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ACCELERATOR PHYSICS CODE WEB REPOSITORY

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Abstract

In the framework of the CARE HHH European Network, we have developed a web-based dynamic accelerator-physics code repository. We describe the design, structure and contents of this repository, illustrate its usage, and discuss our future plans, with emphasis on code benchmarking.

INTRODUCTION

Within the "Accelerator Physics and Synchrotron Design" (APD) work package [1] of the CARE [2] network on "High Energy High Brightness Hadron Beams" (HHH) [3] an accelerator physics code web repository has been constructed. The word "repository" here refers to a central place where data is stored and maintained. The underlying goals are to improve the collaboration between accelerator laboratories, in particular those associated with HHH, to ameliorate the existing accelerator-physics infrastructure for general benefit, and to provide a platform for future code benchmarking. More specifically, the pertinent APD targets are a *common repository* for linear and non-linear optics programs, impedance estimates, and simulation codes for collective effects (conventional instabilities, beam-beam, space charge, and electron cloud); *code verification* by mutual comparisons and benchmarking against machine experiments, and centralised documentation, fostering code reliability; and *extension* of simulation codes to cover relevant beam physics and implementation of effective procedures for beam measurements, machine protection, background control, and performance optimization.

REPOSITORY DESIGN

Two closely linked web sites have been created. The first is a classical 'static' web site [4]. The other web site [5] is dynamically linked to a database. The database approach has four distinct merits compared with the static web site: (1) search-engine capability, (2) standardized format of different code web pages, (3) simple usage, and (4) easy maintenance.

The `ORACLE Designer CASE tool`, the `ORACLE Database Management System`, and the `ORACLE PL/SQL Web Toolkit` were used for programming the database, for facilitating its maintenance, and for creating the dynamic web pages, respectively. In short, `CASE` refers to Computer Aided Software Engineering, and the `CASE tool` contains a development suite for database design, application design and code generation. The `ORACLE` [6] architecture was chosen since an `ORACLE` support team exists at CERN.

The repository thus created displays the code pages dynamically, and features a search engine allowing for multiple queries and usage of wildcards. The database management tool, developed in parallel, provides securised access and helps the web master to manage the data.

The database contains three main tables where important information is stored: (1) codes identified by names, (2) code categories, *e.g.*, 'electron cloud', and sub-categories, *e.g.*, 'build up' or 'self-consistent', and (3) persons, *e.g.*, authors or contacts. Internally, the treatment of the persons differs from that of code names and categories. Codes are linked with categories and with persons. Links must be removed before elements can be deleted, *e.g.*, in case codes are no longer supported. The management tool delivers a query form, records, view pages, and an insertion form. Indexes for the search engine were generated.

REPOSITORY CONTENTS

An enormous number of accelerator physics computer codes has been written by the community over the last six decades. The names of many can be found on the static web site [4]. From these, in each category or sub-category we have selected only a few which are under active development or active maintenance, for inclusion into the dynamic repository, which presently contains 35 codes in total, namely: `ABCI`, `BBSIM`, `BBSS`, `BBTrack`, `BEAMX`, `BeamBeam3D`, `BETA`, `COMBI`, `Ctrack`, `ECLOUD`, `ESA ESTEC`, `EVOL`, `FIIATF`, `grr`, `HEADTAIL`, `LAWAL`, `LAWAT`, `LieMath`, `MADX`, `MICROMAP`, `MOSES`, `NERO`, `ORBIT`, `PATRIC`, `PEI-M`, `PHOTON`, `PLATO`, `POSINST`, `SAD`, `SixTrack`, `SODD`, `SUSSIX`, `TRSIM`, `WARP`, and `WSDIFF`. These codes are distributed among the categories as shown in Table 1. Note that a code may belong to more than one category.

For most codes the following information is now available in a standard format: (1) code name, (2) code purpose, (3) authors, (4) contacts, (5) language, (6) operating system, (7) home page, (8) source code, (9) example

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Table 1: Number of codes in each category (bold) and subcategory (normal)

beam-beam: 7	
strong-strong: 4	weak-strong: 3
electron cloud: 8	
build up: 2	multi-bunch instability: 1
multipacting: 1	self-consistent: 2
single-bunch instability: 1	incoherent: 2
synchrotron radiation: 1	
impedances: 4	**instabilities: 5**
ion effects: 2	**luminosity: 1**
nonlinear dynamics: 8	**optics: 5**
space charge: 4	

input and output, (10) documentation or manual, (11) list of special model features, (12) accelerators for which this code was or is used, (13) benchmarking exercises against other codes, (14) benchmarking against experiments, (15) special programming features, (16) comments, (17) references, and (18) associated categories. For several codes supplementary web pages with extended links and documentation were created. The above information was collected via a standard questionnaire sent to about 60 authors and prospective contact persons. About 75% of the contacted colleagues responded positively. As a first spin-off, several home pages were newly created by the code authors, e.g., those of ABCI [7] and MOSES [8], to the benefit of the users. These complement already existing home pages (e.g., [9]). For a few codes, however, even basic information from the authors is still missing.

BENCHMARKING

The notion of ‘benchmarking’ may have four different meanings [10], namely *debugging*: the code should calculate what it is supposed to calculate; *validation*: results should agree with estabished analytic result for specific cases; *comparison*: two codes should agree if the model is the same; and *verification*: the code should agree with measurements. The need for debugging is obvious, but validation is often difficult for complex simulations of nonlinear processes. The HHH benchmarking focuses on the last two areas, code comparison and experimental verification. Below we give some benchmarking examples.

Code vs. Code

Numerous space-charge codes have been compared with each other. There now is a good agreement for 2-dimensional simulations over 10^3 turns. A comparison of `MICROMAP` and `SIMPSONS` in longer-term simulations has also been performed in great detail [11], with the aim of predicting halo densities. An excellent agreement was demonstrated for both scattering and trapping regimes, except for a factor two discrepancy in the emittance growth, possibly related to differences in the longitudinal dynamics model. A parallel benchmarking of `MICROMAP` against `HEADTAIL` showed an excellent agreement, at the 1% level, even for the emittance growth, which in this case is due to resonance crossing or scattering driven by an electron cloud of constant size and linearly increasing density [12].

Also electron build-up simulation codes were benchmarked against each other at several occasions; see, *e.g.*, [13, 14, 15]. They generally agree within a factor of two or better if the same or a similar model for the secondary emission yield is used. Figure 1 shows a recent comparison of `POSINST` and `ECLOUD` simulations for an LHC arc dipole [16]. The agreement of the two codes’ simulations without re-diffused electrons is considered satisfactory. The biggest uncertainty seems to be the insufficient knowledge of the in-situ surface properties.

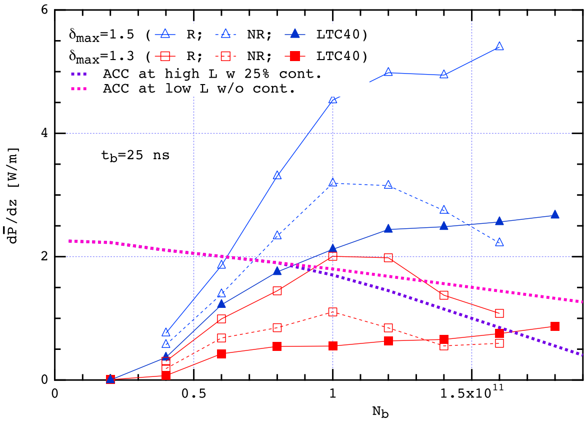

Figure 1: Simulated electron-cloud heat load in an LHC dipole as a function of bunch population for two different value of $\delta_{\max}$. R: `POSINST` code with full SEY model, NR: `POSINST` code with no-rediffused model, LTC40 : result from `ECLOUD` code without re-diffused electrons. The available cooling capacity (ACC) under two different assumptions is also indicated [16].

Code vs. Experiment

Agreement between space-charge codes and experiments is good in some cases and poor in others, especially for larger numbers of turns and dynamic situations. For resonance trapping and scattering, an acceptable agreement between the beam losses simulated by `MICROMAP` simulations and those observed in experiments at the CERN-PS has been achieved by including chromaticity and extending the number of turns simulated to 2.5×10^6 [17].

Electron-cloud build-up simulations with `ECLOUD` are in good agreement with measurements at the CERN SPS after fitting two important input parameters, namely the maximum secondary emission yield $\delta_{\max}$, and the reflection probability of low-energy electrons R [18]. Similarly, `POSINST` simulations well reproduce observations at the ANL APS and the LANL PSR after fitting $\delta_{\max}$ and R. In the same way, RHIC data of peak electron flux and electron decay times have been benchmarked with two different build-up codes, `CSEC` and `ECLOUD`, yielding somewhat different values for $\delta_{\max}$ and R [19].

In the experimental benchmarking of simulation codes modelling the effect of the electron cloud on the beam, a precise knowledge and correct representation of the beam distribution is important, as it is also found in the case of space charge. Figure 2 shows the measured and modelled horizontal phase space of a 5-μs, 180-mA, 1-MeV coasting K+ beam (potential on axis $\sim$ 2 kV) after propagating in a four quadrupole magnetic lattice intentionally flooded with electrons, at the HCX experiment. The electrons were created by intercepting the potassium ions on a conducting plate at the exit of the lattice (for more details see [20, 21]). The highly nonuniform electron distribution in the last magnets results in strongly nonlinear fields. The effect on the beam is illustrated in Fig. 2 by the pronounced phase space distortions. Better agreement with the experimental data (left) is achieved by initializing the K+ beam distribution in `WARP/POSIINST` using phase space measurements upstream of the magnets (right), rather than an idealized semi-Gaussian distribution with second moments based on measurements (center).

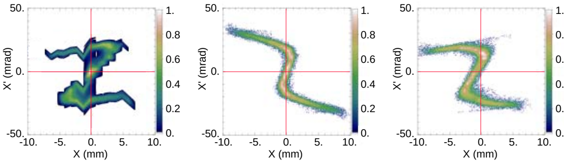

Figure 2: Transverse phase-space distribution at the exit of HCX quadrupole channel: measured (left); simulated with the `WARP/POSINST` code for a semi-Gaussian initial distribution (center); and simulated with the same code, but using the measured initial distribution (right) [20, 21]).

At the KEKB B factory only a single upper synchrotron sideband is observed around the main betatron tune line above the threshold of the single-bunch electron-cloud instability [22]. The reproduction of this feature in simulations was one of the two most important benchmarking challenges identified at the HHH-2004 workshop. Recently simulations with the two codes `HEADTAIL` and `PEHTS` have succeeded in reproducing the observations, partly by adjusting the transverse size of the electron cloud considered in the simulation [23]. Figure 3 presents simulation results from `HEADTAIL`. The left picture shows the turn-by-turn centroid motion obtained with an electron-cloud size equal to 10 or 20 times the rms beam size. In the latter case, the centroid motion is strongly suppressed. The FFTs of either beam motion exhibit only upper sidebands as observed (right picture). Simulations with `PEHTS` yield similar results, but, differently from `HEADTAIL`, a single upper sideband is obtained only for the larger cloud size [23].

OUTLOOK

We plan to further consolidate the code repository, *e.g.*, by posting input and output examples for one or a few standard examples, which should ideally be the same for all codes within one category. The latter condition will make this exercise a part of the code benchmarking, which also needs to include the experimental clarification of critical input parameters, such as initial beam distributions or surface properties. We further aim to expand the program capabilities beyond their traditional range, towards more self-consistency and increased usefulness for accelerator design or operation. The ultimate target is reliable performance predictions.

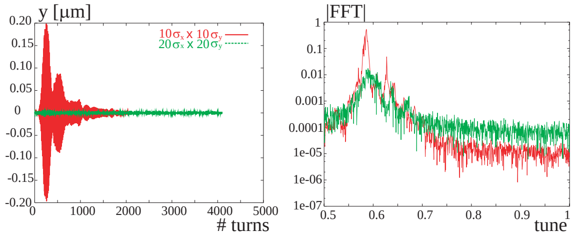

Figure 3: KEKB bunch centroid motion simulated by `HEADTAIL` with two different electron-cloud sizes (left) and the corresponding FFT signal (right) [23].

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