AD/RHIC–76

R H I C P R O J E C T

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A Possible Way to Reduce the Required Power of the Transverse Damping System

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August 1990

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In a conventional transverse damping system, as the one described in reference 1, the beam center position is measured, the signal amplified and the correction applied at a convenient location. The signal and the correction are thus proportional to the beam center displacement and not to the amplitude of the oscillation. As the damping proceeds, the signal and henceforth the correction are reduced. The power required at any time is then proportional to the square of the beam displacement, and is the highest at the beginning.

We propose here an alternative method of damping coherent oscillations, like for instance those induced by errors at injection in RHIC. The beam position signal is used only to trigger the correction by applying a constant kicker voltage. It also controls the sign of the voltage according to the actually measured direction of the beam displacement. This method still provides an effective damping but with considerably reduced peak power. The average power that is to be provided remains unchanged.

The amplitude of the coherent oscillation at the n–th turn, at the kicker location, is given by the

$$A_n^2 = \gamma x_n^2 + 2\alpha_k x_n x_n' + \beta_k x_n'^2 \tag{1}$$

Let θ_n the kick applied, then assuming the position is unchanged, we have a change in amplitude given by

$$\Delta A_n^2 = 2(\alpha_k x_n + \beta_k x_n')\theta_n \beta_k \theta_n^2 \tag{2}$$

If the correction is small we can neglect the quadratic term. Using explicitly equations for x_n and x_n', we obtain

$$\Delta A_n = \beta_k^{1/2} \theta_n \cos\psi_n \tag{3}$$

where ψ_n is the phase of the coherent oscillation which varies from turn to turn.

For the correction kick we take

$$\theta_n = -\theta_0 \frac{|\cos\psi_n|}{\cos\psi_n} \tag{4}$$

where θ_0 is a constant. We have finally

$$\Delta A_n = -\beta_k^{1/2}\theta_0 |\cos\psi_n| \tag{5}$$

which gives the variation of the oscillation amplitude per turn. We can replace $|\cos\psi_n|$ with its average value to obtain a constant change per turn given by

$$\Delta A_n = -\frac{\pi}{2}\beta_k^{1/2}\theta_0 \tag{6}$$

To reduce the oscillation amplitude from the initial value A_0 to $A_0 e^{-1}$ in 100 turns requires a correction of constant value

$$\theta_0 = \frac{\pi}{2}\frac{A_0(1-e^{-1})}{\beta_k^{1/2}}10^{-2} \tag{7}$$

whereas the conventional damping system described in reference 1 requires a variable correction with the largest value at the beginning

$$\theta_{max} = \frac{2A_0}{\beta_k^{1/2}}10^{-2} \approx 2\ \theta_0 \tag{8}$$

Thus one can obtain the same damping effect with about four times less peak power by applying a constant correction. Or the length of the kicker can be reduced by a factor of two, if with the same power.

In the RHIC case, we take the initial coherent oscillation amplitude to be one millimeter and $\beta_k = 50$ meters, then the required kick θ_k is 2×10^{-7} radian. For RHIC parameters, the relation between kicker voltage and produced kick θ_k is

$$V_k = \frac{|\theta_k|}{4.7n\ell}10^{13} \tag{9}$$

where n is the number of kickers and ℓ is the length of each kicker in mm. The required power of the amplifier is

$$P_k = n\frac{V_k^2}{R_k} = \frac{|\theta_k|^2}{(4.7)^2 n\ell^2 R_k}10^{26} \tag{10}$$

where R_k is the shunt impedance of the kicker. The relation between length of each kicker and the required power is shown in Fig. 1. In that figure, $|\theta_k| = 2 \times 10^{-7}$ radian, and $R_k = 50\Omega$.

In order to realize this method, we have to select the locations of the position monitor and damper kicker, so that the phase advance from kicker to monitor is about an odd integer times $\pi/2$ and β_k as large as possible. In this case, the beam center position measured by the monitor is

$$x_{p,n} = A_n \beta_p^{1/2} \sin\psi_{p,n} = A_n \beta_p^{1/2} \cos\psi_n \ .$$

The sign of $x_{p,n}$ is just the sign of $\cos\psi_n$ which can be used to control the sign of the kicker voltage but keeps its amplitude constant. If due to some constructional problem ψ_{kp} can not be exactly odd integer times $\pi/2$, for example $\psi_{kp} = \pi/2+\delta$, then the damping rate expressed by Eq. (6) should be timed by a factor $\cos\delta$. In the conventional damper system, if $\psi_{pk} = \pi/2 + \delta$, the damping rate will be reduced by the same factor.

When the residual coherent oscillation amplitude becomes small enough (approximately equals to ΔA induced by θ_k) we should cut off the damper system.

We make next an analysis of the effect of the off center of BPM. The off center due to momentum off set can be eliminated by using two BPMs π phase advance between them and with the same dispersion or by placing the BPM at a place where $x_p \simeq 0$. But the misalignment of BPM will cause an off center, which is difficult to eliminate. Let $-a$ be the transverse position of the center of BPM relative to the reference orbit. The measured signal will be

$$A_n \beta_p^{1/2} \sin\psi_{p,n} + a = A_n \beta_p^{1/2} \cos\psi_n + a$$

In this case, the kick of the damper is:

$$\theta_n = -|\theta_0| \frac{A_n \beta_p^{1/2} \cos\psi_n + a}{|A_n \beta_p^{1/2} \cos\psi_n + a|} \ .$$

The direction of the kick will be opposite to $(A_n \beta_p^{1/2} \cos\psi_n + a)$ but not to $A_n \beta_p^{1/2} \cos\psi_n$. When $\cos\psi_n$ is negative and $|A_n \beta_p^{1/2} \cos\psi_n| \leq a$, the kick (θ_n) direction will be wrong and there will be antidamping effect. When the amplitude A_n of the coherent oscillations have been damped to values $A_n \beta_p^{1/2} \simeq a$, the damping will stop, the coherent oscillations will smear and the beam emittance will grow by an amount which is a^2/β_p. If we take

$a = 0.25$ mm and $\beta_p = 50$ m then the emittance increase is $\Delta\epsilon = 0.00125$ πmm–mrad, which is very small.

Reference

1. A Feedback Device to Damp the Coherent Oscillations from Injection Errors in RHIC, J. Xu, J. Claus and A.G. Ruggiero, AD/RHIC–74; 1990.

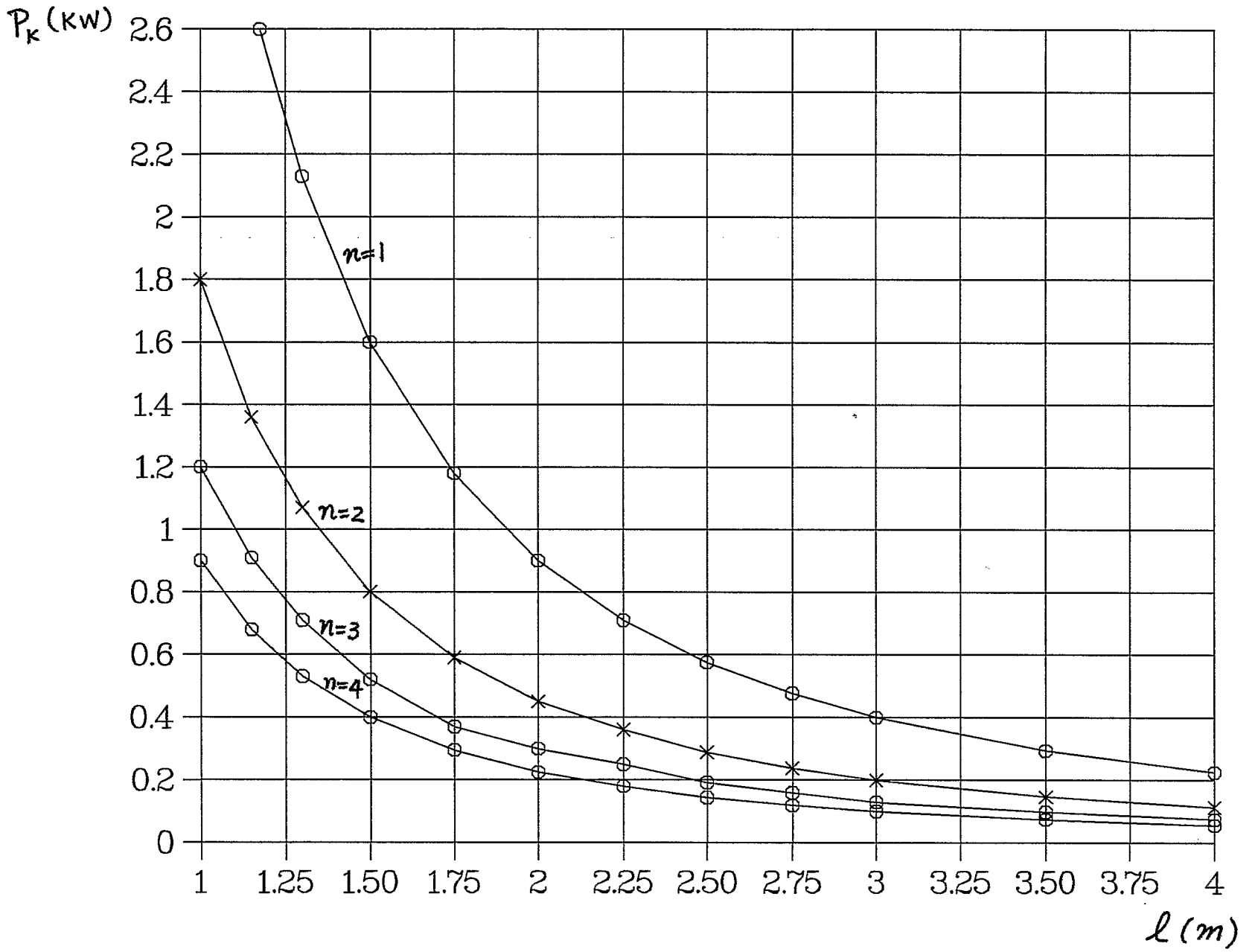
P_K (KW)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
1.25
1.50
1.75
2
2.25
2.50
2.75
3
3.25
3.50
3.75
4
ℓ (m)
n=1
n=2
n=3
n=4

Fig. 1