Head-tail instability

Helena Pikhartova

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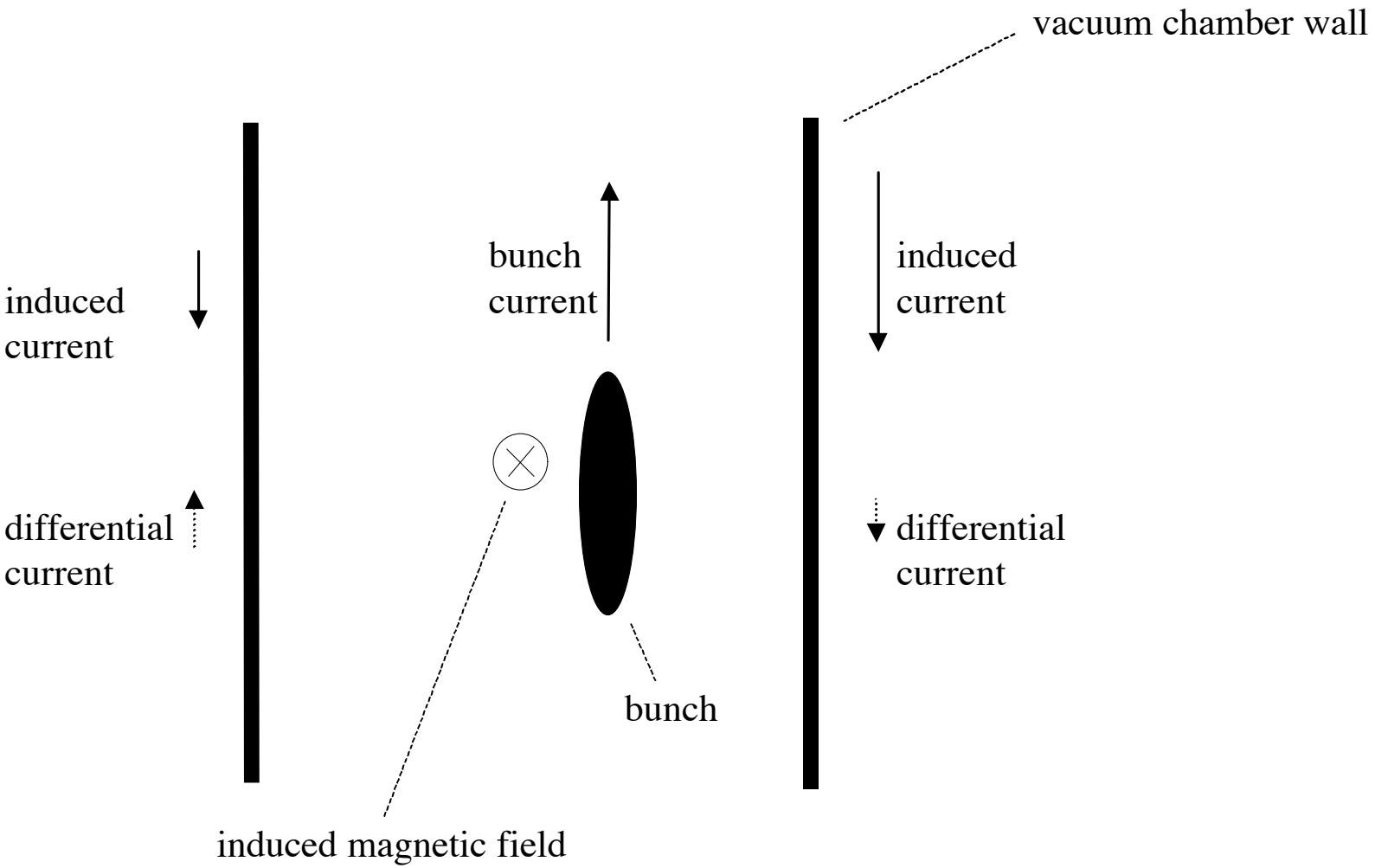
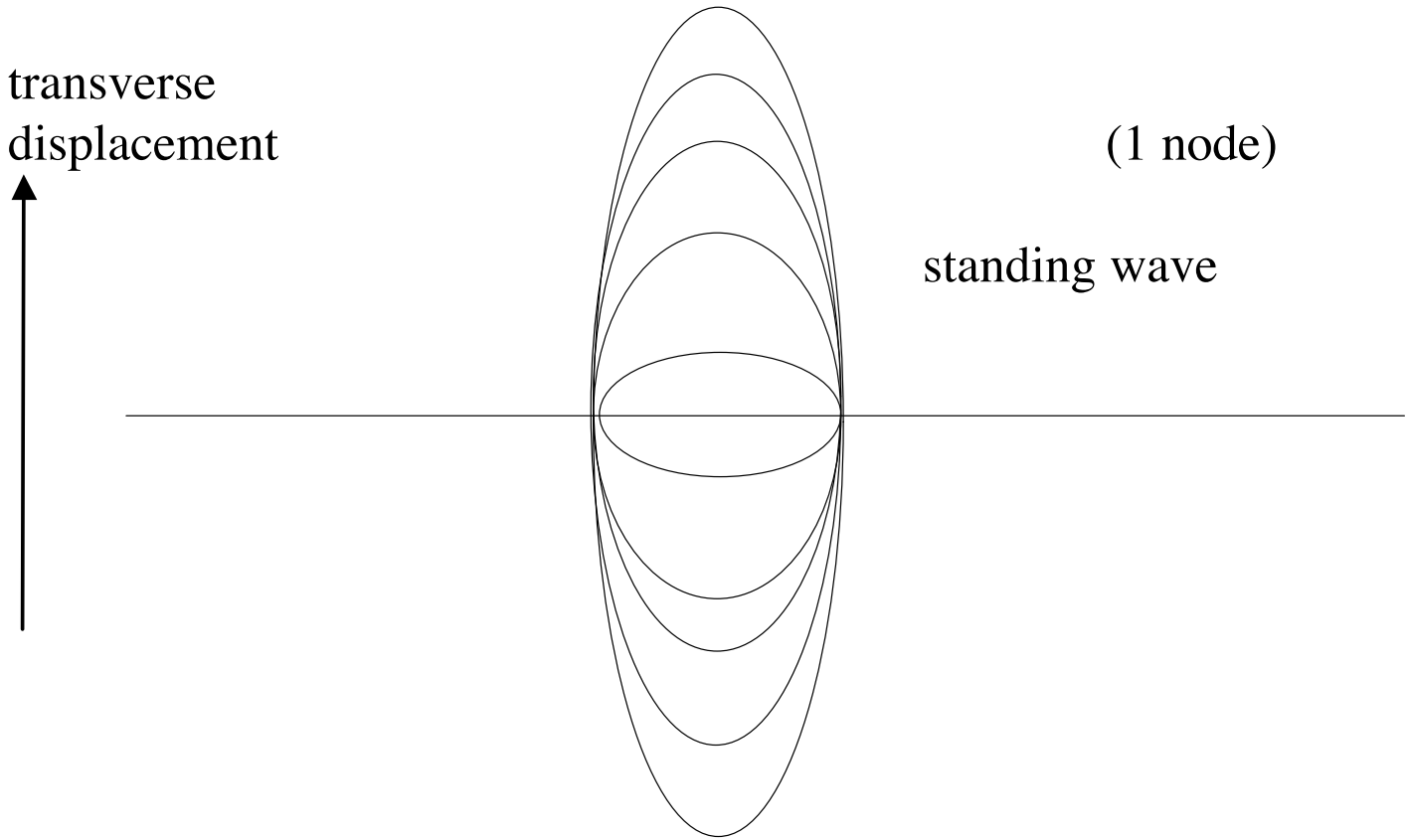
Transverse instabilities - how it begins

The head-tail instability is a transverse instability in which the transverse wake field generated by the head of a bunch exerts a force on the tail of the bunch. Such a condition may lead to unstable motion of the tail, resulting in breakup of the bunch.



Transverse instabilities - 0th mode

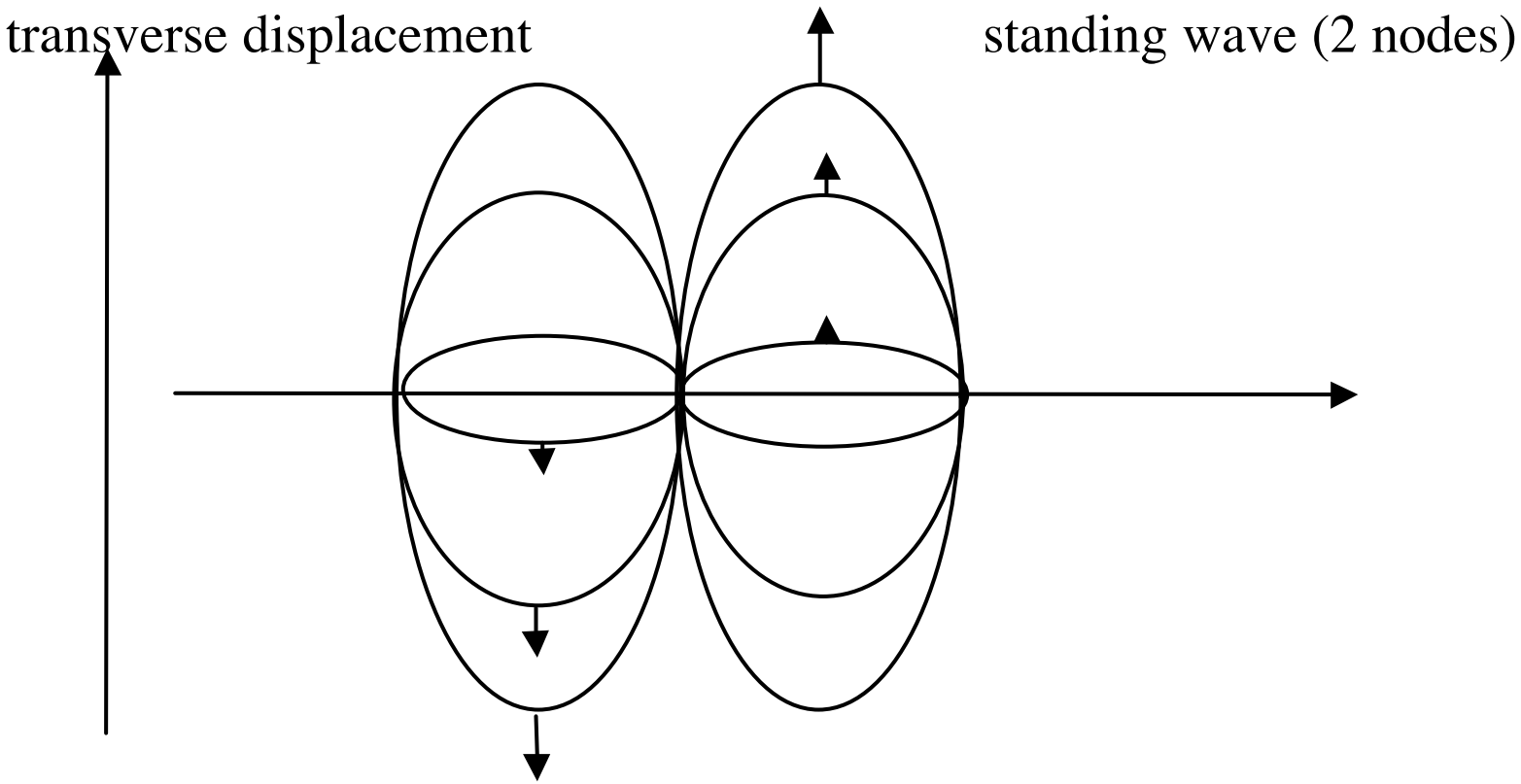
Rigid bunch mode:



The bunch moves transversely as a rigid unit, the change in radial position on each turn will be given by the betatron phase advance per turn.

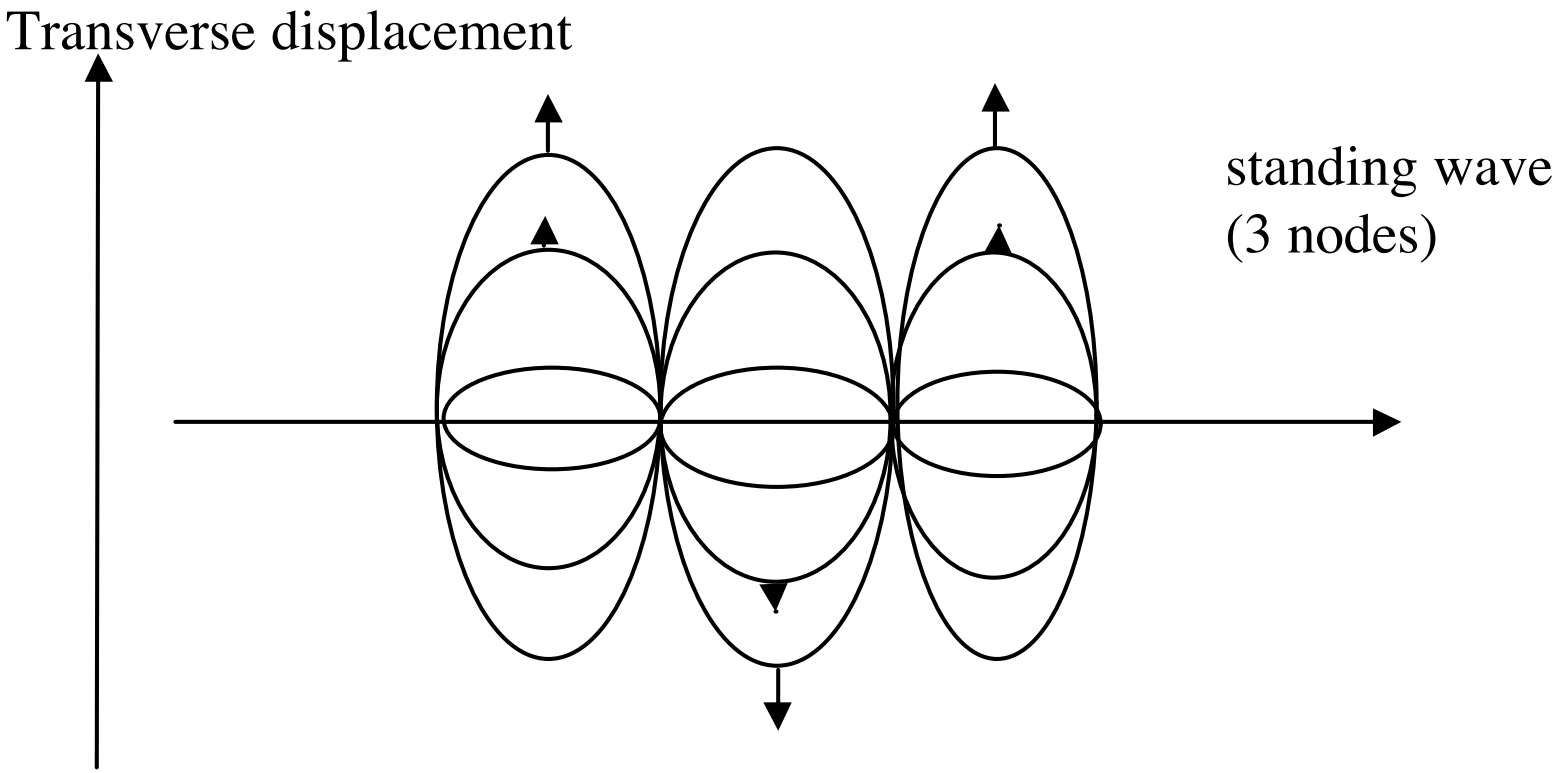
Higher mode modes of transverse oscillation $\rightarrow$ head-tail modes

Transverse instabilities - 1st mode



Here the head and tail move 180° out of phase with each other

Transverse instabilities - 2nd mode



Examples

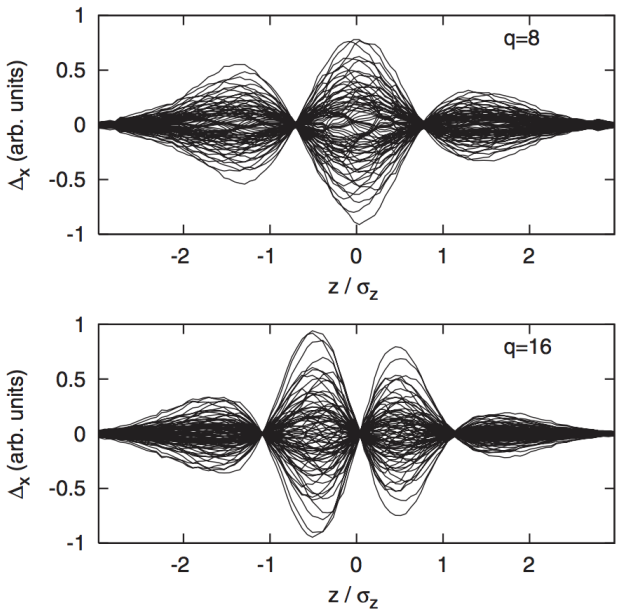
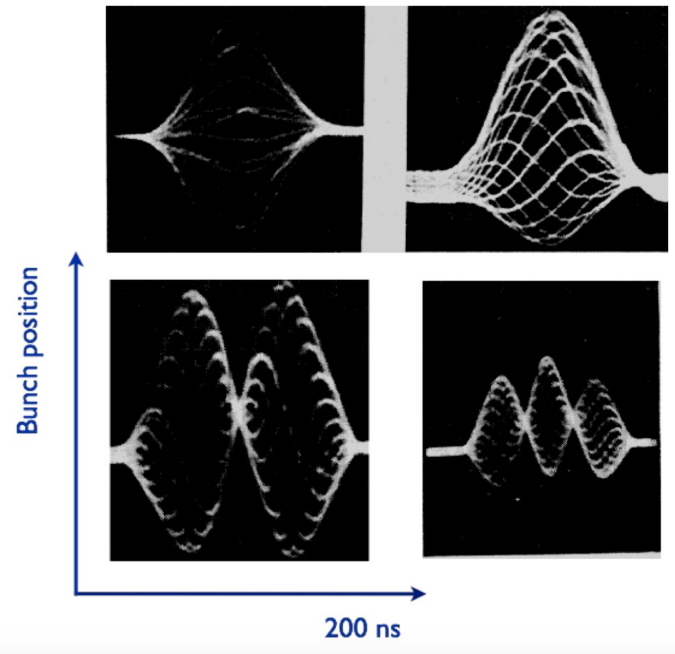


FIG. 11. Examples of bunch dipole traces of head-tail instabilities from Fig. 10 for the head-tail phase $\chi = 4.2$. The upper plot for $q = 8$ demonstrates the $k = 2$ mode, while the lower plot for $q = 16$ shows the $k = 3$ mode.

Kornilov, V. and Boine-Frankenheim, O., Head-tail instability and Landau damping in bunches with space charge, Phys. Rev. ST Accel. Beams



Plots of intra-bunch head-tail instabilities in the PS in 1974 as recorded on an oscilloscope (courtesy of J. Gareyte, Head-Tail Type Instabilities in the PS and Booster, CERN, 1974).

How to reduce head-tail instabilities

- Correct chromaticity (sextupoles)
- Introduce a variation in betatron tune with oscillation amplitude (octupoles)
- Use corrections such as the absorbing antenna to damp transverse modes induced in the cavities

References and further reading

- USPAS Lectures (Lecture 24 - Collective instabilities)
  https://www.classe.cornell.edu/~dugan/USPAS/Lect24.pdf
- https://intranet.cells.es/Intranet/Labs/Elec/chapt10.pdf
- Head-tail instability and Landau damping in bunches with space charge:
  https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.13.114201
- Wake-field and fast head-tail instability caused by an electron cloud:
  https://journals.aps.org/pre/abstract/10.1103/PhysRevE.65.016502
- Head-tail type instabilities in the CERN PS and Booster:
  http://inspirehep.net/record/94029/files/HEACC74_362-367.pdf