national accelerator laboratory

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THE PROGRAM "PROFILE"

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I. INTRODUCTION

Once the first order properties of a beam transport system or charged particle spectrometer have been determined it is often desirable to investigate the effects of aberrations of second and higher order. Both first and second order transmission coefficients may be calculated by means of the program TRANSPORT. However, in TRANSPORT the beam properties are presented in terms of a phase ellipse formalism which is not particularly well suited to calculations of an order higher than first. The reason for this is that, along a given coordinate axis, the number of moments needed to specify completely the properties of a beam is equal to twice the order to which one is doing the calculation. Thus first order calculations can be specified in terms of two moments, the position of the beam centroid and the size of the beam ellipsoid. Specification of the beam properties in a higher order calculation could be accomplished through the use of additional moments. The physical interpretation of such moments, though, is not obvious and a description of the intensity distribution is invariably preferable.

A program called PROFILE was recently obtained from SLAC for this purpose. It was written by Richard Helm and John Ryder. The function of this program is to provide a plot of such an intensity distribution against any of the coordinates at the end point of the beam line. As input one specifies the first and second, and possibly higher order transmission coefficients between an initial and a final point, and a distribution of rays at the initial point. The program then plots a distribution of intensity (number of rays) along a specified axis at the final position.

Below we present a description of how data is entered, what options are available for calculation, and how the results appear at the completion at the calculation.

II. USING THE PROGRAM

The program is on a disk at Argonne in load module form and may be executed by using the following set of control cards.

(job card)

(accounting card)

```
/*SETUP DEVICE=2314,ID=NAT061
//JOBLIB DD DSN=NAL.LOAD,DISP=SHR
// EXEC PGM=DCPROFIL
//FT06F001 DD SYSOUT=A,DCB=LINE
//FT05F001 DD *
      (data)
/*
```

The input of data into PROFILE is effected by means of "keywords." The keyword is a four letter mnemonic enclosed in quotes. It specifies the nature of the data to follow, which is read in a manner appropriate to its nature. At the end of such data another keyword is read which can either cause the reading of additional data, specify certain modes of calculation, actually begin the calculation, or terminate execution. A complete listing of keywords follows:

'INFO' 'COEF' 'COOR' 'PROF' 'PAGE' 'NAME'

'REHE' 'STOP' 'NEWC' 'GAUS' 'UNIF' 'SQUA'

'ELLI' 'AUTO'

Many of the keywords will be seen below to be abbreviations of longer words. If for ones own purposes one wishes to include the longer word in quotes no damage will be done.

The data following each keyword card is in free field format and placement on the card is unimportant, provided all items are separated by spaces. A typical example of a complete set of input data for a run is shown in Figure 1. The results of that run can be seen in Figures 3 and 5 and will be explained below.

III. BASIC DATA

A. 'INFO' - Title

Naturally one would like to have a title for ones histogram. This is specified on a single card in columns 1-72.

B. 'COOR' - Input Coordinates

Here one specifies the distribution of rays at the initial position and the binning for the histogram for the coordinate at the final position. The first number of each card is the number of the coordinate (see Figure 1 for an example). The single coordinate at the final position is numbered 0. The coordinates at the initial position are numbered 1 through 6. Not all coordinates need be specified. If none of the first or second order transmission coefficients couple to a given initial coordinate, then that coordinate can obviously be deleted, as it does not affect the result.

The second and third numbers on a card indicate, for the initial coordinates, the range over which the rays are distributed. For the final coordinate they indicate the range over which the histogram should be plotted. The fourth quantity indicates the number of intervals into which the range is divided. For the initial distribution this number is equal to the number of rays along a given coordinate. Each ray is assumed to come from the center of its interval. Normally the program assumes that the rays are distributed uniformly over a rectangular volume of phase space. A given coordinate may be fixed by having the end points of the interval be identical and specifying only one interval. For the coordinate at the final position this number indicates the number of bins for summary of data and should not exceed 50.

By placing the word SENTINEL on the last card after the data, one indicates the termination of input coordinates. For those users of TRANSPORT who are accustomed to placing SENTINEL on a separate card, this should be done only if fewer than all seven coordinates are specified.

C. 'COEF' - Input Coefficients

If one expands the final coordinate in terms :he initial coordinate one obtains

$$X_i^f = \sum_j R_{ij} X_j + \sum_{j,k} T_{ijk} X_j X_k + \text{(higher order terms)} \qquad (1)$$

Since the program plots in one dimension, one need not specify which final coordinate one is looking at, but simply enter all coefficients for that coordinate.

The coefficients are entered (see Figure 1) via a sequence of pairs of numbers, the first being a six digit integer and the second a floating point in exponential notation. The floating point quantity is, of course, the value of a given coefficient and the integer indicates which coefficient it is. The six digit integer is such that the i'th digit is equal to the number of times the i'th coordinate appears to the right of the coefficient in the series in equation (1).

For example, if we are plotting against X_1^f and we have a series which looks like

$$X_1^f = R_{11}X_1 + R_{11}X_1 + T_{126}X_2X_6 + T_{166}\ X_6{}^2.$$

The coefficient R_{11}, which multiplies X_1 would be represented by the integer 100000, R_{16} by 000001, T_{126} by 010001 and T_{166} by 000002. One can specify higher order coefficients similarly.

At the end of the list one again places a SENTINEL to indicate that the listing is complete.

D. 'NEWC' - New Coordinates

If after making a histogram, one wishes to alter some coordinate specifications, while leaving others unchanged one uses this option. One enters the new coordinates in the same format as the original coordinates, and follows with a SENTINEL.

E. 'NAME' - Variable Names

It is possible to designate the variable names anything one chooses, up to four letters per name. The new names are entered in order, enclosed in quotes, and followed by a SENTINEL. If no new names are entered the program calls the variables Y, X1, X2, X3, X4, X5, X6.

IV. CALCULATION OPTIONS

A. 'UNIF' - Uniform Distribution of Rays

An initially uniform distribution of rays is specified. This is the normal option for the program. This card is needed only if one changes to 'GAUS' and wishes to change back.

B. 'GAUS' - Gaussian Distribution of Rays

If one wishes to represent a gaussian distribution for the initial phase space density one uses this option. Following this card are the data for the distribution in each coordinate. As for 'COOR' there are four quantities per card, one card per coordinate. The first number is the number of the coordinate. The second is the height of the distribution in that coordinate. Third and fourth are the mean and standard deviation of the gaussian distribution in that coordinate. After the data on the last card, one places a SENTINEL.

This data should come after the coordinate data since weights are calculated from the coordinate step size. An example of such data is shown in Figure 2. These data would be included in addition to those in Figure 1.

C. 'SQUA'

The initial rays occupy a rectangularly shaped phase space volume. This is the normal option.

D. 'ELLI' - Elliptical Distribution

The initial rays are constrained to lie within an ellipsoid whose maximum dimensions are those specified in the coordinate input. The number of rays will be diminished accordingly. For example, for a three dimensional initial distribution, the number should be $\pi/6$ times the number for the rectangular case. This will be only approximate due to the non-zero size of the bins.

E. 'AUTO'

Introduces automatic scaling of the coordinate at the final position, i.e. the one we are plotting against. It is reported that there are difficulties with this. Also it requires that the calculation be redone if the initial guess is bad. So, it is better to specify the scaling on the coordinate data if an approximate idea of the scale is known. This is one piece of information the phase ellipse formalism of TRANSPORT can provide.

V. INITIATION OF CALCULATION

A. 'PROF' - Begin Calculation

Here we actually compute and plot the histogram. First the data is printed as shown in Figure 3. In this case we have chosen uniform distribution and rectangular phase space. If we had chosen a gaussian distribution, the data relevant to that could be printed as shown in Figure 4.

Then the histogram is plotted as seen in Figure 5. The horizontal scale is intensity and the vertical is the coordinate being plotted against. At the top is the title read in under 'INFO.' The left hand column indicates the number of rays in each bin and is summed at the bottom. The figures in parentheses in these columns indicate the number of rays which fell outside the range of the graph. The horizontal axis is always scaled automatically. The number of rays in each bin is indicated by a * which falls on the right-hand vertical axis if equal to zero. The first two moments are then given.

The *'s may then be connected by hand. Perhaps the reader might like to do this to his own copy to make it easier to follow. It should be borne in mind that if the calculation is second order that the final distribution can't be overly grainy. Fine structure invariably is due to an insufficient number of rays being used. This can usually be cured by employing a larger number of rays in the coordinate associated with the principal aberrations.

B. 'STOP' - Terminates Execution

This command terminates execution. If omitted the program will stop executing anyway, but you will get one of those ugly IHC900I error messages, which you certainly would want to avoid.

C. 'REHE' - Reheads Page

If you wish to be neat and start a new page at some point with the title at the top, this will do it.

D. 'PAGE' - New Page

You can also start a new page without the title. Maybe you need scratch paper.

REFERENCES

1. Karl L. Brown, SLAC-75, "A First- and Second-Order Matrix Theory for the Design of Beam Transport Systems and Charged Particle Spectrometers" (1969).

2. Karl L. Brown, Barbara K. Kear, Sam K. Howry, SLAC-91, "A Computer Program for Designing Charged Particle Beam Transport Systems." (1969).

```
   'INFO'
THIS IS THE TITLE OF THE PROBLEM
   'COEF'
   010000 .63581     000001    -.78845    200000  4.105-4  110000    6.679-3
   101000 3.289-3    100100    5.443-4    100001  1.441-2  020000   -1.494-2
   011000 -6.603-4   0100100   -1.164-4   010001  3.655-2  1002000   6.394-3
   001100 3.22-3     001001    -4.991-4   000200  4.229-4  000101   -1.055-4
  000002  -1.326-2       SENTINEL
   'COORDS'
   0   -0.1       0.2   30
   1   -1.        1.    10
   2   0.         0.    1
   3   -0.04      0.04  10
   4   -20.       20.   3
   5   0.         0.    1
   6   0.         0.    1     SENTINEL
   'PROFIL'
```

Typical Input Data for Running PROFILE

FIGURE 1

```
                                       'GAUSS'
   1      1.0      0.0   0.5
   2      1.0      0.0   1.
   3      1.0      0.0   0.4
   4      1.0      0.0   20.0
   5      1.0      0.0   0.5
   6      1.0      0.0   0.5         SENTINEL
   'PROFIL'
```

Additional Data to Follow Coordinate Data for Gaussing Weighting

FIGURE 2

```
THIS IS THE TITLE OF THE PROBLEM

COEFFICIENTS IN EXPANSION OF Y
        010000  6.358E-01        100001  1.441E-02        001100  3.220E-03
        000001 -7.885E-01        02000  -1.494E-02        001001 -4.991E-04
        200000  4.105E-04        011000 -6.603E-04        000200  4.229E-04
        110000  6.679E-03        010100 -1.164E-04        000101 -1.055E-04
        101000  3.289E-03        010001  3.655E-02        000002 -1.326E-02
        100100  5.443E-04        002000  6.394E-03

LIMITS:    0      Y      -0.1000      0.2000   ( 30)
           1      X1     -1.0000      1.0000   ( 10)
           2      X2      0.0         0.0      (  1)
           3      X3     -0.0400      0.0400   ( 10)
           4      X4    -20.0000     20.0000   ( 30)
           5      X5      0.0         0.0      (  1)
           6      X6      0.0         0.0      (  1)

DISTRIBUTION IS WEIGHTED UNIFORM_Y1

PHASE SPACE SHAPE IS RECTANGULAR
```

Printing of input data for case shown in Figure 1

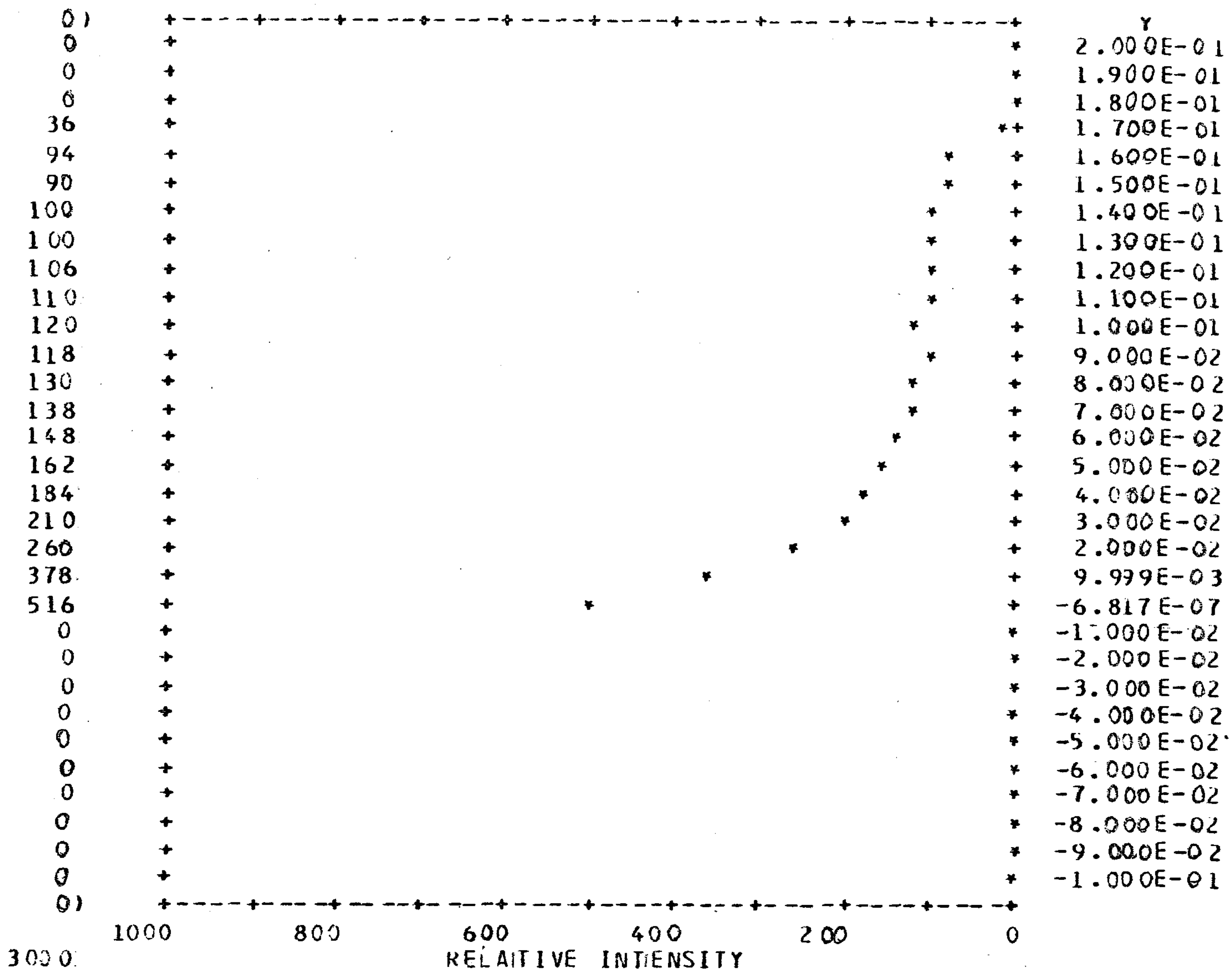
FIGURE 3

```
THIS IS THE TITLE OF THE PROBLEM

COEFFICIENTS IN EXPANSION OF Y
         010000   6.358E-01          100001   1.441E-02          001100   3.220E-03
         000001  -7.885E-01          020000  -1.494E-02          001001  -4.991E-04
         200000   4.105E-04          011000  -6.603E-04          000200   4.229E-04
         110000   6.679E-03          010100  -1.164E-04          000101  -1.055E-04
         101000   3.289E-03          010001   3.655E-02          000002  -1.326E-02
         100100   5.443E-04          002000   6.394E-03

LIMITS      0       Y        -0.1000      0.2000     ( 30)
            1       X1       -1.0000      1.0000     ( 10)
            2       X2        0.0         0.0        (  1)
            3       X3       -0.0400      0.0400     ( 10)
            4       X4      -20.0000     20.0000     ( 30)
            5       X5        0.0         0.0        (  1)
            6       X6        0.0         0.0        (  1)

WEIGHTS     1       X1        1.0000      0.0          0.5000
            2       X2        1.0000      0.0          1.0000
            3       X3        1.0000      0.0          0.0400
            4       X4        1.0000      0.0         20.0000
            5       X5        1.0000      0.0          0.5000
            6       X6        1.0000      0.0          0.5000

PHASE SPACE SHAPE IS RECTANGULAR
```

Printing of data for case represented by Figure 2

FIGURE 4

THIS IS THE TITLE OF THE PROBLEM



MEAN= 5.626E-02 2ND MOMENT= 5.070E-02

Histogram printed for case in Figure 1

FIGURE 5