Summary of Beam Cooling and Intrabeam Scattering

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Abstract

Here, we summarize discussions in the Working Group on “Beam Cooling and Intrabeam Scattering”.

INTRODUCTION

For heavy-particle beams in storage rings where there is no significant synchrotron radiation damping, beam cooling is an essential tool in obtaining high phase-space density high brightness beams. Advances in various types of cooling such as electron, stochastic, laser and muon cooling are covered in dedicated Conferences. In this series of Workshops (HB2002-06), discussions are aimed only at a few specific subjects which are crucial for future projects. The discussion topics in our session closely followed those discussed during the HB2004 workshop [1]. Specifically, we concentrated on the topics of electron cooling and intrabeam scattering, motivated by the design of the future high-energy coolers [2, 3, 4].

These cooling projects at high-energy require accurate numerical modeling and experimental verification. A variety of tasks were put together at HB2004 [1]. In our working group we discussed a progress in addressing these tasks. We had 10 presentations [5]-[14] (with additional presentations in the joint sessions) which followed by dedicated discussions. Our main topics of discussions: intrabeam scattering (IBS), electron cooling, and beam stability are summarised below.

INTRABEAM SCATTERING

A variety of theoretical models to describe diffusion of rms beam parameters due to IBS exist. Most of the models agree with experimental measurements within a factor of two. However, for future electron cooling projects, such as RHIC-II, it is desired to have better than factor of two description of IBS growth rates. To achieve this, a series of dedicated IBS measurements were performed in 2004 with Au ions and in 2005 with Cu ions. Comparison of 2004 data with models showed good agreement for the longitudinal growth rate but still some disagreement for the transverse growth rate [15]. Uncertainties of the measurements were reduced for 2005 experiments with the Cu ions, which resulted in good agreement between the data and models both for the longitudinal and transverse growth rates [12].

As a result, there is a general agreement now, that IBS diffusion in hadron machines at high-energy (well above the transition energy) can be described with existing theoretical models, such as Martini’s [16] or Bjorken-Mtingwa’s [17] model, with accuracy better than 50%.

Further discussions with regard to IBS for Gaussian distributions included vertical dispersion function, relativistic corrections, coupling effects and nuclear scattering [13]. The agreement was that for a general treatment of IBS an accurate treatment of the coupled motion is desired.

Of special interest is IBS for the distribution under electron cooling. As a result of electron cooling, the distribution quickly deviates from Gaussian. In such a case, an accurate description of IBS, for example through the amplitude-dependent diffusion coefficients, is needed. To address this question, the IBS theory was recently reformulated for a bi-Gaussian distribution by Parzen [18]. A treatment of IBS, which depends on individual particle amplitude was proposed by Burov [19], with an analytic formulation done for a Gaussian distribution in approximation that the longitudinal rms velocity in beam frame is much smaller than the transverse. Also, a simplified “core-tail” model, based on different diffusion coefficients for beam core and tails was proposed [20]. An extension of “core-tail” approach based on calculation of the diffusion coefficients via local phase-space density was implemented in BETACOOL code [25], and is presently being benchmarked with other models [22]. Recently, the bi-Gaussian profiles were recorded to provide experimental data for the benchmarking of the IBS models [23].

With regard to models of IBS for distributions under cooling, the agreement was that approach similar to the one used in MOCAC code [24] could be a promising one. This algorithm should be compared with other models and with experimental data.

ELECTRON COOLING

Since cooling times at high-energies are very long it was realized that for future projects with electron cooling a quantitative calculation of cooling times are needed which require an accurate description of the cooling force.

Following discussions at HB2004 Workshop in Bensheim, a systematic study of various models for the friction force was performed using the BETACOOL code both for the nonmagnetized and magnetized case. The models were compared [21] with direct numerical simulations using the VORPAL code [26, 27]. Another code, which also calculates friction force numerically from first principles, is available [28].

For the non-magnetized case, it was found that available model for the friction force with numerical integration over electron velocity distribution is very accurate and agrees with direct numerical simulations within $10-15\%$ [21].

For the magnetized case, available models are more approximate, but the cooling process can be still described with a reasonable accuracy [8, 21]. For description of the magnetized friction force with better than a factor of two accuracy, direct numerical simulations, similar to the one done with VORPAL, are required. If this is needed for a specific project, the BETACOOL code can now calculate the cooling process using the friction force represented by a Table of the friction coefficients, which are generated numerically either using the VORPAL code or the code from Erlangen group [28].

In addition, an innovative approach to cooling with the undulator field to suppress recombination was discussed [14]. The friction force in the presence of the undulator field was simulated with the VORPAL code [14] and found to be in remarkable agreement with the model [29, 30].

An extensive discussion centered on recent measurements of the non-magnetized and magnetized friction force and their comparison with theoretical models.

The first cooling system which is based on the "non-magnetized" approach was successfully constructed at FNAL Recycler ring. It is in operation since July 2005. This system is also the cooler with the highest, by far, energy of the electrons (4.3 MeV) in operation [31].

For the non-magnetized force, the uncertainty in the friction force theoretical expression is very small but comparison with experiments is obscured by the dependence on the transverse rms velocity spread within electron beam which is no longer suppressed by the magnetic field, making its effect on the force value very strong. As a result, a careful characterization of the electron beam is required which is presently being attempted at the FNAL cooler [31, 6].

Some additional measurements were suggested, for example, measurements of the drag rate for several electron currents below 100 mA, to resolve presently observed dependencies.

A series of dedicated measurements of the longitudinal magnetized friction force was recently performed at CELSIUS [32]. The longitudinal friction force was measured using the phase-shift method with a bunched ion beam. The friction force was recorded for various parameters of the cooler, including different currents of the electron beam, various strength of the magnetic field, different strength of the magnetic field errors in the cooling solenoid and the misalignment angle between the beams. In addition, standard parameters of the cooler were altered in order to explore effects that are essential for the understanding of high-energy magnetized cooling such as description of Intrabeam Scattering (IBS) for non-Gaussian distributions which appears as a result of a slow cooling process and various regimes of magnetization [23]. The data was compared vs theoretical models, and some effects, like magnetic field errors, are being explored with the VORPAL code.

The discussion showed that further comparison of the data with the VORPAL code is desired. It was also suggested to compare experimental data obtained in the MOSOL experiment [33] vs VORPAL simulations as well.

BEAM STABILITY WITH COOLING

In addition to recent progress in low-energy coolers [5, 9, 7, 10, 11], discussion centered on instabilities observed in storage rings with coolers. In many cases, the observed instabilities are caused by effects driven by a condition of cooled ion beam, which include [5]: 1) nonlinear lens ("beam-beam") effects of the electron beam leading to ion loss or diffusion; 2) instability development in a well cooled high-intensity ion beam due to interaction with the electron beam ("electron heating"); 3) "three-body" instability when secondary ions are trapped in the e-beam; 4) interaction of a well cooled ion beam with the vacuum chamber elements (LEAR, COSY). The feedback of these instabilities does help when they are of a coherent character. Quantitative comparison of the thresholds of the instabilities observed with the theoretical predictions were not yet attempted and remain as a future task. Some comparison of measured growth rates of the "electron heating" instability with simulations for the HIMAC cooler was also reported [7].

Despite the previous statements at HB2004 workshop that switching on electron cooling and stochastic cooling simultaneously can cause undesirable effects, recent experience at FNAL cooler showed nice operation of both systems together [34]. The tails of the distributions were cooled with the stochastic cooling while the core was cooled with the electron cooling. This observation is very useful since future high-energy cooling systems intend to use electron and stochastic cooling simultaneously as well.

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