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Fast Transverse Damper for the NSNS Accumulator Ring

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Abstract

A fast transverse resistive-wall like instability is expected in the NSNS Accumulator Ring. The growth rate, depending on the impedance model assumed, can be larger than 10^4 s^{-1}. The only method available to damp the instability is to use a positive feedback damper system. The damper is described in this technical note. It operates over an amplifier bandwidth ranging from 0.2 to 10 MHz, with a gain of about 1000 and a total power close to 1kW.

The NSNS Accumulator Ring

The function of the Accumulator Ring is to take the 1.0 GeV proton beam from the Linac and to convert the long Linac beam pulse of about 1 ms into a 0.5 microsecond beam in about 1100 turns [1]. The bunch compression occurs during the injection process, and the beam is immediately extracted at the end of the process. The final beam has an intensity of 2.08 x 10^{14} proton per pulse, resulting in 2 MW average beam power at 60 Hz repetition rate. The lattice of the Accumulator Ring is a simple FODO lattice with four-fold symmetry [2], and the dispersion function is reduced to zero at straight sections by the missing magnet scheme. The total circumference of the ring is 220.7 m and the transition energy is $\gamma_T = 4.93$, higher than the operating energy of 1 GeV. The main parameters of the Accumulator Ring are given in Table 1.

Transverse Coherent Instability

It has been determined [3] that the beam circulating in the NSNS Accumulator Ring may be subject to fast transverse coherent instabilities, caused by the interaction of the beam with the wall components. This instability is driven by the product of the beam current with the lateral displacement z, that is

$$P(t) = I(\theta - \omega_0 t)\, z(t) \tag{1}$$

where θ is the angular coordinate around the circular orbit, and ω_0 the angular revolution frequency. The beam spends at most one millisecond circulating in the ring, that is less or about the period of one synchrotron oscillation. Moreover the beam intensity increases linearly with time. Thus the usual coasting beam theory has been used [3]. As a consequence, coasting beam modes are introduced to describe the instability, and which are used here too to describe the requirement on the bandwidth of the damper.

The lateral displacement of the beam occurs at the betatron frequency, that is

$$z(t) = z_0\, exp\, i\,(Q\omega_0 t) \tag{2}$$

where Q is the number of betatron oscillations per revolution. On the other hand, the Fourier expansion of the beam current gives

$$I(\theta - \omega_0 t) = \Sigma_n I_n \, exp\, i\, n\, (\theta - \omega_0 t) \tag{3}$$

Replacing both (2) and (3) in (1) gives

$$P(t) = \Sigma_n I_n \, exp\, i\, n\, \theta \, exp\, i\, [(Q - n)\, \omega_0 t] \tag{4}$$

which clearly shows the betatron sidebands with angular frequency $\omega = (n - Q)\, \omega_0$. According to the coasting beam theory only the modes n > Q can be unstable.

Table 1: General Parameters of the NSNS Accumulator Ring

Average Power	2 MW
Kinetic Energy	1.0 GeV
Circumference, 2π R	220.7 m
Number of Protons, N	2.08×10^{14}
Betatron Tunes, $Q_{H/V}$	5.82 / 5.80
Transition Energy, γ_T	4.93
Revolution Frequency, f_0	1.1887 MHz
Filling Time	0.925 ms
Synchrotron Period, T_s	0.9 ms
Total Bunch Area, S	10 eV-s
Full Bunch Length	546.6 ns
Full Momentum Spread, Δ	1.6 %
Average Beam radius, a	3.80 cm
Average Pipe Radius, b	10 cm

It was determined [3] that the most unstable mode is n = 6, in proximity of the betatron tune Q = 5.82 which yields a sideband frequency $\omega / 2\pi = 0.23$ MHz. The contributions to the transverse coupling impedance at n = 6 from the various wall components considered, including space charge, are listed in Table 2. The growth rate of the instability is given by the real part of the impedance. The largest contributors are the kicker, the vacuum chamber steps, and the RF cavities.

Table 2: Transverse Coupling Impedance Z_T for n = 6 in khom/m

Contribution	Real	Imaginary
Space Charge	0	2406.8
RF Cavities	146.7	3172.9
Kicker	408.7	132.8
Steps	167.6	-526.6
Vacuum Ports	0	2406.6
Damper	2.9	-16.6
BPM	2.7	-91.2
Bellows	0	-48.96
Resistive Wall	2.8	-2.8
Total	731.4	7433.0

The growth time of the instability is given in Table 3 for the lowest mode numbers n = 6, 7 and 8, for various assumptions which regards the inclusion or less of the wall components, the resistivity of the wall material, and the change of the betatron tune.

Table 3: Grow Time for several assumptions and harmonic numbers

Cavities, Kicker, Steps	included	not included	not included	not included
Wall Resistivity	SS: 15% Al: 85%	SS: 15% Al: 85%	SS: 100% Al: 0%	SS: 15% Al: 85%
Betatron Tune	5.82	5.82	5.82	5.20
Growth Time (ms)				
n = 6	0.006	0.529	0.248	1.540
n = 7	0.048	1.978	0.744	2.422
n = 8	0.112	2.746	1.019	2.958

It is obviously seen the importance to control the impedance from the Kicker, the Steps and the RF Cavities. In order to increase the growth time to 100 μs for the mode number $n = 6$ the real part of the impedance should not exceed 40 kohm/m. The design of the damper system shown below therefore assumes a bandwidth large enough to include all the mode numbers $n = 6$ to 16, that is a bandwidth ranging between 0.2 and 10 MHz, and a damping time of at least 100 μs for $n = 6$, and somewhat higher for the other modes.

The Damper System

The Damper system is shown schematically in Figure 1. It is made of a Beam Position Monitor (PickUp) and of a Kicker. The beam current I and transverse position z, that is the quantity P of Eq. (1), is measured at the Position Monitor. The signal is amplified through an Amplifier by the gain G, and applied across the Kicker, which is made of two parallel striplines. That part of the beam that left the signal during one revolution will receive a transverse kick when, almost one turn around, will traverse the Kicker. The minimum length of the beam sample which leaves the signal and is kicked depends on the bandwidth of the system, mostly limited by the amplifier.

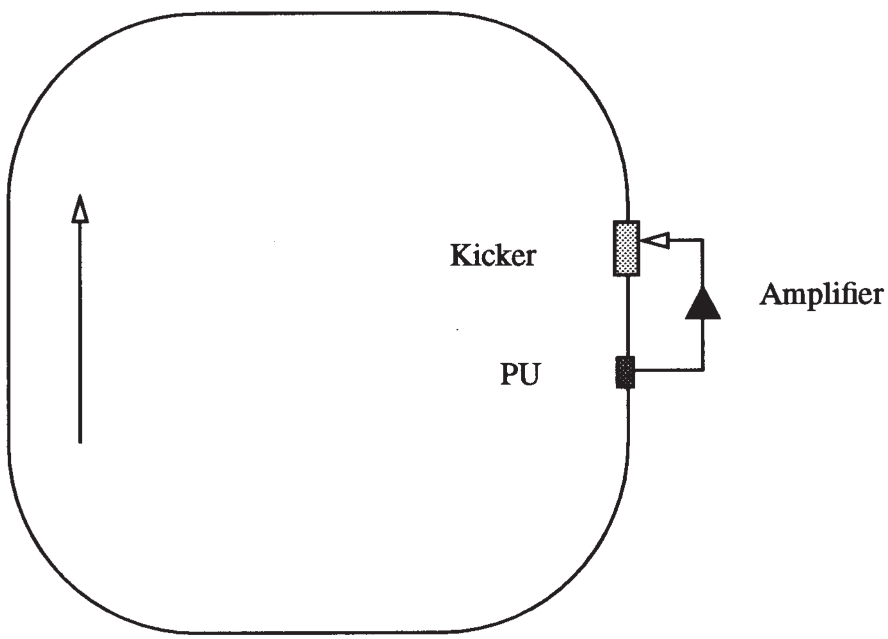

Figure 1. Layout of the Damper System

Let V_{PU} be the voltage signal at the output the Beam Position Monitor, and V_K the voltage across the kicker, denoting with z_{PU} the displacement at the PickUp, we have

$$V_{PU} = g(n\omega_0)\, z_{PU} \tag{5}$$

and

$$V_K = G\, V_{PU} \tag{6}$$

where $g(n\omega_0)$ is the dynamical sensitivity of the PickUp at the current frequency $n\omega_0$. When traversing the Kicker, the beam receives a transverse kick

$$\Delta z_K' = e V_K L_K / 2 b \beta^2 \gamma E_0 \quad (7)$$

where L_K is the length of the Kicker, β and γ the usual relativistic factors, and E_0 the proton energy at rest. Combining Eq.s (5 - 7) together gives

$$\Delta z_K' = [e G g(n\omega_0) L_K / 2 b \beta^2 \gamma E_0] z_{PU} \quad (8)$$

that is a kick that is proportional to the beam displacement at the PickUp.

The equivalent correction of the beam displacement at the pickUp from the kick at the Kicker is estimated by making use of the following relation

$$\Delta z_{PU} = (\beta_{PU} \beta_K)^{1/2} (\sin \psi_{PK}) \Delta z_K' \quad (9)$$

where β_{PU} and β_{PU} are the amplitude lattice function values respectively at the PickUp and the kicker. ψ_{PK} is the betatron phase advance between PickUp and Kicker.

Define the damping rate

$$1 / \tau_D = \omega_0 \Delta z_{PU} / 2\pi z_{PU} \quad (10)$$

Inserting Eq.s (8 and 9) in Eq. (10) finally gives

$$1 / \tau_D = (\beta_{PU} \beta_K)^{1/2} [e \omega_0 G g(n\omega_0) L_K / 4 \pi b \beta^2 \gamma E_0] \, | \sin \psi_{PK} | \quad (11)$$

The other parameter of relevance is the power required at the kicker. We shall assume that the voltage V_K is evenly split between the two parallel striplines, and that each plate is terminated by an impedance Z_0. Then the total required power in the kicker is

$$P_K = V_K^2 / 2 Z_0 \quad (12)$$

PickUps

The NSNS Accumulator Ring is equipped with Beam Position Monitors which are distributed along the circumference. They are made of 20 cm long parallel striplines, shorted at one end and terminated to the characteristic impedance on the other. In principle, it may be possible to use any one of these Beam Position Monitors as the PickUp for the Damper System. The problem with them is that they have a low sensitivity, and thus one should really adopt a dedicated PickUp device just for the Damper. In general, the response of the PickUp is given by

$$g(n\omega_0) = I_0 S(n\omega_0) f_n \quad (13)$$

where I_0 is the average beam current, $S(n\omega_0)$ the frequency response of the device, and f_n the Fourier coefficient of the bunch longitudinal distribution. For a gaussian distribution with rms length σ

$$f_n = exp[-(n\sigma/2R)^2] \quad (14)$$

and for a rectangular uniform distribution over a full length 2 L

$$f_n = sin\ (nL/R)/(nL/R) \quad (15)$$

Thus there is quite an uncertainty of the Fourier coefficient since it strongly depends on the distribution assumed.

On the other hand, for a Beam Position Monitor, made of a pair of matched striplines, the frequency response is

$$S(\omega) = Z_0\ (w/b)^2\ |sin\ (\omega L_{PU}/2c)| \quad (16)$$

where w is the width of a plate, b the pipe radius, and L_{PU} the length of the plates. This yields a too low sensitivity and a different Beam Position Monitor has to be used, for instance with capacitive coupling. In the following we shall leave the dynamical sensitivity $g(n\omega_0)$ unspecified; actually, it will be taken as a variable parameter.

Bandwidth

The restrictions to the bandwidth of the Damper System are essentially consequence of the bandwidth separately of the PickUp, the Amplifier, and the Kicker. The bandwidth of the PickUp and Kicker is determined by their length L_K and L_{PU} which we assume short enough to cover a range larger than the bandwidth of the Amplifier. This length is about 1 meter. Thus the bandwidth of the total system is determined practically by that of the Amplifier.

Discussion

PickUp and Kicker are located next to each other in one of the long straight sections of the Ring. We shall take average values of the amplitude functions, that is $\beta_K \sim \beta_{PU} \sim 10$ m. Also, to cover the possibility to vary the betatron tune from 5.8 down to 5.2, we shall take $\sin \psi_{PK} \sim 0.5$. Finally, we take also $L_K = 1$ m, b = 10 cm, and $Z_0 = 50$ ohm.

Inspection of Eq. (11) shows that, since all the parameters have been specified, it is possible to estimate directly the product $G\ g(n\omega_0)$ needed for a preassigned damping time τ_D. The results are shown in Figure 2. As an example, the following represents a feasible solution that assumes that the system will start damping once the displacement has reached the value of 1 mm. The results shown in Figure 2 have been obtained with the same assumption.

g	1	Volt/mm
G	500	
V_K	500	Volt
P_K	2.5	kWatt

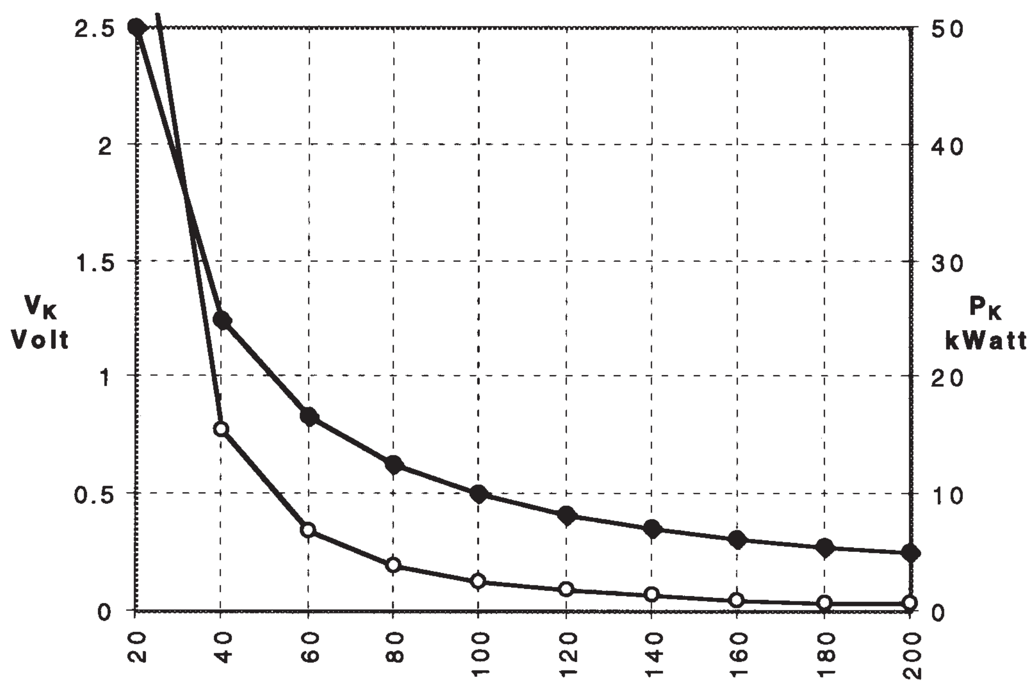

Figure 2. Kicker Voltage V_K and Power P_K vs. Damping Time τ_D in μs

References

[1] W.T. Weng et al., presentation to the 1997 Particle Accelerator Conference, Vancouver BC, May 12-16, 1997.

[2] Y.Y Lee, "The 4 Fold Symmetric Lattice for the NSNS Accumulator Ring", BNL/NSNS Technical Note No. 26, February 19, 1997.

[3] A. G. Ruggiero and M. Blaskiewicz, "Fast Transverse Instability in the NSNS Accumulator Ring", BNL/NSNS Technical Note No. 28, April 24, 1997.