IMPROVEMENTS IN THE PLACET TRACKING CODE

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Abstract

The tracking code PLACET simulates beam transport and orbit corrections in linear accelerators. It incorporates single- and multi-bunch effects, static and dynamic imperfections. It has an interface based on both Tcl/Tk and Octave to provide maximum flexibility and easy programming of complex scenarios. Recently, new functionalities have been added to expand its simulation and tuning capabilities, such as: tools to perform beam-based alignment of non-linear optical systems, higher order imperfections in magnets, better tools for integrated feedback loops. Moreover, self-contained frameworks have been created to ease the simulation of CLIC Drive Beam, CLIC Main Beam, and other existing electron machines such as CTF3 and FACET.

INTRODUCTION

PLACET [1, 2] simulates beam transport and orbit correction in electron/positron linear colliders, from the damping rings exit to the interaction point, and also the CLIC drive-beam. PLACET is written in fast C++ and it implements 4d and 6d tracking using multiple beam models. It can simulate static and dynamic imperfections, such as element misalignment, ground motion, arbitrary failures and provides several counteracting schemes. It simulates single-particle, collective, single-bunch and multi-bunch effects: ISR, CSR, short- and long-range wakefields, collimator wakefields.

CODE IMPROVEMENTS

Static code analysis. PLACET is checked by the commercial static analysis tool Coverity [3]. Coverity is a computer security company with in-depth experience of static analysis. They have conducted many open source scans, on complex and critical software (such as the Linux kernel). Their static analysis tool is thorough and boasts 100% path analysis. Coverity has donated a license of Coverity Static Analysis tool to CERN.

As can be seen in Fig. 1 out of the 541 detected defects 427 have been resolved. For the so called high impact defects 144 out of 172 have been resolved. The remaining open defects are not deemed critical, and will be resolved in due course.

Memory reduction. A full scale simulation of the CLIC main beams through the main linacs and beam delivery systems (BDS) consists of two times 90,000 beamline elements. With a memory footprint of about 3kB per element, such a simulation was using 800 MB. By scrutinizing and optimising the ELEMENT class a significant memory reduction of about 50% was achieved.

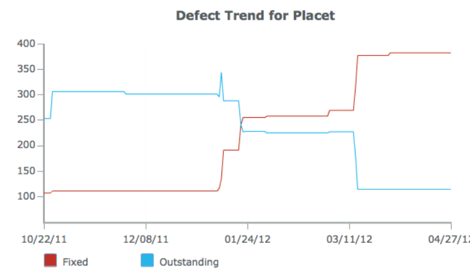

Figure 1: The outstanding (blue) and fixed (red) defects in PLACET over time as discovered by Coverity.

Code cleanup. A large repository and code cleanup was undertaken. This reduced the number of code lines by about 30%.

NEW FUNCTIONALITY

Fringe fields in the bending magnets. Adopting the convention used by MAD-X [4], the simulation of fringe fields in the sector bending magnets has been added to PLACET. The parameters to define the fringe fields are FINT, FINTX, and HGAP. The quantities FINT and HGAP specify the finite extent of the fringe fields as defined in[5]. The default values correspond to the hard-edge approximation, that is a rectangular field distribution.

RF-Multipole. In order to simulate oscillating transverse multipolar RF-kicks, like the kicks present in all the RF elements that break the azimuthal symmetry of the beampipe, a new element has been added to PLACET. The new element is called `RfMultipole` and accepts the following options:

`-strength_list`	Multipole strength list $[\mathrm{GeV/m^{n-1}}]$ $\{\, \mathrm{E_0 * K_1 L, E_0 * K_2 L, ...E_0 * K_n L} \,\}$
`-phase_list_deg`	Multipole phase list [deg] $\{\, \mathrm{Arg(B_n) + iArg(A_n)} \,\}$

Here, the first parameter accepts a list providing the absolute values of the integrated strengths of the oscillating harmonics, while the second and third parameters are equivalent and accept the phases of such harmonics with respect to the synchronous particle (in degrees or alternatively in radians). All inputs are in form of a list of complex numbers, the real part of which is meant to characterise the normal coefficients, whereas their imaginary part is meant to characterise the skew components.

A first application of this element has been the simulation of the RF-kicks in the power couplers of the CLIC

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main linac accelerating structures, to study their impact on the CLIC main beam dynamics. See [6] for further details.

Second-order transfer matrices. A new function has been created to calculate first- and second-order transfer matrices using a fitting procedure on the bunch particles. A bunch is transported through a beamline, then from the linear correlations between its phase space before and after the tracking, the transfer matrix is calculated. This functionality can be accessed only through the Octave interface of PLACET, and its signature is:

```
[T, U] =
     = placet_get_transfer_matrix_fit("beamline",
         "beam", "survey", [start, end]);
```

Input parameters are, in order: the name of the beamline, the name of the bunch to use, the "survey" command to be used, and, optionally, the elements between which the calculation must be performed (i and j in the following). These transfer matrices are calculated via a least-squared fit meant to minimise the following χ^2:

$$\chi^2 = \sum_{\forall \text{particles} \in \text{bunch}} \left\{ \sum_{\forall l,m=1..6} \left(x_l^{(j)} - [T_{i\to j}]_{lm}\, x_m^{(i)} \right)^2 + \right.$$

$$\left. + \sum_{\forall l,m,n=1..6} \left(x_l^{(j)} - [U_{i\to j}]_{lmn}\, x_m^{(i)} x_n^{(i)} \right)^2 \right\},$$

where $x^{(i)}$ is phase-space vector of a particle at the first element, $x^{(j)}$ is the phase-space vector of the same particle at the last element. The parameters that minimise the χ^2, i.e. T_{lm} and U_{lmn}, are the elements of the first- and second-order transfer matrices.

Second-order response matrices. A similar approach to that described in the last paragraph has been adopted to calculate the first and the second-order response matrices of a beamline, that is the response of the beam position monitors to the excitation induced by selected correctors. There are several ways to calculate a response matrix: traditionally, PLACET used an "experimental" approach: each corrector is excited, then the induced excitation is measured and stored. Now, two new methods have been added:

```
[ Rxx, Ryy ] =
     = placet_get_response_matrix_optics("beamline",
         B, C);
[Rxx, Rxy, Ryx, Ryy,
 Rxxx, Rxxy, Rxyy,
 Ryxx, Ryyx, Ryyy] =
     = placet_get_response_matrix_fit("beamline",
         "beam", B, C);
```

Both methods accept a beamline, a beam, and a list of BPMs and correctors (respectively B and C). The first function returns the response matrix as a collection of elements $T_{(i\to j)12}$ taken from the optics. The second function tracks a beam through a beamline, then it performs accordingly a least-squared fit on the beam particles to return the first- and the second-order response matrices, based on the elements of the first- and second-order transfer matrices: $T_{(i\to j)12}$ and $U_{(i\to j)122|124|144}$ for the x axis; and $T_{(i\to j)34}$ and $U_{(i\to j)344|342|322}$ for the y. Figure 2 shows an example of second-order response matrix in the CLIC BDS. Such information was previously inaccessible to PLACET.

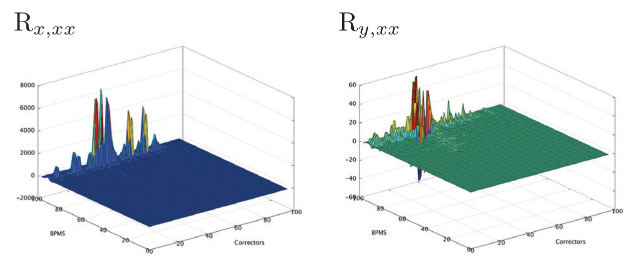

Figure 2: Second-order response matrices $R_{x,xx}$ and $R_{y,xx}$ for the CLIC BDS. The most of the information contained in these matrices comes from the final focus, where indeed non-linearities and couplings occur.

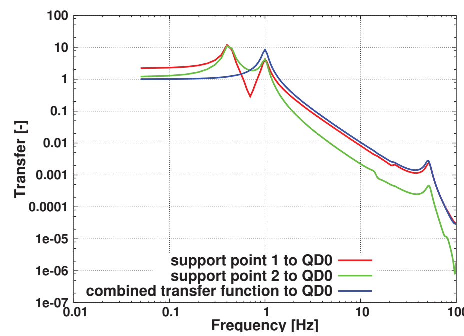

Figure 3: Amplitude of the theoretical transfer functions of the preisolator of the final doublet system.

Ground motion and stabilisation systems. Previously, to simulate ground motion, a stand-alone ground motion generator based on the ground motion models of [7] was deployed. This stand-alone generator has been included into PLACET itself. This inclusion allowed for new functionality. Most notably, frequency responses to the ground motion can now be added to each element and girder. This functionality has been proven crucial in evaluating and improving the active stabilisation system of the CLIC main linac quadrupoles [8].

Preisolator. Related to the last paragraph is the addition of the complex CLIC preisolator description. The CLIC preisolator is a large mass-spring stabilisation system for the final doublet quadrupoles QF1 and QD0, which are very sensitive to ground motion. The preisolator has two support points that each have their own transfer functions, which are shown for QD0 in Fig. 3.

SIMULATION FRAMEWORKS

Common frameworks for different kind of linear collider studies are distributed with the code package. In the following some example of these framework are described.

Integrated simulations of the drive beam. The CLIC drive beam produces the RF power for the CLIC main linac, and in the process the drive beam is decelerated by specially designed power extraction structures [9]. A framework for simulating the CLIC decelerators has been written and is included with the PLACET package. Longitudinal wake effects (beam loading and deceleration along the beam), transverse wake effects (potentially leading to transverse instabilities), both single bunch wakes and multibunch wakes, are included, based on results from RF simulations. Alignment routines, including dispersion-free steering, are implemented. Machine response matrices can be automatically loaded and saved for faster performance. Major parameters for the beam, beam line, cavity and simulation set-up are easily modified from a user configuration file. The drive beam framework has been applied to decelerator alignment, stability and failure mode studies [9].

Integrated simulations of CTF3. The drive beam framework has been utilized an option to simulate the decelerator test beam line in the CLIC test facility (CTF3). This option has been applied to test beam line optics studies and spectrometer studies [10, 11]. Finally, the test beam line part includes an optional integration to the test facility hardware, so that the test beam line can be simulated in flight simulator mode.

Integrated simulations of CLIC main linac and BDS. To study the orbit controller and the dynamic imperfections of the CLIC main beam a framework was setup for the integrated simulations in the CLIC main linac and the BDS. The framework simulates pulse-to-pulse and includes amongst others all possible dynamic imperfections, most notably ground motion and its mitigation techniques (quadrupole stabilisation, preisolator, IP feedback, orbit controller). An example of these simulations is shown in Fig. 4. It is currently being extended to add static imperfections and long-term drifts (such as temperature changes).

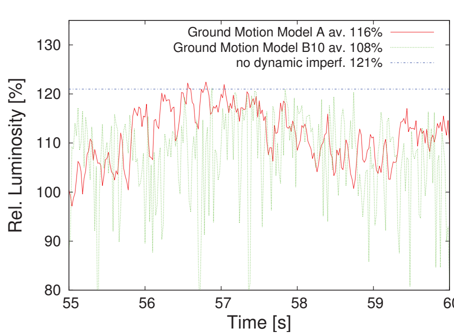

Figure 4: Example of peak luminosity over a longer time scale (60s) for several ground motion models.

Integrated simulations of FACET. PLACET has been employed to simulate and test beam-based alignment algorithms at FACET (SLAC). At this purpose an interface has been developed to connect PLACET with Matlab©, in order to access the Main Control Center data acquisition system and control the SLAC linac (through EPICS and AIDA). The interfacing is such that the real-time status of the machine can directly be imported into PLACET for running simulations with realistic parameters. Figure 5 shows an example. More details can be found in [12].

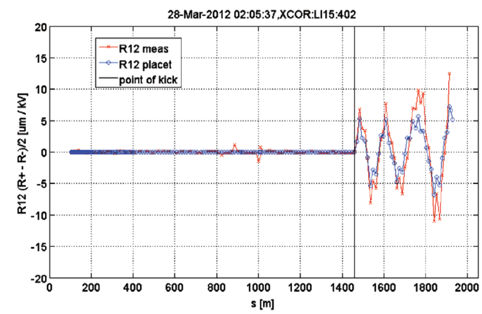

Figure 5: An orbit excited in the SLAC linac by a single corrector: in red the measurement, in blue the PLACET on-line simulation.

CONCLUSIONS AND OUTLOOK

PLACET is more stable and more mature. New features open new simulation and orbit correction capabilities, to be used in the context of beam-based alignment of non-linear systems, as the final focus of CLIC; or in the simulation of higher-order RF-kicks due to the complex geometries of RF-elements, such as the accelerating structures or the crab cavities. PLACET can be further improved, in terms of modularity and in terms of interfacing capabilities: the interface toward Octave should be made more flexible (decoupling the embedding) and the code should be opened to other scripting languages. The possibility to use external detector solenoid field map to track in the interaction region will be delivered in the next future.

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