Advanced beam dynamics for storage rings

O. Boine-Frankenheim[1], A. Dolinskii[1], R. Hasse[1], I. Kadenko[2], A. Lehrach[3], I. Meshkov[4], Th. Weiland[5], P. Zenkevich[6], and V. Ziemann[7]

[1]GSI, Darmstadt; [2]Uni. of Kiev, Ukraine; [3]FZ Jülich, Germany; [4]JINR, Dubna, Russia; [5]TU Darmstadt; [6]ITEP, Moscow, Russia; [7]TSL, Uppsala, Sweden

The challenging storage ring and beam cooling projects at high energies [1] are the driving force behind new efforts in beam dynamics modeling and experimental verification. Optimization of the proposed cooling scenarios, including studies on rf manipulations, stochastic and electron cooling, intrabeam scattering, internal target scattering, as well as other processes, requires not only accurate but also fast numerical models. The main target of the studies performed within the INTAS project "Advanced beam dynamics for storage rings" is the high energy storage ring HESR as part of the FAIR project at GSI. For the HESR, that is presently being designed at FZ Jülich, electron cooling up to 8 MeV is proposed. Electron cooling at very high energies (55 MeV) is proposed for the RHIC upgrade (RHIC-II). At FNAL a 4.3 MeV electron cooler is presently being installed in the Recycler. An important question is the predictive power of the theoretical models, especially for high energy. For example, in case of RHIC-II cooling dynamics must be known with an accuracy better than a factor of 2. We categorize the topics into four sections: intrabeam scattering, electron cooling modeling, internal target scattering, and resulting cooling equilibria.

Intrabeam scattering:

A number of different approximations are used to obtain IBS rates for Gaussian beams. The different approximations can differ by factors of 2, depending on the application. In order to describe the detailed evolution of the bunch density profile and also the beam loss, direct analytical or numerical solutions of the Landau collision term, which has a Fokker-Planck structure, must be obtained. Two alternative simulation approaches (Langevin equation and collision map) have been worked out in Ref. 1. The nonlinear electron cooling forces result in non-Gaussian beam distribution functions. A kinetic treatment of IBS is therefore essential for accurate simulations.

Electron cooling forces:

The cooling force estimations for the HESR and for the RHIC-II projects are based on the Parkhomchuk formula, which is an empirical generalization of the theoretical friction force for unmagnetized electrons. Magnetized electron cooling will be crucial for RHIC-II and for the HESR in order to achieve the required cooling rates. For magnetized cooling theoretical complications arise e.g. from the small Coulomb logarithm. Experimentally, the correction of field misalignments is a challenging technical problem. The precise knowledge of the residual field errors is required for accurate simulations of beam cooling. All these complication will make predictions (within a factor of 2) for magnetized cooling very difficult. A comparison of theoretical models with accurate experimental results obtained at low energy is presently being performed: Longitudinal cooling forces have been measured in the CELSIUS ring using the very accurate phase shift method. Transverse cooling forces have been measured for the first time using a kicked pencil beam in CELSIUS [1].

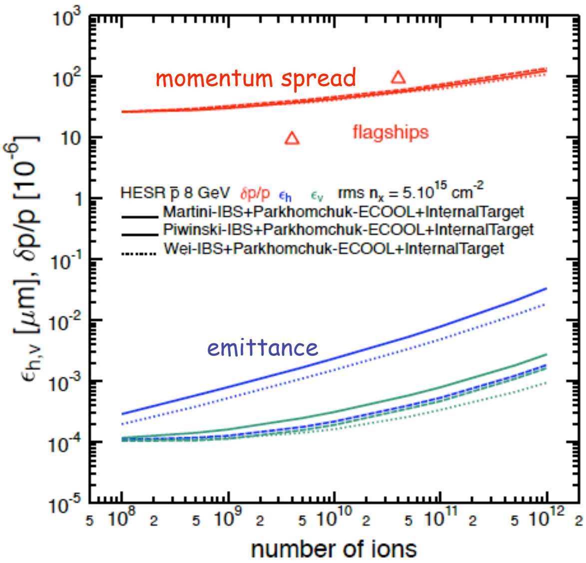

Figure 1: Equilibrium momentum spread and emittance obtained with "betacool" using different IBS models.

Internal target scattering:

A hydrogen pellet target is presently the only possible candidate for high luminosity experiments with antiprotons in the HESR. Compared to the more conventional low density gas targets the main questions are related to the high density and to the granularity of the pellets. First theoretical results show that the energy loss straggling in the pellets can result in strongly non-Gaussian momentum spread distributions [1].

Electron cooling equilibrium:

Extensive simulations of the cooling dynamics have been performed using different models. As an example Fig. 1 shows the rms equilibrium momentum spread together with the emittances obtained with the "betacool" code for the proposed "flagship" experiments in the HESR. It can be seen that the "high resolution" mode (lower triangle) cannot be achieved, whereas the "high luminosity" experiments seem to be possible.

Outlook:

The experiments at COSY, ESR and CELSIUS on cooling forces, target scattering and equilibrium beam distributions will be intensified. Ongoing efforts focus on the 3D kinetic modeling of cooling dynamics and on the stability of cooling equilibria with regard to collective instabilities.

References

[1] R.Hasse, I. Hofmann (ed.), AIP proceedings of the 33rd ICFA advanced beam dynamics workshop, Bensheim, Germany, Oct. 2004