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WITH SPACE CHARGE

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PATH: A LUMPED-ELEMENT BEAM-TRANSPORT SIMULATION PROGRAM WITH SPACE CHARGE*

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Summary

PATH is a group of computer programs for simulating charged-particle beam-transport systems. It was developed for evaluating the effects of some aberrations without a time-consuming integration of trajectories through the system. The beam-transport portion of PATH is derived from the well-known program, DECAY TURTLE.¹ PATH contains all features available in DECAY TURTLE (including the input format) plus additional features such as a more flexible random-ray generator, longitudinal phase space, some additional beamline elements, and space-charge routines. One of the programs also provides a simulation of an Alvarez linear accelerator. The programs, originally written for a CDC 7600 computer system, also are available on a VAX-VMS system. All of the programs are interactive with input prompting for ease of use.

Program Descriptions

PATH consists of four programs: BEAM, TRAN, LINAC, and PLOT. The relationship between the programs is shown in Fig. 1. BEAM creates a file of randomly generated, 6-D particle coordinates. TRAN transports these particles through a beam-transport system and LINAC transports the particles through a linear accelerator. The input file for TRAN or LINAC can be from BEAM or from a previous TRAN or LINAC run; thus, the programs are very flexible. PLOT reads a file of particle coordinates from either BEAM, TRAN, or LINAC and produces one- or 2-D plots of the desired data. A more detailed description of the programs follows.

BEAM

The beam generating program contains four options for phase space distributions: uniform, Gaussian, Kapchinskii-Vladimirskii (K-V)² and binomial. The latter is characterized by a parameter m , and includes the most commonly used distributions.

Fig. 1. A flow chart showing the relationship between the four codes of the PATH group.

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A K-V distribution is obtained with $m=0$, uniform projections for $m=0.5$, and a "waterbag" for $m=1$. A Gaussian would be obtained for infinite m . The input beam parameters may be entered in either TRANSPORT notation³ or Courant-Snyder notation⁴. BEAM contains a table of particle masses for convenience of input.

TRAN

TRAN is a modification of DECAY TURTLE. The input format is identical to TURTLE and TRANSPORT except that the title and initial beam-defining elements are not used. Calculations are done to second order in most elements; however, some elements include third-order calculations. It is anticipated that most elements will be extended to third order in the future. Longitudinal phase space has been included, also to second order, to permit the study of bunched beams and rf elements. The major addition to the program is a 3-D space-charge routine. This allows an element to be broken up into a specified number of segments with the space charge applied after each segment. The space charge is computed by summing forces between macroparticles to minimize artificial collision effects. The 2-D space-charge routines in r - z or x - y are also available. Generation of histograms is done slightly differently from TURTLE. The insertion of a 50; element causes the particle coordinates at that point to be written on a file for subsequent analysis by PLOT. The particle coordinates at the end of the system are automatically written to a file for use as an input file to TRAN or LINAC.

LINAC

LINAC simulates a conventional Alvarez linear accelerator. It is a modified version of the code PARMILA⁵ and includes the capability for generating the drift-tube table. The space-charge routine is 2-D in r and z and normally is applied at the center of the rf gap where the beam is circular.

LINAC is relatively inflexible. It is also possible to simulate a linac with TRAN by individually putting in the quadrupoles and rf gaps. This simulation with TRAN may be preferable if one wishes to study the effects of misalignments, quadrupole harmonic errors, or perturbations to a single rf cell.

PLOT

PLOT is designed to produce graphic output on a Tektronix 4000-Series terminal. Because it is a separate program, one could write various versions to accommodate different output devices. The present version can produce 1-D histograms of any

coordinate, either self-scaled or user scaled. It can also produce 2-D scatter plots or contour plots of any coordinate versus another. Another option is all six 1-D histograms, self-scaled on a single plot. Scatter plots of any phase-space projection can be made also. An encircled energy plot is available for convenience in analyzing the energy distribution of the beam on a target.

In addition to the graphic output, PLOT also produces a summary table giving the rms beam parameters at the end of the system and the number and locations of particles stopped by apertures.

EXAMPLES

Figure 2 shows a bending system consisting of a periodic system of four 90° phase-shift cells, each containing a dipole and two quadrupoles. This system automatically is achromatic to first order and can be made achromatic to second order by the addition of two sets of sextupoles located at the quadrupoles⁶. Figure 3 shows the results of a second-order PATH run through this system for a low-emittance, high-momentum spread beam with no sextupoles; Fig. 4 is the same system with the sextupoles turned on. The calculation was done using a uniform distribution.

Figure 5 shows a set of four, 60° bending magnets used to transport an electron beam. A slit is located at the center of the system to trim the momentum spread from 1 to 0.1%. The system was designed with TRANSPORT so that the monochromatic beam diameter was greater than or equal to the dispersion of a 0.1 % momentum-spread beam to ensure maximum transmission; Fig. 6 shows the result of the PATH simulation with a Gaussian beam. The summary table indicates that the transmission was 10%.

Figure 7 is a PATH calculation for a 20-keV proton beam accelerated to 100 keV by an electrostatic accelerator column. The beam current was assumed to be fully neutralized (0 current) on either side of the column and 0.1 A within the column. The calculation for the accelerator column was done to third order and a uniform distribution was used to enhance the visibility of the aberrations.

Figure 8 shows a longitudinal phase-space calculation for an rf buncher using a 750-keV proton beam. A plot was made every 0.5 m from the buncher to show the bunching action. Again a uniform distribution was used.

Fig. 2. The 180° achromatic bending system consisting of four identical cells. Sextupole magnets are assumed to be incorporated within the quadrupoles.

Fig. 3. A PATH calculation for the system shown in Fig. 2 with no sextupoles.
Shown are scatter and contour plots for (X, X') , (Y, Y') , and (X, Y) planes.

Fig. 4. A PATH calculation identical to Fig. 3 except with the sextupoles turned on.

Fig. 5. An achromatic, four-bend momentum analyzing system.

Fig. 6. A PATH plot of $\Delta P/P$ before and after the slit in the system of Fig. 5. A Gaussian input beam was used.

Fig. 7. A PATH simulation of a dc accelerating column that accelerates a 20-keV proton beam to 100 keV showing the effect of third-order aberrations.

Fig. 8. Longitudinal phase-space plots showing the action of a single rf buncher at distances of 0.5, 1.0 and 1.5 m after the buncher.

Conclusions

PATH has proven to be a versatile and useful beam-transport simulation that has been applied to a wide variety of problems. The code is written in a modular fashion to facilitate inclusion of additional beam-transport elements as well as improved subroutines for existing elements. The compatibility with TRANSPORT and the interactive nature of the program make it easy to use.

Acknowledgment

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