

NEW TUNE JUMPS SCHEME IN THE LOW ENERGY PART OF THE AGS CYCLE*

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Abstract

During the early part of the acceleration of polarized protons, due to strong optical deformations of the lattice, the tune cannot be placed in the spin gap and the first two vertical intrinsic resonances are crossed. Recent multiparticle trackings using the Zgoubi code show that the spin resonances around $G\gamma = 5$ could cause as much as 5% loss of polarization.

The slow acceleration rate, the two vertical and two horizontal intrinsic spin resonances can contribute to the depolarization in the region. While in the current scheme only the two horizontal intrinsic resonances are jumped, it was proposed to use the tune jump system to also accelerate the crossing of the two weak vertical intrinsic resonances and improve the polarization transmission through this region.

We will show the design of this new tune jumps scheme and the expected polarization gains expected from multiparticle Zgoubi simulations. We also compare experimental measurements of the polarization transmission to the Zgoubi simulations.

INTRODUCTION

In a synchrotron with vertical bending field the spin tune is given by $Q_s = G\gamma$ with G the anomalous g -factor of the proton and γ the Lorentz factor. However to overcome spin resonances the AGS uses a dual partial Siberian snakes configuration that modifies the relation between the spin tune and the energy. Figure 1 shows the evolution of the spin

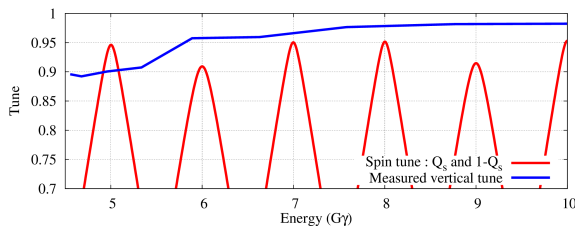


Figure 1: Fractional part of the vertical tune and spin tune at low energy in the AGS, for polarized proton acceleration.

tune in the AGS with the dual snakes configuration. A small forbidden band is opened in which the vertical tune is placed to overcome vertical intrinsic resonances. However, due to strong optics deformation caused by the Siberian snakes at low energy it is not possible to move the vertical tune high enough and the first two vertical intrinsic resonances are not avoided. The crossing of the vertical intrinsic resonances

can be seen in Figure 1, when the vertical tune crosses the spin tune.

While allowing to overcome the vertical spin resonances, the AGS dual snakes configuration also creates a new sort of depolarizing spin resonances called horizontal intrinsic spin resonances [1]. The AGS tune jump system was developed to mitigate the polarization losses through horizontal intrinsic resonances [2]. The AGS tune jump system and the horizontal intrinsic resonances are treated in two companion papers [3, 4].

Although the tune jump system was designed for fast change of the horizontal tune, it also moves the vertical tune by $\Delta Q_y = -0.02$ within $100 \mu\text{s}$. It was proposed to use the vertical tune shift induced by the AGS tune jump system to accelerate the crossing of the two vertical intrinsic resonances around $G\gamma = 5$. Although each tune jump changes the tune in both planes we define the vertical tune jump as the tune jump used to accelerate the crossing of vertical intrinsic resonance. We will present the new scheme and the hardware limitations of the system for this application. Then the gain in polarization will be estimated using multiparticle trackings with the Zgoubi code and compared to experimental data.

TUNE JUMP SCHEME SIMULATION

Figure 2 shows the proposed vertical tune jumps at $G\gamma = 4.9$ and $G\gamma = 5.1$. The first constraint of this scheme is the distance between the vertical and horizontal tunes. Since the tune jump power supplies need around 3 ms between two consecutive tune jumps the case showed in dashed lines was technically impossible. Lowering the horizontal tune allowed to increase the time between the vertical and horizontal tune jumps, as seen in Figure 2. In the final scheme, corresponding to the plain lines in Figure 2, the minimum time between two consecutive jumps is 2.8 ms. This is very close to the usual charging time and can be achieved by the current tune jump system hardware.

Zgoubi Trackings

The tracking code Zgoubi [5] and the Zgoubi AGS online model [6] were used to simulate the effect, and expected polarization gain, of the vertical tune jump scheme. The lattice was setup using measured currents in the magnets and the tunes were maintained fixed at $Q_x = 8.78$ and $Q_y = 8.92$ below $G\gamma = 5.8$ then follow measured tunes above. Realistic longitudinal dynamics was simulated using measured acceleration rate and total RF voltage.

The simulations consist of the tracking of 1000 particles picked in a 6D Gaussian distribution leading to transverse

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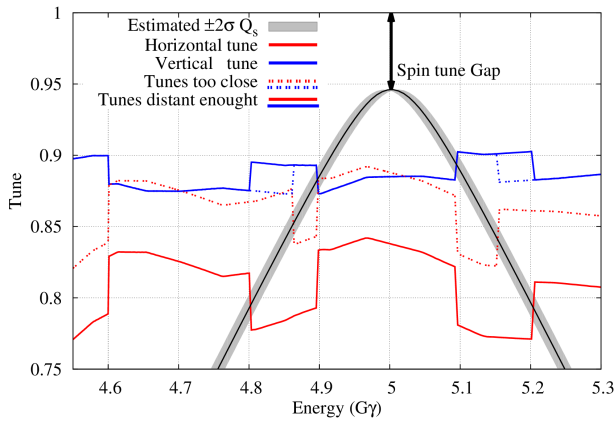


Figure 2: Representation of the proposed tune jump scheme around $G\gamma = 5$ with realistic tunes and energy spread were used.

normalized 95% emittances of 4π .mm.mrad and longitudinal emittance of 1 eV.s. The initial spin vectors were aligned with the stable spin direction, resulting in an initial polarization of 100%. Therefore the vertical polarization profile is flat at $G\gamma = 4.5$, as measured in the machine. Figure 3

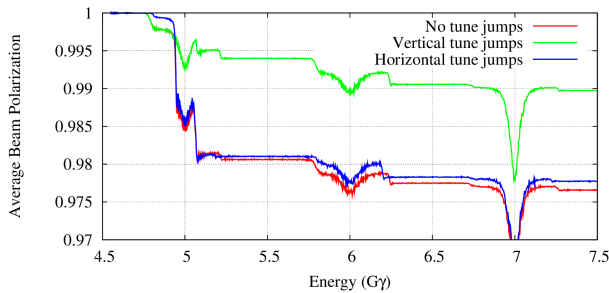


Figure 3: Average polarization over the whole beam as a function of the energy for different tune jump settings simulated using the Zgoubi code.

shows the evolution of the average polarization predicted by the Zgoubi code. The tracking clearly shows that the polarization losses are dominated by vertical intrinsic resonances, located around $G\gamma = 4.9$ and $G\gamma = 5.1$. The horizontal intrinsic resonances cause minor polarization drops at $G\gamma = 4.8$ and $G\gamma = 5.2$ as well as around $G\gamma = 6$ and $G\gamma = 7$.

This is confirmed by the simulations with the tune jumps. While the effect of the horizontal tune jumps is negligible, we can see that the vertical tune jumps greatly reduce the polarization losses around $G\gamma = 5$. The simulations show an increase in the overall polarization transmission from the vertical tune jumps from 97.6% to 99% between $G\gamma = 4.5$ and $G\gamma = 7.5$. Assuming a final polarization of 70% at $G\gamma = 45.5$ the effect of the vertical tune jump would be an increase of 1% average beam polarization, which cannot be measured without excessively long measurements due to the statistical uncertainty inherent to the polarization measurements in the AGS.

In order to take advantage of the larger analyzing power at low energy of the AGS CNI¹ polarimeter it was proposed to measure the effect of vertical tune jumps before the AGS extraction energy of $G\gamma = 45.5$. Measurements of the polarization were done at $G\gamma = 7.5$, simulations are also stopped and analyzed at $G\gamma = 7.5$.

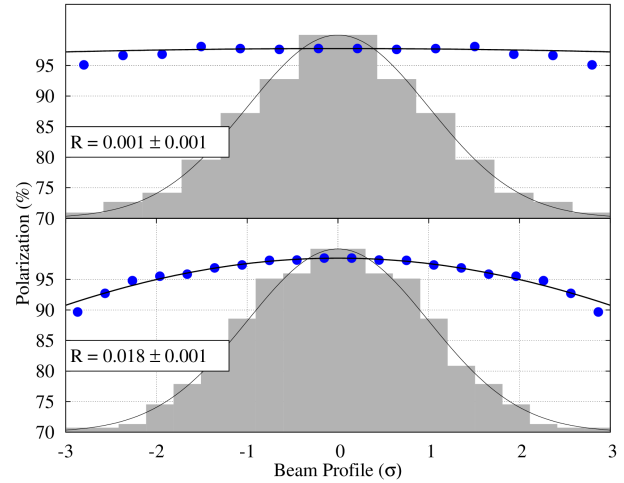


Figure 4: Polarization profile obtained from the Zgoubi tracking at $G\gamma = 7.5$ for the horizontal (top plot) and vertical planes (bottom plot). The grey histogram represents the transverse beam profile while the average polarization of the particles in each bin can be seen in blue. The two black curves show the Gaussian fits of the data points and the R value is computed from the ratio of the standard deviation of the two fits.

Figure 4 shows the polarization profiles predicted by the Zgoubi code at $G\gamma = 7.5$ and without tune jumps. The R value characterizes the polarization profile and increases when polarization is lost through intrinsic polarization resonance. The polarization profile in the vertical plane dominates, which is an other proof that most of the polarization losses occurred through vertical intrinsic resonances.

Following promising results predicted by the Zgoubi simulations, measurements in the AGS were conducted.

EXPERIMENTAL RESULTS

The experimental conditions were very close to the simulations. Even though the machine tunes were slightly different from the ones used in simulations, no major impact on the results is expected. Dedicated tune jump functions were generated with only vertical tune jumps and timed as much as possible to accelerate the crossing of the vertical intrinsic resonances, although the timing of the tune jump is experimentally very hard. Polarization profiles were then measured at $G\gamma = 7.5$ with and without vertical tune jumps.

Polarization measurement at $G\gamma = 7.5$ only gives relative numbers since the analyzing power of the polarimeter is only known at $G\gamma = 45.5$. Therefore comparing simulated

¹ Coulomb-Nuclear Interference

and measured polarization profiles through the R allow to directly compare measurements to simulations using the Zgoubi code. Figure 5 shows the result of a polarization

reach a small enough uncertainty on the measured R value. Each measurement in Table 1 typically takes 2 to 3 hours.

CONCLUSION

The Zgoubi code accurately predicts the vertical polarization profile at low energy. The losses through the first 2 vertical intrinsic resonances were estimated to be large enough for a measurement, and successfully measured.

A new tune jump scheme was designed and tested, again using the Zgoubi code. Hardware limitations were taken into account and the simulated tune jump scheme was easily tested in the machine. Measurement of the vertical profile with vertical tune jumps indicates a polarization gain, in agreement with the Zgoubi code even with the large uncertainties on the measured R values. The polarization gain remains to be balanced with the difficult setup for a possible use of the vertical tune jump for operation, for the AGS pp Run 15.

The method applied here could be extended for many energy between $G\gamma = 7.5$ and $G\gamma = 45.5$ in order to track the evolution of the polarization profiles along the AGS cycle. Possibly allowing to fully explain the measured polarization profiles at $G\gamma = 45.5$.

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Figure 5: Measured vertical polarization profile at $G\gamma = 7.5$ with vertical tune jumps.

profile measurement. The relevant parameter is the R value and can directly be compared to the Zgoubi Simulations.

Table 1: Summary of the Measured and Simulated R Values of the Polarization Profiles

Conditions	Horizontal	Vertical
Zgoubi simulations		
No tune jumps	0.001 ± 0.001	0.018 ± 0.001
Vertical tune jump	0.007 ± 0.001	0.003 ± 0.001
Horizontal tune jumps	0.003 ± 0.001	0.014 ± 0.001
Measured data		
No tune jumps	not measured	0.017 ± 0.005
Vertical tune jump	not measured	0.010 ± 0.005
Horizontal tune jumps	not measured	not measured

Table 1 summarizes the R values determined from the polarization profiles, measured and simulated using the Zgoubi code. The agreement between simulated and measured polarization profiles is very good in the absence of tune jump. Also the larger horizontal profile predicted by the trackings with the vertical tune jump is not yet understood. Similarly the effect of the horizontal tune jumps on the R values are yet to be explained. Further studies with simpler models should help in understanding these effects.

Time constraints limited the quantity of measurements taken, mainly due to the large amount of time required to