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TUNE SPACE MANIPULATIONS IN JUMPING DEPOLARIZING RESONANCES*

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Abstract

In February, 1986, the AGS polarized beam reached a momentum of 22 GeV/c with a 45% polarization and an intensity of 1-2 x 10^{10} polarized protons per pulse at a repetition rate of 2.1 seconds. In order to achieve this, one had to overcome the effect of some 40 depolarizing resonances. In our first commissioning run[1] in 1984, we had reached 16.5 GeV/c using, with suitable modifications, the conventional techniques first used at the Argonne ZGS.[2,3] This worked well, but we found that the fast tune shifts required to cross the intrinsic depolarizing resonances were causing an increase in beam emittance which led to the need for stronger corrections later in the cycle and to diminished extraction efficiency.

For the 1986 run, we were prepared to minimize this emittance growth by the application of slow quadrupole pulses to change the region in tune space in which we operated the fast tune quads. In this paper we give a brief description of the conventional corrections, but our main emphasis is on the descriptions of tune space manipulations.

Conventional Corrections

The horizontal fields due to the normal focusing in the accelerator cause the "intrinsic resonance" depolarization. This condition is characterized by $G\gamma = nP \pm \nu_y$ where G is the proton anomolous magnetic moment, ν_y the vertical betatron tune ($\approx$ 8.75 in the AGS), P the periodicity of the AGS (12), and n an integer. The depolarization produced by this type of resonance can be minimized by a fast shift of the vertical tune from the nominal value and then a slow return to the nominal. Figure 1 shows some typical corrections in tune-energy space for an intrinsic resonance. The resonance line is crossed in less than one turn (~ 2 μsec) and the tune (ν_y) remains a fixed distance from the resonance as the correction pulse decays at a rate comparable to the change of energy during the normal acceleration cycle (1.2 - 2.9 msec depending on the strength of the correction 0.125 - 0.30 tune units).

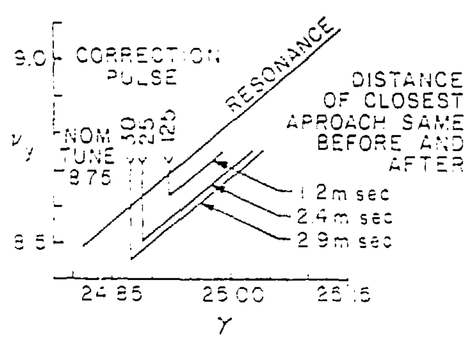

Fig. 1. Typical corrections in tune-energy space.

Five such resonances were crossed in achieving 22 GeV/c. These were $G\gamma = 0 + \nu_y$, $12 + \nu_y$, $36 - \nu_y$, $24 + \nu_y$, and $48 - \nu_y$. Figure 2 shows a typical correction. Surviving polarization measured at an energy above the resonance energy is plotted against jump timing.

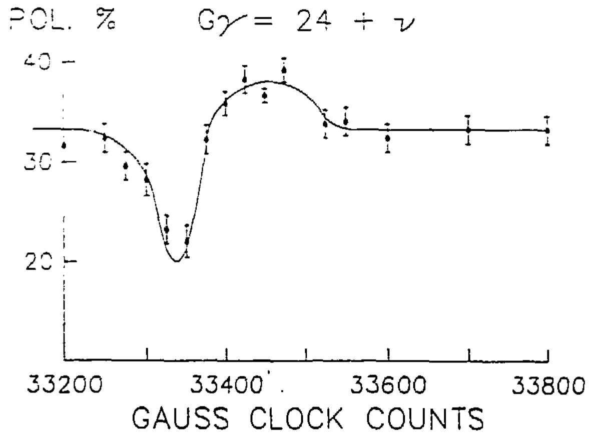

Fig. 2. Typical intrinsic resonance correction.

The fast quads were set with a reasonable tune shift $\Delta\nu \approx 0.15$ and the turn-on time of the quadrupole was varied over a range starting before the resonance and ending after the resonance. The turn-on time is given in Gauss clock counts (a clock generated by the ramping magnetic field) which is proportional to the momentum of the beam. As we see in Figure 2, pulsing before (33200 - 33250) and after (33550 on) has no effect on the final polarization. The perturbation of the resonance occurs between 33250 and 33525. From 33275 - 33375 we see the effect of the slow decay part of the correction pulse enhancing the rsonance and reducing the surviving polarization. As we go later, the fast part of the pulse affects the response and by fast passage through it, eliminates the depolarization (33400 - 33500).

Modified Techniques

One modified technique was used in conjunction with the fast tune shift to jump the intrinsic resonances. For the strongest resonances, we made tune shifts of $\Delta\nu \approx 0.30$ and with the nominal AGS tune of 8.75, we would normally hit integer or half-integer tune resonances at ν = 9.0 and 8.5. In order to avoid this, we used two existing sets of 12 slow quadrupoles each in the AGS ring to change the tune in the oposite direction to the fast pulse. As shown in Figure 3, the slow quad pulse shifts the AGS tune by about 0.1 and we can, for example, then go from 8.85 to 8.55 with a $\Delta\nu$ = 0.3 and not hit any lowest order stopband. This technique, even when applied to smaller tune shifts, reduced the emittance growth that occurred whenever the fast quads were pulsed and their use improved the extraction efficiency as well as the polarization.

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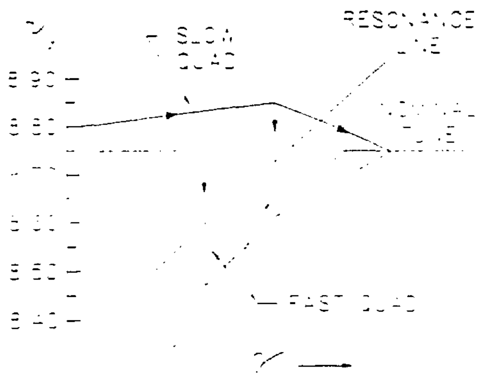

Fig. 3. Slow quad effect.

Although this technique worked, we found some unexpected behavior when we tried to use it on the $G\gamma = 0 + \nu$ resonance. Here instead of moving the tune away from a stopband, we found that the best strategy was to move the tune toward $\nu = 8.5$. This minimized the emittance growth, but we have no explanation of why this is so. Figure 4a shows how different this behavior is compared to the normal behavior as shown in Figure 4b, where the slow tune shift increased the subsequent allowed fast tune shift.

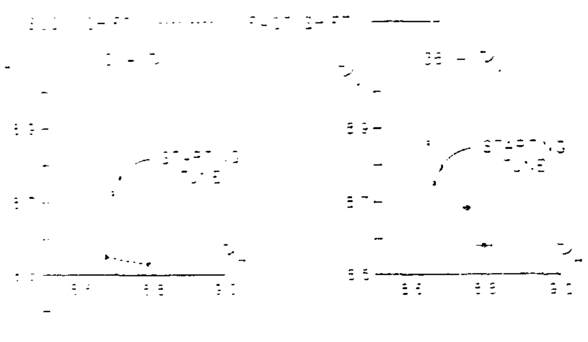

Fig. 4a,b. Motion in tune space at intrinsic resonances.

A mapping of usable tune space (Figure 5), as well as studies of what happens when we drive through the stopbands is part of our continuing study to try to understand this phenomena.

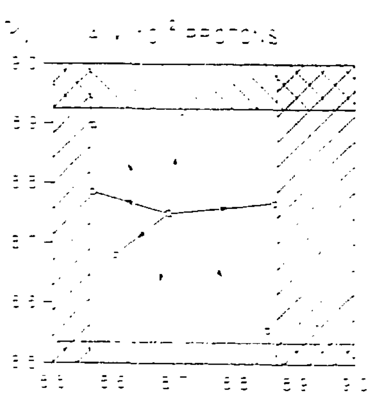

Fig. 5. Available tune space at 14 GeV/c

Emittance Growth

During the polarized proton run and in several studies since then, the effect of the tune space maneuvers on transverse emittance growth has been studied. The rapid fast quadrupole pulses which allow passage through the intrinsic depolarizing resonances inherently cause such growth by (1) causing a non-adiabatic shift in the betatron function around the machine and (2) producing dipole kicks and a shifted equilibrium orbit. The second effect is proportional to the offsets between the quad centers and the equilibrium orbit. The magnitude of the observed growth is large, with the sum of the normalized emittances seen to increase from 20 mm-mrad to 130 mm-mrad over the acceleration cycle during the polarized proton run. The vertical emittance, in particular, grew from 8 to nearly 80 mm mrad. These emittances are measured using the AGS IPM (ionization profile monitor).[4] Subsequent studies with unpolarized beam reproduced this effect (Figure 6) and, in addition, forced the realization that the distribution of this growth between the two transverse planes depends in detail on the trajectories followed in tune space. In an attempt to isolate the cause of the growth, the resonance tune jumps were produced by powering fewer quads harder—which should enhance the betatron function distortion. This had little effect on the growth. The other possible cause studied has been the quad-orbit alignment.

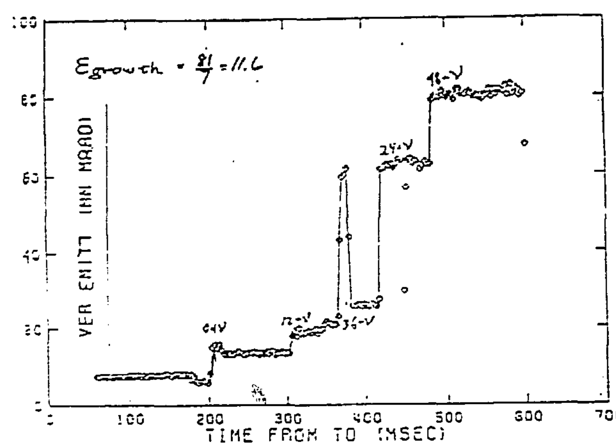

Fig. 6. Emittance growth with slow quad pulses on (except 48 − ν) at $Q = 1.5 \times 10^{11}$.

The degree of misalignment was measured using a normal intensity beam by pulsing quads individually and measuring the resulting distoration in the equilibrium orbit. The quadrupoles were then physically shifted transversely to reduce the relative offsets. Moves were typically of order 2-4 mm in both planes. Growth studies consequent to this work have showed a reduced emittance growth, increasing typically from 20 to 80 mm-mrad over the acceleration cycle with the vertical part as small as 8 to 26 mm-mrad, depending on the slow quad tuning. These results are still being studied and more questions remain unanswered, but one tentative conclusion is that for optimal polarized proton acceleration the quads need to be well aligned on the equilibrium orbit. This constraint must coexist with the requirement that the ring be vertically well aligned to minimize the strengths of the imperfection resonances.

Acknowledgments

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