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CORRECTION OF THE DEPOLARIZING RESONANCES AT THE KEK 12 GeV PS

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ABSTRACT

Acceleration of the polarized proton beam at the KEK PS up to 5.0 GeV is described. In the booster synchrotron, 75% of the linac beam polarization was preserved without any correction, and 90% of the linac beam polarization was preserved by the fast passage method for higher order resonances.

In the main ring, almost 100% of the booster beam polarization was preserved at 3.5 GeV, and 50% of the booster beam polarization was preserved at 5.0 GeV by the fast passage method for the intrinsic resonances and by the closed orbit correction of the imperfection resonances.

INTRODUCTION

The polarized proton acceleration project at the KEK 12 GeV PS was started in 1981. In October 1983, the first acceleration test of the polarized proton beam in the booster was done and the beam polarization extracted from the booster was about 15%.[1] After this acceleration test, the KEK 12 GeV PS experienced a long shut down for 14 months from April 1984 to May 1985 due to construction of the TRISTAN tunnel. During the long shut down, several improvements in the accelerating rf system of the booster were done to achieve stable acceleration for the low intensity beam. Highly sensitive beam position and beam to rf phase monitors were developed. By these improvements, about 75% of the linac beam polarization was preserved in the booster on July 1985. After the linac energy was upgraded from 20 MeV to 40 MeV in the summer shut down of 1985,[2] a half year was spent to tune acceleration of the beam. From Spring 1986, study for acceleration of the polarized beam in the main ring was started. After several studies were done,[3] by December 1986 approximately 45% polarization was recorded in the main ring at 3.5 GeV. From May 1987, the first experiment using polarized proton beam at KEK was started.[4]

DEPOLARIZING RESONANCES IN THE KEK PS

In a strong focusing synchrotron, there are basically two types of depolarizing resonances. One is an intrinsic resonance which is excited by the periodical focusing structure of the machine and the other is an imperfection resonance which is due to the magnet miss-alignment leading to vertical closed orbit distortion (COD). These resonances occur at $\gamma G = n \pm \nu_z$ for the intrinsic resonance, and $\gamma G = n$ for the imperfection resonance, where $G = g/2-1$, n is integer and ν_z is the vertical betatron tune. g is an anomalous magnetic moment.

The polarization after passage through a depolarizing resonance is given by[5]

$$P_f = P_i(2e^{-\frac{\pi\varepsilon^2}{2\alpha}} - 1)$$

where P_i and P_f is the polarization before and after passing through the resonance respectively, ε is the resonance strength, α is crossing speed for the resonance,

$$\alpha = (\dot{\gamma}G \pm \dot{\nu})/\omega \text{ for an intrinsic resonance,}$$

$$\alpha = \dot{\gamma}G/\omega \text{ for an imperfection resonance,}$$

and ω is the angular frequency of the beam. The depolarization is small for $1 \gg \varepsilon^2/\alpha$. On the other hand, the polarization flips for $1 \ll \varepsilon^2/\alpha$.

In the booster there are two strong depolarizing resonances from 40 MeV to 500 MeV. One is the imperfection resonance ($\gamma G = 2$) at 108 MeV and the other is the intrinsic resonance ($\gamma G = \nu_z$) at about 280 MeV. Depolarization is expected to be small in crossing these resonances with an adiabatic spin flip.

Since the KEK booster synchrotron is a combined type strong focusing synchrotron including a strong sextupole magnetic field component to correct the chromaticity, some depolarization occures by the higher order depolarizing resonances. From the result of a calculation by a beam tracking program, about 20% depolarization is expected in passing through the resonance at $\gamma G = \nu_x$ due to the coupling between the horizontal betatron oscillation and the vertical COD. The other depolarizing resonance at $\gamma G = 5 - \nu_z$ due to gradient errors of the machine and coupling between the vertical betatron oscillation and the horizontal COD can cause a few percent depolarization as shown in Fig. 1.

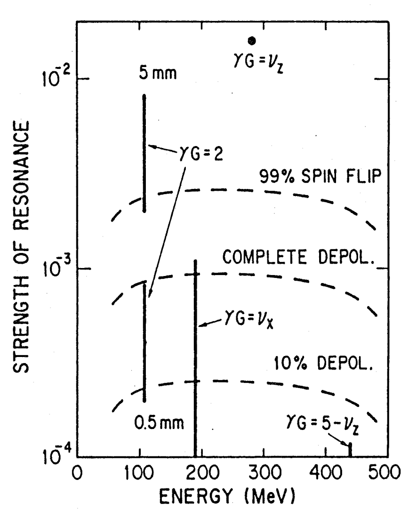

Fig. 1 Resonance Strength in the Booster.

In the main ring, ten intrinsic resonances for $\nu_z = 6.25$ and twenty two imperfection resonances have to be passed through during the acceleration from 500 MeV to 12 GeV as shown in Fig. 2. The intrinsic resonances can be passed by rapidly changing ν_z using four pulsed quadrupole magnets with 40 to 200 μsec rise time. The imperfection resonances can be passed by harmonic correction of the vertical COD using twenty eight correction dipole magnets installed in the main ring.

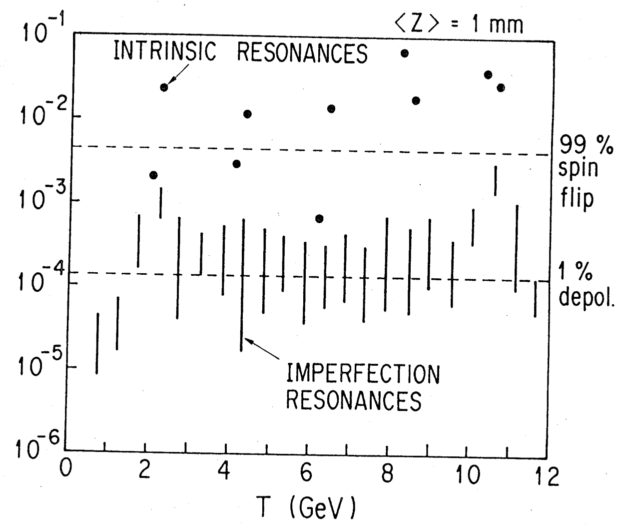

Fig. 2 Resonance Strength in the Main Ring.

EXAMPLE OF THE DEPOLARIZING RESONANCE CORRECTION

Booster

The $\gamma G = 2$ imperfection resonance is caused by the second harmonic component of the vertical COD, which is the main component in the booster since the vertical betatron tune is 2.33.

Two deflector magnets were placed in two straight sections (S2, S5) of the booster to control the second harmonic component of the vertical COD.

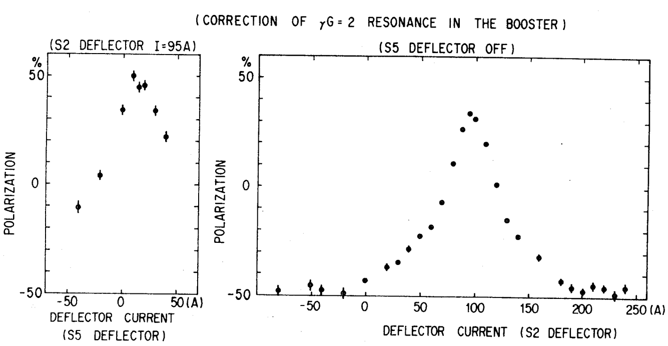

Fig. 3 Harmonic Correction of $\gamma G = 2$ Resonance.

Figure 3 shows the dependence of the polarization on the vertical COD. The abscissa is the excitation current of the vertical deflector magnet which produces the vertical COD. When the deflectors are not energized, the imperfection resonance is strong enough to flip the spin.

On the other hand, there was no depolarization with the deflector current of 95 A and 12 A in S2 and S5, respectively. At the $\gamma G = \nu_z$ intrinsic resonance, measurement of the dependence of the polarization on the vertical beam size showed that the strength of the resonance was strong enough to flip the spin.[1]

For the $\gamma G = 5 - \nu_z$ resonance, any sizable depolarization could not be measured in passing through this resonance although some depolarization was expected from the calculation.

In order to investigate the higher order depolarizing resonance at the $\gamma G = \nu_x$, we tried the fast crossing method by changing the horizontal betatron tune using pulsed quadrupole magnets with 70 µs rise time. The resulting $\gamma G = \nu_x$ timing curves for the pulsed quadrupole magnets shown in Fig. 4 indicate that the polarization increased by 1.2 times at the timing of 10.8 msec. The two peaks are due to the effect of

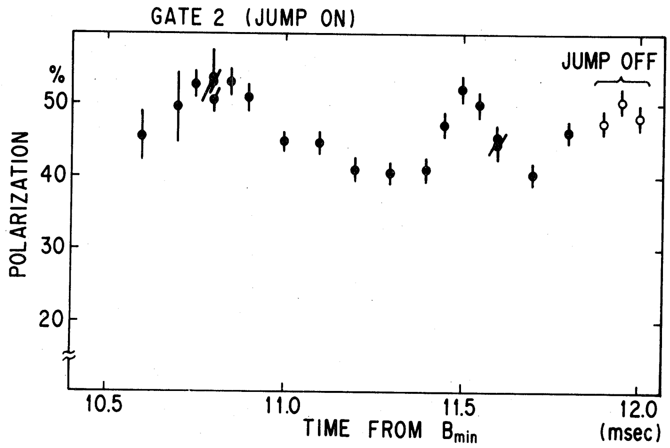

Fig. 4 Tune Jump Correction of $\gamma G = \nu_x$ Resonance.

interference between the neighbouring resonances $\gamma G = \nu_x$ and $\gamma G = 2 - \nu_x + \nu_z$. The latter resonance is normally very weak but is excited by the gradient error due to energizing the pulsed quadrupole magnets. As the result, 90% of the linac beam polarization was obtained at 500 MeV.

Main Ring

Ten intrinsic resonances and twenty two imperfection resonances must be crossed for $\nu_z = 6.25$ during acceleration in the main ring from 500 MeV to 12 GeV. By December 1986 the acceleration test has been successfully performed up to 3.5 GeV.[6][7]

There are two intrinsic resonances and six imperfection resonances in the energy range from 500 MeV to 3.5 GeV. Without any correction for the depolarizing resonances, complete depolarization was observed at 3.5 GeV.

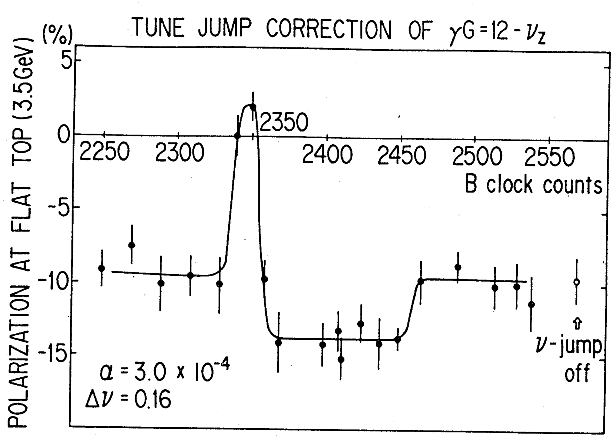

Fig. 5 Tune Jump Correction of $\gamma G = 12 - \nu_z$ Resonance.

Figure 5 shows a correction curve for the intrinsic $\gamma G = 12 - \nu_z$ resonance correction. The abcissa is the number of B-clock counts (a magnetic field generated number, that is one clock per gauss) which is proportional to the momentum of the accelerated beam. We have successfully jumped the resonance at 2430 B-clock and a spin flip ocurred at 2350 B-clock. The second intrinsic resonance at $\gamma G = \nu_z$ was planned to be crossed without any correction because this resonance is strong enough to flip the spin with small depolarization.

Slow passage was tried for this resonance by adjusting the falling tail of the pulsed quadrupole magnetic field to pass the resonance. No increase of the polarization by slow passage as shown in Fig. 6 indicates that a complete spin flip ocurred in passing through this resonance.

The resonance strength of $\gamma G = 12 - \nu_z$ and $\gamma G = \nu_z$

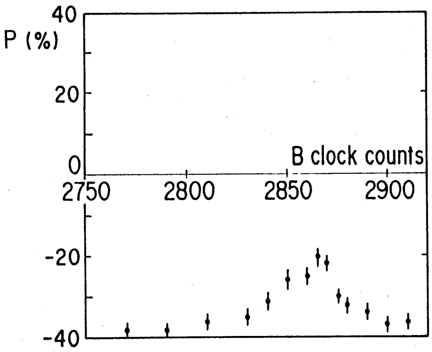

Fig. 6 Slow Passage Correction of $\gamma G = \nu_z$ Resonance.

derived from these results are $1.1 - 1.8 \times 10^{-3}$ and $1 - 2 \times 10^{-2}$ respectively, and these are consistent with the calculated values as shown in Fig. 2.

There are 6 imperfection resonances from 500 MeV to 3.5 GeV at γG = 3,4,5,6,7 and 8. Correction curves for the γG = 6 and 8 resonances are shown in Fig. 7 and 8, respectively.

The polarization at 3.5 GeV is plotted against the phase matched 6th and 8th harmonic correction amplitudes, respectively. The sharp dip at 0.06 A and 0.1 A indicate that the 6th and 8th harmonics of COD were corrected successfully. Complete spin flip occures at the ends of the graph, where COD was excited due to strong over correction. For the imperfection resonance at γG = 7, no depolarization was observed without correction and spin flip occured at 0.4 A of 7th harmonic excitation current as shown in Fig. 9. The investigation for γG = 3,4 and 5 resonances indicate that the strength of these resonances were weak and no depolarization was observed without correction. We obtained almost perfect polarization of the booster beam when each harmonic of COD was over corrected for the γG = 6,7 and 8 resonances. That is, 43.5 ± 1.5% polarization was obtained at 3.5 GeV when the polarization at 500 MeV was 44.2 ± 2.0%.

By July 1987 preliminary results were obtained at 5.0 GeV.[8] From 3.5 GeV to 5.0 GeV, there are two intrinsic resonances and three imperfection resonances. We tried to correct these resonances and obtained preliminary results was about 20% polarization.

In the near future we are planning to accelerate the polarized beam to 7 GeV.

Finally we summarize the averaged beam intensity and polarization.

Intensity	
Linac	(7-10) × 10^8 ppp
Booster	(3-10) × 10^8 ppp
MR injection	(2-7) × 10^8 ppp
Extraction (3.5 GeV)	(3-9) × 10^8 ppp
	(5 bunch acceleration)
Polarization	
500 MeV	(40-50)%
3.5 GeV (circulating beam)	(30-40)%
3.5 GeV (extracted beam)	(30-40)%
5.0 GeV (circulating beam)	(15-20)%

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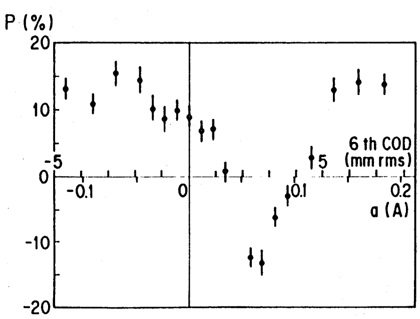

Fig. 7 Harmonic Correction of γG = 6 Resonance.

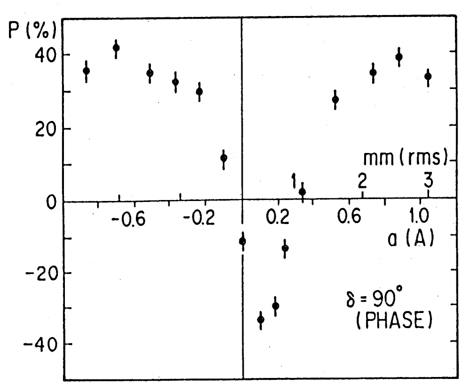

Fig. 8 Harmonic Correction of γG = 8 Resonance.

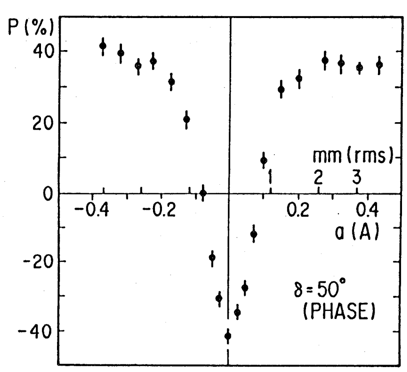

Fig. 9 Harmonic Correction of γG = 7 Resonance.