MAD-X PTC INTEGRATION

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Abstract

MAD-X is CERN's successor for MAD8, a program for accelerator design with a long history. MAD-X is a modular, better maintainable re-write of MAD8 with data structures written in 'C'. Early on in the design of MAD-X we relied on the fact that older or doubtful modules could be replaced by new modules using the PTC code by E. Forest. Both codes remain independent entities but are linked via a converter to the MAD-X data structures. PTC is used for symplectic tracking of smaller machines and transfer line using better defined physical models of the elements and taking into account of how the elements are placed in the tunnel. The matching of the LHC will profit from the fact that the high order nonlinear parameters are provided by a PTC Normal Form analysis.

INTRODUCTION

MAD-X is now in its third year after having been launched in June 2002. We are attempting to keep up the set of module keepers at CERN and have found successors for outgoing members of the module keeper team. External collaborators are particularly welcome! Tab. 1 holds all MAD-X module keepers who are presently working on MAD-X modules.

Module	Description	Keeper
MAD-X C Core	Maintenance & Debug	H. Grote
APERTURE	Modeling LHC Aperture	I.K. Waarum [1] J.B. Jeanneret
C6T [2]	SixTrack Converter	F. Schmidt
CORORBIT	Orbit Correction	W. Herr
DYNAP	Tracking Postproc.	F. Zimmermann
EMIT	Emittance, Radiation	R. Aßmann
ERROR	Error Assignment	W. Herr
IBS	Intra-Beam Scattering	F. Zimmermann
MAKETHIN	Thin lens Converter	H. Burkhardt
MATCH	Matching Procedures	O. Brüning
PLOT	Plotting	E.T. d'Amico
PTC [3]	PTC proper	E. Forest KEK
PTC_NORMAL	Normal Form Coeff.	E.T. d'Amico
PTC_TRACK	Thick lens Lattice Track	V. KapinITEP (RU)
PTC_TWISS	Ripken Optics Para.	F. Schmidt
SODD	Resonance Comp.	E.T. d'Amico
SURVEY	Machine Survey	F. Tekker
SXF [4]	Stand. eXchange Format	F. Pilat BNL
TOUSCHEK	Touschek Effect	C. Milardi IFNL/LNF F. Zimmermann
TWISS	Classical Optics Para.	F. Schmidt
TRACK	Thin lens Lattice Track	A. Verdier A. Koschik

Table 1: Module Keepers, People in RED are collaborators from outside CERN, corresponding laboratories in BLUE.

* MAD-X Module keepers see Tab.1

MAD-X PROPER

The main emphasize of this report is on PTC (Polymorphic Tracking Code) related issues in MAD-X. However, it should also be mentioned that during the last two years after introducing MAD-X to the accelerator community at large [5] considerable progress has been achieved on various MAD-X proper modules. Some of these advances are described in the following.

PLOT Module

This module has been upgraded and largely extended. The information on the MAD-X version and on the date can be suppressed from the title line to free more space for the user's title. The TWISS parameters are no more computed inside the module but taken from the TWISS module. This ensures automatic synchronization with any change done inside that module and it avoids the known inconsistencies in MAD8 due to code duplication. True interpolation inside each accelerator element is now available based on building a temporary sequence of new elements obtained by slicing. Access to the TWISS module for each slice provides the needed data to be plotted. Tracking data generated by a previous TRACK command can now be selected by using the attribute PARTICLE and plotted individually or all joined together on the same plot by using the attribute MULTIPLE. The actual display is done by the open source plotting package gnuplot. Thus, the PLOT module can easily be used under Windows by downloading and installing the gnuplot package zip GP400win32.zip that can be retrieved from the web [6].

SODD Module

The stand-alone program SODD [7] calculates analytically the detuning, distortion and Hamiltonian functions [8] up to second order. All first and second order detuning and Hamiltonian terms are normalized to MAD-X coordinate system and are put into a special SODD table for easy use in following MAD-X commands [9], e.g. they have been compared and found to be in perfect agreement with the ones calculated with the Normal Form technique by PTC_NORMAL (see below).

Aperture Module

The APERTURE module allows computing the transverse 2D-normalized aperture along a sequence [1]. The geometrical aperture and tolerance of elements are defined in the sequence with APERTYPE, APERTURE and APER_TOL attributes for every class or element. The most useful predefined type is APERTYPE=RECTELLIPSE, which is the intersection of an ellipse and rectangle. Mechanical tolerances can be specified from circular to rectangular in a continuous way. Data files from measured profiles can be read in to supersede the APER_TOL attribute defaults. Global parameters affecting aperture are specified in the APERTURE command (Peak radial closed orbit, beta-beating, parasitic dispersion, bucket width, etc). Elements can be displaced with respect to the central orbit via a quadratic function. The beam is considered to be circular in the normalized transverse plane with radius of n1 betatronic σ. The beam area can be enlarged to allow for a clearance between the primary beam and the vacuum chamber (in LHC this is used for the secondary halo produced by the collimation system). The aperture n1 is then computed for the halo and for any number of slices for each element. The TWISS table reports the minimum n1 obtained for the current element.

Touschek Module

The TOUSCHEK module is a new addition to MAD-X. It computes the Touschek lifetime and the scattering rates around a lepton or hadron storage ring, based on the formalism of Piwinski [10]. TOUSCHEK should be called after a TWISS command. One or several cavities with RF voltages should be defined prior to calling TWISS and TOUSCHEK. The momentum acceptance is taken from the bucket size taking into account the energy loss per turn U_0 from synchrotron radiation. The value of U_0 is computed from the second synchrotron radiation integral synch_2 in the TWISS summary table (TWISS CHROM attribute required) using Eq. (3.61) of Ref. [11] which was generalized to the case of several harmonic RF systems. The results are stored in the TOUSCHEK tables and can be written to a file. Beam lifetime and U_0 are summarized in the Touschek table along with the contributions due to each lattice element. All these data provide a useful framework to understand the origin of Touschek lifetime limitation. The module has been tested for DAΦNE and the LHC at injection and top energy. The results agree with experimental and/or theoretical expectations.

PTC

E. Forest's Polymorphic Tracking Code PTC [3] is a kick code or symplectic integrator and therefore ideally suited to describe all elements symplecticly and to arbitrary exactness. The degree of exactness is determined by the user and the speed of his computer. The code is written in an object oriented fashion using Fortran90. Therefore, it becomes much easier to describe arbitrarily complex accelerator structures. The other main advantage is that the code is inherently based on the map formalism [12] and provides MAD-X with all the associated tools.

One particular advantage is the fact that PTC allows to treat more complex beam line arrangements that can no longer be described by a simple sequence of elements. Fig. 1 shows an example in which the beam comes back to the same element but with a different energy. PTC handles all the coordinate system transformations by a built-in PATCHING mechanism.

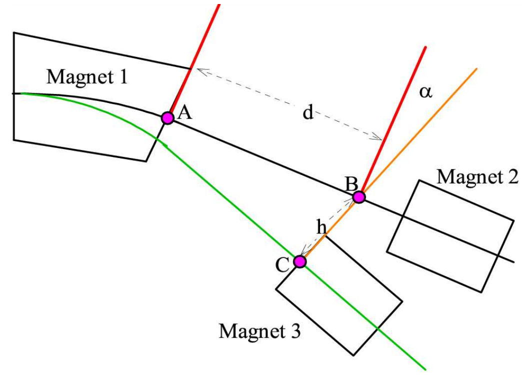

Figure 1: Patching 2 Beam Lines (taken from Ref. [3]).

PTC allows to treat elements correctly even for very large momentum deviations. This becomes apparent in the simple cyclotron example that can be described analytically. The authors of Ref. [13] have demonstrated that MAD8 disagrees at large momentum deviation. In Fig. 2 one finds the same problem with MAD-X (green diamonds). However, using the very same MAD-X input file as an input for PTC (blue circles), one can perfectly reproduce the analytical result (red line).

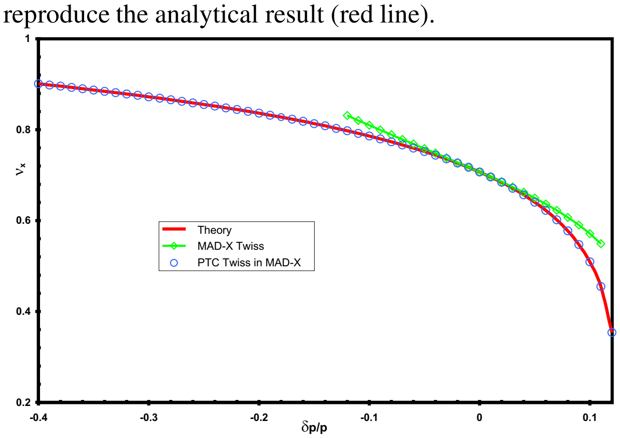

Figure 2: Off-momentum tune of a simple cyclotron.

PTC MODULES

One has to understand that PTC is really a library that can be used in many different ways to create an actual module that calculates some property of interest. At CERN we are still gearing up to make full advantage of PTC in MAD-X. The most important application will be the inclusion of PTC to the MATCHING module to allow for non-linear matching of such quantities like anharmonicities or Hamiltonian terms. This feature of MAD-X is expected to be released by the end of the summer of 2005 together with a documentation of how to use PTC in general in the context of MAD-X. In the following one finds described three PTC modules that are presently developed by the MAD-X team.

PTC_TWISS

The TWISS module based on PTC calculates Ripken-style TWISS parameters (invented by G. Ripken in 1968 and most accessible in Ref. [14]) which were available in MAD8 using the TWISS3 command. This module is a typical example of the advantages when using PTC and its Normal Form technique (and of course the object–oriented Fortran90 coding): once the rather modest programming has been performed the TWISS calculation will always be automatically correct for all machine conditions like closed orbit, coupling or after a new element has been introduced into the code. In traditional coding like in MAD8/X this depends on reprogramming and modifying the code at various places which is inherently error-prone.

Plotting in PTC

The PLOT module has been extended to include plotting of the Ripken TWISS parameters as generated by the PTC_TWISS module and plugged into the PTC_TWISS table. From this PTC_TWISS table any column can be plotted in the same way as for the standard TWISS table. The default name of the table is PTC_TWISS but this name can be changed for better flexibility. For the time being interpolation like in the standard TWISS module is not available because the powerful but complex PTC slicing mechanism has yet to be used for this purpose.

PTC_NORMAL

This module is the first one that takes full advantage of the PTC Normal Form analysis which is a considerable upgrade of what was available with the Lie Algebra technique used in MAD8. It allows to calculate dispersions, chromaticities, anharmonicities and Hamiltonian terms to very high order. In fact, the order is only limited by the RAM memory of your commuter and your patience to wait for the results.

The number of terms per order increases with some power law. The internal MAD-X tables are not adequate to keep such large amounts of data. On the other hand, only a reduced set of this data is actually needed by the user. Thus a much easier and flexible solution is to gather the users' requirements with a series of special MAD-X command called select_ptc_normal. A special MAD-X table is dynamically built using just those commands and it will be filled by the next call to the PTC_NORMAL command. Another essential advantage of this table is the fact that it is structured to facilitate exchange of Normal Form (including Hamiltonian terms of high order) between MAD-X modules. The immediate goal is to use this table to allow non-linear matching inside the present MAD-X MATCHING module.

PTC_TRACK

One of the essential code design decisions of MAD-X was to take out the thick lens part from the TRACK module. The reason is that in MAD8 the thick lens tracking is inherently not symplectic, which implies that the phase space volume is not preserved during the tracking, i.e. contrary to the real particle the tracked particle amplitude is either growing or decreasing. Instead, we have provided a thin lens TRACK module which tracks symplecticly through drifts and kicks and by replacing the end effects by their symplectic part in form of an additional kick on either end of the element.

The second part of this design decision is to produce a thick lens PTC_TRACK module based on PTC that allows a symplectic treatment of all accelerator elements giving the user full control over the precision (number of steps and integration type) and exactness (full or extended Hamiltonian) of the results. A prototype of this module has been prepared in collaboration with ITEP (Moscow, Russia) featuring the main functionality (e.g. plotting tracking data) as provided for the thin lens TRACK module. Completion of this PTC_TRACK module is scheduled for the summer 2005, including documentation and examples.

CONCLUSIONS

MAD-X has well progressed over the last 2 years featuring several new modules. It fulfilled its promise to become the LHC optics design code. Several long-term collaborations with other Labs have been launched to work on various aspects of MAD-X. In general, the concept of having one MAD-X custodian and several module keepers inside and outside of CERN has been proven to guarantee effective program development. The full integration with Forest's PTC code is the next big goal for MAD-X. To this end several important PTC modules are being prepared and expected to be completed end of summer 2005. Another one day MAD-X review is planned at CERN[15] to discuss the future development of MAD-X and you are welcome to participate!

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