national accelerator laboratory

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2040

BEAM TRACING PROGRAM FOR TIME SHARING TERMINALS

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A. GENERAL DESCRIPTION

A program has been written for the CALL/360 system to accumulate transfer matrices (3 x 3 horizontal and 2 x 2 vertical) for a sequence of quadrupoles, drift spaces, and bending magnets. An initialization section asks the user for the number of elements in his system and the central momentum (GeV/c). Next, he chooses the desired type of tracing from the options

1. transfer matrices
2. beam envelope matrices
3. ray trace
4. aperture projection on source phase planes

Undesired options are indicated by zero; desired options are indicated by a positive number. For ray tracing, this number is the number of rays to be traced. For example,

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ENTER DESIRED OPTIONS (MATRIX, ENVELOPE, TRACE, APERTURE)?1,0,3,0
                   (program)                               (user)
```

will initialize for transfer matrix output and tracing of three rays. If other than Option 1 are specified, further prompts for initial conditions are given. These prompts are described below in the discussion of the options. The program proceeds into an accumulation loop where the user enters four parameters for each element, viz. TYPE, LENGTH, FIELD, PRINT. The currently valid type codes and the meaning of the associated LENGTH and FIELD parameters are

	TYPE	LENGTH	FIELD
focusing quadrupole	1	effective length (m)	gradient (kG/m)
defocusing quadrupole	2	effective length (m)	gradient (kG/M) sign optional
drift space	3	length (m)	any number, e.g., 0
bending magnet	4	effective length (m)	bending field (kG)

If the PRINT parameter is non-zero, the results for the system, including the element just entered, are printed after the element entry. When the accumulation loop has been satisfied, the program may be terminated, executed with the same initialization, reinitialized completely, or reinitialized selectively by entering a number from zero to three in response to the prompt

QUIT(0), RERUN(1), CHANGE(2), SELECTIVE CHANGE(3)?

The last option requires a knowledge of internal names for quantities in the program which are given in Section C. To use the program one signs onto the CALL/360 system under his own user number then uses the commands

ENTER PL/I (CR)

LOAD *BEAMTRC (CR)

RUN (CR)

B. DETAILS OF OPTIONS

1. Transfer Matrices

If Option 1 (MATRIX) is non-zero, the horizontal and vertical transfer matrices are available after each element. The interpretation of these is that an initial ray $X_o = (x_o, x_o', \Delta p/p)$ $Y_o = (y_o, y_o')$ becomes at the end of the nth element

$$X_n = H_n X_o \quad Y_n = V_n Y_o$$

where H_n and V_n are respectively the vertical and horizontal transfer matrices. Point-to-point focusing is indicated by a zero 1,2 element and point-to-parallel focusing by a zero 2,2 element.

2. Beam Envelope Matrices

If Option 2 (ENVELOPE) is non-zero, initial ellipsoidal distributions of x, x', Δp/p and y,y' are transported through the system. A prompt for the horizontal and vertical half widths, divergences and Δp/p at the source is issued. The units are meters, radians and fractional Δp/p. The code assumes that the beam is uncorrelated at the source. Thus, the beam matrices at the source

$$(\sigma_x)_o = \begin{pmatrix} x_o^2 & 0 & 0 \\ 0 & (x_o')^2 & 0 \\ 0 & 0 & \frac{\Delta p}{p} \end{pmatrix} \quad (\sigma_y)_o = \begin{pmatrix} y_o^2 & 0 \\ 0 & (y_o')^2 \end{pmatrix}$$

are transformed to the end of the nth element:*

$$(\sigma_x)_n = H(\sigma_x)_o H^T \qquad (\sigma_y)_n = V(\sigma_y)_o V^T.$$

The square roots of the diagonal elements give the beam envelope dimensions and the off-diagonal elements give the beam correlation:

$$r_{12} = \frac{\sigma_{12}}{\sqrt{\sigma_{11}\sigma_{22}}}$$

A useful formula for the distance along a drift space to a waist is

$$d_{waist} = -\frac{\sigma_{12}}{\sigma_{22}}$$

3. Ray Trace

The program prepares to trace the number of rays (≤ 6) given in response to Option 3 (TRACE). The initialization section asks for values x_o, x_o', $\Delta p/p$, y_o, y_o' for the required number of rays. The transported values are printed after the element entry if the PRINT parameter is non-zero.

4. Aperture Projection

If Option 4 (APERTURE) is non-zero, the program prompts during initialization for the $\Delta p/p$ used in the projection. After the element entry there is a prompt for the horizontal

*These beam envelope formulas are discussed in greater detail in Appendix A of the TRANSPORT manual: TRANSPORT A Computer Program for Designing Beam Transport Systems, C. H. Moore, S. K. Howry, and H. S. Butler, SLAC internal report.

and vertical half apertures in meters. Each element edge is represented by a vertical line in phase space. Two points on each edge are transported to the source plane by the inverse of the accumulated transfer matrix. Entrance edges are projected prior to the accumulation of the current element, then exit edges are projected after accumulation. The arbitrary chosen points transported back determine a line for each of the eight edges. The printed results are the intercepts of these lines with the coordinate axes. The format is

		x(x'=0)	x'(x=0)	y(y'=0)	y'(y=0)
Entrance face	+ edge	*	*	*	*
	- edge	*	*	*	*
Exit face	+ edge	*	*	*	*
	- edge	*	*	*	*

C. REPETITIVE EXECUTION

When the first transport system has been completed, the user may end execution by typing "0" to the continuation prompt. If he wishes to run the same number of elements with the same initial conditions he types "1." If he types "2" the entire cathechism will be repeated. If he wishes to change only a few of the parameters, it may be more convenient to enter them selectively by name. He then responds "3"; to the resulting prompt PARAMETER CHANGES?
he responds

namel = valuel,..., namen = valuen;

where namel to namen are the program names of the quantities to be changed. A list of these names in order of program occurrence follows:

QUANTITY	NAME	REMARKS
number of beam element	N	
central momentum	P	GeV/c
MATRIX parameter	OPTIONS(1)	
ENVELOPE parameter	OPTIONS(2)	
TRACE parameter	OPTIONS(3)	
APERTURE parameter	OPTIONS(4)	
initial beam envelope	BEAMH(I,I) I=1,3 BEAMV(I,I) I=1,2	Note that these must be squares of half widths if entered by name.
initial conditions for rays	XX(I,J) I=1,6;J=1,3 YY(I,J) I=1,6;J=1,2	meters, radians & fractional Δp/p
Δp/p for aperture projection	DP	fractional