# DIAGNOSING THE PEP-II INJECTION SYSTEM*

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*Abstract*

The injection of beam into the PEP-II B-Factory, especially into the High Energy Ring (HER) has some challenges. A high background level in the BaBar detector has for a while inhibited us from trickling charge into the HER similar to the Low Energy Ring (LER). Analyzing the injection system has revealed many issues which could be improved. The injection bump between two kickers was not closed, mainly because the phase advance wasn't exactly 180° and the two kicker strengths were not balanced. Additionally we found reflections which kick the stored beam after the main kick and cause the average luminosity to drop about 3% for a 10 Hz injection rate. The strength of the overall kick is nearly twice as high as the design, indicating a much bigger effective septum thickness. Compared with single beam the background is worse when the HER beam is colliding with the LER beam. This hints that the beam-beam force and the observed vertical blow-up in the HER pushes the beam and especially the injected beam further out to the edge of the dynamic aperture or beyond.

## INTRODUCTION

For injecting charge into a PEP-II bucket the stored beam is kicked in $y$ close to a current sheet septum and the injected beam should be as close as possible to the other side of that septum (Fig. 1). After one turn both beams are on the inside of the septum, but the injected beam can be very close depending on the kicker amplitude and how strong it is mismatched.

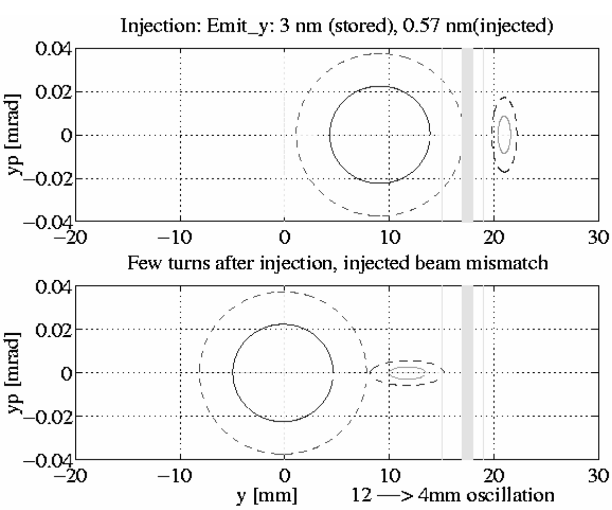


Figure 1: Stored, flat beam (6 and 10 $\sigma_y$) and injected beam (3 and 6 $\sigma_y$) at the septum (top at injection, bottom turns later). The 12 mm separation will cause a typical 4 mm orbit oscillations.

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The first goal is to get a low loss injection with a low background for the BaBar detector (a). Second, the stored beam shouldn't oscillate to avoid luminosity dips especially for trickle injection [1] and to avoid beam excitation which could cause an abort. (b). There are many issues for the lattice and the kickers to consider for achieving these goals (a and b):

Lattice:

1. Inject inside dynamic aperture (a)
2. Betatron phase advance between kickers 180° (b)
3. Dispersion of bump (a,b)
4. Nonlinear field near septum (a,b)

Kickers:

1. Kicker amplitudes not matched (b)
2. Kicker timing not matched (b)
3. Kicker reflection too big, not canceling (b)
4. Big excitation might cause aborts (b)
5. Kicker amplitude too big (a,b)
6. $x$-oscillation due to roll/coupling (a,b)

## LATTICE ISSUES

The dynamic aperture was never carefully measured in the PEP-II rings. A hint, at which amplitude the beam motion becomes nonlinear, is obtained by looking at a beam abort with vertical motion (Fig. 2).

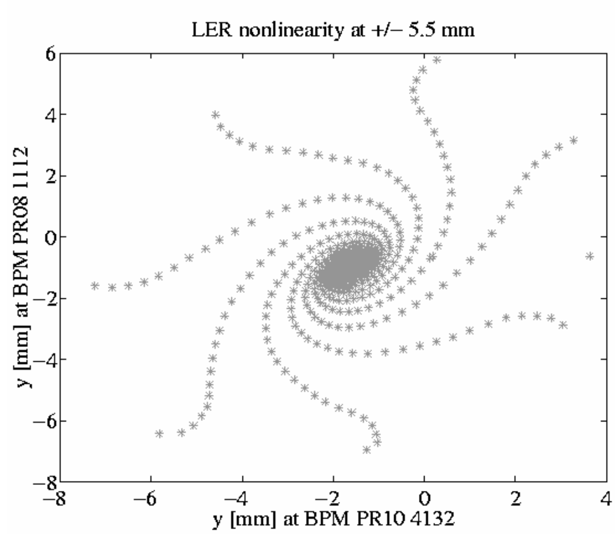


Figure 2: Beam abort caused by vertical motion. The outwards spiraling trajectories, seen by two beam position monitors (BPM) become nonlinear at around ±5.5 mm.

The nonlinear region starts at about 5.5 mm amplitude for the LER and 4.5 mm for the HER. This amplitude has to be compared with the typical first turn injection oscillation amplitude which was around 6.0 mm for the HER and was reduced to 4.5 mm for cleaner injection.

Two parts were essential to get this reduction, first bringing the beams closer at the septum and second reducing a kicker amplitude mismatch.

Initially the beams at the septum were setup so that there was no beam loss detected nearby. This was especially tricky for HER beam since it gets blown up in *y* by beam-beam forces. This caused an additional separation of the stored beam at the septum. By allowing a small beam loss of the halo particles the beam could be pushed closer to the septum by about 2.5 mm (or 0.8 mm less oscillations around the ring). Any reduction in the 13.5 mm dynamic aperture (number at the septum), which corresponds to a 4.5 mm oscillation around the ring due to different betatron function, should be avoided.

## INJECTION KICKERS

The injection system consists of two kickers 180° apart in betatron phase. Looking at Fig. 1 the minimum required kick should be around 9 mm, the center of the two ellipses. Measurements showed an amplitude of more like 21 mm which could be reduced to 14 mm by bringing the beam close by a DC bump. High kicker strengths don't hurt in principle, but a lower strength has the following advantages. Any non-closure effect is less (amplitude, timing, reflection, 180°, coupling), also if the injected part of the beam is bad for any reason and is too far away from the center it will be lost near the septum in the following turns instead of the detector.

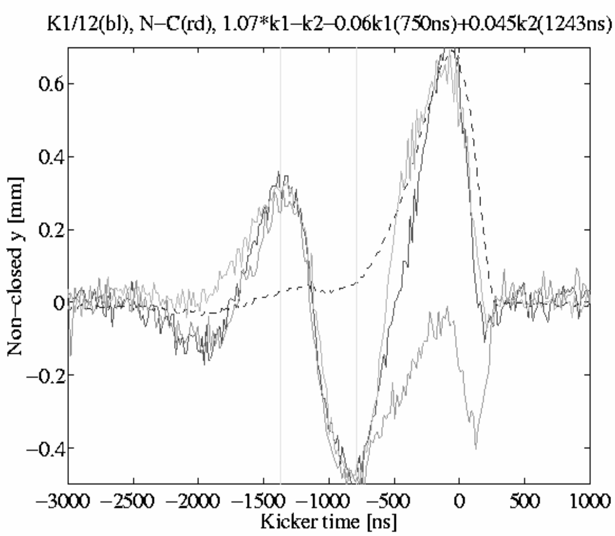


Figure 3: Non-closure of kicker bump. BPM responses in *y* of the stored beam were measured versus the kicker time, so the time of the beam goes from right to left! The blue (dashed) curve is at a BPM in side the bump (1/12), showing some ringing of kicker 1 (K1). The red curve shows three oscillations. The cyan curve is a try to fit these. The 1st (+0.7 mm) tells that K1 is 7% stronger than K2. The 2nd (-0.5 mm) shows a 6% reflection from K1 and the 3rd (+0.3 mm) a 4.5% from K2. The yellow vertical lines indicate when a reflection is expected from the different cable length to the kickers. The light, green curve shows the beam response after the ratio of K1/K2 was reduced by -10%.

### *Kicker Closure*

Figure 3 shows and explains the many non-closure effects of the kicker system, which consists of only one thyratron pulser supplying one pulse which goes to both kickers over different-length cables. This ensures that always both kickers work or none. But it has many disadvantages since the timing and the amplitude of each kicker cannot be adjusted separately. Also if the cable is not perfectly matched to the kicker the reflected pulses kick again the stored beam at two different times. Reflections in a two-pulser system with equal cable length would cancel and make only a small 2nd but closed bump. The HER kicker amplitude difference of 7% was intentionally over-corrected (-10%) during BaBar data taking by moving one of the resistors installed in front of the cables from one kicker to the other. The over-correction brings the injected beam closer to the beam center and offsets the stored beam somewhat.

The LER kicker timing was different by 10% of the cable length difference due to a ft/m conversion mistake and had to be fixed by adding cable to the second kicker. The connector of the splice seems to create an induction and therefore delays the pulse more than intended (Fig. 4). This delay and the reflection of the two kickers with the different cable lengths can be easily tuned out with a two pulser kicker system, which will be installed in the next down time.

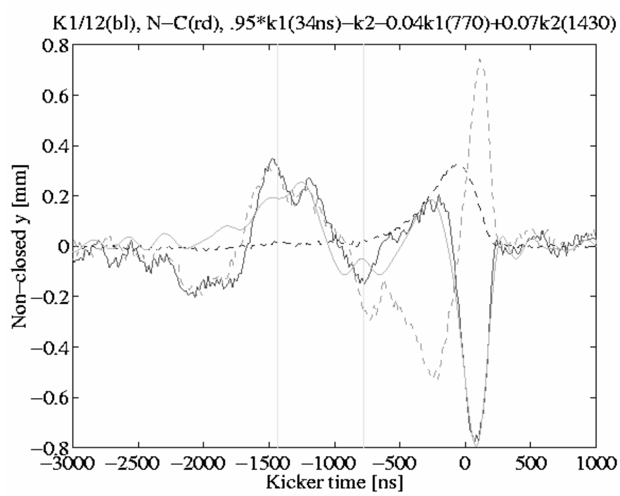


Figure 4: LER injection kicker closure shows timing problem. The sharp spike to the right comes from a mis-match in the timing. The yellow stripes show first and second kicker reflection. The green, dashed curve after a 'fix' shows that the cable delay was overcompensating.

### *Effects on the Beam*

The injection related background in BaBar has been described in another paper [2]. Mainly synchrotron oscillations were visible in LER and in HER the background rose slowly over 5 ms, which might have been an early indication of a dynamic aperture problem. Beyond the background any stored beam excitation is bad since it brings the beams out of collision reducing luminosity, which makes beam tuning harder (Fig. 5).

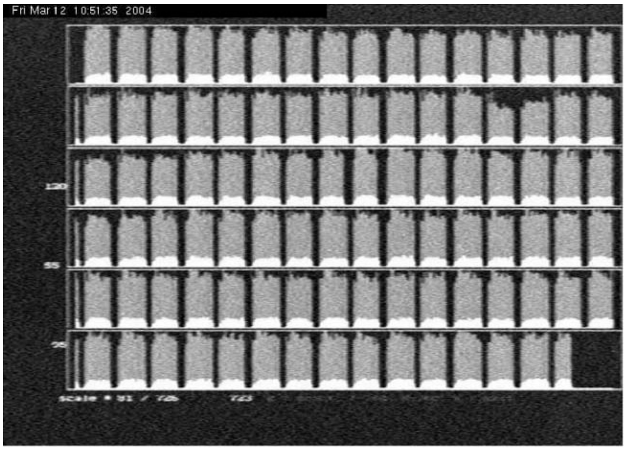


Figure 5: Luminosity versus bucket number. The LER injection non-closure brings the beam out of collisions and causes luminosity dips of up to 30%. The bunch pattern is basically by-2 with 95 trains of 14 or 15 bunches out of 18 places.

The HER had luminosity dips up to 50% and the LER up to 30%. Both could be reduced by bringing the stored beam closer to the septum with a DC bump and reducing the kicker strengths by 1/3. So the luminosity dips are now less than 15-20% and since the injection rates are about 1 Hz (HER) and 4 Hz (LER) the overall integrated effect is with <0.5% quite small (Fig. 6).

Since the beam is now very close to the septum, this area starts collimating any bigger injection oscillations, especially for LER. Due to some coupling in this area the LER non-closure in $x$ is as big as in $y$. Beam losses are often visible in $x$ where the dispersion is highest in the whole ring and the aperture is restricted by the vertical DC bend magnets at high $\beta_x$.

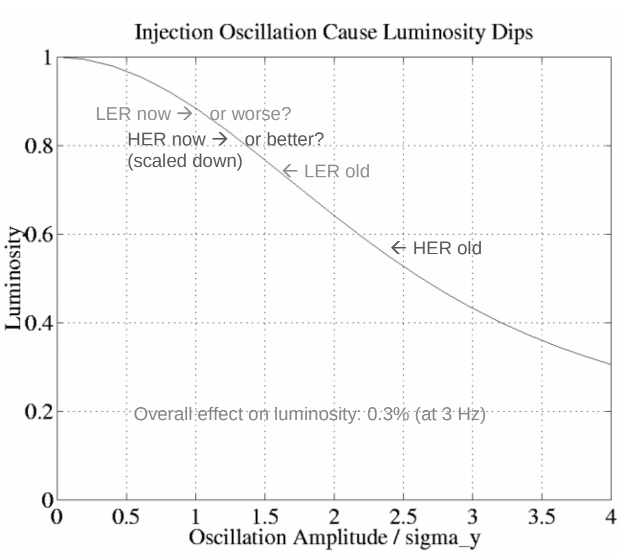


Figure 6: Simulated luminosity dips. 3-sigma oscillations don't bring the luminosity down to zero since the beam is sometimes in the center.

Beyond the detector background and the luminosity dips there seems to be another disturbing effect probably due to injection. Sometimes a beam abort in the LER, due to longitudinal instability and/or current loss, is preceded by an oscillation which is similar in amplitude to an injection oscillation (Fig. 7).

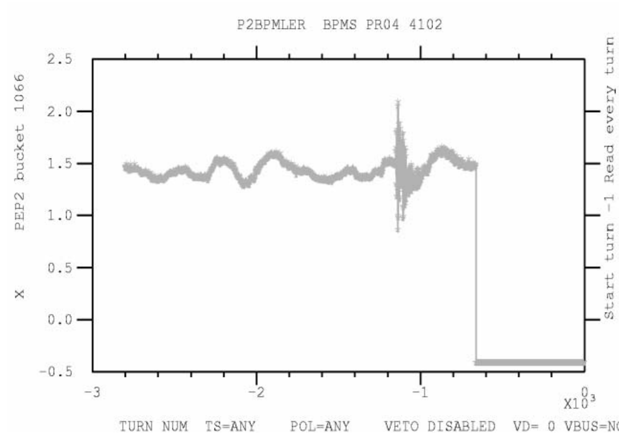


Figure 7: LER beam abort might be initiated by an injection about 500 turns earlier. The lower frequency wiggles are not real; they are from the BPM system.

The LER injection couples some part of the vertical bump into $x$ leaving an oscillation of about ±400 µm, which is very similar to the observed amplitude. Since the BPM buffer data acquisition for an abort measures only six buckets around the ring (±20 ns) it is possible that the beam gets excited and looses some charge undetected. This additional gap could then cause the beam to get longitudinally unstable. Some injection-like decaying oscillation seems to create an increasing instability in another part around the circumference or even in the other beam. This pointed to a marginal feedback setup.

## SUMMARY

The short event from an injected beam to a damped stored beam has many challenges. The injected beam and the stored beam have to be as close as possible at the injection septum. This helps to bring the injected part inside the dynamic aperture. After injection the stored beam should have the smallest about of excitation. These and other smaller problems were identified and fixed or reduced, so that trickle injection into both rings is now the routine operation.

## REFERENCES

[1] U. Wienands et al., "Trickle Charge: A new Operational Mode for PEP-II", EPAC'04, Lucerne, July 2004.

[2] F.-J. Decker et al., "Injection Related Background due to the Transverse Feedback", PAC'03, Portland, May 2003.