Presentation 26

Optics Errors

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26.1 Introduction

The optics imperfections directly relevant to the beam-beam effect are:

- $\Delta\beta^*/\beta^*$, the error in the β function at the interaction point,
- $\Delta\alpha^*$, the error in the derivative of β^*, which causes a displacement of the waist,
- $\Delta\Phi_Q$, the error in betatron phase advance between two successive IP's,
- ΔD^*, the parasitic dispersion at the interaction points.

Estimates of these imperfections were made long ago [1, 2, 3]. In parallel the consequences on the luminosity of an imperfect optics were calculated using numerical simulations [4]. For each kind of imperfection, it was verified that both the methods and the hardware were available to correct them to insignificant levels [2, 3].

One should note however that there is almost no dedicated hardware and, in general, no provision to correct defects more than 2 or 3 times the expectations.

The strategy depends thus on the magnitude of the imperfections:

- if they are significantly larger than the expectations, the source must be searched and fixed,
- if they are comparable to the expectations, corrections at the most likely sources can be attempted,
- after the previous steps, direct corrections, irrespective of the sources may be done.

We will thus discuss the expectations, the most likely sources, the measurement and correction techniques.

26.2 Expected imperfections

26.3 Magnetic and alignment imperfections

The expected (design) [5] and presently estimated imperfections [6] are shown in Table 26.1. The required tolerances are met, with the exception of the skew quadrupole due to the Ni layer. Its value is a rough estimate which needs confirmation.

26.3.1 TWISS PARAMETERS

The expected imperfections of β^*, α^* and Φ_Q arise from focusing imperfections and can all be expressed in terms of $\Delta\beta/\beta$ [3]:

- Absolute error on β^*: $<\beta^*>=\beta^*<\Delta\beta/\beta>$

Imperfection	Symbol	Unit	Expectation	Estimate
H. alignment error	$< \Delta x >$	mm	0.24	0.30
V. alignment error	$< \Delta x >$	mm	0.24	0.10
Gradient dispersion	$\Delta K/K$		$5\ 10^{-4}$	$3\ 10^{-4}$
Gradient in the dipoles	$< \Delta K_d >$	m^{-2}	$1\ 10^{-6}$	$0.5\ 10^{-6}$
Tilt of the quads	ψ	mrad	0.24	0.10
Skew quad per 1/2 cell	$< K_s >$		0	$5\ 10^{-5}$?

Table 26.1: Expected and present imperfections

- Error on the derivative of β^* and waist displacement: $< \alpha^* > = < \Delta\beta/\beta >$ and $< \Delta s^* > \approx < \alpha^* > \beta^* \approx < \beta^* >$
- Asymmetry of the β_{max} measured at the QS0's: $< \Delta\beta_{max} > \approx 4\sqrt{\beta^*\beta_{max}} < \alpha^* >$
- Error in the betatron phase advance between interaction points: $< \Delta\Phi_Q > = \sin 2\pi Q < \Delta\beta/\beta >$

The expected errors in the Twiss parameters and derived quantities are shown in Table 26.2 [3]. They were calculated for the optics N07A46.

Imperfection	Unit	Expected value $\beta^*_y = 7$ cm
$< \Delta\beta^*/\beta^* >_x$	%	3.7
$< \Delta\beta^*/\beta^* >_y$	%	6.1
$< \alpha^* >_x$		.037
$< \alpha^* >_y$		.061
$< \Delta s^* >_x$	mm	64.8
$< \Delta s^* >_y$	mm	4.3
$< \Delta\beta_{max} >_y$	m	0.89
$< \Delta\Phi_Q >_x$	degree	1.75
$< \Delta\Phi_Q >_y$	degree	3.35

Table 26.2: Expected imperfections of the Twiss parameters and related quantities on N07A46

The breakdown of the contributions shows the important sources (Table 26.3). The horizontal orbit deviations are by far the dominant source of errors. This is, however, only valid if the orbits in sextupoles at π are not correlated.

Source	$< \Delta\beta^*/\beta^* >_x$	$< \Delta\beta^*/\beta^* >_y$
$\Delta K/K$ in Quads	1.8	2.0
QF	1.2	0.4
QD	0.4	1.0
QS0's	0.1	1.0
QS1's	0.6	0.1
QS4's	0.2	0.4
QL1's	0.1	0.2
QL2's	0.2	0.1
QL4's	0.1	0.5
all others	1.1	1.1
H. orbit in sextupoles	2.7	3.7
Sextupole alignment	0.5	0.7
K_d in dipoles	1.1	0.9

Table 26.3: Contributions of various imperfections to the β beating on N07A46

26.3.2 DISPERSIONS

The expected sources of dispersion are given in Table 26.3.2 at an average β of 70 m for N07A46 [2]. The strongest source is the vertical closed orbit in the QS0's.

Source	D_x	D_y
ORBIT total	3.6	7.9
F Quad/Sext.	2.2	2.0
D Quad/Sext	1.6	4.1
QS0's	1.0	5.7
QS1's	1.1	0.9
QS4's	0.4	0.8
QL1's	0.6	1.7
QL2's	0.7	0.6
QL4's	0.3	0.9
all others	1.4	2.1
QUAD alignmt	0.5	1.3
lattice only	0.3	0.4
SS's only	0.4	1.2
$\Delta K/K$	1.9	
$< \Delta K_d >$	1.8	
ψ		2.2
SEXT alignmt	0.7	
TOTAL	4.6	8.4
at the PU's	4.4	10.1

Table 26.4: Parasitic dispersion in cm

26.4 The measured optics imperfections and their consequences

We have very little data on optics imperfections. In fact the optics commissioning could not be finished, given the absolute priority to the production of Z^0's. The present knowledge is summarised in Table 26.5 [7, 8, 9]:

Imperfection	Unit	Measurements
$< \Delta\beta^*/\beta^* >_y$	%	20
$< \Delta s^* >_y$	mm	9.0
$\Delta\Phi_{Qy}$	degree	10
$< D_y >$	cm	20

Table 26.5: Measured imperfections

If a pathological longitudinal displacement of some QS0's explains the large disturbance to the Twiss parameters [10], the high dispersion is not yet understood. With respect to the expectation given in Tables 26.2 and 26.3.2, several parameters have changed: the tuning of the low-β, the strength of the sextupoles, the Ni effect and the closed orbit which is worse than expected. A re-evaluation of the expectations will be carried out.

The numerical simulations of the maximum luminosity in the presence of optics errors [4, 2, 3] show a drastic reduction on the 70/78 optics, i.e. in the absence of strong systematic beam-beam resonance (Figures 26.1 and 26.2). The gain that may be expected from the correction of the imperfections is comparable to the gain expected from the change of the integer tunes.

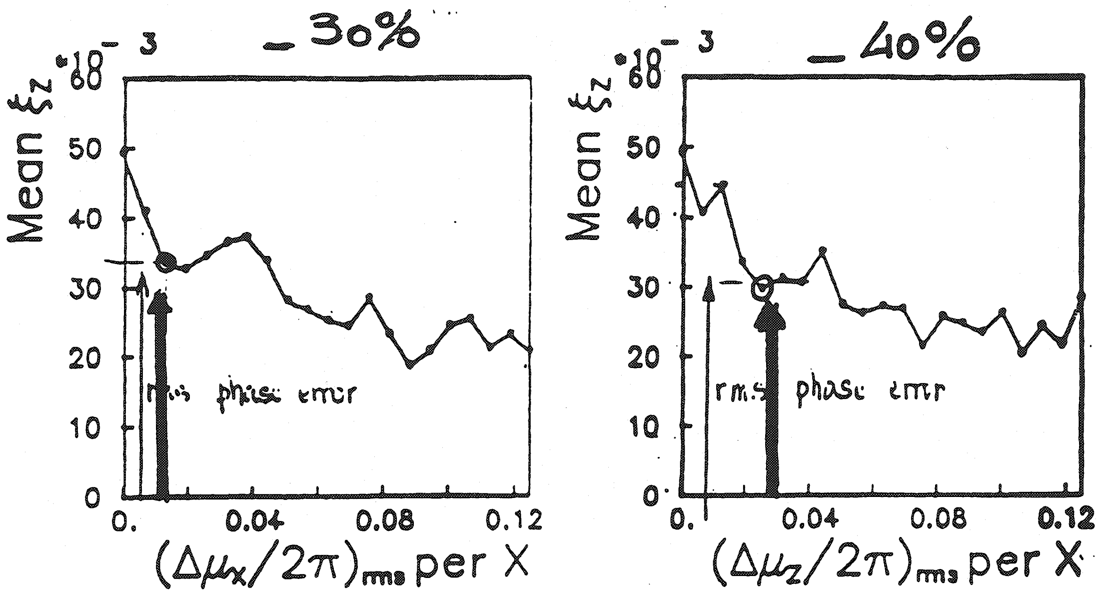


Figure 26.1: Maximum Luminosity versus phase advance errors

26.5 Measurement techniques

26.5.1 DISTRIBUTION OF THE PHASE ADVANCE AROUND LEP

Two commissioning tools exist, available as C programs in the control system:

- Measurement of the average phase advance per cell in one octant,
- Measurement of the total phase advance in one straight section.

These tools were hardly ever used. The estimated accuracy of the technique is very good. It is based on orbit/trajectory measurements [11, 12].

26.5.2 TEST OF OPTICS SYMMETRY

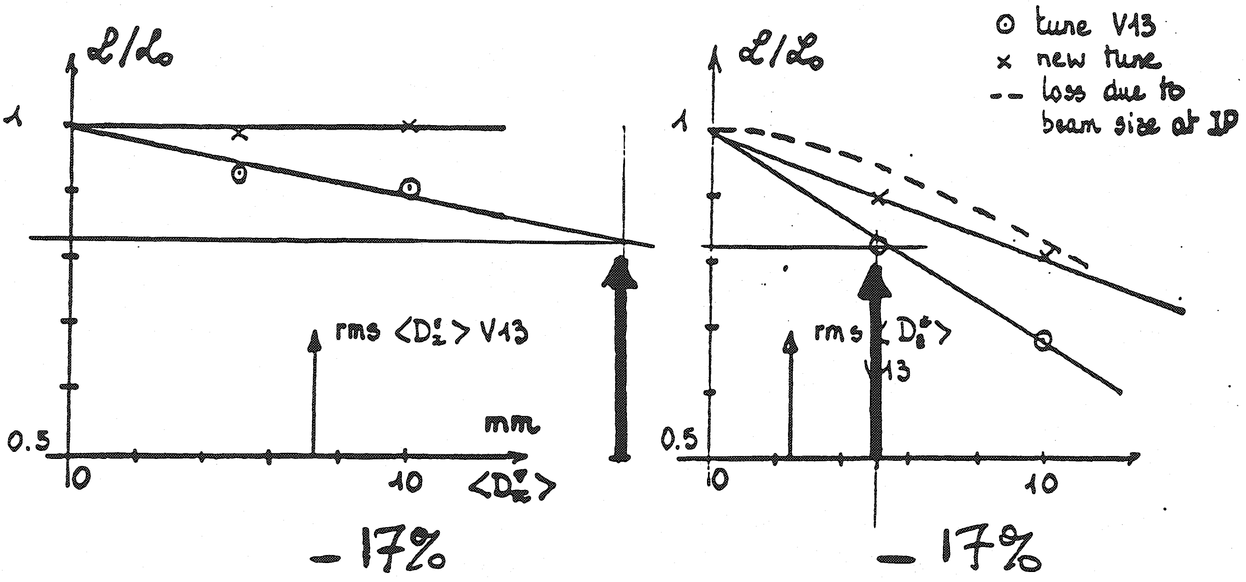
Another simple but less informative method is to measure the average β function at symmetric places around the machine. A tool is available to produce a matched phase shift in the HIBL. It was used to discover the β-beating [7]. One must be careful with the hysteresis effect which is not taken into account.

26.6 Measurement of β^*

The method is defined [13]. Some preliminary experiments were done (hysteresis of QS0's,...). A systematic measurement of β^* could not be done.

26.6.1 POSITION OF THE WAIST

If there is a suspicion that the waist is displaced due to an error in the focusing doublet, then the closure of an orbit bump extending over these lenses is an accurate means of measuring the waist displacement. The method was used in L3. It is not documented.



Luminosity loss due to a spurious horizontal dispersion in the insertion.

Luminosity loss due to a spurious vertical dispersion in the insertion.

Design optics ($Q_x = 70.35$, $Q_y = 78.20$)

Figure 26.2: Maximum Luminosity versus dispersion errors

The other method used lately was to measure the luminosity as a function of an antisymmetric β bump [7]. It requires the production of a bump of α^*. In the vertical plane, an antisymmetric increment of the QS0's gives a good match. In the horizontal plane, a match with the LepModel is required. The hysteresis effect is not taken into account.

26.6.2 SEARCH AND IDENTIFICATION OF FOCUSING IMPERFECTIONS

Binary search using as a criterion the closure of an orbit bump is certainly the easiest and most sensitive technique. It requires the ability to compute arbitrary bumps at any place in the machine. This is feasible with MAD. A dedicated control software was analysed [15] but not implemented yet. Given the experience with the QS0's, a simple checking procedure should be developed. It can be based on symmetric bumps in the IP.

26.6.3 DISPERSION MEASUREMENT

It is presently limited by a suspected phase oscillation of the beam, the accuracy of the PU's, the limitations of their software and the small damping aperture of LEP. Besides the scheduled improvement of the BOM, measurements closer to Q=integer should help. If the wigglers can be used at full strength, the damping aperture will increase as well as the accuracy of the measurement.

26.7 Correction techniques

26.8 Closed orbit

26.8.1 GLOBAL ORBIT

Apart from pathological cases (e.g. quadrupole misalignments) which require correction at the source, the closed orbit is the strongest source of imperfections. A logical approach is to concentrate on it first. Computed at the PU's, the expected and estimated rms orbit residuals are given in Table 26.6.

Imperfection	Expected	Measured	Actual
$< x >$	0.63	1.2	1.5
$< y >$	0.91	0.9	1.13

Table 26.6: Orbit imperfections in mm

/noindent Priority should be given to the horizontal orbit. It is necessary to improve the PU data collection (missing ECA's), the processing of the orbit (offset, calibration, rejection of bad readings) and the correction algorithm (reconditioning of the response matrix, flexibility). Although MICADO should be optimal if the PU noise was Gaussian, experience has shown that the present correction strategy does not make full use of the information contained in the PU data. Other algorithms less sensitive to noise could be tried (e.g. harmonic correction). Programming effort is required. Another aspect is that, unlike smaller machines, an efficient correction can only be reached if **a large number of correctors is used.**

26.8.2 LOCAL ORBIT CORRECTION

After the global closed orbit, the local orbits in the QS0's, and to some extent in the near-by warm quadrupoles and in the HIBL are the next source of imperfections. The tools available to correct locally are:

- the antisymmetric bumps in the experimental IP's; MD procedures exist and have been used for the last year.

- at least one local correction algorithm is available in the standard package (a 'twisted' MICADO).

There is a definitive lack of a flexible bump procedure to center the beam at arbitrary positions.

26.8.3 CORRECTION OF THE TWISS PARAMETERS

Until a systematic management of the machine settings such as the one proposed by AAWG is put into use, the correction of the Twiss parameters should remain an MD activity. There is indeed a significant risk to mismatch the optics.

For MD purposes, the control of β^*, α^* (waist) and phase advance between IP's, is available through the MAD program. The program was modified to produce TFS files directly usable by the control system. The principle to change the phase advance between IP's is to rematch the HIBL. It requires the separator bump to be readjusted. **The hysteresis effect, which is not negligible, is not taken into account and will require a dedicated study.** MAD runs on a DN10000 and is thus immediately available. By LEP control system standards, matching with MAD is a real-time calculation.

To prepare the operational use of such applications, a user-friendly interface has been built [14]. It presently allows some useful calculations on the LEP model in the control room. A few programming weeks would be necessary to implement the modules required for the control of the Twiss parameters at the IP's. Unfortunately the SL/AP group has lost the expert. Help from the Controls Group has been requested.

26.8.4 GLOBAL CORRECTION OF DISPERSION

It is first necessary to apply global correction as **no specific tools are available to correct the residual dispersion.** They are being prepared [9].

26.8.5 LOCAL CORRECTION OF DISPERSION

It was foreseen to correct the insertions with closed dispersion bumps [2]. The principle is to excite 4 closed orbit bumps in the arcs. The method is not implemented. Alternatively, one may use the QTA's, as has already been tried (Moshammer). However, the present arrangement of QTA's does not allow one to create dispersion without betatron coupling. A study is required. The scheme could be complemented by the QT4's or the QTA's re-arranged.

26.9 Conclusion

The methods and tools necessary to study and correct optics imperfections are essentially there. In 1989 and 1990, this subject was not given priority. Therefore time, machine experiments and some programming effort are needed before they are turned into standard procedures to optimise luminosity.

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