WORKING SESSION B SUMMARY : SPACE CHARGE THEORY, SIMULATIONS, AND EXPERIMENTS

S. Cousineau and I. Hofmann

Abstract

This paper gives a summary of the working group B session on space charge theory, simulations, and experiments.

PRESENTATION SESSION

During the working group B session on space charge theory, simulations, and experiments, 6 invited talks and six contributed talks were given, followed by a working session where the status of the field and the current challenges were discussed.

The talks in this session covered a diverse range of space charge problems, with the majority of the talks highlighting space charge issues in synchrotrons and accumulator rings, and a small sampling of talks dedicated to space charge in linacs and transport lines. A combination of experimental and simulation results were presented, including a substantial number of quantitative code benchmarks with experimental data. Altogether, this was an outstanding demonstration of the advancement in code capability in recent years. An additional theme which emerged from the talks was the investigation of a variety of space-charge-driven resonance crossing scenarios. The presentations on this subject generally contained both experimental and simulated data, giving a complete picture of the space charge physics under investigation. Some highlights from each of the talks given are listed below.

On the topic of resonances, G. Franchetti explained emittance growth and beam loss for high intensity synchrotrons in terms of strong tune modulation by space charge and synchrotron motion leading to nonlinear resonance trapping. He additionally touched on the effect of chromaticity on observed beam loss in an octupole driven resonance, and showed that the inclusion of chromaticity into the simulation improved the agreement with an experiment at the CERN Proton Synchrotron.

At the Fermilab booster, P. Spentzouris presented experimental studies and benchmark simulations of sum-resonance studies. Benchmarks were qualitatively successful, with some quantitative disagreement, possibly due to the lack of independent data on resonance strengths. Results also indicate that space charge enhances the sum-resonance effect.

Also for the Fermilab Booster, K.Y. Ng presented the effect of magnet errors on experimentally observed emittance growth, resulting in the conclusion that skew errors are an important source of emittance growth.

Again within the arena of resonance crossing, S. Igarashi presented experimental evidence of emittance growth in the KEK PS machine due to a space-charge driven 4^{th} order structure resonance ($4Q_x=28$). The measured profile broadening data was in good agreement with ACCSIM simulations and showed the same tune dependence.

Moving away from particle in cell simulations, but still in the arena of resonance crossing, I. Hofmann introduced scaling laws governing emittance growth in the Montague resonance for both fast and slow resonance crossing, and for the 4^{th} order space charge coupling resonance. These laws provide a convenient alternative to time consuming PIC simulations.

From J-PARC, A. Molodozhentsev reported on simulation studies undertaken to optimize the working parameters in the J-PARC Main ring. Using the ORBIT code, it was found that the tune shift is large and dominated by chromaticity and space charge, and that emittance growth is due to excitation of non-structure resonances caused by the introduction of the injection dog-leg magnet. Nonetheless, results indicate that the beam loss budget is well within the acceptable limit.

S. Bernal spoke about recent developments at the University of Maryland Electron Ring (UMER), where the maximum space charge tune shift of the machine can be greater than $\Delta Q=5.0$. Issues currently under investigation at UMER are the new pulsed injection system which gives rise to high first turn beam losses. Additionally, experimental results of a study on asymmetric beams were presented, where large beam halo is observed. This beam halo has not yet been replicated with simulations.

In a dedicated code development and benchmarking effort, A. Adelmann presented work done with the new multi-scale 3D parallel code Mad9p. Quantitative comparisons were made of beam widths and profiles in the PSI machine beamlines, resulting in reasonable agreement. Beam loss on the collimation system was also benchmarked, and agreement was reached at the 10% level.

Two talks were given on space charge issues in linacs. In the first of these, R. Duperrier described a computational model for space charge neutralization in linac beams, which gives quantitative results for the neutralization rise times for a variety of different cases, including different species of beams (H- and H+), as well as bunched versus DC beams. In general, it was determined that the neutralization is weak at high energies, and rise times can be impractically large. Thus, the neutralization effect is most important for the low energy linac regime of the accelerator (LEBT and MEBT areas).

Also in the area of linacs, J.B. Lallement presented beam halo and beam loss issues in the design of the CERN Linac4 accelerator. End-to-end simulations showed that the main beam dynamics issues (emittance growth and halo) come from the chopper system. Simulations of the chopping system predict a chopping efficiency of 99.8%. In order to measure longitudinal beam structure in the real machine, a longitudinal beam shape and halo monitor with sensitivity down to 0.001%, a large dynamic range, and fast on/off time (~1ns), is under development.

Finally, in the area of code development, J. Qiang discussed recent developments of the IMPACT code, whose capabilities have now been extended to include multiple charge states, and bend, multipole and wake fields.

DISCUSSION SESSION

Following the presentations, a working group session was held, where the current state of the field was reviewed, and the most critical challenges were identified.

In reviewing the presentation session, the group acknowledged and applauded the advances in the area of space charge simulation. It was particularly apparent during the presentation session at this workshop that successful space charge benchmarks of experimental data have now become the norm rather than the exception, thanks to a wealth of sophisticated PIC simulations codes which have been developed in the last decade. The group felt that simulations had reached a level of accuracy and reliability that justifies their use as a primary tool in machine design. Most machines on the horizon, including CERN, FAIR, and J-PARC, are relying on simulation results to help in the design and optimization of machine parameters.

It was also noted that the community is now beginning to produce quantitative benchmarks of beam losses. This is an inherently difficult problem which requires knowledge of the entire machine state in addition to the space charge relevant parameters. Because of the this, and the fact that beam loss is ultimately the limiting factor in most high intensity machines, beam loss benchmarking is somewhat of a “holy grail” of space charge code benchmarking. Though we are still far from producing accurate, routine benchmarks of beam loss patterns, some efforts toward this goal have begun, and benchmarks with the total level of beam loss in machines have shown reasonable success.

In the area of cross-code benchmarking, it was suggested that a benchmark of a space charge coupling resonance is desirable; no concrete plans for this were formulated during this session.

Despite the great advances in simulations described above, little progress was observed in the area of long-duration experimental benchmarks, i.e., more than a few tens of thousands of turns. Historically, this area has been limited by the computation expense of such simulations, which require a large parallel computer system, and a code with very good scalability. This problem will become important for future RCS machines, such as J-PARC and the CERN PS upgrade. Many codes have recently gone parallel or upgraded their scalability, and long-duration, self-consistent simulations are likely on the horizon.

Finally, there was uniform consensus within the group that there has been disproportionately little work dedicated to understanding the initial beam distribution in the accelerator, which is particularly important for linacs. This was felt to be a major limiting factor for modeling space charge in linacs, especially since, once the initial distribution is known and understood, there are a number of sophisticated codes which can be used to propagate the beam under the influences of high space charge.