MULTI-PULSE EXTRACTION FROM LOS ALAMOS PROTON STORAGE RING FOR RADIOGRAPHIC APPLICATIONS

H. A. Thiessen, F. Neri, K. Rust, and D. B. Redd, Los Alamos National Laboratory,
Los Alamos, New Mexico 87544

Abstract

In Proton Radiography, one of the goals is a motion picture of a rapidly moving object. The Los Alamos Proton Storage Ring (PSR) in its normal operating mode, delivers a single pulse approximately 120 ns wide (fwhm). In development runs at the PSR, we successfully demonstrated operation of a technique to deliver two pulses, each 40 nsec wide, with adjustable spacing.

1. INTRODUCTION

For radiography of moving objects, two or more pulses with adjustable time spacing are required. The existing Proton Storage Ring (PSR) extraction system is configured to extract the entire beam in a single turn. Two kickers and two kicker modulators fired at the same time perform the normal extraction function. By reconfiguring the two kickers and two modulators, it is possible to obtain two half-sized extraction kicks with adjustable time spacing. In this way, we have extracted two pulses with adjustable relative timing. The setup will be described and experimental results will be presented.

2. SETUP

The basic idea of the setup was to rearrange the existing kickers and modulators of the PSR extraction system as shown in Fig. 1 below.

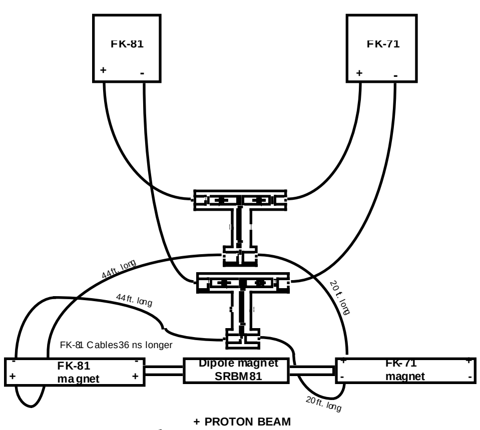

Fig: 1 Arrangement of two kickers and modulators used to deliver two pulses from PSR. In the standard mode of operation, each kicker is excited by a separate modulator.

In this arrangement, one modulator drives two kickers in parallel, but with half the voltage of the standard operation mode. The second modulator is timed to deliver its pulse after adjustable delay. Diodes are used to isolate the two modulators from each other as shown in the circuit of Fig.1. Ideally, the beam responds to the first of the two kicks by moving to a position corresponding to the center of the septum. Approximately 25% of the beam is extracted and 50% of the beam is lost on the septum. When the second kick is applied later, the remaining 25% of the beam is extracted.

3. EXPERIMENTAL RESULTS

In our first experiment (November 24 1996) we ran the PSR with a nominal 30 ns wide injected pulse at 4 Hz. The injection time was limited to 200 microseconds and the repetition rate was limited to 4 Hz to limit the beam injected to 100 nA, well below the normal loss in the PSR, in order to limit activation and minimize risk to components in the event of a spill at a single point. The separation between modulator pulses was limited to the range of 1-10 microseconds by the existing timing system.

At the best operating point found in the first experiment, approximately 83% of the beam was lost, with 10% and 7% delivered in two pulses to the Fast Current monitor in Line D. (The accuracy of our fractional beam calibrations is ± 30%.) Pulse width measured by the fast current transformer in Line-D was 40 ns, consistent with a slight broadening of the 30 ns injected pulse. The observed beams were similar over the range of 1 to 10 microseconds, and nothing was seen that would preclude extending the separation time to 100 microseconds or more. The extracted beams were “clean”, showing no side lobes or unwanted spurious pulses. The observed pulse pair is shown in Fig.2.

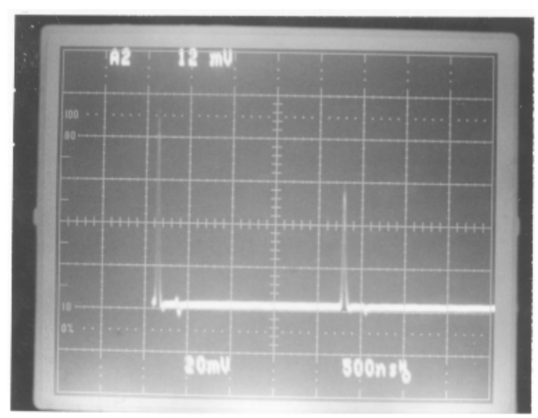

Fig: 2. Observed pulse shape in two-pulse extraction mode from PSR.

0-7803-4376-X/98/$10.00 © 1998 IEEE

The observed beams at the fast current transformer contained approximately 1.6×10^{10} protons per pulse, more than 5x more protons per pulse than available in a batch of 6 micropulses from the linac. (which would have the same time width as the observed pulses at PSR).

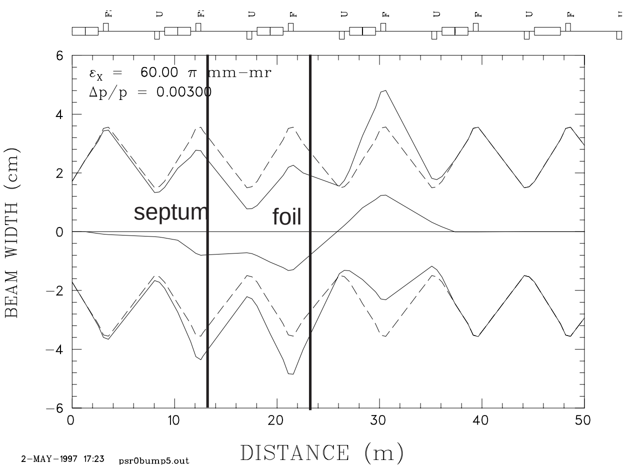

Fig: 3 The closed-orbit bump used in the two-pulse extraction experiments. Two vertical lines show the position of the septum and of the foil. The closed-orbit displacement is -8 mm at the septum, -10 mm, +3 mr at the foil.

In the February 24 1997 experiment, using the bump scheme illustrated in Fig: 3 we increased the efficiency to about 35% of the stored beam. The bump is designed to move the beam closer to the septum and to move the closed-orbit away from the center of the injected beam at the foil. Moving the beam closer to the septum places the center of the beam kicked the first time on the center of the septum. Without the bump, the beam center would be on the inside edge of the septum.

The closed-orbit offset at the foil is designed to produce an hollow beam in phase-space, whose projection in the horizontal direction has two peaks, with a separation of about 10 mm. This reduces the percentage of the beam lost on the septum, when the two pulses have equal intensity. The nominal bump is calculated to be the largest one that does not produce significant beam loss.

The results of the second experiment are shown in Fig. 4. After the first modulator is fired, about 50% of the beam is extracted or lost on the septum. After the next turn, only about 33% of the beam remains in the ring. About 6 turns later, more beam is lost. The remaining 17% stays in the ring until the second modulator is fired. The horizontal fractional tune is close to 1/6, so that the two modulators are fired with a separation that is a multiple of six times the revolution period, or 2.16 μs. We observed that he second modulator had to be fired n×6 or n×6+1 turns after the first, in order to extract the beam. Firing the second modulator on any other turn resulted in a neglegible second extracted beam pulse.

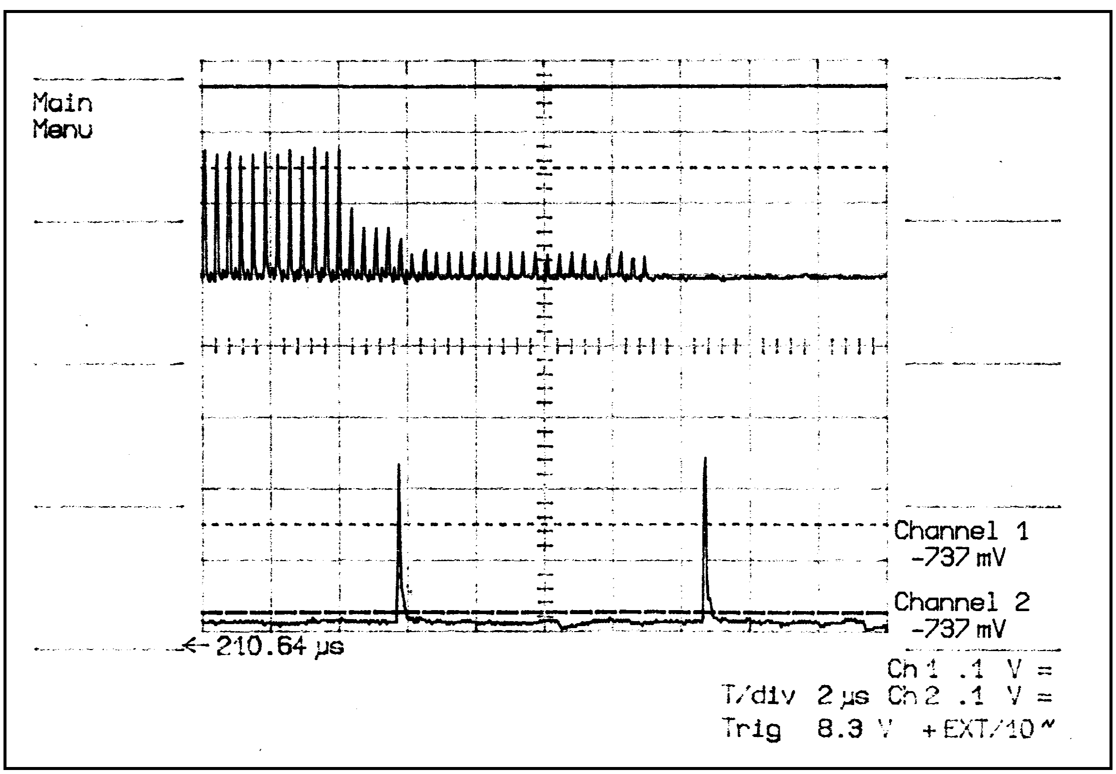

Fig: 4 The top trace shows the ring current from the wall current monitor. The bottom trace is the signal from a fast current transformer in Line-D. One time division is 2 μs. The two modulators are fired 9 μs apart.

With the nominal bump, shown in Fig. 3, most of the beam is lost on the septum, after the first kick. Increasing the bump at the foil (to make the stored beam more hollow) reduces the percentage of the beam lost when the kickers are fired but increases the percentage of beam lost during accumulation. The efficiency is not increased.

The pulses in the extraction line have the same width as the ring current profile. The "tails" noticeable in the two bottom pulses of Fig. 4 are actually due to the line not being correctly terminated. We observed 100% transmission of the extracted pulses to the LANSCE target 1. This means that both pulses fit in the acceptance of the extraction line, even though they are not centered in the extraction channel. Two steerers could be used in the extraction line to correct for this offset for proton radiography experiments. However, as shown in Fig. 5 the two pulse will not completely overlap in phase space, so that a DC steerer cannot exactly correct the offsets of both pulses. Adjusting the tune of the ring away from exactly 1/6 can help correct for this, but to to illuminate the same object with the same spatial distribution on both pulses will not be possible.

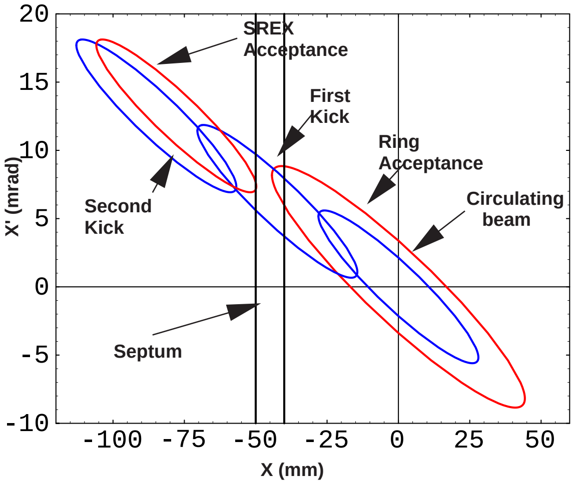

Fig: 5 The phase-space locations of the circulating beam, beam after the first kick and beam after the second kick. The ring acceptance of the ring and extraction line are also shown.

In a future run, we hope to improve the extraction efficiency, extend the injection pattern width, and extend the injection time. Our goals are to increase the available beam in each pulse by a factor of 10-20 with a pulse width of 50 nsec, and demonstrate separation of extracted pulses out to 100 microseconds. After the SPSS enhancement program is complete, it would be possible to generate up to 6 pulses in a nearly arbitrary pattern if a suitable six-pulse modulator were to be developed.

In summary, we have demonstrated the ability to produce from the PSR two pulses, each with a width of about 40 nsec and at least 3×10^{10} protons per pulse, an order of magnitude more protons than a train of linac bunches with a similar width. The separation between the pulses can be adjusted from 2 μs up to 100 μs. These pulses could be used for high-resolution freeze-motion radiography of moving objects.