NuMI Extraction Geometry with Current Main Injector Orbits, Quad Offsets, and Correctors

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Current Closed Orbits and Correctors

The current closed orbit used for pbar production is shown in Figure 1. This is actually the “next to last” turn flash. Here the flattop momentum, according to page I2 is 119.7 GeV/c. The I6 LLRF control file contains a “ramptoFset” command to ramp the flattop frequency to 53.103040 Mhz. Additionally, there is a RPOS curve with a final 120 Gev level to 2.875. This produces about a 7 mm rpos offset, also shown in Figure 1. The dp/p is calculated to be 0.0042 from the BPM data, beam to the outside. The positions at the end of the 60 straight due to the momentum offset agree reasonably well with the

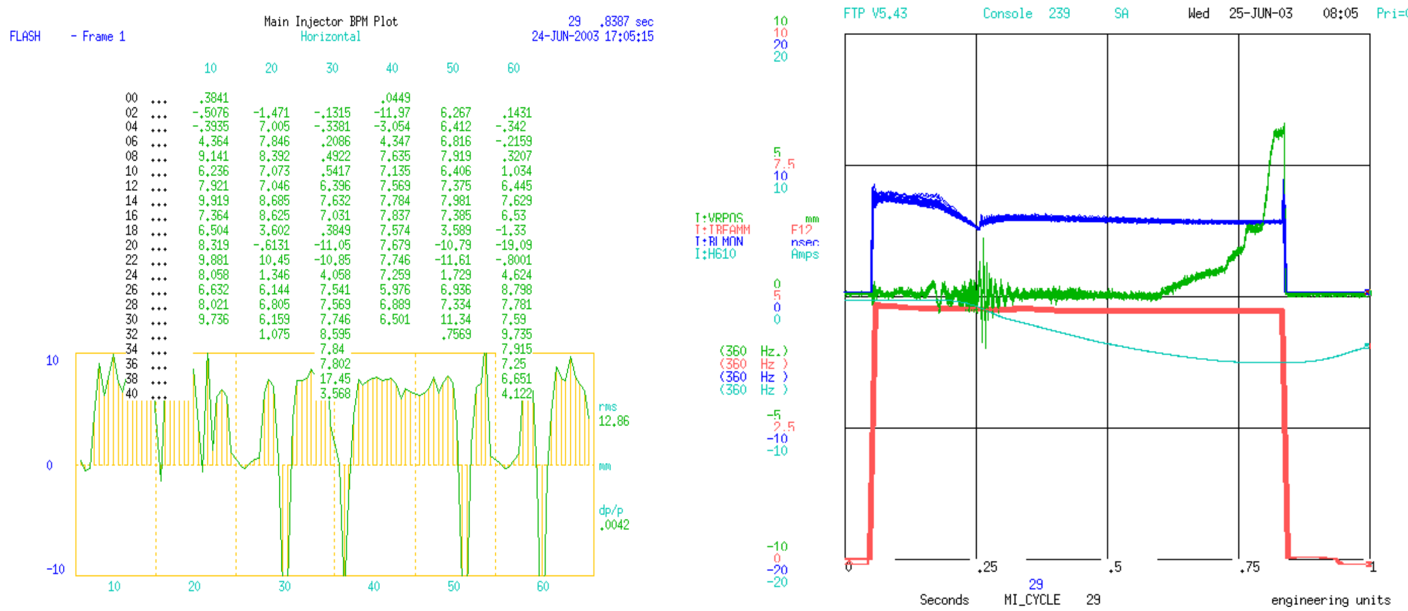

Figure 1. Flattop orbit and RPOS signal. Momentum offset is 0.0042.

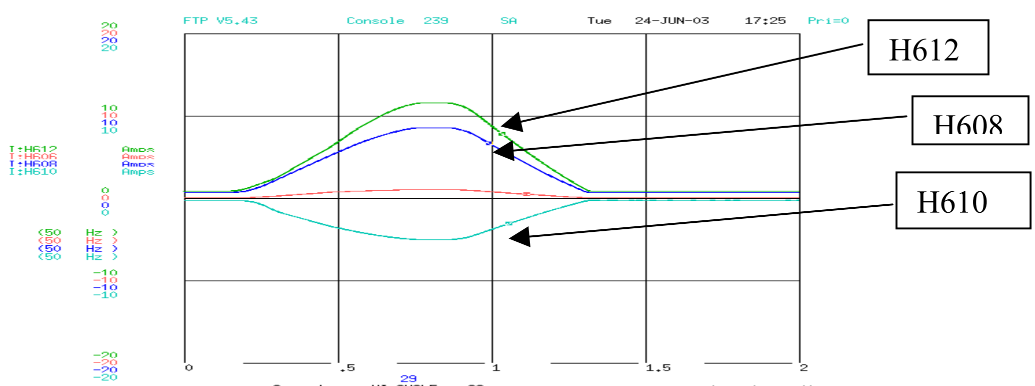

Figure 2 Current ramps for H606/H608/H610/H612

model. Specifically, HP608 (0 mm/0.32 mm), HP610 (1.2 mm/1.03 mm), HP612 (7.08 mm/6.45 mm), and HP614 (7.73 mm/7.6 mm) where the numbers in parenthesis are the (model/measured). The model does not include any closed orbit information.

The current ramps for the correctors around the Lambertson 608 are shown in Figure 2. It is clear that the current ramp is correcting an orbit distortion through out the complete ramp, not only at flattop. This suggests, potential alignment issues.

Figure 3 shows the current corrector settings at the flattop energy slot [6]. The parameter I:H606A is scaled in terms of amps. Also shown is the rms current (over 1-2 min time scale ?). Also, one can clearly see that the nominal currents in the first mult are close to zero which implies that the full current of the supply could be available for the kicker counterwave and we should not need to use quads for this motion.

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I65  120 GEV MI60 NUMI BUMPS        SET      D/A    A/D   Com-U  .COPIES.
-<FTP>+ *SA. X-A/D  X=TIME      Y=I:VRPOS ,I:IBEAMM,I:BLMON ,I:H610
COMMAND ---- Eng-U  I= 0        I=-10     , 0      ,-20     ,-20
-<18>+  s_MI AUTO   F= 1        F= 10     , 10     , 20     , 20
8g p/extr. 120 pbprod 120 SLOW   150 p/ext. reset levl 150.pb/ext

 H604     [6]:3
-I:H602A [6]*.1   Horizontal Trim @Q602      -.234      .134  Amps ..
-I:H604A [6]*.00553rizontal Trim @Q604      -.726     -.071  Amps ..
-I:H606A [6]*.09998rizontal Trim @Q606      1.022      .036  Amps ..


 H608     [6]:3
-I:H606A [6]*.1   Horizontal Trim @Q606      1.022      .036  Amps ..
-I:H608A [6]*-.00989izontal Trim @Q608      8.564      .656  Amps ..
-I:H610A [6]*.11681rizontal Trim @Q610     -5.039     -.271  Amps ..

 H610     [6]:3
-I:H608A [6]*.1   Horizontal Trim @Q608      8.564      .656  Amps ..
-I:H610A [6]*.02001rizontal Trim @Q610     -5.039     -.271  Amps ..
-I:H612A [6]*.12105rizontal Trim @Q612      11.55      .874  Amps ..

 H612     [6]:3
-I:H610A [6]*.1   Horizontal Trim @Q610     -5.039     -.271  Amps ..
-I:H612A [6]*.02041rizontal Trim @Q612      11.55      .874  Amps ..
-I:H614A [6]*.08404rizontal Trim @Q614     -4.866     -.304  Amps ..

 H608     [6]:4
-I:H606A [6]*.1   Horizontal Trim @Q606      1.022      .036  Amps ..
-I:H608A [6]*.09011rizontal Trim @Q608      8.564      .656  Amps ..
-I:H610A [6]*.13682rizontal Trim @Q610     -5.039     -.271  Amps ..
-I:H612A [6]*.12105rizontal Trim @Q612      11.55      .874  Amps ..


 I:H602I       H602 RMS Current                        .138  Amps
 I:H604I       H604 RMS Current                        .239  Amps
 I:H606I       H606 RMS Current                        .403  Amps
 I:H608I       H608 RMS Current                       3.239  Amps
 I:H610I       H610 RMS Current                       1.896  Amps
 I:H612I       H612 RMS Current                       4.276  Amps
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Figure 3. Current corrector settings and mult ratios.

Note that both H608 and H612 are already at approximately 10 amps and H610 is ~ -5 amps. to keep the orbit centered. The ratios of the current in these magnets imply that the beam is being steered inside by about 8 mm at HP610 and outside by about 5 mm at HP612. Also, these currents would add to any required for NuMI orbit control around the Lambertson.

However, further investigation of the currents at flattop showed a section of the ring with an average of ~ -7A indicating a potential alignment issues. Figure 4 shows all the horizontal corrector currents at 120 Gev. It should be noted there that some of the correctors are used to steer the beam around Lambertsons (such as H220 and H224) so the larger currents are not unexpected. I have indicated in the figure the regions where the

Lambertsons are installed (with black circles) and where we expect larger corrector currents. The 608-612 correctors are denoted in red.

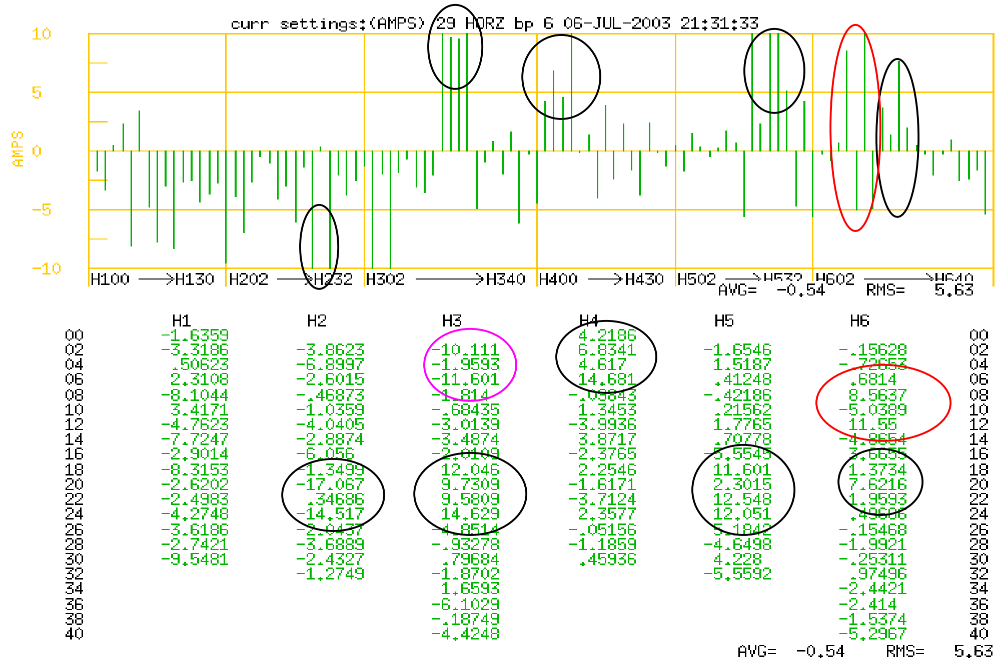

Figure 4: Corrector currents at 120 GeV/c. Correctors enclosed by black ellipses indicate those used to bump around Lambertsons. The ones enclosed in red are the ones we would like to reduce. The magenta ones shouldn't have to be that big, they can be reduced

The position at HP604 was adjusted via the H604:3 bump, to both the inside and outside. Figure 5 shows fast time plots of the H602 corrector current and the position at HP604, and the loss monitor at HP604 on a $29 120 GeV/c stacking cycle. For 28 amps in

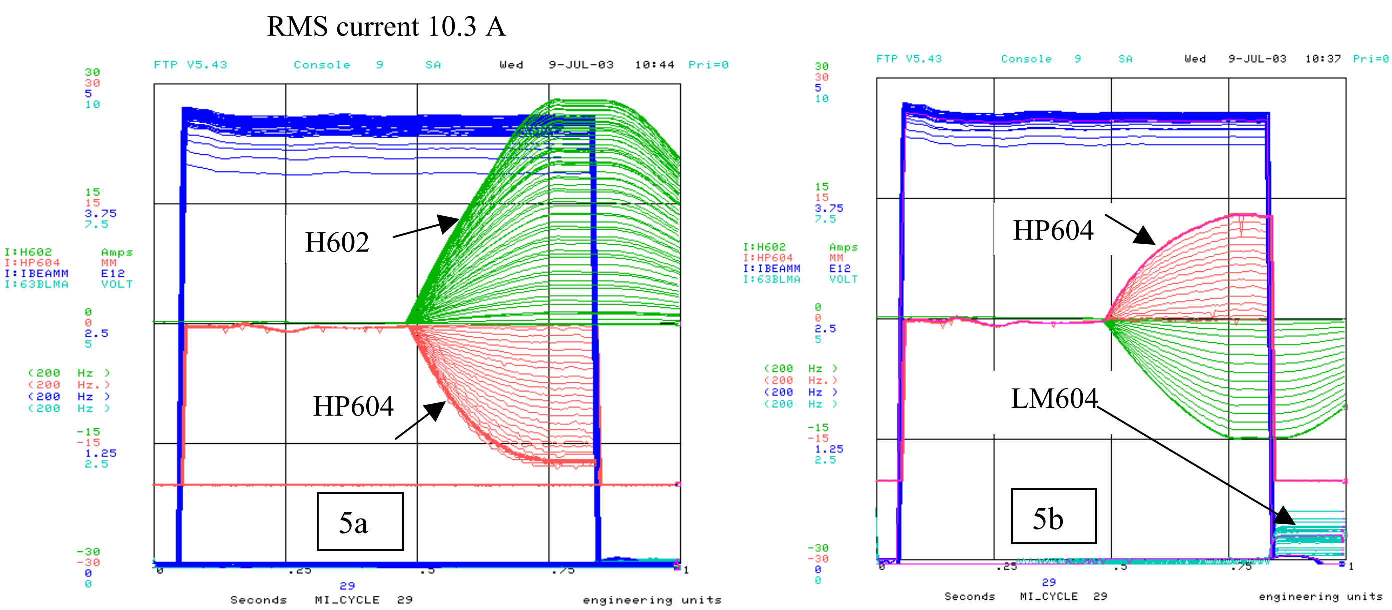

Figure 5: Position change due to H604:3 bump. a) inside and b) outside

For 28 amps in H602, the RMS current was 10.3 Amps, under the 12A rms suggested by Technical Division. Keeping the maximum current to 20 amps, the RMS current should not be a problem. In Figure 5a, the peak corrector current was achieved with no beam so the position/current cannot be determined from this plot (use 5b).

When the beam was moved outside, Figure 5b, to about 15 mm (the direction we want to move the counterwave), we begin to see losses at LM604 at extraction time for pbar production cycles. This is not understood and needs further attention.

Estimate Requires Corrector Currents and Quad Offsets

I would like to calculate the currents for the dipole fields listed in the current design report, Oct 2002. To do this, I assume the transfer constant, K, for the MI horizontal corrector is ~0.00712 T-m/A. With a length of 0.3048 meters this translates into a field/amp of ~0.2337 kG/A. For a 30A peak current (not suggested we run at this level) the maximum field (neglecting saturation) would be about 7 kG. At a more reasonable level, say 25 A, the maximum field is about 5.8 kG. Table 1 summarizes the "baseline design" corrector fields. The field and current values for H606 in the first three columns are a superposition of the currents required for the H604:3 counterwave mult and the Lambertson bump. The last column breaks this up into the two estimated values.

Table 1 Corrector fields and currents required for baseline orbit control with and without quad displacements

corrector	Baseline field w/ quad alignment [kG]	Current [A]	Baseline w/o quad alignment [kG]	Current [A]
H602	-0.726	-3.11	-3.67	-15.70
H604	-0.039	-0.17	-0.198	-0.85
H606	0.2076	0.89	1.101	4.71 (-15.7+20.4)
H608	1.3405	5.74	6.575	28.13
H610	1.4372	6.15	7.28	31.15
H612	1.5092	6.46	7.44	31.83

Clearly, the current in the 608/610/612 correctors is too high and we should not completely eliminate the quad displacements. However, based upon the present corrector settings and the required currents for the 15 mm bump at 604, I do not see any requirement for displacing quads Q602 or Q604. This would then mean we need to determine the relative contribution to the closed orbit bump for the H608:4 bump from quad displacements and corrector strength (making sure both components are closed).

If we limit the maximum corrector current to be used for the Lambertson closed orbit bump to 20 Amps, how far do the quads need to be displaced? The angle is then, $I*K/(\beta\rho)$ or 20*0.007125/400 ~ 356 ur maximum angle from a corrector at 20 Amps. I used MAD to determine the kick necessary to produce an 8 mm closed orbit offset at HP608 and HP610, then translated that into an approximate quad displacement from $dx = \vartheta/(K_1L)$ where L for IQB (84" quad) and IQE (84" quad/star vacuum chamber) is

2.1176 m and IQD (116"quad) is 2.93040 m, and K_1 for the QF bus is 0.04068 m^{-2}. Table 2 shows the kicks required for this 8 mm bump and the associated quad displacements. A

Table 2 Approximate* reduced quad displacements as calculated from the kick from the adjacent corrector.

Quad	β [m]	Ψ [2p]	ϑ [ur]	ΔX* [mm]
Q606	56.7	0	-129.26	-1.5
Q608	59	.254	-185.61	-2.15
Q610	43.1	.234	-199.06	-1.67
Q612	41.3	.29	-209.06	-1.75

* **A detailed calculation of the offsets is needed to assure the offsets produce a closed bump.**

Use these offsets, determine the corrector angle/strength to create the effective 22 mm closed orbit bump at 608 and 610. Table 3 shows the results..

Table 3 Required corrector strength for Lambertson bump in the presence of reduced quad displacements

corrector	ϑ [ur]	Current [Amps]	Mult ratio
H606	240.74	13.5	1.0
H608	290.52	16.3	1.2068
H610	349.38	19.6	1.4513
H612	356.05	20	1.479

Note the mult ratio's in the last column have changed compared to the current ratios for the four bump H608:4. This is due to the change in position of the corrector at H608 (it will be moved up stream by about 3 meters to a position in front of the LAM608A.

Summary

In reference to the Oct 2002 Design Report, several changes are suggested: 1) the quad Q602 offset has been zeroed, 2) a maximum of 20 amps in the corrector design is suggested, 3) the quad offsets around the Lambertsons were reduced. The correctors involved in the Lambertson bump are already running positive currents. Adding the corrector currents listed in Table 2 to those where we are presently running will put the supply over the limit. So, we need to address the current corrector strengths.

As can be seen from Figure 4 there are really several issues: 1) the negative avg current in 10 and 20 and 2) the large currents at the end of 60 straight. To reduce the currents HP610 needs to move outside and HP612 should move inside which counteract the natural dispersion suppressor off momentum orbit (as shown in figure 1 and 2). **This will need to be investigated before a final solution is accepted.**

The offsets and currents presented here are estimated. A future document will install the offsets and currents in MAD and generate orbits. Cross sections will be generated showing beam ellipse.

<u>Bottom line is that the quad off sets have been reduced or eliminated in the case of Q602 and the corrector currents for the specifiec three bumps should be well within power supply limitations, provided the present values of the H608, H610, and H612 120 GeV/c current are understood and reduced to approximately zero. IF this cannot be done, the quad offsets will be have to be increased or additional correctors installed.</u>