

COMPUTER PROGRAMS FOR DESIGNING, INVESTIGATING AND COMMISSIONING CHARGED PARTICLE BEAM LINES

U. Rohrer

INTRODUCTION

PSI has a long tradition in designing and building outstanding quality beam lines for protons, μ - and π -mesons. Since the transition to high intensities (proton beam currents up to 2 mA) the required optical performance of these beam transport systems has been pushed to new extraordinary limits. This was only possible due to the fact that good computer programs for simulation are available. Three of them shall be presented here in this article. They were all initially developed at other laboratories (CERN, SLAC, FNAL, LAMPF & TRIUMF) and were all running on CDC mainframe computers. Then they were transferred here at PSI to VAX-VMS computers, where they are still running (e.g. control-room of the PSI proton accelerator). Some enhancements, the customization to PSI needs and the adaptation to modern operating systems (Windows and Linux for Intel architecture) as well as to graphic user interfaces (GUI) were also done here at PSI [1], [2].

TRANSPORT CODE

This modernized version consists mainly of the old CERN-SLAC-FERMILAB version of Transport coded in portable FORTRAN-77 [4]. Some enhancements have been added [1], mainly the possibility to compute space charge effects, an alternative stochastic fit algorithm, which allows it to do envelope fits [3] with second order or space charge. To vary parameters by imposing constraints (fitting to desired values) is the most powerful option in Transport. This improved version of Transport has been embedded in a new shell written in C++ (or Tcl/Tk + csh for Linux) and is providing some pretty and handy GUI type tools (much more elaborated under Windows than under Linux), which makes

it a lot easier and swifter to either design new beam lines or debug and investigate existing ones online. A screen shot of a modern GUI Transport Input Editor for Windows is shown in Fig. 1. This fruitful and valuable symbiosis of legacy and modern coding shows that you don't have to break with tradition in order to stay up-to-date. The computational part of this version of Transport contains plenty of new and old - but still needed - features and has been well tested over the last 30 years by many expert physicists from PSI and elsewhere around the world.

TURTLE CODE

Also this modernized edition of the Monte Carlo computer program TURTLE (Trace Unlimited Rays Through Lumped Elements, deducted from Transport) consists in principle of the former CERN-SLAC-FERMILAB version of Decay Turtle coded in portable FORTRAN-77 [5]. But many new features have been added [2]. The most important one is the inclusion of multiple scattering and absorption of charged particles in matter, which makes it possible to forecast losses of protons (or mesons) in beam lines furnished with collimators, slits and splitter strips and wires to a relative accuracy in the parts per million range (important for designing high intensity/low loss proton beam lines or low electron-background μ -meson beam lines). For this purpose some code fragments have been extracted from the computer code REVMOC [6], which has been developed at TRIUMF. This enriched and improved Turtle FORTRAN Code has also been embedded in a new shell written in C++

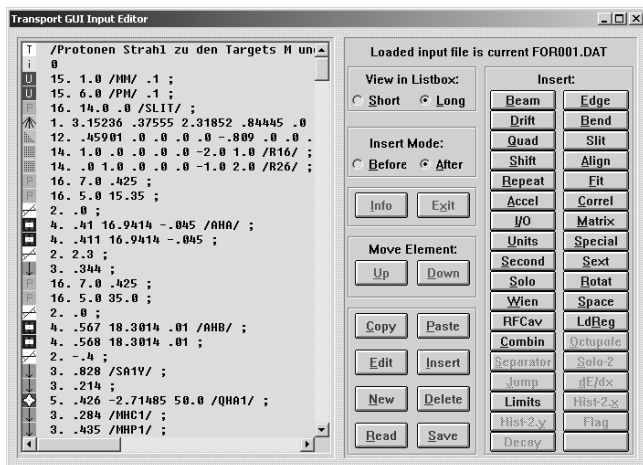


Fig 1: A sample picture showing the context-sensitive GUI input editor for Transport and Turtle. Inside the list-box to the left each type code (representing a transport element) has its mnemonic icon in front of the parameter line. All edit functions and all type-codes have a push button on the right side, which open-up dialog-boxes when clicked at.

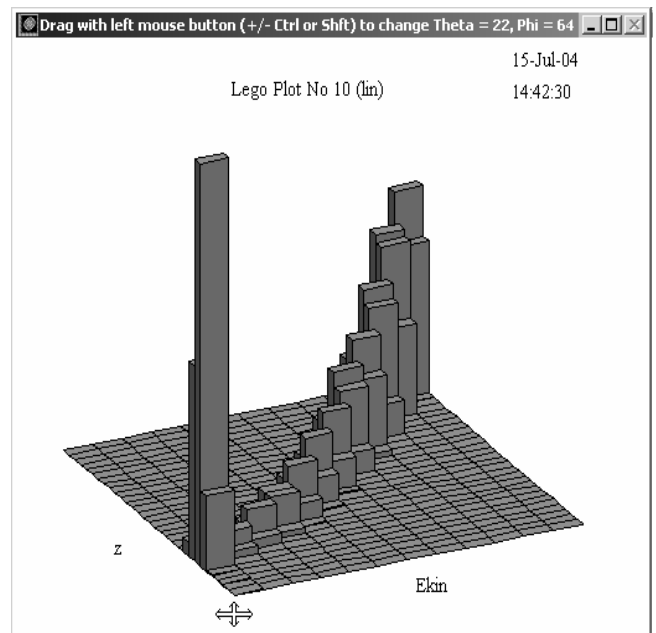


Fig 2: A sample histogram output of Turtle, showing the energy distribution of lost protons along a copper collimator. The 2-dim histogram may be rotated on-line in both directions in order to inspect the Bragg peak.

(or Tcl/Tk + csh for Linux) and is providing some pretty and handy GUI type tools (e.g. 1 [for Linux] or 2 [for Windows] graphic histogram option[s], see Fig 2.), which make it easier to run TURTLE and to interpret the results. It should be mentioned here, that the usage of this program was responsible for the successful design of the proton beam line to the SINQ (low losses in the beam cellar) and the reduction and containment of the losses after the electrostatic high-energy beam splitter (EHT).

MENT CODE

The **Maximum Entropy Tomography (MENT)** program has been developed at the Los Alamos Scientific Laboratory in New Mexico (USA) [7] and some time later successfully applied to Beam Tomography by scientists at the same laboratory. This program is also coded in FORTRAN-77 with the exception of the Xlib-interface for the graphics, which is done in C. Versions for OpenVMS, Windows NT and Linux are available. MENT offers a very useful method to do non-destructive emittance measurements on a beam transport line. Usually one can only get a few (between 3 and 6) different views (profiles), which is by far not sufficient for conventional tomography programs to reconstruct the originating source. With MENT the lack of data is compensated by selecting from the infinite amount of possible solutions the one with the lowest information content consistent with the available data (maximum entropy). At PSI this method has been applied successfully to several proton beam lines (780 keV DC beam line, 72 MeV injection beam lines 1 and 2, 590 MeV beam line (see Fig. 3) and the peeled off beam to the Pirex target). For some more details see also reference [8]. A disturbing problem of the beam tomography at the PSI proton beam lines is often the excessive, uncorrelated noise added to the measured profiles. This noise is mostly due to intensity fluctuations and position jitter of the beam ($f = 50$ Hz). By using an automatic Fast Fourier Transform (FFT) filter applied to the measured beam profiles, the quality of the reconstruction

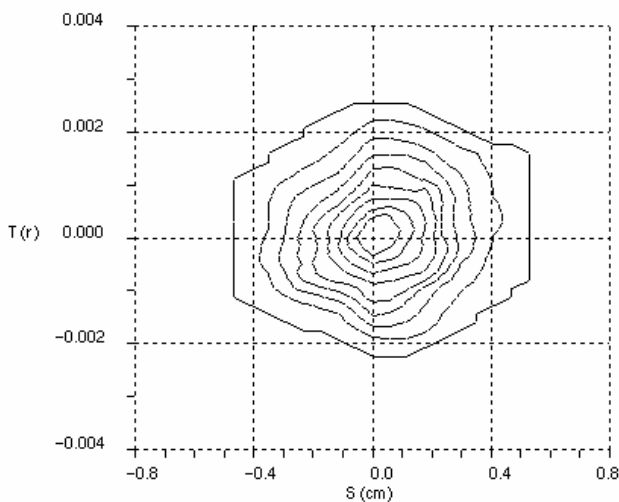


Fig. 3: Typical sample picture for the reconstructed projected vertical phase space y/y' (done with 4 measured profiles) of the 590 MeV proton beam line. The 86 % emittance is about 2.5π mmmr as confirmed by transport envelope fits with the same beam data.

may be substantially improved. It should be mentioned here that the application of the MENT code is not restricted to proton beams. For example it may also be applied to alpha particle beams for testing large aperture multi-pole magnets or to pulsed electron beams from a linac (e.g. SLS). The beam profiles may be measured with different devices such as wire scanners, harps, strip detectors or photographic (CCD) cameras. Instead of gathering profile information at different locations along the beam line it may also be preferable to measure only at one location and getting the multitude of information through the variation of the optics (by controlled modification of the settings of some quadrupoles) between the source and the location of the beam profile observation device.

CONCLUSIONS

Though the presented programs are old-timers, their modernized versions are still very useful for today's beam optics problems. Current new beam line projects at PSI (PROSCAN, UCN and LEM) are making usage of them and because of their electronic availability via anonymous FTP [9], they have also found happy users at laboratories in some countries around the world (e. g. Belgium, Brazil, China, England, Finland, France, Germany, Holland, India, Indonesia, Israel, Italy, Japan, Poland, Russia, South Africa, South Korea, Spain, Sweden and USA). Recent developments at the PSI-SLS have also shown, that these programs are well suited for investigating electron transfer beam lines.

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