MI NOTE: #0161

Revised Recycler Pbar Transfer Lines

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Introduction

The initial concept for the transfer lines required for injection and extraction of pbars into and out of the Recycler and been described elsewhere. This note describes the geometry, optics, aperture, and magnet requirements for the transfer of pbars between the Main Injector (MI) and Recycler Ring (RR).

The Recycler was designed to follow the footprint of the Main Injector by utilizing the same basic cell geometry, with the exception of the RR-60 bypass. Therefore, the Recycler is directly over the Main Injector except in the region between 529 and 613 where the Recycler moves to the outside of the MI RF straight section (MI-60) by about 18 inches to bypass the MI RF cavities. The nominal elevation of the Recycler has been specified as 84 inches above the floor of the MI tunnel . The nominal elevation of the MI tunnel floor is 713.5 feet. The Main Injector beam center is nominally 27 inches above the floor, therefore the nominal separation between the Main Injector and Recycler is 57 inches.

The transfers of pbars to/from the Recycler are based about the MI-30 straight section where a single kicker, located between Q303 and Q304 (approximately 1 meter upstream) in the MI, is used for both pbar injection into and extraction from the MI. The MI/RR transfers take place in the straight sections on either side of MI-30. The transfer of pbars FROM the Main Injector TO the Recycler takes place in the MI-22 straight (via beamline BL22) while the transfer of pbars FROM the Recycler TO the Main Injector takes place in the MI-32 straight (via beamline BL32. Figure 1 shows the location of the kicker and the injection/extraction Lambertsons within the

Main Injector lattice. Here, pbars travel from right to left. Note that the both the injection (at MI-32) and extraction (at MI-22) Lambertsons are located approximately (modulo) 90 degrees in phase from the kicker.

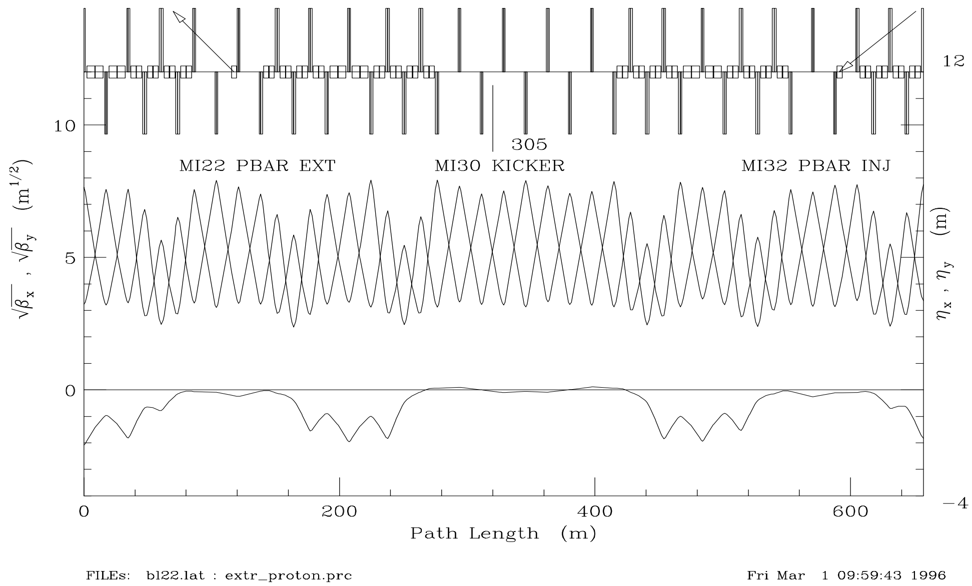

Figure 1: Main Injector lattice from quad 214 through 326 showing the pbar injection and extraction Lambertsons and the common kicker. Here pbars travel from right to left.

Pbar Injection into Recycler

Currently, all transfers of pbars into the Recycler are from the Main Injector at 8.9 GeV/c. Pbars from either the Accumulator (or recycled from the Tevatron) are injected into the MI at MI-52. Pbars from the Accumulator are injected into the MI at 8.9 GeV/c and the part of the MI from MI-52 to MI-30 simply acts as a single turn transport line. Recycled pbars from the Tevatron are injected at 150 GeV/c and require establishing a closed orbit around the Lambertsons and decelerated to 8.9 GeV/c before they are transfered into the Recycler. The pbars are extracted from the MI by the kicker at Q304 into the BL22 beamline and the Recycler. Figure 2 shows the

Main Injector lattice between 305 and 214and the locations of the extraction kicker and Lambertson. Pbars travel from left to right.

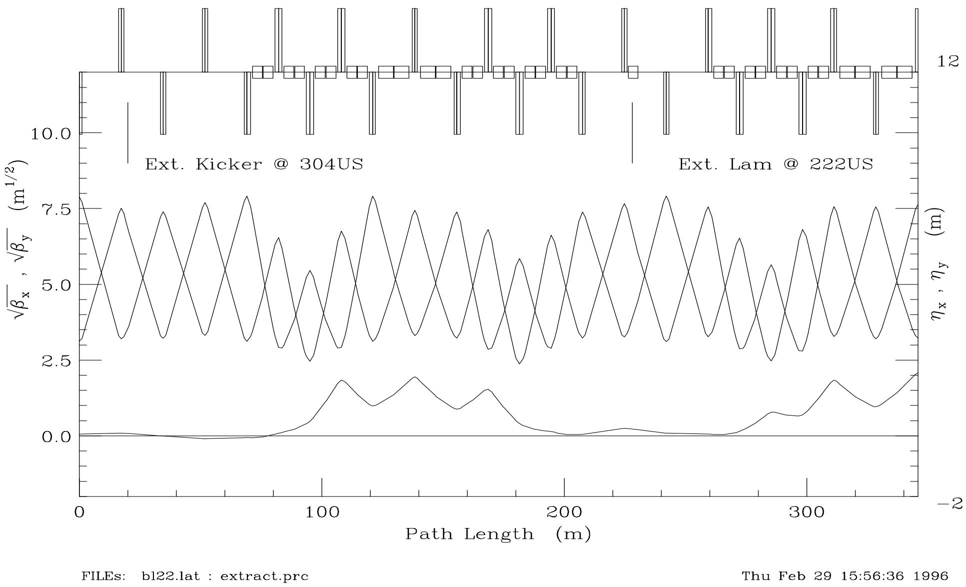

Figure 2: Main Injector lattice b etween 305 and 214 in the pbar direction showing the extraction kicker and Lambertson

The injection Lambertson in the Recycler Ring is located between magnets 215.2 and 216.1 in the first arc half-cell (215) next to the MI-22 dispersion suppressor insert. The injection kicker in the Recycler is located just upstream of Q104. This is the same kicker used for 8.9 GeV/c proton injection into the Recycler from Booster. Figure 3 shows the Recycler lattice between the injection Lambertson and the kicker. Pbars travel from left to right in this figure. The orientation of the Lambertsons in the MI for this study are such that the extracted/injected beam is always to the radial inside and the circulating beam is to the radial outside. The implication of this geometry is that the kickers at 304 need to change polarity between injection and extraction.

The beamline, BL22, connecting the two rings is made up of approximately four 90 degree Recycler cells. The lattice functions for the this beamline are shown in Figure 4.

The vertical bending is accomplished by the extraction and injection Lam-

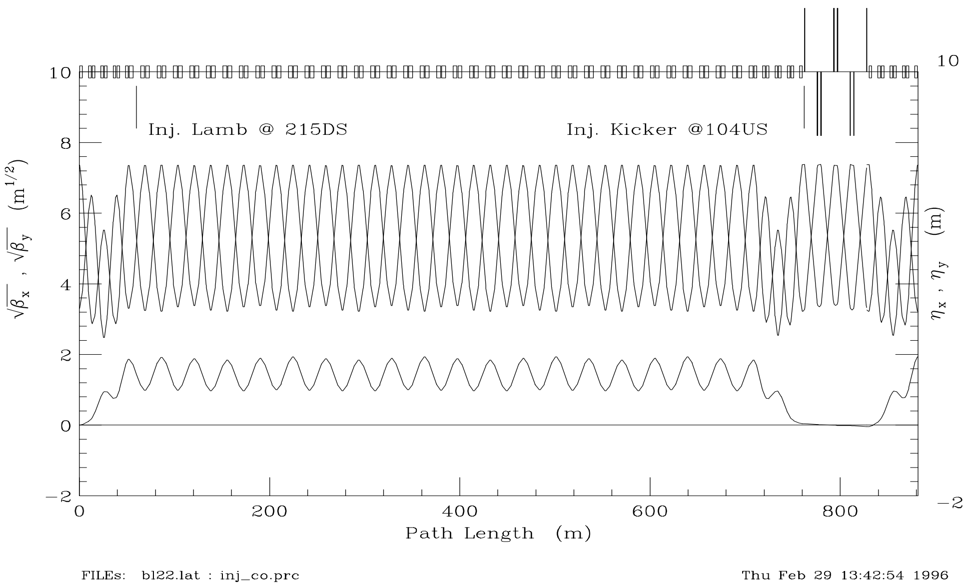

Figure 3: Recycler lattice between 220 and 638 showing the location of the injection Lambertson within the first arc cell after the dispersion suppressor and the location of the pbar injection kicker in the RR-100 straight section.

bertsons in addition to two vertical dipoles. The transfer line is composed of entirely of permanent magnets (including Lambertsons). Since the optics of the Recycler are very close to that of the Main Injector little additional matching is necessary. The extraction Lambertson ELAM bends the trajectory up by approximately 22 mr. to clear the downstream MI quad, vertical bend V1 levels the trajectory at approximately midway between the MI and Recycler. The vertical bend V2 produces a second up bend to intersect the Recycler ring at the injection Lambertson, ILAM. All four vertical bends are the same strength such that the vertical dispersion may be canceled by placing the ELAM and V2 (the up bends) 180 degrees apart and V1 and ILAM (the down bends) 180 degrees apart.

The RR arc gradient magnet closest to the injection Lambertson, in the direction of the beamline, will require a specialty magnet in the current beamline design due to the close proxmity of the beamline to the RR. There is on the order of only 3.6 meters between the Lambertson and the next arc magnet. At 22 mr of bend from the Lambertson, the transport trajectory

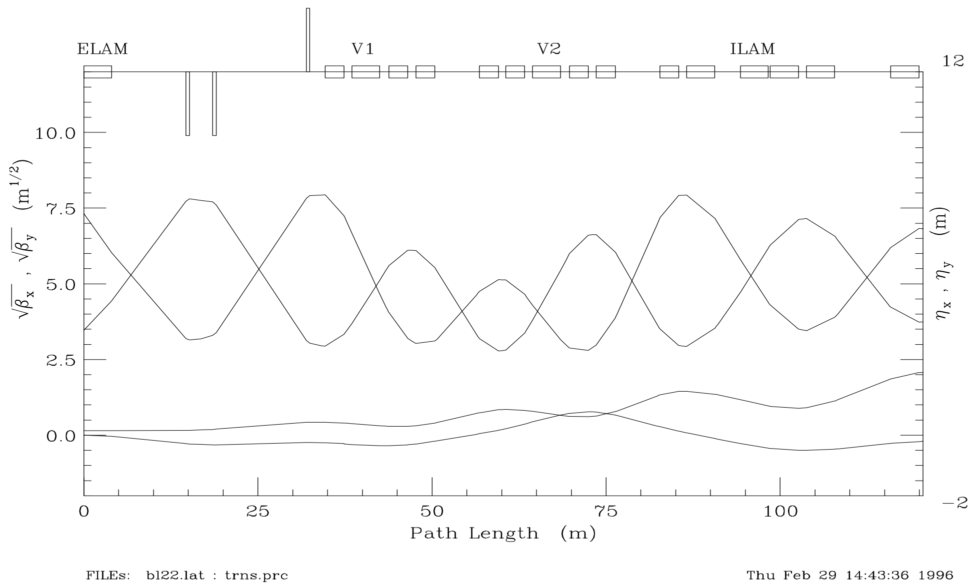

Figure 4: Pbar injection transport line, BL22, transporting pbars from the MI inot RR, showing the location of the vertical bends.

below the arc gradient magnet ranges from about 4.5 inches at the entrance to about 8 inches at the exit of the magnet. Inorder to accomodate this a special 2 in 1 magnet with the same field, gradient, and sextupole as the RR needs to be constructed.

Pbar Extraction from Recycler

Cooled pbars are extracted from the Recycler by the proton abort kicker located at Q400 in the Recycler. The Recycler pbar extraction Lambertson is located modulo 90 degrees downstream of the kicker between gradient magnets 327.2 and 328.1 in the arc half-cell 327. There are approximately 7.9 meters of free space between the gradient magnets at 327.2 and 328.1 to place the extraction Lambertson. The correct location for this is as far upstream in the pbar direction (as close to 328.1 as possible) to provide enough room to verticaly clear the downstream gradient magnet. Figure 5 shows the Recycler lattice from the RR-40 straight section (location of the extraction kicker) to the RR-32 downstream dispersion suppressor (location of the extraction Lambertson). Pbars travel from left to right.

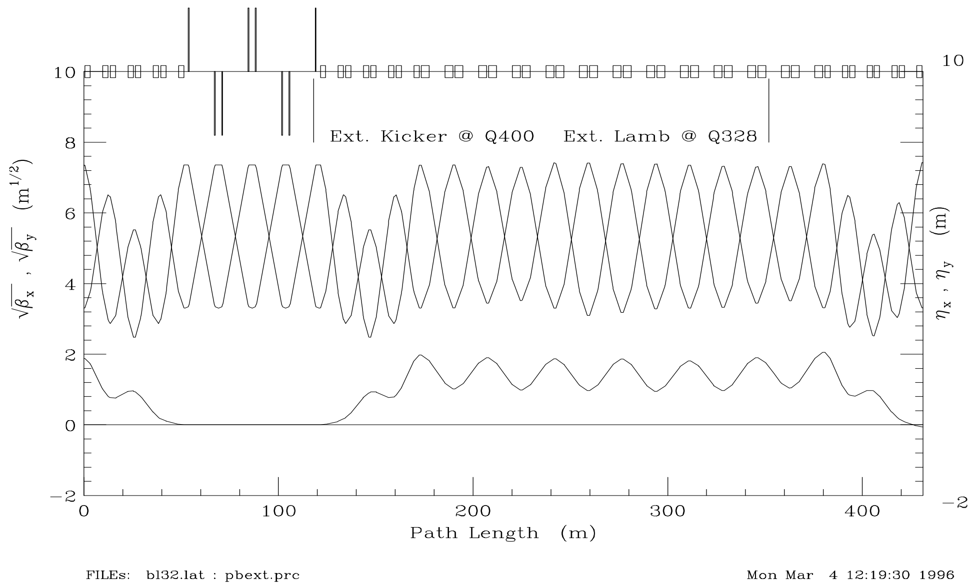

Figure 5: Recycler lattice from straight section RR-40 to RR32 showing the location of the extraction kicker and Lambertson.

The beamline geometry of BL32 is the same as that for the BL22 beamline with the exception that the beamline is shifted one half-cell farther from the MI-30 kicker to maintain the modulo 90 degree phase between kicker and Lambertson. Figure 6 shows the extraction beamline and locations of the major bends. In this figure, pbars travel from left to right. The four gradient magnets on either side of V1 and the three adjacent to V2 are recycler dispersion suppressor magnets while those between cell boundry 326 and ILAM are Recycler arc magnets. The lone quad in the beamline is the same as the Recycler straight section quad. The arc gradient magnet adjacent (in pbar direction) to the Lambertson is the second special 2 in 1 arc gradient magnet.

MI Closed Orbit and Aperture

The Main Injector beam pipe has a physical aperture of about ±63mm horizontally by about ±24mm vertically. The addition of the Lambertson into

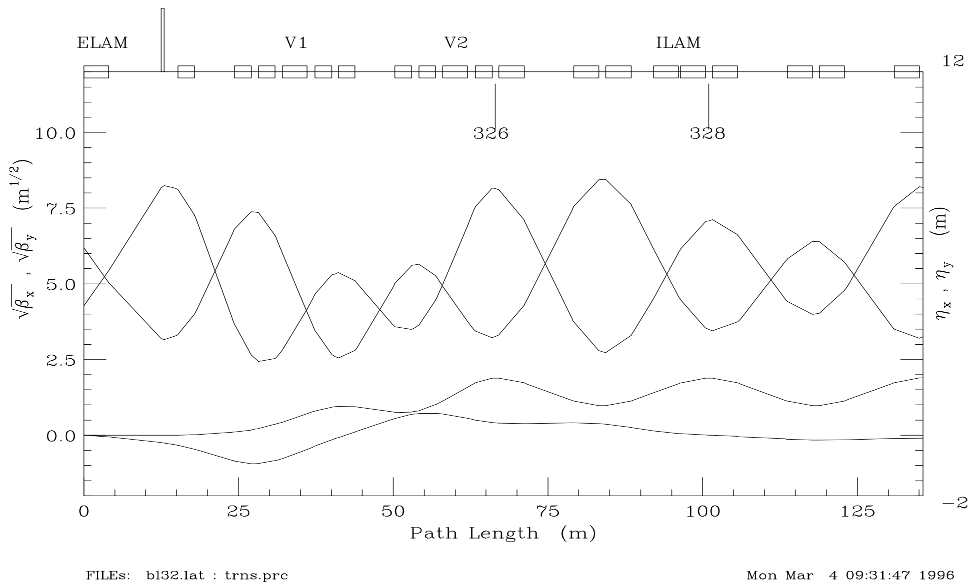

Figure 6: Pbar extraction transport line, BL32, transporting cooled pbars from the RR into the MI. Shown are the Lambertsons and vertical bends. Pbars travel from right to left.

the Main Injector aperture at 222.1 and 321.1 requires orbit control around the Lambertson to maintain a maximum the circulating beam aperture. This may be accomplished with dipole correctors or special quad alignment to produce the desired local orbit distortion or some combination. For the purposes here, correctors have been utilized. The requirement that the MI be able to circulate 40 πmm-mr beam must and has been maintained. The aperture requirement at these locations for slow spill has yet to be determined although they appear to be modulo 90 degrees from the MI-52 Lambertson.

Since the pbar extraction Lambertson is located 630 degrees upstream of the kicker, the extracted orbit undergoes two positive and two negative orbit excursion maxima. To transport a 40π normalized beam through both the field and field free regions of the Lambertson, a separation of about 50 mm between the centroids is required. This uses up approximately 85mm of the 126mm of aperture available. To get a 50 mm separation the kicker angle must be approximately 1 mr and kicks to the outside to produce the required excursion to the inside at the Lambertsons. The location of the Lambertson septa within the MI aperture determines the maximum excursion of both the circulating and extracted beam. To balance the excursions, the septa is placed closed to the center of the aperture and a kicker compensation bump is used to reduce the amplitude of the maximum excursion of the extracted beam. Figure 7 shows the MI closed orbit and the extracted beam orbit between the extraction kicker and Lambertson. Pbars travel from left to right.

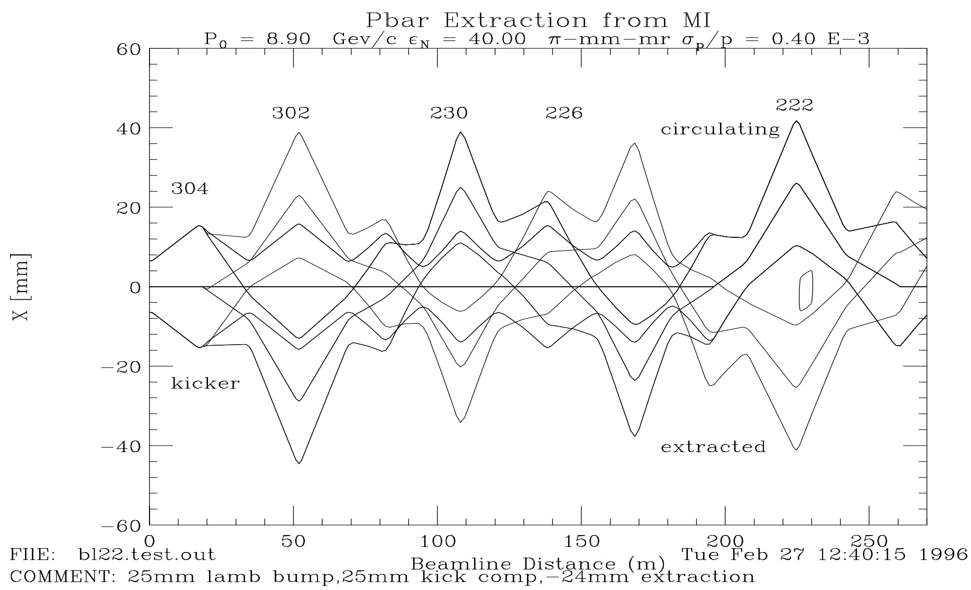

Figure 7: Circulating and extracted beam envelopes in the MI between the kicker at 304 and the Lambertson at 222.

The extraction kicker is located at about 20 meters and the Lambertson is located at about 225 meters in the figure. The septa of the Lambertson is assumed to be 8mm (0.315 inches) which includes the iron septa plus beampipes. The closed orbit is made up of two parts a Lambertson compensation bump and a kicker compensation bump. The Lambertson compensation bump produces a positive orbit distortion (to the outside of the ring) using the correctors at 220, 222, and 224. The kicker compensation bump produces a local distortion equal in amplitude and opposite in polarity of that produced by the kicker. The distortion is between 304 and 224 which are separated in phase by modulo 180 degrees and uses correctors at 304, 230, and 224. The required corrector strength of about 0.6 mr at 8.9 GeV/c is well within the range of the new MI correctors. In addition to these correctors, an additional corrector at 218 is required to give angle control at the Lambertsons, bringing a total of six correctors for circulating and extracted beam orbit control.

Due to the proximity of the extraction Lambertson to the MI quad, the extracted beam has an angle of approximately 1.2 mr toward the outside of the ring. This angle may be removed in the beamline by either displacing the first quads in the beamline or providing a corrector at the upstream end of the beamline. Beamline correctors 90 and 180 degrees upstream of the injection Lambertsons in each plane may be utilized fpr position and angle control of the injected beam at the Lambertson. The angle at the Lambertsons along with the injection kicker amplitude are used for matching onto the closed orbit.

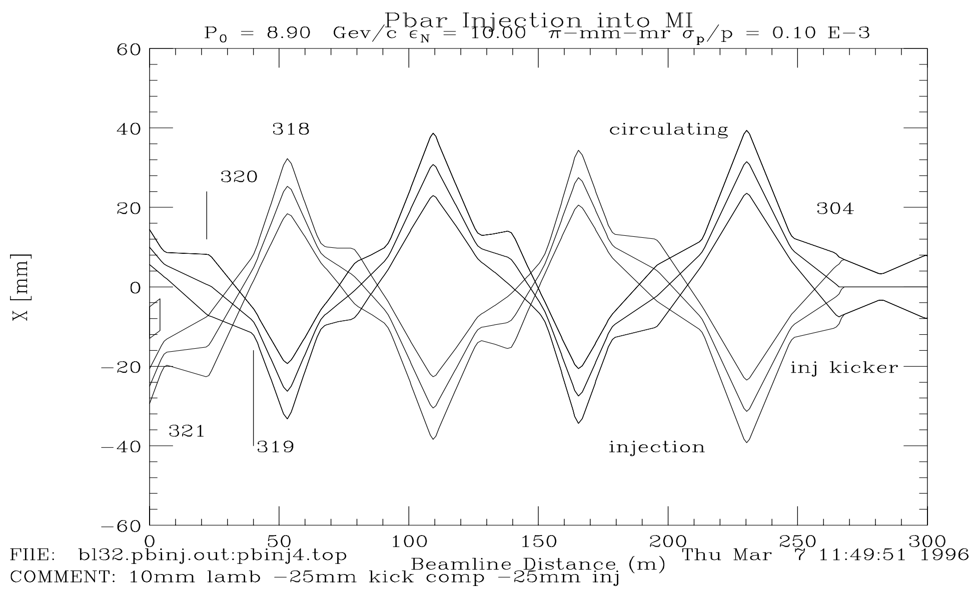

Figure 8: Circulating and injected beam beam envelopes in the MI between the injection Lambertson and the kicker at 304.

The MI pbar injection Lambertson is located adjacent to quad 321, therefore, the injection orbit undergoes two inside/outside maxima before being placed on the nominal MI closed orbit by the kicker at 304. Figure 8 shows the circulating and injected orbit in the MI for cooled pbars with an emittance (95% normalized) of 10π, the expected emittance of the cooled pbars. The location of the Lambertson septa within the Recycler aperture may be modified slightly from that of the pbar extraction Lambertson in that it may be moved farther from the circulating beam (to the inside) due to a smaller injected beam emittance. The circulating beam aperture still has to support 40π. The current solution bumps the beam to the outside by 10mm by using MI correctors located at 320, 322, and 324. Again, this orbit distortion may be generated using quad moves to assure that beam dose not scrape on the Lambertson septa if power is lost to the MI correctors. Similarly, the injection kicker closed orbit compensation bump is used to reduce the maximuma in the injection orbit, by using correctors at 320, 318, and 304. Standard MI correctors have plenty of strength.

RR Closed Orbit and Aperture

The Recycler aperture has been assumed to be 3.75 inches ($\approx \pm 48$ mm) horizontal by 1.75 inches ($\approx \pm 22$ mm) vertical. This reduced aperture, as compared to the MI, reduces the magnitude of the allowed closed orbit kicker compensation bump and the injected (or) extracted beam orbit. Figure 9 shows the circulating and injected pbars around the RR injection Lambertson for a 20π beam. The maximum excursion takes place in the arc at 212. Pbars travel from left to right in this figure. The injection kicker is not shown. A 15 mm Lambertson compensation bump has been shown using recyeled Main Ring correctors at 214, 216, 218. In addition, a -24mm kicker compensation bump has been added to reduce the excursion of the injected beam. This bump uses correctors at 214, 208, and 104.

Extraction of cooled pbars from the Recycler is initiated by the proton abort kicker at 400. Figure 10 shows the circulating and extraction orbit between the extraction kicker and Lambertson. As in other locations, the distorted circulating orbit is made up from contributions by a Lambertson compensation and an extraction kicker compensation bump. The beam envelope for 10π beam is shown. A circulating beam with 40 π will fill the circulating aperture. Correctors will be located at 400,340, 330, 328, and 326. An additional corrector located at 324 will add the capcbility of limited angle control into the extraction channel. Again these correctors will be

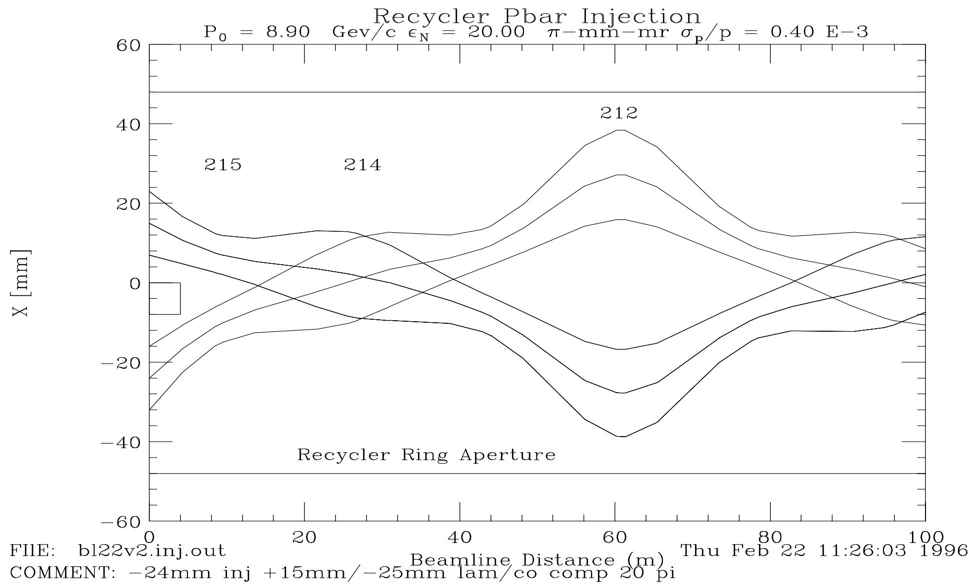

Figure 9: Circulating and injected beam envelope in the RR for the first 2 cells.

recycled from Main Ring.

Magnets

As indicated earlier, both injection and extraction beamlines are constructed of almost entirely of Recycler permanent magnets. They will use the Recycler arc and dispersion suppressor gradient magnets, straight section quads, new permanent magnet dipoles (as used in the 8 Gev line) for vertical bends, new permanent magnet Lambertsons, and a new design 2-in-1 arc gradient magnet using a mirror plate. This last magnet will be utilized for the Recycler and beamline and is adjacent to the Lambertson in the Recycler. The kicker requirements for the risetime, pulse length, and strength have been specified elsewhere.[**?**] The magnet specifications are summarized in Tables 1 and 2 for the injection and extraction lines, respectively.

The correction magnets to be used in the Main Injector will be the standard MI correctors. All correctors for use in the beamlines (BL22 or BL32) or the recycler are visioned to be recycled from Main Ring. Additionally, the

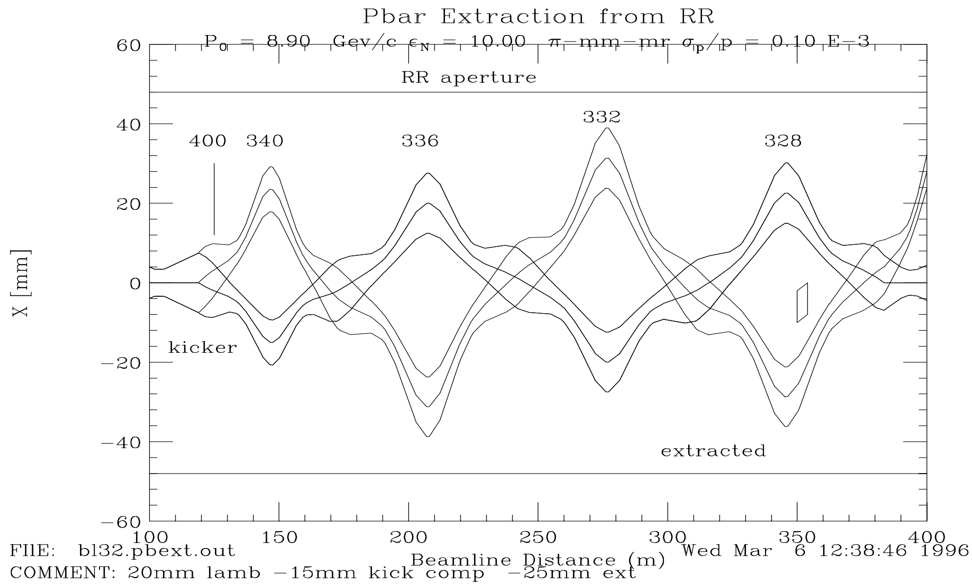

Figure 10: Circulating and extracted beam envelopes for a cooled pbar beam in the Recycler between the extraction kicker at 400 and the extraction Lambertson at 328. The physical aperture and Lambertson septa are indicated.

correctors should only be used to distort the orbit during the injection or extraction process and NOT for circulating beam. Table 3 summerizes the required correctors.

Additional Information

To incorporate this design, the tunnel inteferences must be throughly investigated. As of now, it is clear that the LCW headers for the Main Injector will have to be moved in the region between 212 and 222 and also between 320 and 330 to make room for the transfer line.

For this study, the Recycler has been assumed to be right over the Main injector at the nominal elevation. Final adjustment of vertical bends, roll angles, gradients, corrector strengths, will require better more precise knowledge of the relative geometry between the two rings.

Additional work is needed in both beamlines to resolve the question of how to construct the 2 in 1 ARCD and ARCF magnets. There are several schemes floating around but no clear solution exists at this time.

Table 1: BL22 Magnet Requirements

Magnet	Location	Length [m]	Number Req'd	Theta [mr]	B_0 [kG]	B_1 $[kG - m^{-1}]$
Ext. Kicker	MI-304	1.143	1	0.93	0.242	
Ext. Lambertson	MI-222	4.064	1	+23	1.678	-
BDISF (SGF)	beamline	3.0988	4	13.9	1.3301	6.682
BDISD (SGD)	beamline	3.0988	4	13.9	1.3301	-6.824
QF (RQM)	beamline	0.508	1	-	-	26.270
QD (RQM)	beamline	0.508	2	-	-	-25.318
V1 (4-4-30)	beamline	0.76	2	12.57	4.904	-
V2 (4-4-30)	beamline	0.76	2	-12.98	5.06	-
ARCF (RGF)	beamline	4.064	1	20.9	1.3752	3.355
MIRROR (RGMD)	ring(1)/beamline(2)	4.064	3	20.9	1.3752	-3.238
Inj. Lambertson	RR-214	4.064	1	-23	1.678	-
Inj. Kicker	RR-130	1.143	1	1.17	0.304	

Table 2: BL32 Magnet Requirements

Magnet	Location	Length [m]	Number Req'd	Theta [mr]	B_0 [kG]	B_1 $[kG - m^{-1}]$
Ext. Kicker	MI-400	1.143	1	0.91	0.270	
Ext. Lambertson	MI-328	4.064	1	+23	1.678	-
BDISF (SGF)	beamline	3.0988	3	13.9	1.3301	6.682
BDISD (SGD)	beamline	3.0988	4	13.9	1.3301	-6.824
QF (RQM)	beamline	0.508	1	-	-	26.270
V1 (4-4-30)	beamline	0.76	2	-11.52	4.49	-
V2 (4-4-30)	beamline	0.76	2	11.33	4.42	-
ARCF (RGF)	beamline	4.064	1	20.9	1.3752	3.355
MIRROR (RGMD)	ring(1)/beamline(2)	4.064	3	20.9	1.3752	-3.238
MIRROR (SGMF)	beamline	3.0988	1	13.9	1.3301	6.682
Inj. Lambertson	RR-321	4.064	1	-23	1.678	-
Inj. Kicker	RR-304	1.143	1	1.16	0.301	

Table 3: Corrector Summary

Purpose	location	size
MI ext. kick compensation (circ)	304,230,224	-25mm
MI ext. lamb position (circ & ext)	224,222,220	25mm
MI ext. Lamb angle (ext)	222,220,218	none
MI inj. kick compensation (circ)	304,318,320	-25mm
MI inj. lamb position (circ)	320,322,324	10mm
Beamline horizontal correctors	802,804,806	none
Beamline vertical correctors	801,803,805	none
RR ext. kick compensation (circ)	400,340,330	-15mm
RR ext. lamb position (circ & ext)	330,328,326	20mm
? RR ext. Lamb angle (ext)	328,326,324	none
RR inj. kick compensation (circ)	212,210,130	-25mm
RR inj. lamb position (circ)	216,214,212	15mm
Beamline horizontal correctors	702,704,706	none
Beamline vertical correctors	701,703,705,706	none