MODELLING OF THE AGS USING ZGOUBI - STATUS*

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Abstract

Models of the Alternating Gradient Synchrotron, based on stepwise ray-tracing methods using both mathematical modelling or field maps so to represent the optical elements, including the siberian snakes, are being developed based on stepwise ray-tracing numerical tools. The topic is introduced in earlier PAC and IPAC publications, a status is given here.

INTRODUCTION

Models of the Alternating Gradient Synchrotron lattice, including the two siberian snakes represented by their OPERA field maps, are being developed, based on the use of the stepwise ray-tracing code Zgoubi [1]. The objective is to work at getting the best understanding of machine optics and spin dynamics, with the goal of providing on-line simulation tools that help improving the transmission of the polarization during RHIC injection cycle.

Details regarding the methods and results in matter of optics and spin dynamics have already been subject to publication in earlier conferences [2, 3], a lot more can be found in the minutes of dedicated meetings at C-AD [4].

To summarize here, three different ways of modelling the AGS combined function main dipole are available at present,

(i) a "centered multipole" analytical model [2],

(ii) an "off-centered multipole" model [3], which has the virtue of exhibiting the right magnet-end symmetries,

(iii) measured magnetic field maps, in view of high accuracy on magnet modelling and of further use of OPERA field maps.

The present paper reports on three progress areas, 1/ refinements regarding (i) and (ii) in view of the on-line modelling of the AGS, 2/ modelling of the AGS using measured field-maps of the main dipoles (iii), 3/ installation of Zgoubi model as on-line tool on AGS operation computers.

"MULTIPOLE" MODEL

We refer here to the modelling of the AGS, and in particular to the modelling of the main dipole, using the "MULTIPOL" keyword in Zgoubi, as it is described in Refs. [2, 3] : the transverse field components are derived from the solution of Laplace equation, including possible longitudinal dependence (end field fall-offs). This requires the multipole strengths of concern, which is dealt with as follows.

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The AGS is 12-superperiodic, a superperiod is comprised of 20 combined function main dipoles, of six different species named AD, BD, CD (defocusing), AF, BF, CF (focusing), described further in the next Section.

For all six types of magnets, the value of the dipole component is derived from the geometry of the "optimal closed orbit" (OCO[1]), whereas, a refinement compared to [2, 3], the quadrupole strengths K1 as well as the residual sextupole strengths K2 are at present drawn from momentum-dependence polynomials which have been installed both in Zgoubi and in the MAD[8,X]→Zgoubi translator :

$$K1AD := K1ADM3/p^3 + K1ADM2/p^2 + K1ADM1/p + K1AD0 + K1AD1*p+K1AD2*p^2+K1AD3*p^3+K1AD4*p^4+K1AD5*p^5+K1AD6*p^6$$

$$K1AF := K1AFM3/p^3+K1AFM2/p^2+K1AFM1/p+K1AF0+K1AF1*p + K1AF2*p^2 + K1AF3*p^3 + K1AF4*p^4 + K1AF5*p^5 + K1AF6*p^6$$

$$K1BD := K1BDM3/p^3 + K1BDM2/p^2 + K1BDM1/p + K1BD0 + K1BD1*p+K1BD2*p^2+K1BD3*p^3+K1BD4*p^4+K1BD5*p^5+K1BD6*p^6$$

$$K1BF := K1BFM3/p^3+K1BFM2/p^2+K1BFM1/p+K1BF0+K1BF1*p + K1BF2*p^2 + K1BF3*p^3 + K1BF4*p^4 + K1BF5*p^5 + K1BF6*p^6$$

$$K1CD := K1CDM3/p^3 + K1CDM2/p^2 + K1CDM1/p + K1CD0 + K1CD1*p+K1CD2*p^2+K1CD3*p^3+K1CD4*p^4+K1CD5*p^5+K1CD6*p^6$$

$$K1CF := K1CFM3/p^3+K1CFM2/p^2+K1CFM1/p+K1CF0+K1CF1*p + K1CF2*p^2 + K1CF3*p^3 + K1CF4*p^4 + K1CF5*p^5 + K1CF6*p^6$$

and similarly for K2AD, -AF, -BD, -BF, -CD, -CF.

We dispose of two series of coefficients for these K1(p) and K2(p) polynomials. A first one is that currently in use in the MAD model of the AGS and has its origin as described in Ref. [8]. The second series has been derived from recent works on the measured field maps of the main dipole, this is addressed in the next Section.

Having these polynomials installed in the MAD[8,X]→Zgoubi translator was an early step in these developments, and allowed straightforward comparisons between the two codes. Their further installation in Zgoubi came in complement with a newly implemented "AGS dipole" option in the "MULTIPOL" keyword, allowing for instance $p\uparrow$ acceleration with appropriate K1(p) and K2(p) evolutions along the cycle, accurate spin dynamics simulations, etc.

Either one of the two methods (regular "MULTIPOL" keyword at fixed momentum, or AGS-option "MULTIPOL" at arbitrary momentum) can be used when producing zgoubi.dat input data files from AGS snap ramps, see last Section.

FRINGE FIELDS

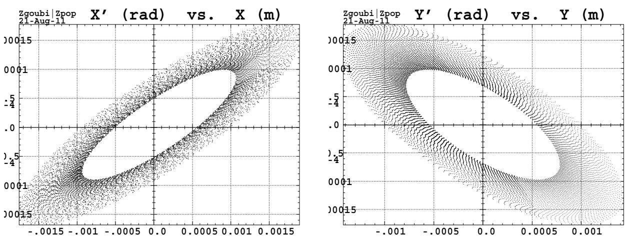
A note in passing. Measured field maps as discussed in the next section have allowed producing end-field fall-

[1]OCO coincides with the closed orbit in all straight sections. In the main dipoles OCO coincides with the chord of the arc of trajectory, it is localized by its distance to the socket line (the survey line). OCO coincides with optical axis of all elements placed in the drifts, as tuning quads, sextupoles, control instrumentation, etc.

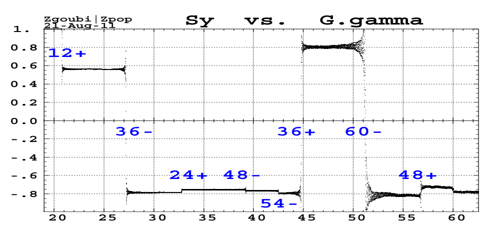
offs, as well as their matching using Enge model [1]. These fringe fields can be accounted for in Zgoubi "MULTIPOL" based model. The evaluation of their impact on beam and spin dynamics is in order.

LONG TERM TRACKING

To conclude with the "MULTIPOL" based AGS model, the Figures below display phase space and spin tracking over a full acceleration cycle from 9 to 32 GeV (above 8.5 GeV, so to avoid γ_{tr} gymnastics for simplicity), at a rate of 150 keV/turn, for a particle launched with $\epsilon_x \approx \epsilon_y \approx 0.2$ mm.mrad normalized. It can be checked that the damping does satisfy $\beta\gamma\epsilon = C^{st}$, whereas spin resonance crossing does satisfy $P_f/P_i = 2\exp(-\pi\epsilon_k^2/2a) - 1$ (ϵ_k is the resonance strength, a is the crossing speed).



Damped phase space motion, from 9 to 32 GeV, horizontal (left) and vertical (right).

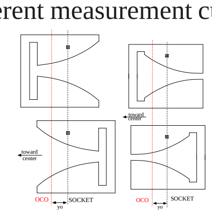


Crossing of intrinsic resonances, from 9 to 32 GeV.

That tracking takes less than 2 hours. These allowed foreseeing significant statistics on polarization transmission, by launching large amounts of particles on CPU arrays. This is presently being worked on.

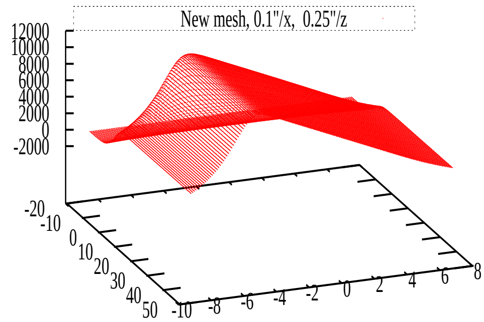
AGS MODEL FROM FIELD MAPS

In order to simulate the six different AGS magnet types we dispose of two series of measured field maps, A-type magnet series and C-type magnet series. B-type series is derived from A-type by shortening the central region of the field map ; reverse focusing, schemed in the Figure below, is obtained by x-flip of field data. Each series comprises 12 different measurement currents from 30 to 5850 Amps.

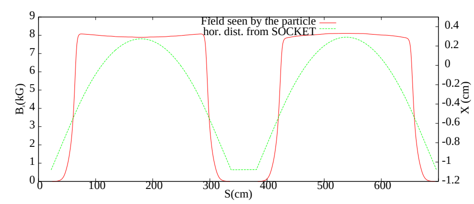


Center of ring is to the left.
Top : AD, CF,
bottom : AF, CD.

The mesh size in all these maps is $\Delta x = 0.1$ inch transverse and, longitudinally, $\Delta z = 0.25$ inch in high dB/dz regions, 1 inch in flat field regions (end and body). However Zgoubi only takes uniform mesh, so these maps have been converted to new sets with identical node distances over the all mesh, namely, $\Delta x = 0.1$ inch, $\Delta z = 0.25$ inch.



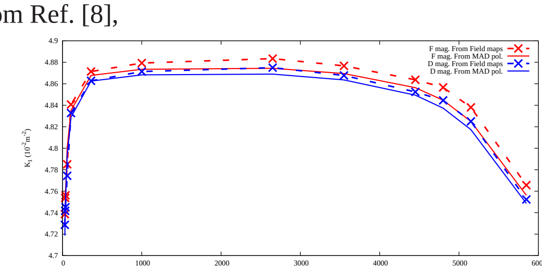
Typical measured field map. Horizontal axes in inches, vertical axis in Gauss.



Typical field along OCO in a D/F doublet, and distance to the "Socket line"

K1(p) AND K2(p) POLYNOMIALS

These field maps have been used to determine the quadrupole strengths $K1(I)$ and sextupole strengths $K2(I)$, typical results in Figure below - dashed lines represents the present polynomials, solid lines are the strengths from Ref. [8],



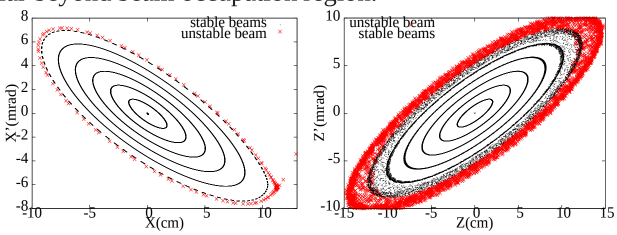
Sample results : K_1 versus current in AF and AD magnets.

On the other hand, the correspondence between magnet current, I, and reference momentum p in the ring, is given in Ref. [9], thus allowing matching $K1(p)$ and $K2(p)$ with polynomials of the form detailed above.

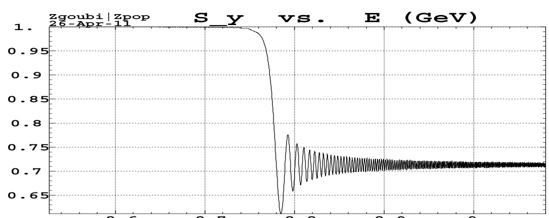
The original K1(p) and K2(p) series (from Ref. [8]) and those obtained in the present manner, slightly differ (Figures above), this is still to be understood. Their comparison in terms of optics and spin dynamics effects is still in order.

TRACKING TRIALS

Sample multiturn tracking results are shown in the Figures below. The stability limit in these transverse phase spaces stems from limited field map size (over-extrapolation of field values out of the map). It is clear however that the field map extent is large enough to get reasonable tracking quality, over a few 1000 turns range, far beyond beam occupation region.



Numerical stability limits, horizontal (left) and vertical phase space (right).



Evolution of S_y across $0 + Q_y$. The amount of depolarization agrees with analytical expectations.

These tracking samples also show that the accuracy on motion computation using measured field maps is reasonable enough to yield first order machine parameters, chromaticities, etc., and allows tracking spin motion, bottom Figure.

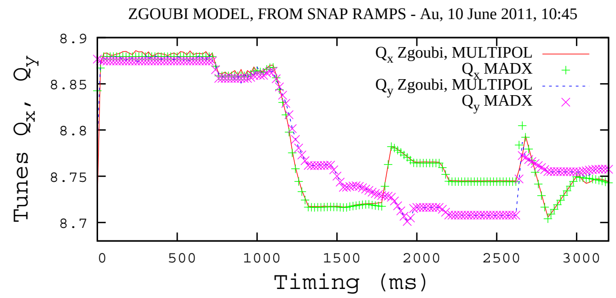
However settling these tools is seen as a preliminary stage in view of further use of AGS main dipoles OPERA field maps. It has been shown in various other occasions that computed field maps do give access to accurate long-term tracking, even in highly non-linear context [6].

FROM AGS SNAP-RAMPS TO ZGOUBI

Zgoubi AGS models so developed are being installed on the AGS operation computers. Input data files to Zgoubi are created from AGS magnet settings during acceleration cycle (by reading in the so-called "snap-ramps", a series of ascii files containing records of magnet power supply settings, at millisecond scale intervals over the full acceleration cycle). Conversion from snap-ramps to zgoubi.dat at arbitrary timing involves a conversion procedure, drawn from the very one used for the same purpose in the on-line MADX model [7], which translates power supplies currents into magnet strengths.

The snap-ramps→Zgoubi software so installed allows producing zgoubi.dat files in either one of the three models above, "centered MULTIPOL", "off-centered MULTIPOL" or "field map based".

A series of software tools have in addition been developed to allow functionalities as fast calculation of tunes and chromaticities along the ramp, optical functions at arbitrary timings, etc., as well as for possible interfacing to the "AGS model viewer" [7]. This is illustrated in the Figure below which shows the tunes so computed over an acceleration cycle during a Gold run (tuning quadrupoles are varied along the cycle, chromaticity is corrected).



Tunes over AGS cycle, including MADX for comparison.

This Figure shows in particular the excellent agreement with MADX values in the present restrictive working hypothesis : defect-free lattice, ideal orbit (on "OCO"), siberian snakes off, all magnets hard-edge.

These tools are aimed at thorough investigation of beam and polarization dynamics in AGS, by sophisticating the AGS model, thanks to the stepwise ray-tracing based engine, in close relation with experimental data taking. This work is in progress, more on that can be found in the AGS Online Model Meeting Minutes [4], it will be subject to further reports.

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