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NEAR INTEGER TUNE FOR POLARIZATION PRESERVATION IN THE AGS *

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Abstract

The high energy (T=250 GeV) polarized proton beam experiments performed in RHIC, require high polarization of the beam. In order to preserve the polarization of the proton beam, during the acceleration in the AGS, which is the pre-injector to RHIC, we have installed in AGS two partial helical magnets [1,2,3] which minimize the loss of the beam polarization caused by the various intrinsic spin resonances occurring during the proton acceleration. The minimization of the polarization loss during the acceleration cycle, requires that the vertical tune of the AGS is between the values of 8.97 and 8.985 during the acceleration. With the AGS constrained to run at near integer tune ~8.980, the perturbations to the beam caused by the partial helical magnets are large and also result in large beta and dispersion waves. To mitigate the adverse effect of the partial helices on the optics of the AGS, we have installed in specified straight sections of the AGS compensation quads [4] and we have also generated a beam bump at the location of the cold partial helix. In this paper we present the beam optics of the AGS which ameliorates the adverse effect of the two partial helices on the beam optics.

INTRODUCTION

The high energy (T=250 GeV) polarization experiments performed in RHIC require high beam polarization. To provide highly polarized beam to RHIC, we should obviously maintain high polarized beam in AGS, which is a pre-injector to RHIC. The preservation of the beam polarization during the acceleration of the beam in the AGS is not a trivial task since the polarized beam encounters many spin resonances which may depolarize the beam. In order to overcome these spin resonances, it was suggested [1] to insert partial helical magnets in the AGS. These partial helical magnets, act both, as strong artificial resonances which minimize the polarization loss at the imperfection spin resonances, and also eliminate the intrinsic spin resonances. This idea of using multiple helices, proved to be successful, when it was applied to the AGS synchrotron [2,3] by inserting into the AGS ring two partial helices. Although the high field partial helices are beneficial for the preservation of the beam polarization during the beam acceleration, the high fields of the helices generate local beam bumps, distort the betatron ($\beta_{x,y}$) and dispersion ($\eta_{x,y}$) functions, and also introduce linear beam coupling. Some of the adverse effects, introduced by the partial helices on the beam optics, are mitigated by introducing compensation quadrupoles at the vicinity of the partial helices and by generating local beam bumps [5] at the location of the partial helices.

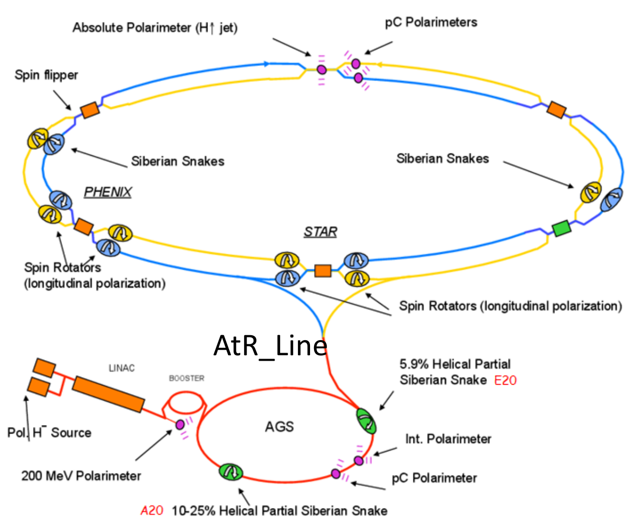

Figure 1. The RHIC Complex with the location of the A20 and E20 partial helices of the AGS.

During the beam acceleration, both partial helices maintain a constant field therefore the adverse effect of the helices on the beam optics of the AGS is significant at low beam energies and diminishes as the inverse of the beam momentum, with the effect becoming insignificant at the extraction energies of p~25.5 GeV/c. Similarly the strength of the compensation quadrupoles, which help minimize the effect of the helices, is reduced by the inverse of the square of the momentum ($1/p^2$). In this paper we present the beam optics of the AGS as a function of the beam momentum, and we also discuss the various beam constraints that should be satisfied during the beam acceleration.

LAYOUT OF THE TWO HELICES AND OF THE COMPENSATION QUADS IN AGS

The location of the two partial helices on the ring was chosen such as to provide maximum "spin tune gap", where we could place the fractional part of the vertical betatron tune Q_y, for the relation $\nu_{sp}=nP\pm Q_y$ which specifies the condition of the intrinsic resonance, never to

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be satisfied. Table 1. provides information of the location of the compensation quads relative to the partial helices and Ref. [5] provides detailed information of all the devices introduced to modify the beam optics of the AGS.

Table 1: The location of the Cold, and Warm helices, and of the compensation quads is shown in 2nd column.

Name	SS	Description	Optical Properties
CQ_A17	SS-A17	Tune Quad QH_A17	Defocusing
CQ_A19	SS-A19	Thin Quad	Defocusing
Cold Helix	SS-A20	Super Conducting Helical Magnet	Defocusing in both planes
CQ_B1	SS-B1	Thin Quad	Defocusing
CQ_B3	SS-B3	Polarization Quad	Defocusing
CQ_E17	SS-E17	Tune Quad QH_E17	Defocusing
CQ_E19	SS-E19	Thin Quad in series with CQ-F1	Defocusing
Warm Helix	SS-E20	Warm Helical Magnet	Defocusing in both planes
CQ_F1	SS-F1	Thin Quad in series with CQ-E19	Focusing
CQ_F3	SS-F3	Polarization Quad	Not in use

BEAM CONSTRAINTS ON THE BEAM OPTICS

In addition to the obvious beam constraint, which requires that the maximum beam size fits into the available aperture of the accelerator, an additional constrain, which is relevant to the preservation of the polarization, requires that the vertical tune maintains a value between 8.97 and 8.985 during the acceleration. The first constrain is satisfied by keeping the maximum values of the beta ($\beta_{x,y}$) and dispersion ($\eta_{x,y}$) functions below a specified limit. For example at injection energies the maximum value of the beta functions should be constrained such that $(\beta_{x,y})_{max}$<50 [m] , and the values of the dispersion function ($\eta_{x,y}$) should be within the limits of { -4 [m]< η_x <-0.5 [m] }. Assuming an rms value for the normalized beam emittance, of $\varepsilon_{x,y}$~1.7π[mm.mrad] and an rms value for the momentum spread of σ_p~$7x10^{-4}$,the maximum rms values of the beam sizes at injection energies corresponding to Gγ=4.5 is: $(\sigma_y)_{max}\leq 0.61$ [cm] $(\sigma_x)_{max}\leq\{(\varepsilon_{x,y}\cdot\beta_{x,y})/(\beta\gamma)+(\eta_x\cdot\sigma_p)^2\}^{1/2}$=0.67[cm] . G=1.7928 is the anomalous magnetic moment of the proton.

BEAM OPTICS OF THE AGS DURING THE ACCELERATION OF PROTONS

The "MAD" computer code [6] was the code used to design the beam optics of the AGS which includes the two helices and the compensation quadrupoles. The optical properties of the Warm and Cold helices are provided in the description of the AGS model in the form of 6x6 R-matrices. These R-matrices had been previously calculated as a function of the proton momentum, by raytracing charged particles in the 3D magnetic field maps of the helices as calculated by the OPERA computer code [7]. During the beam acceleration, the beam rigidity increases therefore the optical effect of the partial helices on the beam optics is reduced. This in turn reduces the strength of the compensation quadrupoles which are exclusively used to correct for the effect of the helices on the beam optics of the AGS. When the beam momentum reaches the value which corresponds to the value of γ≈6.0, the strength of all compensation quads is zero and the R-matrices of the helices are almost identical to the matrices of drift space. Fig. 2 shows the beta ($\beta_{x,y}$) and, dispersion ($\eta_{x,y}$) functions along the AGS at injection energy, when both helices and the compensation quadrupoles are on. During beam injection we excite two beam bumps; the "L20 Bump", which is part of the injection system of the AGS, and the "Cold helix A20 Bump" which displaces the beam transversely inside the cold helix to counterbalance the displacement of the beam caused by the helix, and prevents the beam from hitting the beam pipe of the helical magnet. Figure 3 shows the beam displacement of the central orbit at injection when both the L20 and A20 beam bumps are excited. The magnetic elements which generate these beam bumps are included in the AGS model which is used as input for the MAD computer code. Details on how these beam bumps are generated can be found in ref [5]. The "L20 Bump" is reduced to zero just after injection, and the "Cold helix A20 Bump" remains excited, but its strength is diminishing gradually to zero when the energy of the beam reaches a value corresponding to γ≈6.0. Figures 4 and 5 show the maximum values of the β functions (top graph) along the AGS ring , and also of the horizontal and vertical tunes (bottom graph) respectively as a function of Gγ.

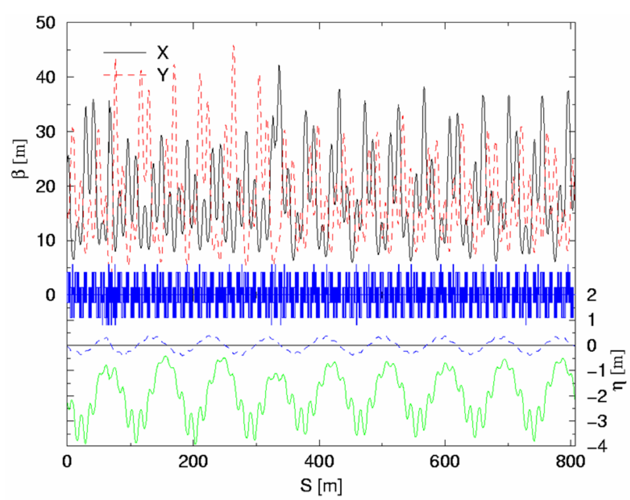

Figure 2. The beta ($\beta_{x,y}$) functions, and the dispersion functions ($\eta_{x,y}$) at injection energy (Gγ=4.5) plotted along the AGS. The vertical dispersion function (blue dashed line) is due to the coupling of the partial helices.

In Figures 4 and 5, the red line corresponds to the AGS optics when we constrain the Q_y tunes to have the value of 8.985 for values of Gγ>7.5, and the black line corresponds to the AGS optics when we constrain the Q_y tunes to have the value of 8.980 for values of $G\gamma>7.5$. Although the linear coupling introduced by the helices requires to run the mad8b version of the MAD computer code in the "coupled mode", it appears that the coupling is very weak, and for all practical purposes the results of running the code in the "coupled mode" are almost identical to those when we run the code in the "uncoupled mode". We have chosen the uncoupled mode because it alows us to use the optimization feature of the mad8b code which is available in the uncoupled mode only.

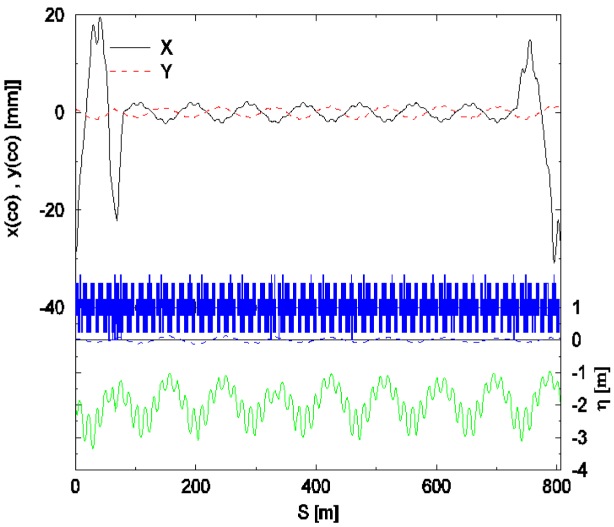

Figure 3. The Horizontal (X_{cod} lack solid line), and the vertical (Y_{cod} red dashed line) closed orbit displacements, at beam injection in AGS. The X_{cod} , is generated by the excitation of the "L20 Bump", and the "Cold helix A20 Bump" (see text). The linear coupling introduced by the helices generates the nonzero value of the Y_{cod} .

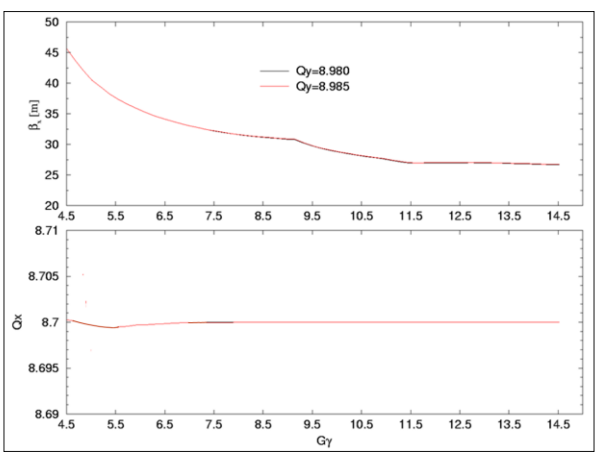

Figure 4. The beta function (β_x) (top), and the horizontal tune Q_x (bottomm) as a function of $G\gamma$.

SETTINGS OF THE COMPENSATION AND TUNE QUADS

Part of the optics design was to establish the required settings of the tune quads and compensation quads of the AGS, to allow for the placement of the fractional part of the vertical betatron tune Q_y in the "spin tune gap" generated by the helices. This constrain on the vertical betatron tune, prevents the relation $\nu_{sp}=nP\pm Q_y$ which specifies the condition of the intrinsic spin resonance, of being satisfied, therefore the vertical intrinsic resonances are eliminated. Information on the settings of the tune quadrupoles and compensation quadrupoles which help for the condition $\nu_{sp}=nP\pm Q_y$ not to be satisfied during the acceleration cycle, can be found in ref.[5]

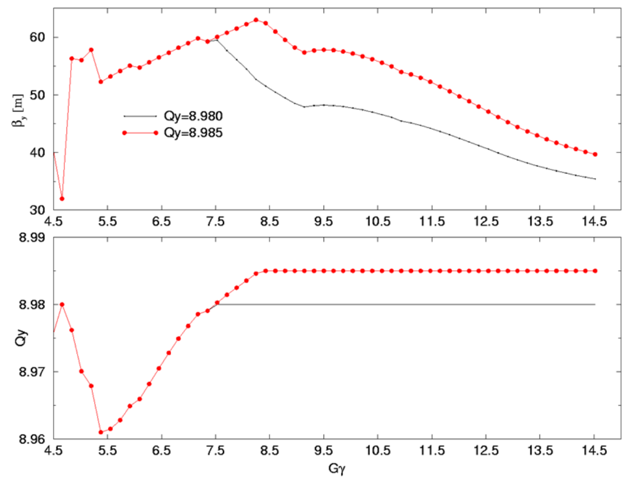

Figure 5. The beta function (β_y) (top), and the vertical tune Q_y (bottom) as a function of $G\gamma$. The red line corresponds to the AGS optics where we constrain the Q_y tunes to have the value of 8.985 for values of $G\gamma>7.5$, and the black line corresponds to the AGS optics where we constrain the Q_y tunes to have the value of 8.980 for values of $G\gamma>7.5$.

CONCLUSIONS

The introduction of compensation quadrupoles at the specified straight sections of the AGS and the introduction of the "A20" beam bump at the location of the A20 partial helical magnet, minimize the adverse effect of the partial helices on the optics of the AGS. As a result it is possible to accelerate polarized protons in the AGS with no beam loss and with minimal loss of polarization.

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