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POLARIZED BEAMS AT THE ZGS AND THE AGS*

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INTRODUCTION

Before talking about the polarized beams, I would like to add a couple of thoughts that were inspired by the reminiscences of previous speakers. The memories of the MURA days 1950 - 1960 were especially interesting since I was in Berkeley at that time and knew very little about the activities east of the Rockies. Oddly enough, one of my first activities at the Lawrence Radiation Lab in 1950 was working on a Thomas model cyclotron, which was indeed like the FFAG models of MURA. I did not meet Kent during this time, but I did meet him in the sixties after I came to Argonne. Our paths crossed again in 1972 when Kent came to CERN just as I was leaving after spending a year at the ISR. We finally came to know each other after Kent joined Alan's group and we worked again at the ZGS. To me, Kent was the perfect example of the phrase "A Gentleman and a Scholar".

POLARIZED BEAMS

I have had, and still do, a feeling of Deja Vu as I have gone through the development of the polarized beam at the AGS. There were many similarities both scientifically and sociologically, and of course, some significant differences between the AGS and the ZGS. We traded the 12 GeV ZGS for the 28 GeV AGS, we traded Ron Martin for Derek Lowenstein, but having the lowest energy, high energy machine did not change. Paraphrasing some remarks of Bob Sachs, the AGS replaced the ZGS as the tail of the dog, and it appears that now the tail loppers are again on the loose. However, some things never change and that is the standard characters in the Control Room as seen in the first figure. You will probably see them again somewhere in the world using body english to help polarize a beam.

Basically, I would like to describe a little of the progression of events and the hardware in both accelerators that allowed Kent and his colleagues to do a great deal of very interesting spin physics. I will flash a picture of some of the terrain we mapped, (Fig. 2) but leave all the physics for our next speaker.

MASTER

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Figure 1 A Control Room with Alan Krisch and Larry Ratner.

Figure 2 World Data sample of high energy spin-spin measurements (A_{NN}).

The polarized beam grew out of our interest in p - p elastic experiments where it appeared that some not understood effects took place at 90° and we began to think about whether particle identity and spin states could lead to explanations. We were working at the ZGS and performing our ISR experiment at that time, and I recall spending some time at CERN on learning about spin, as well as working on our ISR experiment. Anyway, our interest became aroused in the late 60's which was an opportune time since polarized sources were reaching useful intensities, there were good polarized targets, and we were at an ideal accelerator. In the mid and late 50's, the triple scattering experiments at the University of Chicago led Al Crewe, when he came to Argonne, to consider the possibility of polarizing beams at the ZGS to continue spin experiments. In 1962, D. Cohen¹ came up with the scheme for tune jumping resonances to preserve the polarization. It appeared to us that all the ingredients for accelerating polarized protons were at hand and by 1971 we were getting serious about the project. Let me now quote from the volume "The History of the ZGS"².

"However, the most significant event of 1973 was the successful acceleration of polarized protons to high energy. The ZGS was the world's first high energy accelerator with this capability. The sequence of events began to move rapidly when the polarized source arrived at ANL on May 2, 1973. The pulsed quadrupole system for preserving polarization had already been installed in the ZGS and a polarimeter in EPBI had been set up to measure the beam polarization. On July 11th, polarized protons were accelerated to 3 GeV/c and on July 22nd to 6 GeV/c with 65% polarization. This eleven day period was a hectic and sometimes frustrating time as one searched for the depolarizing resonances. The uncertainty in the knowledge of the tune and magnetic field of the ZGS gave about a 100- to 200-gauss region in which the resonance could exist. Since one had to be within about 10 gauss to find it, a long time was necessary to search this window. The low beam intensity made the operation difficult, since it took a long time to accumulate enough data to get reasonable statistical and systematic errors. One was not sure if the theoretical prediction as to strength and width were correct or if indeed it was even possible to overcome the depolarizing resonances. The real break came when it was found that the depolarization could be enhanced and a sharp dip was found. This finally located the resonance and one was able to adjust the strength and timing of the quadrupoles. Five resonances were corrected and the optimistic design goal of 65% was achieved. One now knew that the theory was correct and that polarized protons could be accelerated to high energies.

The polarized proton project was a whole division effort with many systems coming together and working reliably at the moment of truth. The theory work of T. Khoe and the work of J. Bywater, R. Lari, E. Parker, C. Potts, W. Praeg, N. Sesol, R. Stockly, and R. Timm produced the designs and the hardware that made it possible. The efforts of the University of Michigan group led by A. Krisch and the efforts of R. Martin, E. Parker, and L. Ratner through

eleven days and eleven sleepless nights finally guided the polarized protons through the resonances and into a fruitful era of new results in high energy physics. Even during this brief initial period the experimenters were able to measure the difference in the total cross section between the parallel and anti-parallel alignment of the protons' spin. For the first time, one had information on pure spin cross sections at high energy. Later in the year, physics runs started with 1.6×10^8 polarized protons per pulse being extracted by the resonant method. It was gratifying to find that this extraction process did not depolarize the beam as a priori no one knew whether or not this would happen."

Now, let's look at a large number of figures that show the similarities and the differences in the two accelerators.

First the ZGS, (Fig. 3) with only 2 fast quads (10 - 20 μ sec rise times), no vertical orbit correction magnets, a 50 MeV polarimeter, an external polarimeter, and the Beam 1 absolute polarimeter. Then the AGS, (Fig 4) with RFQ, 200 MeV polarimeter, 12 pulsed quadrupoles, 96 vertical orbit correctors, an internal polarimeter, and the D line absolute polarimeter. The ZGS taught us a lot of things that needed to be implemented in the AGS.

Figure 3 Layout of the Zero Gradient Synchrotron (ZGS).

Figure 4 Layout of the Alternating Gradient Synchrotron (AGS).

Next, schematics of the sources, the $30\ \mu\text{A}$ polarized proton atomic beam source with high field ionizer for the ZGS (Fig. 5) and the $30\ \mu\text{A}$ polarized H^- cesium charge exchange source for the AGS (Fig. 6) with the next figure showing the actual hardware (Fig. 7). Then the large Cockcroft-Walton for the ZGS preaccelerator (Fig. 8) and the 2 meter long RFQ for the AGS (Fig. 9) followed by the very pretty picture of an end view of the RFQ (Fig. 10).

Figure 5 Schematic of the ZGS polarized proton source.

Figure 6 Schematic of the AGS polarized H^- source.

Figure 7 View from the rear of the AGS source.

Figure 8 Cockcroft-Walton Preaccelerator.

Figure 9 RFQ Preaccelerator.

Figure 10 End view of RFQ showing tapered focusing and accelerating structure.

Linacs are linacs, one 50 MeV, one 200 MeV followed by the appropriate polarimeters one at 50 MeV (Fig. 11) with scattering measured at 55° and the 200 MeV, (Fig. 12) somewhat more complicated with polarization measured at both 12° and 16° . It also has counters in the vertical plane to measure transverse polarization. The 200 MeV polarimeter in the flesh (Fig. 13). Well, injection in the ZGS was with P^+ and a septum and H^- with a stripper foil in the AGS.

Figure 11 ZGS 50 MeV Polarimeter schematic.

Figure 12 AGS 200 MeV Polarimeter schematic.

Figure 13 The MeV Polarimeter in HEBT line at the AGS.

With the beam in the machines, we now have the polarization preservation problem to concern us. In the ZGS, when we started, we only were concerned with a few intrinsic resonances and indeed up to 6 GeV/c we saw no unexpected polarization losses. For the AGS, as the next figure (Fig. 14) shows we expected a lot more action, and we got it.

Figure 14 Map of the intrinsic (x) and imperfection (Lines) resonances at the AGS.

The 96 correction dipoles were absolutely necessary to correct the many imperfection resonances. For the intrinsics as we noted earlier, we used 2 quads in the ZGS, a schematic is shown in the next figure (Fig. 15). Rise times of 10 - 20 μ sec. For the AGS we needed 2 μ sec rise times and we needed ceramic vacuum chambers and ferrite quads (Fig. 16). By the way, the ferrite came from the spare ZGS rf cavity and this stock of ferrite is still useful having recently supplied a couple of kicker magnets for our Siberian Snake experiments at IUCF. Well the beam gets accelerated and corrections are made.

Figure 15 Schematic of the ZGS correction quadrupole.

Figure 16 AGS ferrite quadrupole with ceramic vacuum chamber.

Typical ZGS intrinsic resonance crossing is shown in the next two figures. Figure 17 shows the timing of the quadrupole pulse with respect to the resonance line going from pulsing too early, to pulsing to enhance the resonance, to pulsing to correct the resonance, and finally too late to affect the resonance.

Figure 17 Schematic of quadrupole pulse timing effect.

Figure 18 shows a plot of the polarization as a function of pulsing time and shows all the regimes mentioned in the timing figure.

Figure 18 ZGS intrinsic resonance correction.

In the AGS, correction pulses for imperfections and intrinsic resonances in reaching 16.5 GeV/c are shown in the next figure (Fig. 19) as a function of cycle time. Well, the beam is accelerated, gets extracted, and goes down the line to the absolute polarimeters and to the experiments.

Figure 19 AGS corrections for imperfection and intrinsic resonances as a function of machine energy.

The next two figures (20 and 21) show the setups in the ZGS Beam 1 and the AGS D line. The experts in the audience can figure out which is which. You can see the double, double arm polarimeters and the double arm experiment spectrometer in each case and the next figure (Fig. 22) shows the experimental trailer and again the audience can guess at which lab. Well, we have gone through the beams we built at the AGS and the ZGS, and now I would like to spend a little time on what we learned about polarized beams.

Figures 20 and 21 Spectrometers at the AGS and ZGS.

Figure 22 Experiment trailer.

We had much more dedicated time at the ZGS to do accelerator experiments and let me give you the highlights of what we learned. First of all, the energy of each particle fluctuates around the average value due to synchrotron oscillations as depicted schematically in the next figure (Fig. 23). We thought we should see if this would affect adiabatic spin flip passage through a resonance which might be thought of for new machines.

Figure 23 Schematic of synchrotron oscillations.

The next figure (Fig. 24) shows some calculations of the effect of momentum spread, and the next (Fig. 25) shows some measurements which indicated that spin flip passage was far from being 100% for intrinsic resonances. Lesson-plan for fast passage in other machines.

Figure 24 Calculation of spin flip at different $\Delta P/P$.

Figure 25 ZGS measurement of spin-flip showing about a 30% efficiency.

Some theoretical models³ indicated that imperfection resonances might not exist. Well, we found them in the ZGS and since we had no vertical correction magnets, we had to improvise. We were able to differentially energize our top and bottom pole face windings in the octants and thereby introduce field components to change the vertical orbit distortions. This was really necessary to reach 12 GeV/c with good polarization in the ZGS. The next figure (Fig. 26) shows the PFW currents and the produced orbit distortions in Fig. 27 and the next Fig. 28 shows the world's first map of an imperfection resonance.

Figure 26 Poleface winding excitation function.

Figure 27 Orbit distortion produced by PFW excitation around the ZGS.

Figure 28 Polarization as a function of PFW excitation at an imperfection resonance.

We were reasonably prepared by these studies for the move to the AGS. However, there were new surprises awaiting us. First of all, the imperfection resonances were stronger than expected and we had to correct them at low energies as well as high. Then we found that the $G\gamma = 27$ imperfection resonance was very poorly corrected by using the 27th harmonic. Here a simple model⁴ proposed by Kent of the so called "beat mechanism" gave us a 100% correction. This was a new phenomenon and I would like to spend a couple minutes explaining it.

The "beat resonances" are due to a beat between an integer multiple of the periodicity nP and an imperfection driven betatron oscillation of periodicity k , so that these will occur at $G\gamma = nP \pm k$ and are strongest near the strongest intrinsic resonances ($G\gamma = 0 + \nu$, $G\gamma = 36 \pm \nu$). The machine response to correcting a $G\gamma = n$ resonance by correcting with harmonic k rather than n is the strongest when k is close to the natural tune of the machine $\nu = 8.75$. Thus, $k = 7, 8, 9, 10$, etc., have a larger response than other integers further away from ν . For $G\gamma = n = 27$, we found very little correction using the 27th harmonic, but using the $k = 9$ th harmonic ($G\gamma = nP - k = 36 - 9 = 27$), we found a 100% correction as shown in Fig. 29.

Figure 29 Correction of the $G\gamma = 27$ using a 9th harmonic instead of the 27th.

During the 1986 run, we applied a number of possible magnetic harmonics in order to correct particular resonances. Kent's model of the beat mechanism was extended to all values of nP and the model predictions can be compared to experiment. The next figure (Fig. 30) shows the comparison in terms of the ratio

$$R = \frac{\text{FWHM Direct Correction}}{\text{FWHM "Beat" Correction}}$$

for $G\gamma \geq 20$. For those $G\gamma$ where $R \leq 1$, the direct correction (i.e., the n th correction for $G\gamma = n$ is better). For $R \geq 1$, the beat correction (i.e., the k th harmonic for $G\gamma = nP \pm k$) is better. We see in Fig. 30 that the experimental results for $nP = 12, 24, 36, 60$ agree very well with the model predictions. This has a real significance for going to higher energy since the beat harmonics require less excitation than the direct correction and we will not need to obtain higher current power supplies for the correction dipoles.

"BEAT" RESONANCE CORRECTIONS

Figure 30 "Beat" resonance corrections.

There are still many things I haven't talked about: the polarimeter at the AGS, without which it would have been even more painful to correct the resonances, the enormous number of people at BNL, ANL, RICE University, Yale University, and the University of Michigan whose knowledge and perspiration made the AGS beam a reality, the very enthusiastic support we received from DOE and Bill Wallenmeyer for the BNL project, the performance of the AGS in reaching 22 GeV/c with 45% polarization and 2×10^{10} polarized protons extracted, the several weeks of AGS tuneup which made our 11 days at the ZGS seem like a picnic, and there's the fact that the experiments are still yielding unexpected results; I hope you have gotten the flavor and some of the excitement we felt in pioneering these beams.^{5,6} Hopefully, we will get to higher energies and new machines someday. I look forward to seeing a report, one of these years, on the polarized beam at the SSC and we will remember that Kent also had an input in its design.

REFERENCES

1. D. Cohen, Rev. Sci. Instrum. 33, 161 (1962).
2. History of the ZGS, AIP Conference Proceedings 60 (Argonne 1979). Edited by Joanne S. Day, Alan D. Krisch, and Lazarus G. Ratner, P. 436.
3. V. Ernst, Nucl. Inst. Meth. 60 (1968), P. 52.
4. K.M. Terwilliger et al., IEEE, Trans. Nucl. Sci., NS-32, 2635 (1985).
5. T. Khoe, et al., Part. Accel. 6, 213 (1975)
6. F.Z. Khiari et al., Phys. Rev. D 39, 45 (1989)

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