EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - AB Department

CERN-AB-2006-062

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Presented at
EPAC'06, Edinburgh, UK, June 26-30, 2006

Geneva, Switzerland
June 2006

MAD-X/PTC LATTICE DESIGN FOR DAPHNE AT FRASCATI

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Abstract

In absence of a program that takes as an input the desired or known location of the magnets in the tunnel, accelerator designers have been using MAD that looks at a ring as a sequence of magnets without a connection to the tunnel. In many simple examples that is just fine, but once more complicated structures are treated one is bound to play tricks with MAD. Here PTC comes to the rescue. It is shown how pieces of this machine that exist in MAD-X format are used in PTC to create this double ring, as found on the accelerator floor, with a proper survey in the forward and backward direction. Special elements have been implemented in MAD-X to allow the full PTC description of the machine.

INTRODUCTION

The Frascati Φ-factory DAΦNE is an e^+e^- collider operating at the energy of the Φ-resonance (1.02 GeV c.m.) [1].

DAΦNE is an accelerator complex consisting of a double-ring collider, an S-band linear accelerator, an intermediate damping ring to make injection easier and faster and 180 m long transfer lines connecting the different parts.

In the past five years DAΦNE has delivered luminosity to three different experiments: KLOE [2], FINUDA [3] and DEAR [4] running one at a time, and installed the first one on IR1 and the other two, alternatively, on IR2. The best peak luminosity reached is 1.5×10^{32} $cm^{-2}s^{-1}$ with a maximum daily integrated luminosity of ~10 pb^{-1}[5].

High current bunched beams are stored in each ring, usually the number of adjacent filled buckets is in the range 109÷111 out of 120 available. A short gap is needed for ion clearing. It's worth mentioning that in DAΦNE the bunch separation is the shortest among all existing colliders and particle factories (2.7 ns). In order to minimize the effect of parasitic crossings [6] of the closely spaced bunches, the beams collide under a crossing angle in the range of 10 to 20 mrad.

The DAΦNE model has been implemented using the MAD8 [7] design code which imposes some severe limitations. In fact MAD cannot handle two rings at the same time, cannot describe correctly the beam trajectory off-axis in the IRs, does not evaluate correctly the beam emittance and damping times, computed by using the synchrotron integrals, and cannot predict correctly the beam lifetime.

It therefore came handy when CERN introduce the new MAD-X [8] code that combines most of the valuable ingredients of MAD with the object oriented PTC [9] code, called MAD-XP in the following, which provides all the more advanced features that should be expected from a modern accelerator design code.

In particular, PTC offers a proper description of all accelerator elements available in MAD-X. With PTC the notorious MAD problem of incorrect delta-p/p dependence of various accelerator parameters is a thing of the past. A proper treatment of SBEND and RBEND magnets has been provided with PTC early on. Recently, it became apparent to some of our users that the CAVITY is treated in PTC with the proper transit time factor while in MAD this has always been ignored. The code offers the exact or expanded Hamiltonian of each element. Accelerator elements can be placed at their proper three-dimensional position according to the accelerator floor in the real world. Besides particle tracking, PTC does perform also MAP tracking with all the subsequent and well tested Normal Form techniques and it allows to track the beam envelop tracking that can be used to get correct values for the beam emittance and for the beam dynamic aperture. This has been achieved by keeping both MAD-X and PTC as independent codes but linking them via a converter that transforms the MAD-X accelerator data base into the PTC world. Since PTC has in principle more options for the proper treatment of accelerator elements we are using the very flexible input structure of MAD-X to add more and more features that are controlled by MAD-X but only available in PTC.

With MAD-XP one can therefore avoid all the typical MAD limitations. In fact, it can deal with the real three dimensional disposition of the ring elements in space and can handle two rings at the same time.

The DAΦNE model has been first converted to MAD-X format and then the MAD-X input file has been used to generate the double ring model by means of PTC.

A reliable design code is expected to be even more important for the future DAΦNE upgrade options [10] looking for an increase at least of a factor 3 in the peak luminosity by means of higher currents, smaller emittances and a sophisticated crabbed waist collision scheme [11], much more demanding in terms of dynamic aperture and beam lifetime estimate.

DAΦNE MODEL

DAΦNE is a very compact machine (97.98 m long), with no periodicity at all. The KLOE and FINUDA detectors are surrounded by large superconducting solenoid magnets with a 2.4 Tm field integral, that is not negligible if compared to the ring magnetic rigidity (Bρ = 1.7 Tm), and must be taken into account in the machine model.

Each ring in DAΦNE consists of a long external arc and a short internal one based on a quasi-achromatic cell

built using a bending-wiggler-bending sequence. The cells are based on four different kinds of dipoles: two sector magnets and two rectangular ones deflecting the beam respectively by 49.5^o and 40.5^o.

The MAD limitation in evaluating the beam emittance comes from the estimate of the I4 synchrotron integral for the rectangular magnets which does not include the contributions coming from the magnet wedges. Such terms are negligible for large accelerator with long dipoles with small deflection angles but become very relevant for short magnets as in the case of DAΦNE.

The presence of the wiggler in the region of maximum dispersion doubles the radiation emitted in the dipoles, reduces the damping times and, as a consequence, increases instability thresholds. Moreover the optimal optics flexibility (all quadrupole magnets are powered independently), makes it possible to tune the beam emittance by changing the dispersion in the wigglers at constant field.

In a low energy lepton collider the beam lifetime is mainly limited by the Touschek effect which in MAD is computed assuming the RF energy acceptance as a limit for the stable particle. As a matter of fact in DAΦNE the energy acceptance due to the dynamic aperture is smaller than the RF energy acceptance and this leads to overestimate the beam lifetime by a factor 2.

PTC MODEL OF DAΦNE

The code PTC contains Fortran90 structures which allow two novel things: the placements of magnets in arbitrary locations and the sharing of beam lines. Beam lines can be shared between different lattices as in a collider or shared within a single lattice as in a recirculator or a combination of both.

The present example consists of a collider made out of two rings. The first ring is depicted below in ure 1. This ring is made of 4 parts which are quite standard. In fact in MAD-X, they are created as 4 standard beam lines.

They are then passed to the code PTC as 4 simple "layouts" of PTC. While a beam line in MAD-X is a simple link list of magnets, in PTC, the layout is a slightly more complex object: a link list of containers (Fibres) with pointer to a magnet.

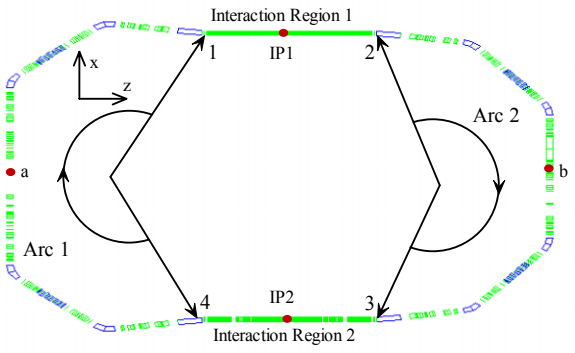

Figure 1: First Ring of DAΦNE.

The fibre also contains a pointer to a 3 dimensional chart locating the magnet precisely in space and a pointer to patches. The patches permit the dynamical connection between different magnet maps. They are translations and rotations. The two rotations which involve the direction of propagation become drifts in polar coordinates while the translation along the direction of propagation is a regular Cartesian drift.

SURVEY COMMAND OF PTC

When fibres are created "à la MAD", the magnets are all located at the origin. The survey command places them in the usual MAD survey position. The PTC survey command propagates the initial frame of reference through the lattice using the local coordinate frames attached to the magnets and the patches. Since the patches are all set to identity, we get the regular MAD survey by construction. This is an arbitrary choice in PTC. PTC could have any survey convention. Ideally, PTC should be connected to a CAD program and the magnet placed where ever we want.

POSITIONING THE 4 LAYOUTS

Thus initially, the 4 layouts are created and surveyed. Since all the magnets within each of them are at a standard position, the beam lines are properly constructed. However they all start at the global origin. Looking at the engineering floor plans, we can move and rotate the four beam lines into their real positions. In practice, the position of red dots (a, b, IP1, IP2) was read and the beam lines were placed.

At the four intersections (1, 2, 3, 4), the beam lines were not matched properly. Thus 4 patches were computed between PTC's fibres at locations 1, 2, 3, and 4. The PTC survey command serves as a self-consistency check. We survey the ring. If it moves, the patches are incorrect or forgotten. If the ring stays in place, then the ring is ready for tracking.

SECOND RING

DAΦNE is a collider. The two interaction regions are common to two rings. PTC has reversed propagators and thus the exact same magnets can be traversed in opposite directions. These magnets are exact in the computer sense as well: though a common magnet belongs to a different layout and a different fibre, it occupies the same place in memory. Anything that happens to this magnet in one ring (misalignments, mispowering, etc.) automatically happens in the other ring.

In Figure 2 both rings are shown with an indication of direction of particle motion. Note that the lines going through the centre of the elements are actually obtained by tracking a trajectory through each separate ring.

To our knowledge this is the first time ever that an accelerator modelling code has been successfully applied to track trajectories backwards and forwards in a model of

an existing accelerator which consists of a double ring structure with long common beam-line sections.

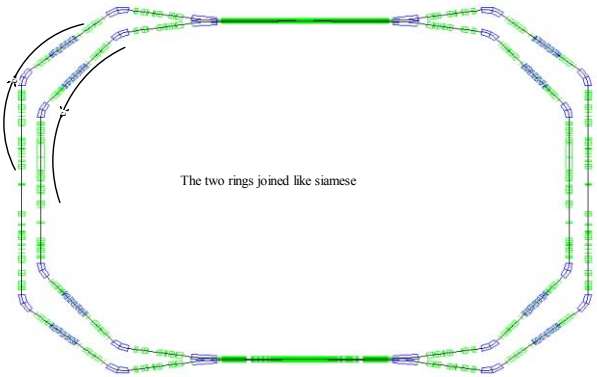

Figure 2: Both Rings of DAΦNE.

CONCLUSIONS

It has been shown that the combined code MAD-XP can be used to study complex double ring structures with common beam lines. MAD-X plays the part of the front-end to read-in the various beam lines with the standard and flexible MAD-X input language. The accelerator data base is then transferred to the PTC code which is used to actually build up the complex double ring structure DAΦNE using forward and backward propagators. Closing trajectories have been tracked through both rings.

We are at the starting point of applying MAD-XP to complex structures like DAΦNE for which the full capabilities of PTC are required. Considerable progress has been made but further effort will be needed to handle properly various subtle issues.

In particular the reader should not yet expect a turn key ready code for any kind of complex structures which is the goal to be reached in the near future. Presently, some expert intervention is still mandatory.

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