MODELLING OF THE AGS USING ZGOUBI - STATUS*

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Abstract

This paper summarizes the progress achieved so far, and discusses various outcomes, regarding the development of a model of the Alternating Gradient Synchrotron at the RHIC collider. The model, based on stepwise ray-tracing methods, includes beam and polarization dynamics. This is an on-going work, and a follow-on of code developments and particle and spin dynamics simulations that have been subject to earlier publications at IPAC and PAC [1, 2, 3]. A companion paper [4] gives additional information, regarding the use of the measured magnetic field maps of the AGS main magnets.

INTRODUCTION

The modelling of the Alternating Gradient Synchrotron lattice, based on stepwise ray-tracing methods [5], including the two Siberian snakes simulated using their 2-D or 3-D OPERA field maps, has been described in earlier Conference publications [1, 2, 3]. The present paper gives an update regarding these works, and addresses various simulations and results so obtained, in the recent past. The reader may refer to the articles cited and to the companion paper in the present Proceedings [4], for more details on the methods and for additional simulation results. Even more can be found in the minutes of dedicated meetings at BNL C-AD [6].

MODELLING

We limit this discussion to a new ingredient in the modelling, introduced recently in Zgoubi [5], namely the procedure "AGSMM", for dedicated simulation of the AGS main magnet. It is based on the routines involved in the "MULTIPOL" procedure as used in earlier AGS simulations [1, 2, 3]. However the combined function "AGSMM" takes its magnetic field and indices $K1$ (quadrupole), $K2$ (sextupole), at arbitrary momentum p, from the so-called "transfer functions", namely the p-dependent polynomials K1-AD, -AF, -BD, -BF, -CD, -CF, K2-AD, -AF, -BD, -BF, -CD, -CF that had been installed in the code as discussed in Ref. [1].

Fields and indices are therefore *not* part of the input data in "AGSMM". These are shown in the data list below, as it appears in the AGS ring input data file to Zgoubi.

```
'AGSMM'  A01BF
!(1) dL/L  gap  db/b dK1/K1 dK2/K2
     0.    0.   0.   0.     0.
!(2) #blw  N  I   N I
     2     10 0.  1 0.
!Entrance fringe field
 10.0  4.0  0.8 0. 0. 0. 0. 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0. 0.
!Exit fringe field
 10.0  4.0  0.8 0. 0. 0. 0. 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0. 0.
!Roll angle of multipoles
 0. 0. 0.
!Integration step size
 2.0  Dip MM_A01BF
!(3) Misalignement: X-shft, Y-shft, Z-rot, Z-shft, Y-rot
 4 0. 0. 0. 0. 0.
```

Line (1) above, self-explicit, allows introducing defects with respect to the transfer functions. Line (2) accounts for the existence of back-leg windings (1 or 2) in some of the AGS main magnets, and for each, its number of turns and intensity. Line (3) allows various misalignments, it can be combined with roll angles of any of the 3 multipoles. For the rest, "AGSMM" data are as for "MULTIPOLE" [5].

Typical Optics Outcomes

The delicate part as to getting stable optics from the Zgoubi model over the AGS cycle in the presence of the helical snakes (this is also true for the MAD model), is in the low rigidity range, typically in the region $G\gamma$: 4.5 to $\sim$6. The reason is that in this range, the snakes have a substantial effect on the optics, in terms of focusing and coupling (these effects diminish with increasing momentum since the snakes are operated at constant field).

For that reason, in its present state, the Zgoubi model uses an *ad hoc* modelling of the local bump at the cold snake[1] : whereas in reality the orbit bump encompasses some of the lattice and snake compensation quadrupoles, in our model the bump extent has been limited to the snake itself, Fig.1. In addition, whereas there is no local bump at the warm snake in the AGS[2], the model includes one. These carefully designed orbit bumps in the model have two essential effects : (i) it allows almost-exact zero-ing of the reference closed orbit outside the snakes, (ii) the orbit will maintain its zero value whatever change is imposed on the quadrupole settings (tunes, snake optics compensation, etc.). It is planned in a future approach to account for realistic orbits at the snakes, instead.

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[1] The role of the local bump in the operation of the AGS cold snake is to center the spiraling orbit on the longitudinal axis of the helix. The bump magnets are switched-off when that orbit effect becomes small enough to be tolerable, namely beyond $G\gamma = 13.6$

[2] The orbit effect of the warm snake is considered weak enough not to necessitate compensation.

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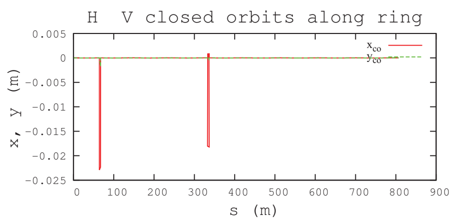

Figure 1: Zero closed orbit with local orbit bumps at snakes, injection $G\gamma = 4.5$. The bumps decrease to less than 2 mm at extraction $G\gamma = 45.5$.

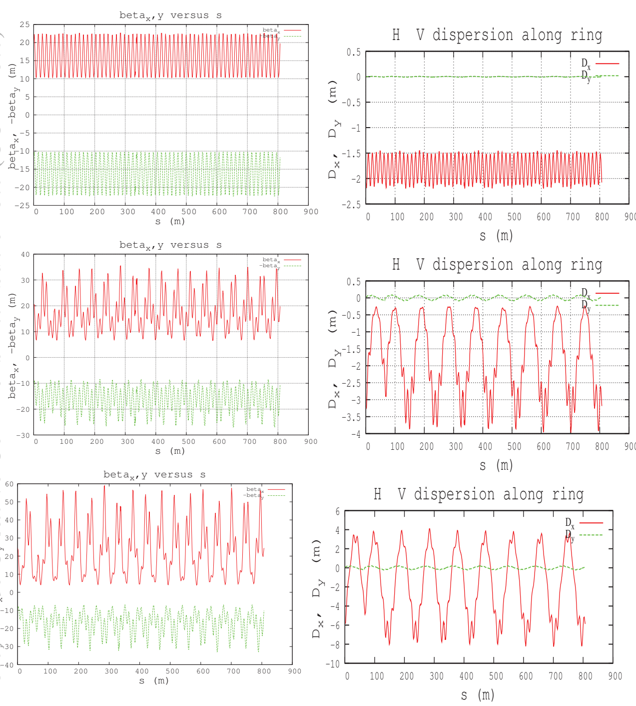

Figure 2: Betatron functions (left col.) and dispersion (right) at extraction energy, $G\gamma = 45.5$ (top, there the effect of the snake is very weak), at $G\gamma = 6$ (middle), and $G\gamma = 4.5$ (bottom).

Fig. 2 shows the betatron and dispersion functions at various energies, in the case of the bare AGS with the sole cold snake. The strong perturbation of the optics by the snake at low rigidity is visible.

Coupling

Studies based on the Zgoubi model have shown that the snakes excite all sorts of non-linear coupling resonances. These may cause emittance increase. Fig. 3 display sample outcome, including tune path as measured in the AGS during the polarized proton run, and a short path in the diagonal region, ending up on $|Q_x - 2Q_y| = 17$ (driven by normal sextupole). The motion ends up coupled (right plot, single particle).

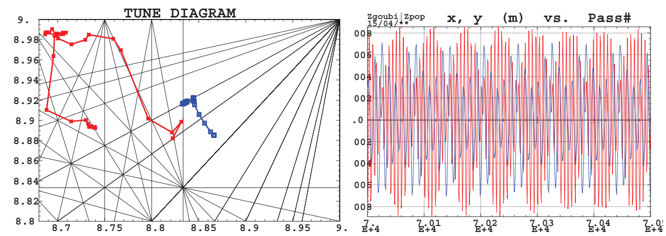

Figure 3: Left : tune diagram, including actual, measured, AGS cycle (red) and a simulation, single particle moved onto the $Q_x - 2Q_y$ resonance line (blue). Right : in the latter case, coupled motion as the particle stands on the $Q_x - 2Q_y$ line.

TUNE SCANS

Comparing tune scans, measured and computed, is part of the validation of the modelling. Zgoubi data here are drawn from the AGS "snap-ramps" (magnet current read-back), using the "ZgoubiFromSnaprampCmd" command [1]. Fig. 4 shows that good agreement between measurements and the model can be obtained. In the present case this required introducing a weak $dK1/K1 \approx 10^{-3}$ perturbation on the AGS main magnet field index (line (1) in the "AGSMM" data list above). Given that ingredient, both static computation of tunes (from multi-turn or first order mapping, at fixed energy) and dynamic computation (Fourier analysis during acceleration) yield results consistent with one another and with the measurements done at AGS.

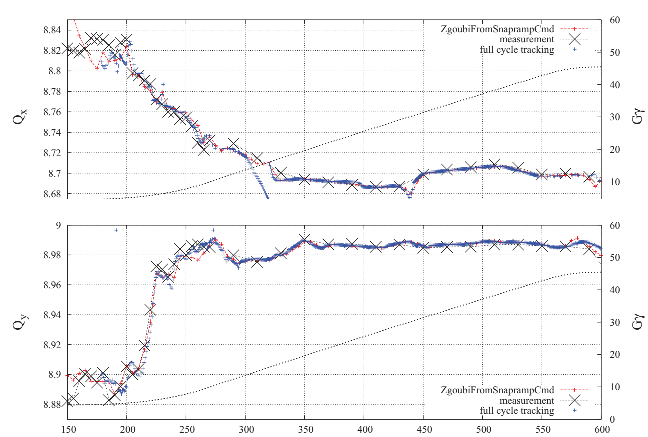

Figure 4: Tune scans over full AGS acceleration cycle, horizontal (top) and vertical (bottom).

Tune Jump

Further, tune jump at $G\gamma \pm Q_x$ =integer (they yield quicker crossing) can be introduced in the simulation, this is shown in Fig. 5. The optical setting over the AGS cycle is obtained by translation from a snap-ramp taken on February 2012, the tune jump series has been superimposed afterwards. The effect of the γ_{tr} jump on the horizontal tune is visible, $G\gamma \approx 17$ region. These simulations are at present being used for investigating optimization of polarization transmission and other emittance growth effects.

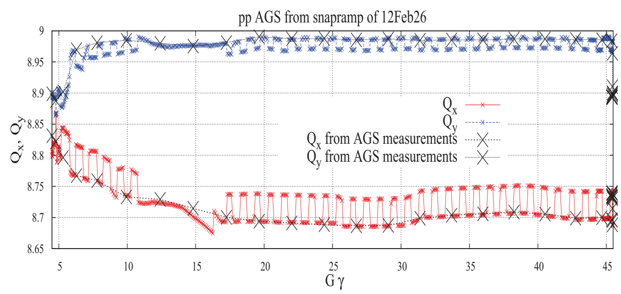

Figure 5: Simulation of tune jumps over AGS cycle (there is no tune jump in the γ_{tr} region).

SPIN MOTION

Fig. 6 is a simulation of the dynamics of the spin vector in the case of a single particle, with (blue) and without (red) the jump quad gymnastics. The beneficial effect of the jump quads is visible. Thorough simulations aimed at exploring the best conditions of the optimization of polarization transmission, in the region of the strong depolarizing resonance $G\gamma = 36 + Q_y$, have been undertaken recently.

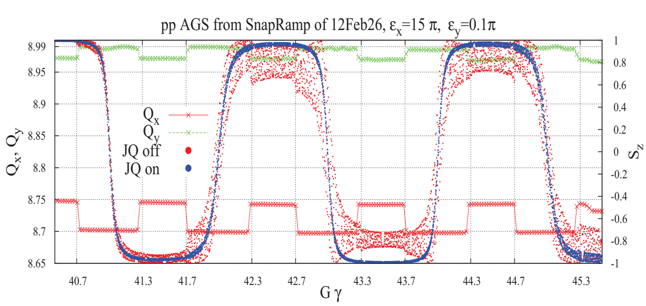

Figure 6: Spin motion with (blue) and without (red) tune jumps. Tune jumps at $G\gamma \pm Q_x$ =integer are also shown.

SURVEY DATA

A future stage in modelling the AGS will concern the simulation of the actual closed orbit, namely, having it derived from the actual defects in the machine. As a preliminary step, AGS survey data have been included in Zgoubi input file, they are comprised of the δx and δy positioning errors and of the pitch, yaw and roll rotations.

These defects had been installed in MADX, some outcome and comparisons are displayed in Fig. 7.

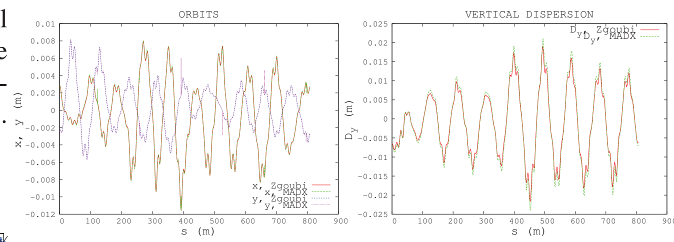

Figure 7: Left : closed orbit in AGS as stemming from alignment survey data. Right: vertical dispersion.

COMPUTING SPEED

An acceleration cycle in the AGS from 4.5/G GeV to 45.5/G GeV (G=1.79284735) at a rate of 0.15 MeV per turn, is approximately 143000 turns (the actual acceleration rate may slightly differ), and takes about 2 hours to simulate (on a regular CPU, with frequency 2 GHz about). This is fine for single particle studies, on a multipole core office computer for instance. On the other hand Zgoubi has been installed on NERSC computers, these provide thousands of units, hence allowing tracking as many particles, with similar CPU time. In other words, tracking a few thousands particles (this ensures reasonable statistics in most cases) over the AGS cycle takes about 2 hours.

CONCLUSION

In this paper we have shown the wide variety of particle and spin dynamics simulations in the AGS now made available thanks to the past two years extensive, dedicated development works in the ray-tracing code Zgoubi. The code is now routinely used in a number of studies, aimed at further investigation of beam optics and spin dynamics in the presence of the helical snakes.

Series of measurements : orbits, tunes, betatron functions, chromaticities, coupling, etc., have been undertaken during the polarized protons Run 12. Comparisons with the Zgoubi model are in progress.

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