

SET CODE DEVELOPMENT AND SPACE CHARGE STUDIES ON ISIS

BG Pine, DJ Adams, CM Warsop, RE Williamson
 Rutherford Appleton Laboratory (STFC), Oxfordshire, UK.

Abstract

The ISIS Facility at the Rutherford Appleton Laboratory in the UK produces intense neutron and muon beams for condensed matter research. It is based on a 50 Hz proton synchrotron which accelerates $\sim 3 \times 10^{13}$ protons per pulse (ppp) from 70 to 800 MeV, corresponding to beam powers of ~ 0.2 MW. Studies are under way for major upgrades in the Megawatt regime. Underpinning this programme of operations and upgrades is a study of the high intensity effects that impose limitations on beam power.

The behaviour of the beam in the 50 Hz rapid cycling synchrotron (RCS) is largely characterised by high space charge levels and the effects of fast ramping acceleration. High intensity effects are of particular importance as they drive beam loss, but are not fully understood with only limited analytical models available. This paper reviews development of a new space charge code Set, which is designed to address key issues on ISIS and similar RCS machines.

INTRODUCTION

ISIS high intensity operation is restricted by beam loss, as irradiation of equipment limits access for essential maintenance. Understanding beam loss is therefore of vital importance, however due to the complex interactions between the beam particles and their environment such understanding is challenging both analytically and numerically.

The ISIS Synchrotron Group is actively studying high intensity effects of the beam in a number of different ways, both to improve performance of the accelerator and also to enable the design of upgrades which can achieve significantly higher beam intensities. This paper focuses on developments of the beam tracking code Set.

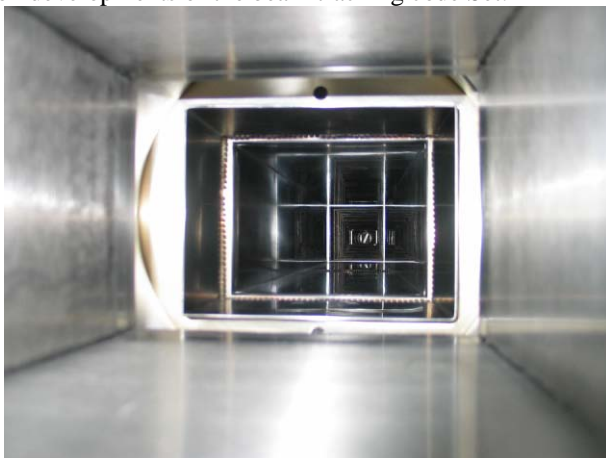


Figure 1: Rectangular ISIS vacuum vessel.

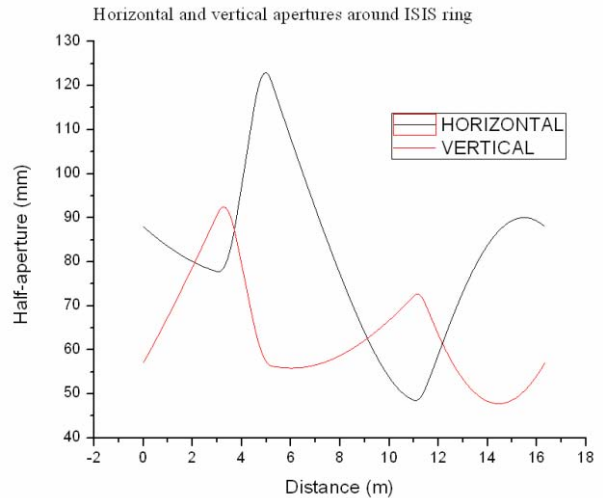


Figure 2: Profiled vacuum vessels in ISIS super-period.

SET

A new code Set is under development at ISIS. This code is intended to supplement the use of ORBIT [1] for 2D and 3D beam tracking simulations, as a tool that can be readily modified and redeployed as required to meet a given purpose. In particular, the focus is on the challenges of the ISIS RCS, including image forces from the unique profiled vacuum vessel (Figures 1 and 2), halo predictions, 2D and 3D RCS space charge effects and overall to understand and predict beam loss. Set works using either MAD input data or its own matrix routines for generating lattices, and has an FFT based Poisson-solver for calculating the beam's space charge. Early simulation work [2, 3] focused on replicating ORBIT results for the half integer resonance. Example results for the ISIS lattice (2D, coasting beam) driven with a $2Q_V = 7$ resonance are shown in Figures 3, 4 and 5.

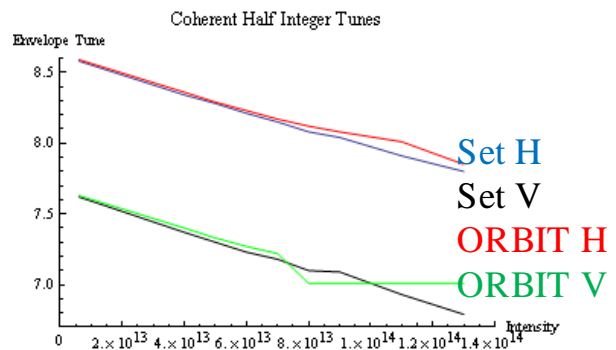


Figure 3: Envelope frequencies intensity sweep.

Figure 3 shows Set and ORBIT envelope frequencies as the intensity is swept from $1 - 14 \times 10^{13}$. Figure 4 shows the incoherent tune footprints after 100 turns, as the intensity

is varied from 6E12 ppp to 13E13 ppp. Figure 5 shows beam phase and real space on the 100th turn for an intensity of 6E13.

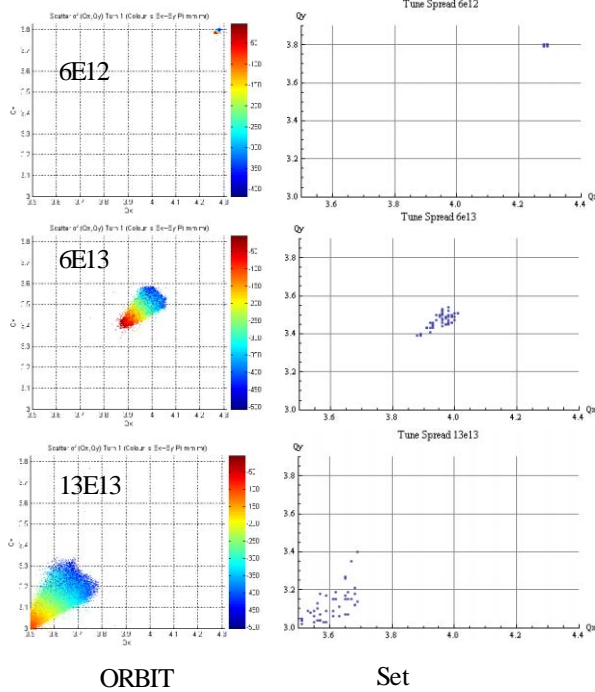


Figure 4: Incoherent tune comparison ORBIT - left, Set - right.

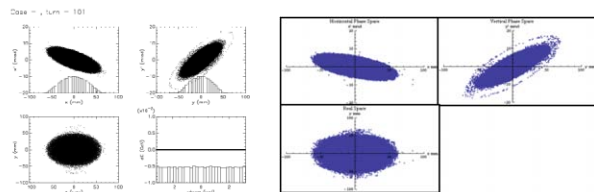


Figure 5: Phase space on 100th turn ORBIT - left and Set - right.

Set has been used to study tune shifts from image forces and closed orbits [4] and the results compared with Laslett theory (Figure 6). Direct space charge should have no influence on the coherent dipole tune, as the charge distribution of the beam moves with the centre of charge. However image forces will affect the coherent tune, as the centre of charge does move relative to the vacuum vessel. This is of particular interest on ISIS due to the vacuum vessel which follows the design beta function of the beam. At high intensities the machine is very sensitive to closed orbit changes, which may indicate beam loss driven by image forces.

Present upgrade studies are investigating the benefits of increasing injection energy from 70 to 180 MeV. Set has been used to study the space charge limitations at this higher energy. The half integer simulations carried out for the nominal ISIS ring were reproduced, but for an injection energy of 180 MeV rather than 70 MeV.

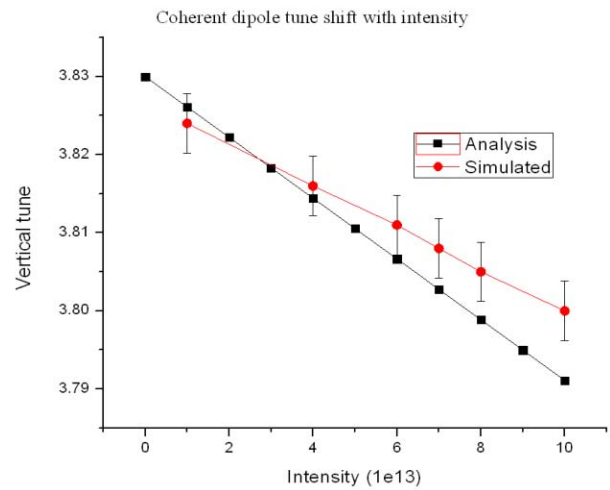


Figure 6: Simulated versus analytical tune shift.

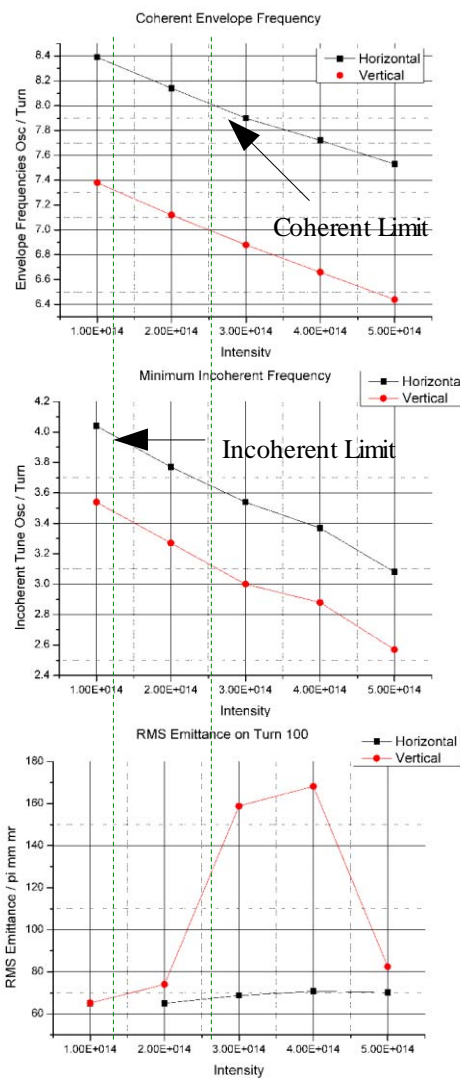


Figure 7: Envelope frequencies, incoherent tune and RMS emittance growth associated with half integer resonance for 180 MeV injection energy.

Simple scaling of the space charge force indicates peak intensities should increase by a factor of 3 over 70 - 180 MeV. As can be seen from Figure 7, the RMS emittance begins to rise at 3 times the intensity seen in the previous case. Image forces become more significant when the beam is executing a closed orbit, as image forces from the beam pipe only cancel when the beam is well centred. Figures 8 and 9 show the results of simulation runs including half integer driving terms from the trim quadrupoles (ISIS has special programmable quadrupoles distinct from the main lattice), and also an angular kick once per turn. Each set of simulations was run twice, to allow the resulting perturbed beam distribution to be matched into the lattice. Figure 8 shows the variation of closed orbit (RMS position) around the ring as a function of intensity, from 1 - 5E14 ppp. Figure 9 compares RMS emittance with and without a closed orbit at an intensity of 2E14 ppp. Image forces are clearly influencing the behaviour of the beam, much as we expect on ISIS. A more complete analysis, and eventually experimental work on the ISIS synchrotron, are to follow.

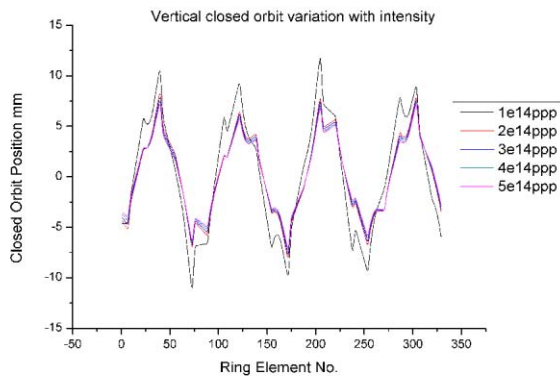


Figure 8: Matched closed orbit variation with intensity.

FUTURE WORK

Set

Work is also under way on a 1D longitudinal code which includes space charge and impedances. This will eventually be added to Set to make it fully 3D. Results are shown in Figure 10 for bunch length and phase convergence versus macro-particle number.

A parallel version of 2D Set has been implemented, and successfully run on the SCARF cluster [5]. Further work will add a realistic injection scheme, including the effect of foil scattering. The long term goal is to carry out a full simulation of the ISIS cycle and recreate the beam loss patterns seen on the real machine.

SUMMARY

Understanding space charge, and hence beam loss, is essential for the operation of a high intensity RCS, and even more important for the design of an upgrade.

A new code Set is being developed to enable further study of key beam dynamics issues that are important for ISIS, such as image effects and any dominant loss mechanisms.

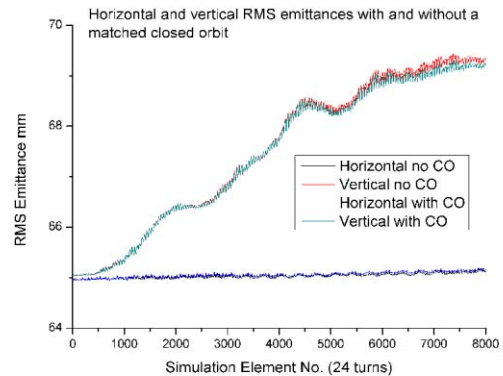


Figure 9: RMS emittance with and without matched closed orbit errors for 2E14 ppp intensity.

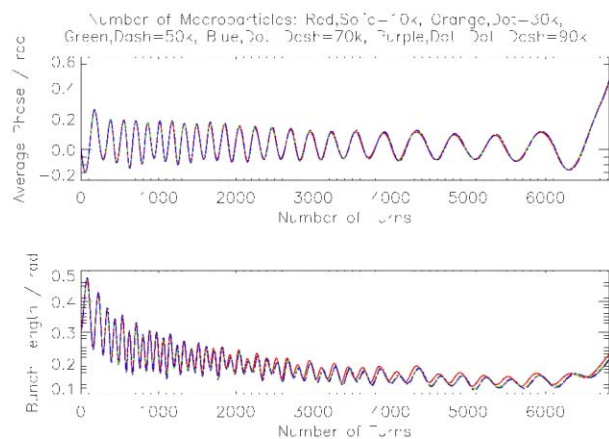


Figure 10: 1D convergence tests showing results for phase and bunch length.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge essential collaborations with ISIS Diagnostics, ISIS Operations and STFC e-Science.

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- [5] <http://sct.esc.rl.ac.uk/SCARF/index.html>.