

## TOM, A PROGRAM FOR INTERACTIVE LATTICE DESIGN

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### Abstract

An interactive program to help design accelerator lattices and lattice insertions is described. Present limitations and directions of future development are indicated.

### Introduction

Most lattice design codes are based on card or card image input, where the user has to create a file containing instructions and data to be read by the computer. Interactive design codes as used in other engineering disciplines for some time are not very common in accelerator design.

The work stations of the Tevatron control system have provided a unique opportunity to demonstrate a contemporary way to design complicated structures like SSC lattices. These work stations have a variety of input/output devices which are linked together by a fast CAMAC bus. Results of calculations are quickly seen on the graphics screen, TV monitor, or storage scope.

The PDP-11/34 work station computer is linked to a powerful VAX-11/780 computer so that interactively created information can be used as input for time consuming calculations in batch mode. Using this hardware, it was easy to write a fast-responding interactive code which allows the designer to develop his intuition without being concerned about technical details of the code.

### Goals

Important features of an interactive lattice design code are fast response, a convenient way of entering input data, and excellent graphics. It should be possible to design large and complicated structures

Many problems like the determination of dynamic aperture or chromatic behavior of a particular design cannot be solved interactively because the calculations take too much time even with a powerful CPU. It is therefore essential to provide interfaces to pass on the interactively created lattice information to more powerful computers and/or additional codes.

Routine operations like producing input lists and saving intermediate results which occupy a large time in lattice design work should be handled automatically by the code. It should also be possible to stop the processing at any time and to restart later while the code automatically takes care of saving and storing the information already created, so that the user is not burdened by bookkeeping problems.

An important aspect is to restrict the necessity of a manual to a minimum. A help option should be available as a part of the program.

Being part of the Tevatron control system, it should be easy to retrieve all the parameters which determine the machines actual optical status. This allows one to perform on-line optics calculations which are needed for various machine functions like closed orbit, tune, and chromaticity corrections and local orbit bumps.

Though being in a preliminary stage the lattice design code TOM meets most of the design goals mentioned above:

TOM takes full advantage of the possibilities available on a Tevatron work station:

Input can be entered into TOM by using a conventional keyboard. In addition to that it is possible to use a track ball as a quasi-analog knob to enter data. Program options can be selected by moving a cursor on the TV screen and pressing an interrupt button or using the work station touch panel.

Program output is made visible on the TV screen, on a fast, high-resolution color graphics screen, or on a storage scope. At any time it is possible to obtain hard copies from any of the output devices.

The track ball can be assigned to any pair of lattice parameters like the length or the strength of a magnetic element or its position in the lattice. The lattice functions can be calculated and displayed at a 15 Hz rate on the color graphics display which makes the impact of changes in the lattice parameters very obvious.

Besides these interactive features TOM offers the optimizing and matching procedures necessary to construct complicated lattice functions. Interactive and optimizing options can be used in a complementary manner; having the option to change parameters interactively or by letting the program search for solutions is quite effective. This is very helpful when the designer has to deal with a large number of soft constraints which must be balanced against each other. The designer is encouraged to use his intuition and experience while the code provides routine matching and optimizing procedures.

Information on procedures, definitions, and techniques is available at any time with the on-line help feature.

The information created during a TOM session is stored in a file accessible for a program running on any DECNET VAX computer. The data are structured so they can be read by PETROS[1], a very powerful code for complementary design work. Because PETROS is linked to other lattice design codes (for example, the nonlinear tracking code RACETRACK[2]) there is almost no limit for extensions of a design started with TOM in an interactive fashion.

### Optics Calculation

In its present version, TOM calculates the uncoupled optics of a planar machine. There are three modes of lattice calculation available:

beam line mode requires initial values of lattice functions to be entered by the user.

periodic mode assumes the defined structure is a superperiod of a closed ring.

mirror symmetric mode assumes the initial and final lattice points are mirror symmetry points.

The actual optical data set contains the information of a small section of a large structure only. The rest of the lattice is described by a complementary transport matrix, which is calculated by TOM automatically using the information stored in other data sets. This allows one to construct arbitrarily large structures without losing the advantage of dealing with small sections.

The Twiss parameters are calculated and displayed after each element. Calculations are restricted to on-energy and to the ideal machine. Extension to the linearly coupled case, to off-energy, or to perturbed machine calculations are available using the PETROS program which is linked to TOM by a common data file.

### Program Organization

The code is structured in 6 branches which are all on the same logical level and can be accessed directly from each other. In each of these branches specific input/output data may be entered via the TV screen. Data are assigned to internal variables by positioning the cursor at appropriately marked fields on the tv screen. Plotting of data produced in a particular branch is supported by a plot control routine. Figure 1 shows a schematic of the program.

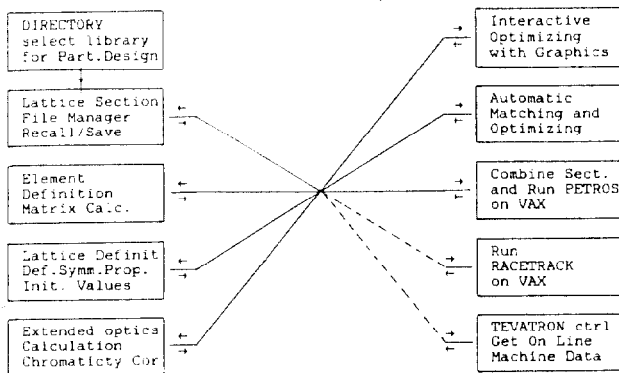


Figure 1 TOM Flow Diagram. All options lie on an equal logical footing. Dashed lines indicate future extensions.

Before one branch is left and another one is entered, TOM automatically performs all calculations and manipulations to make the information just created available in all the other branches. Thus there is no hierarchy or order by which data have to be entered. If, for example, an additional element becomes necessary during the design, the element definition branch can be entered immediately and the element inserted in the element list. When leaving the element branch the transport matrices are recalculated and the element is available for insertion into the lattice.

The branches serve the following purposes:

Directory. Each user can define a directory containing a number of files for a particular lattice design problem. Each optics file contains the complete information specified in a previous session. This branch is called first after the program is started to select an optics file to be modified. It can be accessed from any other branch to save intermediate results.

Element Definition. This branch is for initial definition and for display of existing elements. The existing element list can be extended easily. TOM recognizes dipoles, quadrupoles, sextupoles, and drifts.

Lattice Definition. The sequence and positions of elements in the lattice is defined and displayed. The Twiss parameters can optionally be calculated and displayed while the lattice is being defined which is very useful for immediate error checking. Another task of this branch is the definition of symmetry branches and the definition of a complementary lattice which is described in detail in other files of the same directory.

Interactive Change of Lattice Parameters. Here one specifies a pair of elements and which of their properties are to be modified (length, strength, horizontal curvature, or lattice position). The track ball is used to change the two parameters while the corresponding Twiss parameters are plotted immediately on the graphics screen. The most recent Twiss parameters are plotted in different colors than old ones so that the time development of a particular situation is always apparent.

Optimizing and Matching. This branch allows automatic adjustment or optimizing of the Twiss parameters. Up to 12 parameters may be matched at the same time. They may consist of up to 10  $\beta$ -functions in each plane at different locations, the tunes, and the dispersion functions. Inserts are matched automatically to the surrounding FODO cell structure. A beam line solution can be closed automatically to a periodic or mirror symmetric solution.

Optics Calculation. Here lattice functions are calculated at each element and displayed numerically on the storage scope. This option also serves to calculate integral lattice properties like momentum compaction factor and chromaticities. Chromaticity can be corrected using two sextupole families.

### FUTURE EXTENSIONS AND CONCLUSIONS

Experiences made with TOM so far have been very encouraging. Very time consuming lattice design work, such as designing low beta insertions, has been carried out significantly faster than using conventional codes. Moreover, the designer obtains a good feel for the stability of the lattice solutions and how they depend on each of the determining parameters.

TOM has been used to design a Fermilab pre-booster,[3] and for the design of the second low beta insertion (D0) of the Tevatron[4].

Figure 2 shows an example of the use of TOM in the design of a standard cell for a 200 MeV to 4 GeV prebooster for the Fermilab complex.

Figure 3 shows as another example the graphics generated by TOM in the interactive mode for the Tevatron D0 low beta design.

Up to now the use of TOM has been restricted to off-line optics calculations. We intend to extend the code to the case where the input parameters for the optics calculations are read directly from the machine, so that the actual machine optics will be available at any time in the control room providing important machine parameters.

