Beam Effects From an Increase of LINAC Current From 40 ma to 49 Milliampères

Ray Tomlin
FNAL

On March 25, 2002 the FNAL Linac had been running at a decreased 40 ma of beam current for some time. Both the 400 MeV Linac and the 8GeV Booster had been tuned to optimum running during that time. Optimum running for the Booster was at $4.1e12$ per pulse. Losses at injection and at transition were limiting intensity at the time.

By March 26, 2002 the Linac beam current had been increased to 49 ma. The optimum Booster intensity immediately jumped to $4.5e12$ per pulse and increased in the next few days to $4.8e12$ and $5e12$ per pulse. Booster was not retuned until early April when a low-loss $5.0e12$ was obtained for stacking operations. Linac current had sagged to 47 ma by then. Measurements were made on the 25th at 40 ma and the 26th and 27th at 49 ma. This is a report and discussion of those measurements.

Beam From Booster

A higher current Linac seemed best.

Main Injector flying wires were flown to catch beam when it arrived from Booster. Transverse emittances remained unchanged despite the 10 % increase in intensity from $4.1e12$ (40 ma Linac) to $4.4e12$ from Booster (49 ma Linac). The MI bunch length monitor showed 6.7 nanosecond bunches for both a 40 ma Linac (Booster at $4.1e12$) and a 49 ma Linac (Booster at $4.4e12$).

8 GeV multiwires showed no increase in (beam width) sigma despite running $4.8e12$ at 49 ma rather than the $4.1e12$ at 40 ma.

Beam in Booster

A higher current linac seemed best.

Beam width measurements during Booster acceleration were done with the Ion Profile Monitors. Vertical beam width was increased roughly 2.6% for the higher linac current. A 5% increase in width was seen in the last 3 milliseconds of acceleration at 8 GeV. Horizontal beam width was approximately 3% larger at injection and shrank to less than 1% larger after transition. Beam intensities were $4.1e12$ in Booster for 40 ma Linac and $4.4e12$ from the 49 ma Linac.

Beam energy lost in Booster decreased significantly when Linac current increased. BELOST was double during the first 5 milliseconds of acceleration for 40 ma Linac beam.

A lower current Linac seemed to lower losses seen on Booster BLMs.

Booster radiation monitors above ground showed nothing notable except a sharp increase at Booster period Short 8. These are the chipmunks that constitute the e-berm. Beam loss monitors in the tunnel scaled up with intensity. Losses were integrated over the acceleration cycle. Losses doubled at Period 13, a known aperture restriction. BLM data differentiated with respect to time showed most of the increase to be before 9 milliseconds. Beam intensities for these measurements were 4.1×10^{12} at 8 GeV for 40 ma Linac current, and 4.4×10^{12} at 8 GeV for 49 ma Linac current. None of these loss measurements are scaled or normalized to the two beam intensities encountered during these tests.

400 MeV injected beam

Low or high intensity beams are not favored here. Rather, one needs to consider how the Booster will handle beam having a larger energy range.

A look at 200 MHz bunches arriving at a Long 18 resistive wall pickup during 1st, 2nd, and 3rd revolutions shows an increase in bunch population. For the LINAC current increase of 22.5% (40 to 49 ma), there was a 35% increase in the observed 200 MHz bunches, a 2% increase in DC beam during the 1st turn, a 50% increase in DC beam during the 2nd turn, and no increase in DC beam during the 3rd turn. If the Booster acts like a mass spectrometer during the first 6 microseconds, then this shows that a lower current LINAC delivers a more monochromatic beam. But we know from the previous section (Beam in the Booster) that Booster could capture the increased energy spread associated with an increase in LINAC current from 40 to 49 milliamperes. Linac bunches are unevenly populated so an increase in observed bunch intensity that is larger than the beam current increase is possible.

Beam in the 400 MeV line

Trace 3D models used the same multiwire profile files and the BPM data for the line did not change significantly. Consequently the Trace 3D models were about the same for 40 and 49 ma beam.

There are two stripline beam pickups in the 400 MeV line. By measuring the phase between them, we can see the beam energy changing during the LINAC spill. This phase detector showed no difference between 40 and 49 ma beam currents save one; the 40 ma spill was actually a bit longer than the 49 ma spill.

Horizontal position at Q4, HPQ4, located downstream from MH1 remained unchanged in total slew (1.15mm), intra-spill 125 KHz, intra-spill 5MHz oscillation. Vertical position at Q8, VPQ8, located after vertical benders MV1-MV2 showed an increase in the 5 MHz vacuum instability as the spill ended. This improved on the second day. Since the 49 ma spill was actually shorter, this implies that an increase in beam current in the I- source has

a similar effect as lengthening the spill; that is growing vacuum oscillations in the 750KeV line.

400 MeV BPMs showed no change other than about a millimeter at HPQ4 and HPQ7. Beam on W5H showed a 10% increase in area. The tail to the left which was present during 40 ma running disappeared during 49 ma running. Beam on W5V showed a 31% increase and a significant lower tail went away with increased beam current.

400 MeV line losses stayed about the same except at Q4 which decreased from 0.5 R/S to 0.15 R/S when beam current increased from 40 to 49 milliamperes. This counterintuitive decrease may be due to the disappearance of the 40 ma beam tails.

Beam on 400 MeV multiwires generally showed a small decrease in horizontal sigma for 49 ma beam. MW3 was out of service. Vertical sigmas generally increased a small amount for 49 ma current. That increase might be attributed to the predominately vertical fast vacuum oscillations. These fast oscillations do paint Booster injection, and render single and multiwire scanners ineffective for monitoring beam quality.

Beam in the LINAC

Linac losses were smaller at 49 ma. 40 ma conditions showed higher losses at 51LM, 31LM and 400 MeV DELM4.

LINAC BPMs >2 mm horizontal change at 43BPH and 1 and 2 mm changes at 42BPV and 62BPV.

These changes in losses and positions are likely within the normal tuning range and do not matter. Since there are a couple hundred quads, their effect was not monitored.

Beam on BPMs in the low energy drift tube LINAC generally showed a marked increase of vertical vacuum oscillations during and especially near the end of spill. Horizontal position was slewing a lot as beam left tank 3 out. This slewing and the growth of vacuum oscillations with time attests to using a short, high current beam pulse rather than a longer, low current beam pulse.

Klystron beam loading was measured by measuring the difference due to beam as seen on L:CxPOWR where x is 1 through 7 and D (for the debuncher). In general beam loading increased by a half to one percent. Beam loading is approximately 3% for 40 ma beam and 4% for 49 ma beam.

Beam in the PREACC

This is where changes were made to increase the beam. Vacuum pressure remained unchanged. Vacuum pressure determines vacuum oscillations seen on the beam to Booster injection. These are the significant changes:

		<u>40 ma</u>	<u>49 ma</u>
IEXTV	extractor voltage	16.62 KV	21.47 KV
IEXTI	extractor current	-2.615 ma	-3.271 ma
IMAGI	Magnet current	-5.8 Amps	-7.6 Amps
IARCSV	arc voltage	296.4 V	301.5 V
Gas valve open		85 μ sec	87 μ sec
I- ground vacuum		2.6 μ torr	2.9 μ torr
I- Toroid #1		58.2 ma	78 ma

Summary

This data is fairly incomplete but a couple items listed favor 49 milliamper operation. In addition, other known operating limits favor 49 milliamper operation over 40 milliamper operation. Not included here is a set of LINAC single wire scans. This was not completed for two reasons; they are not particularly useful given the intra-beam instabilities in LINAC, and I ran out of time.

When seen from the LINAC, a higher current beam can cause a small increase in beam loading. The low energy quads (pulsed sine wave) would favor a shorter beam pulse. The klystron charging circuits favor a shorter beam pulse. Linac beam instabilities favor a shorter beam pulse. The slewing of beam position and the growth of vacuum oscillations with time attests to using a short, high current beam pulse rather than a longer, low current beam pulse. However pulse lengths were within 5 μ sec for the two beam currents tried here. The higher current did seem to produce vacuum instabilities not seen at the lower current, but the effect was not as severe as seen when spill continues long enough for the instabilities to grow.

When seen from the Booster, a short, high current pulse is best. This is likely because LINAC beam quality is better with a shorter 49 milliamper pulse than with a 40 milliamper pulse.

Finally, a couple other known things were happening during the time of these tests. Many of the LINAC DTL quads were not timed in so beam went through on the slopes of sine waves rather than at peaks. This has since been adjusted. The Booster longitudinal dampers were in a state of flux and only stable to first order rather than well tuned. Both runs were done using the I- source. The H- source has a completely different and much worse effect on beam position slewing and vacuum oscillations. Experience suggests that if H- is used, a shorter spill is much better. See Appendix A.

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3358&button=yes&inve>

Close Duplicate

Close Duplicate

Graphic

<http://www.bd.fnl.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3460&button=yes&invr>

49 ma

4.5 - 4.4e12

0.4

Close Duplicate

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3492&button=yes&invr>

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3418&button=yes&inve>

49 ma
4/4e12

Close Duplicate

40 ma
4.3e12

Close Duplicate

4.1e12 from 40 ma beam, 4.8e12 from 49 ma beam

4.1e12 from 40 ma beam, 4.8e12 from 49 ma beam.

MI8 MW vs 40 to 49 ma Linac Current

graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3362&button=yes&inve>

4.1e12

40 ma

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3420&button=yes&invr>

49 ma
4.4e 12

Close Duplicate

4.1e12
40 ma

Close Duplicate

Close Duplicate

49 ma
4.4e12

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3463&button=yes&inve>

4.1e12
40 m/s

49 ma

4He12

49 mtd
4.5e12

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3402&butto>

25-Mar-02
12:43:18

26-Mar-02
14:45:17

2 ns
17.3mV
17.3mV

200MHz bunches
49ma
1st pass at L18

2 ns

← 898.2 ns

1 disabled
2 10 mV 500 Ω
3 disabled
4 disabled

Δt 0.00 ns $\frac{1}{\Delta t}$ ∞

Ext DC 300mV 50 Ω

4 GS/s

NORMAL

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3403&butto>

25-Mar-82
12:43:42

26-Mar-02

14:45:50

2 ns
33.3 mV
33.3 mV

49 mA
200 MHz bunches
2nd pass L18
with 2nd turn on top.

2 ns

← 3.1538 μs

1 disabled
2 10 mV 500 Ω
3 disabled
4 disabled

Δt 0.00 ns 1/2 ∞

4 GS/s

Ext DC 300 mV 50 Ω

NORMAL

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3404&butto>

25-Mar-02
12:44:16

1 ← 2
2 ns
80.0 mV
80.0 mV

40 ma 200 MHz bunches
3rd pass, L18

2 ns
1 disabled
2 10 mV 500 Ω
3 disabled
4 disabled

Δt 0.00 ns 1/Δt ∞
Ext DC 300 mV 50 Ω

4 GS/s

NORMAL

Close Duplicate

26-Mar-02
14:46:30

2
2 ns
56.5 mV
56.5 mV

2 ns

← 5.5678 μs

1 disabled
2 10 mV 500 Ω
3 disabled
4 disabled

Δt 0.00 ns 1/2 ∞

Ext DC 300 mV 50 Ω

4 GS/s

NORMAL

Close Duplicate

49 ma @ L18
3rd pass of 1st turn
2nd pass of 2nd turn
1st pass of 3rd turn

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3470&button>

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3364&button=yes&inv>

40 ma

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3414&button=yes&invr>

49 mV

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=hooster&action=view&page=-3365&button=yes&inve>

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3416&button=yes&inve>

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3370&button=yes&invr>

40 mrad

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3424&button=yes&inv>

49 ma

Close Duplicate

i10 ma

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3425&button=yes&inv>

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3382&button=yes&inve>

40 ma

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3451&button=yes&inve>

W5H
49ma

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3385&button=yes&inv>

4.1e12
40 mA

Close Duplicate

Graphic

<http://www.bd.fnl.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3486&button=yes&inve>

49 ma

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3383&button=yes&inve>

40ma

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3452&button=yes&inv>

Close Duplicate

400 MeV Multiwire Sigma

4/1/02

4/1/02

4Pma

49 mva

Klystron Beam Loading

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3407&butto>

Tek Run: 5.00MS/s Envelope **IT02**

$\Delta: 39.4\mu s$
 $@: -100ns$

I⁻ source

BPV20T

40ma

Ch1 5.00mV

M 5.00μs Ch3 -130mV

25 Mar 2002
11:57:18

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3406&button>

Tek Run: 5.00MS/s Envelope 11102

26 Mar 2002
13:56:48

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3409&button=yes&inv>

Tek Run: 5.00MS/s Envelope

Close Duplicate

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3436&button>

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3408&butto>

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3435&button>

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=-3411&button>

Close Duplicate

PC-LAB		SOURCE PARAMS	
L48 I- SOURCE SURVEY	SET	D/A	H/D Con-U *COPIES*
-<FTP>+ *SA* X=H/D X=TIME	Y=B:BPBMA,M:TOR109,B:CHOB	A:PRDCTN	
COMMAND ... Eng=H I= 0	I= 0	0	0 10
-< 1>+ One+ AUTO F= 500	F= 200	10	10 20
SURVEY 750-key timers also	toroids	radmon reset	
-L:IBAOULT*1 I HIGH VOLTAGE	< >	745.2	KV
-L:IBARCEM I ARC SUPPLY VLTS	260.6	296.4	V
-L:IBAGCI I MAGNET CURRENT	-5.73	-5.801	A
-L:IBEXTV I EXTRACTION VLTS	16.95	16.62	KV
-L:IBEXTI I EXTRACTOR CURR		-2.615	MA
-L:IBGASV I GAS PULSED VLTS	100.9	99.19	V
-L:IBGASO I GAS OFFSET VLTS	-0.98	0	V
-L:IBGASOFF I GAS VALVE OFF	990.3	990.3	US
-L:IBGASON I GAS VALVE ON	905.6	905.6	US
-L:IBIPES I SRC PRES MAN AUT	21	21	UT
-L:IBIRCI I ARC CURRENT		-52.17	A
-L:IBIRCV I ARC VOLTAGE		-148	V
-L:IBITACFF I ARC OFF TIME	1994	1994	US
-L:IBICTEMP I CATHODE TEMP		357	DEG
-L:IBISTEMP I SOURCE TEMP		268.2	DEG
-L:IBITEMP I CS BOILER TEMP		144.6	DEG
-L:IBIGILV I CESIUM BOILER	-16.87	85.54	V
-L:IBIVAC I I GROUND VACUUM		2.558	UTR
-L:IBITOP1 I TOROID 1		* 68.19	MA
-L:IBTOLIN T1 TOROID IN		* -1.28	MA
-L:IBOTCR Module 7 Out Toroid		* 0	MA

40 ma

Close Duplicate

```

L48 I- SOURCE SURVEY          SET      D/A  A/D  Com-U ♦♦♦♦♦
-<INJ>+ *LINAC      TOROID FS < 80> MA      LOSSES FS < 20> MV
COMMAND *BOOSTER  INTENSITY < 5> E12
-< 1>+
SURVEY 750-key timers misc  toroids ..... radmon reset
-L: IHVOLT*.1 I  HIGH VOLTAGE          <  > 745.2 KV
-L: IARCSV    I  ARC SUPPLY VLTS        285.5 301.5 V
-L: IMAGI     I  MAGNET CURRENT        -0.52 -7.593 A
-L: IEXTIV    I  EXTRACTION VLTS       21.84 21.47 KV
-L: IEXTI     I  EXTRACTOR CURR        -3.271 MA
-L: IGASY     I  GAS PULSED VLTS       100.9 99.24 V
-L: IGASO     I  GAS OFFSET VLTS       -1.098 -1.006 V
-L: ITGSOFF   I  GAS VALVE OFF        992.9 992.9 US
-L: ITGON     I  GAS VALVE ON         905.6 905.6 US
-L: IPRES     I  SRC PRES  MAN AUT      23 22.94 UT
-L: IARCI     I  ARC CURRENT           -53.99 A
-L: IARCV     I  ARC VOLTAGE           -143.7 V
-L: ITAUFF    I  ARC OFF TIME          1994 1994 US
-L: ICTEMP    I  CATHODE TEMP           365.5 DEG
-L: ISTEMP    I  SOURCE TEMP            273.2 DEG
-L: ISTEMP    I  CS BOILER TEMP         145 DEG
-L: IBOLLY    I  CESIUM BOILER        -16.87 63.51 V
-L: IVAC      I  I GROUND VACUUM        2.867 UTR
-L: ITOR1     I  TOROID 1              * 78.08 MA
-L: ITORIN    I  TOROID IN              * -1.107 MA
-L: D7TOR     I  Module 7 Out Toroid    * 0 MA

```

49 ma

Appendix A

Beam from the H- source is described here as seen on early LINAC BPMs. These pictures illustrate why a short linac pulse is shorter. This also illustrates why we need to get a better handle on source conditions. We have merely “tuned up”, blind to the real character of the beam, for many years when switching sources. If the sources could deliver consistent and more monochromatic beam which held its position during the spill the linac would be much more stable.

The H- source has often been better for the Booster despite delivering poorer beam. A good deal more work needs to be done to move these observations from the realm of “lore” to that of knowledge. Scope signals of the horizontal BPM at the output of tank 3, relayed to the control room, could be used to tune the sources.

Any study which does not consider beam from BOTH sources is incomplete. Policies or opinions about whether low or high beam current is advantageous must include data from both sources.

BPH20T

H⁻ source

~46 ma

Graphic

<http://www-bd.fnal.gov/cgi-mach/machlog.pl?nb=booster&action=view&page=3669&button=y>

H⁺ source
BPH30T
note
doubling
to mv/div
= 10

4.1e12
40 ma