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Towards Achieving the Design Number of Bunches in PEP-II*

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Abstract

PEP-II, the asymmetric B-Factory at SLAC, has delivered a luminosity of $2.20 \cdot 10^{33}$ cm^{-2} s^{-1}. This was achieved with 553 bunches in each ring, about a third of the design bunch number of 1658. Different problems arise when we tried to increase the number of bunches and keep the single bunch current constant: increased loading of the RF, heating of the vacuum chamber with synchrotron radiation, and more background in the detector. Lowering the current can reduce these effects, while also reducing the luminosity. The lower beam currents allow us to study the effects of parasitic crossings, different higher order modes, rate dependent effects of the luminosity monitor and other equipment like feedbacks, intensity monitors, etc. Instead of going directly from 829 to 1658 bunches, we tried to increase the number of bunches in steps by adding additional bunches between the 829-bunch pattern or by increasing the bunch number by 33% leaving every third bucket position empty (2,4,2,4 bunch spacing). The first scenario gives two parasitic crossings for the added bunches, while the +33% case gives half of the bunches a left and the other half a right parasitic crossing. The vertical tune shifts due to the parasitic crossing (all together four: left, right for both beams in HER and LER) were measured to be about 0.01. A 30% difference of the left and right side in LER indicates a possible asymmetric beta function set up near the interaction point.

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TOWARDS ACHIEVING THE DESIGN NUMBER OF BUNCHES IN PEP-II

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PEP-II, the asymmetric B-Factory at SLAC, has delivered a luminosity of $2.20 \cdot 10^{33}$ cm^{-2} s^{-1}. This was achieved with 553 bunches in each ring, about a third of the design bunch number of 1658. Different problems arise when we tried to increase the number of bunches and keep the single bunch current constant: increased loading of the RF, heating of the vacuum chamber with synchrotron radiation, and more background in the detector. Lowering the current can reduce these effects, while also reducing the luminosity. The lower beam currents allow us to study the effects of parasitic crossings, different higher order modes, rate dependent effects of the luminosity monitor and other equipment like feedbacks, intensity monitors, etc. Instead of going directly from 829 to 1658 bunches, we tried to increase the number of bunches in steps by adding additional bunches between the 829-bunch pattern or by increasing the bunch number by 33% leaving every third bucket position empty (2,4,2,4 bunch spacing). The first scenario gives two parasitic crossings for the added bunches, while the +33% case gives half of the bunches a left and the other half a right parasitic crossing. The vertical tune shifts due to the parasitic crossing (all together four: left, right for both beams in HER and LER) were measured to be about 0.01. A 30% difference of the left and right side in LER indicates a possible asymmetric beta function set up near the interaction point.

1 INTRODUCTION

By increasing the number of bunches in the PEP-II rings the luminosity should rise linearly, if the bunch currents are kept constant. As the total current increases, there are direct effects like higher backgrounds, more synchrotron radiation, or higher order mode heating of the beam pipes. Besides these direct effects there seems to be a beam size increasing effect. There is the RF phase slippage over the bunch train, which shifts the interaction point (IP) and therefore affects the beam size. This should be visible as a different per bunch luminosity at the front and end of the bunch train. So far only different lifetimes near the train ends, especially the front, were observed.

The main reason, our push to more bunches is limited, is a blow-up of the positron beam, which is most likely due to a photo-electron cloud instability. This was first observed in November 1999, when we had to lower the HER electron beam current from 650 mA to 300 mA due to a leak in the vacuum chamber. The number of bunches was reduced from 829 to 415 bunches, but the peak luminosity dropped only from 1.1 to $1.0 \cdot 10^{33}$ cm^{-2} s^{-1} (Fig. 1). The positron current was only reduced slightly from 950 mA to 800 mA. Later beam size measurement with the synchrotron light confirmed the blow-up in single beam mode.

Besides the tune shift due to parasitic crossings in the design pattern ("by-2" = every second bucket is filled), we will present the various effect from bunch to bunch and along the bunch train for different bunch pattern, gaps, current ratios.

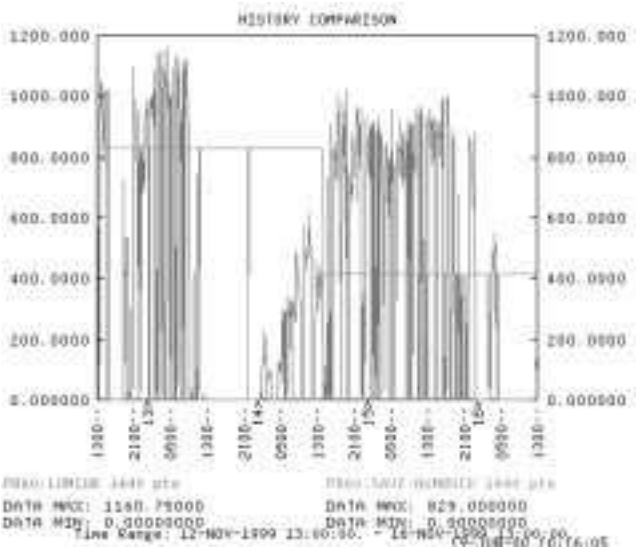

Fig. 1: Luminosity in November of 1999. The luminosity in unit of 10^{30} cm^{-2} s^{-1} and the number of bunches is plotted versus time. A change in the number of bunches from 829 to 415 decreased the luminosity only slightly from 1100 to $1000 \cdot 10^{30}$ cm^{-2} s^{-1}.

2 PARASITIC CROSSINGS

2.1 General

In the design (by-2) bunch pattern there are two parasitic crossings one on the left and one the right side of the collision point 630 mm from the IP. The beam separation is only 2.83 mm at the parasitic crossing [1]. The expected tune shifts normalised to the current are $\Delta\nu_{y,+} = 0.010$ and $\Delta\nu_{y,-} = 0.002$ per mA per bunch.

+ Now at DESY, Germany.

* Work supported by the Department of Energy, contract DE-AC03-76SF00515.

2.2 *Measurements*

The tune shifts were measured by having eleven separated bunches (or 2*11) per ring. They were offset at the IP by two buckets to the right, having only one parasitic crossing (or with a right and left parasitic crossing). The tunes of one beam were measured as a function of the current of other beam. Fig. 2 shows the results for the *y*-tunes. The LER tune shift (p1 of steeper graph) is within 10% of the expected, while the HER tune shift is nearly three times bigger than expected. By comparing tune shifts of a right crossing with the one on the left, it might be possible to identify an asymmetric set-up. The result that two crossings are not exactly twice the value of one crossing might indicate some asymmetry.

The small horizontal tune shifts were measured too with $\Delta\nu_{x,+}$ = -0.0009±0.0002, $\Delta\nu_{x,-}$ = -0.0002±0.0002.

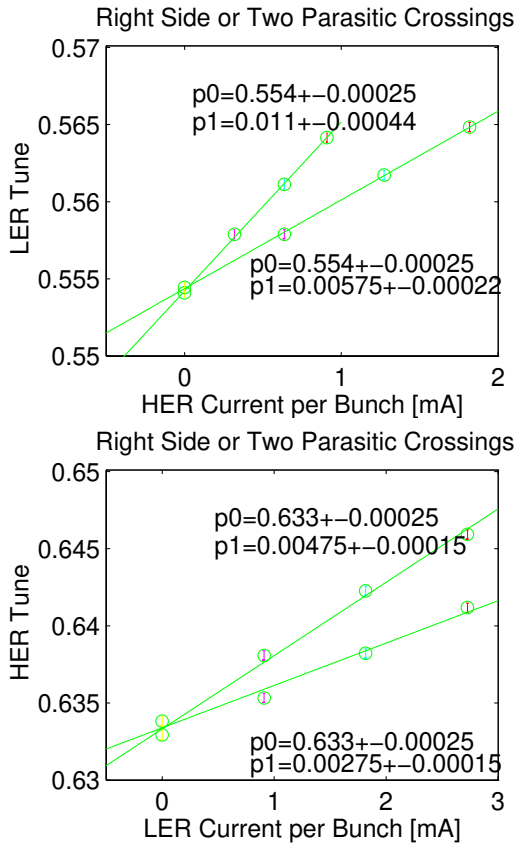

Fig. 2: Parasitic Crossing Tune Shifts. The vertical tune shifts per current (p1) for LER and HER is shown for one and two parasitic crossings.

3 BUNCH PATTERN

The bunch pattern was changed to increase the number of colliding bunches and therefore the luminosity (Tab. 1). By going from "by 8" to "by 4" (8 bucket spacing to 4 bucket spacing) we increased the luminosity, but not by the expected value. Any attempts to push to the design "by 2" pattern did not come close to the expected performance.

Table 1: Pattern for different number of bunches.

Pattern	# Bunches	"Quasi" Patterns
By 8	415	
By 6	554	4,8,4,8; 4,6,8,4,6,8
	604	5,6,5,6
By 5	664	4,6,4,6
	738	4,5,4,5
By 4	829	
By 3	1107	2,4,2,4
By 2	1658	

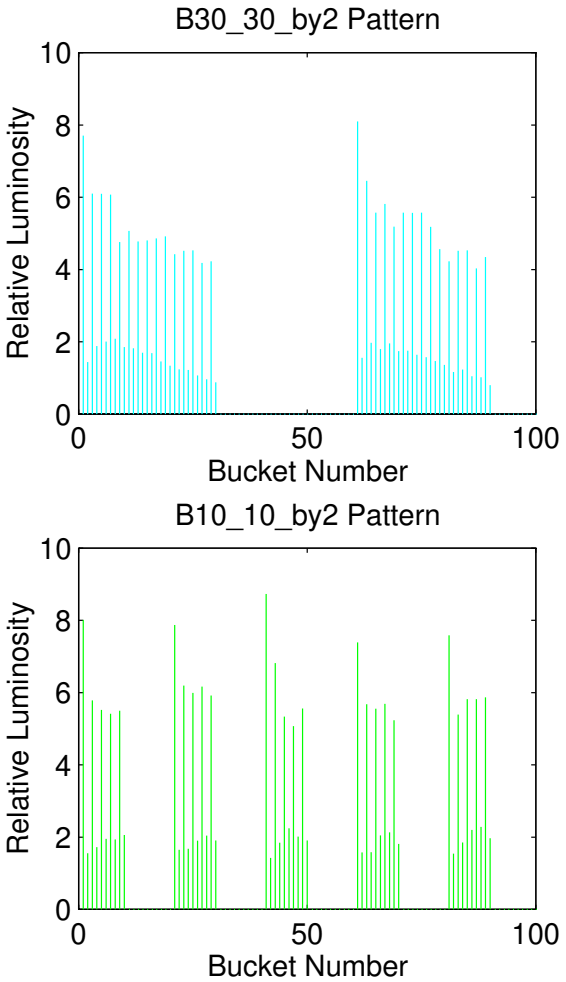

Fig. 3: Luminosity for "by 2" Pattern with Gaps. The luminosity is plotted versus the number of buckets for the first 100 buckets ("by 2"). The gaps appear to clear out the electron clouds around the positron beam, giving the next bunch more luminosity.

3.1 *Gaps in the bunch train*

We tried putting gaps in the bunch train it was tried to clear the electron clouds around the positron beam.

Though successful for the bunch (or bunches) following the gap, this did not make a big difference for the whole fill. Figure 3 shows as an example the luminosity per bunch for a pattern with 30 bunches "by 2" with a 30-bunch wide gap (top), or 10 bunches with a 10-bunch wide gap (bottom).

The first bunch after the gap is about 25% higher than the peaks of the rest. Then there is a further slow decrease along the mini train. A flip-flop behaviour, one high, one low with a 3:1 ratio has also been seen here and in the straight "by 6" pattern (Fig. 4).

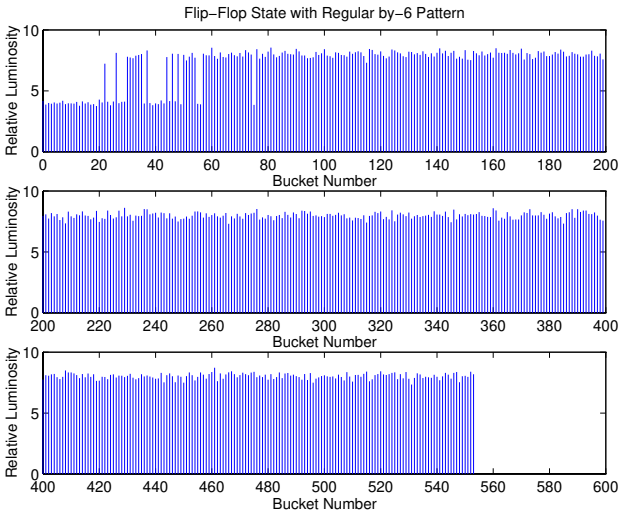

Fig. 4: Flip-Flop Behaviour in the "by 6" Pattern. The positron beam after the gap is small, blowing up the electron beam, which gives less luminosity. Later the electron cloud around the positrons blows this beam up, giving the electron beam a chance to reduce its size. This results in a higher luminosity. By adjusting the tunes it was possible to flip some bunches from one state to the other. The current distribution was flat in both rings.

3.2 Straight and quasi pattern

A straight "by *n*" pattern (*n* = 2,3,4,5,6, …) can be mimicked by a "quasi by *n*" pattern (e.g. *n*-1, *n*+1, *n*-1, *n*+1, … or … -2, +2). There are some differences, which can make a "quasi" pattern more advantageous. The longitudinal feedback was not set up initially to handle odd bucket pattern ("by 3,5,7, …"), so a 4,6,4,6, … pattern was used instead of a straight "by 5" pattern. It performed better than the "by 4" pattern at that time, and was equal to the first shift of the "by 5" pattern. With more time for luminosity optimisation the "by 5" pattern eventually performed better. With a "quasi" pattern there are also in between solution possible, like 5,6,5,6, … which would be a "quasi by 5.5". This can be useful since there is an optimum in the number of bunches, fewer bunches give too much beam-beam single bunch blow up, while more bunches give more electron cloud blow-up of the positron beam. Higher order mode heating in bellows is very sensitive to the bunch pattern. The 5,6,5,6, … pattern could actually not be used since it heated a bellow six times faster than the "by 5" or "by 6" pattern. An optimum of the number of bunches was achieved by eliminating every 5th or10th bucket in the "by 5" pattern.

3.3 Photo-electron cloud blow-up

The blow-up of the positron beam can be seen above about 900 mA single beam, with a gated camera at the beginning and the end of the train, and indirectly by the luminosity along the bunch train (Fig. 5). This drop equalises during the coasting of the beams for luminosity production. Solenoids wound around most of the straight beam pipes have helped to keep the photo-electrons close to the wall, reducing multipacting and therefore lowering the number of electrons close to the positron beam. More solenoids are necessary.

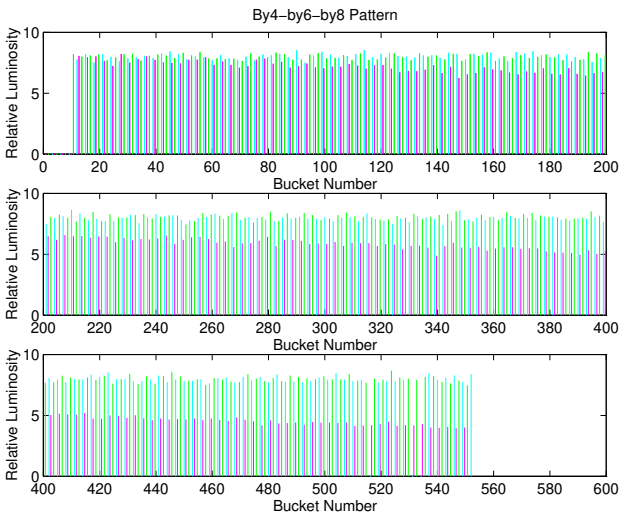

Fig. 5: The Luminosity Drop across the Fill. In most patterns there is a luminosity drop across the fill. In this 4,6,8 pattern the bunch after only 4 buckets is much less than its neighbours and with a long time constant dropping along the bunch train. Some electron bunches in the back of the train were totally kicked out after some bigger 8 bucket gaps leading to no luminosity.

4 SUMMARY

The electron cloud blow-up of the positron beam probably due to photo-electrons and/or multipacting seems to be the major problem in going to more bunches in PEP-II. Solenoids wound around the beam pipe have helped to push the current a little bit higher.

REFERENCES

[1] Conceptual Design Report, "An Asymmetric B Factory – Based on PEP", SLAC-372, Feb 1991, page 184.