Kinetic Theory of Periodic Holes in Debunched Particle Beams

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Observations as well as numerical simulations of coasting hadron beams in circular accelerators and storage rings have revealed the excitation of long-lived coherent structures superimposed on the beam. Such beams, which are interacting with the electromagnetic fields induced by the ring environment, can develop holes (or notches) in the longitudinal distribution function and in the associated line density at thermal velocities where linear wave theory would predict strong Landau damping. It is hence a nonlinear kinetic feature of the VLASOV-POISSON system which is responsible for this ubiquitous phenomenon in beam and plasma physics.

In our contribution we report about recent progress [1-6] in the theoretical understanding of these holes, including those structures found recently at the CERN PSB [7].

We show how the VLASOV-POISSON system can be solved self-consistently in the small amplitude, steady state limit. The method, which was proposed by one of the authors earlier [8], consists first in solving the VLASOV equation in terms of the constants of motion (one of which is the single particle energy $H = \frac{mv^2}{2} + q\Phi$), from which the line density as a functional of the electrostatic potential Φ can be obtained by a velocity (momentum) integration of the distribution function. In the second step, POISSON's equation, being a second order ordinary differential equation in the resistive or purely reactive case, can be solved easily for given boundary conditions.

The analysis reveals new intrinsic modes which owe their existence to a deficiency of particles trapped in the self-sustained potential well, showing up as notches in the thermal range of the distribution function, see Fig. 1.

Several conclusions can be drawn immediately:

1) resonant (trapped) particles require a full nonlinear analysis ($\frac{q}{m}E\partial_u f_1$ is of the same order as $\frac{q}{m}E\partial_u f_0$, namely $O(\Psi)$, where $f_1 \equiv f - f_0$ and $E = -\partial_z \Phi$, f_0 is the undisturbed and f the actual distribution function), no matter how small the amplitude Ψ is;

2) the linear wave spectrum, obtained by a Landau (Keil-Schnell-Ruggiero-Vaccaro) or a van Kampen analysis, is incomplete even in the small amplitude limit and hence does not provide an appropriate basis for a general wave theory, as it is usually assumed;

3) for their existence in plasmas, holes do not require a linear instability as they can be excited nonlinearly even in linearly stable regimes due to their property of being negative energy modes [9].

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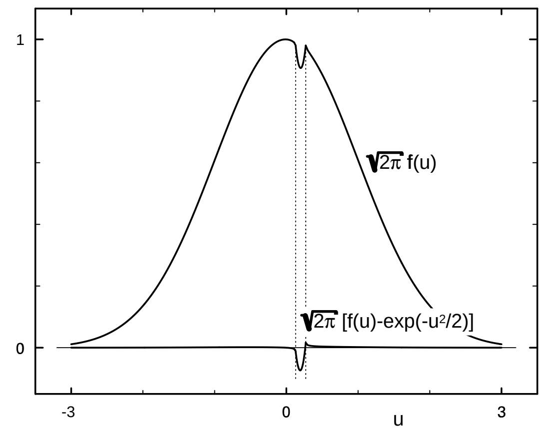

Figure 1: The distribution function $f(u)$ and its deviation from the unperturbed distribution $f_0(u)$ at potential maximum.

In beam physics, holes are reported in bunched beams, as well, and the presence of an e-cloud may provide a similar environment for a nonlinear destabilization of the beam by the negative energy concept as in plasma physics. Of interest seems to be also a non-perturbative finite amplitude analysis of holes in beams, as it was carried out in plasma physics (see [10] and the references cited therein).

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1 REFERENCES

[1] H. Schamel, *Phys. Rev. Lett.* **79**, 2811 (1997).
[2] H. Schamel, *Phys. Scr.* **T75**, 23 (1998).
[3] H. Schamel, in *Nonlinear and Stochastic Beam Dynamics in Accelerators: A Challenge to Theoretical and Computational Physics, Lüneburg, 1997* (DESY, Hamburg, Germany, 1998), pp. 224-235.
[4] H. Schamel and R. Fedele, in *Proceedings of the 7th European Particle Accelerator Conference, Vienna, 2000,* http://accelconf.web.cern.ch/Accelconf/e00/index.html.
[5] H. Schamel and R. Fedele, *Phys. Plasmas* **7**, 3421 (2000).
[6] J.-M. Grießmeier, H. Schamel and R. Fedele, *Phys. Rev. ST Accel. Beams* **5**, 024201 (2002).

[7] S. Koscielniak, S. Hancock and M. Lindroos, *Phys. Rev. ST Accel. Beams* **4**, 044201 (2001).
[8] H. Schamel, *Plasma Phys.* **14**, 905 (1972).
[9] J.-M. Grießmeier and H. Schamel, *Phys. Plasmas* **9**, June 2002.
[10] H. Schamel, *Phys. Rep.* **140**, 161 (1986).