The Influence of the Vertical Closed Orbit on Luminosity Performance in LEP

P. Collier and H. Schmickler
CERN, Geneva, Switzerland

Abstract

During LEP operation in 1993 the luminosity performance, i.e. the vertical beam-beam tune shift has varied by almost a factor of two between 'good' and 'bad' coasts. High tune shifts could systematically be reproduced by correcting the vertical orbit towards a "golden reference orbit", that had been saved during a previous good physics coast. This paper gives the results of machine studies undertaken in order to find the relevant physics parameters that vary with the vertical closed orbit and determine the luminosity performance. In this paper we will concentrate on the effects of residual vertical dispersion and machine coupling. We show that in the case of LEP, after careful realignments [1], already with coarse orbit corrections the residual vertical dispersion is small and no longer limits the luminosity performance. On the other hand the strategy for correcting the vertical orbit affects the quality of the machine coupling compensation and hence the luminosity performance.

1. INTRODUCTION

During the 1993 LEP run it was discovered that certain closed orbits produced high vertical beam-beam tune shifts. By correcting systematically back to one of these orbits at the beginning of each physics coast, a reproducibly good luminosity performance was achieved. These so called "golden orbits" were initially found by trial and error. The most common method was to use a 'bare orbit' correction strategy. With this method a theoretical orbit is computed from a measured orbit by zeroing all the correctors in the machine. A standard MICADO type correction on the result was then used to establish a list of correctors to use. This method has the advantage that it re-seeds the closed orbit with a completely new set of correctors. Further corrections on the resulting orbit often lead to small vertical beam sizes and hence high vertical beam-beam tune shifts. In general this strategy worked one time in three attempts. Once established the golden orbit was used as the basis for correction in later fills. The technique of performing a bare orbit correction was maintained, but then difference to the reference orbit was corrected, usually with many correctors.

The difference between good and bad orbits proved difficult to quantify. In all cases the rms. value of the orbit at the pickups was less than 0.8mm. In general orbits with the smallest rms. values were not necessarily the best for luminosity. Studies were undertaken to try and understand the influence of the orbit on the vertical beam size, and hence luminosity. These concentrated on two parameters which play a significant role in determining the vertical beam size, namely the vertical dispersion and the machine coupling.

2 EMITTANCE RATIO IN PHYSICS

The ratio of the vertical to the horizontal emittance gives a measure of the coupling in the machine. This can be computed from the luminosity seen by the four LEP experiments and the horizontal emittance at the LEP UV light monitors (BEUV)[2]. The vertical beam size at the BEUV is not used, as beta-beating from beam-beam has been found to significantly affect the vertical beam size readings. The emittance ratio, κ, is then given by:

$$\sqrt{\kappa} = \frac{1}{4\pi e^2 f_o k_b} \cdot \frac{I_e I_p}{\beta_y^* \sqrt{\beta_x^*/\beta_y^*}\, \varepsilon_x L}$$

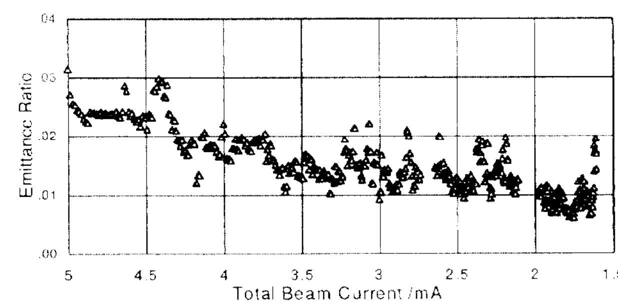

Figure 1: Emittance Ratio From Luminosity and Horizontal BEUV Beam Size. Fill 1891.

The data for the LEP physics fill 1891 is shown in Figure 1. The emittance ratio quickly settles down to a value of about 2%. During the coast it decreases slowly to about 1% towards the end of the fill. For optimum performance the horizontal and vertical beam-beam tune shifts should be equal. For this the emittance ratio and the beta ratio (at the IP's) should be the same. In 1993 the beta ratio was 2%. If the emittance ratio is larger than the beta ratio the vertical beam-beam tune shift (which determines luminosity) will be relatively lower than the horizontal. It is therefore important to keep the emittance ratio at, or below, the beta ratio. This was achieved during this fill. In order to reach this limit, all contributions to the vertical beam size need to be kept small. Dispersion, betatron tune and coupling are obvious parameters.

3. OBSERVATIONS ON RESIDUAL VERTICAL DISPERSION

During the middle part of 1993 a series of measurements were made of the dispersion at the beginning and end of physics coasts. Logged luminosity data was used to compute the vertical beam-beam tune shift at the time of each dispersion measurement. The results are shown in Figure 2.

There is no correlation between the vertical beam-beam tune shift and the measured rms. vertical dispersion. It should be noted, however, that the data is biased towards "average" quality fills. The physics coasts with very high luminosity performance are absent from this plot - as there was a natural tendency of the operators to not measure dispersion with a very high luminosity. With this caveat, and within this range of dispersion, we conclude that the luminosity is not being dominated by the residual rms. vertical dispersion.

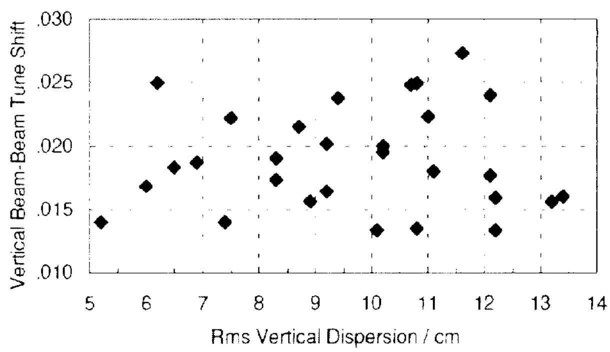

Figure 2: Beam-Beam Tune Shift vs. Vertical Dispersion

Measurements on the variation of single beam size with residual vertical dispersion are shown in figure 3. Dispersion was varied by using different orbit correction strategies and, in the case of large dispersions, by the use of dispersion bumps. Data was recorded for dispersions in the range between 6 and 44cm. The beam sizes used are those read by the BEUV in a place of zero horizontal dispersion.

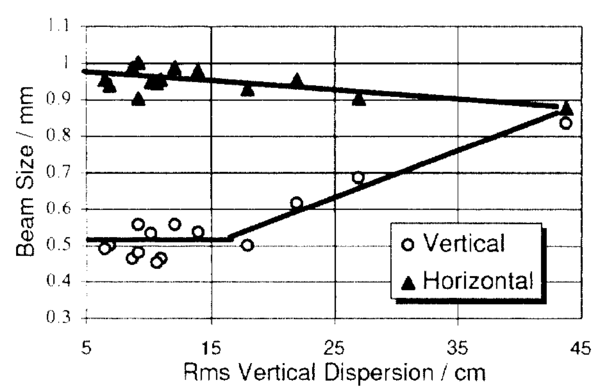

Figure 3: Horizontal and Vertical Beam Sizes, Measured at the BEUV as a Function of rms. Vertical Dispersion

The data of figure 3 indicates that below a certain value the vertical beam size is no longer dominated by residual vertical dispersion. In the case shown, the critical value of dispersion was about 15cm. As the dispersion in physics is generally lower than this, other processes must be dominating the beam sizes and hence luminosity.

4 ORBIT CORRECTION AND ITS EFFECT ON COUPLING

Figure 4 summarizes the results of measurements made of the effect of vertical orbit correction strategy on coupling. The simplest way to measure coupling is via the closest tune approach[3]. Here the two betatron tunes are crossed with the Q-meter measuring continuously in PLL mode. The smallest distance in tune between the two is a measure of the strength of the coupling resonance. Each curve shows the variation of the closest tune approach with changes to the imaginary part of the machine coupling for a particular orbit. The complete machine coupling compensation used for LEP is purely imaginary and has a value of 1.6 in the same units. Several strategies were used to correct the orbit. In all cases the resulting orbit had an rms. value of less than 0.5mm and all orbits were qualitatively similar. In each case the measured mean vertical dispersion was less than 8cm. The strategies used to correct the orbit were:

Standard :	Multiple standard corrections.
64 Bare :	Bare orbit using only 64 Correctors.
Special 64:	Correction with many correctors (~250) then a bare orbit with 64 correctors on the result.
Golden :	Correction of the difference to an good orbit for luminosity, found empirically.

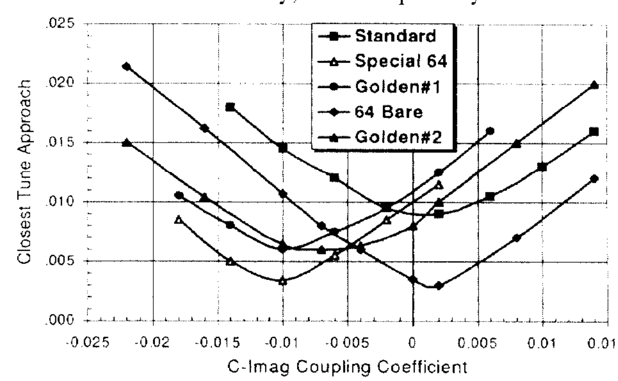

Figure 4: Coupling Curves for Various Vertical Orbit Correction Strategies.

The resulting variation in the minimum of the curves is about a factor two. In addition there is a significant shift in the imaginary coefficient at which the minimum occurs. The normal trimmed setting for this parameter in physics coasts is -0.01. At this point there is a factor three between of the closest tune approach given by the different orbit correction strategies. As the closest tune approach is directly related to the amount of coupling in the machine, the effect is considered to be significant. The curves of figure 4 were checked with and without pretzel separators and were found to be identical.

5. COUPLING AND ITS EFFECT ON BEAM SIZE

In a machine with no vertical dispersion, the relationship between the emittance ratio and the closest tune approach is given by the equation [4]:

$$\kappa = 1 - \frac{(2r^2+1)}{(4r^2+1)}$$

where [1]

$$r = \frac{\delta q}{2|q_h - q_v|}$$

Where δq is the measured closest tune approach and $|q_h\text{-}q_v|$ is the distance to the main coupling resonance. LEP is operated in physics with tunes; Q_h= 90.3, Q_v= 76.16. Thus $|q_h\text{-}q_v|$ = 0.14. In LEP the synchrotron sidebands of the coupling resonance have proved important [5]. Assuming the above equation [1] holds also for the first synchrotron sideband, the distance from this resonance is only 0.075, as the standard synchrotron tune,Q_s=0.065. Figure 5 shows the variation of the emittance ratio with the closest tune approach based on equation [1], for the case of the main coupling resonance and the first synchrotron sideband.

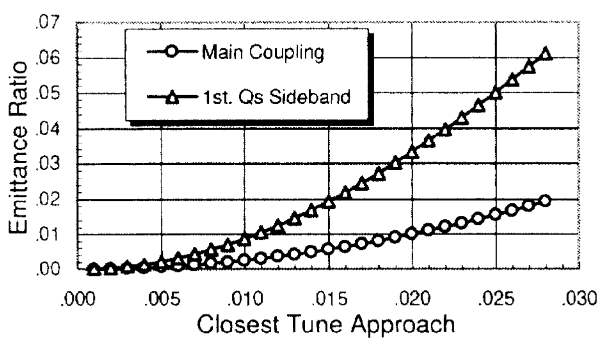

Figure 5: Emittance Ratio vs. Closest Tune Approach for Main Coupling and the 1st Qs Sideband Resonances.

In order to keep the emittance ratio below 2% the closest tune approach must be better than 0.028 for the main coupling resonance. From figure 4 it can be seen that this is achieved for all correction strategies. If the 1st synchrotron sideband of the coupling resonance is strong, then the closest tune approach must be less than 0.015. This may not always be reached. Of course the strength of the 1st synchrotron sideband is not exactly the same as the main coupling resonance and, in both cases, the dispersion is neglected.

During some of the measurements made to form the curves of figure 4, the beam sizes on the BEUV were recorded. The data is shown in figure 6. The same beam was used for the three data sets and the machine conditions kept constant (except orbit). The beams were separated and measured vertical dispersion was in the range 6 to 8 cm. A clear correspondence can be seen between the closest tune approach data of figure 4 and the beam size variations of figure 6. In each case the changes in the beam size with variations in the imaginary coupling coefficient are similar and much larger than would be expected with the distance of the tunes from the main coupling resonance. The data of figure 6 is, however, qualitatively similar to that expected if the first synchrotron sideband of the coupling resonance is causing the emittance ratio to increase.

The data of figure 6 can be used to estimate the effect of coupling and orbit on luminosity. From figure 6 a change in beam size of 40% can easily be generated by using different orbit correction strategies.

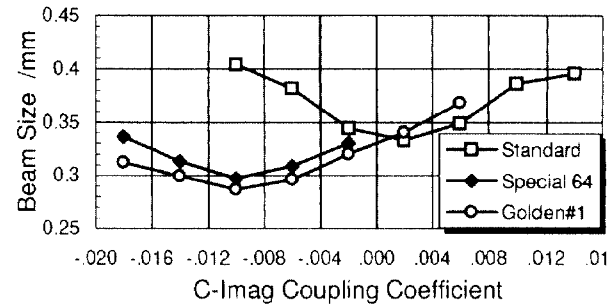

Figure 6: The Variation of Beam Size with the Imaginary Coupling Coefficient and Orbit Correction Strategy.

5 CONCLUSIONS

Of several machine parameters which contribute to the beam sizes in collision and the hence to the luminosity delivered to the experiments, the residual vertical dispersion is recognized as being very important. Since a re-alignment of the LEP machine in the vertical plane was done, the residual dispersion has been routinely maintained at relatively small values. At these low levels of dispersion other parameters seem to dominate the beam size

Another parameter has been studied; coupling. Here it has been found that the residual coupling in the machine is a strong function of the way in which the vertical orbit has been corrected. Theoretical studies are underway to look at how the orbit correction strategy might affect the beam position at the sextupoles (the major cause of coupling). The idea of an orbit where the beam position in the sextupoles is such as to cause very little coupling links quite well with the operations groups recent use of "golden orbits".

The large changes in the beam size as a function of the (relatively small) measured changes in coupling cannot be explained by the standard coupling theory as the distance from the main coupling resonance is too great. However the first Qs sideband of the main coupling resonance is strong in LEP. It is possible that this resonance causes the observed beam size variation with coupling.More investigations will be made during 1994.

6. REFERENCES

1. Verdier A., "Effect of LEP Re-Alignment", Proc. 4th Workshop on LEP performance, Chamonix, 1994.
2. Castro P. et al, "Comparative Precision Emittance Measurements in LEP", this conference.
3. Burr, G. et al., "Dynamic Tune and Chromaticity Measurements in LEP", Proc. EPAC, Gif-Sur-Yvette, 1992.
4. Guignard. G,"Adjustment of Emittance Ratio by coupling Control in e-p Storage Rings", Proc. XI High Energy Accelerator Conference, CERN, Geneva, 1980.
5. Myers S. et al, "Synchro-Betatron Resonances in LEP", this conference.