AGS FAST SPIN RESONANCE JUMP, MAGNETS AND POWER SUPPLIES*

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Abstract

In order to cross more rapidly the 82 weak spin resonances caused by the horizontal tune and the partial snakes, we plan to jump the horizontal tune 82 times during the acceleration of polarized protons. The current in the magnets creating this tune jump will rise in 100 µs, hold flat for about 4 ms and fall to zero in 100 µs. Laminated beam transport quadrupole magnets have been recycled by installing new two turn coils and longitudinal laminated pole tip shims that reduce inductance and power supply current. The power supply uses a high voltage capacitor discharge to raise the magnet current, which is then switched to a low voltage supply, and then the current is switched back to the high voltage capacitor to zero the current. The current in each of the magnet pulses must match the order of magnitude change in proton momentum during the acceleration cycle. The magnet, power supply and operational experience are described.

INTRODUCTION

Physics Background

After introducing two partial snakes in the AGS, extraction intensity and polarization reached higher levels. However, as the stable spin direction is moved away from vertical, a new kind of depolarizing resonances has been observed causing about a 10% polarization loss.[1] These horizontal depolarizing resonances happen when $G\gamma = N \pm Qh$ where $G = (g - 2)/2 = 1.7928$ is the gyromagnetic anomaly of the proton, and γ is the Lorentz factor, N is an integer and Qh is the horizontal tune.[2, 3] For example, with Qh = 8.70, and AGS injection energy of $G\gamma = 4.5$ and extraction energy of $G\gamma = 45.5$, the first and last locations would be: $G\gamma = -4 + Qh = 4.7$ and $G\gamma = 54 - Qh = 45.3$. The total number of the resonances in this energy range is 82. The depolarization from each one of them is tiny but the overall effect is about 10% polarization loss.

Correction Method

To overcome these depolarizing resonances, two pulsed quadrupoles that can change the horizontal tune by +/-0.04 in 100µs will be installed in horizontal β-max sections. The sections are three quarters of a wave length or 1.5 beta waves apart to reduce lattice distortion. The intent is to cross the resonances more quickly by jumping the horizontal tune (see Figure 1).

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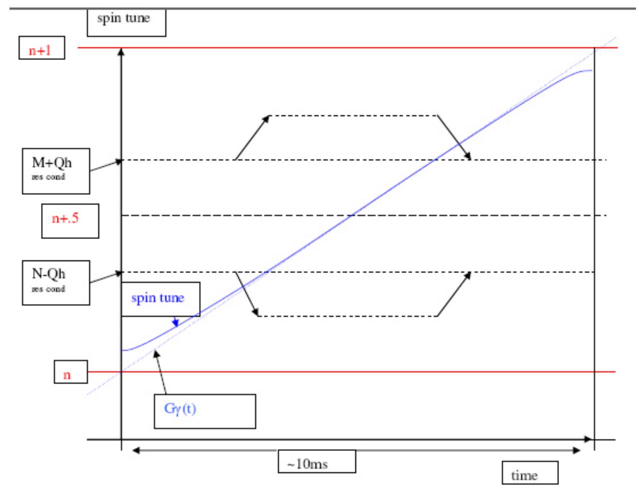

Figure. 1: The sketch of tune jump of a .pair. of resonances (indicated by the dotted lines).

In general, the spin tune is equal to Gγ value; near the integers they deviate due to the presence of partial snakes. Fig. 1 shows, the tune jump making the resonance crossing speed faster. It also demonstrates that the tune jump must be up at N - Qh and down at N + Qh.

During normal acceleration, the rate of change of Gγ is 100/s and we plan to at least quadruple the resonance crossing speed. Thus Qh must change at a rate of 400/s. The resonances are crossed during the 100 us fall or rise.. Each quad causes a tune jump of 0.02. The rigidity goes from 8 to 80 T-m and beta at the quads is 20 meters thus the required quad strength goes from 0.1 to 1 T, stepping up by 0.024 T for each of the 41 pulses

HARDWARE

Magnets

We have available laminated beam transport magnets that have a 20 cm bore and 80 cm length. Ringing tests show they would operate with a 100 µs rise. Losses may reduce peak field by 20%, though these losses may be in the large 22 turn coils not the iron, (Figure 2). The magnets can operate at 15 T. The needed aperture is only 15 cm and the length of less than 90 cm. As the amount of stored energy in a quadrupole, for the same gradient, is proportional to the fourth power of the bore, reducing the bore reduces the power supply requirements by a factor of three. requirements by a factor of three.

Shims

To reduce the aperture, the pole tips needed 2.5 cm shims that have to be laminated due to the fast rise. There are

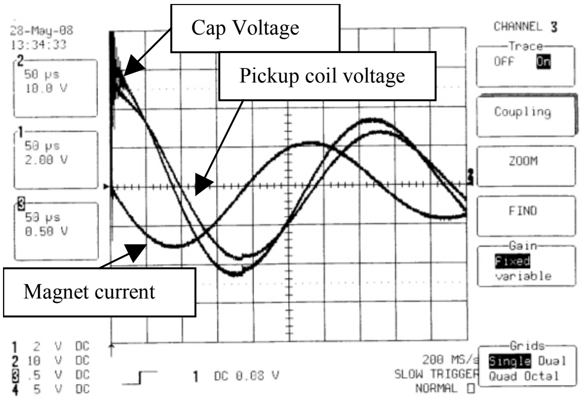

Figure 2: Ring Test showing response to impulse voltage.
#1- Cap Voltage/200;
#2- Two turn pickup on one magnet pole;
#3 – Magnet Coil Current 100A/V.

about a thousand radial laminations in the magnets. To manufacture thousands of shims that fit the pole face then stack and encapsulate them would have been a formidable job. We decided to make the shims longitudinal, reducing the number by an order of magnitude and having a simple rectangular shape. Because the required field at peak energy is 1.2 T/m and the pole tip field is 0.09 T, the pole shims can be crenulated further reducing the amount of laminations and improving field quality. They were stacked with 1.2 mm iron and 3.2 mm of G10 spacers in a mold shaped to the pole contour and encapsulated in fiberglass epoxy to hold them and insulate them from the radial laminations (Figure 3).

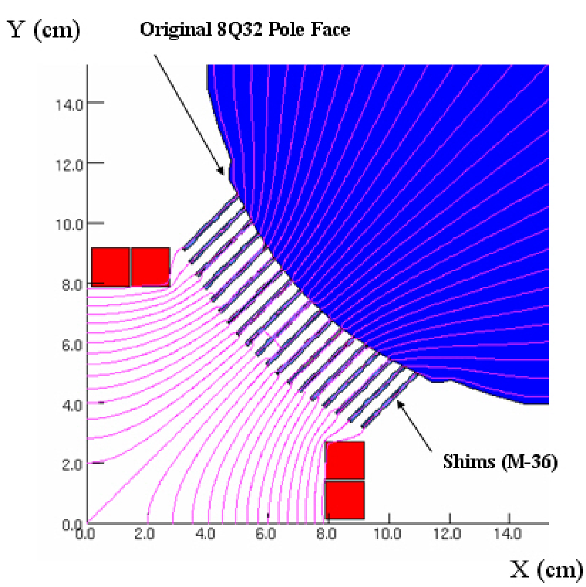

Figure 3: Modeled field with shims added.

Coils

The original magnet coils were 22 turns designed for 3 kA for full field. As only 2500 Amp-turns are needed, we avoided the high inductance and losses of the 22 turns which would have required excessive charging voltage. The coils could not be moved into the gap, thus unused high field volume would be created further increasing inductance and detracting from the field quality. New coils were designed which are two turn 1.27 cm square copper with a total resistance of 2.2 mΩ and 36 μH inductance. With an rms current of 220 A only 100 W are generated so we do not need forced air or water cooling. The coils were also encapsulated in fiberglass/epoxy. The old coils were removed and the voids filled with G10 pieces that hold the pole shims and coils in place. New England Technicoil in New Hampshire manufactured both the pole tip shims and the coils.

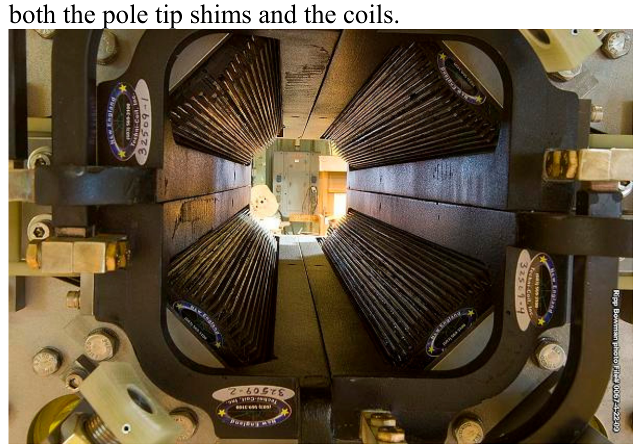

Figure 4 Completed Magnet assembly

Vacuum Chambers

The 100 μs rise time is equivalent to a 2.5 kHz frequency, too high for normal walled vacuum chambers. Using a bellows allows for a thinner wall of 200 μm, and a longer longitudinal current path due to the convolutions, keeping the eddy currents to a manageable level. The eddy current field reduction is expected to be about 1.2 %

Power Supplies

Each supply drives a series of 42 pulses of current in its magnet, each with a 100 us rise, a flat top of 4 to 10 ms and a fall of 100 us. The required current pulses go from 140 to 1400 A in steps of 30 A for each of the 42 pulses. A supply consists of two systems (Figure. 5). The high voltage circuit uses a 1.5 kV supply with switches to charge the 100 μF pulse capacitor. Charging is switched off about 50 μs before the beam crosses the resonance, then the capacitor is switched to the magnet bringing the current to the required value. The current is then switched to a low voltage supply which keeps the current constant until just before the tune must fall to cross the next resonance. Then the current is switched to the discharged 10 μF capacitor to drop the current to zero in 100 us. A fly back switch and local inductor then partially recharges the magnet.

The low voltage supply must supply bursts of current from 140 - 1400 A as beam is accelerated. To reduce the strain on the supply its output is heavily filtered with a 0.45 mH choke into a 2F capacitor bank and a 34 mΩ damping resister. With a double pole at 33 Hz, the reference for this supply must have the voltage of the

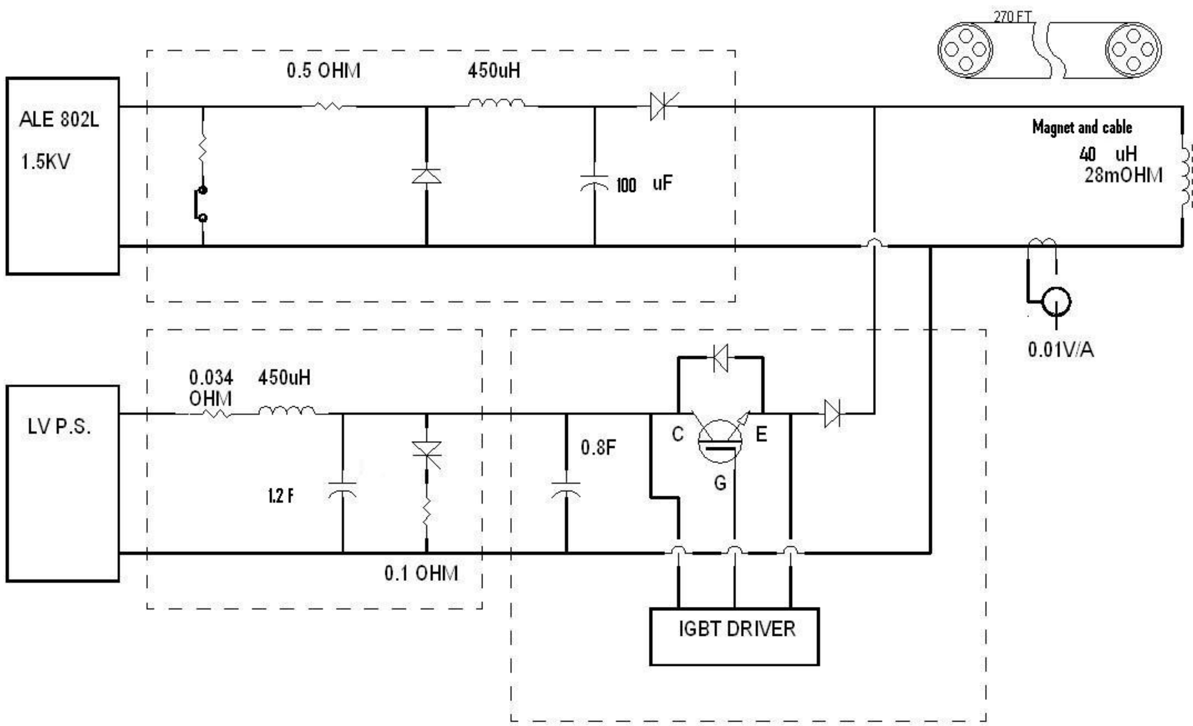

Figure 5: Power Supply Layout

rectifier lead the required filter output voltage. The charge is dumped at the end of the 42 pulses into a 100 mΩ dump resister.

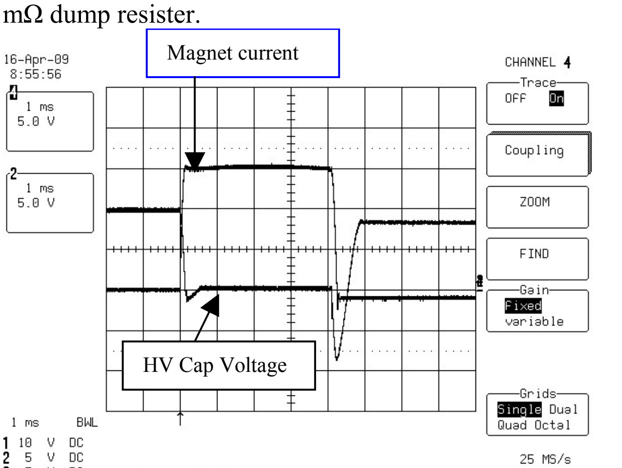

Figure 6: One pulse of Power supply current and HV Capacitor voltage

Cabling

The cable runs from the pulsed power supplies to the magnets in the accelerator are over 70 m long so low inductance and resistance are important. With 100 µs rise time coxal cable is not necessary, so four parallel quadraplex cables were installed. The measured resistance of each run is 35 mΩ and the inductance is 5.8 µH.

Testing

A prototype magnet with temporary coils was assembled to check the performance. The field was measured using a system of stationary tangential coils during the ramp. The measurements showed an integrated quadrupole field of 0.36 T at 500A which is at the 50% point in the ramp. This is consistent with expectations. The 12 pole error is ~0.65% of the quadrupole field at 35 mm radius. The magnets will be installed this run for beam tests.

COST SAVINGS

There was little time and money to create this system. Using old magnet cores, which were slightly radioactive and thus had negative value, eliminated design and lamination cutting which was a big saving in time and cost. Making the shims only 30% iron with longitudinal laminations also had big cost and time savings. Using qudraplex cable was less expensive and much easier to run from the power supplies to the magnets. The large low voltage supplies were recycled from beam lines as well as magnets used as chokes. Lastly, ceramic vacuum chambers could not be delivered on time and bellows vacuum chambers are much less expensive.

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