In June 1973, a polarized proton source was installed at Argonne National Laboratory (ANL) for the ZGS to produce the world's first high energy polarized proton beam. The source is an atomic beam-type source designed and built by the Auckland Nuclear Accessory Company, Ltd. (ANAC) of Auckland, New Zealand. Figure 1 is a photograph of the source and its associated electronics taken just before shipment to the United States. The source installation at the ZGS has been previously described. 1, 2 Figure 2 is a diagram of the source as originally constructed. The dissociator operates at 20 MHz, and the intermediate field transition at 1500 MHz. The solenoid field is $\approx 2$ kG and the sextupole field is $\approx 7$ kG. Polarization reversal was accomplished by reversing the solenoid field. As originally constructed, the source produced an average dc current of 8 µA with the waveform shown in Figure 3. The average polarization (as measured at 50 MeV after the 750 keV preaccelerator and 50 MeV linac) was 70%. After the initial burnout of weak components, the source operated very well, except for three basic problems. Firstly, the 120 Hz modulation of the current caused large and very undesirable pulse-to-pulse variations in the accelerated beam intensity. Secondly, spin reversal using the solenoid was accompanied by a significant difference in the beam intensity of the two spin states. The optimum source and beam line tune for one polarity of the solenoid is not optimum for the other. This was a serious problem for the users since it could cause intensity effects to look like spin effects. Also, the life expectancy and speed of the reversing switch made frequent spin reversals impractical. Thirdly, the three grids in the source have a very limited life; i.e., less than 100 hours for the original grids. When the grids burn out, the source often becomes quite unstable due to the resulting field distortions and insulator arc-over caused by sputtered grid material.

While not an operational problem, the maintenance requirements of the source were rather substantial. This was due primarily to the need to clean the diffusion pumps and dissociator tube every 200 to 400 hours. The dissociator RF plates out diffusion pump oil and other contaminants that find their way into the dissociator tube. As this surface layer builds up, atomic recombination at the wall increases, with a resulting fall-off in beam current. The diffusion pumps must be cleaned because the atomic hydrogen turns the pump oil to a jelly-like substance which gradually builds up on the pump surfaces and kills the pump.

In the two years the polarized source has been at ANL, some effort has been made to correct these problems. The results to date of this exercise are discussed below.

Improvements and Modifications

The 120 Hz modulation of the output current is due to the absence of any filtering in the plate supply of the dissociator RF amplifier. Filtering this supply would have meant rebuilding the amplifier, since the RF tube could not handle the required power on a dc basis. Also, it was not clear that the dissociator tube would have an acceptable life at that level. Since the ZGS is a pulsed machine with a maximum repetition rate of about 25 pulses/min, we switched over to pulsing the RF system so that adequate RF power could be obtained from the amplifier without a redesign. This also had the very nice side benefit of reducing the frequency of diffusion pump and dissociator tube cleaning to almost zero, since atomic hydrogen is produced with a 0.1% duty factor instead of 100%. Figure 4 shows a typical current pulse, along with the RF envelope. There is a short delay between the RF turn on and dissociation. When the RF turns off, there is a rapid drop to about half amplitude, then a slow decay from there on. The initial delay is dependent upon the gas pressure in the dissociator and RF level. For the maximum RF output, this delay increases from zero at 0.8 Torr to 2 ms at 1.5 Torr. At 1.6-1.7 Torr, dissociation is not obtained. The long decay from half amplitude is characteristic of the clearing time of the dissociator tube. The rapid decay indicates that the degree of dissociation at the tip of the tube nozzle is much higher than in the volume of the tube, even though the RF coupling coil is 6 cm above the nozzle tip.

With pulsed RF, beam currents of 25 µA have been obtained, compared to 12 µA peaks on the modulated dc beam. This increase is about what is expected from the $T^{-3/2}$ dependence for the sextupole acceptance and ionizer efficiency for a decrease in the gas temperature from 400°C to 300°C. The dissociator is cooled with 15°C water, but the glass wall of the tube will support an $\approx 100$°C drop, with a 400 W dissipation in the gas. If the RF is suddenly turned on in the dc mode after allowing the tube to cool to the water temperature, the peak current drops about 40%, with an $\approx 200$ ms time constant. The current decrease is consistent with a $T^{-3/2}$ temperature effect; however, the time constant appears too short. It is, therefore, not absolutely clear that the current increase in the pulsed mode is just a temperature effect.

A limited evaluation of further cooling of the dissociator tube was made using nitrogen gas. Temperatures down to about 250°C were reached and a
slight (≈ 5-10%) increase in beam intensity was obtained. A 30% increase would be expected from the T^{-3/2} relation.

A second significant improvement in beam current comes from pulsing the dissociator gas supply. The gas pulse is timed so that the pressure at RF turn-on is well below the maximum possible for dissociation with dc gas and rises above the maximum before the end of the RF pulse. This allows us to take advantage of the fact that once dissociation is initiated at some RF level, the pressure, and therefore the dissociator output, can be increased to a value greater than the maximum pressure at which dissociation can be initiated. Pulsing the gas also reduces the ambient pressure in the atomic beam stage and, therefore, reduces beam loss due to scattering. We have obtained beam currents of 30-40 μA with pulsed RF and gas.

A third modification of the atomic beam stage involved removing skimmer No. 1 and the baffle that separates the two upper chambers, and reducing the dissociator tube-sextupole separation. This allows improved pumping in the upper stage and maximizing the matching of the beam into the sextupole. Figure 5 is a plot of the output current versus dissociator tube-sextupole separation. There is a 10% increase, followed by a rapid decrease. This decrease is probably due to gas scattering in the sextupole, which has too much impedance to conduct the higher gas load.

Figure 6 shows the beam current versus dissociator tube pressure when the dissociator RF level is at its maximum value. These data show that the beam is still increasing with pressure up to the point where dissociation cannot be initiated. This indicates that a more powerful dissociator RF supply should produce more beam. We plan to make this modification in the next year.

The difficulties associated with spin reversal were solved by adding a weak field transition and expanding the controls to allow switching either transition on a pulse-to-pulse basis. This greatly increased the usefulness of the beam by improving the beam stability and allowing the users to do a much better job of reducing systematic errors.

The grid failure problem has been reduced, but not solved, by using heavier grid material. The solution will be available later this year when a gridless curved plate analyzer will replace the electrostatic mirror.

Summary

The ANL polarized proton ion source has been operating for almost two years. In that time, the improvements and modifications discussed here have increased the peak current by a factor of 3 and the polarization to 75 to 80%. The beam stability and spin reversal are no longer problems, and the maintenance requirements have been significantly reduced. Some further increases in the output current of the source may be possible. Adding up all of the current gains discussed above and applying them to a well-tuned source with a clean, efficient dissociator tube; beam currents of 50-60 μA may be possible. A new RF amplifier and a higher voltage electron gun in the ionizer may allow currents in the 75 μA range. However, beam currents beyond this level will probably require a radically new approach to the design of atomic beam sources.

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References


Fig. 1. ANL Polarized Proton Ion Source

Fig. 2. Diagram of the ANL Polarized Proton Ion Source
Fig. 3. Beam Current Waveform. The lower trace shows the beam current (2 μA/division) versus time, and the upper trace shows the dissociator RF envelope. The RF waveform is that of an unbiased full wave rectified 60 Hz sine wave. The current peaks correspond to 10 μA.

Fig. 4. Pulsed RF Beam Current Waveform. The lower trace shows the beam current versus time waveform for a 4 ms RF pulse. The RF envelope is shown in the upper trace.

Fig. 5. Beam Current Versus Dissociator-Sextupole Separation

Fig. 6. Beam Current Versus Dissociator Tube Pressure for a Constant Dissociator RF Level.