

IDENTIFYING LATTICE, ORBIT, AND BPM ERRORS IN PEP-II*

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Abstract

The PEP-II B-Factory is delivering peak luminosities of up to $9.2 \cdot 10^{33} \text{ 1/cm}^2 \cdot \text{s}$. This is very impressive especially considering our poor understanding of the lattice, absolute orbit and beam position monitor system (BPM). A few simple MATLAB programs were written to get lattice information, like betatron functions in a coupled machine (four all together) and the two dispersions, from the current machine and compare it the design. Big orbit deviations in the Low Energy Ring (LER) could be explained not by bad BPMs (only 3), but by many strong correctors (one corrector to fix four BPMs on average). Additionally these programs helped to uncover a sign error in the third order correction of the BPM system. Further analysis of the current information of the BPMs (sum of all buttons) indicates that there might be still more problematic BPMs.

BIG IR ORBIT

There are many approaches with MIA [1], ORM, BMAD, etc. to try to figure out the LER lattice and why its orbit has to be so big especially in the interaction region (IR). The orbit is far of the center up to about 12 mm in x and y . With this orbit the best luminosity got achieved and any attempt to reduce ended up in much lower luminosity and got therefore backed out. Figure 1 shows a typical orbit in y . It could be fitted by just a few corrector kicks indicating that most of the BPM read actually right. Only two bad modules at 3132 and 3042 were found and confirmed. BPM 2203 has a larger design offset.

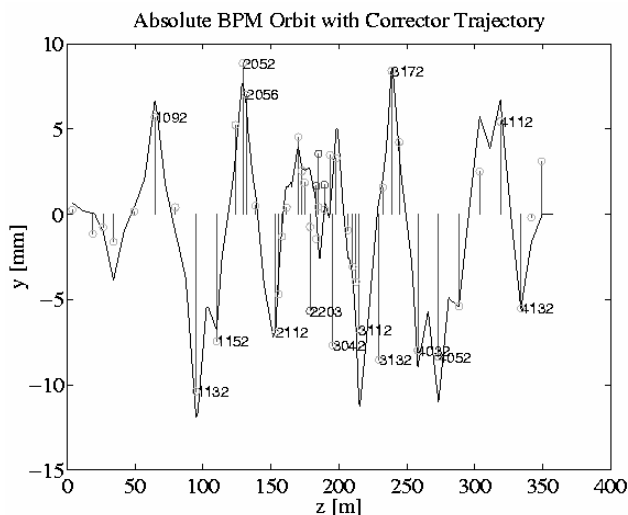


Figure 1: LER absolute orbit near IP. The black line is a rough fit with one corrector for about four BPMs. There is no big absolute BPM problem.

The rest fits nearly within 1 mm, except near sextupoles, not included in this model. The locations for the necessary correctors were at the launch, at the sextupoles, at some special bend magnets indicating a real strength problem, and at the interaction point (IP) indicating a model problem.

BPM difference orbits should be even easier to fit, so it was surprising to see big unexpected coupling. An excitation of tune mode 1 made about $\pm 2 \text{ mm}$ orbit oscillation in x and in y the expected values should be quite small. Especially in BPM 2203, where the beam has a big absolute offset in x and y the result had an inconsistent 25% coupling (Fig.2).

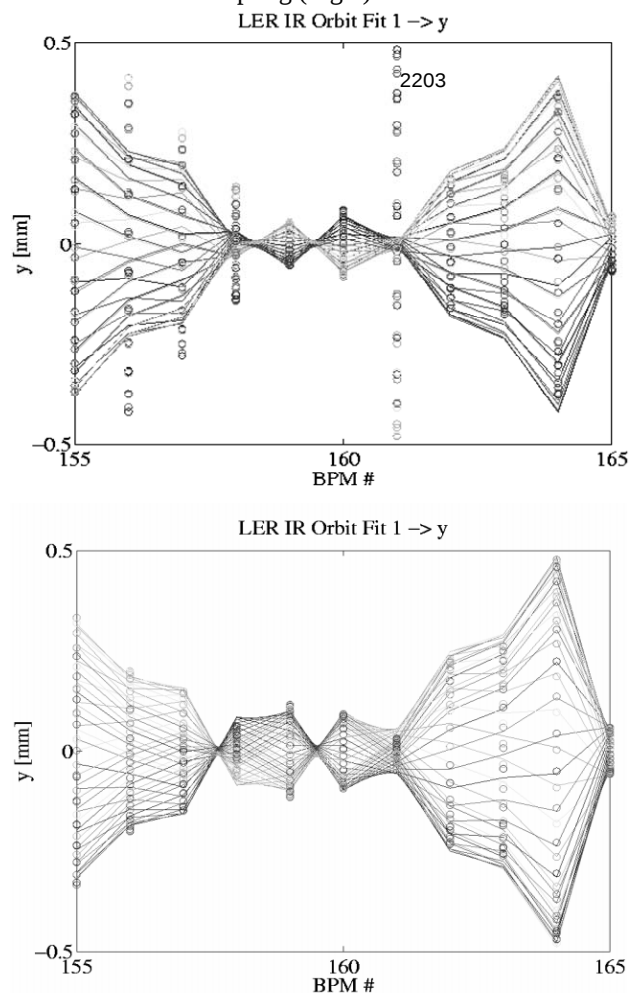


Figure 2: Orbit fit for 10 BPMs around the IP. This is for the coupled part, where mode 1 (mainly x) goes into y . The large coupling like at BPM 2203 in top picture seems to be unphysical compared to beam dynamics and points to an instrumental BPM problem. The bottom picture shows the fits after the fix.

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THIRD ORDER BPM PROBLEM

The problem was finally identified by recalculating the BPM results x and y from the four raw numbers of the BPM buttons including six scaling numbers (1st and 3rd order), two offsets, eight module offsets and gains and an attenuation factor. It was found that the first order non-linearity (compare Fig. 3) was ‘corrected’ to third order but effectively with the wrong sign. The error occurred when we changed the algorithm from $u, v \rightarrow 3^{\text{rd}} \rightarrow x, y$ to $u, v \rightarrow x, y \rightarrow 3^{\text{rd}}$. After correcting this big error the fit (Fig. 2, bottom) looks much better. Now we have still the problem that some of the offsets like module offset are done after the 3rd order correction and should be done before, since the module offset don’t experience higher order geometric aberrations.

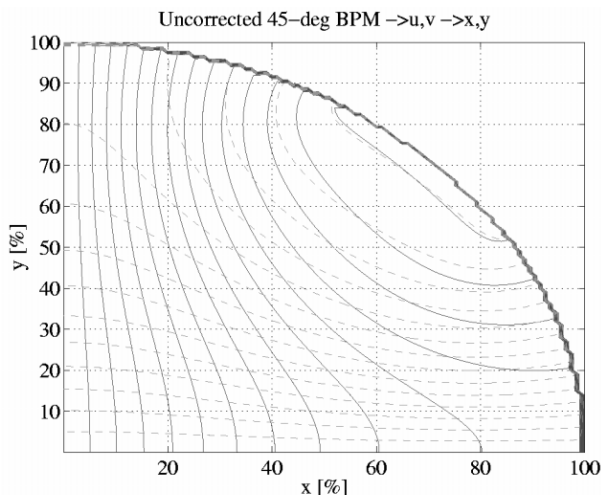


Figure 3: Calculated non-linearity of BPM response. Each line gives the same BPM reading in steps of 5 mm, e.g. the fourth solid red line gives always a 20 mm reading in x even when the beam is at (22,0) or at (15,40). This can be corrected to third order, but the implementation had a sign error making it even worse.

LATTICE ISSUES

Dispersion

The dispersion is measured by changing the RF frequency by ± 300 Hz and looking at the difference orbit. Fig. 4 shows the x and y dispersion for the LER. The displayed RMS numbers are for design, measurement, and difference to the design. The difference is typically still quite high from 50 to 100 mm. Any value over 50 mm in the vertical hurts already the emittance. There are step changes in the amplitude visible and a gradual variation on the right side. But the problem is mainly the low current measurement. When the data are taken to characterize the machine, we do it normally at low current, at higher, typical running currents the y dispersion is normally less [2].

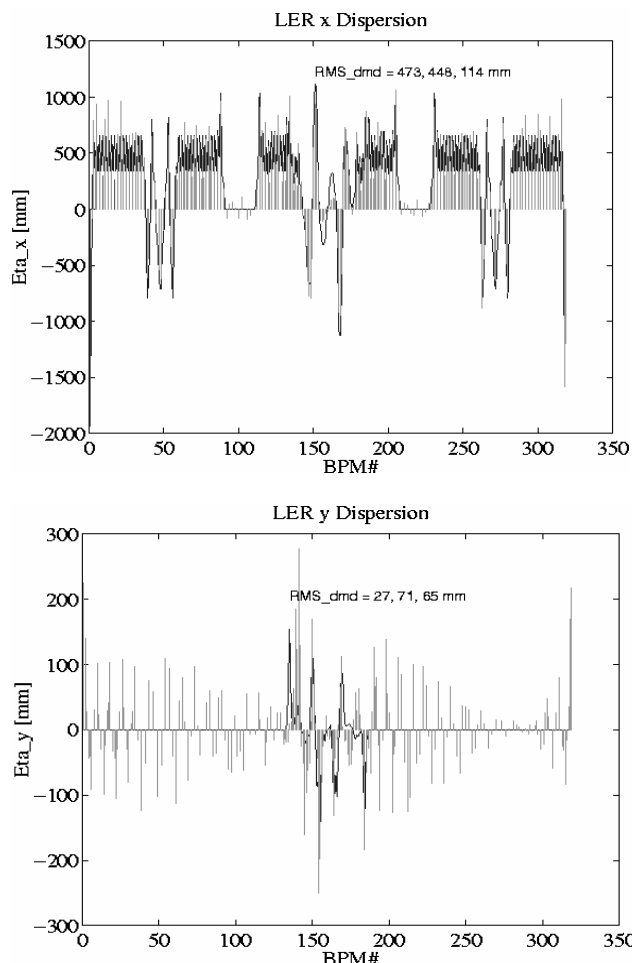


Figure 4: LER dispersion function. In blue lines are the design and the measurement is in green bars. The RMS numbers are the design, measurement, and difference. An RMS above 50 mm in y starts to hurt the emittance.

Betatron function

Here we describe a simple way to compare beam excitation (MIA) and orbit oscillation data with the online model. Since the LER ring is highly coupled there are all four betatron functions to consider, two in x and y each for the two modes 1 and 2 (Fig. 5). The off-diagonal terms should be zero except near the interaction region (IR). The measured values were derived just from the maximum amplitude; the phase information was not used. It would give a more complete analysis [3]. The β -value of about 1 mm outside the IR must be compared to the typical 25 m beta-function. This means that with a 25:1 emittance ratio the beam size coupled from mode-1 into y is the same as the mode-2 size in y . The resulting beam size increase is only critical at the collision point, and maybe at the septum, where a small y size is the goal. But also the coupling from mode-2 into x is important. It doesn’t increase the x size significantly, but any effect which makes the x emittance big (mainly dispersion) will couple also into the y emittance. This effect is different from the dispersion, since a dispersion measurement will only reveal a big horizontal dispersion, but there mode 2 might not be zero.

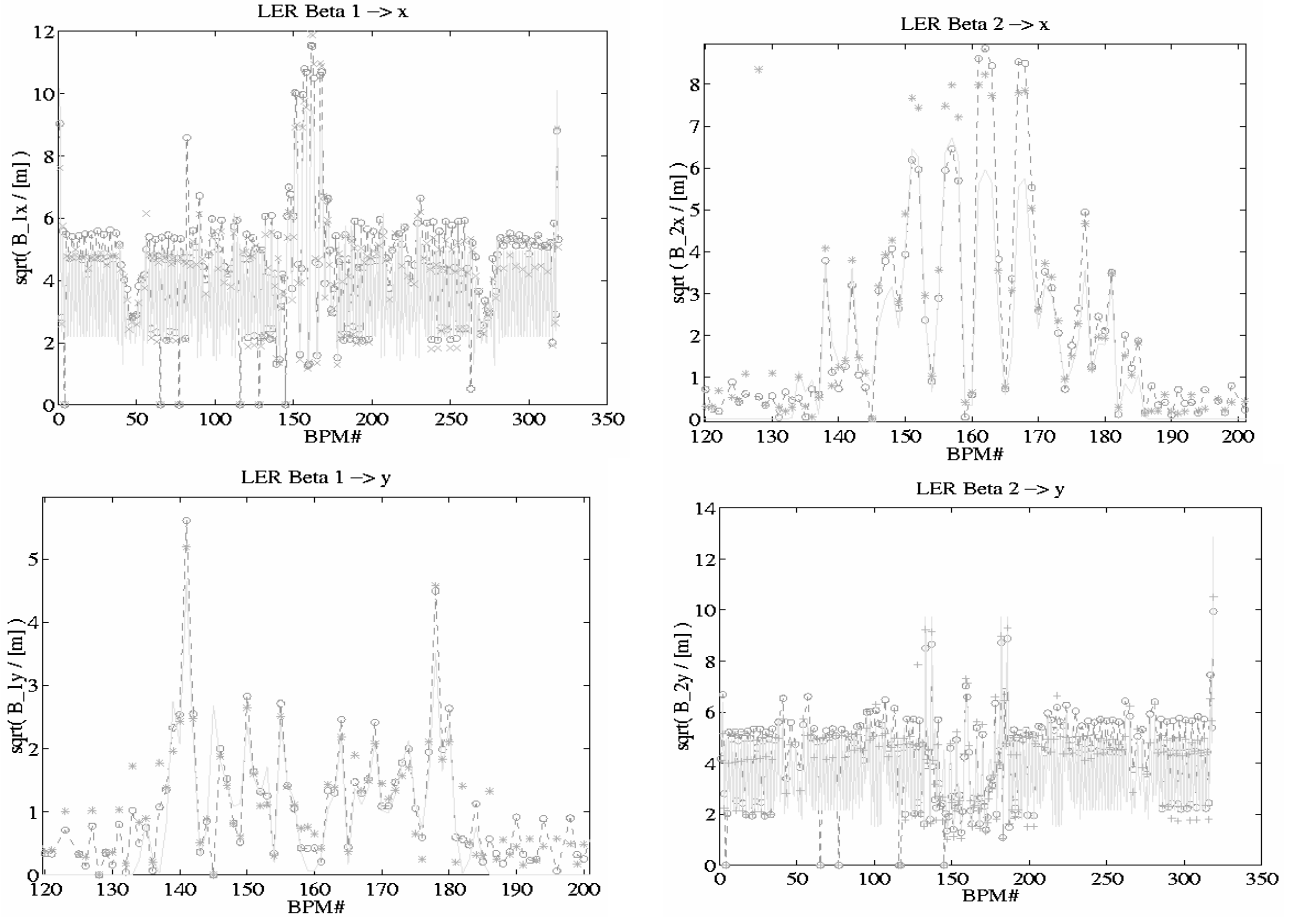


Figure 5: LER coupled betatron functions, model and measurement. The left column shows the betatron function of mode 1 (mainly horizontal) going into x and y . The right side is for mode 2 (mainly vertical). In yellow lines is the design and in dashed green and circles are the tune excitation data. In cyan symbols are the results from oscillation data. The off-diagonal terms show the coupling from mode 1 into y and mode 2 into x . It should be zero except close to the IP (BPM # 159-160). The beam size is the square root of the mode emittance times the betatron function, also for the coupled case.

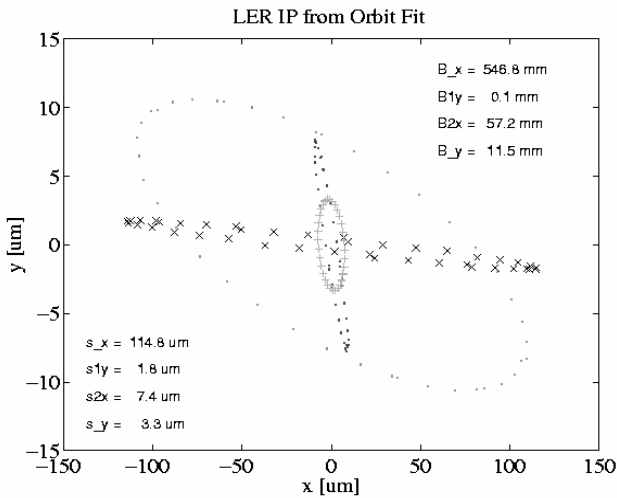


Figure 6: Orbit fit results for IP. The envelope of the orbits gives the beam sizes and therefore betatron functions. The symbols x and $+$ are for mode 1 and 2. The coloured dots are the average of the nearest IP BPMs showing the strong solenoid coupling in this area.

The formula used in MATLAB to get the design function around the ring is

$$\begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}(s) = \mathbf{R} \left\{ \begin{pmatrix} \beta_0 & -\alpha_0 \\ -\alpha_0 & \gamma_0 \end{pmatrix} \mathbf{R}' \right\} \quad (1)$$

where β_0 is for instance the betatron function at one location and $\mathbf{R}$ is the online 6x6 R-matrix to all BPM locations (s) around ring. Fig. 6 shows the fitted result with sizes and betatron functions at the IP.

REFERENCES

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- [3] M. Woodley, A. Wolski, T. Raubenheimer, "Normal Form Analysis of Linear Beam Dynamics in a Coupled Storage Ring", EPAC'04, Lucerne, June 2004.