

Resonance Jumping for Polarized Protons

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ABSTRACT

Tune jump through the spin resonance for the polarized proton is studied by solving the system of the linear equation. We found that the speculative side-peaking of the tune-jump curve does not exist. The oscillatory structure obtained via the spin transfer matrix has also disappeared.

1.) Introduction

Tune jump through the intrinsic depolarization resonances is unavoidable for the polarized proton operation in the lower energy region ($E \approx 10 - 20$ GEV). There has been many experimental results (ref.1) in the past few years from the AGS polarized proton operations. Theoretical calculations (ref.2) based on the spin transfer matrix method (ref.3) has been used to obtain the polarization vs. the tune-jump time. Fig. 1 taken from refs.2 and 3 shows reasonable agreement between the experiment and theory. It was noted that the side-peaking in the experimental result can not be understood from the calculation, besides the theoretical calculation shows oscillatory behavior not observed in the experiment. These oscillatory structure may arise from the difficulty in the calculation of the confluent hypergeometric function in that specific region (using the asymptotic series) (refs.2 and 4).

More recent experimental results (Fig. 2) of 1985-1986 AGS experiment however do not exhibit the side peaking. It was argued (ref.5) that the side-peaking may result from an inappropriately tuned power supply for the fast tuning quadrupoles.

In this short note, we shall report the result of the calculation on the spin tune jump through an intrinsic depolarization resonance via the differential equation solver (DEABM). Section 2 briefly reviews the problem and section 3 discusses the result of our calculation.

2.) Polarization with tune-shift model

A tune shift is obtained by firing a special set of quadrupoles, which shift the tune of the machine upward or downward suddenly and then decay linearly to the nominal tune value within a characteristic time t . This tune shift can be represented by a simple model for resonance tune shift as

$$\Delta(k\nu \pm \nu) = \begin{cases} \mp \Delta\nu + \alpha_\nu (\theta - \theta_1) & \theta_1 \leq \theta \leq \theta_2 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where $\alpha_\nu = \Delta\nu / (\theta_2 - \theta_1) = \Delta\nu / \omega \Delta t$ corresponds to decay slope of the jumping quadrupoles. At $\theta = \theta_1$, the quadrupoles were fired. At $\theta = \theta_2$, the tune of the machine is back to its nominal value.

Let us assume further that the particle is accelerated uniformly with

$$G\gamma(\theta) = (G\gamma)_{\text{resonance}} + \alpha\theta \quad (2)$$

where α is the acceleration rate. For AGS, $\alpha = 4.86e(-5)$ with θ measured in radian, which corresponds to 160 KeV energy gain per revolution. The parameters for the tune jump is given as follows:

$$\begin{aligned} \Delta\nu &= 0.2 \\ \Delta t &= 2.5 \text{ ms} \end{aligned} \quad (3)$$

In the present study, we shall use the resonance strength of $G\gamma = \nu$ resonance, i.e.

$$\epsilon = -.007862 - i 0.00004$$

calculated from DEPOL(ref.6) with normalized emittance $\epsilon_N = 8.03$ pi-mm-mrad. The polarization of the proton can be calculated from the system of the linear equations:

$$\begin{aligned} \frac{ds_1}{d\theta} &= -G\gamma(\theta) s_2 + [\text{Im } \zeta(\theta)] s_3 \\ \frac{ds_2}{d\theta} &= +G\gamma(\theta) s_1 + [\text{Re } \zeta(\theta)] s_3 \\ \frac{ds_3}{d\theta} &= -[\text{Im } \zeta(\theta)] s_1 - [\text{Re } \zeta(\theta)] s_2 \end{aligned} \quad (4)$$

with the depolarization resonance function expanded into a Fourier series(ref. 6).

$$\begin{aligned} \zeta(\theta) &= -(1+G\gamma) (\rho z'' + i z') + i\rho(1+G)\left(\frac{z}{\rho}\right)' \\ &= \sum_{\ell} \epsilon_{\ell} e^{-iK_{\ell}(\theta)} \end{aligned} \quad (5)$$

We shall study the tune jump of a single resonance, i.e. only one term in eq. (5) will be important. When the accelerator is operating at a constant tune, the dominant resonance frequency are

$$K_{\ell}(\theta) = (k\rho \pm \nu)\theta$$

which is a linear function of θ . When the tune of the accelerator is shifted according to that of eq.(1), the resonance frequency becomes

$$\begin{aligned} \frac{dK_q}{d\theta} &= \nu - \Delta\nu + \alpha_\nu (\theta - \theta_1) \\ &= \nu + \alpha_\nu (\theta - \theta_2) \end{aligned} \quad (6)$$

Thus

$$K_q = \nu\theta + \frac{1}{2} \alpha_\nu (\theta - \theta_2)^2 + \text{constant} \quad (7)$$

The constant of integration in eq.(7) is indeed irrelevant to the final result of the polarization (Similarly, either form of eq.(6) can be used).

The system of the differential equation (4) can then be solved easily by the differential equation solvers. We shall use the double precession version of the program DEABM with Adams methods(ref.7).

3.) Result and Discussion.

Fig.3 shows the polarization as a function of the tune jump time(THETA1). Note here that the second peak does not appear at all. There are three distinct times 0 , θ_a , and θ_b , which characterize the spin tune jump (ref.1).

$$|\theta_a| = \Delta\nu / \alpha \quad (8)$$

$$|\theta_a - \theta_b| = \Delta\nu \left(\frac{1}{\alpha_\nu} - \frac{1}{\alpha} \right)$$

Region I corresponds to successful spin tune jump, where the quadrupole firing time is $\theta_a \leq \theta_1 \leq 0$ (see also fig.1). Region II corresponds to $\theta_b \leq \theta_1 \leq \theta_a$, where the effective acceleration rate is $\alpha - \alpha_\nu$. Smaller acceleration is the main reason of larger spin flip in this region. The width of this region depends on $\alpha - \alpha_\nu$. However, the polarization can not flip fully through an intrinsic spin depolarization resonance due to different betatron amplitudes of the beam particles. Note that Fig.2 for $24 + \nu$ and $48 - \nu$ shows similar larger depolarization region.

One interesting result from the present calculation is that neither the oscillatory region nor side-peaking are observed in the calculation. We thus conclude that the oscillatory behavior obtained from ref. 1 is spurious.

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Figure Captions:

- Fig.1 Taken from ref.2. The experimental polarization(upper) and the theoretical result using the transfer matrix method (lower part) are shown as a function of the quadrupole firing time (θ_1) in radian as the angle of the particles around the accelerator. $\theta_1=0$ is chosen to be the resonance position.
- Fig.2 Obtained from ref.1. The AGS operation data. These data does not represent the best run. They are used for the calibration for the AGS polarized proton operation. Note that a stronger resonance strength is apparent in region II for the resonance at $24 + \nu$ and $48 - \nu$.
- Fig.3 The polarization is plotted as the function of the fast quadrupole firing time (THETA1), where $\theta_1 = 0$ is chosen to be the resonance position as that of Fig.1. The polarization is obtained through solving the system of linear differential equation. In comparison with that of Fig.1, we can conclude that the oscillatory structure and the side-peaking are spurious.

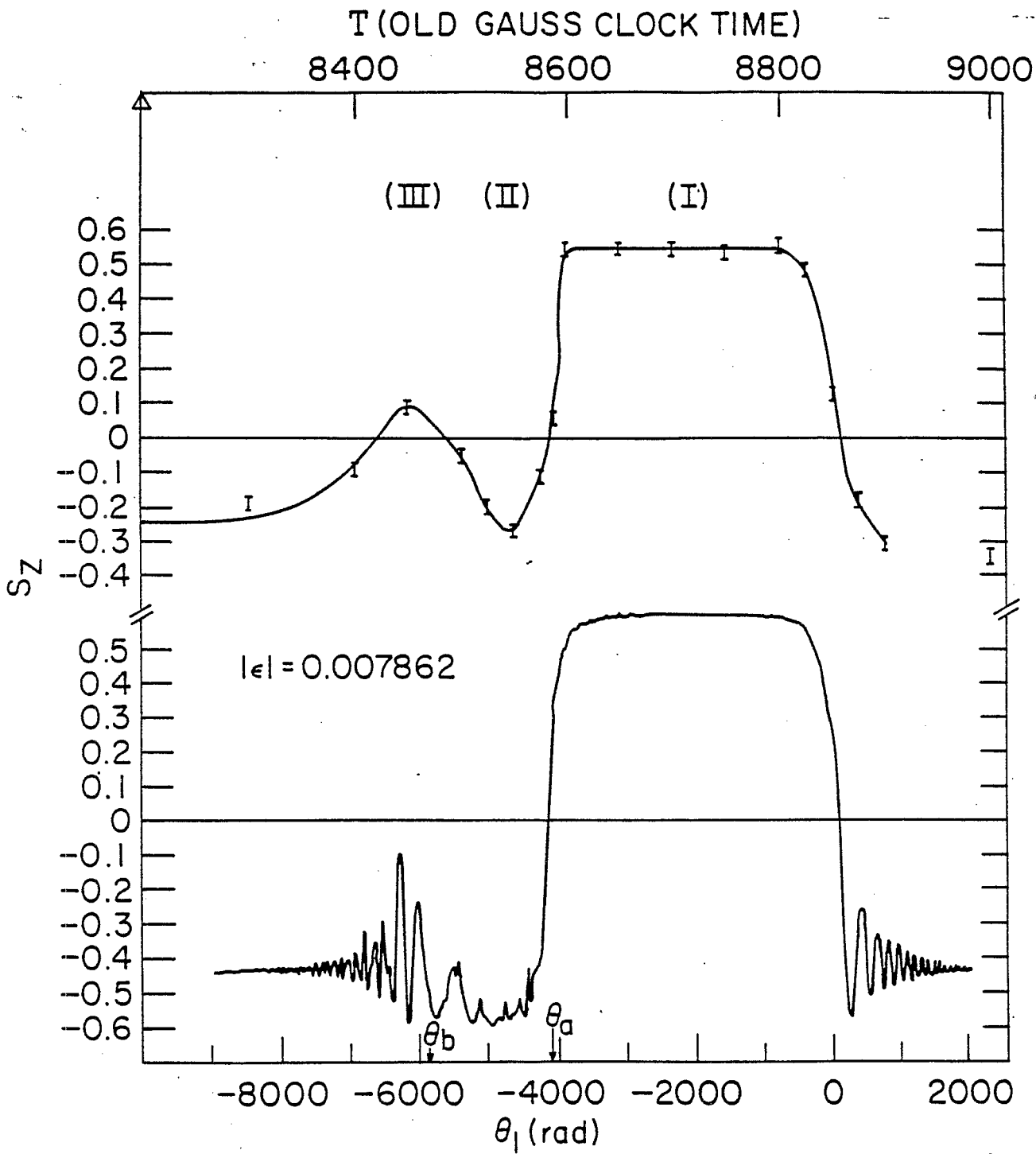


Fig. 1

21 Dec 1985
ST KRB 17
RDK

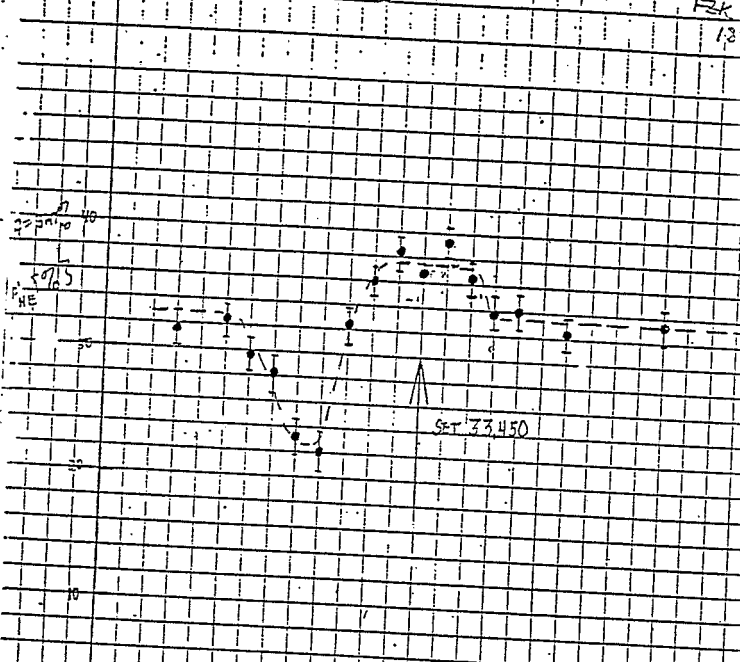
68 = 0 +)

QHV1 480/465
QHV2 310/280



24 +)

2 Feb 86



W.A. LAAR JR

(ry = 48 - 2)

(4)

Polarization

point used in cal.

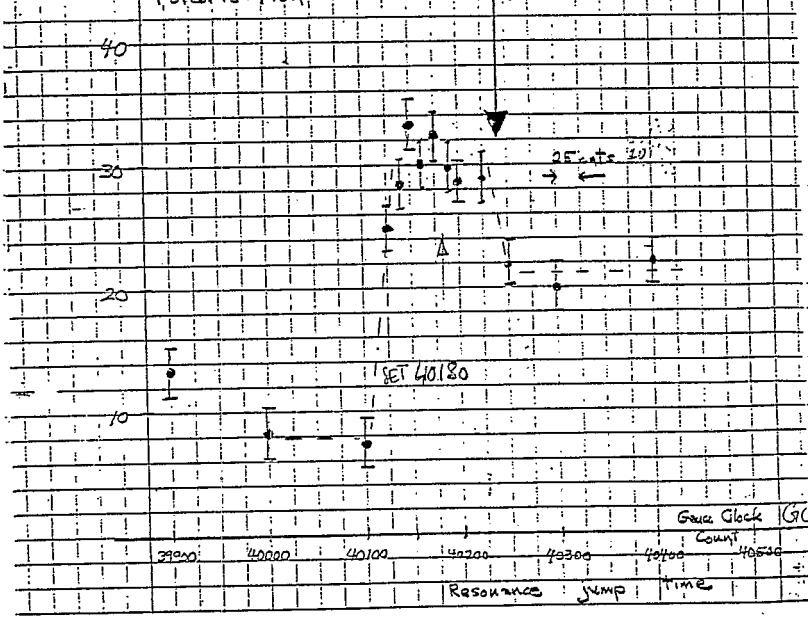
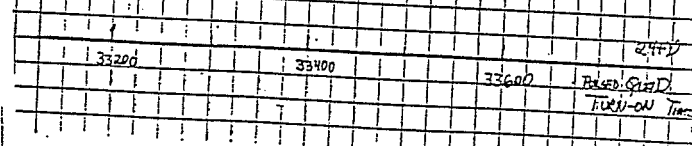


Fig. 2



POLARIZATION vs TUNE JUMP TIME

$d\nu = .2$ $dt = 2.5\text{ms}$ $\alpha = 4.86e-5$

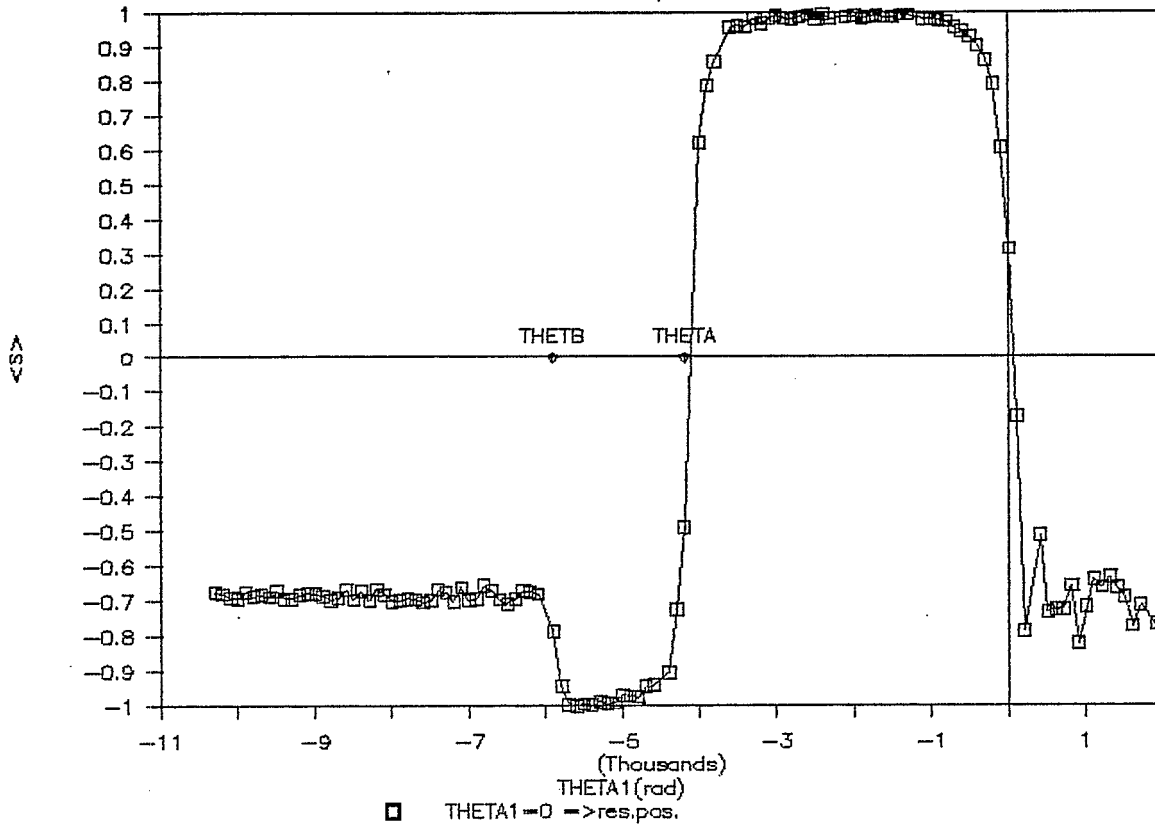


Fig. 3