Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I., N.Y.

AGS DIVISION TECHNICAL NOTE

No. 37

A.W. Maschke
(Prepared and written while at CERN)

June 5, 1967

SOME REMARKS ABOUT COHERENT OSCILLATIONS

Coherent oscillations may arise in a synchroton because of interaction of the beam with its image in the walls (resistive wall instability), or due to interactions with its image in the gas of the vacuum chamber (ionic oscillations). A quite general property of any coherent motion is that the larger the spread in oscillation frequencies, the harder it is to drive the beam coherently. Now there are a number of mechanisms which contribute to the bandwidth of a beam. The energy spread enters via a term $\Delta \nu \propto \frac{2\nu}{2r} \Delta E$

Octopole moment causes particles with different amplitudes of oscillation to oscillate at different frequencies. However, there is another effect which spreads the bandwidth. This is the frequency modulation of the transverse $\Delta \nu$ shift at twice phase oscillation frequency. This produces a spread in ν values equal to $\approx \Delta \nu_{sc} \cdot F(\beta)$,* where $\beta = \frac{\Delta \nu_{sc} \omega_r}{4 \omega_s}$.

For β large, $F(\beta) \to 1$. For the AGS, at injection $\beta \approx 2.5$ $F(2.5) \approx 1.5$, say, and for the P.S, we have $F \approx 2$.

In both the AGS and the PS, at present intensities, this effect is probably the dominating factor in suppressing coherent oscillations at low energy.

* Most good texts on communication theory have a plot of the bandwidth function for FM transmission.

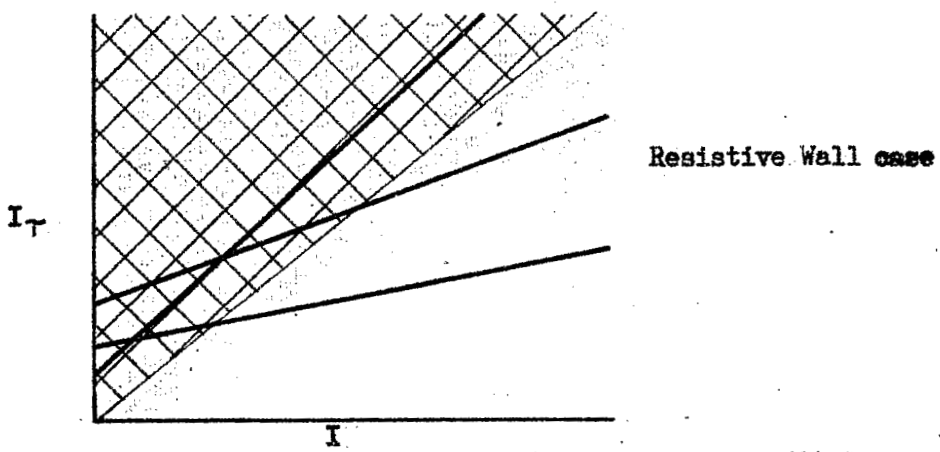
This has some interesting consequencies, for the threshold intensity for coherent oscillation, I_τ, now becomes a function of I. Consider the following simple case.

Consider a beam at some fixed energy, and energy spread, in a machine with fixed parameters. Then we could calculate an intensity threshold in the conventional manner. We obtain instability when the force driving the instability becomes larger than some value proportional to the $\Delta\nu$ spread due to ΔE, octopoles, etc. i.e. $I_\tau = I_o$.

However, if we add an intensity dependant $\Delta\nu$ spread, we obtain: $I_\tau = I_o + \alpha I$, where α is some positive constant.

We assume the intensity can be varied, but oscillation amplitudes, energy spreads, etc., are left alone.

We can now make a plot:

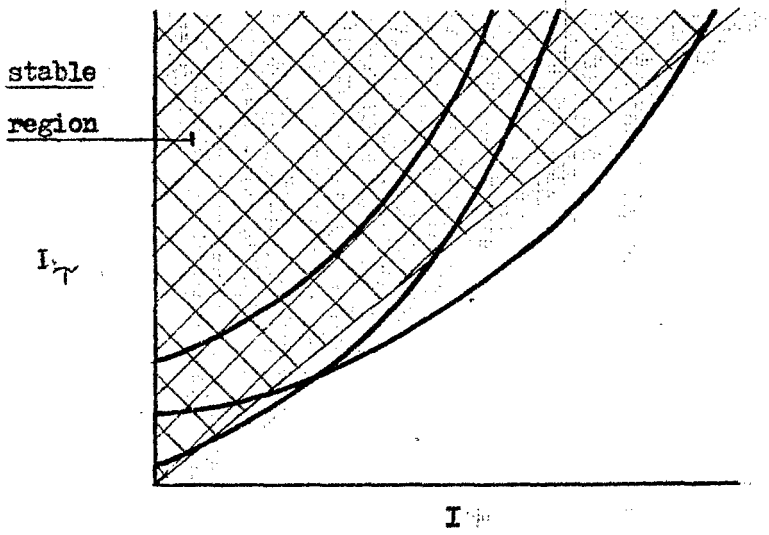


The shaded region indicates values where the beam will be stable. We see therefore that the threshold intensity could be much higher than the "zero" intensity threshold I_τ.

The above analysis held for the resistive wall instability. In that case, the forces are proportional to the intensity. For the ionic oscillations, the force is only proportional to $I^{\frac{1}{2}}$, as first pointed out by H.G. Hereward. This is because the beam itself repels the ions, and so they spend less time in the neighbourhood of the beam as the intensity goes up. Therefore when we pursue the same analysis for the ionic case, we obtain:

$$I_{\tau} = (I_{o} + \alpha I)^{2}$$

Now look at a plot of the function:



Note an interesting point here. The threshold for instability may drop as the intensity is decreased. That is to say, one may have a stable beam at high intensity, but then at low intensity coherent oscillation may start. This effect has been seen in the AGS on occasion, but usually was considered to be a result of some change in machine parameters, beam size, etc.

However, the effect was very clear in the P.S. last week. When a 20% sieve was placed after the linac, the beam in the machine started to exhibit vertical ionic oscillation at about 5 ms. after injection. This caused a loss of about 25% of the beam. When the beam was decreased by "jaws", thereby resulting in a beam of the same intensity, but smaller emittance, the vertical coherent oscillations were reduced almost entirely. This can be explained by pointing out that the space charge $\Delta\nu$ shift depends only on the phase space density, not the total current in the machine. A similar situation applied also to radial ionic oscillations which caused beam loss at about 25 ms. after injection.

AGS Division Staff
A^2D^2 Staff
Conversion Staff