AGS Dynamic Aperture at Injection of Polarized Protons and Helions[1]

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Introduction

The goal for helions in the AGS at injection is to have both ν_x and ν_y inside the spin tune gap at injection.

- For protons at $G\gamma$ =4.5 has proven operationally difficult due to excessive losses and tuning.
- With helion injection at $|G\gamma| = 7.5$ being at a lower rigidity than protons at $|G\gamma| = 4.5$ $(\mathrm{B}\rho = 7.203\ \mathrm{Tm})$ with $\mathrm{B}\rho = 6.967\ \mathrm{Tm}$, concern over both the available aperture and dynamic aperture (DA) due to these strong optical distortions of the cold snake being raised [3, 4].

DA is defined as the maximum amplitude at which a particle will not be lost from single particle dynamics and not from physical apertures [1].

- The physical aperture of the AGS is the beampipe at the cold snake which is round with a 3.85 cm radius.

AGS Snakes

To quantify the optical defects, particles are tracked through only the cold snake to calculate the transport matrix.
From the transport matrix, the total focusing (FC) and coupling (CP) are calculated[2],

$$FC = R_{12}^2 + R_{34}^2 \tag{1}$$

and the coupling, CP, is

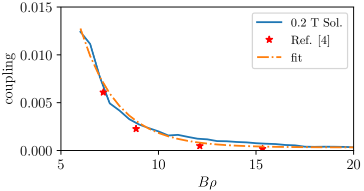
$$CP = LL + UR \tag{2}$$

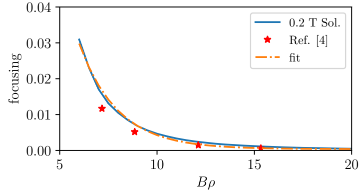
with

$$LL = R_{31}^2 + R_{32}^2 + R_{41}^2 + R_{42}^2 \tag{3}$$

$$UR = R_{13}^2 + R_{14}^2 + R_{23}^2 + R_{24}^2. \tag{4}$$

As seen in Fig. 3, these optical distortions reduce exponentially with $B\rho$.





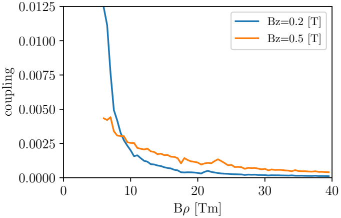
Snake Coupling Correction

The partial snake magnet assembly also contains a solenoid magnet for coupling correction.

- The nominal current used is $\mathrm{I_{sol}}$=220 A which corresponds to a field of $\mathrm{B_{sol}}$=0.2 T.
- There is an engineering limit of $\mathrm{I_{sol,max}}$=235 A, although the magnet it has been tested up to 300 A.

From this, there are only marginal improvements that can be made on correcting the coupling so these simulations will use the I_{sol} =220 A.

An example of the coupling from $\mathrm{B_{sol}}$=0.5 T field is shown in Fig. 4, when the coupling at low energy is improved but is larger at higher energy.

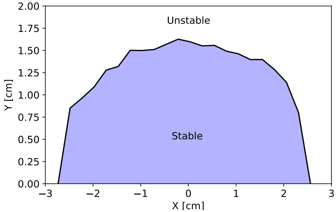


Dynamic Aperture Calculation

The DA is calculated with various tune configurations to compare working points at injection. The methodology of the DA calculation follows:

1. Fit model to tunes and find closed orbit.
2. Find $\pm$x limit where beam survives
3. Populate range $[X_L, X_U]$ with 20 particles separated by dx, and find Y_M (maximum stable Y) at each X coordinate.
4. Simulations with 169 points ($\nu_x = \{0.69 + 0.02k | k \in \{1, 2, ..., 13\}\}$ and $\nu_y = \{0.85 + 0.01k | k \in \{1, 2, ..., 13\}\}$)
5. The binary search resolves at a resolution of ± 0.008 *mm*.

This process is shown in figure for $[\nu_x, \nu_y]$=[8.77, 8.88]



This implementation uses a combination of zgoubi and pyzgoubi where:

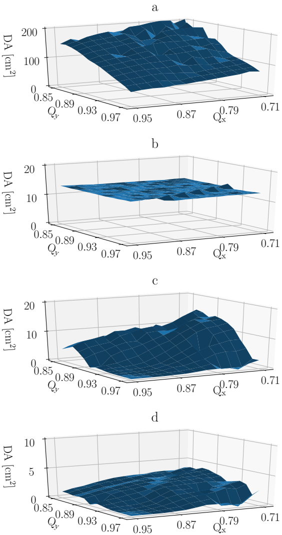
- zgoubi handles all the tracking and optics computations,
- pyzgoubi handles particle coordinates and fitting algorithms described above,
- pyzgoubi creates a thread for each ν_y and ν_x configuration.

Simulation Results

A comparison of the DA is made for the AGS in the absence and presence of snakes, in addition to the absence and presence of the physical limiting aperture. This is shown for helions at $|G\gamma|$=7.5 in Figure on left with:

- a snakes off, no limiting aperture;
- b snakes off with limiting aperture;
- c snakes on, no limiting aperture;
- d snakes on, with limiting aperture.

Comparison of a with Fig. 6b shows that in the absence of the snakes, the DA is larger than the limiting aperture of the machine. Comparison of Fig. 6c with Fig. 6d shows that in the presence of snakes, the strong optical defects cause a further reduction in the DA when the limiting aperture is introduced.



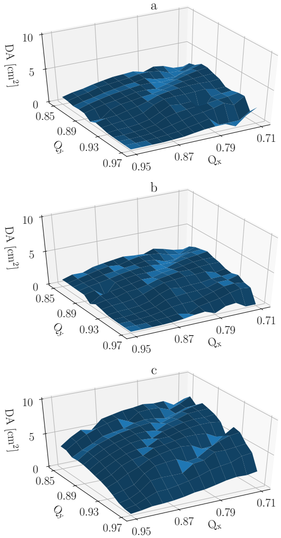
Simulation Results II

Simulations are performed at $B\rho = 6.968$ Tm, $B\rho = 7.203$ Tm, and $B\rho = 10.780$ Tm as seen in figure.

- There are subtle differences in the DA between helions at $B\rho = 6.968$ Tm and protons at $B\rho = 7.203$ Tm
- Factor of 2 gain in DA when comparing to the $B\rho = 10.780$ Tm case.

The DA calculations are done for 1,000 turns to minimize computing time.

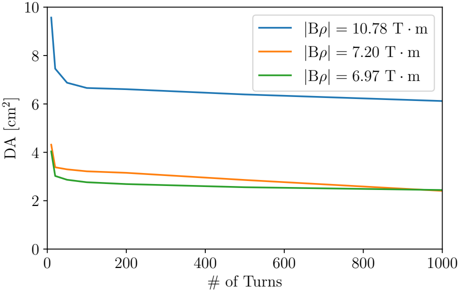
- Idealized DA tracking would be for a number of turns equal to the time the particles are at injection energy.
- Computationally problematic since the time for simulations is linearly proportional to the number of turns.



Simulation Summary

From figures on previous slides, one notes there is virtually zero DA available in the region of interest with $[\nu_x, \nu_y] \geq [8.9, 8.9]$ for helions at $|G\gamma| = 7.5$ and protons at $|G\gamma| = 4.5$.

- This further supports extraction of helions at $|G\gamma|$=10.5 as the available DA is substantially larger.
- This is also observed in Fig. below where the three configurations are compared at a fixed tune of $[Q_x,\ Q_y]$=[0.75, 0.91].



Conclusion

- Simulations showed that the available DA increases with magnetic rigidity due to reduced optical defects from the AGS snakes.
- Extraction for helions at $|G\gamma| = 10.5$ provide a larger dynamic aperture that would allow the tunes to be put within the spin tune gap at injection.
- This extraction energy also allows the $|G\gamma| = 0 + \nu_y$ resonance to be avoided in the AGS.

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