

A LEGO PARADIGM FOR VIRTUAL ACCELERATOR CONCEPT

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Abstract

The paper considers basic features of a Virtual Accelerator concept based on LEGO paradigm. This concept involves three types of components: different mathematical models for accelerator design problems, integrated beam simulation packages (i. e. COSY, MAD, OptiM and others), and a special class of virtual feedback instruments similar to real control systems (EPICS). All of these components should interoperate for more complete analysis of control systems and increased fault tolerance. The Virtual Accelerator is an information and computing environment which provides a framework for analysis based on these components that can be combined in different ways. Corresponding distributed computing services establish interaction between mathematical models and low level control system. The general idea of the software implementation is based on the Service-Oriented Architecture (SOA) that allows using cloud computing technology and enables remote access to the information and computing resources. The Virtual Accelerator allows a designer to combine powerful instruments for modeling beam dynamics in a friendly way including both self-developed and well-known packages. In the scope of this concept the following is also proposed: the control system identification, analysis and result verification, visualization as well as virtual feedback for beam line operation. The architecture of the Virtual Accelerator system itself and results of beam dynamics studies are presented.

INTRODUCTION

In modern accelerator physics there gives much attention both to the information support problems as a process of constructing the accelerator systems and the maintenance of corresponding experiments. In other words, it is necessary to create an integrated package of special software oriented for modeling of operating characteristics of an accelerator considered as a control system. Here we mean a distributed control system for both electromagnetic structural elements and a beam state. In the corresponding package is it necessary to take into account consider both the most important procedures like measurement of the beam, control elements characteristics and technologies required for a comprehensive evaluation design for each of these key questions before manufacturing and testing physical prototypes. In the VA package there are integrated different approaches to both numerical modeling problems beam dy-

namics and beam control system operation. More over, the corresponding approaches involve necessity to carry out a global optimization procedure of an accelerator in whole (or its components) with a given criteria family.

The Virtual Accelerator package implements a unique hybrid approach to modeling the dynamics of the beam, based on a combination of a large number of proven methods of analysis based on a combination of numerical and symbolic operations, in which the model as components of the accelerator and beam models are combined with virtual models and synthesized control fields. By combining environmental test and virtual simulation the package VA speeds up the design process and makes it more accurate and stable because it has a built-in validation of models based on test results.

The VA package allows users to:

- combine proven components models with virtual models of new components;
- develop reliable data on the beam with a virtual simulation and, if possible, the results of environmental tests;
- improve the accuracy and speed of simulation at the system level, using real data and reliable virtual model;
- adapt the virtual assembly control system for assessing critical characteristics of the beam;
- estimate the characteristics of the whole control system before natural testing of a prototype.

Virtual Accelerator package provides users a set of well-proven packages of modeling of dynamics (such as MAD, Trace3D, COSY Infinity, MaryLie and others developed by the authors of this article, see, for example, [1]), as well as the software package that allows you to implement the concept of a global optimization (see, for example, [2]). In the process of the corresponding research the model includes the necessary edge effects, nonlinear aberrations of different nature, the effects of space charge and so on. For problems of long-term evolution there is supposed to use different methods of symplectic integration. This gives us the necessary accuracy for long time evolution (it is very important for cyclic accelerators).

The VA package will provide “transparent” access to data modeling and its results, making it an integral part of the process numerical simulation and monitoring of existing accelerator facilities. Construction and integration of computational models with specific characteristics is a key point of virtual simulation. Therefore, the package should

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contain necessary tools to edit the structure of the accelerator control system, models of control fields, the description of the beam as a family of particles (including taking into account its charge), modeling and assembly for fast virtual models with the necessary visualization tools. The VA package allows users to combine a numerical model of the system-level virtual and the resulting test model components. It should also be pointed out that this package provides several opportunities for optimization of one or more of the criteria (including antagonist). With the help of neural network modeling techniques designer can determine the possible structures corresponding to their requirements. Using effective methods and optimization algorithms (e. g. using genetic algorithms, see, for example, [2]) one can find a set of appropriate solutions. The global optimization concept is proposed to use the method of finding rational alternative, based on the combination of the decision and Pareto method optimization using both integral criterion and using different methods and algorithms for accelerator modeling. This technique was tested for the solution of optimization problems of control systems particle beams [2]. It is also expected to use the methods and algorithms involving expert systems for optimization of complex systems with incomplete information. This approach allows the concept to use data mining methods and technologies for control problems in complex systems. For the analysis of investigated alternatives are used both numerical modeling procedures and the corresponding analytical model using the tools and techniques of Computer Algebra [3].

It should be noted that all above mentioned approaches are based on the LEGO-objects concept (see, for example, [4, 5, 6]), which on one hand allows to unify the mathematical objects at all stages of modeling and maintenance of the necessary computational procedures and on the other – to provide the necessary flexibility and scaling the appropriate software.

SOME PRINCIPLES OF THE LEGO-OBJECTS CONCEPT

The main idea of the LEGO-objects concept is based on a deep hierarchy of *elementary blocks* for presentation of both *physical elements* and corresponding *computational tools*. These blocks can be separated in three groups: the first corresponds to physical objects, the second has a virtual character and the third describes computational procedures. For the second type a beam line researcher can not relate such virtual block to any physical element. As an example of such *virtual element* the fringe field description block can be mentioned. These elementary blocks are used for decomposition of the whole physical system into a set of subsystems. The symbolic representation of these blocks allows to create databases of elementary classes of such subsystems. Manipulation by these classes is similar to manipulation by LEGO-blocks. The similar approach is developed in some works [7], but the authors do not use symbolic representation for solution to be found.

The first two types of LEGO-objects can be connected with objects having some different (not only physical) interpretation. LEGO-objects of the third type are accountable for computational procedures of different kind. As an example we can mention two groups of methods of integration: non-symplectic and symplectic integration methods. So the VA package has to involve other types of LEGO-objects which generated by operations above LEGO-objects of the first two types. All types of LEGO-blocks have corresponding presentation on at all phases of simulation process: from physical models up to computing models. Including and excluding any elementary block have to be realized quietly, without distortion of the whole model. This approach is an essence of the *dynamic modeling paradigm* [1].

The above pointed approach is based on a hierarchical sequence of approximation models, which can be built for an investigated beam line. The modeling process (including optimization procedures) has several major phases:

- *the initial phase of problems formalization on physical understanding level — creation of a set physical models for problem under consideration;*
- *construction of approximating models in conformity with experiments data — creation of a hierarchy of approximating models;*
- *the phase of problems formalization on mathematical understanding level — creation of a hierarchy of mathematical models;*
- *creation of computing models (including algorithms and corresponding software) realized mathematical models;*
- *realization of the computing process for modeling and optimization — a set of computing experiments;*
- *the phase of the interpretation of computing results and testing on adequacy to the physical model.*

The basic stages of computational processes are presented in Fig. 1. All presented modules are not only necessary for correct realization of computational experiments, but they gives designer effective tools for necessary computational experiments. It is necessary to note that usage of symbolic algebra tools give us additionally the necessary flexibility and effectiveness of the computational process.

The process of ordering and accumulation of used knowledge, decomposition of complex systems into a set of simple subsystems (real and/or virtual) must guarantee good maintainability, reasonability, and extensibility of designed codes for numerical modeling. On this step a researcher forms his understanding of practical problems under study. Complexity of modern problems have to lead to necessity of using of databases and knowledge bases ideology and corresponding tools. On this phase of modeling it is necessary to pay attention to classification and

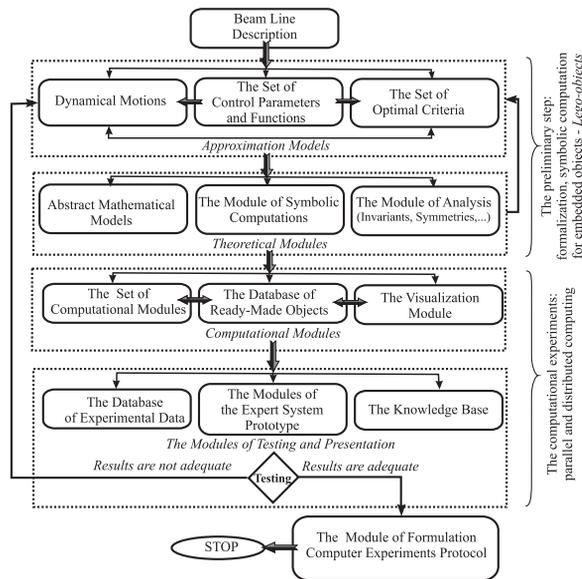


Figure 1: The total cycle of the computational experiment.

systematization of used knowledge about the problem under study (in term of LEGO-objects this means an in-depth classification and structuring). Similar approach may be suggested on the phase of mathematical models forming too. Moreover, the deep mathematical formalization helps researchers to create adequate mathematical models easily than it is done on the previous phases. Naturally effectiveness of computer algebra methods and codes usage depends on selected mathematical methods and tools. These methods must admit a deep hierarchy of LEGO-objects. These objects have their own characteristics needed for sewing together in a whole physical element.

All elementary blocks have their representatives on all phases of modeling process: from physical up to computing models. Including and exclusion either elementary block must be realized quietly, without distortion of the whole model. This approach is realized using dynamic modeling paradigm [8]. It should be note that the visualization procedures must be included to the computing model as its integral part. Indeed the results of visualization process help us understand dynamical processes occurred in either situation. Here it is necessary to tell some words about optimization procedure particularly. Usage of symbolic representation for problems under study can realize the corresponding optimization process more effectively (see, for example, [2]). As the conclusion it is necessary to note that realization of discussed approach allows to carry out the analysis in a special virtual laboratory – Virtual Accelerator, that is not only favorable from the economic point of view, but also allows us to investigate many effects more detail and carefully, usually this is unacceptable to only natural experiments.

CONCLUSION

The above described approach can be realized using two mathematical and computational frameworks. The first is enough traditional for the most published Virtual Accelerator concept: a combination well known and approved beam line packages and EPICS instruments. The second is based on the first approach (based on numerical modeling first of all) and more extended application of symbolic computational procedures. In our case we use the matrix formalism for Lie algebraic tools [9]. This approach gives the designer more effective and extensible toolbox. The most of modules presented on the Fig. 1 were realized using this formalism and were applied for different problems of beam physics (see, for example, [1, 10, 11]).

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