

Sub Microsecond Notching of a Negative Hydrogen Beam at Low Energy Utilizing a Magnetron Ion Source with a Split Extractor

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Abstract. A technique for sub-microsecond beam notching is being developed at 20 keV utilizing a Magnetron ion source with a slit extraction system and a split extractor. Each halve of the extractor is treated as part of a 50 ohm transmission line which can be pulsed at ± 700 volts creating a 1400 volt gradient. This system along with the associated electronics is electrically floated on top of a pulsed extraction voltage. A beam reduction of 95% has been observed at the end of the Fermilab 400 MeV Linac and 35% notching has recently been achieved in the Booster.

INTRODUCTION

Expanding neutrino research at Fermilab has created a demand for 8 GeV proton intensities greater than the existing Proton Source (Linac and Booster) has ever provided¹. Increases in proton intensity are presently limited by component activation associated with proton losses at high energies. Several projects have been initiated to address this problem including realignment, new magnets, and beam collimation in the Booster. As part of this effort, beam notching at low energies is being developed specifically to reduce the losses associated with beam injection and extraction from one accelerator to the next.

Effort to cleanly notch low energy beams has persisted, despite complications associated with space charge², due to the low beam rigidity and the relatively low cost associated with fast kilovolt pulsed-power supplies. At the SNS, a pulsed electric quadrupole in the 65 keV LEBT is being used to create chopped beams³. At KEK a modulated surface-plasma converter source has modulated beams with 70 ns rise and fall times⁴. Furthermore, a traveling wave chopper utilizing special timing for a 35 keV beam was presented at the LINAC 2002 conference⁵. The split extractor technique presented here is complementary to these efforts. It is hoped that low energy space charge problems will be avoided by notching in the extraction region where the beam is expected to be space charge limited, due to the strong electric field of the extractor. The high gas pressure inherent to this region should also facilitate fast space charge recovery.

EXPERIMENTAL SETUP

A Magnetron ion source with a slit extraction system is used at Fermilab for the production of H minus ions⁶. Ions are extracted from the source at 20 keV, magnetically bent through 90 degrees and then further accelerated through a 750 kV column. In order to deflect the ion beam without adding additional electrodes to the cramped source region the extractor has been split down the middle. Figure 1 shows the Fermilab magnetron ion source and the split extractor. The 30 kV standoff and electrical feed through, on the left, replaced an observation window. Glass beads are now used to insulate the cables inside the vacuum instead of the Kapton tubing, shown in fig. 1, which would turn greenish-black after several month of use and start to conduct along its exposed surfaces.

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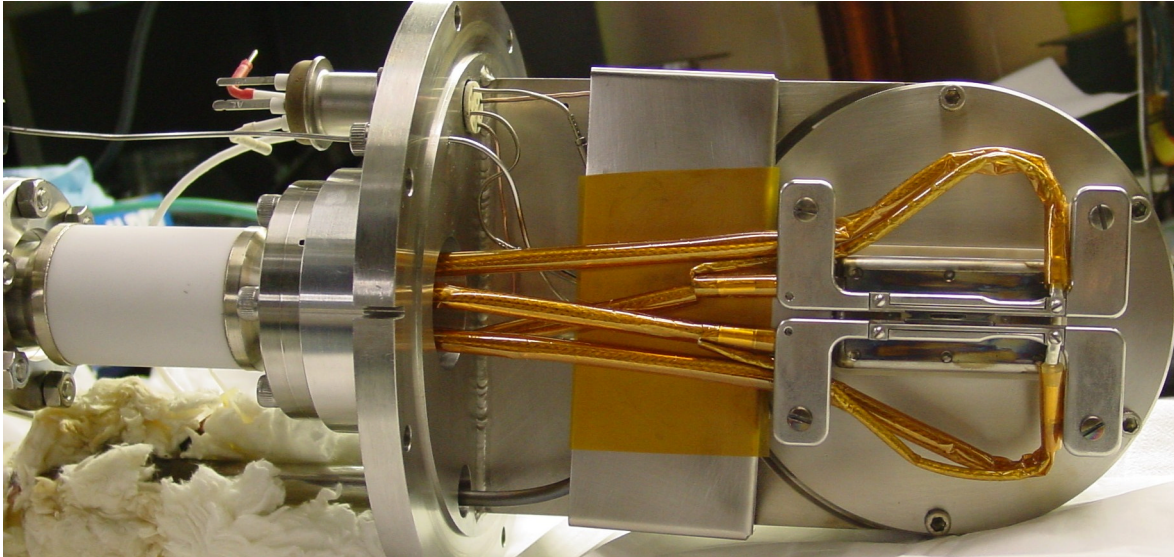


Fig. 1. A picture of the split extractor used to extract H minus ions from the magnetron. The extractor components are mounted on 2.54 cm ceramic standoffs and are aligned by eye with the anode slit. The Kapton tubing shown here has been replaced by glass beads in recent experiments.

The tip of the extractor and the anode slit are aligned by eye and separated by approximately 2 mm using ceramic standoffs as mounting posts. The extractor slit width is also set to 2 mm using a feeler gauge. The anode slit is currently 0.7 x 10 mm.

Beam notching is accomplished by treating each half of the extractor as part of a 50 ohm transmission line which can be pulsed at ± 700 volts creating a 1400 volt gradient across the split extractor. Electrically the extraction electrodes appear as a 10 cm break in the transmission line. A 20 ns electrical pulse in standard 50 ohm coax has about a 4 m wave front so the extractor component of the transmission line should be invisible to the pulse. To verify this assumption, the reflected power was measured using TTL pulses and time domain reflectometry. A reflected power of 5-10% was measured. This result was strongly coupled to the connection quality at the extraction electrodes. The polarity of the voltage gradient is significant and is selected in order to optimize beam notch.

The ± 700 volt high-voltage (HV) pulser, the 50 ohm loads and the vacuum feed through are electrically floated on top of the pulsed extraction voltage, typically 20 kV. The gate for the HV pulser is provided by a fiber optic network producing TTL pulses of the desired width. At least 3 Booster buckets, each 26 ns in width, are required to fire the Booster extraction magnet so the notch should be at least 78 ns wide.

The effective beam transition time can be computed by summing the electrical transition time of the HV pulser, the ion transit time through the extractor, and the curved path through the 90 degree bending magnet. The beam dynamics for a pair of deflection plates is described with more detail in reference 7. An in house, dual-polarity high-voltage FET power supply was built for this application. Occasional sparking of the extraction system does not appear to be a problem for this supply. The electrical rise times are around 25 ns while the 55 ns fall times are slower than expected. Due to path length differences in the magnet, ions extracted from the source simultaneously will exit the magnet at different times. A SIMION model of the magnet suggests that 20 keV ions are dispersed in time by roughly 10 ns. Adding the above times to the 5 ns ion transit time through the extractor, 9.5 mm wide along the beam path, gives effective beam fall and rise times of 40 ns and 70 ns respectively.

ACCELERATOR RESULTS AND DISCUSSION

Figure 2 shows a beam trace from a Pearson current transformer with a 50 ns response time in the 750 keV beam transport line. In this case, 8 notches were created to match the number of turns being injected into the Booster. The burst frequency is set to match the Booster

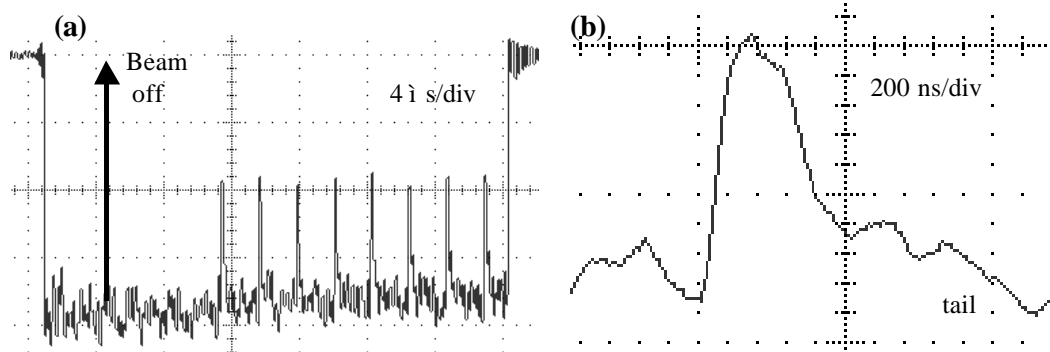


Fig. 2a. A 20 mA beam of H minus with 50% notching observed at 750 keV using a Pearson current transformer. The rise and fall times of one notch is magnified in figure 2b.

injection frequency of 454 kHz. The applied voltage gradient at this time was 1200 volts, limited by resistors in the HV supply. In figure 2, the notches are 100 ns wide with approximately 40 ns and 70 ns rise and fall times respectively, as expected. The droop in beam intensity over the notching period, in this case about 1.5 mA, is associated with an extended tail in the beam recovery time of each notch. The cause of this tail is not yet understood. Theories being investigated include electrode charging, meniscus disruption and recovery, and beam space charge recovery.

The low energy end of the Fermilab Linac⁸ operates at 200 MHz. Once the H minus ions are bunched and captured in the Linac the beam structure should be retained. A Beam Position Monitor (BPM) was used to measure one notch at 10 MeV. The raw BPM signal as observed by a fast oscilloscope is shown in fig. 3. The beam current is proportional to the signal strength so the notch depth at 10 MeV is 50% as expected.

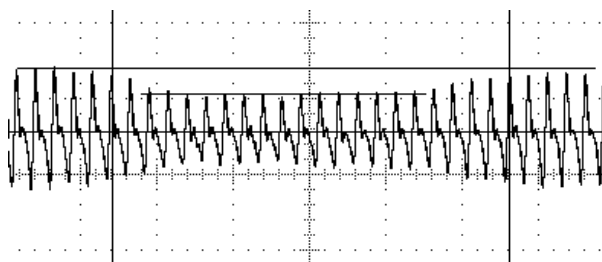


Fig. 3. The raw BPM signal of a single notch measured at 10 MeV. Vertical and horizontal lines are added to guide the eye. The RF frequency is 200 MHz and the horizontal scale is 20 ns/div.

Figure 4(a) shows the first 4 turns of charge being injected into the Booster as measured by a torroid. The notch appears to grow with each injection. Figure 4(b) shows the signal from a phase detector in the Booster and compares notched and un-notched beam at 400 MeV, 2.4 ns into the machine cycle, just before the Booster extraction magnet would fire creating the traditional Booster extraction gap. In turn 4, right side of fig. 4a, the notch appears to be about 50%, however in figure 4b the beam reduction is only 35%. During charge injection into the Booster the Booster RF is turned down allowing the 200 MHz linac

structure to fade prior to rebunching at 38 MHz for acceleration to 8 GeV. Thus the notch is adversely affected by the longitudinal space charge forces and in this case a reduction of 15% in notching efficiency was observed.

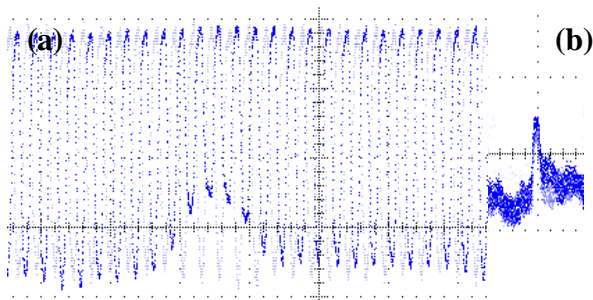


Fig. 4. (a) Torroid signal of the first 4 turns of charge being injected into the Booster with the notch present on the left of each step. (b) Phase detector signal showing the Booster notch at 400 MeV, before acceleration. The lighter trace shows an un-notch Booster cycle.

In this experiment, only a trigger was available from the Booster. Thus the 100 ns pulse train, shown in figure 2, was created by a pulse generator in burst mode. The frequency of the pulse generator was adjusted to optimize the notch efficiency. Better timing and a cleaner notch at 750 keV should help improve the notching efficiency in the Booster. Once implemented, the notch will be timed in reducing the amount of beam kicked out at 4 MeV.

An attempt has also been made to reduce the losses at the Linac switching magnet, where beam is sent to the Booster. A 150 ns notch was created and timed in using BPM's near the switching magnet at 400 MeV. Under normal operating conditions, a reduced activation rate of 25% was observed at the front end of the switching magnet. In this experiment, a beam reduction of 95% was measured at 400 MeV, during the notch, while the reduction at 750 keV was only 50%. This suggests that under certain conditions ions may continue to fall out of the notches as they propagate down the Linac. Efforts to scrape the beam in the 750 keV line have begun in hopes of improving the low energy notch.

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