

PLACET2: A NOVEL CODE FOR BEAM DYNAMICS IN RECIRCULATING MACHINES

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Abstract

Efforts have been taken to enable the simulation of recirculating machines in PLACET. The new version, PLACET2, allows handling multiple interconnected beamlines in order to obtain a realistic model of a machine. Two new elements, injectors and dumps, have been introduced and are active components of any working machine. Trains of bunches are routed through beamlines and tracked simultaneously in a parallel manner. Tracking through time-dependent elements is possible, and care is made to preserve the correct time-structure of the beam in case of beam recombination. This allows straightforward computations of multi-bunch effects arising with high-charge and shortly spaced bunch trains, even with variable train structure. The main features of the code are presented together with its working principles and its key ideas. Two case studies are introduced: LHeC and the CTF3 combiner ring.

INTRODUCTION

The parameters of the electron beams achievable adopting recirculation techniques outperform linacs in terms of average current, but also rings in terms of the longitudinal emittance.

Today we find a flourishing number of Energy Recovery Linacs projects. Many low energy machines like ALICE in England, the cERL in Japan and the JLab FEL in the USA are already operating, but the spectrum extends to the energy frontier with studies like the LHeC and the eRHIC.

Energy recovery and multi-pass linacs are not the only kind of machines that exploits beam recirculation. CTF3 at CERN routinely applies it to fold a train of bunches on itself achieving currents up to 30 A and bunch frequency of 12 GHz. The Drive Beam Complex, a key component of the CLIC technology, will adopt the same concepts to reach a current of 100 A.

The complexity of both the topology and the operation of those machines is a big obstacle for traditional tracking codes, which describe the machines as sequences of elements and/or adopt a very rigid definition of the beam. Single-bunch start-to-end simulations with these codes requires can be pursued unrolling the lattice, however the evaluation of multi-bunch effects, that may be critical, is not feasible.

For these reasons we decided to take advantages from the experience matured with the developing of the tracking code PLACET [1], to create a new version that allows to set up realistic simulations of the operation of recirculating machines: PLACET2. A new tracking core has been entirely written from scratch in the latest C++ standards. Efforts are being taken to implement the same physics effects handled

by PLACET and more. In the next sections we will give an overview of the new-developed concepts and up-to-date code functionalities that provide to our users a powerful tool to tackle these new challenges in accelerator physics.

OVERVIEW OF THE FEATURES AND FUNCTIONALITIES

PLACET2 is developed with a wide spectrum of machines in mind, in particular ERLs like the LHeC [2], but also peculiar lattices like the CLIC Drive Beam Complex [3]. It offers a great tunability of the trade-off between speed and accuracy. On one hand the beam can be represented using multiple models, on the other hand the lattice is implemented in an innovative way that allows to split the thick element cores in order to insert the desired physical effects at the required computational precision.

PLACET2 tracks many bunches simultaneously in recirculating lattices. The bunches enter each beamline in the correct time sequence. This makes possible to compute multibunch effects.

The most common accelerator components are implemented in PLACET2. The initial global phases of time dependent elements are locked by default to the first passing bunch, this resolves any synchronization issues in an automatic manner and relieves the user from tedious initializations. Elements can be misaligned and have apertures, with the possibility to track losses. Physical effects currently include the synchrotron radiation and the multi-bunch long-range-transverse wakefields.

With a bunch-based beam structure, the beam properties can be computed and monitored in any location of the simulated machine. This allows great flexibility. Moreover it is possible to set up a bunch to collect its properties such as orbit and Twiss functions, along its path in the machine.

Although PLACET2 is entirely written in C++, a TCL scripting interface similar to the one of PLACET is provided using SWIG [4]. Recently an Octave interface have also been added following the mechanism developed for PLACET.

COMPONENTS OF PLACET2

PLACET2 adopts an intuitive way to describe a machine based on traditional concepts, but with expanded capabilities and new elements such as injectors, dumps and joints, which allows to simulate the recirculation.

Beam PLACET2 represents the beam as a collection of bunches. Bunches can be routed independently through multiple beamlines, and are recombined together where the beamlines join. PLACET2 is designed to support many

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bunch models: e.g. the single particle and the many particles are already implemented. Each particular bunch model can be treated differently in various situations: for instance the synchrotron radiation for the many-particles bunch is a stochastic process, while the average energy loss is applied with the single-particle bunch. Each bunch has an internal timer which is used for the synchronisation of the tracking, but also to update time-dependent elements (phase, damping, ...).

Machine The machine is the core concept of PLACET2. It is the collection of beamlines, injectors, dumps and joints plus the methods to create and manage all of them. An important component of the machine is its internal timer, necessary to synchronise the tracking. The creation of a machine is always the first step in a PLACET2 script.

Beamlines Beamlines are standard, linear sequences of elements. PLACET2 supports the creation of many beamlines, each of them is defined appending the elements after each other. Elements can be added specifying their properties, or being copied from previously defined models. Girders are also supported. The extremities of each beamline must be connected through joints to an injector, a dump and/or other beamlines.

Injectors Injectors are special elements that allow to define the list of bunches to be tracked. The creation of an injector is very similar to the one of a beamline: bunches can be appended one after each other specifying their properties, including their time distance from the previous. If many equal bunches are to be tracked, the injector can automate the copy with memory efficient routines. During the tracking, the injectors release bunches as time goes.

Dumps Dumps are very simple elements that terminate a line. When a bunch reaches a dump, it is destroyed. Dumps can be instrumented to collect the required properties from the bunches that reaches them.

Joints and Links Beamlines, injectors and dumps (in short: jointables) are connected together using joints and links. Joints are placed where at least one connection is required. Links are internal objects of the joint and are used to describe the possible connections between the jointables attached to it. Each link connects two jointables together (one on the left and one on the right side) allowing to specify a routing criterion and the patching, when required. PLACET2 provides some powerful methods that make the creations of links a trivial task.

ELEMENT STRUCTURE

PLACET2 models the elements as shown in Fig. 1. When a bunch is tracked through an element a number of kicks are applied. The first step is to apply the misalignment modifying the reference frame. The tracking through an aperture follows, allowing to keep track of losses. A special

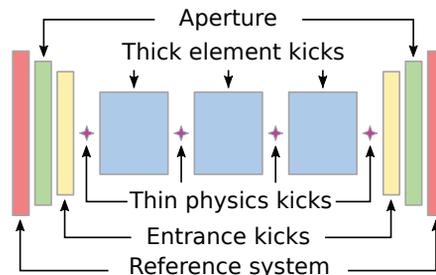


Figure 1: Sliced structure of the element

kick right before the core can implement the fringe-fields. The thick core can be sliced a number of times. Between each slice one can place thin kicks which compute physical effects. We pursue tracking accuracy more than symplecticity as in recirculating machines the bunches travel a limited distance.

LINKING BEAMLINES

We consider as an example a multi-pass linac which is travelled by bunches at different energies. At the end of the linac a dipole magnet separates the bunches according to their energies. As shown in Fig. 2 there are more ways to model this in PLACET2.

In Fig. 2a the dipole is placed in linac beamline (*bl1*), the bunches can then be routed according to their positions after the dipole. In this case, when creating the two links, it will be necessary to specify the patching: a change of reference frame when moving from *bl1* to *bl2* or *bl3*.

In Fig. 2b the linac is terminated before the dipole and two copies of the dipole are placed in the downstream beamlines. In this case the links can use the bunch energy as the criterion to select *bl2* or *bl3* and no patching is needed. This method is simpler and improves the numerical stability, while the first one allows to better handle imperfections and time dependencies, as in the case of an RF-deflector instead of a static dipole.

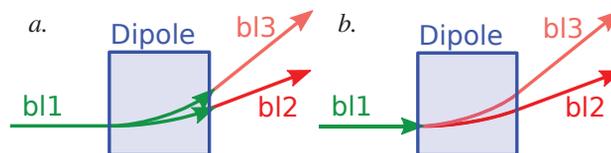


Figure 2: Two different connections between beamlines.

RUNNING THE MACHINE

The first step in running the machine consists in setting the machine timer. Each joint then collects the bunches that have reached it and sorts them according to their internal timers. If a bunch timer is smaller than the machine timer, the joint evaluates the routing criteria and send it through the link whose merit function has returned the smaller value. The bunch then travels straight down to the end of the beamline, waiting at the subsequent joint. The work of the joints terminates when all the bunches have a time bigger than the machine one. At this point the machine timer can be

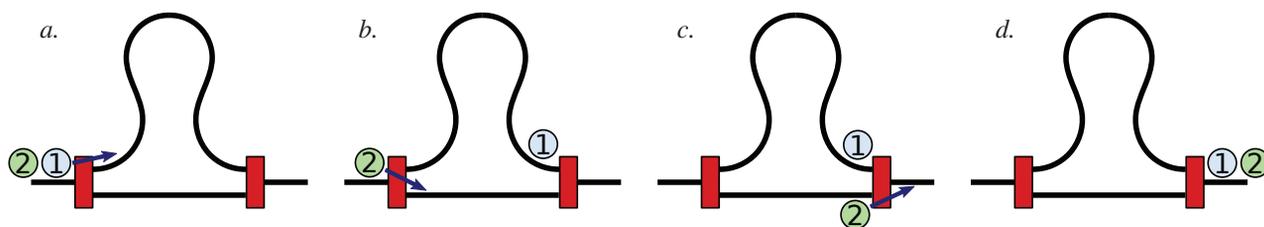


Figure 3: Operation of a simple machine.

incremented, iterating the joint procedure until all the bunch have left the machine or a certain time has been reached.

The key ingredient to preserve the bunch time sequence everywhere in the machine is to keep the step of the machine timer smaller than the time taken to travel the shortest beamline. Given that the tracking in each beamline is an independent task, PLACET2 runs the tracking in parallel over different beamlines, taking advantages of multicore CPUs. Backtracking a beamline, as would be required by a dogbone RLA [5], has been taken into account but is not currently implemented.

AN EXAMPLE OF OPERATION

Fig. 3 shows a simple machine that has two joints (the red rectangles). Two bunches with a small time separation are sitting in the injector. (a): the first bunch is routed to the longer beamline and goes straight down ending up in future; the second joint cannot advance it yet. (b): the second bunch goes to the shorter beamline arriving at the second joint with a timer smaller than the one of the first bunch. (c): the second joint routes to the dump bunch 2 first and then bunch 1 (d).

The following minimal listing shows how to describe a simple machine like the one in Fig. 3. It can be run by PLACET2 as it is. The dump prints a message when a bunch reaches it, showing that bunch 2 arrives before bunch 1.

```
Machine my_mac

my_mac new_injector my_inj
BunchSingle -energy 1.0 \
            -time_before_next 10e-9
BunchSingle -energy 1.0

my_mac new_beamline my_bl_long
Drift -length 10
my_mac new_beamline my_bl_short
Drift -length 1

my_mac new_dump my_dmp

my_mac link -in my_inj -out my_bl_long \
            -cmd {[bunch time_s] > 5e-9}
my_mac link -in my_inj -out my_bl_short \
            -cmd {[bunch time_s] < 5e-9}
my_mac link -in my_bl_long -out my_dmp
my_mac link -in my_bl_short -out my_dmp

my_mac run
```

RELEASE PLANS

The PLACET2 concepts and implementations have been established and the code is currently being deeply tested and polished. It has been already applied to different case studies such as the LHeC [6] and CTF3 [7] to compute physical results. We expect to make it available by the end of the year.

CONCLUSIONS

A new version of the tracking code PLACET, capable to handle recirculating machines, has been developed. PLACET2, suites a number of new concepts previously unavailable in a tracking code. Its newly written tracking core handles multi-bunch tracking in recirculating lattices, allowing to compute the impact of multi-bunch effects even with these complex boundary conditions. It comes with an intuitive interface that simplifies its usage allowing to set up simulations with a minimal amount of efforts.

PLACET2 has already been applied to real life case studies such as the CTF3 combiner ring [7] and the LHeC study [6]. At CTF3, the simulation has been compared against measures on the machines and previous studies. For the LHeC the first end-to-end tracking has been performed and the impact of multi-bunch wakefields has been assessed.

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