Using MOTER To Design PILAC*

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Abstract

A pion linear accelerator (PILAC) is being designed as a new experimental facility for the Los Alamos Meson Physics Facility (LAMPF). The design goal is a flux of 10^9 pions per second at an energy of 920 MeV into a spectrometer having a resolution of 200 keV. To meet this design goal the system will have to accept a large phase space of particles which, in turn, implies that higher-order aberrations will be significant and have to be corrected. The computer program MOTER is being used to investigate the size of the aberrations and their effect on the resolution of the system. To meet this challenge a number of improvements were made to MOTER. This paper describes those improvements, shows how MOTER can be used to design the high resolution channel and indicates the direction that future developments of this program will take.

I. INTRODUCTION

The proposed PILAC facility involves a target for zero-degree pion production from protons, an injection beamline to transport the pions to a superconducting pion linear accelerator that will raise the energy of the pions from 0.38 to 0.92 MeV, a high-resolution dispersed beamline and associated spectrometer. A second beamline following the linac and feeding a medium resolution spectrometer is part of the proposal.

The success of the PILAC project depends upon delivering 10^9 pions/sec to the spectrometer. That large a flux can only be achieved by transporting a large phase space of particles through the system. To do that and still meet the 200 keV resolution requirement means that higher-order aberrations in the system will have to be corrected. MOTER is the only transport design code that can optimize a system to fifth order using rays traced through the system. All other codes make n-th order matrix approximations and overlook details of the fringe fields which are the crux of the problem.

II. HISTORY OF MOTER

MOTER is not a new code. It is about to enter its third decade, having been developed in the early 1970's by Arch Thiessen and Morris Klein to support the design of two spectrometers at the Los Alamos Meson Physics Facility -- HRS, the High Resolution Spectrometer and EPICS, the Energetic Pion Channel and Spectrometer. Since its debut in 1972[1], MOTER has been used by other groups in this country to design a variety of spectrometers.

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The structure of MOTER, which stands for Morris's Optimized Tracing of Enge's Rays, can be seen in Figure 1. It has as its kernel an early version of the code RAYTRACE[2] developed at MIT by Stanley Kowalski and Harald Enge. That code traces a particle through an arrangement of external fields, typically a system of magnets, by integrating the equations of motion of the particle through these fields. Although this approach is cpu-intensive, it retains effects to all orders so that the accuracy is limited only by the models used in calculating the external fields.

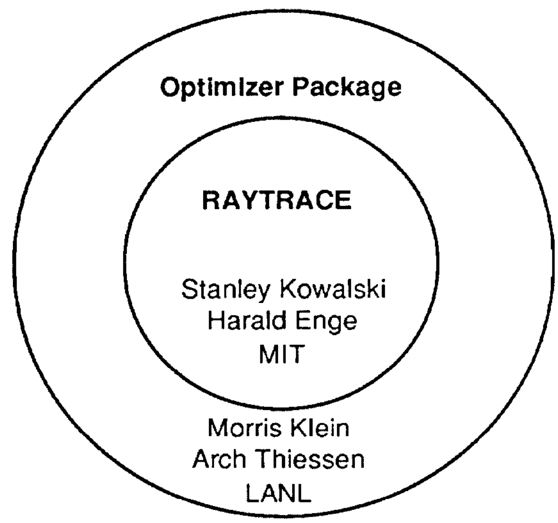

Figure 1. Structure of MOTER -- an optimizer package built around the RAYTRACE kernel.

Wrapped around RAYTRACE is an optimizer package that allows the user to formulate one or more merit functions for the system, each involving multiple demands, in a way that includes software corrections and finite detector resolution. A random ray generator that includes realistic apertures in all optical elements allows MOTER to work like the program TURTLE in calculating the six-dimensional acceptance of the optical system. These random rays, which correctly represent the phase space of particles actually accepted, are used in the optimization.

III. RECENT IMPROVEMENTS

It is our plan to raytrace the entire PILAC system from the end of the LAMPF linac to the focal plane of the spectrometer using MOTER. In preparation for this task it was necessary to modify the existing version of the code.

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1) To get more speed we converted it to run under the UNIX operating system on a DECstation 5000/200. This cut the running time of jobs by a factor of 10 compared to our MicroVAX-III.
2) Next we changed the equations of motion to handle correctly particles having finite mass and traveling at less than the velocity of light.
3) Then we added an rf cavity element to allow simulation of a buncher and the linac. The fact that a particle's velocity would change because of acceleration induced another series of changes.
4) To facilitate the checking of our calculations with RAYTRACE, we replaced the subroutine packages existing in MOTER for dipoles, quadrupoles-dodecapoles, and rectangular multipole correctors with the corresponding software from the latest version of RAYTRACE.
5) Since these new subroutines did not monitor for the particle hitting an aperture, the appropriate modifications were made to provide this feature which is important to the selection of rays to trace.
6) Finally, a draft of a new users manual was completed since the format of some of the input files was changed.

IV. SAMPLE APPLICATION OF MOTER

To check the efficacy of the updated version of MOTER, we used it to calculate the parameters for the magnets of the high-resolution channel. Figure 2 shows the elements in this channel -- four dipoles (D) with edge corrections, two quadrupole magnets (P) with multipole corrections and three rectangular multipole magnets (M). The matching section preceding this line was omitted in this exercise since it can be appended later. This channel is for pions with a central momentum of 1050 MeV/c and a momentum spread of ±0.75%. The design for this channel has to provide a dispersion of 25 cm/% and has to pass 100π mm-mrad with a momentum resolution of better than 1.0×10^{-4} and an angular resolution in the non-bending plane of less than 5 mrad.

PILAC High-Resolution Channel

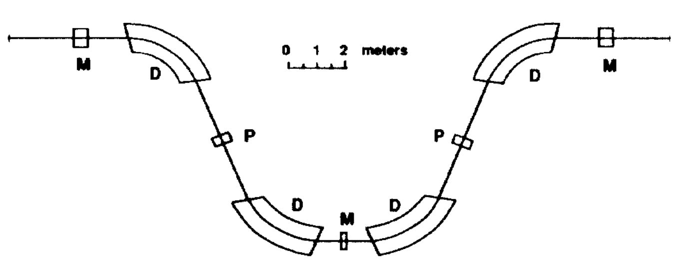

Figure 2. Layout of high resolution channel. Bending is in the vertical plane. A matching section goes ahead of this line.

When starting on a new design, it is best to work out the solution in first order with TRANSPORT and then progress to MOTER. Figure 3 shows the first-order envelopes in x and y along with a plot of the spatial dispersion in the bending plan as calculated by TRANSPORT. A dispersion of about 25 cm/% was achieved. The optical design in the bending plane, which happens to be physically in the vertical direction, is point-to-point-to-point-to-point. The beam width in the dipoles is about ±60 cm. In the non-bending plane the optics requirement is waist-to-waist-to-waist-to-waist and the maximum beam size is about ±4 cm.

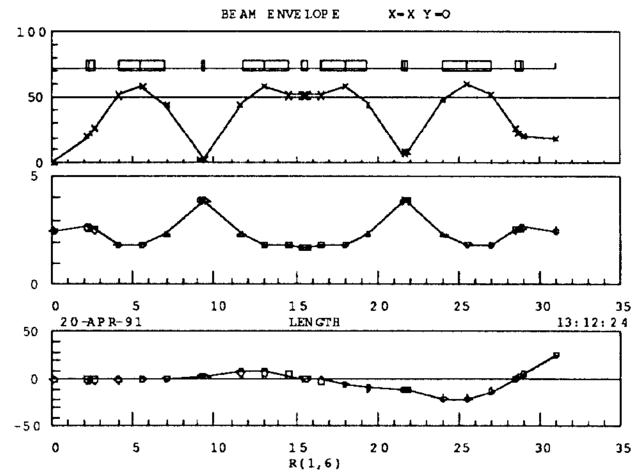

Figure 3. Beam envelopes and dispersion function for the high resolution spectrometer. Boxes in the upper graph show location of magnetic elements.

Using the first-order parameters from the TRANSPORT solution, we set up a run in MOTER to optimize the momentum resolution by adjusting the second order parameters of the system. Three parameter files are required to specify a problem when optimization is involved. The .MAG file specifies (1) the parameters for each element in the system, (2) the rays to be used for tracing, and (3) miscellaneous other parameters to control printing, etc. The .DMD file contains the merit functions to be optimized, each composed of one or more demands. The .OPT file contains parameters that allow the user to tune the optimizer package for most efficient operation. If raytracing is all that is desired, only the .MAG file is required.

The merit functions that went into the .DMD file for this system are given in expressions (1)-(3). The first two specify that the tune in the non-bending plane should match the first-order matrix solution -- the waist condition. Expression (3)

$$y_{foc} - 0.73586\, y_{in} - 0.37452\, y'_{in} \qquad (1)$$

$$y'_{foc} + 1.22427\, y_{in} - 0.73586\, y'_{in} \qquad (2)$$

$$\delta_{in} + ax_{foc} + bx^2_{foc} + cy^2_{foc} + \text{const} \qquad (3)$$

asks that we be able to determine the momentum as accurately as possible from the measurables of the system. δ stands for Δp/p; *a* is the inverse of the dispersion. MOTER was asked to find values for *a*, *b*, *c* and *const* which minimized these expressions in a least squares sense when summed over all 100 particles in the distribution and to return a histogram representing the final result for each function. A total of 13 second-order variables were made available to the program for optimization, the result of which is shown in Table I.

The momentum resolution improved to 2.76×10^{-4} from 12.8×10^{-4}, FWHM. In the non-bending plane the angular resolution decreased about 20%. Since the momentum resolution did not meet specification, we froze the second order parameters and went on to third order. The next line shows an improvement in the momentum dispersion but a deterioration in the angular resolution. At this point we tried 4th and 5th order fits but they did not seem to make any significant enhancement in δ. But what did work very well was a simultaneous fit of 2nd and 3rd order parameters, a total of 27 variables. That run more than achieved our target values.

Table I
Results of MOTER Runs

100 particles	Mom Res $\delta x 10^{-4}$ FWHM	Ang Res y' mrad FWHM
1st Order	12.79	1.13
2nd Order	2.76	0.93
3rd Order	0.69	1.81
2nd and 3rd Order	0.55	0.45

To ensure that the optimization was not a quirk of some specific particle distribution generated by a lucky choice of the seed, we traced 400 particles from each of three different distributions through the system tuned to the optimized solution. All three gave comparable values for δ and y'.

Figure 4 shows a histogram of the momentum resolution accumulated by tracing 400 patricles through the optimized system. The corresponding histogram for the angular resolution is shown in Figure 5. These histograms verify that the design goals were met and that there are no untoward tails in the distribution.

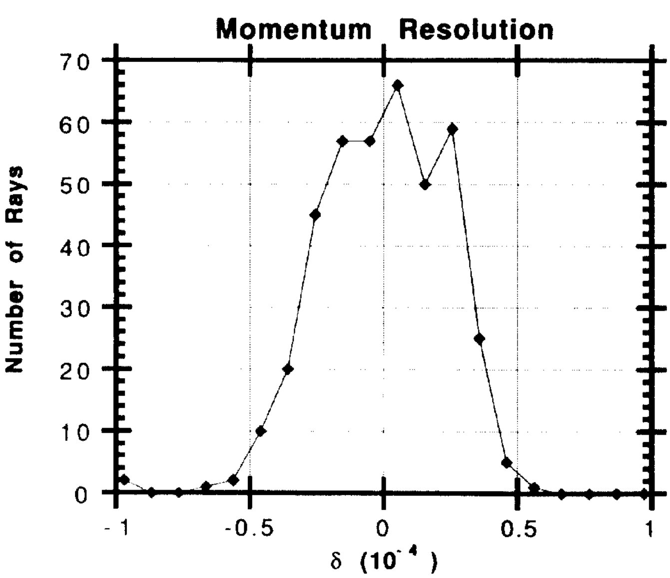

Figure 4. Histogram of momentum resolution from 400 rays.

These results and those from other test cases are evidence that MOTER survived the modifications identified earlier and that the current version is ready to serve as a platform for design studies and further improvements. The next section indicates what we have in mind in that regard.

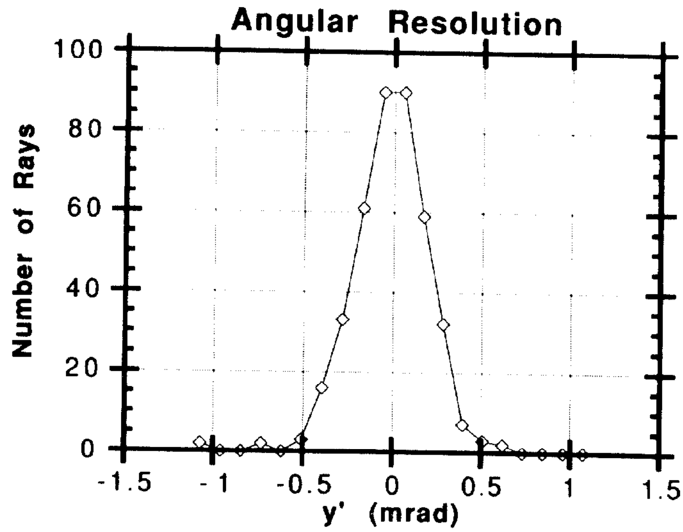

Figure 5. Histogram of angular resolution from 400 rays.

V. PLANNED IMPROVEMENTS

We will complete work on the cavity element and validate it against linac calculations based on another code. As part of that effort we will modify the encoding of the demand terms so that time or phase difference can be specified in the merit functions. Then in response to other users of MOTER we will upgrade the separator element by installing the velocity selector subroutine package from RAYTRACE.

Next, we plan to increase various limits in the code. In one recent instance, we needed to vary more than the limit of 30 parameters. In another situation we needed to use more demand terms in a merit function than permitted. The present limit is 40, which allows for third-order software corrections but not fourth-order and we have been found these to be important for the spectrometer when it goes into saturation. In order to allow better accuracy, we must also raise the number of rays that can be handled above the present limit of 400.

We also want to improve the accuracy of our fringe-field models. For this work we intend to study the fringe fields of the large-aperture magnets of the spectrometer with a 3-D code such as TOSCA. By comparing field calculations from TOSCA and from the models used in RAYTRACE, we expect to gain insight into the terms that must be added to improve the field models.

In summary we note that MOTER is alive and well and is being groomed to play an important role in the design of the PILAC facility and in any other design project that requires its capabilities.

VI. REFERENCES

[1] H. A. Thiessen and M. M. Klein, "Spectrometer Design at LASL", Proceedings of the 4th International Conference on Magnet Technology, Brookhaven National Laboratory, NTIS CONF-720908-12, 1972, pp. 8-17.

[2] S. B. Kowalski and H. A. Enge, NIM A258 (1987) 407.