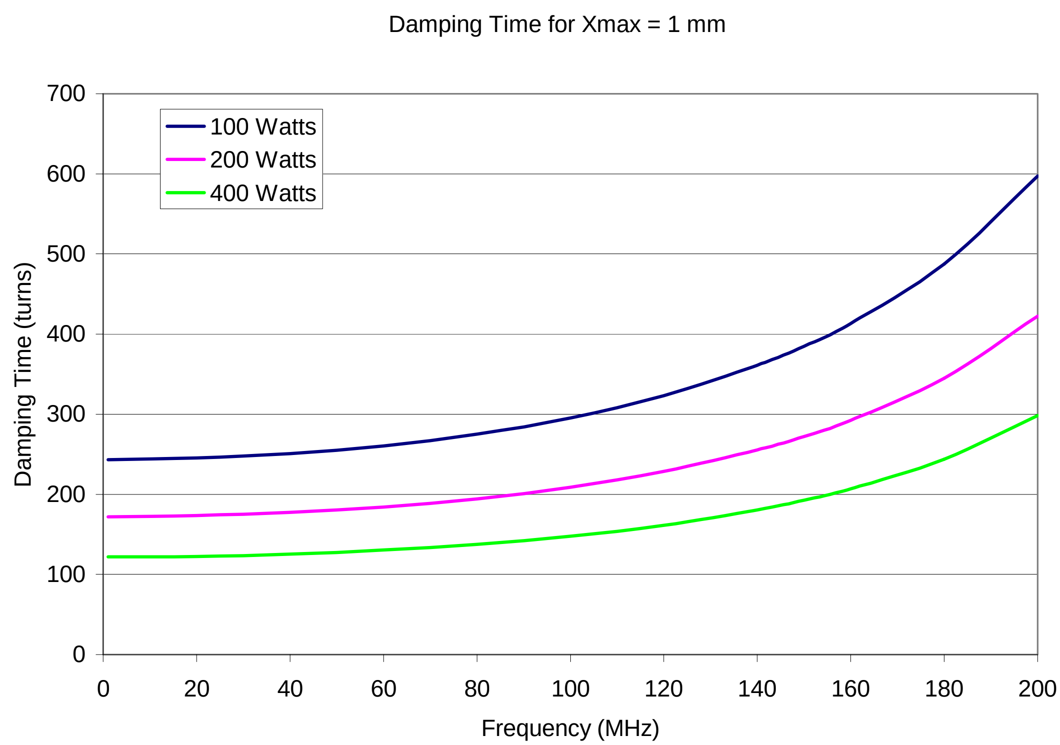

Figure 3: Damping time vs. frequency for different amplifier output powers assuming full power output at a displacement of 1 mm.