

# FERMILAB BOOSTER CHARGE AS A FUNCTION OF LINAC INTENSITY

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## *Abstract*

A common belief at Fermilab has been that the Booster performed best when the Linac operated at the highest possible beam currents. In order to provide these high currents the Linac has been running at least 50% above the design intensity since shortly after the Linac upgrade in 1993. Early in 2002 it was decided to investigate this dependence to see if the Booster operated more efficiently with a higher Linac current and a low number of turns.

## 1 INTRODUCTION

Steady increases in Linac current over the last five years with simultaneous increases in the Booster performance has led to a belief that higher Linac currents produce more protons out of the Booster with higher efficiency. This trend toward higher intensities is driven by the demands of the high energy physics program. Further demands on the Booster for increased proton output continue to exist. To meet this demand it was assumed that the Linac output current would need to be increased from 50mA to 80mA. To achieve this the ion source output would need to go from 70mA to 115 mA. Roughly 30% of the beam is lost in bunching between the ion source and the output of Tank 1. A research and development program was laid out to increase ion source performance prior to the initiation of this study.

The capacity of the side-coupled structure to accelerate higher beam currents was studied in a 1999 proton beam experiment\*, which determined that a beam of 86 mA at a pulse length of 90  $\mu$ s could be accelerated to 400 MeV[1]. This study also found that at the highest beam intensities improvements in the beam quality would be necessary to minimize activation of accelerator components.

Because of the demands that increased beam currents would place on the Linac and H<sup>+</sup> ion source it was proposed that increased proton yields could also be achieved by increasing the number of turns injected into the Booster without loss of transmission efficiency. Operational experience suggested that 10-12 injection turns optimized Booster transmission, which is of fundamental importance in minimizing activation in the Booster tunnel. To test this theory, it was proposed to decrease the Linac current to 30 mA while increasing the ion source pulse length to 90  $\mu$ s to achieve 20 injected turns. Assuming it was possible to achieve a comparable Booster output of  $5 \times 10^{12}$  proton per pulse (ppp) a test operational period would be used to assess the pros and

cons of this mode of operation. Should antiproton production suffer during that period normal high current operation would be resumed.

## 2 EXPERIMENT DESCRIPTION

The current from the ion source can be reduced in several ways such as lowering the gas pressure, reducing the arc current or the extraction voltage. Although these techniques have advantages for long term operation, changing source parameters requires time for stabilization as the temperature, gas load and cesium coverage migrate toward a new equilibrium. For the initial Booster tests it was necessary to be able to quickly switch back to a 50mA beam should the required  $5 \times 10^{12}$  ppp not be achievable in the lower Linac current. Two ways of reducing the beam intensity at the end of the Linac were tested and the beam quality was compared to that of reducing the source pressure. In each case, the beam intensity at the end of the Linac was set to 30 mA and diagnostic wires (81 and wire5) near the end of the Linac were passed through the beam to measure the average spot size and energy spread. Two beam line methods are available for reducing the current. The first method is to change the phase on the RF buncher but this proved to be unstable to use. This method also had a detrimental effect on the bunch shape at 201 Mhz. The second method is to detune one of the early quadrupole magnets. This method proved to be easier and more stable.

In order to provide the Booster with 20 turns of beam the RF pulse lengths in the 805 MHz section of the Linac were increased, providing at least 48.6 $\mu$ sec for beam acceleration corresponding to 21.3 injected turns into the Booster. The 201 MHz RF Stations have a flat-top length of 130  $\mu$ sec and of this 80 $\mu$ sec is available to accelerate the beam.

Booster tests were made at a Linac output current of 30mA to determine whether the  $5 \times 10^{12}$  ppp, required for antiproton production, could be maintained. With very little retuning it was found that in this mode  $4.6 \times 10^{12}$  ppp could be achieved with approximately 16 injected turns. At this point, it was decided that the low current mode of operation would be given a trial operational period. The trial went well but at 30mA the maximum number of turns were being used to achieve  $5 \times 10^{12}$  ppp leaving no room for fluctuations in Linac current. For this reason, it was decided to increase the Linac output current to 40mA and operation continued successfully for two months. Finally in order to verify results the beam intensity was returned to peak values.

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### 3 RESULTS

#### 3.1 Linac and Ion Source

The beam intensity at the end of the Linac was reduced from the nominal 50 mA to approximately 30 mA by mistuning an a quadrapole in the 750 keV transport line, detuning the phase of the RF Buncher and reducing the ion source gas pressure. Horizontal (X) and vertical (Y) beam profile measurements from wire 81 for each of the three reduction techniques are shown in Fig. 1 along with the nominal 50 mA beam profile. Similar beam profiles were observed on the other wires.

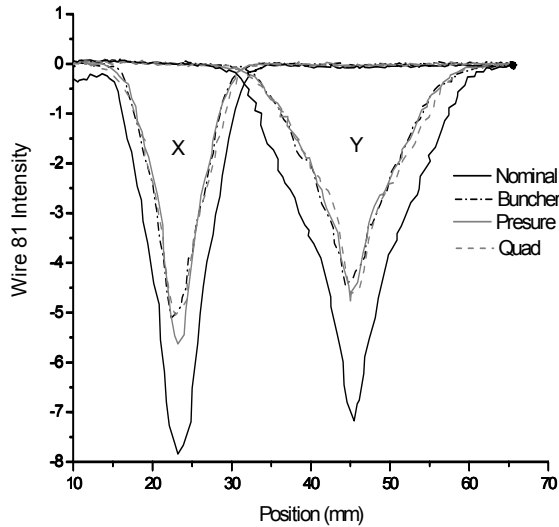


Fig 1. Wire 81 horizontal (X) and vertical (Y) beam profiles. The nominal beam current was 50 mA while the other measurements represent 30 mA beams.

Based on the beta function for a drift space a three-wire measurement can be used to measure the emittance. However, in this case only a general comparison was made based on the fact that emittance scales as the beam width squared in a drift space. From Fig. 1 there is roughly a 13 % decrease in emittance for the 30 mA beam as compared to the nominal 50 mA beam. Wire 5 has the potential to measure the energy spread in the beam if the transverse emittance is well known. In this case, only the profiles were compared and as expected they were similar. Since no gross deviations were evident in any of the wire scans all of the reduction techniques are considered analogous in the transverse direction.

Under reduced beam intensities the losses and beam loading in the Linac decrease proportionally. Figure 2 illustrates the average of all Linac loss monitors on a given day. Shown are the raw loss values and losses normalized to beam current. The values are not calibrated but show day to day changes. Figure 3 shows linac intensity for the same period. At 55 mA the beam loading on the klystron RF stations is approaching the level where some LLRF modifications are necessary for compensation [2].

Reducing the beam current by reducing the gas pressure, arc voltage and extraction voltage of the source

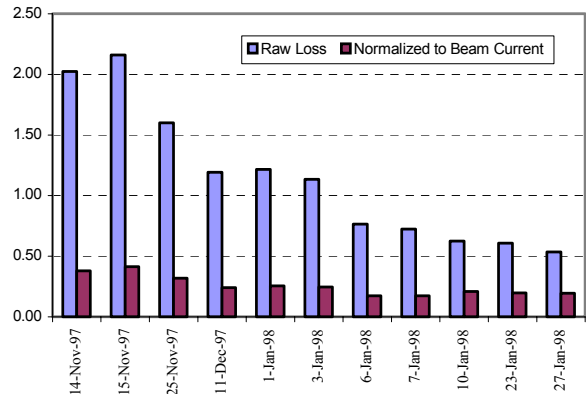


Fig. 2. Average of All Linac Loss Monitors

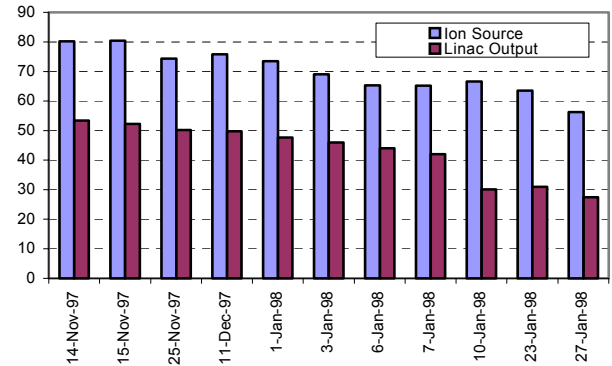


Fig. 3 Linac Ion Source and Output Intensity at 400MeV

has a number of advantages, all of which contribute to a longer source lifetime. Under nominal operating conditions the ion source needs to be replaced about once every 4 months. At 30 mA a magnetron source typically has a 6-month lifetime and at 40 mA the lifetime should be somewhere in between. In addition sparking around the ion source extractor is reduced with a lower extraction voltage. Lower gas consumption increases lifetime of the ion pump used to evacuate the 750keV column. Furthermore, in this low intensity mode of operation it may be possible to reduce the width of the source extraction aperture thereby improving the overall emittance of the Linac and possibly helping source stability.

#### 3.2 Booster

Booster performance was primarily studied in terms of output intensity and transmission efficiency. In both the high and low input current modes of operation peak intensities were achievable and thus transmission efficiency became the primary benchmark. Because there are many different Booster operating conditions that frequently, attempts were made to study the data as a function of intensity. Typical outputs from the Booster are around  $4.3 \times 10^{12}$  ppp and peak intensities at the present repetition rate of 0.4 Hz are around  $5.0 \times 10^{12}$  ppp. Somewhat higher values can be achieved but this results in unacceptable losses primarily at transition. Table 1 shows Booster transmission efficiency during antiproton

production cycles as a function of Linac current and charge out of the Booster. The Linac current was measured on D7TOR, a toroid at the end of the Linac. Booster charge was measured using device CHGA and

Table 1. Booster transmission efficiency  
Both Mean and Range Values Given

Dates	Linac Current(mA)	Booster Charge( $5 \times 10^{12}$ )	Booster Eff. (%)
1/10 to 2/13	29.7 26.6 to 32.2	4.6 4.5 to 5.0	66.2 62.2 to 73
2/16 to 3/15	40.2 37.5 to 43.4	4.6 e12 4.5 to 5.0	68.3 60.2 to 75.6
3/26 to 3/25	47 45.5 to 50.3	4.6 4.5 to 4.8	67.5 62.8 to 73

CHGB, which measure charge at injection and extraction respectively. Efficiency measurements were made during antiproton production cycles by dividing CHGB by CHGA for the same acceleration cycle. The data here only represent CHGB values greater than  $4.5 \times 10^{12}$  ppp since only the highest intensities out of the Booster are of interest. Figure 4 is a correlated plot of the entire data set. The gaps seen in CHGB and the efficiency were caused by faulty CHGA readings, which could not be reconstructed. From this data it appears that transmission efficiencies are comparable over this range of Linac currents.

### 4 CONCLUSIONS

It appears that moderately reduced Linac currents coupled with a higher number of injection turns into the Booster is a practical mode of operation with specific advantages for the Linac and the H<sup>-</sup> ion source. This mode of operation also provides a way of injecting more charge into the Booster than it can presently use. In addition, it creates some immediate headroom in Linac current, which may be tapped as Booster operation improves. Increases in Linac current, the other means to obtain more charge out of Booster, is not as readily available. Ion source research and development is underway and some progress has been made toward increasing H<sup>-</sup> currents [3]. Further tests of this conclusion will be made should stable higher current Linac beams become available.

### 5 REFERENCES

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 [2] R. E. Tomlin, Fermilab TM-2173, 2002.  
 [3] D.P. Moehs "Studies On A Magnetron Source", 9th International Symposium on the Production and Neutralization of Negative Ion Beam, CEA/Saclay France 2002.

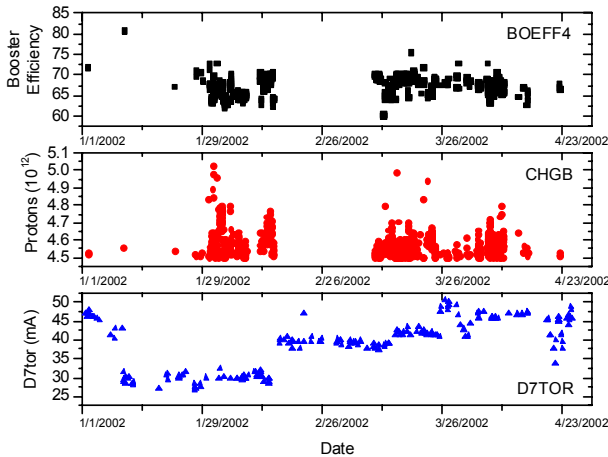


Figure 4. A correlated time plot of Booster transmission efficiency (BOEFF4) with the Charge out of the Booster (CHGB) and Linac current (D7TOR).