A FAST OPTICS AND ORBIT CORRECTION PROGRAM*

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Introduction

CEBAF is a large recirculating linear accelerator with approximately 1600 magnet power supplies in the beam transport system. The average beam power can be as great as 800 kW, concentrated into a spot of area less than 0.01 mm². Control of the transport is therefore quite critical, to avoid missteering the beam. To prevent dangerous beam losses and to prepare optics changes, the control programs must read the magnet power supplies and calculate the optics in a virtually real-time manner.

A program named OLE (On-Line Envelope) has been developed at CEBAF to give a graphical display of the calculated machine β function or, equivalently, the beam envelope. The time interval necessary to execute the program is somewhat less than one second, short enough that the operator can use it for setting up his lattice. Emphasis in the design was placed on speed of program execution at the expense of generality of application. As a result, the accelerator operator will be able to alter the magnetic field in any element in the machine, calculate the β functions in both planes at the entrance and exit of each magnet, and display graphs of the functions, all within one second. The time that is required is short enough that the process approximates fairly well real-time operation.

The program has several distinguishing features that are employed to speed the execution time: (1) Some of its subroutines are written in FORTRAN, while others are in C. This is done to exploit the capabilities of each in areas where it is superior. (2) The program is rather tightly coupled to the computer on which it runs. (3) Input data from the magnet power supplies are stored in shared memory, so input/output functions do not slow down program execution. (4) The basic map of the accelerator transport system is stored in a binary file that is used by OLE; each time a magnet is added, moved, or removed, this file must be rewritten.

In order to achieve the rapid results that are demanded of the program, two features of modern computers must be exploited: the availability of large random access memories (RAMs), and the development of high-resolution, bit-mapped color displays. These can now be found in fast, moderately priced computer systems. We use a Hewlett-Packard series 800 computer.

The computer

The computer that is used to run OLE is a Hewlett-Packard 835, which is a reduced instruction set computing (RISC) machine. It is rated at 14 million instructions per second, and is configured with 16 Mbytes of RAM. It uses a high-resolution (1270 × 1024), high-speed (200 K vectors/second), bit-mapped display.

Input-output (I/O) time is minimized by using shared memory. The local computers that read and control the magnet settings deliver the active values of the shunt voltages to the supervisory computer once every read cycle.

The calculations

The purpose of OLE is to calculate the β function or the beam envelope throughout the accelerator. It does this by representing each element of the machine by an appropriate 2 × 2 matrix for the horizontal and vertical planes. Because the transfer matrices are of rank 2 rather than 4, we do not allow for the possible existence of horizontal-vertical coupling. The algorithm that is used for matrix multiplication is a special routine that works only for 2 × 2 matrices.

The initial beam matrix, at the injector, is at present merely a reasonable conjecture. As we get experience with the actual accelerator, we will insert corrected values for this input.

The display

The most generally useful display presented by OLE is a pair of bar graphs for the horizontal and vertical planes that represents each point at which β is calculated by one horizontal pixel (see Figure 1). The depiction of the horizontal separation between each element and its nearest neighbors is thus a constant. This means that the horizontal axis is not a correctly-scaled representation of the beamline, although it is topologically equivalent. The beam radius ($\sqrt{\beta\epsilon}$) is depicted by the height of the bar. Color, which is not reproduced in print, is used diagnostically. The initial values of the bars are colored green. When a magnetic field is changed, and consequently all downstream β functions are altered, the changes are depicted in other colors. If the increase is positive, the increment is colored red; if negative, the increment is blue. In this way, the program allows the operator to recognize at a glance the changes that are produced by setup alterations.

Other displays will be developed as the occasion demands. An example is seen in Figure 2, which shows the beam dispersion function in a way analogous to the envelope display.

Programming languages

In the interest of speed of execution, OLE has been written with parts in FORTRAN and other parts in C. The reason for this programming anomaly is that the two languages have different strengths and weaknesses. The difficulties with I/O in FORTRAN are widely known, whereas C is regarded as excellent for data transfer operations. Therefore, the I/O parts of the program were written in C. On the other hand, C is so loosely structured that its compilation of computations ("number crunching") is not optimized, a point strongly in favor of FORTRAN. In the flowchart (Figure 3) for the program, each subroutine is labeled with either a 'C' or an 'F,' according as to whether the subroutine is written in C or FORTRAN.

Results

Since the CEBAF accelerator has not been built yet, we must test OLE by simulations of the final machine. We have set up a database containing an array of magnets that matches the lattice designed for CEBAF by David Douglas.[1] To test OLE, we have programmed another computer to mimic the currents in a few magnets in such a way that they can be altered by turning the knobs attached to the computer. This enables the operator to adjust the current in a magnet in precisely the same way that it would be done in actual machine operations, and allows the program response to be demonstrated as it would appear. We have observed that the response is quite rapid, fulfilling the hopes we had raised for the program when we set out. The time lag between the knob motion and the display of the new orbit is well less than a second, which means that we will be able to calculate other beam properties, such as dispersion, without harmful degradation.

References

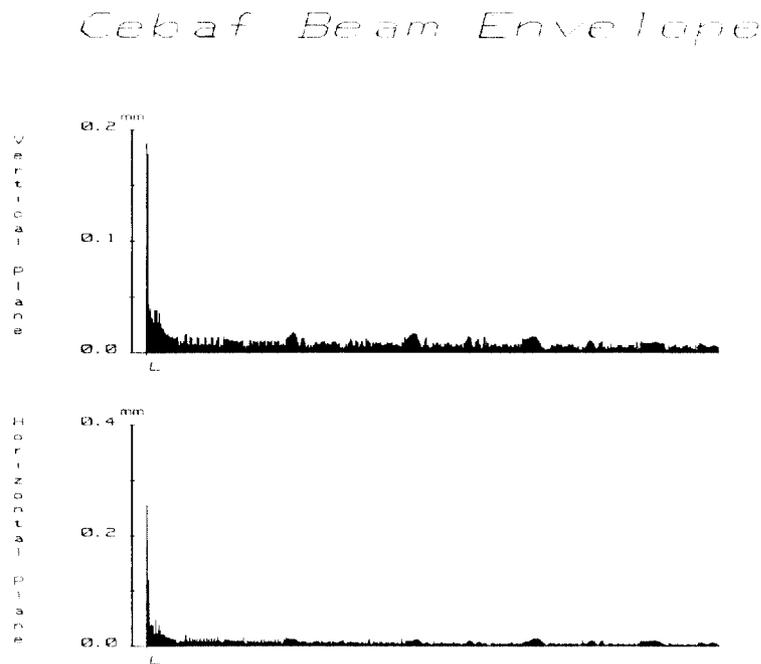[1] David Douglas, Richard York, and Jörg Kewisch, CEBAF PR-89-008.
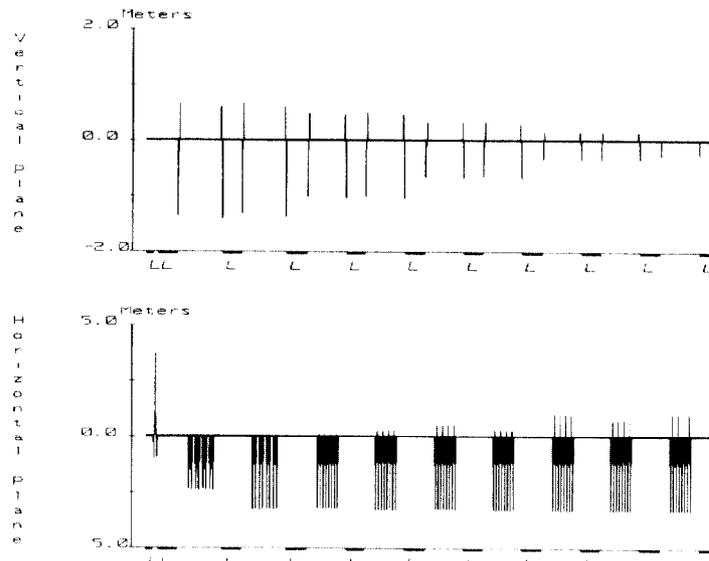
Figure 1. Beam envelope display

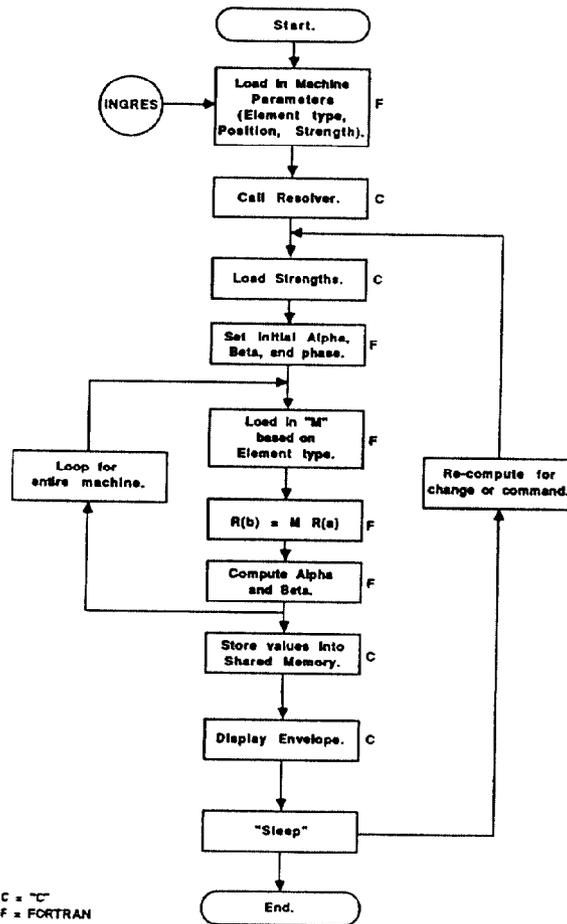_Cebaf Beam Dispersion_

Figure 2. Beam dispersion display

C = "C"
f = FORTRAN

Figure 3. OLE flow diagram