

THE PARTICLE BEAM OPTICS LABORATORY: ENHANCING THE SCIENTIFIC PRODUCTIVITY OF THE ACCELERATOR COMMUNITY

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Abstract

The increasing use of accelerators for a variety of practical applications, as well as for many types of research programs, has resulted in an expanding need for software that focuses on the requirements of the accelerator community. This paper summarizes several recent advances in software developed to meet a number of those requirements. The Particle Beam Optics Laboratory (PBO Lab™) family of software applications was designed to support three primary areas: accelerator operations, beamline design, and personnel training. The PBO Lab Basic Package provides a unique and intuitive GUI whose signature feature is a drag and drop graphical beamline construction kit. An interactive tutorial system links physics and engineering concepts and discussions to individual icons, providing a unique computer based teaching tool that has been used for several years by the U. S. Particle Accelerator School. Particle optics codes have always been important tools for accelerator science, and a number of popular optics codes have been integrated into the framework and several are now available commercially as PBO Lab Application Modules, including MARYLIE, TRANSPORT, TURTLE, DECAY-TURTLE and TRACE 3-D. Complex optimization problems can be addressed by using a new Optimization Module which seamlessly integrates the NPSOL and MINOS nonlinear, constrained, optimization programs into PBO Lab. An overview of the current version of PBO Lab is described and several of the capabilities are discussed.

1 INTRODUCTION

All of the PBO Lab applications are based upon an innovative software framework designed specifically for the accelerator community: the Multi-Platform Shell for Particle Accelerator Related Codes (SPARC-MP). The SPARC-MP framework [1] includes a sophisticated beamline object model, an extensive library of graphic user interface (GUI) components, and supports a variety of particle optics codes and add-on tools. A key part is the beamline object model, which provides the foundation for the icon-based graphical manipulation of accelerator components, models and various mathematical operators.

The ability to easily integrate third-party physics codes was a driving force behind the design of SPARC-MP and is a salient feature of the PBO Lab software. A number of such codes are available as individual Modules for PBO Lab [2]. The current suite of Modules includes the

particle optics codes MARYLIE, TRANSPORT, TURTLE, DECAY-TURTLE and TRACE 3-D, two specialized Modules for electrostatic and traveling wave accelerators, as well as an Optimization Module that utilizes the two nonlinear, constrained optimization programs NPSOL and MINOS. Detailed references for all of these third-party codes may be found in previous papers [3,4]. Several other Modules have been developed for specific customers, or for in-house use.

2 ACCELERATOR OPERATIONS

An emerging application of the PBO Lab 2.0 is in support of accelerator operations. PBO Lab utilizes conventional optics codes such as TRANSPORT and TRACE 3-D to support transfer line tuning and similar operations activities that require some degree of matching, fitting or optimization of adjustable parameters. This is a common use of such codes and does not require PBO Lab. However, the ease with which problems may be set up, and the improvement in scientific productivity that PBO Lab provides, allows operations and research staff to complete tasks in a much shorter time period or to carry out many more such tasks within a given time period. Perhaps equally important, users do not need to have any knowledge of the somewhat archaic text-based input files that are required in order to run codes like TRANSPORT or TRACE 3-D using the traditional approach. Coutrakon and collaborators have capitalized on these and other features of PBO Lab to find improved optics solutions for transporting 70-250 MeV beams through the Loma Linda University Medical Center beamline switch yard and into their gantry-based proton therapy treatment rooms [5].

Other features that make PBO Lab especially useful to support operations are some of the "Special" attributes that users can assign to any beamline parameter. For each parameter, for example a quadrupole gradient, there is an "S" button to the left of the parameter Name field in the corresponding Piece Window (or parameter input window, see Ref. [1] for a description). The "S" button opens a Special Parameter Settings window, an example of which is shown in Figure 1. Each Special Parameter Settings window provides two types of attributes: (1) those that are independent of any given optics code and (2) attributes that have significance within the context of a particular code. Figure 1 shows a Special Parameter Settings window for the context of the TRANSPORT code. The Symbolic Parameter Name is a code independent attribute, whereas the other attributes displayed are TRANSPORT specific.

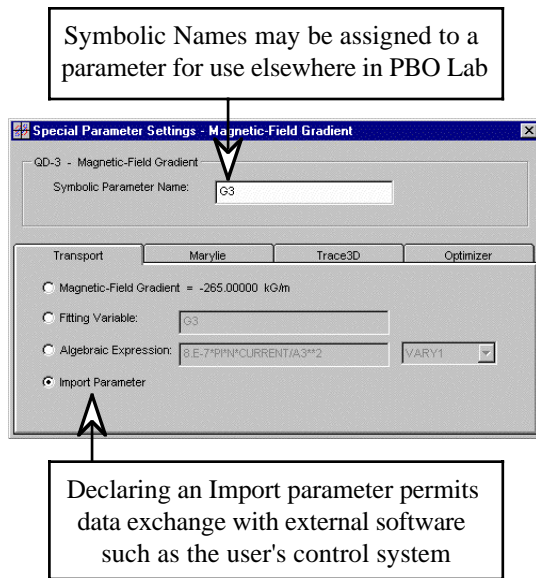


Figure 1: Window used for setting Special Parameters allows any parameter to be assigned different attributes.

The window illustrated in Figure 1 shows a quadrupole gradient that has been declared to be an Import Parameter. This choice of attribute permits the parameter value to be obtained from an external source, such as from a text file written by the user's control system. The ability to also use Algebraic Expressions for parameters allows scale factors to be incorporated into the import scheme. This permits, for example, the easy and routine updating of the PBO Lab beamline model when magnet currents are changed by the control system.

Import parameters can also be exported to external software, providing for a general data interchange capability. Both import and export capabilities are implemented using ASCII text files in the standard version of PBO Lab 2.1. However, the external data interface (EDI) tools developed for PBO Lab [6] have also been used to develop custom versions with interfaces to control systems using MATLAB™ [7] and the channel access protocol of the Experimental Physics and Industrial Control System (EPICS) [8].

3 BEAMLIN DESIGN

Perhaps the most common application of the PBO Lab software is in support of beamline and accelerator design. The same types of design problems that can be addressed by codes such as TRANSPORT, MARYLIE or TRACE 3-D using a conventional application of those codes, can also be addressed by the corresponding PBO Lab Modules. The same is true for using TURTLE, DECAY-TURTLE or MARYLIE to evaluate the performance of a design. The PBO Lab advantage is again associated with the ease of use and the improvement in the productivity of the

designer. Examples of first- and second-order design applications using the PBO Lab TRACE 3-D and TRANSPORT Modules are given in References [9] and [10] respectively.

The expanding suite of optics codes available to PBO Lab permits users to readily explore a variety of approaches to solving design problems. Any given optics code can typically be applied to a variety of fitting, matching or optimization problems. Nevertheless, most codes are more successful at finding solutions to particular types of problems than to other types of problems. One optics code is often not adequate to address all of the design requirements encountered in practice. PBO Lab makes the use of multiple optics codes a routine matter by deriving all optics code inputs from the same intuitive graphical manifestation of the beamline object model described in the introduction. An example of a second-order comparison between MARYLIE and TRANSPORT is given in Reference [11]. It is impossible to overstate the ease with which such code comparisons are carried out; this capability is one of the most frequently mentioned advantages of PBO Lab that is cited by users.

Another PBO Lab tool that is unique in its abilities to support both design and operations is the Optimization Module [3]. The Optimization Module permits the formulation of a large, complex, constrained, nonlinear optimization problems that are not possible to be implemented using the individual optics codes alone. The Module includes two nonlinear constrained optimization packages, NPSOL and MINOS, which each focus on different optimization approaches depending on whether the (effective) constraint matrix is dense or sparse. The Optimization Module works seamlessly with the PBO Lab optics codes, which provide the model-specific calculations of (nonlinear) constraints and merit functions. One application of this capability has provided a new approach to solving a common type of transfer line problem, and helped to find new solutions for SLAC beamlines that were not identified using standard optics codes alone [12].

4 EDUCATION & TRAINING

One of the initial objectives of the PBO Lab development effort was to provide a quality tool for computer assisted teaching of particle optics. In addition to allowing students and researchers, often initially unfamiliar with optics codes, to be able to quickly and productively use the standard optics codes of the accelerator community, the software was also designed to provide standalone tutoring. The PBO Lab Basic Package includes several major components that focus specifically on supporting education and training: (1) a dynamic interactive tutorial system on charged particle optics and accelerator technology, (2) a set of trajectory and envelope modules that allow users to graphically and interactively explore the first-order impact of parameter changes, and (3)

an expert system type of rule base to assist users in inputting and editing parameters. These features, which make the PBO Lab a unique training and education aid, were summarized at the EPAC98 conference [13].

The PBO Lab provides a visually rich environment which is not possible to illustrate in a paper of this size. Various parts of the PBO Lab Basic Package have been shown in other works. A detailed overview of the two-component interactive tutorial system was presented in Reference [13]. The trajectory and envelope modules include a first order optics code, where the results are displayed using the Focusing and Bending Tools of the PBO Lab GUI. An example of the Focusing Tool is given in Reference [14] while illustrations of the Bending Tool can be found in Reference [12]. For a more complete overview of the Basic Package, readers are encouraged to download from the internet a portable document format (PDF) version of the user manual, see Reference [2].

The usefulness of PBO Lab as an aid to teaching optics has been well recognized. In addition to its use at a number of colleges and universities, the U. S. Particle Accelerator School (USPAS) has now used PBO Lab in one or more courses for four consecutive years.

5 SUMMARY

The PBO Lab Basic Package was developed with two goals in mind: (1) to make the use of a variety of optics codes exceptionally easy and (2) to provide an intuitive tool that makes the study of particle optics a pleasant, even engaging, endeavor. The success in achieving these two goals has established the PBO Lab as a quality package that is now used at numerous scientific institutions, industrial laboratories and medical facilities in over fifteen countries.

The economic benefits to users of PBO Lab are also not insignificant. Since the cost of a user license for PBO Lab with several Application Modules is about the same as the cost of a week (or less) of senior scientist time, the initial investment cost is quickly recovered through productivity improvements. This is probably the most important single factor that has allowed the software to become so widely adopted in just a few short years.

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