THE AGS SYNCROTRON WITH FOUR HELICAL MAGNETS*

N. Tsoupas#, H. Huang, W. W. MacKay, T. Roser, and D. Trbojevic BNL, Upton, NY 11973 USA

Abstract

The idea of using two partial helical magnets was applied successfully to the AGS synchrotron [1,2] to preserve the proton beam polarization. In this paper we explore in details the idea of using four helical magnets placed symmetrically in the AGS ring. The placement of four helical magnets in the AGS ring provides many advantages over the present setup of the AGS which uses two partial helical magnets. First, the symmetric placement of the four helical magnets allows for a better control of the AGS optics with reduced values of the beta functions especially near beam injection, second, the vertical spin direction during beam injection and extraction is closer to vertical, and third, it provides for a larger "spin tune gap", which allows the vertical and horizontal tunes to be placed, and prevent the horizontal and vertical intrinsic spin resonances of the AGS to occur during the acceleration cycle. Although the same spin gap can be obtained with a single or two partial helices, the required high field strength of a single helix makes its use impractical, and that of the double helix rather difficult. In this paper we will provide results on the spin tune and on the optics of the AGS with four partial helical magnets, and compare these results with the present setup of the AGS that uses two partial helical magnets [3].

INTRODUCTION

The preservation of the polarization of a polarized proton beam during the acceleration of the beam in a synchrotron is not a trivial task since the polarized beam encounters many imperfection and intrinsic resonances [2] which may depolarize the beam. In order to overcome the spin resonances, which cause depolarization an idea was suggested [1] of inserting partial helical magnets in the synchrotron. These partial helical magnets, act as strong artificial resonances, which minimize the polarization loss at the imperfection resonances and also eliminate the intrinsic spin resonances. This idea of using multiple partial helices was applied successfully to the AGS synchrotron [2]. Although high field partial helices are beneficial for the preservation of the beam polarization during the beam acceleration, the high field of the helices generates local beam bumps which distort the betatron and dispersion functions, and also introduce linear or even higher order beam coupling. Although these adverse effects, introduced by the partial helices on the beam optics can be mitigated by the introduction of compensation quadrupoles at the vicinity of the partial helices and by generating local beam bumps at the location of the partial helices [3,4] the effect of the helices on the beam optics of the AGS, especially at low energies is still a problem. In this paper we further explore the idea of ref. [1] by introducing four partial helices, placed symmetrically around the ring. The results of the calculations of four partial helices, will be compared with those derived from the calculations of the two partial helices [3] in the AGS.

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#tsoupas@bnl.gov

SPIN CONSIDERATION IN ACCELERATION

As we mentioned earlier the function of the partial helical magnets is twofold; first, to minimize the effect of the imperfection resonances ($G\gamma=n$), and also to eliminate the intrinsic resonance by generating a spin tune ν_{sp}, which does not satisfy the condition $\nu_{sp}=nP\pm Q_y$. In the expression above n is an integer and P is the super-periodicity of the AGS and Q_y is the vertical betatron tune. Although a single partial helix can be used to eliminate the imperfection and intrinsic resonances, the strength of a single helix is too high and may affect adversely the optics of the circulating beam. A simple solution to this problem is to substitute a single partial helix by two or four partial helices of lower strength. An arrangement of four partial helices is shown in Fig. 1.

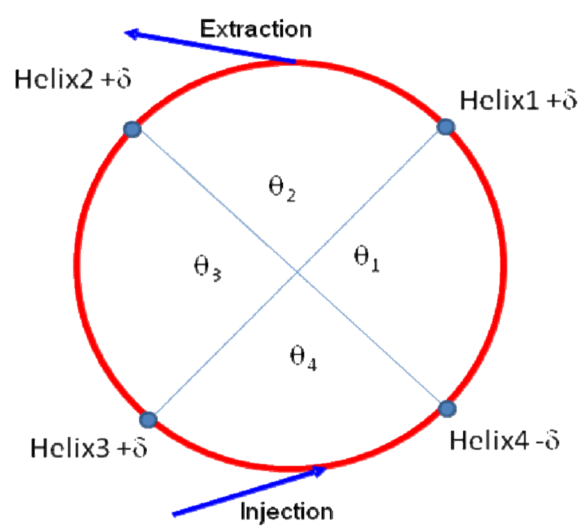

Figure 1: Schematic diagram of the AGS ring with four Helices symmetrically placed around the ring. Each pairs of Helices(1,3) and Helices(2,4) are separated by an angle π. The spin rotation angles about the stable spin direction of each of the helices is δ, except of the helix4 which provides a spin rotation angle -δ.

The condition of the intrinsic resonance $\nu_{sp}=nP\pm Q_y$ may be avoided by setting the fractional part of the betatron tune Q_y to be larger than the fractional part of the spin tune ν_{sp}, $(Q_y)_{frac} > |\nu_{sp}|_{frac}$. Knowing the location and the strength of the partial helices one can calculate the spin tune [5]. The calculated spin tune ν_{sp} is plotted as a function of Gγ in Fig. 2, for various strengths of the partial helices. The black trace in Fig. 2, corresponds to the spin tune generated by the two partial helices [1,2] which are presently installed in the AGS. The spin rotation angle δ in one of the partial helices is δ=19.08° (10.6%) and that of the second helix, which is located in the ring 120° away from the first helix is δ=10.62° (5.9%). The other three traces (red blue and green) correspond to the spin tune when the AGS has four partial helices of equal strength, separated azimuthally by an angle of 90°. The corresponding strengths of each of the four helices are 8.06% (red) 10% (blue) and 11.098% (green). At higher values of Gγ than those indicated in the graph, the spin tune repeats itself with only one of the periods shown in the graph. In the case of four helices, the values of the spin tune allows for a "wider spin tune gap" where the betatron tunes can be placed, thus providing a larger "spin tune gap" for the placement of the betatron tunes, even at lower strength of the helices.

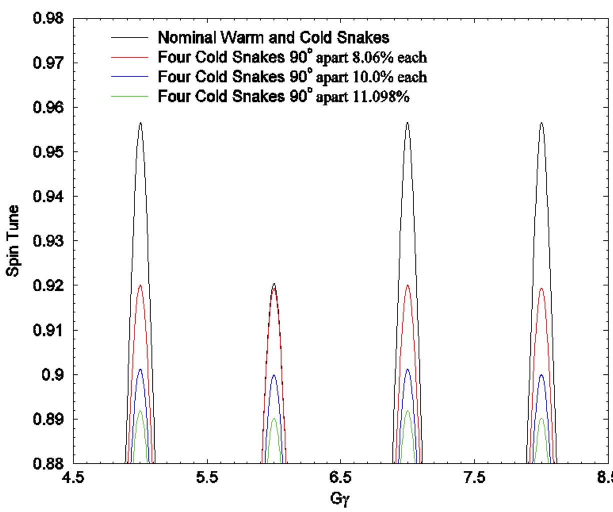

Figure 2: The spin tune ν_{sp} in AGS as a function of Gγ. See text for details.

Another issue, related to the spin, when four helices are placed in the AGS, is the stable spin direction at the injection and extraction points of the AGS. Since there are no spin rotators at the injection or extraction transport lines to align the stable spin direction of the injected/extracted beam to the stable spin direction of the circulating beam in the AGS, it is preferable that the stable spin direction of the circulating beam at the injection and extraction points, is as close to the vertical as possible. The directional cosines of the stable spin direction at the injection and extraction points for both cases of two and four helical magnets appear in Table 1.

BEAM OPTICS CONSIDERATION

A challenging task of introducing helices into a medium energy synchrotron is to minimize the effect of the relatively high field helical magnets on the beam optics of the circulating beam. This effect is especially large at injection energy where the beam rigidity is low and the size of the beam is large. In this section we describe the beam optics of the circulating beam in AGS at injection, and discuss a possible method to ameliorate the effect of the helical magnets on the circulating beam. The required constrains on the beam parameters, dispersion functions and betatron tunes, during the beam acceleration, will also be discussed.

Table 1: The directional cosine of the stable spin direction with the vertical, at injection and extraction points (2nd,3rd colns), for the case of two and four helices (2nd,3rd rows).

	Dir_cos S_z Injection Gγ=4.5	Dir_cos S_z Extraction Gγ=45.5
Two Helices A20 and E20	0.9979	-0.9763
Four Helices	1.0000	-0.9828

The AGS synchrotron consists of 240 combined function magnets and has a super-periodicity P=12, with 20 combined function magnets per superperiod. Twelve pairs of quadrupoles, each pair located at the straight section SS03 and SS17 of every superperiod , are used to adjust the horizontal and vertical betatron tunes respectively. Fig. 3 shows the beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions of the circulating beam for a closed orbit, over three superperiods of the bare-AGS, where the tune quadrupoles are set to zero excitation. The corresponding tunes for a bare AGS, at Injection energy are shown in columns 2 of Table 2.

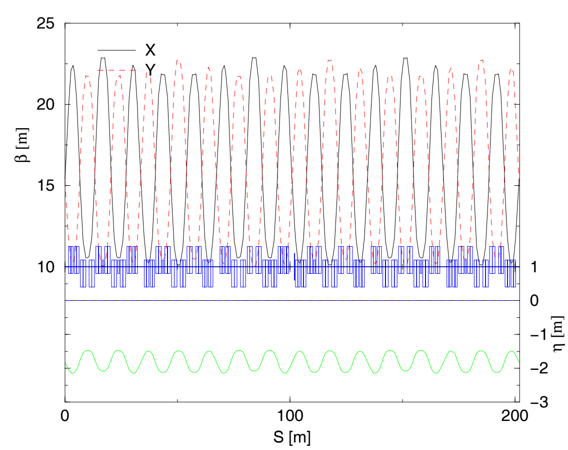

Figure 3: The beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions over three super-periods of the bare AGS. The horizontal and vertical tune qudrupoles (one pair in each super-period) are set to zero. The corresponding betatron tunes appear in the 2nd column of Table 2.

The insertion of four partial helices symmetrically placed around the AGS ring, reduces the super-periodicity of the AGS to four, at near injection energies when the effect of the partial helices is important. Fig. 4 shows the beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions of the central particle of the circulating beam over three superperiods of the bare-AGS, with one of the four helical magnets placed at the

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center. The corresponding tunes for a bare AGS, at injection energy are shown, in columns 2 and 3 of the 3rd row of Table 2. Here we assume that the focusing properties of each of the four helices are identical. Although this is valid for the three helices which rotate the spin by an angle +δ, it may not be true for the fourth helix which rotates the spin by an angle –δ and requires further investigation.

Table 2: The Hor. and Ver. betatron Tunes (Q_x , Q_y) for Various AGS Settings

AGS Setting	Q_x	Q_y
Bare_AGS	8.7127	8.7675
Bare_AGS 4(Cold Helices)	9.1864	8.9884
Non-Bare-AGS 4(Cold Helices)	8.9785	8.9874

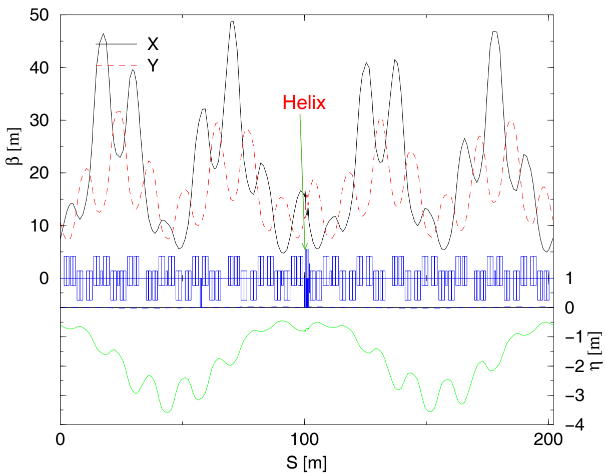

Figure 4: The beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions over three super-periods of the bare AGS with a helical magnet inserted at the middle, as shown by the green arrow in the figure. The horizontal and vertical tune qudrupoles (one of each in each super-period) are set to zero. The corresponding betatron tunes appear in Table 2.

Although the insertion of the helix distorts the beam optics of the AGS, the beam is still stable, and the betatron tunes can be set at the required values with the use of the tune quadrupoles as shown in the third row of Table 2. It is desired however to reduce the values of the beta and dispersion function and provide more control in the AGS during the beam acceleration. This can be accomplished by the insertion of thin quadrupoles in the straight section at the vicinity of the helices, as well as by connecting floating power supplies across the tune quadrupoles. The effect of such compensation quads on the beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions is shown in Fig. 5 which shows the beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions of the circulating beam in closed orbit, over three superperiods of the AGS, with a helical magnets placed at the center of the three superperiods. The beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions shown in Fig. 5 can be compared with those shown in Fig. 4. The relative location and the strength of the compensation quads appear in Table 3. The betarton tunes which correspond to the beam optics shown in Fig. 5 have been adjusted by using the tune quadrupoles, and the values of these tunes appear in Table 2.

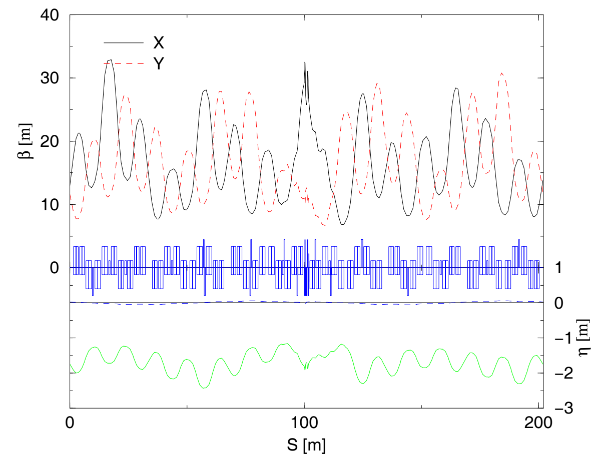

Figure 5: The beta ($\beta_{x,y}$) and eta ($\eta_{x,y}$) functions over three super-periods of the bare AGS with a helical magnet inserted at the middle. A number of compensation quads (see Table 3) has been inserted in various straight sections to help reduce the values of the beta and eta functions as compared to those shown in Fig. 4. The horizontal and vertical tune qudrupoles have also been adjusted to provide the required tunes which appear in Table 2.

Table 3: The Location of the Compensation Quadrupoles Relative to the Helix, and their Strength in m^{-2}.

1st SuPer	2nd Super period					3rd SuPer
CQ1	CQ2	CQ3	Helix	CQ4	CQ5	CQ6
SS03	SS07	SS09	SS10	SS11	SS13	SS17
0.041	-0.303	0.320		-0.471	0.159	0.003

CONCLUSIONS

Calculations show that the insertion of four partial helices in the AGS provides an improved beam optics which can eliminate both the horizontal and vertical intrinsic resonances during the acceleration of polarized protons.

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