G. López

New Transverse Damper Correction Scheme

**Superconducting Super Collider
Laboratory**

APPROVED FOR RELEASE ON
PUBLICATION - O.R. PATENT GROUP
BY...*es*...DATE...*4/9/95*...

Disclaimer Notice

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government or any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Superconducting Super Collider Laboratory is an equal opportunity employer.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

New Transverse Damper Correction Scheme*

G. López

Superconducting Super Collider Laboratory[†]
2550 Beckleymeade Avenue
Dallas, Texas 75237

October 1993

---

* To be submitted to *IEEE Transactions on Nuclear Science*.

[†] Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

NEW TRANSVERSE DAMPER CORRECTION SCHEME

Gustavo López

Superconducting Super Collider Laboratory*

2550 Beckleymeade Avenue

Dallas, Texas 75237

Abstract

A transverse damping system for providing beam motion stability against Dipole Mode Multibunch Instabilities (DMMI) in the Superconducting Super Collider (SSC) is outlined. This damper makes use of two monitors and one kicker, as in existing designs. The novel feature is the use of a new correction scheme, which provides exact orbit compensation within two turns.

I. INTRODUCTION

The new generation of high energy accelerators, such as the Superconducting Super Collider (SSC) and the Large Hadron Collider (LHC), requires storage of thousands of bunches circulating in the machine to achieve the very high luminosity ($10^{33} \text{ cm}^{-2}\text{sec}^{-1}$) required to find new physics. Consequently, multibunch transverse instabilities may appear. Such instabilities can be caused by injection errors, resistive wall impedance, higher order modes of the rf cavities, or external vibrations (ground, running fluids, *etc.*). The most dangerous instability is the so-called Dipole Mode Multibunch Instability (DMMI) which represents the rigid motion of the bunch with respect the closed orbit. To control these instabilities, a transverse damper system is required. A traditional damping system consists of one

---

* Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

Beam Position Monitor (BPM)* followed downstream by a kicker (mostly electrostatic), with a betatron phase advance that is an odd multiple of $\pi/2$, where a correction to the bunch orbit is done that is proportional to the displacement measured at the BPM. The primary problem with this scheme is that it requires a very high gain for fast DMMI to be controlled [1], resulting a potential problem for controlling the emittance growth due to BPM resolution (noise) [2]. In addition, even if the gain is equal to one and no other perturbation exists, the completed cancellation of the coherent motion is carried out after several turns (exponential decay behavior with “2/gain” as the decay constant).

This paper presents a new scheme that allows DMMI damping with a very low gain and complete cancellation of the coherent oscillations within two turns when gain is equal to one. Although this scheme was mentioned elsewhere [3], its advantages were not considered and no analysis was made.

II. ANALYSIS AND RESULT

Figure 1 shows a simplified diagram of the two-BPM, one kicker feedback system. This system assumes a fully decoupled motion and is restricted to a single plane, say horizontal. In Figure 1, **B1**, **B2** and **K** are the locations of the two BPMs and the kicker, ϕ and ψ are arbitrary relative phase advances between the elements, and $\alpha's, \beta's$ are the Courant-Snyder [4] parameters associated to the location of each element. For simplicity, the phase advances will be taken as $\pi/2$. However, this must not be thought of as a possible limitation of the scheme. In the first turn (1), the kicker gives a kick (U_1) to the bunch such that the new trajectory (2) will make the bunch to come back to the kicker with zero amplitude in the second turn. Then, the final correction kick (U_2) is applied to fully cancel the coherent oscillation of the bunch.

---

* Actually, there is another BPM upstream used for correction in the tune changes.

The coordinates of the bunch at position B2 (X_2, X'_2) are linked with coordinates at position B1 (X_1, X'_1) through the following relation:

$$\begin{pmatrix} X_2 \\ X'_2 \end{pmatrix} = \begin{pmatrix} \alpha_1 \sqrt{\frac{\beta_2}{\beta_1}} & \sqrt{\beta_1 \beta_2} \\ -\frac{1 + \alpha_1 \alpha_2}{\sqrt{\beta_1 \beta_2}} & -\alpha_2 \sqrt{\frac{\beta_1}{\beta_2}} \end{pmatrix} \begin{pmatrix} X_1 \\ X'_1 \end{pmatrix}, \quad (1)$$

where X and X' represent the amplitude and the angle of the coherent oscillation. Since X_1 and X_2 are known, from Eq. (1) it follows

$$X'_1 = \frac{X_2}{\sqrt{\beta_1 \beta_2}} - \frac{\alpha_1}{\beta_1} X_1 \quad (2)$$

and

$$X'_2 = -\frac{X_1}{\sqrt{\beta_1 \beta_2}} - \frac{\alpha_2}{\beta_2} X_2. \quad (3)$$

The coordinates of the bunch at the kicker location, (X_3, X'_3), are connected with those of the second BPM, B2, as

$$\begin{pmatrix} X_3 \\ X'_3 \end{pmatrix} = \begin{pmatrix} \alpha_2 \sqrt{\frac{\beta_3}{\beta_2}} & \sqrt{\beta_2 \beta_3} \\ -\frac{1 + \alpha_2 \alpha_3}{\sqrt{\beta_2 \beta_3}} & -\alpha_3 \sqrt{\frac{\beta_2}{\beta_3}} \end{pmatrix} \begin{pmatrix} X_2 \\ X'_2 \end{pmatrix} + \begin{pmatrix} 0 \\ U_1 \end{pmatrix}, \quad (4)$$

where the kick (U_1) is unknown at this moment. Using Eq. (3) in Eq. (4) results in

$$X_3 = -\sqrt{\frac{\beta_3}{\beta_1}} X_1 \quad (5a)$$

and

$$X'_3 = -\frac{X_2}{\sqrt{\beta_3 \beta_2}} + \frac{\alpha_3 X_1}{\sqrt{\beta_3 \beta_1}} + U_1. \quad (5b)$$

If μ is the tune of the machine, the coordinates of the bunch at the kicker location in the next turn (X_4, X'_4) are determined by the relation

$$\begin{pmatrix} X_4 \\ X'_4 \end{pmatrix} = \begin{pmatrix} \cos \mu + \alpha_3 \sin \mu & \beta_3 \sin \mu \\ -\frac{1 + \alpha_3^2}{\beta_3} \sin \mu & \cos \mu - \alpha_3 \sin \mu \end{pmatrix} \begin{pmatrix} X_3 \\ X'_3 \end{pmatrix} + \begin{pmatrix} 0 \\ U_2 \end{pmatrix}, \quad (6)$$

where U_2 is the new kick given to the bunch. Using Eqs. (5a) and (5b) in Eq. (6), the following relations can be deduced:

$$X_4 = -\sqrt{\frac{\beta_3}{\beta_1}} X_1 \cos \mu + \beta_3 \sin \mu \left(-\frac{X_2}{\sqrt{\beta_3 \beta_2}} + U_1 \right) \quad (7a)$$

and

$$X'_4 = \frac{X_1}{\sqrt{\beta_3 \beta_1}} (\sin \mu + \alpha_3 \cos \mu) - \frac{X_2}{\sqrt{\beta_3 \beta_1}} (\cos \mu - \alpha_3 \sin \mu) + (\cos \mu - \alpha_3 \sin \mu) U_1 + U_2. \quad (7b)$$

Finally, imposing in Eqs. (7a) and (7b) the conditions $X_4 = 0$ and $X'_4 = 0$ give the kicks required for fully nullifying the coherent motion of the bunch in two turns,

$$U_2 = (-\cos \mu + \alpha_3 \sin \mu) U_1 - \frac{X_1}{\sqrt{\beta_3 \beta_1}} (\sin \mu + \alpha_3 \cos \mu) + \frac{X_2}{\sqrt{\beta_3 \beta_2}} (\cos \mu - \alpha_3 \sin \mu) \quad (8a)$$

and

$$U_1 = \frac{X_2}{\sqrt{\beta_3 \beta_1}} + \frac{X_1}{\sqrt{\beta_3 \beta_1}} \frac{\cos \mu}{\sin \mu}. \quad (8b)$$

One interesting modification in the Eq. (8) scheme that has been already explored in reference [5] for damping DMMI due to resistive wall impedance, is assuming $U_1 = 0$, and then the successive kicks are given by

$$U_n = (-\cos \mu + \alpha_3 \sin \mu) U_{n-1} - \frac{X_1^{(n-1)}}{\sqrt{\beta_3 \beta_1}} (\sin \mu + \alpha_3 \cos \mu) + \frac{X_2^{(n-1)}}{\sqrt{\beta_3 \beta_2}} (\cos \mu - \alpha_3 \sin \mu). \quad (9)$$

III. COMMENTS

In a practical system, the perturbation in the beam (due to resistive wall, bellows, rf cavities, vibrations, *etc.*) makes a full cancellation of the coherent beam motion in two turns unlikely, requiring additional turns for gain equal to one.

As Eqs. (8) and (9) indicate, this system keeps a record of the previous turn correction. However, this does not represent any major problem for the feedback electronics. In principle, this damping scheme can be used for all stages of the Collider operation (if the bandwidth is wide enough, ≥ 30 MHz), the power requirements and the qualitative differences of the DMMI for injection, rf cavities, resistive wall impedance, and external noises will demand different dampers (gain, bandwidth, power, and BPM resolution) but with the same scheme of Eqs. (8) or (9). The BPM resolution (noise) of this feedback system is not more restricted than the traditional scheme, and it must be determined by the emittance growth allowed in the Collider, see reference [2].

REFERENCES

1. S. Chen and G. López, "Simulation Studies of the Transverse Dipole Mode Multibunch Instability for the SSC Collider," SSCL-614, Jan., 1993.
2. V. Lebedev *et al.*, SSCL-Preprint-188, March 1993. G. López, SSCL-625, May 1993.
3. E. Tsyganov *et al.*, SSCL-Preprint-202, March 1993.
4. E.D. Courant and H.S. Snyder, *Ann. of Phys.*, **3**, 1-48 (1958).
5. G. López, "New 2BPM-1K Scheme and Resistive Wall Instability," SSCL-, to appear.

FIGURE CAPTIONS

Figure 1. Coherent oscillations of the bunch.