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Side Effects of Bunch Trains with Actual Separator Bump Amplitudes

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Abstract

A new program `train`, written by F.C. Iselin, is used to find the individual closed orbits of all bunches circulating in LEP with bunch trains, in the presence of the beam-beam kicks, caused by the parasitic and nearly head-on beam-beam collisions. Once the closed orbits are known, many side effects of bunch trains are calculated in a truly self-consistent manner, in particular the vertical offsets and separations, the vertical slopes and crossing angles, the vertical dispersion, the CM energy shifts and spreads, and the relative luminosities, in the even pits. The tunes and chromaticities are also computed. All calculations are done for trains of three bunches, using the amplitudes of the electrostatic separator bumps which were recently adopted for future running of LEP, and two bunch currents, 0.2 and 0.4 mA. When the horizontal and vertical emittances are scaled such that the beam-beam tune shifts at the head-on collision points are the same at both bunch currents, all parameters scale as expected. In particular, the vertical chromaticity split and the CM energy split are rather independent of the bunch current.

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1 Introduction

When LEP is operated with bunch trains, the strengths of the beam-beam collisions at the parasitic collision points in the neighbourhood of the even pits are reduced by separating the beams there with electrostatic separator bumps, while the two beams are in collision at the head-on collision points in the even pits themselves. Nevertheless, the two beams receive beam-beam kicks of the order of a μr at the parasitic collision points, and their closed orbits get distorted. Since the pattern of collision points is different for different bunches in a train, and since the bunch currents are not perfectly identical in all bunches, the orbits of all bunches are different. One particular consequence of this fact are vertical offsets of the order of a few μm at the head-on collision points in the even pits, and a drop in luminosity when the separation between the two beams is not small compared to the vertical rms beam radius there.

I recently discussed the results of a truly self-consistent calculation of the closed orbits in LEP for trains with four, three, and two bunches [1], obtained with the `train` program, written by F.C. Iselin [2]. I used the amplitudes of the electrostatic bumps recommended earlier this year [3]. In this note, I describe results of the same calculation, using new amplitudes of the electrostatic bumps which were recently adopted for future operation of LEP, for trains of three bunches. I discuss the assumptions in Section 2. The main results are in Section 3. My conclusions are in Section 4.

Table 1: Vertical offsets y in mm of the positron beam at the collision points CP near the pits at 45.6 GeV. The interaction point IP is at the third CP.

CP	IP1	IP2	IP3	IP4	IP5	IP6	IP7	IP8
1	-6.3977	-7.2909	8.0301	6.8054	-5.4224	-7.3062	8.0303	5.9430
2	-4.9531	-2.4344	6.2020	3.5228	-4.6772	-2.4665	6.2043	2.7789
3	-6.4024	.0001	7.9961	.0002	-6.3972	-.0001	7.9998	.0001
4	-4.9651	-2.4332	6.1915	3.5190	-4.6893	-2.4648	6.1915	2.7819
5	-6.4246	-7.3137	8.0068	6.7868	-5.4492	-7.3323	8.0018	5.9264

2 Bumps, Bunch Currents, Emittances, Beam-Beam Tune Shifts

The electrostatic bumps of the LPv6 configuration are in the files `sepevencol.specs` and `sepodd46.specs`, respectively, in the directory `/users/slath/machines/lep95/LPv6`. I scale their values in the odd pits by 8/9, their values in Pits 2 and 6 by 0.7, and leave their values in Pits 4 and 8 unscaled. I call these bump amplitudes the "July 1995" bumps. The vertical offset y of the positron beam around LEP with these bumps is shown in Fig. 1. The vertical offsets y of the positron beam at all five collision points CP in the neighbourhood of the pits are tabulated in Tab. 1. The results in Fig. 1 and Tab. 1 apply at 45.6 GeV to beams colliding in the even pits. They were calculated with vanishing bunch current, hence the beam-beam kicks are absent. The bumps in Pits 1 and 5 are nearly the same, and so are the bumps in Pits 3 and 7. The bumps in Pits 1 and 3 have the opposite sign. The ratio of their amplitudes was adjusted to keep the vertical crossing angles small in the even pits [3].

Table 2: Assumed bunch current I in mA, horizontal and vertical emittances ϵ_x and ϵ_y in nm, and relative momentum spread δ in units of 10^{-3}

Set	I/mA	ϵ_x/nm	ϵ_y/nm	$\delta/10^{-3}$
1	0.2	18.234	0.3398	1.2
2	0.4	36.468	0.7018	1.2

at the second and fourth or at the first and fifth collision points CP in the even pits. Not surprisingly, doubling the bunch current causes a doubling of ξ_x and ξ_y.

Table 3: Horizontal beam-beam tune shifts ξ_x in units of 10^{-3} at the collision points CP near the pits for bunch currents $I = 0.2$ mA and $I = 0.4$ mA at 45.6 GeV in the upper and lower half, respectively. The head-on interaction point is CP=3.

CP	IP1	IP2	IP3	IP4	IP5	IP6	IP7	IP8	sum
1	.0576	.1078	.0366	.0818	.0802	.1081	.0365	.1216	.6302
2	.5728	3.2953	.3647	1.4586	.6419	3.2590	.3656	2.0874	12.0453
3	.0857	.0000	.0550	.0000	.0862	.0000	.0549	.0000	.2819
4	.5700	3.2946	.3671	1.4602	.6382	3.2707	.3659	2.0843	12.0510
5	.0571	.1072	.0367	.0827	.0795	.1071	.0369	.1220	.6292
1	.1151	.2157	.0732	.1635	.1605	.2162	.0730	.2431	1.2603
2	1.1455	6.5907	.7294	2.9172	1.2839	6.5180	.7311	4.1747	24.0905
3	.1714	.0000	.1100	.0000	.1724	.0000	.1099	.0000	.5637
4	1.1400	6.5893	.7341	2.9204	1.2764	6.5415	.7318	4.1686	24.1020
5	.1141	.2145	.0734	.1654	.1590	.2142	.0737	.2441	1.2585

3 Results of the `train` Program

The results below apply to trains of three bunches a, b, c with a bunch spacing of $87\lambda_{\mathrm{RF}}$. Most tables were generated by the **train** program. The symmetries of the results between electrons and positrons were amply discussed earlier [1], and do not change with the bump amplitudes. Therefore, I shall present tables for the positron bunches only, but for the two sets of bunch currents. All tables are supposed to be read line by line, not left half followed by right half. The files needed are stored in the directory **/users/keil/LEP95/L05P46/Aug1995/01Aug95** on the hp system of the SL/AP group. The MAD data are in the file **aug01a.dat**. The **train** data are in **aug01a.opt**, **aug01a.forw**, and **aug01a.back**.

3.1 Vertical Offsets in the Even Pits

The vertical offsets y in the even pits for all positron bunches of the first train and the bunch 2a are shown in the upper half of Tab. 5 for $I = 0.2$ mA, and in the lower half for $I = 0.4$ mA. The difference between the highest and lowest bunch doubles when the bunch

Table 6: Vertical separation Δy in μm in the even pits for the positron bunches in trains of three bunches at 45.6 GeV and a bunch current $I = 0.2$ mA in the upper half and a bunch current $I = 0.4$ mA in the lower half, for the "July 1995" bumps, using the data file `aug01a`

B	IP2	IP4	IP6	IP8	B	IP2	IP4	IP6	IP8
1a	.757	-1.313	1.232	-.011	1b	-.079	-.284	.326	1.484
1c	.757	-1.313	1.232	-.011	2a	.757	-1.313	1.232	-.011
mx	.757	-.284	1.232	1.484	mn	-.079	-1.313	.326	-.011
av	.478	-.970	.930	.486	df	.836	1.029	.905	1.496
1a	1.694	-2.353	2.199	-.152	1b	-.022	-.353	.343	2.680
1c	1.694	-2.353	2.199	-.152	2a	1.694	-2.353	2.199	-.152
mx	1.694	-.353	2.199	2.680	mn	-.022	-2.353	.343	-.152
av	1.122	-1.686	1.581	.791	df	1.717	1.999	1.855	2.833

3.3 Vertical Slopes in the Even Pits

The vertical slopes y' in the even pits are shown in Tab. 7 for all positron bunches of the first train and the bunch 2a, in the upper half for a bunch current $I = 0.2$ mA, and in the lower half for $I = 0.4$ mA.

Table 7: Vertical slopes y' in mrad in the even pits for the positron bunches in trains of three bunches at 45.6 GeV and a bunch current $I = 0.2$ mA in the upper half and a bunch current $I = 0.4$ mA in the lower half, for the "July 1995" bumps, using the data file `aug01a`

B	IP2	IP4	IP6	IP8	B	IP2	IP4	IP6	IP8
1a	4.356	-17.552	0.657	-13.361	1b	-2.022	14.978	-7.890	18.050
1c	3.048	34.125	-0.210	37.788	2a	4.356	-17.552	0.657	-13.361
mx	4.356	34.125	0.657	37.788	mn	-2.022	-17.552	-7.890	-13.361
av	1.794	10.517	-2.481	14.159	df	6.378	51.677	8.547	51.148
1a	-0.173	-39.752	-6.952	-33.827	1b	-10.318	25.616	-0.885	29.147
1c	3.373	64.899	-2.715	69.629	2a	-0.173	-39.752	-6.952	-33.827
mx	3.373	64.899	-2.715	69.629	mn	-10.318	-39.752	-20.885	-33.827
av	-2.373	16.921	-10.184	21.650	df	13.691	104.651	18.169	103.457

3.4 Vertical Crossing Angles in the Even Pits

The vertical slopes y for the two beams listed in Tab. 7 can be used to compute the vertical crossing angles $\Delta y'$ between the two bunches of pairs which collide in the even pits. The results are displayed in Tab. 8 for the first bunch train and bunch 2a. The average crossing angles vanish.The difference between the highest and smallest crossing angle is about proportional to the bunch current. It is quite small in Pits 2 and 6, and about 200 μr in Pits 4 and 8, at $I = 0.4$ mA.

When the horizontal and vertical emittances are scaled such that the beam-beam tune shifts at the head-on collision points are the same at both bunch currents, all parameters scale as expected. In particular, the vertical chromaticity split and the CM energy split are rather independent of the bunch current.

References

[1] E. Keil, CERN SL/95-75 (AP) (1995).

[2] F.C. Iselin, private communication.

[3] A. Verdier, private communication.

[4] E. Keil, SL Note 95-07 (AP) (1995).

[5] J.M. Jowett, J. Wenninger and J. Yamartino, SL Note 95-46 (AP) (1995).