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ABOUT THE FEASIBILITY OF STOCHASTIC DAMPING IN THE ISR

by

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1. Introduction

Van der Meer[1] proposes to damp incoherent vertical betatron oscillations - and hence increase the luminosity - by detecting and compensating statistical variations of the beam's centre of gravity. All it needs is a system that detects these variations, which are due to the finite number of particles, and corrects them fully (within 10% or so) once every revolution.

Hybrid semiconductor amplifiers with 2 GHz bandwidth and very short group delay are now commercially available. Several would have to be cascaded and a power amplifier added at the output. An overall risetime, τ, of 100 ps is perhaps a reasonable, though still rather optimistic, assumption for calculating damping times.

We further assume the total number of protons, N, to be 4×10^{14} and a total momentum spread $\Delta p/p = 2.7\%$. With this spread, and at 26 GeV/c, protons of extreme momenta differ by 0.94 ns in revolution time. Figure 2 of ref.[1] then gives a relative increase of damping time, due to incomplete randomization between successive corrections, by a factor, a = 1.1. The formula on top of p. 5, including the factor a, viz

$$T_d = 2N\tau a \qquad (1)$$

yields a damping time $T_d = 8.8 \times 10^4$ s = 24.5 h. This is just short enough to be interesting since it is likely to be competitive with the natural decay of luminosity under good vacuum and clearing conditions. At present, the damping would be 2 to 3 times faster, because of the lower beam currents. As suggested by Van der Meer, one could decrease the damping time by using several systems around the ISR. Since the beam is a flat ribbon one may also consider employing several systems working on different radial portions of the beam.

2. Pathlength and signal delay

An odd number of quarter betatron wavelengths is needed between the points of measuring a position error and correcting it by a deflector.

For the assumed risetime, it seems that this number could be about 5 at

where p is the particle momentum, ℓ the length, $2d_2$ the spacing of the deflecting plates, and β_1, β_2 the vertical β-functions at the locations of the displacement and of the deflector. At 26 GeV/c and for $\ell = \tau c = 3$ cm, $2d_2 = 10$ mm, one finds

$$V_k = 13 \text{ V}.$$

The total gain required is, therefore, 1.45×10^4 or 83 db, the output power, assuming 50 Ω deflector impedance, 3.4 W.

The total gain is certainly compatible with 13 ns total group delay. The output power is much more problematic. Travelling wave amplifiers seem to be totally ruled out, because of their large group delay.

In any case, one should try to develop more elaborate pick-up and deflecting structures than simple plates or loops, so as to increase V_Δ and decrease V_k. A straightforward but cumbersome way of easing the problem would be to employ several completely separate sets of pick-up amplifier and deflector, staggered by a small amount along the orbit.

Since the vacuum chamber begins to propagate well below 2 GHz, obtaining flat response and avoiding reflections in the pick-up and the deflector will not be easy.

4. Noise and common mode rejection

At 2 GHz bandwidth, room temperature, 50 Ω source and input impedance and 12 db noise figure (quoted for the HP 35005A amplifier) the input noise voltage is 80 μV. This looks acceptable compared to the 920 μV signal calculated above, and further improvement might be possible. Several parallel channels, as proposed in section 3, would also help, in proportion with the square root of their number. The r.m.s. longitudinal Schottky noise current of the circulating beam is given[2)] by

$$I_\ell = \sqrt{2eI\Delta f} \qquad (5)$$

where Δf is the bandwidth, assumed to be 2 GHz.

$$\delta = \frac{\sigma_o}{\sqrt{n}} = \sigma_o\sqrt{\frac{C}{N\tau c}} \qquad (2)$$

where σ_o is the r.m.s. vertical betatron amplitude, n the number of particles passing through the pick-up during the risetime τ and C is the machine circumference. Assuming

$$\sigma_o = 2.5 \text{ mm}$$

one finds

$$\delta = 2.3 \times 10^{-8}\text{m}.$$

The sensitivity of a set of transverse pick-up electrodes can be written as

$$\frac{V_\Delta}{\delta} = g\frac{Z}{d_1} I \qquad (3)$$

where V_Δ is the output voltage, $2d_1$ the electrode spacing, Z a coupling impedance relating total induced voltage to the total beam current I and g a geometrical factor. For a simple pair of plates or loops connected to a difference forming network one can take Z as the sum of the induced voltages in both plates over the beam current, and $g \sim 1$. For a frequency response up to 2 GHz

$$Z = 10\ \Omega$$

seems a reasonable assumption. (Our present microwave loops have about this impedance.) Assuming $2d_1 = 10$ mm and I = 20A, one gets

$$V_\Delta = 920\ \mu\text{V}$$

r.m.s. output voltage.

The voltage V_k, between the plates of an electrostatic deflector, required to produce the displacement δ is given by

$$V_k = \frac{\delta c p 2 d_2}{\sqrt{\beta_1\beta_2}\, e\ell} \qquad (4)$$

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If this should lead to a spurious output voltage of less than ε times the signal voltage V_Δ (eq. (3)), the common mode rejection (spurious output over sum voltage $I_\ell Z$) must be better than

$$\varepsilon \frac{\delta g}{d_1} \sqrt{\frac{I}{2e\Delta f}} \qquad (6)$$

or, because of eq. (2) and I = eNc/C,

$$\varepsilon \frac{\sigma_o}{d_1} g \sqrt{\frac{1}{2\tau\Delta f}} \qquad (7)$$

For our choice of parameters and ε = 0.1 the common mode rejection must be better than 8%, over the entire band. With a well designed difference unit and careful positioning of the closed orbit this seems quite possible.

If the total number of particles is smaller than assumed (as it is at present, or because each damping system covers a fraction of the radial aperture only) the damping time decreases in proportion with N and the required common mode rejection remains unchanged. All other problems become worse. The required gain increases with N^{-1}, and the deflection with $N^{-\frac{1}{2}}$. The signal to noise ratio decreases with $N^{\frac{1}{2}}$.

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References

1) Stochastic Damping of Betatron Oscillations inthe ISR by S. van der Meer. CERN/ISR-PO/72-31, August 1972.

2) H.G. Hereward, private communication (ISR Performance Report, 4.5.1972.)