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Effect of RF Noise on Stored Beams

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A few weeks ago, on the New York television news, we heard about a lady who obtained a court order against her neighbor in an apartment house: a young boy, a very talented piano student, who would play the piano several hours a day. Now many of us would regard Beethoven as played by a talented pianist as a very well-organized signal that conveys pleasure to us and improves the quality of our lives. But to this lady it was simply noise.

Now to a proton or electron in a circulating beam, which signals are appreciated as music and which are noise? How cultured are the particles?

Consider a bunched-particle beam in a storage ring such as PEP or ISABELLE. One obvious source of noise is the fluctuation in the holding RF voltage. This has been analyzed by Neil and Cooper[1] as presented at this conference.

The fluctuations in the RF voltage on successive passages through an accelerating cavity have correlations depending on the Q of the cavity. Neil and Cooper show that, for a given amplitude of the fluctuations, the effect is worst if the Q is such that decay time is about one synchrotron oscillation period. In that case the mean diffusion time for amplitude growth is a number of revolutions,

$$n = \frac{1}{\pi \nu_s} \left\langle (\Delta V/V)^2 \right\rangle,$$

where ν_s is the number of synchrotron oscillations per revolution. If we estimate $\langle(\Delta V/V)^2\rangle \sim 10^{-7}$ and take a revolution time of 8×10^{-6} sec (for PEP or ISABELLE) we find:

PEP: $\nu_s = 0.01$; $\tau_{diff} \approx$ 1 hour

ISABELLE: $\nu_s = 6 \times 10^{-5}$; $\tau_{diff} \approx$ 1 week.

Clearly the diffuse bunches of ISABELLE are much less sensitive to noise than the sharp bunches of PEP. Actually, as pointed out by Neil and Cooper,[1] the fluctuation amplitude $\Delta V/V$ may be considerably smaller than assumed here.

The major signal seen by the particles, namely, the holding RF voltage itself, is of course music to the synchrotron oscillations. But what is it to the other degrees of freedom? This is the problem of Arnold diffusion. Motion - even according to a simple deterministic law - in one degree of freedom may in part be effectively noise as well as music to the other degrees of freedom, and in general is. The criterion for noise, according to Chirikov,[2,3] is: If the spacing of the resonances is comparable to their width, noise results.

Synchrotron oscillations may result in repeated crossings of nonlinear resonance, because of the momentum swing in the oscillations. On every crossing there is a change of betatron amplitude, depending on the phase of crossing. Now if the frequency of betatron oscillations depends on their amplitude, the phase coherence of successive crossings of the resonance tends to be destroyed, so that the proton is unable to distinguish music from noise. One can - possibly pessimistically - compute diffusion rates on the basis of complete incoherence; in this case the diffusion rate becomes independent of the synchrotron frequency ν_s and depends only on the total amplitude of the frequency swing and on the strength of the damaging nonlinear resonance. F. E. Mills[4] has computed that, for example, if the decapole component of the ISABELLE magnetic field is about $10^{-4}/cm^4$ and the synchrotron oscillations pass through a fifth-order resonance, the lifetime of the beam will be of the order of one hour. Clearly more complete calculations are needed, especially to determine the degree of coherence.

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[1] V. K. Neil and R. K. Cooper, Particle Accelerators 1, 75 (1972) and paper presented at this conference (K-3)

[2] B. V. Chirikov, Thesis, Novosibirsk 1969 (Translation: CERN Trans. 71-40, 1971)

[3] G. M. Zaslavskii and B. V. Chirikov, Sov. Phys. Uspekhi 14, 549 (1972)

[4] F. E. Mills, private communication