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A QUADRUPOLE DOUBLET FITTING PROGRAM

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I. INTRODUCTION

An interactive program for determining the gradients of a quadrupole doublet has been created. This program offers many advantages over previous doublet fitting programs or the use of tables. Specifically it permits one to fit to any physically realistic set of two focal conditions, stigmatic or astigmatic, and to display any first order or second order chromatic matrix element at any point in the system. One can also work in any units desired, input initial transfer matrices, and fit up to five doublets in sequence, with two focal conditions after each doublet.

II. ADVANTAGES OF AN INTERACTIVE PROGRAM

The great advantage of an interactive program is that it allows you to solve a sequence of problems, the input

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for each depending on the results of the previous. Typically the new problem will differ from the old by the change of but a few parameters. One would therefore like to be able to retain the data from the old problem and input only the desired changes to reinitiate the calculation. Also a teletype is a slow device and one would like to be able to specify exactly what information is to be printed. One could then have access to a wide range of information without being delayed by the printing of irrelevant items.

In the problem of fitting of quadrupole doublets, one typically wishes to satisfy more than two focal conditions. However, the creation of a program that will solve this problem directly without having to supply approximate gradient values in the input is a practical impossibility. It is more convenient to solve the problem using two of the conditions. One can then vary some of the input parameters, such as the lengths of the quadrupoles or the drift spaces, to satisfy the additional constraints.

The doublet fitting program described here is optimized to satisfy the above criteria. In addition an attempt has been made to have the input data in a natural format, and to be able to correct easily for errors.

III. USE OF THE PROGRAM

The program begins by listing a number of options and then requesting the user to select one of those listed. The options correspond to the different things a user might want to do and are as follows:

1 for Input of Initial Matrices

2 for Input of Basic Data

3 for Alteration of Data

4 for Alteration of Constraints

5 for Display of R and T Matrices

6 for Stopping Execution

7 for Changing Units

8 for Fitting

One typically begins with either options 1, 2, or 7.

The structure of the program is based on what we will call a cell. A cell consists of two quadrupoles with drift spaces before, between, and after, and two constraints which may or may not be at the same location. The location of the further constraint is considered to be the end of the cell. A diagram of a cell is shown in Fig. 1.

In the use of the program, reference is made to numbered lengths and locations. The numbers for the lengths are shown in the diagram. The locations are at the ends of the corresponding lengths.

One now selects an option by typing the number of the option plus a carriage return. The individual options are explained below.

Option 1: Input of Initial Matrices

Often there are intervening elements between the beginning of the beam line and the cell in question. Yet one wishes to fit elements of the transfer matrix from the beginning of the beam line to the end of the cell. One can

then represent the portion of the beam line up to the beginning of the cell via a transfer matrix. The transfer matrices are represented in the same manner as in the program TRANSPORT[1]. Only the chromatic elements of the second order matrix are given, as these are the only ones affected by quadrupoles.

After the user selects Option 1 the program will print

R MATRIX

and then

TYPE O FOR IDENTITY, TYPE 1 FOR INPUT.

Typing 'O' sets the initial first order transfer matrix equal to the identity matrix, meaning that the beginning of the beam line is the beginning of the cell. If option 1 has never been selected the input matrix is assumed to be the identity. One need only specify the identity matrix explicitly if one has previously introduced a different matrix and wishes to return to the identity. If one types '1' the program will respond by asking for the elements of the R matrix, two on a line. The values of the matrix elements should then be entered on the same line in the units being used. See the description of Option 7 for a listing of the units used.

If one is interested in studying chromatic aberration and wishes to represent part of the beam line by a transfer matrix, one can then enter the chromatic elements of the second order transfer matrix. The program will type

T MATRIX

and then

TYPE O FOR O, TYPE 1 FOR INPUT

If one is not interested in chromatic terms or wishes the beam line to start at the beginning of the cell, one types '0'. This sets all second order chromatic elements equal to zero and is the option assumed by the program unless otherwise specified. If one wishes to introduce chromatic T matrix elements explicitly one types '1'. The program then asks for the values of the elements two at a time and one responds by entering the values on the same line.

Option 2: Data for Beam Line

The parameters specifying the physical configuration of the cell(s) being considered and the constraints imposed are entered here. The program will first request the value of the designed central momentum of the beam line by typing

ENTER MOMENTUM IN GEV/C.

The user responds by entering the value of the momentum on the same line, followed by a carriage return. The units for momentum may be changed in Option 7 and the request for a value will be made in terms of the units specified.

Next the program asks for the number of cells to be considered by printing

HOW MANY CELLS?

One responds by entering the number of cells followed by a carriage return. A sequence of up to five cells in succession may be considered, each cell beginning at the

farthest downstream point of the previous cell. Two focal conditions are to be specified for each cell and the conditions will be fitted in succession, each cell being considered after the conditions specified for the previous cell have been satisfied. If more than one cell is specified, for many of the options it will be necessary to specify a cell number. They are numbered sequentially proceeding downstream. If there is only one cell, naturally the program will never ask for a cell number.

Having had the number of cells specified we now need specifications of the physical parameters of each cell and the constraints imposed. If there is more than one cell the program will print the cell number before requesting any information pertaining to that cell. First one needs to specify the desired polarity of the quads. The program will now type

FD OR DF.

The letter 'F' indicates a horizontally focussing quadrupole while 'D' indicates a horizontally defocussing quadrupole. The quads are in sequence proceeding downstream. One enters the option desired by typing 'FD' or 'DF' and executes a carriage return. Next the program will type

ENTER LENGTHS, SS, QUAD, SS, QUAD, SS, (SS)

and will execute a carriage return. These quantities represent the lengths of the straight sections and quadrupoles as they occur in sequence proceeding downstream, in the units being used. In other options these quantities

are referred to as lengths one to six respectively. After the second quad there are two straight section lengths provided to allow for the possibility of astigmatic focal conditions. If the two focal conditions occur at the same location only one distance need be specified. If the two conditions are imposed at different locations two drift lengths are needed. The length specified gives the distance of the constraint from the end of the second quad in the cell being considered. There is no restriction as to which constraint is more distant from the second quad. The only requirement is that when the constraints are specified they occur in the same order as the distances that pertain to them. If another cell follows it is taken to begin at the location of the constraint further downstream. One enters the values of the quantities requested and executes a carriage return.

The two constraints for the cell being considered are now requested by the program by typing
CONSTRAINTS, ENTER I, J, DESIRED VALUE, TOLERANCE
followed by a carriage return. Since there are two constraints for each cell it requests them by typing
NO 1 or NO 2.
One then enters the numbers specifying the constraint on the same line followed by a carriage return. The quantities I and J are integers indicating the row and column of the R matrix element on which the constraint is being imposed. The R matrix considered is always taken from the beginning of the entire beam line specified. The third quantity is

the desired value of the R matrix element indicated. The tolerance is used as a criterion for the accuracy to which the fitting is to be done. A value of 0.001 is usually appropriate. One wishes to obtain an accurate fit without being subject to eccentricities caused by round off errors of the computer.

Option 3: Alteration of Input Data

One may now wish to change one or more of the input parameters and again obtain a solution. The use of Option 3 allows one to change any or all of the lengths of the quadrupoles or straight sections. The program will print

HOW MANY CHANGES?

One then enters the total number of such length parameters one wishes to alter, followed by a carriage return. If, at this point, one changes ones mind and would rather select another option, one simply presses carriage return.

The program will now ask in sequence for the information describing each change. If there is but one cell it will print

ENTER LENGTH NO, LENGTH.

If the problem involves more than one cell the program will print

ENTER CELL NO, LENGTH NO, LENGTH

The length number for a given cell is an integer, can range from one to six, and is as given in Fig. 1. The length parameter is the new value for the given length. One enters the requested parameters followed by a carriage return.

A word of warning is appropriate. When entering the initial data in Option 2, there is provision for astigmatic fitting, where the distance of the two constraints from the second quad differ. If length No. 6 is omitted it is assumed equal to length No. 5 and whenever length No. 5 is changed, length No. 6 is automatically changed accordingly. If the two are initially different, they may subsequently be changed independently. However, if the two are initially different and one changes either such that they become equal, then the two are assumed equal from then on and both will change when length No. 5 is changed. In order to restore the astigmatic case one must reset length No. 6 when one again wishes them to differ.

Option 4: Alteration of Constraints

Sometimes one will wish to alter some of the constraints imposed and observe the effect on the soltuion. If one selects Option 4 the program will print

HOW MANY CHANGES?

One then enters the number of constraints one wishes to alter, followed by a carriage return. If at this point one decides one doesn't really want Option 4 after all, one simply presses carriage return.

If the problem involves only one cell the program will now print

ENTER CONSTRAINT NO, I, J, DESIRED VALUE, TOLERANCE.

If more than one cell is being considered it will print

ENTER CELL NO, CONSTRAINT NO, I, J, DESIRED VALUE, TOLERANCE.

The program next requests the changes one by one.

Before the first change it will print

CHANGE NO 1.

One then enters the requested items followed by a carriage return. The constraint number is the number given to the constraint when it was entered in Option 2. The subsequent items are as entered in Option 2. The program proceeds similarly for the remaining changes, until the requested number have been made.

Option 5: Display of R and T Matrices

In addition to the required quadrupole gradients for a solution, one is often interested in obtaining the values of certain elements of the first order transfer matrix or chromatic terms of the second order transfer matrix (perfect quadrupoles have no other second order terms) at certain locations in the beam line. It is possible to display any such set of matrix elements at the end of any straight section or quadrupole in any cell. The locations in a cell are numbered one through six and occur at the downstream ends of the correspondingly numbered lengths. Location six exists only if one is doing astigmatic fitting. Otherwise a print request at location six is ignored.

One first specifies the number of different locations at which one wishes to obtain values of either R matrix or chromatic T matrix elements. The program will print

DISPLAY AT HOW MANY LOCATIONS?

One enters this number followed by a carriage return. The program will then request complete information concerning the matrix element display desired, at the number of

locations specified. The locations need not be considered in any particular order. If at this point one changes ones mind and would rather have another option, one simply presses carriage return.

The program then goes through the following steps a number of times equal to the number of locations specified. If a problem involving only one cell is being considered it will print

LOCATION?

If more than one cell is being considered it will print

CELL, LOCATION?

One then enters the appropriate integers and executes a carriage return. The program will then type

ENTER NO OF R ELEMENTS AND NO OF T ELEMENTS.

One enters the number of matrix elements of each type one wishes to have displayed at the location being considered.

If the number of R matrix elements to be printed is non-zero the program will then print

FIRST ORDER MATRIX ELEMENTS

and subsequently for each element desired will print

I = , J = .

One types the row and column of each element desired, followed by a carriage return, until all have been specified. Then if any chromatic T matrix elements are desired the program will print

SECOND ORDER ELEMENTS.

Once again, for each element the program will print

I = , J = .

One enters the first two subscript of the desired T matrix element, the third subscript being understood to be equal to 6.

If any any point one ceases to be interested in a certain matrix element, one can eliminate its printing. After the program types

I = , J =

one types in the row and column with a minus sign in front of the row. For example, if one were to specify four R matrix elements then one could cause two to be printed and eliminate two others.

The format of the program is based on the assumption that one is interested in only a very few matrix elements. If one wishes to produce entire R matrices the process of specifying all their elements will become very tedious. In this case the interactive feature of this program loses much of its value and one should seriously consider going to batch processing.

Option 6: Termination of Execution

Option number 6 causes program execution to be terminated. It means you are done with all your probelms. It is not necessary for starting a new problem as that may be entered using Option 2, and possibly Options 1, 5 and 7.

Option 7: Change of Units

The units in which the various physical parameters are expressed may be changed to any desired. The program will print

HOW MANY CHANGES?

One replies by typing the number of changes desired, followed by a carriage return. If one simply presses carriage return the program will then ask for another option. The program will then ask for each change by typing

UNIT, SIZE, NAME.

The quantity "UNIT" specifies which unit is to be changed. The quantity "SIZE" is the magnitude of that unit in terms of what had previously been used. For example the size of an inch in terms of centimeters is 2.54. The designation "NAME" indicates a two-letter mnemonic for that unit. In the case of momentum units a continuation of "V/C" is understood, giving "MEV/C" or "GEV/C".

A table of units with the standard unit ordinarily used by the program is given below.

Unit Number	Quantity	Standard Unit
1	Transverse dimensions	cm
2	Transverse angles	mr
8	Longitudinal length	meters
9	Magnetic field	kilogauss
11	Momentum	GeV/c

If unit number 0 is specified the program resets all units to the standard units. If two changes are made successively on a single unit the factors will be multiplied. All quantities specified by the user are interpreted as being in the units in effect at the time. If one wishes to give a length in feet one must first change units to feet and then enter the length in question.

Option 8: Fitting

Once all the conditions of a problem have been specified, one will want to determine the solution. This is done by selection Option 8.

The program will obtain an initial solution by the use of a thin lens approximation. Then it will iterate, using a two-dimensional Newton's method, until it has found a solution within the accuracy specified. If more than twenty iterations are necessary it will print out the message

FAILED TO CONVERGE.

Usually when this happens a solution will have been obtained anyway and the constraints specified will have been too restrictive for the accuracy of the computer. In this case one may proceed as normally. It might be helpful to check on the matrix elements fitted using Option 5.

Once a solution has been obtained, the program will print out the quadrupole gradients and the matrix elements specified at the desired locations. If more than one cell is under consideration, it will print the cell number before the information pertaining to that cell. When the printing is completed the program will once again request an option and one may alter the problem and try again as desired.

IV. AVAILABILITY OF THE PROGRAM

The program is currently on file on the NCN commercial

time-sharing service under ID 189. It may be executed by typing in the command

LRUN RABBIT.

The source file is named DUMBO, and a listing may be obtained by typing

LIST DUMBO.

REFERENCES

[1] Karl L. Brown, Sam K. Howry, SLAC report No. 91 (1970).

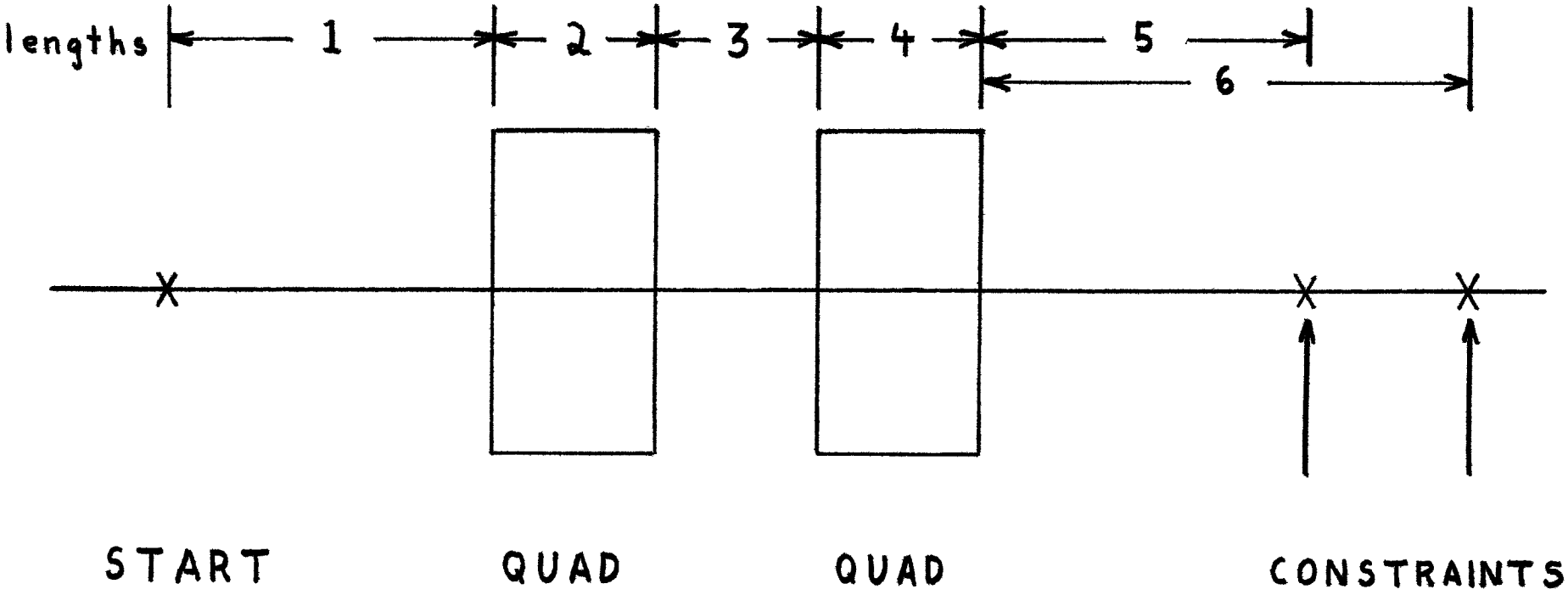

Fig. 1 A "cell", consisting of a doublet with drift spaces. Positions of constraints are indicated.