Project Name: Coherent Synchrotron Radiation

Classification(accelerator/detector:subsystem): Accelerator

Institutions and personnel:
James Ellison, Professor of Mathematics, U. of New Mexico
Robert Warnock, SLAC Physicist Retired and Current Visiting Scientist, also Adjunct Professor of Mathematics, UNM
Paul Alsing, Senior Research Physicist, Albuquerque High Performance Computing Center, UNM

Contact Person: James Ellison, ellison@math.unm.edu, (505)277-4613

Project Overview

There is great current interest in coherent synchrotron radiation (CSR) in two general contexts. First, CSR may seriously degrade transverse emittance in bunch compressors, which are essential components in designs of the next-generation linear collider (NLC/JLC, CLIC, TESLA). Second, there is evidence that CSR may contribute to longitudinal bunch instabilities in storage rings, especially in the case of short, intense bunches of low emittance [1]. To our knowledge this possibility has not been ruled out in designs for damping rings of the linear collider. The theory of both these topics is complicated, at the level of solving the electromagnetic field equations, and also at the level of self-consistent, many-particle dynamics. Moreover, when the theory is exercised in design questions one confronts a multi-dimensional space of design parameters, which puts a premium on fast and convenient computations. We think that there is an urgent need to improve the theoretical formulation and the range of physical effects included, and at the same time improve numerical algorithms for better accuracy and much greater speed.

Study of CSR in the single-pass situation of bunch compressors and the like is more complicated than in the steady-state case based on circular orbits. Here the prototypical problem is finding the energy change or wake field during transit of a point particle through a single bend, and even that limited problem leads to a complicated analysis [2]. The steady-state case with non-circular orbits is similarly complicated, but of practical interest for realistic modeling of storage rings with straight sections between bends. Ambitious codes for CSR from arbitrary orbits have been developed by Li (with Bohn and Bisognano)[3] and by Dohlus, Kabel, and Limberg [4]. The field solutions are carried out in the space-time domain, and involve rather intricate considerations of retarded times and singularities associated with the Lienard-Wiechert potentials. Computation time is rather long, especially with shielding treated by the method of images.

The expense is even greater in a "self-consistent" calculation in which the bunch is allowed to deform under the action of the CSR force. As we understand it, such calculations (emphasized particularly by Li) have been done only at rather low levels of approximation (few macroparticles). There is now strong evidence from simulations (Borland, Emma, Limberg *et al.*in presentations at The Physics and Applications of High Brightness Electron Beams, 1-6

July 2002, Sardinia, Italy.) and theoretical arguments [5] that bunch instabilities can develop in the short transit time of a bunch compressor. Here the simulations have been done with the macroparticle method, which involves relatively high noise. We believe that a Vlasov treatment in place of the macro-particle approach would lead to a much clearer separation of real dynamics from numerical noise.

For the solution of the field equations it may be simpler and perhaps more efficient in computations to do a modal analysis, taking a Fourier transform in spatial dimensions but not in the time (this for the single-pass case). This avoids retarded times and singularities, and allows an easier treatment of shielding by choosing the Fourier series to satisfy automatically the boundary conditions on metallic plates. Moreover, a reversal of time and wave number integrations leads to a stationary phase problem, which promises to allow an analytic reduction of the dimension of the problem, by one or even two dimensions. If this reduction can indeed be accomplished, there will be a tremendous speed-up in the field computation.

The Vlasov solution, following the Perron-Frobenius method of Ref.[6], is a problem in which parallel computation can probably have a big impact. A parallel program for the Vlasov part would be an important achievement in itself. It could be applied to the usual retarded-time computation of fields, even if the method using modal analysis does not succeed.

Description of first year project activities

We will begin by improving the calculation of the electromagnetic field using the modal analysis and also working out the details of a numerical solution of the Vlasov dynamics using the Perron-Frobenius method with a parallel implementation.

Budget

Ellison is funded by DOE grant DE-FG03-99ER41104 for "Investigations of Beam Dynamics Issues at Current and Future Accelerators". He plans to work on the CSR problem as funded by the grant and is discussing this area as possible Ph.D thesis problem with a graduate student. Warnock is working on the CSR problem gratis and would like two months salary, although his efforts will entail significantly more than three months. Paul Alsing is expert in HPC and a well trained physicist. His expertise will be key in developing a code with the speed up needed and we are requesting two months support for him. Our total request is for $60K which will cover approximately two months salary including overhead for both Alsing and Warnock. We would like more than two months support, however we appreciate that $60K is already a significant fraction of the $400K allocated.

References

[1] M. Venturini and R. Warnock, *Burst of Coherent Synchrotron Radiation in Electron Storage Rings: a Dynamical model*, to be submitted. M. Venturini, R. Warnock and R. Ruth,

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[3] R. Li, Proc. of ICFA Workshop *The Physics of High Brightness Beams, UCLA, Nov.9-12, 1999* (World Scientific, Singapore, 2000).

[4] A. Kabel, M. Dohlus, and T. Limberg, *Nucl. Instr. Meth. A* **455** pp. 185-189, (2000).

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