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# A problem found with Low Momentum Multiple Bunch Extraction into the U Line

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| **AGS Complex Machine Studies** |
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| **A problem found with Low Momentum Multiple Bunch Extraction into the U Line** |
| **Study Period**: 18-22 July 1997 |
| **Participants**: L. Ahrens, T. Roser, W. Glenn |
| **Reported by**: L. Ahrens |
| **Machine**: AGS |
| **Beam**: Proton |
| **Tools**: Extraction Bumps, Back leg monitors |
| **Aim**: To understand the difficulties with multiple SBE at Low Momentum |
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AGS Complex Study Note

Title: A Problem Found with Low Momentum Multiple Bunch Extraction into the U Line
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Protons with kinetic energies 1.6, 2.0 and .8 GeV were extracted from the AGS into the U line during the E939 physics run. The beams were in all cases accelerated in the Booster to nominal HEP transfer momentum, and transferred into AGS in nominal fashion. At this point the beam was accelerated or decelerated to the desired momentum (definitely not nominal, but smooth), and then extracted into the U line using the same FEB equipment used for g-2 and RHIC transfers. The primary constraint on this strategy is the acceptance of the FEB extraction channel and in particular the G10 kicker magnet. It was anticipated and observed that about half of the accelerated beam would be lost either when the beam was bumped into this magnet or in fact slightly earlier in the cycle due to deliberate scraping elsewhere. The low beam intensity requirements and the low momentum made this loss tolerable.

A second, unanticipated beam loss was observed when multiple bunch extraction was attempted. The seven bunches surviving the first G10 kick would disappear within a few hundred μs of that kick. A systematic variation of the major parameters affecting extraction was carried out. Survival was sensitive to one component of the slow bump that distorts the equilibrium orbit into the kicker and against the H10 septum, the "G9 B bump". An ad hoc solution with modest efficiency was arrived at by distorting this piece of the bump in time and amplitude and adjusting the beam radius. Figure 1 shows the current waveforms in the four sections making up the full orbit distortion. Note that the second trace (G9B) is shifted early. The kicker firing (and extraction) occurs at the peaks of the other waveforms (the upward arrow).

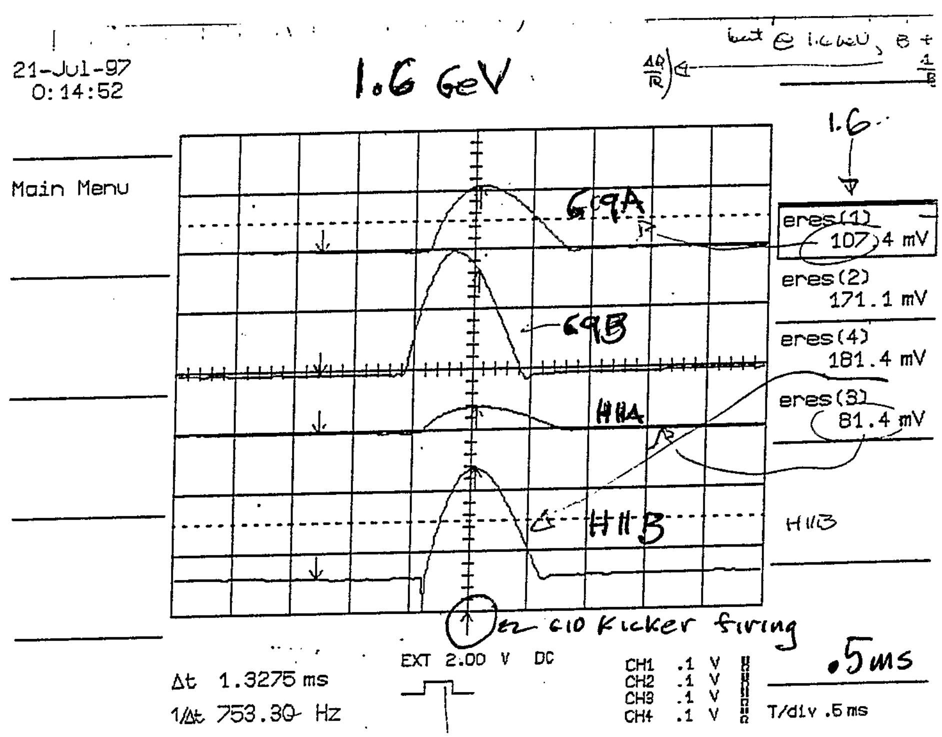


Figure 1. The "ad hoc" Solution for the G9B Bump at 1.6 GeV

The existence of the loss, and the apparent localization of the relevant contributor motivate the rest of the study being described. The questions remained: 1) what is special about the G9 B bump? and 2) why isn't this a problem at full energy extraction?

A possible answer to the first part becomes fairly clear once the actual magnet configuration used to create the extraction bump is understood. The G10 kicker and the H10 septum are separated by roughly ¾ of a betatron wavelength. The "standard" backleg winding bump configuration frequently used at the AGS involves sequences of four main magnets at 1/2 lambda spacing. Two increase the normal bending field and two decrease the normal bending field. The result is a 3/2 lambda orbit deformation with no perturbation to or from the main magnet power supply and with the central lobe of the resulting orbit distortion about twice as large as the two side lobes. A pair of such bumps was not used here. If they had, with one bump centered at G10 and another at H10, the two bumps would have overlapped generating an inward lobe near G20 of amplitude close to that of the outward lobes at G10 and H10. The required aperture on the inside probably does not exist. A modified solution was taken which doubled the strength of the "third" magnet in each bump and eliminated the last magnet and the inward overlapping lobes. One power supply (A) powers the two balanced magnets and one power supply (B) powers the doubled magnet in each modified bump. This solves the aperture problem but leaves the two "doubled" magnets which transformer couple in an uncompensated way into the rest of the main magnet circuit. The circuits associated with these doubled magnets are referred to as the G9B and H11B "bumps".

What does the current pulse induced on the main magnet current look? By luck, the main magnet was still available after the run when this question was formulated, and an empirical measure of the interaction was possible albeit without beam. The bumps had already been returned to their high momentum extraction configuration (more about this later) and were left that way. With the Siemens set at "dwell" the components of the full extraction bumps were pulsed. The accumulated up and down Gauss clock counts (at MCR3 console) were measured at several time intervals to see the effect of interaction between the bumps and the main magnet system. The Gauss clock counts come from voltage induced on a long coil in the "242 magnet", a standard AGS main magnet wired in series with the working string and located in the basement of the Siemens building. An "up" ( "down") count is produced whenever the magnet's field increases (decreases)by .05 Gauss. By logging the net change ("up-down") one learns the main magnet field change. This change was measured while pulsing the G9B bump and the H11B bump separately, with both on, and with both on at about half value. Figure 2 gives this data.

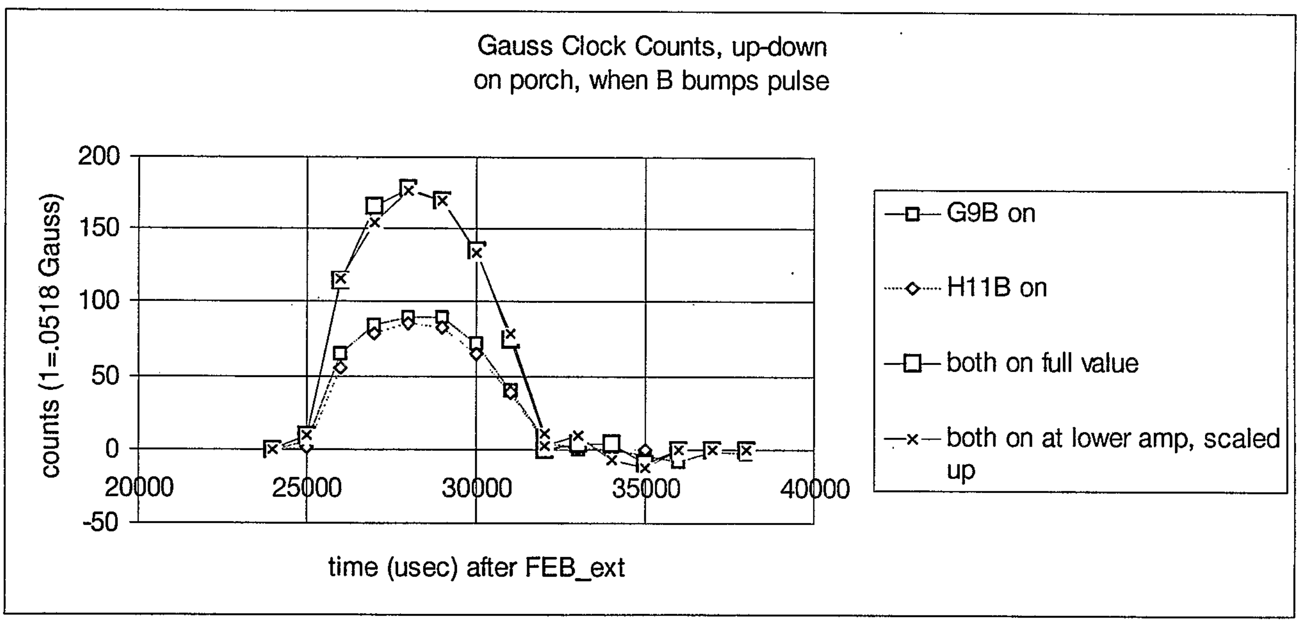


Figure 2 Response of the AGS Main Magnet to Pulsing the FEB Extraction B Bumps

The scope traces of figure 3 are included to show some other aspects of this pulsing. Here both the B bumps are pulsing at HEP "full" values. Figure 3a gives the current waveforms in the two bumps. It also includes the response from the A and B Siemens "bank" voltages. The rest of the traces are from backleg diagnostic windings (windings which are different from any mentioned above) cabled to MCR3 from each of the main ring magnets. These backlegs were observed (scope, high impedance) again while pulsing both of the B bumps which of course are just "power" backleg windings on main magnets {G16,G17} = G9B and {H4,H5}=H11B. A truncated view of the voltage induced on these primary magnets is given in Figure 3b. Figure 3c shows some typical voltages induced on nearby magnets and figure 3d gives on magnets on the other side of the main magnet circuit.

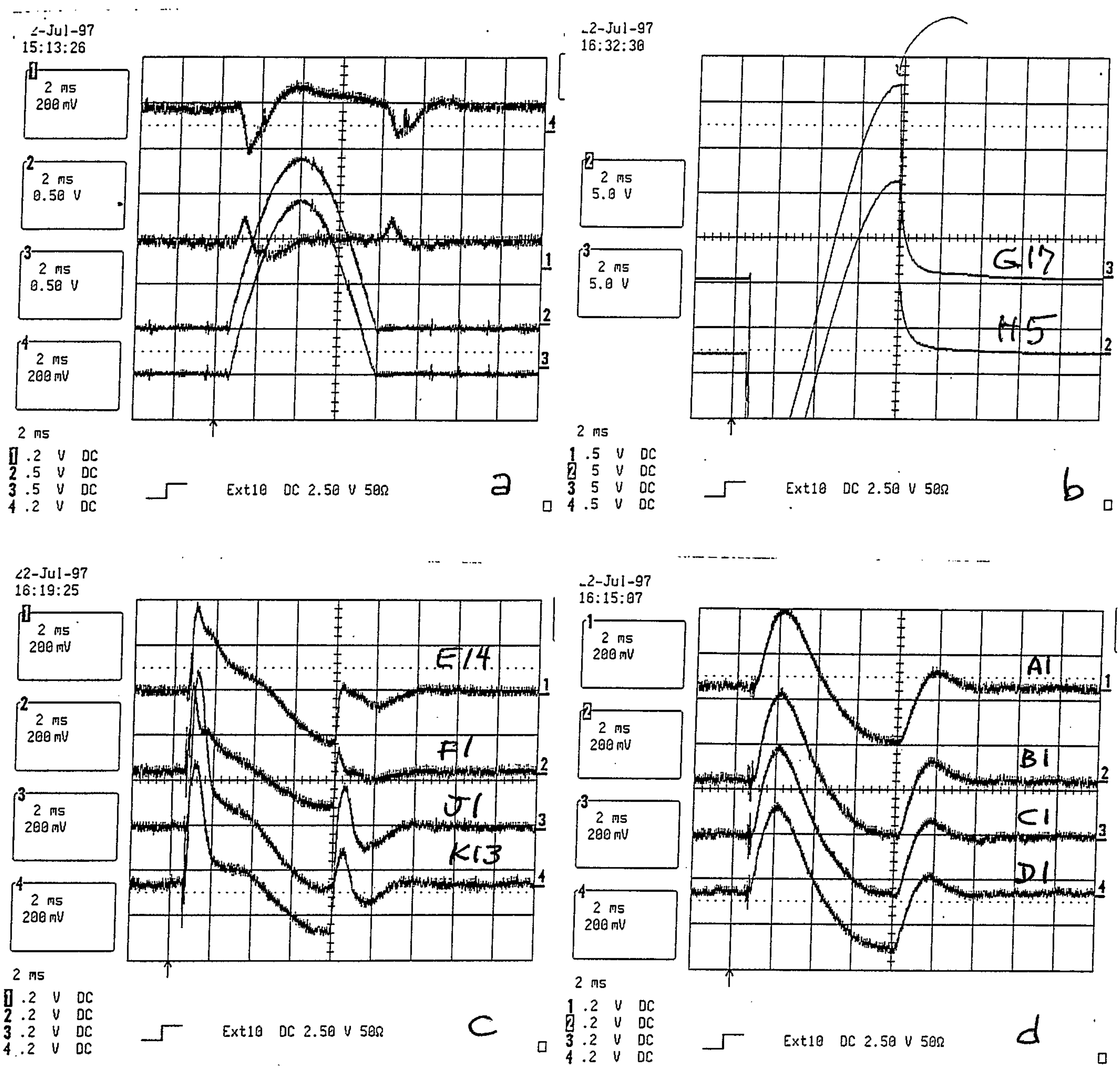


Figure 3 Scope Traces of Main Magnet Response to the B Bump Pulse

Comparing Figure 2 with 3a one sees that the pulse on the main magnet very much follows the current in the bump. Pulsing either B bump has the same effect on the main magnet system; pulsing both doubles the effect; and the effect scales with the size of the pulse. Figure 3b is the diagnostic backleg winding measure of the pulse being applied one of the B magnets, and to the rest of the magnets through the transformer coupling into the main magnet string. The integral of this signal should be proportional to the induced field, as should the current pulse – allowing a cross calibration if desired. In the simplest model the 20 Volt pulse should couple (16 main magnet turns/10 "power" backleg turns) into the rest (239 magnets in series) of the system. The 20 Volts would be reduced to (20V)*(16/10)*(1/240)=133mV from each of the 4 pulsed magnets, giving a pickup on a diagnostic backleg winding of 533mV at the edge of the pulse. Both the shape of the Gauss Clock reconstructed pulse and the qualitative response of the diagnostic windings shown in 3c and 3d agree with this simple picture. The details in 3c and 3d are clearly much richer in structure than the simple picture can explain.

To pursue this a bit – in part to judge whether the diagnostic signals are plausible – two were digitized and further analyzed . For magnets B1 and J1, the measured voltage and the integral of that voltage are presented in figure 4. Figure 5 directly compares the integrals – which should be proprotional to the induced magnetic fields – for these two magnets. The time development is significantly different though qualitatively similar. The magnet close to the B bump has a faster rise. Both have similar amplitude. There appears to be some longer time scale ringing.

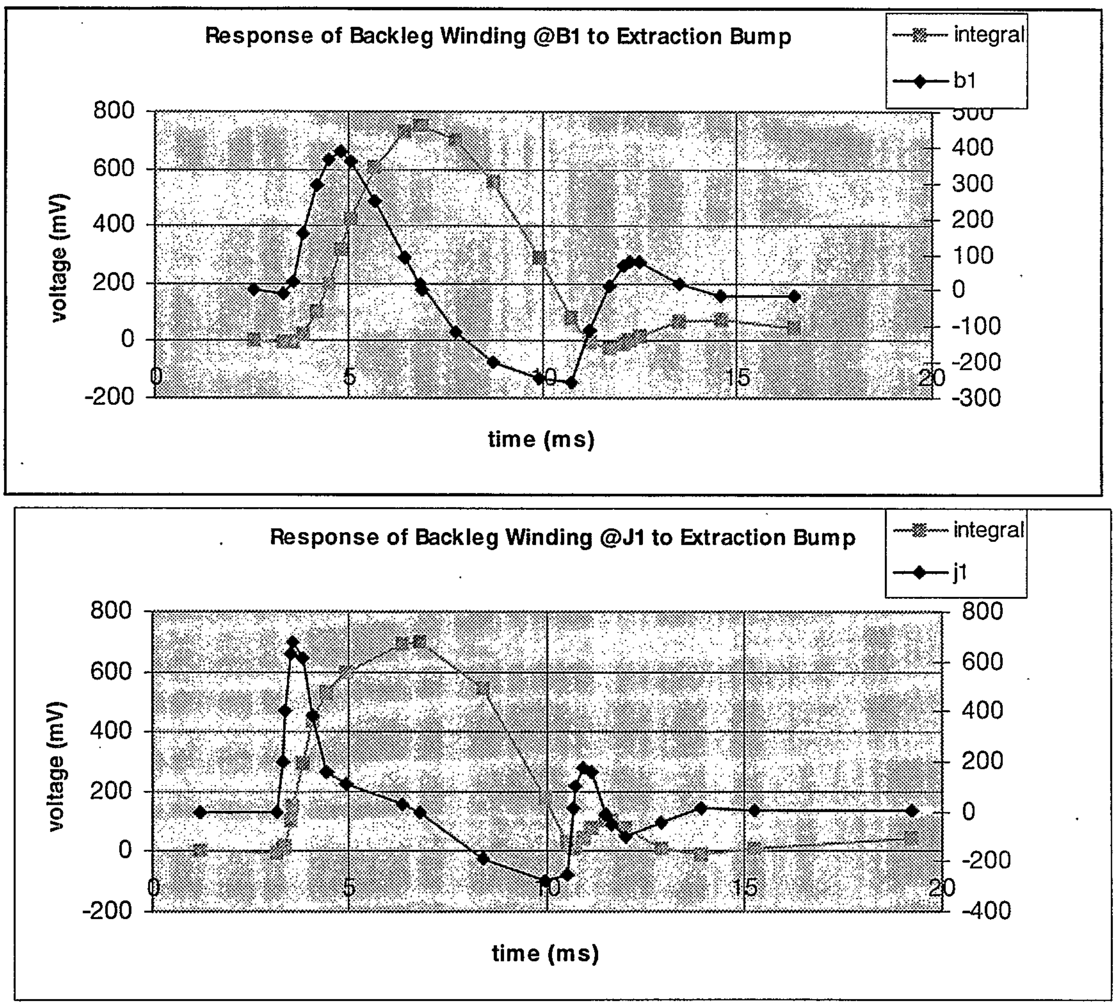


Figure 4 Response of the B1 and J1 Magnets to the FEB B Bump

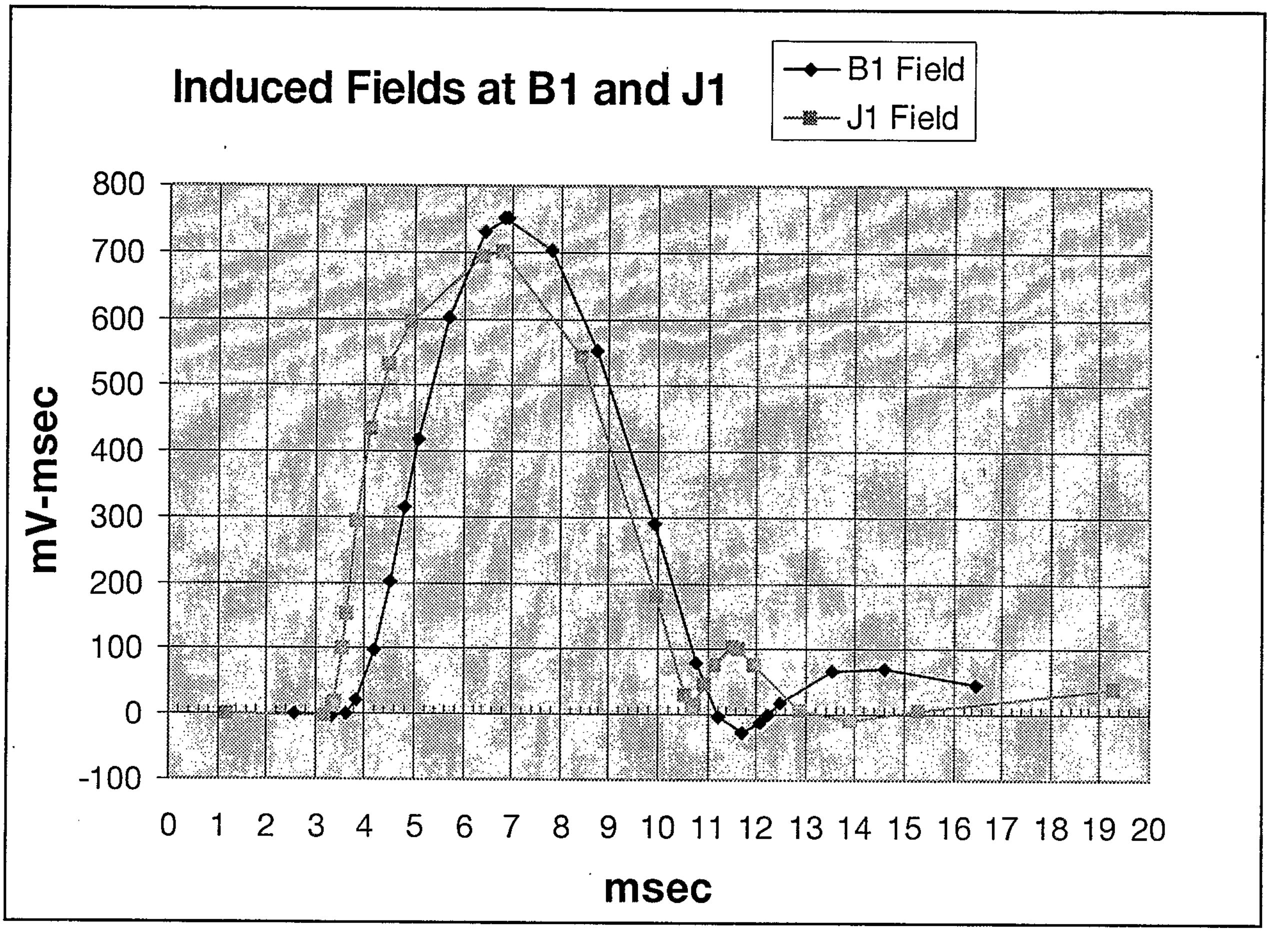


Figure 5: The Inferred Induced Fields in two of the AGS Main Ring Magnets

From the measured field change one can make some statements about the importance of this induced field during the normal high energy extraction. The average field change - using the Gauss clock measure (Gauss Clock Counts = GCC) - is about (200 GCC/ 200,000 GCC) = .1%. This is a number consistent with the simple model mentioned above. If this change is not accompanied by any change in beam momentum, the beam would shift (at a point of average dispersion) inward by 1.8mm. What really happens may be more complicated if the rf system can change the beam momentum via the radial loop during the 3.5 ms that the high energy bump is rising.

A search for documentation of the rf frequency and the beam radius during the fast extraction period for the recent g-2 run produced some very different pictures at different times. Sometimes the frequency shows two fast excursions, one at each edge of the bump. At other times the frequency more or less follows the bump. No radial average pictures were uncovered.

Now while this is all interesting, it describes a phenomenon which has not been an identified problem for normal high energy extraction – which really means for high intensity extraction to g-2. The question motivating this "study" remains: what makes things much worse for the low momentum extraction. Some more information about modifications to these bumps for the low momentum extraction setup is relevant. The bump power supplies use the discharge of a capacitor into the inductance of the backleg winding to generate the half sine wave current waveform. The currents required to extract the lowest momentum beam (.8 GeV kinetic) is reduced from high energy extraction by a factor of 17. The required current stability could not be achieved simply by reducing the voltage reference sent to the existing capacitor charging power supply. To reduce the requirements on the voltage the time constant for the circuit was modified by reducing the size of the capacitor – by a factor of 40. This allowed the desired currents to be generated without further modifications. What it also gave was a much faster bump – by $\sqrt{40}$ (the width of the half sine decreased from 7 ms to about 1ms [figure 1]as expected) and much less reduction in the voltage applied across the (backleg) magnet than would have otherwise been necessary.

So what? The simple model if applied to this faster bump would again give a magnetic field bump proportional to the current in the B bump with the same proportionality as for the slower high energy setup. So we are left to wonder what the pictures 3c and 3d and figure 5 would look like if the exciting B magnet voltage waveform were of similar amplitude but all over in 1 millisecond. That is as fast as the confusing structure on these traces. Maybe the main magnet wouldn't follow the applied bump. We didn't measure the response of the main magnet for the fast bump setup. The other piece of the puzzle has to do with the response of the beam, via the rf system. The low momentum bump is faster. Maybe the rf cannot follow while at high energy it can. But now we are into the loops and for example the synchrotron frequency is also very different in the two cases.

Further discussion:

If we return to low momentum extraction in the future, and use the FEB extraction equipment to get the beam into the U line, having a low voltage solution for the B bumps is valuable. This is presumably doable given enough time to prepare alternative charging supplies. The time constant for the bump would then be long and maybe the problem would go away.

It is also important to better understand this stuff for the high energy situation. Does the shifting of the main magnet at high energy affect the stability of the transfers. Here we know the effect is not great enough to kill extraction, but it may affect the quality of the beam if emittance preservation and hence reproducibility are important.

Although the discussion in this note belongs to Ahrens, he appreciates a discussion with Soukas, and of course his fellow participants (who did not get to review the note).