SL Note 95-07 (AP)

The ORBIT Program for Studying Side Effects of Bunch Trains

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1 Introduction

The short FORTRAN program ORBIT computes several side effects [1, 2] of bunch trains in LEP [3, 4, 5, 6, 7, 8]. It reads a MAD optics file [9] and instructions from the terminal, and lists its results on a file specified by the user. The current version of the program is called `ORBIT7`. The executable version is available in the file `/users/keil/bin/orbit7`.

2 The MAD Optics File

`ORBIT7` expects the MAD optics file to contain a table of the following quantitiesat all head-on and parasitic collision points in the order listed: Element name, distance s along beam line, horizontal orbit x, horizontal β-function β_x, horizontal phase μ_x, horizontal dispersion D_x, vertical orbit y, vertical β-function β_y, vertical phase μ_y, vertical dispersion D_y.

The namess of the head-on collision points must start with IP as in the standard LEP data. The parasitic collision points must be named BB. An example of a MAD input file is shown in Table 1. It first loads a description of a standard LEP, installs the parasitic collision points, using the file `install_bb87`, excites the electrostatic separation bumps at the parasitic collision points, using the file `dec05a.zlset`. The `seqedit` command cycles LEP such that the parasitic collision points around Pit 1 appear in successive lines of the optics file. MAD then computes the optics table, and finally uses the `emit` and `envelope` commands to obtain the emittances ϵ_x and ϵ_y and the relative rms momentum spread δ.

3 Terminal Dialog

The ORBIT7 program asks the user to take the following actions:

Please enter name of optics file `ORBIT7` opens the optics file with the **apopen** subroutine [10].

Please enter name of listing file `ORBIT7` open the listing file with the **apopen** subroutine. If a file with the name entered already exists, `ORBIT7` asks for another file name.

Table 1: Example of MAD Input Data

```
option echo=f warn=f
call filename="/users/keil/LEP/LEP95/L05P46/lep954.seq"
call filename="/users/keil/LEP/LEP95/L05P46/l05p46.mad"
call filename="/users/keil/LEP/install_markers"
call filename="/users/keil/LEP/install_bb87"
call filename="/users/keil/LEP/LEP95/L05P46/05Dec94/dec05a.zlset"
option echo warn
seqedit lep;  cycle start=rfl.l1; endedit
beam energy=45.6; use lep; select optics ip bb
KMWEMID := 0.84*clight*1e-9/45.6 !-- Excite emittance wigglers
optics filename="jan21a.opt" column=name,s,x,betx,mux,dx,y,bety,muy,dy
beam energy=45.6 radiate; vrfc := 2; lrfc := 0.4; emit; envelope
stop
```

Please enter epsx and epsy in nm and deltap in 0.001 Enter the horizontal and vertical emittances ϵ_x and ϵ_y and the relative rms momentum spread δ as calculated by the `emit` and `envelope` commands in the example.

Please enter energy in GeV - CR=45.6 GeV Entering a carriage return instead of a number sets the energy to the default value 45.6 GeV.

Please enter bunch current in A - CR=0.5E-3 A Entering a carriage return instead of a number sets the bunch current to the default value 0.5 mA. The bunch current is assumed to be equal in all bunches of both beams. Effects caused by bunch current variations are not calculated.

Please enter horizontal beam-beam limit - CR=0.03 Entering a carriage return instead of a number sets the horizontal beam-beam tune shift limit $\hat{\xi}_x$ to the default value 0.03.

Please enter vertical beam-beam limit - CR=0.03 Entering a carriage return instead of a number sets the vertical beam-beam tune shift limit $\hat{\xi}_y$ to the default value 0.03.

Please enter limit on horizontal offset - CR=1 mm Horizontal offsets with $|x|$ below the limit are considered as head-on collisions. Entering a carriage return instead of a number sets the horizontal offset limit x to the default value 1 mm.

Please enter limit on vertical offset - CR=1 mm Vertical offsets with $|y|$ below the limit are considered as head-on collisions. Entering a carriage return instead of a number sets the vertical offset limit y to the default value 1 mm.

4 Listing

The listing file from `ORBIT7` starts with the descriptors of the optics table and the terminal input. Several tables follow. Many of them are written such that they can be included in LaTeX documents.

4.1 Table at IP using input emittances

The table with this heading contains parameters at the head-on collision points whose names start with IP. The parameters are a serial number, the name, $\sqrt{\beta_x}$ and $\sqrt{\beta_y}$, the offsets x and y in mm, the rms beam radii $\sigma_x = \sqrt{\epsilon_x\beta_x + (D_x\delta)^2}$ and $\sigma_y = \sqrt{\epsilon_y\beta_y + (D_y\delta)^2}$, the linear beam-beam tune shifts ξ_x and ξ_y, and the luminosity L, calculated from

$$\xi_x = \frac{Nr_0\beta_x}{2\pi\gamma\sigma_x(\sigma_x+\sigma_y)} \qquad \xi_x = \frac{Nr_0\beta_y}{2\pi\gamma\sigma_y(\sigma_x+\sigma_y)} \qquad L = \frac{N^2fk}{4\pi\sigma_x\sigma_y} \tag{1}$$

Here, N is the bunch population, f is the revolution frequency, k is the number of bunches in one beam, r_e is the classical electron radius, and γ is the usual relativistic factor. In these calculations, any offsets x and y are simply ignored. The luminosity L is calculated for one bunch collision per turn.

4.2 Adapted emittances

It often happens that ξ_x and/or ξ_y are larger than the limiting values entered by the user. In this case, `ORBIT7`increases the emittances ϵ_x and ϵ_y such that the maximum beam-beam tune shifts in the even pits remain below the limits. The emittances are printed. The fact that these emittance increases are most likely to be accompanied by an increase of the momentum spread δ is ignored. The algorithm works as follows: While building the tables at the IP, `ORBIT7` finds the maximum beam-beam tune shifts in the even pits $\widehat{\xi_x}$ and $\widehat{\xi_y}$. Comparing these to the limits $\hat{\xi}_x$ and $\hat{\xi}_y$, entered by the user, determines the rms beam radii σ_x and σ_y needed. Subtracting the contribution of the dispersions fixes the adapted emittances. Specifically, the adapted beam sizes Σ_x and Σ_y are related to the input beam sizes at the limiting even pit by:

$$\Sigma_x(\Sigma_x + \Sigma_y) = (\widehat{\xi_x}/\hat{\xi}_x)\sigma_x(\sigma_x + \sigma_y) = a_x \tag{2}$$

$$\Sigma_y(\Sigma_x + \Sigma_y) = (\widehat{\xi_y}/\hat{\xi}_y)\sigma_y(\sigma_x + \sigma_y) = a_y \tag{3}$$

Taking the ratio of these equations, $\Sigma_x/\Sigma_y = a_x/a_y$, and substituting it into one of them yields the results:

$$\Sigma_x = a_x/\sqrt{a_x + a_y} \qquad \Sigma_y = a_y/\sqrt{a_x + a_y} \tag{4}$$

Using Σ_x instead of σ_x and Σ_y instead of σ_y in the equations linking dispersion, emittance and beam size, and solving them for the emittances yields the adapted emittances.

4.3 Table at IP using adapted emittances

This table is very similar to the previous one, but uses the adapted emittances instead of input emittances.

4.4 Tables at collision points

`ORBIT7` associates the parasitic collision points BB to particular head-on collision points IP by imposing an upper limit of 250 m on the distance between them. This is the reason why the LEP sequence is cycled in the MAD data such that it starts to the left of Pit 1. All collision points in the neighbourhood of an IP are numbered consecutively from left to right with the IP at the centre. `ORBIT7` uses the number of collision points n near a pit to determine the number of bunches in a train $k = (n+1)/2$. The following quantities are printed in these tables: $\sqrt{\beta_x}$, $\sqrt{\beta_y}$, offsets x and y, beam-beam kicks p_x and p_y in μrad, beam-beam tune shifts ξ_x and ξ_y in units of 10^{-3}. If the beams are horizontally separated at the collision points with $\sigma_x \ll |x|$, the following equations are used:

$$x' = -\frac{Nr_e}{\gamma x} \qquad \xi_x = -\frac{Nr_e\beta_x}{8\pi\gamma x^2} \qquad \xi_y = \frac{Nr_e\beta_y}{8\pi\gamma x^2} \tag{5}$$

If the beams are vertically separated at the collision points with $\sigma_y \ll |y|$, the following equations are used:

$$y' = -\frac{Nr_e}{\gamma y} \qquad \xi_x = \frac{Nr_e\beta_x}{8\pi\gamma y^2} \qquad \xi_y = -\frac{Nr_e\beta_y}{8\pi\gamma y^2} \tag{6}$$

4.5 Response matrices

The response matrices contain the response of the closed orbit at all head-on collision points IP to the beam-beam kicks received from the parasitic collision points BB near all head-on collision points IP. The response for horizontally separated beams is:

$$x(m,i,n) = \left(\frac{Nr_e}{2\gamma\sin\pi Q}\right)\frac{(\beta_m\beta_{in})^{1/2}\cos\left(|\mu_m-\mu_{in}|-\pi Q\right)}{x_{in}} = \left(\frac{Nr_e}{2\gamma\sin\pi Q}\right)R_x \tag{7}$$

Here, m labels the IP where the offset is observed, and n labels the collision points near the i-th IP which causes the offset. The elements $y(m,i,n)$ of the response matrix for vertically separated beams are very similar with y_{in} replacing x_{in}. In either plane, the values of Q, β and μ in that plane are used. The response matrices R_x (R_y) are an intermediate step in computing the offsets, and only calculated and printed when horizontal (vertical) offsets $x \neq 0$ ($y \neq 0$) are found in the data.

4.6 Offsets

The offsets δx (δy) at the head-on collision points IP from all collision points for all bunches in a train are obtained by adding the appropriate elements of the response matrices R_x (R_y). They are different for different bunches in a train because each bunch encounters the opposite beam in a different pattern of parasitic collision points. Therefore the offset tables contain one line for each bunch. In addition, the maximum `mx`, minimum `mn`, average `av` values, and the difference `df` between maximum and minimum values are listed.

4.7 Optimum offsets

By fine adjustments of the electrostatic separators, the offsets δy can be changed separately in each even pit, but common for all bunches in a train, such that the contribution of a whole bunch train to the luminosity becomes a maximum. The penalty function is

$$F = -\frac{1}{4}\sum\exp\left[-\left(\frac{\delta_{yk}-D}{\sigma_y}\right)^2\right] \tag{8}$$

Here δ_{yk} is the offset for the k-th bunch in a train, D is the optimum offset, found by the minimization, and σ_y is the adapted vertical beam radius in a given even pit. `ORBIT7` reports the result of the optimization in a table which for all even pits contains the optimum offset `oy`, the optimum value of the penalty function `of`, and the optimum luminosity `lu`.

The tables of the offsets and of their optimization are printed for one, two, ..., bunches in a train up to the maximum given by the number of collision points near a pit.

5 Example

An example is stored in the directory `/users/keil/LEP/LEP95/L05P46/21Jan95` which contains the files listed in Tab. 2:

Table 2: Example Files

`jan21a.dat`	MAD data shown in Tab. 1
`jan21a.lis`	Listing of MAD "print" file
`jan21a.opt`	MAD "optics" file
`jan21a.orb`	`ORBIT7` output listing

References

[1] E. Keil, CERN SL/93-16 (AP) (1993).

[2] E. Keil, CERN SL/94-76 (AP) (1994).

[3] E. Keil, Lecture Notes in Physics **425** (Springer, 1994) 106, also CERN SL/92-55 (AP) (1992).

[4] W. Herr, CERN SL/94-06 (DI) (1994) 323.

[5] R. Bailey et al., CERN SL/94-16 (AP) (1994).

[6] R. Bailey et al., CERN SL/94-65 (AP) (1994).

[7] C. Bovet et al., CERN SL/94-72 (AP) (1994).

[8] C. Bovet et al., CERN SL/94-95 (AP) (1994).

[9] H. Grote and F.C. Iselin, CERN SL/90-13 (AP) Rev. 3 (1993)

[10] H. Grote, private communication.