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# BEAMPARAM - A PROGRAM FOR COMPUTING BEAM DYNAMICS AND PERFORMANCE OF $e^+e^-$ STORAGE RINGS

by

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## ABSTRACT

The program, BEAMPARAM uses data which describes the lattice of an $e^+e^-$ storage ring or of an $e^+/e^-$ synchrotron to compute its beam dynamics and performance parameters. The formulae, used by the program, are given in the Appendix.

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CONTENTS

## 1. INTRODUCTION

The BEAMPARAM program computes the beam-dynamics and performance parameters for an $e^+e^-$ storage ring. The required data is on two files, INPUT and TAPE3. The INPUT file is in the form of a NAMELIST $DATA, and a list of the variables is given in TABLE I. An example of the input data is shown in Fig. 1. The TAPE3 file contains AGS [1)] output, which describes the lattice of the storage ring. TA output from both versions of AGS is accepted.

The output from the program consists of several sections:

i) The overall beam dynamics and lattice parameters, which are summarised in Fig. 2. The output includes the damping times, the beam sizes at the crossing point, the luminosities and the RF parameters.

ii) The beam sizes and the apertures calculated along the lattice (see Fig. 3).

iii) The parameters of the synchrotron radiation such as the radiation power and the critical energy calculated along the lattice can be seen in Fig. 4.

iv) The sensitivity of the closed orbit to misalignments of the quadrupoles and field errors in the bending magnets is calculated, and a table of "amplification factors" for the individual elements is shown in Fig. 5.

## 2. INPUT DATA

### 2.1 Input data from INPUT

The NAMELIST variables, their meaning and preset values are shown in TABLE I. Once read, a variable will remain unchanged until it is redefined by a subsequent set of data. The program is terminated by putting EGEV = 0. For an example see Fig. 1.

### 2.2 Input data from TAPE3

The lattice parameters obtained from AGS for IEL elements are: name, length $\ell$, bending angle $\phi$, focussing strength K, horizontal and vertical amplitude functions $\alpha_x$, $\alpha_y$, $\beta_x$, $\beta_y$, dispersion $\eta$ and its derivative $\eta' = d\eta/ds$, horizontal and vertical phase $\mu_x/2\pi$ and $\mu_y/2\pi$. All orbit parameters refer to the entrance of the elements, for all forms of AGS output. The maximum number of elements from AGS output, allowed by DIMENSION statements is 1200. At the beginning of execution, TAPE3 is rewound and the first lattice is read in. Subsequent lattices must be asked for explicitly, by using the NEXT variable in the NAMELIST $DATA.

The following constants are used by the program:

- electronic charge $e = 1.6021917 \times 10^{-19}$ As,
- velocity of light $c = 2.997925 \times 10^{8}$ m/s,
- electron rest energy $E_o = m_c^2 = 0.511041$ MeV,
- classical electron radius $r_e = 2.817939 \times 10^{-15}$m,
- Planck's constant $\hbar c = 1.9732891 \times 10^{-13}$ MeVm.

## 3. OVERALL MACHINE PARAMETERS

An example of the output for the overall machine parameters is shown in Fig. 2.

### 3.1 Configuration specification

This gives a table of 3 lines, containing NAME, length, bending angle, K, $\eta$, $\eta'$, $\beta_x$, $\beta_y$, $\alpha_x$, $\alpha_y$ for 3 elements with numbers 1, INT and IEL. This should be sufficient to identify the lattice generated by AGS.

### 3.2 Synchrotron integrals

This table gives the synchrotron integrals $I_1$ to $I_5$ as defined in ref. 2. The integrals depend on the shape of the magnets which is communicated to BEAMPARAM by the logical variable WEDGE. With WEDGE = T.(.F.) wedge (straight) magnets are used. WEDGE = .F. is the default value.

### 3.3 Machine parameters

This table contains the tunes ($Q_x$, $Q_y$), the betatron functions $\beta_x^*$ and $\beta_y^*$ and the dispersions $\eta_x^*$ and $\eta_y^*$ at the crossing point. Since BEAMPARAM does not handle vertical dispersion, $\eta_y^*$ is set to zero. Also printed are the momentum compaction $\alpha$, the machine circumference L and the revolution time $T_o$, the damping partition numbers $J_x$, $J_y$, $J_e$ and their derivatives with respect to $\Delta p/p$.

### 3.4 Beam parameters and luminosities

This table gives the beam energy E, the coupling $\kappa$, the larger of the horizontal and vertical tune shifts $\Delta Q$, the energy loss per turn due to synchrotron radiation $U_o$, the rms energy spread $\sigma_e$, the magnetic rigidity $B\rho$, and the damping times for the horizontal and vertical betatron oscillations, $\tau_x$ and $\tau_y$, and for synchrotron oscillations $\tau_e$. SIGX and SIGY are the rms beam radii at the crossing point, defined by INT:

$\sigma_{xo}^*$ and $\sigma_{yo}^*$ are the uncoupled betatron values,
$\sigma_{xc}^*$ and $\sigma_{yc}^*$ are the values due to coupled betatron oscillations,
$\sigma_{xT}^*$ and $\sigma_{yT}^*$ are the total values, including coupled betatron oscillations and energy oscillations.

#### Convention for the coupling $\kappa$

If a non-zero value of the coupling parameter $\kappa$ is read in, it is used for calculating $\sigma_{xc}^*$, $\sigma_{yc}^*$, $\sigma_{xT}^*$, $\sigma_{yT}^*$, $E_{xc}$, $E_{yc}$ etc. and never gets changed. In the output, $\kappa$ is labelled 'D'. If the input value $\kappa = 0$, BEAMPARAM computes $\kappa$ such that the beam-beam tune shifts $\Delta Q_x$ and $\Delta Q_y$ vary with the current as schematically shown in Fig. 6. For currents at the beam-beam limit $\Delta Q$ and above, the coupling $\kappa$ is adjusted such that $\Delta Q_x = \Delta Q_y$, by having $\sigma_{xT}^*/\sigma_{yT}^* = \beta_x^*/\beta_y^*$. This is usually called optimum coupling. For currents below the beam-beam limit $\Delta Q$, the coupling $\kappa$ is adjusted such that $\Delta Q_x < \Delta Q$ but $\Delta Q_y = \Delta Q$.

Three different methods are foreseen for calculating the circulating current I, the stored number of particles N in each beam, and the luminosity L. A partial flowchart for this part of the program is shown in Fig. 7.

i) If neither a value for the current $I_{xy}$ nor a value for the RF generator power $P_g$ is given in the data i.e. $I_{xy} = P_g = 0$, then the currents $I_x$ and $I_y$ are calculated such that $\Delta Q_x = \Delta Q$ and $\Delta Q_y = \Delta Q$, respectively. These currents are then used to calculate the stored number of particles $N_x$ and $N_y$ and the luminosities $L_x$ and $L_y$. For optimum coupling, $I_x = I_y$, $N_x = N_y$ and $L_x = L_y$.

This option is typical for storage rings in the energy range where the luminosity is limited by the beam-beam tune shift.

ii) If a value for the current $I_{xy}$ is specified in the data i.e. $I_{xy} \neq 0$, then $I_x = I_y = I_{xy}$ and these values are used to calculate the beam-beam tune shifts $\Delta Q_x$ and $\Delta Q_y$, $N_x$ and $N_y$ (= $N_x$), and $L_x$ and $L_y$ (= $L_x$). This option typically applies to storage rings in the energy range where the current is limited, and to sychrotrons. The $\Delta Q$ printed is the larger of $\Delta Q_x$ and $\Delta Q_y$, it may well exceed the beam-beam limit.

iii) If an RF generator power $P_g \neq 0$ is specified in the data, the current $I_x$ is adjusted such that the RF generator power necessary to sustain it is equal to the input value $P_g$. The current $I_x = I_y$ is then used to calculate $\Delta Q_x$ and $\Delta Q_y$, $N_x$ and $N_y$ (= $N_x$) and $L_x$ and $L_y$ (= $L_x$).

In the output, the input parameters ($\Delta Q$, $I_x$, $P_g$) are labelled 'D', the calculated parameters 'C'.

The beam-beam bremstrahlung lifetime $\tau_{bb}$ is calculated according to ref. 3, using the bucket height obtained in the calculation of the RF parameters, and assuming that there are $N_{int}$ identical crossings. For machines with different crossings the calculated $\tau_{bb}$ must be scaled appropriately.

### 3.5 RF related parameters

The RF parameter calculation is done in two different ways, depending on the value of the RF generator power in the data. If $P_g = 0$, there exists two possibilities for the current $I_x$. Either $P_g = I_{xy} = 0$, in which case a value for $I_x$ is calculated, or $P_g = 0$ and $I_{xy} \neq 0$ in which case $I_x = I_{xy}$. Once one has a value for $I_x$ then a single-pass calculation is sufficient to obtain all the output parameters described below. If $P_g \neq 0$, the current $I_x$ is adjusted such that the input value and the calculated value of $P_g$ agree, before the rest of the output parameters is calculated.

The output contains the harmonic number $f_{RF}/f_o$, the peak RF voltage $V_{RF}$, the stable phase angle $\phi_s$, the synchrotron tune $\nu_s$ and the synchrotron frequency $f_s$, the half-height of the buckets $\sigma_b$, the rms bunch length $\sigma_z$, and the Touschek lifetime TOUSCHEK, calculated according to ref. 4.

Since the calculation involves an integration along the orbit, it is quite time-consuming. It may be turned off by setting TOUSCH = .F. The formulae for the Touschek lifetime [4] involves some approximations, hence the results may be unreliable for extreme parameters.

Convention for RF frequency $f_{RF}$

The harmonic number $f_{RF}/f_o$ is computed such that it is the largest multiple of $k_b$ yielding an RF frequency $f_{RF}$ smaller than the input value.

Convention for RF voltage $V_{RF}$

The RF voltage $V_{RF}$ is computed such that an energy loss ($U_o + I_{xy} Z_{hm}$) is compensated, at the specified quantum lifetime $\tau_q$, where $Z_{hm}$ is the higher-mode impedance.

In addition to the above simple calculations BEAMPARAM performs a complete beam-loading calculation according to ref. 5. The input data [5] required are the length of the active RF system $L_c$, its shunt impedance per unit length Z and its unloaded filling time $T_{fill}$. The beam is described by parameters which are already known such as the current $I_x$ and the number of bunches $k_b$, and by the logical variables SINGLE and MIDARC. If SINGLE = .T., the calculation is done for a single beam circulating in the machine; otherwise, the calculation is done for two counter-rotating beams of $e^-$ and $e^+$. The arrival times of the $e^-$ and $e^+$, bunches at the RF cavities are controlled by the variable MIDARC. If MIDARC = .T., the $e^-$ and $e^+$ are assumed to be interleaved with equal spacing; otherwise, they are assumed to be coincident. The small difference in arrival times which occurs in practice [6] is neglected. For single beams, the MIDARC parameter is irrelevant.

The output of the beam loading calculation consists of the RF coupling parameters $\beta_{RF}$ and the cavity tuning angle $\psi$ which minimize the RF generator power $P_g$ required.

## 4. EVALUATION OF THE BEAM SIZE

If BMSIZE = .T., a table of beam sizes is printed for element numbers from ILO to IHI. For each element, it gives the name, length, bending angle, K, $\eta$, $\eta'$, $\beta_x$, $\beta_y$, $\alpha_x$, $\alpha_y$, $F_x\sigma_x$ and $F_y\sigma_y$, all taken at the entrance of the element. $F_x$ and $F_y$ are input data.

Convention for beam radii

The horizontal beam radius $\sigma_x$ is calculated for an uncoupled beam, the vertical one for a fully coupled beam.

Because of this convention, the actual beam sizes for all amounts of coupling should be smaller than or equal to the figures printed. It may be found useful to split elements with strong variations of $\beta_x$ and $\beta_y$, e.g. low-$\beta$ quadrupoles, into several pieces in the data in order to get better results for the beam size variation in these elements.

## 5. SYNCHROTRON RADIATION

If SYNRAD = .T., a table of synchrotron radiation parameters is printed for element numbers from ILO to IHI. For each element, it gives the name, length, bending angle, K, horizontal beam divergence $\sigma_x'$ vertical beam divergence $\sigma_y'$ bending radius $\rho$, critical photon energy $E_c$, synchrotron radiation power/metre, and the number of photons/m/s/keV at the critical energy.

Convention for divergences

$\sigma_x'$ is calculated for an uncoupled beam, $\sigma_y'$ is calculated for a fully coupled beam. $\rho$, $E_c$ etc. are only calculated for bending magnets ($\phi \neq 0$), or quadrupoles ($K \neq 0$). Combined function magnets are not permitted ($K\phi \neq 0$). In quadrupoles, $\rho$, $E_c$ etc. as defined in ref. 7 are calculated for a fully coupled beam.

Again it may be found useful to split elements with strong variations of $\beta_x$ and $\beta_y$, e.g. low-$\beta$ quadrupoles, into several pieces in the data in order to obtain better results for the variation of the synchrotron radiation parameters in those elements.

## 6. CLOSED ORBIT CALCULATIONS

The sensitivity of the closed orbit to alignment errors of the quadrupoles, and excitation errors and tilts of the bending magnets can be expressed by integrals around the machine circumference of appropriate powers of the amplitude functions $\beta_x$ and $\beta_y$, and the focusing parameter K.

If CLORB = .T. a table is printed for element numbers from ILO to IHI. It contains running sums $\Sigma_x$ and $\Sigma_y$, and amplification factors $P_x$ and $P_y$ for all quadrupoles and bending magnets. For quadrupoles, $P_x$ and $P_y$ are amplification factors for horizontal and vertical misalignments. They are the ratio between the closed orbit distortion in that element which will not be exceeded in 98% of all machines, to the rms displacement of the quadrupoles, assumed to be the same for all quadrupoles. For bending magnets, $P_x$ is the 98% ratio between closed orbit distortions in metres and relative rms magnet errors $\Delta B/B$, and similarly $P_y$ is the ratio between closed orbit distortions in metres and the rms tilt of the magnets. The program treats quadrupoles and bending magnets which are split into pieces in the AGS output as single elements.

## 7. RUNNING BEAMPARAM

The binary version of BEAMPARAM is stored on a permanent file. The file TAPE3 must be made available either as a permanent file or as a local file by executing AGS prior to BEAMPARAM (for an example, see Fig. 1).

The program card of BEAMPARAM is: PROGRAM BMPAR (INPUT, OUTPUT, TAPE3, TAPE1 = INPUT, TAPE2 = OUTPUT).

## 8. REFERENCES


1) E. Keil, Y. Marti, B.W. Montague and A. Sudboe, CERN 75-13 (1975).

2) R.H. Helm, M.J. Lee, P.L. Morton and M. Sands, IEEE Trans. Nuclear Science, NS-20, 900 (1973)

3) A. Wrulich and H. Meyer, DESY report, PET-75-2 (1975).

4) U. Völkel, DESY 67-5 (1967).

5) P.B. Wilson, 8-th Internat. Conf. High Energy Accelerators, Stanford 1974, 57 (1974).

6) P. Bramham, H. Henke, private communication (LEP-70/107).

7) E. Keil, CERN/ISR-LTD/76-23 (1976).

Table I

Variables in NAMELIST $DATA
in alphabetical order

| Name | | Preset values | |
|---|---|---|---|
| BMSIZE | | .T. | Logical variable pertaining to the beam-size calculations. If these are not required put BMSIZE = .F. |
| CLORB | - | .T. | Pertains to the closed-orbit calculations. If these are not required put CLORB = .F. |
| DELQ* | $\Delta Q$ | 0.06 | Maximum permissible beam-beam tune shift per crossing. |
| GEV | E | - | Energy in GeV. |
| FRF | $f_{RF}$ | - | RF frequency in MHz. |
| FX, FY | fx, fy | 10, 10 | Horizontal and vertical multiplication factors. |
| ILO, IHI | - | 1, IEL | Lower and upper printout for beam size, closed orbit and synchrotron radiation calculations. NB. if not specified there will be printout for all the elements. |
| INT | - | - | The element number at the entrance of which crossing occurs. |
| IXY* | $I_{xy}$ | 0 | Stored current in Ampères. |
| KAPPA* | $\kappa$ | 0 | Coupling parameter between horizontal and vertical betatron oscillations. |
| KBUNCH | $k_b$ | - | Number of bunches in one beam. |
| LC | $L_c$ | 1 | Active length of RF cavities in m. |
| MIDARC | - | .F. | Logical variable pertaining to the position of the RF cavities. If MIDARC = .T. then the $e^+$ and the $e^-$ bunches are interleaved. If MIDARC = .F. then they coincide at the RF cavities. |
| NEXT | - | - | Logical variable. To be used only if more than 1 lattice is to be read from TAPE3. If this is the case put NEXT = .T. |

| Name | | Preset values | |
|---|---|---|---|
| NINT | $N_{int}$ | 2 $k_b$ | Number of crossing points. |
| PG* | $P_g$ | 0 | RF generator power in MW. |
| SHUNT | Z | 20.0 | Shunt impedance of the RF cavities in MΩ/m. |
| SINGLE | – | .F. | Logical variable. SINGLE = .T. for one beam<br>SINGLE = .F. for two beams. |
| SYNRAD | – | .T. | Logical variable pertaining to the synchrotron radiation calculations. If these are not required put SYNRAD = .F. |
| TAUQ | $\tau_q$ | 600.0 | Specified quantum lifetime in minutes. |
| TFILL | $\tau_{fill}$ | 25.0 | Unloaded filling time of the RF cavities in μs. |
| TOUSCH | – | .T. | Logical variable pertaining to the Touschek lifetime. If it is not required put TOUSCH = .F. |
| WEDGE | – | .F. | Logical variable pertaining to the shape of the bending magnets. Put WEDGE = .T. for wedge magnets and WEDGE = .F. for straight magnets. |
| ZHM | $Z_{hm}$ | 0 | Higher mode impedance in MΩ. |

*CONVENTION: The variables DELQ, KAPPA, IXY and PG may be read in as data or calculated. In the output they will be preceded by (D) or (C) accordingly.

For "unconstrained" current

| | | |
|---|---|---|
| data IXY = 0, PG = 0, ΔQ ≠ 0 | | IX, PG are calculated |

For "fixed" current

| | | |
|---|---|---|
| data IXY ≠ 0, PG = 0 | then IX = IXY | ΔQ, PG are calculated |
| or PG ≠ 0 | then IX = f(PG) | ΔQ, PG are calculated |

Once a quantity has been defined it remains the same until it is changed by a subsequent set of data. The program is ended by a $DATA EGEV = 0.0 $.

# APPENDIX A

Definition and formulae used by BEAMPARAM. This appendix contains the definitions of the various quantities printed out by BEAMPARAM and the formulae used to obtain them. The list follows the order of the output.

## A1) SYNCHROTRON INTEGRALS

The synchrotron integrals $I_1$, $I_2$, $I_3$, $I_4$ and $I_5$ are defined in reference [2) ] for both straight and wedege magnets.

In a machine with elements whose field and gradient are piecewise constant the integrals can be written in the form of sums over the elements [2)].

The shape of the magnets is controlled by the WEDGE parameter.

## A2) MACHINE PARAMETERS

$Q_x$ horizontal betatron tune.

$\beta^*_x$ horizontal amplitude function at crossing.

$\eta^*_x$ horizontal dispersion at crossing.

$Q_y$ vertical betatron tune.

$\beta^*_y$ vertical amplitude function at crossing

$\eta^*_y$ vertical dispersion at crossing, set to zero because AGS does not allow for vertical dispersion.

$\alpha$ momentum compaction factor.

L circumference.

$T_o$ revolution time.

$$\alpha = I_1/L$$

$$L = N_s \sum_{i=1}^{n} \ell_i$$

$$T_o = L/(\beta . c)$$

Damping partition numbers

Horizontal $J_x = 1 - I_4/I_2$

Vertical $J_y = 1$

Energy $J_e = 2 + I_4/I_2$

Energy variation of damping partition numbers

$$\frac{\partial J_x}{\partial E/E} = -\frac{2}{I_2}\int_0^L K^2 \eta_x^{\,2}\, ds$$

$$\frac{\partial J_y}{\partial E/E} = 0$$

$$\frac{\partial J_e}{\partial E/E} = -\frac{\partial J_x}{\partial E/E}$$

In a machine with piecewise constant gradient the integral can be expressed in closed form as a sum over the elements.

Since the AGS output on TAPE3 usually contains only a section of the whole machine (1 super period or ½ super period) the program finds the number of sections $N_s$ by summing the bending angles $\phi_i$.

$$N_s = \left| \frac{2\pi + 0.02}{\sum_{i=1}^{n} \phi_i} \right|$$

Here the constant 0.02 agrees with the tolerance on the total bending angle in AGS [1].

A3) BEAM PARAMETERS AND LUMINOSITIES

E the energy, read in as data.

κ the coupling, may be read in as data or calculated.

ΔQ maximum tune shift/crossing.
May be read in as data or calculated (see section 3.4).

If a value for κ is not read in as data then its optimum value is calculated by solving $\sigma_{xT}^*/\sigma_{yT}^* = \beta_x^*/\beta_y^*$ for κ:

$$\kappa = \left\{ \frac{\sigma_{x0}^{*2}\,\beta_y^{*2} + \sigma_e^{2}\,\beta_y^{*2}\,\eta_x^{*2}}{\sigma_{x0}^{*2}\,\beta_x^{*}\,\beta_y^{*} - \sigma_e^{2}\,\beta_y^{*2}\,\eta_x^{*2}} \right\}^{1/2}$$

for $\sigma_{xo}^*$ see below.

At this value of $\kappa$ the horizontal and vertical beam-beam tune shifts are equal.

In the cases with fixed current ($I_{xy} \neq 0$ or $P_g \neq 0$ in the data), the calculated $\kappa$ is reduced if $\Delta Q_y = \Delta Q_x < \Delta Q$, such that $\Delta Q_y = \Delta Q$ and $\Delta Q_x < \Delta Q$. This is achieved by solving

$$(\sigma_{xT}^* + \sigma_{yT}^*)\, \sigma_{yT}^* = \frac{N_{xy}\, r_e\, \beta_y^*}{2\pi\, k_b\, \gamma\, \Delta Q}$$

for $\kappa$. This implies solving the following quadratic equation in $\kappa^2$:

$$0 = \kappa^4 (BD^2\sigma^2 - B^2\sigma^4 - C^2 + 2\,BC\,\sigma^2) + \kappa^2\,(BD^2\sigma^2 + B\sigma^4 - 2C^2 + 2\,BC\,\sigma^2) - C^2$$

where $B = \beta_y^*/\beta_x^*$, $C = \frac{N_{xy}\, r_e\, \beta_y^*}{2\pi\, k_b\, \gamma\, \Delta Q}$, $D = \sigma_e\, \eta_x^*$ and $\sigma = \sigma_{x0}^*$

$U_o$ the synchrotron radiation loss per turn

$\sigma_e$ the relative rms energy spread

$B\rho$ the magnetic rigidity

$$U_o = \frac{2}{3} \frac{r_e\, E^4\, I_2}{(mC^2)^3}$$

$$\sigma_e = \frac{1}{E} \left\{ \frac{55}{32\sqrt{3}} \cdot \frac{\hbar}{mc} \cdot \frac{E^2}{(mc^2)^3} \cdot \frac{I_3}{2I_2 + I_4} \right\}^{\frac{1}{2}}$$

$$B\rho = 10E/0.299925$$

<u>$\tau_x$, $\tau_y$, $\tau_e$ damping times</u>

$$\tau_x^{-1} = \frac{r_e c}{3} \left(\frac{E}{mc^2}\right)^3 \frac{I_2 - I_4}{L}$$

$$\tau_y^{-1} = \frac{r_e c}{3} \left(\frac{E}{mc^2}\right)^3 \frac{I_2}{L}$$

$$\tau_e^{-1} = \frac{r_e c}{3} \left(\frac{E}{mc^2}\right)^3 \frac{2I_2 + I_4}{L}$$

$E_{xo}$, $E_{xc}$, $E_{yc}$ emittances

$$E_{xo} = \frac{55}{32\sqrt{3}} \frac{\hbar}{mc} \left(\frac{E}{mc^2}\right)^2 \frac{I_5}{I_2 - I_4}$$

$$E_{xc} = E_{xo}/(1 + \kappa^2)$$

$$E_{yc} = \kappa^2 E_{xc}$$

$\sigma_{xo}^*$, $\sigma_{xc}^*$, $\sigma_{xT}^*$ horizontal beam radii at the crossing

$$\sigma_{xo}^* = (E_{xo}\ \beta_x^*)^{\frac{1}{2}}$$

$$\sigma_{xc}^* = (E_{xc}\ \beta_x^*)^{\frac{1}{2}}$$

$$\sigma_{x_T}^* = \left[\sigma_{xc}^{*2} + (\eta_x^*\ \sigma_e)^2\right]^{\frac{1}{2}}$$

$\sigma_{yo}^*$, $\sigma_{yc}^*$, $\sigma_{yT}^*$ vertical rms beam radii at the crossing

$$\sigma_{yo}^* = 0$$

$$\sigma_{yc}^* = (E_{yc}\ .\ \beta_y^*)^{\frac{1}{2}}$$

$$\sigma_{yT}^* = \sigma_{yc}^*$$

$L_x$, $N_x$, $I_x$ and $L_y$, $N_y$, $I_y$.

There are three ways of obtaining the circulating currents $I_x$ and $I_y$, the numbers of stored particles $N_x$ and $N_y$, the beam-beam tune shifts $\Delta Q_x$ and $\Delta Q_y$, and the luminosities $L_x$ and $L_y$ as described in section 3.4.

i) Currents given by beam-beam limit ($I_{xy} = P_g = 0$ in data)

$$N_{x,y} = 2\pi\gamma\Delta Q\, k_b(\sigma_{xT}^* + \sigma_{yT}^*)\, \sigma_{xT,yT}^*/(r_e\, \beta_{x,y}^*)$$

$$I_{x,y} = N_{x,y}\, e/T_o$$

$$L_{x,y} = N_{x,y}^2/(4\pi\, k_b\, \sigma_{xT}^*\, \sigma_{yT}^*\, T_o)$$

ii) Fixed current ($I_{xy} \neq 0$ in data), $P_g = 0$

$$I_x = I_y = I_{xy}$$

$$N_x = N_y = I_{xy}\, T_o/e$$

$$L_x = L_y = N_x^2/(4\pi\, k_b\, \sigma_{xT}^*\, \sigma_{yT}^*\, T_o)$$

$$\Delta Q_{x,y} = \frac{N_{x,y}\, r_e\, \beta^*_{x,y}}{2\pi\, k_b(\sigma^*_{xT} + \sigma^*_{yT})\, \sigma^*_{xT,yT}\gamma}$$

$$\Delta Q = \max(\Delta Q_x, \Delta Q_y)$$

iii) Fixed RF generator power $P_g$ ($P_g \neq 0$ in data)

$I_x$ is calculated from $P_g$ (see below), and then the formulae for the fixed current case ii) are used.

$k_b$ is the number of bunches (data)

$\tau_{pol}$ polarisation time

$\tau_{bb}$ beam-beam bremstrahlung lifetime

$$\tau_{pol} = \frac{98.66488\ L}{I_3\ E^5}$$

$$\tau_{bb} = N_{xy}/(\sigma\ L_{xy}\ N_{int})$$

where

$$N_{xy} = \min\ (N_x,\ N_y)$$

$$L_{xy} = \min\ (L_x,\ L_y)$$

$$\sigma = \frac{16}{3}\ r_e{}^2\ \frac{1}{137.03602}\ \left\{ (\ell n\ 4\gamma^2 - \tfrac{1}{2})(-\ \ell n\ \sigma_b - \tfrac{5}{8}) + \tfrac{1}{2}(\ell n\ \sigma_b)^2 + 0.804\ \ell n\ \sigma_b - 0.2 \right\}$$

$\sigma_b$ bucket half-height (see section A4)

$N_{int}$ number of crossing points (data)

A4) <u>RF RELATED PARAMETERS</u>

$h$ harmonic number

$V_{RF}$ peak RF voltage

$f_{RF}$ RF frequency (data)

$$h = k_b\ \left[ \text{integral part of } (f_{RF}\ T_o/k_b) \right]$$

$$V_{RF} = (U_o + Z_{hm}\ I_{xy})/\Gamma$$

$\Gamma$ is the solution of:

$$2(\Gamma^{-2} - 1)^{\frac{1}{2}} - 2\cos^{-1}\ \Gamma = \frac{\pi(\sigma_b\ E)^2\ h\ \alpha}{(U_o + Z_{hm}\ I_{xy})E}$$

The RF frequency is chosen as follows (see section 3.5):

$$f_{RF} = h/T_o$$

$$I_{xy} = \min (I_x, I_y)$$

$\phi_s$ stable phase angle.

$\nu_s$ synchrotron time.

$f_s$ synchrotron frequency.

$$\phi_s = \pi - \sin^{-1} (\Gamma)$$

$$\nu_s = \frac{1}{\beta}\left[- h \alpha \cos \phi_s \frac{V_{RF}}{2\pi E}\right]^{\frac{1}{2}}$$

$$f_s = \nu_s/T_o$$

$\sigma_b$ bucket half height

$\sigma_z$ rms bunch length

$\tau_q$ quantum lifetime (data)

$$\sigma_b = \sigma_e . \sqrt{2x} \quad \text{where x is the solution of:}$$

$$\frac{1}{2} \tau_e/\tau_q = x \exp(- x)$$

$$\sigma_z = \alpha.\sigma_e.L/(2\pi \nu_s)$$

$Z$ shunt impedance per unit length of RF system (data)

$L_c$ length of active RF structure (data)

$T_{fill}$ filling time of RF system (data)

$P_g$ RF generator power may be calculated or read in as data

$Z_{hm}$ higher mode impedance

$\tau_{\frac{1}{2}}$ Touschek lifetime (see below)

$\underline{P_g}$ $\underline{\text{(calc)}}$ = $(R_{pg}.V_{RF})^2/(Z.L_c)$

Values are found for $\beta_{RF}$ and $\psi$ such that $R_{pg}$ is a minimum

$$R_{pg} = \frac{1}{2.V_{RF}.\cos\psi\sqrt{\beta_{RF}}}\left\{\left[(U_o + V_{hm})(1+\beta_{RF}) + i_o.Z.F_1(\tau,\psi)\right]^2\right.$$

$$\left.+\left[\left(V_{RF}^2 - (U_o + V_{hm})^2\right)^{\frac{1}{2}}(1+\beta_{RF}) + i_o.Z.F_2(\tau,\psi)\right]^2\right\}^{\frac{1}{2}}$$

$$F_1(\tau,\psi) = \frac{\tau(1-e^{-2\tau})}{2\left[1 - 2e^{-\tau}\cos(\tau\tan\psi) + e^{-2\tau}\right]}$$

$$F_2(\tau,\psi) = \frac{\tau e^{-\tau}.\sin(\tau\tan\psi)}{1 - 2e^{-\tau}\cos(\tau\tan\psi) + e^{-2\tau}}$$

$$V_{hm} = Z_{hm}.\min(I_x, I_y)$$

$$i_o = \begin{cases} 2.I_x & \text{if SINGLE = .F.} \\ I_x & \text{if SINGLE = .T.} \end{cases}$$

$$\tau_z = \begin{cases} T_o/(2k_b\,T_{fill}) & \text{if SINGLE = .F. and MIDARC = .T.} \\ T_o/(k_b.T_{fill}) & \text{if SINGLE = .T.} \end{cases}$$

$$\tau = \tau_z/(1+\beta_{RF})$$

In the output $P_g$ will be preceeded by (C)

$\underline{P_g}$ $\underline{\text{(data)}}$

If $P_g \neq 0$ then a value of $I_x$ is found such that $P_g$(calc) = $P_g$(data) using the above equations as implicit for $I_x$. In this case, in the output, $P_g$ will be preceeded by (D).

<u>Touschek lifetime $\tau_{\frac{1}{2}}$</u>

$$\tau_{\frac{1}{2}} = \frac{\gamma^2.\sigma_b^2.k_b}{4\pi r_e^2.c < J/V > .N_{xy}}$$

$$\langle J/V\rangle = \frac{\sum_{i=1}^{n} \int_{o}^{\ell_i} \frac{J(s)}{\sigma_x(s).\sigma_y(s)} ds}{8\pi^{3/2}.\sigma_z \sum_{i=1}^{n} \ell_i}$$

$$\sigma_x(s) = \left[E_{xc}\, \beta_x\,(s) + \eta^2(s)\,\sigma_e^2\right]^{\frac{1}{2}}$$

$$\sigma_y(s) = \left[E_{yc}\, \beta_y\,(s)\right]^{\frac{1}{2}}$$

$$\sigma_{x'}(s) = \left[E_{xc}\, \gamma_x\,(s) + \eta'^2(s)\,\sigma_e^2\right]^{\frac{1}{2}}$$

$$\delta = \sqrt{3}.\gamma.\sigma_x'(s)$$

$$J(s) = \frac{(1+\delta^2)^{\frac{1}{2}}}{\delta} + \frac{1}{2\delta}\left\{\ell n\left(\frac{2}{\sigma_b}\right) - \frac{23}{4} + \frac{1}{2}\,\ell n\left(\frac{(1+\delta^2)^{\frac{1}{2}} - 1}{(1+\delta^2)^{\frac{1}{2}} + 1}\right) + \frac{2}{\delta}\,\ell n\left(\delta + (1+\delta^2)^{\frac{1}{2}}\right)\right\}$$

## EVALUATION OF THE BEAM SIZE

Printout of the lattice between element numbers ILO and IHI (data). The last two columns are:

$F_x.\sigma_x$ and $F_y.\sigma_y$ where $F_x$, $F_y$ are data.

$$\sigma_x = \left\{E_{xo}\,\beta_{xi} + \sigma_e^2\,\eta_i^2\right\}^{\frac{1}{2}}$$

$$\sigma_y = \left\{\frac{1}{2}\,E_{xo}\,\beta_{yi}\right\}^{\frac{1}{2}}$$

As may be seen from these formulae, the radial beam size is assumed to be $F_x$ times the rms horizontal beam radius without coupling; while the vertical beam size is $F_y$ times the rms vertical beam radius with full coupling i.e. $\kappa = 1$.

SYNCHROTRON RADIATION

The output, besides length, angle and gradient, lists the following quantities:

$\sigma'_x$, $\sigma'_y$, $\rho$, $E_c$, Power, Photons.

Horizontal rms beam divergence $\sigma'_x = \left\{ \sigma_x^2 \frac{1 + \alpha_x^2}{\beta_x^2} + (\sigma_e . \eta')^2 \right\}^{1/2}$

Vertical rms beam divergence $\sigma'_y = \sigma_y \left( \frac{1 + \alpha_y^2}{\beta_y^2} \right)^{1/2}$

Bending radius $\rho = \begin{cases} 1/(K\sigma) \text{ for } K(\text{gradient}) \neq 0 \\ \text{length/angle for angle} \neq 0 \end{cases}$

where $\sigma = \left( \sigma_x^2 + \sigma_y^2 \right)^{1/2}$

Critical energy $E_c = \frac{3}{2} \frac{\hbar c \gamma^3}{|\rho|}$

Spectral density of photons at the critical energy $E_c$ (photons)

$$= \frac{\partial P\gamma}{\partial s} \cdot \frac{N_{bq}}{E_c^2}$$

where $N_{bq} = N_b$ for angle $\neq 0$ $\qquad N_b = 0.404/e$

and $N_{bq} = N_q$ for gradient $\neq 0$ $\qquad N_q = 0.319/e$

CLOSED ORBIT AMPLIFICATION FACTOR

The formulae for the quantities SUMX, SUMY, PX, PY depend on whether the element is a quadrupole or a bending magnet.

Quadrupoles

$$S_{x,y} = \sum_{i=1}^{n} K_i^2 \cdot \ell_i^2 < \beta_{x,y} >_i$$

$$< \beta >_i = \frac{1}{\ell_i} \int_o^{\ell_i} \beta(s)\ ds$$

SUMX is the running sum for $S_X$

$$P_{x,y_i} = \left| \left[ \frac{<\beta_{x,y}>_i \; S_{x,y} \; N_s}{\sin^2 (\pi \; Q_{x,y})} \right]^{\frac{1}{2}} \right|$$

Bending Magnets

$$S_{x,y_i} = \sum_{i=1}^{n} \phi_i^{\,2} <\beta_{x,y}>_i$$

$$P_{x,y_i} = \left[ \frac{<\beta_{x,y}>_i \; S_{x,y} . N_s}{\sin^2 (\pi \; Q_{x,y})} \right]^{\frac{1}{2}}$$

EVALUATION OF THE BEAM SIZE

| NO | NAME | LENGTH M | ANGLE MRAD | K 1/M**2 | ETA M | ETA' M | BETAX M | BETAY M | ALPHAX | ALPHAY | 10 SIGX MM | 10 SIGY MM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 5.0000 | 0.0000 | 0. | .0000 | -.0000 | 1.60 | .10 | 0.000 | 0.000 | 3.2939 | .5823 |
| 2 | Q11 | 5.0000 | 0.0000 | .5000E-01 | .0000 | -.0000 | 17.23 | 250.11 | -3.125 | -50.001 | 10.8079 | 29.1209 |
| 3 | | 2.3000 | 0.0000 | 0. | .0001 | .0000 | 137.33 | 385.48 | -30.161 | 35.277 | 30.5173 | 36.1528 |
| 4 | Q12 | 5.0000 | 0.0000 | -.2547E-01 | .0001 | .0000 | 311.15 | 240.30 | -45.412 | 27.846 | 45.9350 | 28.5440 |
| 5 | | 35.7500 | 0.0000 | 0. | .0001 | -.0000 | 569.61 | 115.43 | 5.186 | 2.214 | 62.1507 | 19.7835 |
| 6 | Q13 | 1.7400 | 0.0000 | -.5390E-02 | .0000 | -.0000 | 261.38 | 22.47 | 3.435 | .386 | 42.1009 | 8.7278 |
| 7 | | 7.9000 | 0.0000 | 0. | .0000 | -.0000 | 245.46 | 21.63 | 5.664 | .096 | 40.7985 | 8.5643 |
| 8 | Q14 | 1.7400 | 0.0000 | .7757E-02 | .0000 | -.0000 | 164.37 | 23.03 | 4.600 | -.273 | 33.3864 | 8.8369 |
| 9 | | 40.2000 | 0.0000 | 0. | .0000 | -.0000 | 152.41 | 23.57 | 2.326 | -.034 | 32.1491 | 8.9396 |
| 10 | QDH | .8700 | 0.0000 | .2108E-01 | -.0001 | -.0000 | 33.38 | 94.95 | .635 | -1.742 | 15.0450 | 17.9427 |
| 11 | QDH | .8700 | 0.0000 | .2108E-01 | -.0001 | -.0000 | 32.83 | 96.47 | .000 | -.000 | 14.9206 | 18.0860 |
| 12 | | 26.7600 | 0.0000 | 0. | -.0001 | -.0000 | 33.38 | 94.95 | -.635 | 1.742 | 15.0450 | 17.9427 |
| 13 | QF | 1.7400 | 0.0000 | -.2075E-01 | -.0003 | -.0000 | 97.49 | 32.16 | -1.760 | .605 | 25.7117 | 10.4421 |
| 14 | | 26.7600 | 0.0000 | 0. | -.0003 | .0000 | 97.49 | 32.16 | 1.761 | -.605 | 25.7117 | 10.4421 |
| 15 | QDH | .8700 | 0.0000 | .2108E-01 | -.0002 | .0000 | 33.38 | 94.95 | .635 | -1.742 | 15.0446 | 17.9429 |
| 16 | QDH | .8700 | 0.0000 | .2108E-01 | -.0002 | .0000 | 32.83 | 96.47 | -.000 | .000 | 14.9202 | 18.0862 |
| 17 | | 26.7600 | 0.0000 | 0. | -.0002 | -.0000 | 33.38 | 94.95 | -.635 | 1.742 | 15.0446 | 17.9429 |
| 18 | QF | 1.7400 | 0.0000 | -.2075E-01 | -.0003 | -.0000 | 97.49 | 32.16 | -1.761 | .605 | 25.7117 | 10.4420 |
| 19 | | 26.7600 | 0.0000 | 0. | -.0003 | .0000 | 97.49 | 32.16 | 1.760 | -.605 | 25.7117 | 10.4419 |
| 20 | QD | 1.7400 | 0.0000 | .2108E-01 | -.0001 | .0000 | 33.38 | 94.95 | .635 | -1.742 | 15.0450 | 17.9424 |
| 21 | | 1.2300 | 0.0000 | 0. | -.0001 | .0000 | 33.38 | 94.95 | -.635 | 1.742 | 15.0451 | 17.9424 |
| 22 | B1 | 24.2200 | 1.0329 | 0. | -.0001 | .0000 | 35.01 | 90.73 | -.687 | 1.689 | 15.4073 | 17.5392 |
| 23 | | 1.3100 | 0.0000 | 0. | .0125 | .0010 | 92.95 | 33.81 | -1.706 | .661 | 25.1071 | 10.7076 |
| 24 | QF | 1.7400 | 0.0000 | -.2075E-01 | .0139 | .0010 | 97.49 | 32.16 | -1.761 | .605 | 25.7131 | 10.4418 |
| 25 | | 1.2300 | 0.0000 | 0. | .0152 | .0005 | 97.49 | 32.16 | 1.761 | -.605 | 25.7132 | 10.4419 |
| 26 | B2 | 24.2200 | 8.9050 | 0. | .0159 | .0005 | 93.23 | 33.71 | 1.709 | -.657 | 25.1443 | 10.6909 |
| 27 | | 1.3100 | 0.0000 | 0. | .1360 | .0094 | 35.12 | 90.46 | .690 | -1.686 | 15.5231 | 17.5129 |
| 28 | QD | 1.7400 | 0.0000 | .2108E-01 | .1483 | .0094 | 33.38 | 94.94 | .635 | -1.741 | 15.1567 | 17.9423 |
| 29 | | 1.2300 | 0.0000 | 0. | .1696 | .0152 | 33.38 | 94.94 | -.635 | 1.742 | 15.1909 | 17.9422 |
| 30 | B3 | 24.2200 | 10.9286 | 0. | .1884 | .0152 | 35.01 | 90.72 | -.687 | 1.689 | 15.5826 | 17.5389 |
| 31 | | 1.3100 | 0.0000 | 0. | .6892 | .0261 | 92.95 | 33.80 | -1.705 | .661 | 26.5146 | 10.7060 |
| 32 | QF | 1.7400 | 0.0000 | -.2075E-01 | .7236 | .0261 | 97.49 | 32.15 | -1.760 | .605 | 27.2254 | 10.4401 |
| 33 | | 23.7600 | 0.0000 | 0. | .7458 | -.0005 | 97.49 | 32.15 | 1.760 | -.604 | 27.3178 | 10.4400 |
| 34 | +WIG | .5000 | 0.0000 | 0. | .7334 | -.0005 | 37.57 | 84.85 | .761 | -1.614 | 18.3607 | 16.9616 |
| 35 | | .2500 | 0.0000 | 0. | .7331 | -.0005 | 36.82 | 86.47 | .740 | -1.635 | 18.2199 | 17.1231 |
| 36 | -WIG | .5000 | 0.0000 | 0. | .7330 | -.0005 | 36.45 | 87.29 | .730 | -1.646 | 18.1506 | 17.2041 |
| 37 | | .2500 | 0.0000 | 0. | .7327 | -.0005 | 35.73 | 88.95 | .709 | -1.667 | 18.0141 | 17.3666 |
| 38 | -WIG | .5000 | 0.0000 | 0. | .7326 | -.0005 | 35.38 | 89.79 | .698 | -1.677 | 17.9469 | 17.4480 |
| 39 | | .2500 | 0.0000 | 0. | .7324 | -.0005 | 34.69 | 91.47 | .677 | -1.699 | 17.8149 | 17.6113 |
| 40 | +WIG | .5000 | 0.0000 | 0. | .7322 | -.0005 | 34.35 | 92.33 | .667 | -1.709 | 17.7500 | 17.6931 |
| 41 | | .2500 | 0.0000 | 0. | .7320 | -.0005 | 33.70 | 94.05 | .646 | -1.731 | 17.6225 | 17.8571 |
| 42 | QD | 1.7400 | 0.0000 | .2108E-01 | .7318 | -.0005 | 33.38 | 94.91 | .635 | -1.741 | 17.5599 | 17.9393 |
| 43 | | 26.7600 | 0.0000 | 0. | .7544 | .0266 | 33.38 | 94.91 | -.635 | 1.741 | 17.7055 | 17.9394 |
| 44 | QF | 1.7400 | 0.0000 | -.2075E-01 | 1.4659 | .0266 | 97.49 | 32.16 | -1.761 | .604 | 31.4669 | 10.4419 |
| 45 | | .2100 | 0.0000 | 0. | 1.4659 | -.0266 | 97.49 | 32.16 | 1.760 | -.605 | 31.4668 | 10.4422 |
| 46 | SF2 | .4400 | 0.0000 | 0. | 1.4603 | -.0266 | 96.75 | 32.41 | 1.752 | -.614 | 31.3473 | 10.4837 |
| 47 | | .5800 | 0.0000 | 0. | 1.4486 | -.0266 | 95.22 | 32.96 | 1.733 | -.633 | 31.0972 | 10.5721 |
| 48 | B | 24.2200 | 10.3287 | 0. | 1.4331 | -.0266 | 93.22 | 33.71 | 1.709 | -.658 | 30.7682 | 10.6914 |
| 49 | | 1.3100 | 0.0000 | 0. | .9135 | -.0163 | 35.12 | 90.49 | .690 | -1.686 | 19.1291 | 17.5161 |

Figure 3.

## SYNCHROTRON RADIATION

| NO | NAME | LENGTH M | ANGLE MRAD | K 1/M**2 | SIGX' MRAD | SIGY' MRAD | RHO | EC KEV | POWER WATT/M | PHOTONS 1/M/S/KEV |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 5.0000 | 0.0000 | 0. | .2059 | .5823 | | | | |
| 2 | Q11 | 5.0000 | 0.0000 | .5000E-01 | .2059 | .5823 | .6438E+04 | 118.179 | 86.001 | .122E+14 |
| 3 | | 2.3000 | 0.0000 | 0. | .6706 | .3310 | | | | |
| 4 | Q12 | 5.0000 | 0.0000 | -.2547E-01 | .6706 | .3310 | .7261E+04 | 104.790 | 67.618 | .122E+14 |
| 5 | | 35.7500 | 0.0000 | 0. | .0576 | .0416 | | | | |
| 6 | Q13 | 1.7400 | 0.0000 | -.5390E-02 | .0576 | .0416 | .4315E+05 | 17.633 | 1.915 | .122E+14 |
| 7 | | 7.9000 | 0.0000 | 0. | .0956 | .0398 | | | | |
| 8 | Q14 | 1.7400 | 0.0000 | .7757E-02 | .0956 | .0398 | .3733E+05 | 20.382 | 2.558 | .122E+14 |
| 9 | | 40.2000 | 0.0000 | 0. | .0534 | .0380 | | | | |
| 10 | QDH | .8700 | 0.0000 | .2108E-01 | .0534 | .0380 | .2026E+05 | 37.556 | 8.685 | .122E+14 |
| 11 | QDH | .8700 | 0.0000 | .2108E-01 | .0454 | .0187 | .2023E+05 | 37.605 | 8.708 | .122E+14 |
| 12 | | 26.7600 | 0.0000 | 0. | .0534 | .0379 | | | | |
| 13 | QF | 1.7400 | 0.0000 | -.2075E-01 | .0534 | .0379 | .1736E+05 | 43.817 | 11.822 | .122E+14 |
| 14 | | 26.7600 | 0.0000 | 0. | .0534 | .0380 | | | | |
| 15 | QDH | .8700 | 0.0000 | .2108E-01 | .0534 | .0380 | .2026E+05 | 37.555 | 8.685 | .122E+14 |
| 16 | QDH | .8700 | 0.0000 | .2108E-01 | .0455 | .0187 | .2023E+05 | 37.605 | 8.708 | .122E+14 |
| 17 | | 26.7600 | 0.0000 | 0. | .0534 | .0380 | | | | |
| 18 | QF | 1.7400 | 0.0000 | -.2075E-01 | .0534 | .0380 | .1736E+05 | 43.817 | 11.822 | .122E+14 |
| 19 | | 26.7600 | 0.0000 | 0. | .0534 | .0379 | | | | |
| 20 | QD | 1.7400 | 0.0000 | .2108E-01 | .0534 | .0379 | .2026E+05 | 37.555 | 8.685 | .122E+14 |
| 21 | | 1.2300 | 0.0000 | 0. | .0534 | .0379 | | | | |
| 22 | B1 | 24.2200 | 1.0329 | 0. | .0534 | .0379 | .2345E+05 | 32.447 | 6.483 | .155E+14 |
| 23 | | 1.3100 | 0.0000 | 0. | .0534 | .0380 | | | | |
| 24 | QF | 1.7400 | 0.0000 | -.2075E-01 | .0534 | .0380 | .1736E+05 | 43.819 | 11.823 | .122E+14 |
| 25 | | 1.2300 | 0.0000 | 0. | .0534 | .0380 | | | | |
| 26 | B2 | 24.2200 | 8.9050 | 0. | .0534 | .0380 | .2720E+04 | 279.744 | 481.882 | .155E+14 |
| 27 | | 1.3100 | 0.0000 | 0. | .0550 | .0379 | | | | |
| 28 | QD | 1.7400 | 0.0000 | .2108E-01 | .0550 | .0379 | .2020E+05 | 37.670 | 8.738 | .122E+14 |
| 29 | | 1.2300 | 0.0000 | 0. | .0571 | .0380 | | | | |
| 30 | B3 | 24.2200 | 10.9286 | 0. | .0572 | .0380 | .2216E+04 | 343.317 | 725.788 | .155E+14 |
| 31 | | 1.3100 | 0.0000 | 0. | .0650 | .0380 | | | | |
| 32 | QF | 1.7400 | 0.0000 | -.2075E-01 | .0651 | .0380 | .1653E+05 | 46.039 | 13.052 | .122E+14 |
| 33 | | 23.7600 | 0.0000 | 0. | .0567 | .0379 | | | | |
| 34 | +WIG | .5000 | 0.0000 | 0. | .0614 | .0379 | | | | |
| 35 | | .2500 | 0.0000 | 0. | .0616 | .0379 | | | | |
| 36 | -WIG | .5000 | 0.0000 | 0. | .0617 | .0379 | | | | |
| 37 | | .2500 | 0.0000 | 0. | .0618 | .0379 | | | | |
| 38 | -WIG | .5000 | 0.0000 | 0. | .0619 | .0379 | | | | |
| 39 | | .2500 | 0.0000 | 0. | .0620 | .0379 | | | | |
| 40 | +WIG | .5000 | 0.0000 | 0. | .0621 | .0379 | | | | |
| 41 | | .2500 | 0.0000 | 0. | .0623 | .0379 | | | | |
| 42 | QD | 1.7400 | 0.0000 | .2108E-01 | .0623 | .0379 | .1890E+05 | 40.262 | 9.982 | .122E+14 |
| 43 | | 26.7600 | 0.0000 | 0. | .0709 | .0379 | | | | |
| 44 | QF | 1.7400 | 0.0000 | -.2075E-01 | .0732 | .0379 | .1453E+05 | 52.348 | 16.874 | .122E+14 |
| 45 | | .2100 | 0.0000 | 0. | .0732 | .0380 | | | | |
| 46 | SF2 | .4400 | 0.0000 | 0. | .0732 | .0380 | | | | |
| 47 | | .5800 | 0.0000 | 0. | .0732 | .0380 | | | | |
| 48 | B | 24.2200 | 10.3287 | 0. | .0732 | .0380 | .2345E+04 | 324.469 | 648.288 | .155E+14 |
| 49 | | 1.3100 | 0.0000 | 0. | .0692 | .0380 | | | | |

TOTAL SYNCHROTRON RADIATION POWER INCLUDING QUADRUPOLES 9.548824

Figure 4.

CLOSED ORBIT AMPLIFICATION FACTOR

| NO | NAME | LENGTH M | ANGLE MRAD | K 1/M**2 | ETA M | ETA' M | BETAX M | BETAY M | SUMX | SUMY | PX | PY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 5.0000 | 0.0000 | 0. | .0000 | -.0000 | 1.60 | .10 | | | | |
| 2 | Q11 | 5.0000 | 0.0000 | .5000E-01 | .0000 | -.0000 | 17.23 | 250.11 | 3.528 | 24.729 | 198.0 | 607.7 |
| 3 | | 2.3000 | 0.0000 | 0. | .0001 | .0000 | 137.33 | 385.48 | | | | |
| 4 | Q12 | 5.0000 | 0.0000 | -.2547E-01 | .0001 | .0000 | 311.15 | 240.30 | 11.382 | 27.280 | 580.2 | 383.3 |
| 5 | | 35.7500 | 0.0000 | 0. | .0001 | -.0000 | 569.61 | 115.43 | | | | |
| 6 | Q13 | 1.7400 | 0.0000 | -.5390E-02 | .0000 | -.0000 | 261.38 | 22.47 | 11.405 | 27.282 | 420.2 | 143.2 |
| 7 | | 7.9000 | 0.0000 | 0. | .0000 | -.0000 | 245.46 | 21.63 | | | | |
| 8 | Q14 | 1.7400 | 0.0000 | .7757E-02 | .0000 | -.0000 | 164.37 | 23.03 | 11.433 | 27.287 | 331.1 | 147.7 |
| 9 | | 40.2000 | 0.0000 | 0. | .0000 | -.0000 | 152.41 | 23.57 | | | | |
| 10 | QDH | .8700 | 0.0000 | .2108E-01 | -.0001 | -.0000 | 33.38 | 94.95 | | | | |
| 11 | QDH | .8700 | 0.0000 | .2108E-01 | -.0001 | -.0000 | 32.83 | 96.47 | 11.478 | 27.416 | 151.5 | 299.3 |
| 12 | | 26.7600 | 0.0000 | 0. | -.0001 | -.0000 | 33.38 | 94.95 | | | | |
| 13 | QF | 1.7400 | 0.0000 | -.2075E-01 | -.0003 | -.0000 | 97.49 | 32.16 | 11.606 | 27.457 | 261.7 | 172.3 |
| 14 | | 26.7600 | 0.0000 | 0. | -.0003 | .0000 | 97.49 | 32.16 | | | | |
| 15 | QDH | .8700 | 0.0000 | .2108E-01 | -.0002 | .0000 | 33.38 | 94.95 | | | | |
| 16 | QDH | .8700 | 0.0000 | .2108E-01 | -.0002 | .0000 | 32.83 | 96.47 | 11.651 | 27.586 | 151.5 | 299.3 |
| 17 | | 26.7600 | 0.0000 | 0. | -.0002 | -.0000 | 33.38 | 94.95 | | | | |
| 18 | QF | 1.7400 | 0.0000 | -.2075E-01 | -.0003 | -.0000 | 97.49 | 32.16 | 11.779 | 27.628 | 261.7 | 172.3 |
| 19 | | 26.7600 | 0.0000 | 0. | -.0003 | .0000 | 97.49 | 32.16 | | | | |
| 20 | QD | 1.7400 | 0.0000 | .2108E-01 | -.0001 | .0000 | 33.38 | 94.95 | 11.824 | 27.757 | 151.5 | 299.3 |
| 21 | | 1.2300 | 0.0000 | 0. | -.0001 | .0000 | 33.38 | 94.95 | | | | |
| 22 | B1 | 24.2200 | 1.0329 | 0. | -.0001 | .0000 | 35.01 | 90.73 | .000 | .000 | 19.2 | 24.5 |
| 23 | | 1.3100 | 0.0000 | 0. | .0125 | .0010 | 92.95 | 33.81 | | | | |
| 24 | QF | 1.7400 | 0.0000 | -.2075E-01 | .0139 | .0010 | 97.49 | 32.16 | 11.952 | 27.798 | 261.7 | 172.3 |
| 25 | | 1.2300 | 0.0000 | 0. | .0152 | .0005 | 97.49 | 32.16 | | | | |
| 26 | B2 | 24.2200 | 8.9050 | 0. | .0159 | .0005 | 93.23 | 33.71 | .005 | .005 | 31.3 | 14.9 |
| 27 | | 1.3100 | 0.0000 | 0. | .1360 | .0094 | 35.12 | 90.46 | | | | |
| 28 | QD | 1.7400 | 0.0000 | .2108E-01 | .1483 | .0094 | 33.38 | 94.94 | 11.996 | 27.927 | 151.5 | 299.3 |
| 29 | | 1.2300 | 0.0000 | 0. | .1696 | .0152 | 33.38 | 94.94 | | | | |
| 30 | B3 | 24.2200 | 10.9286 | 0. | .1884 | .0152 | 35.01 | 90.72 | .012 | .012 | 19.2 | 24.5 |
| 31 | | 1.3100 | 0.0000 | 0. | .6892 | .0261 | 92.95 | 33.80 | | | | |
| 32 | QF | 1.7400 | 0.0000 | -.2075E-01 | .7234 | .0261 | 97.49 | 32.15 | 12.125 | 27.969 | 261.7 | 172.3 |
| 33 | | 23.7600 | 0.0000 | 0. | .7458 | -.0005 | 97.49 | 32.15 | | | | |
| 34 | +WIG | .5000 | 0.0000 | 0. | .7334 | -.0005 | 37.57 | 84.85 | | | | |
| 35 | | .2500 | 0.0000 | 0. | .7331 | -.0005 | 36.82 | 86.47 | | | | |
| 36 | -WIG | .5000 | 0.0000 | 0. | .7330 | -.0005 | 36.45 | 87.29 | | | | |
| 37 | | .2500 | 0.0000 | 0. | .7327 | -.0005 | 35.73 | 88.95 | | | | |
| 38 | -WIG | .5000 | 0.0000 | 0. | .7326 | -.0005 | 35.38 | 89.79 | | | | |
| 39 | | .2500 | 0.0000 | 0. | .7324 | -.0005 | 34.69 | 91.47 | | | | |
| 40 | +WIG | .5000 | 0.0000 | 0. | .7322 | -.0005 | 34.35 | 92.33 | | | | |
| 41 | | .2500 | 0.0000 | 0. | .7320 | -.0005 | 33.70 | 94.05 | | | | |
| 42 | QD | 1.7400 | 0.0000 | .2108E-01 | .7318 | -.0005 | 33.38 | 94.91 | 12.169 | 28.098 | 151.5 | 299.3 |
| 43 | | 26.7600 | 0.0000 | 0. | .7544 | .0266 | 33.38 | 94.91 | | | | |
| 44 | QF | 1.7400 | 0.0000 | -.2075E-01 | 1.4659 | .0266 | 97.49 | 32.16 | 12.298 | 28.139 | 261.7 | 172.3 |
| 45 | | .2100 | 0.0000 | 0. | 1.4659 | -.0266 | 97.49 | 32.16 | | | | |
| 46 | SF2 | .4400 | 0.0000 | 0. | 1.4603 | -.0266 | 96.75 | 32.41 | | | | |
| 47 | | .5800 | 0.0000 | 0. | 1.4486 | -.0266 | 95.22 | 32.96 | | | | |
| 48 | B | 24.2200 | 10.3287 | 0. | 1.4331 | -.0266 | 93.22 | 33.71 | .018 | .018 | 31.3 | 14.9 |
| 49 | | 1.3100 | 0.0000 | 0. | .9135 | -.0163 | 35.12 | 90.49 | | | | |

Figure 5.

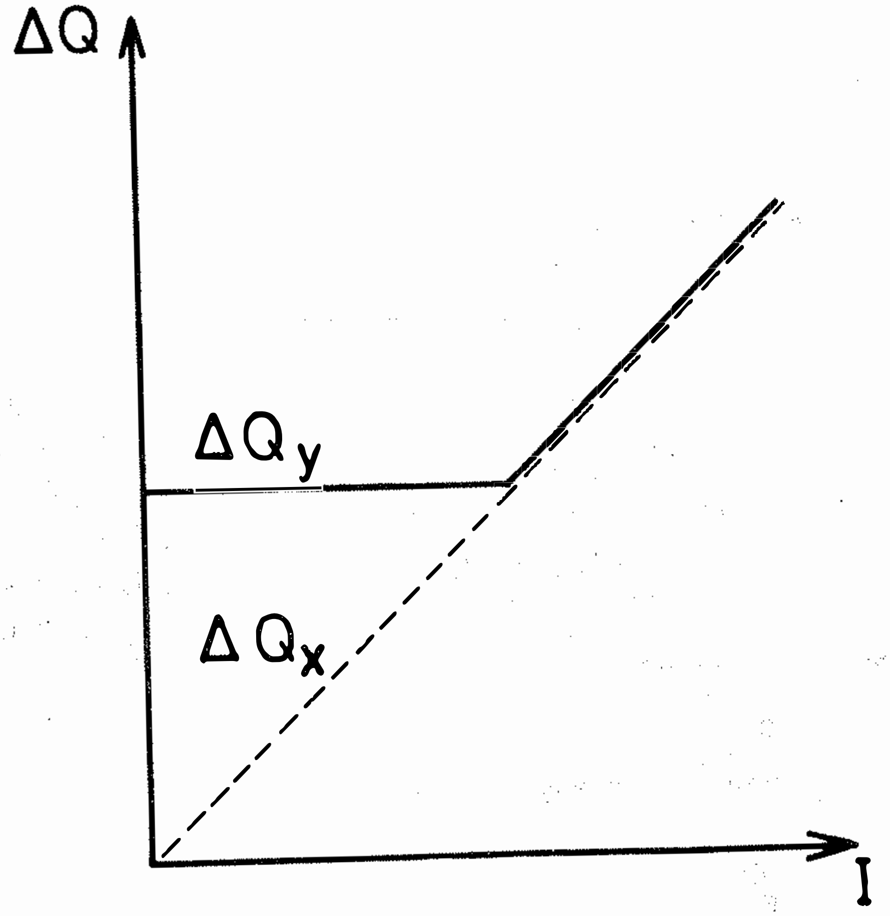


Figure 6.

Three different ways for obtaining the current $I_x$ depending on data $P_g$ and $I_{xy}$

1) Fixed generator power $P_g$.
2) Fixed current.
3) Currents given by beam-beam limit.

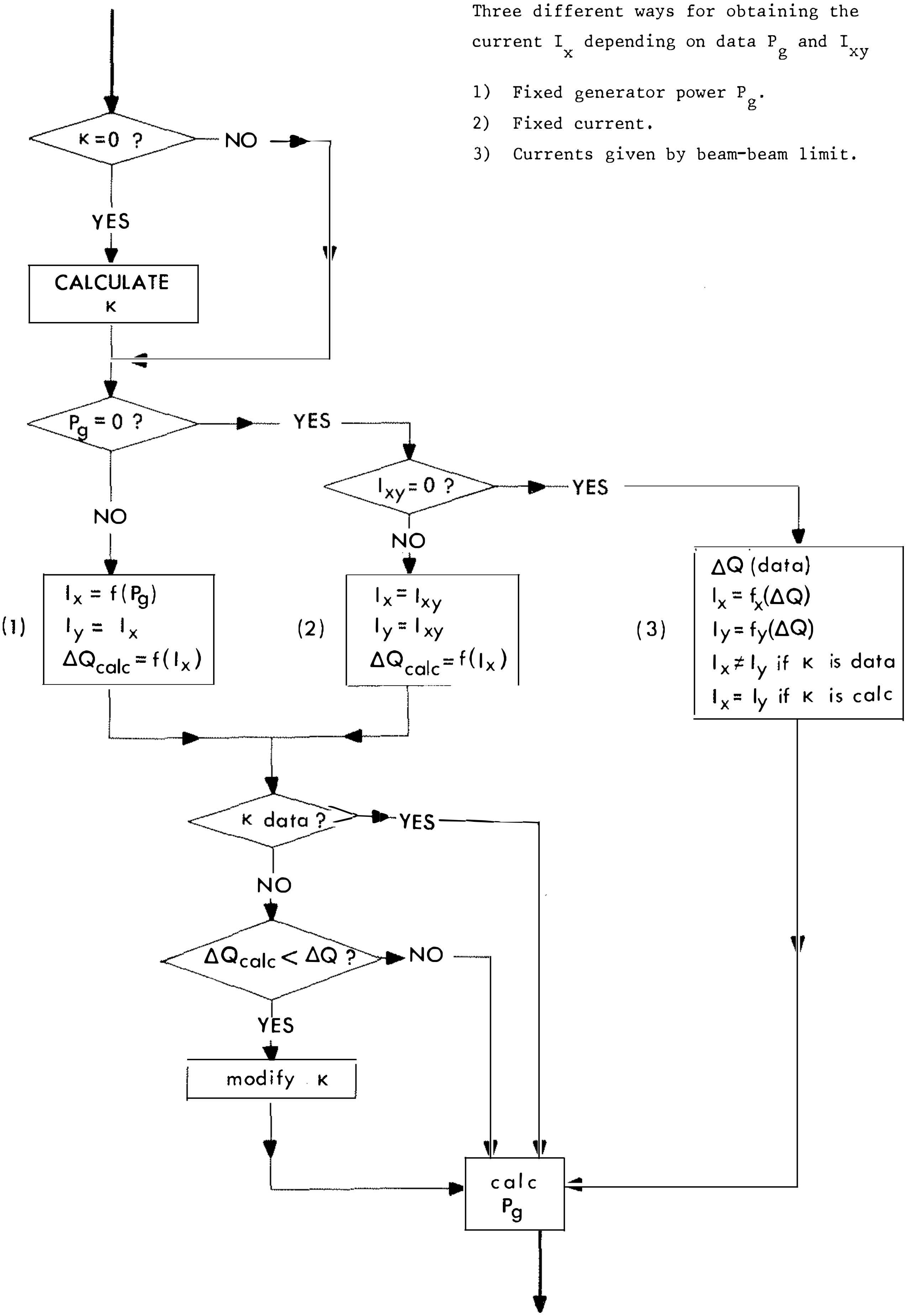


Figure 7.