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CAD INTEGRATION FOR PETRA-IV

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Abstract

The PETRA-IV next-generation synchrotron radiation source at DESY is currently in preparation with a completely new accelerator and a new experimental hall, retaining as much of the existing PETRA-III buildings, tunnels and experimental beamlines as possible.

We have set up a CAD integration model for the complete accelerator and photon science complex. The model hierarchy has levels reflecting decisions on project organisation, project phases, design process, and overall product structure. Modularisation and designing in three levels of detail help to manage the complexity and keep the model performant. Placement of accelerator components is determined by the lattice through direct access to spreadsheet data, allowing fast design changes after a lattice update and ensuring consistency between mechanical and lattice design. The resulting model will support engineering processes over the complete facility lifecycle.

INTRODUCTION

Lifecycles of accelerator facilities extend over decades, spanning a number of phases from concept over design, construction, and operation to dismantling. Computer Aided Design (CAD) is an essential tool for supporting the engineering in the various stages of the lifecycle. CAD applications include space allocation, basic and detailed engineering, matching of interfaces, clash checks, technical documentation for installation, operation, and maintenance. Figure 1 shows a simplified lifecycle of an accelerator facility and highlights phases with important CAD contributions. The CAD integration model accumulates and conserves all mechanical engineering designs, decisions, and knowledge throughout the entire lifecycle. It is implemented and maintained in the CAD software Siemens NX and the PLM system Teamcenter.

OBJECTIVES

The integrated CAD model of PETRA-IV [1] is intended to serve as a comprehensive mechanical model of the entire system: the accelerators with all their components, photon beamlines with optics and experiments, supporting infrastructure such as water, electricity, ventilation, and buildings. It will be maintained throughout the project life span and remain usable during its whole life cycle for all stakeholders with their differing needs. The overarching objectives of the model are to establish vision sharing, support interface management, enable early detection of potential clashes, foster design collaboration, and to support better and faster decision making

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REQUIREMENTS

Performance is a major requirement: the model has to provide the means to efficiently edit the data and provide the necessary design context. Collaboration across different trades and organisational units needs to be supported with minimal side effects from changes in one trade to other parts of the model and with data protection against unwanted changes from third-party groups.

Collaboration with external groups and suppliers, who do not have access to the integration model, demands support for work with minimal context: clearly defined interfaces and space reservations for import of the contributed data, are required.

Accelerator design starts from a mathematical model of the components governing the beam dynamics (the so-called lattice). An associative relation between the CAD model components and their lattice representations and the ability of automatic geometry updates are needed for fast design iterations.

Collaboration with civil engineering requires the import of the building and tunnel CAD models from dedicated architectural CAD systems into the integration model, with accurate placement of the buildings and an exchange of space reservations as input for the civil engineering design process. Infrastructure, such as water and electricity supplies and heating and ventilation, has interfaces to the buildings and the accelerator and experimental facilities that need to be present in the model.

METHODS

In the following, we describe briefly some of the methods we have employed employed in response to the CAD model objectives and requirements.

Model Structure

CAD models are typically structured according to a spatial and functional decomposition of the product. A close correspondence between CAD model structure and the product breakdown structure (PBS) supports processes that are closely linked to the PBS such as verification of requirements, validation, and testing.

The structure has a consistent set of levels corresponding to a logical hierarchy, namely program, complex, facility, area, and unit, inspired by the physical model of the ISA–106 set of standards, as illustrated in Fig. 3. Additional interim levels (not shown in the figure) implement different levels of detail, organize responsibilities and access rights of the different trades and work packages, and manage different configurations.

We find that the CAD model structure reflects, and often necessitates, project decisions on topics such as responsibil-

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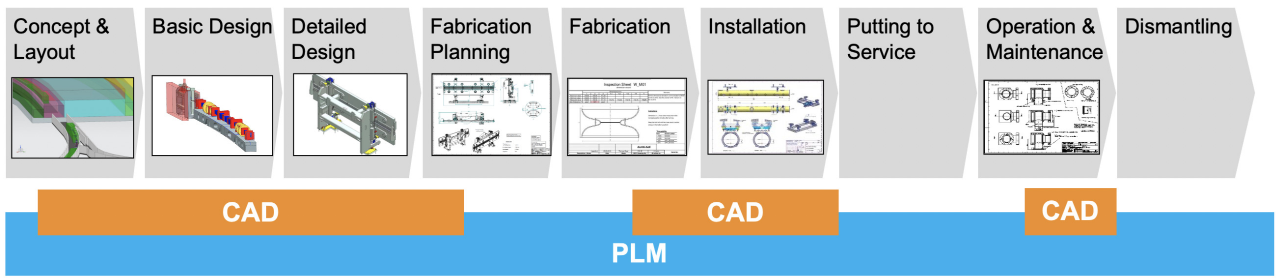

Figure 1: Accelerator lifecycle. The orange boxes indicate which phases update the CAD integration model. The PLM system ensures data management throughout the entire lifetime of the facility.

ities (connected to different trades), work package organisation (reflected in the PBS and functional decomposition), design process (levels of detail), and project phases (configurations).

Modularisation

Modules are functionally and spatially coherent subsystems that occupy a specific space and have a defined interface to their surroundings. In the PETRA-IV integration model modularisation is used extensively and recursively at different levels. Examples for modules are an arc cell of the accelerator, the optics of a photon beamline, an experiment, a section of the water supply system, or a section of free space for transport, escape routes etc.

Levels of Detail

We represent elements in the CAD models at different levels of detail (DG "detail grade"), which can be switched according to purpose:

- DG1: This coarsest level of detail indicates the space required for the module, typically as a box.
- DG2: The required space required is modelled precisely enough for collision checks and external interfaces modelled.
- DG3: A fully detailed model with the full internal structure of the module, suitable for tendering, production and installation.

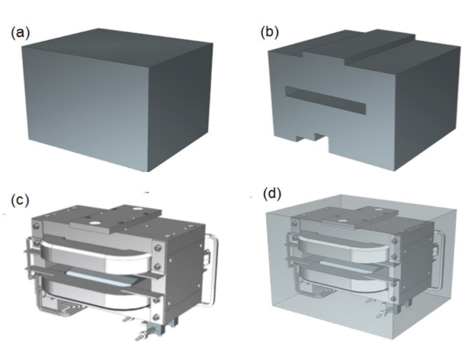

Figure 2: Example of a magnet model in three levels of detail: (a) DG1, (b) DG2, (c) DG3, (d) DG1 and DG3 overlaid.

Fig. 2, illustrates the DG mechanism for a component such as a magnet. Figure 3 illustrates the application of the DG mechanism, where a unit is represented in DG1 for studying its placement in an area and in DG3 for assembly and installation (right, top and bottom).

The DG approach was extensively used at the European XFEL (E–XFEL) project [2]; it was applied in NX for the ARES project [3], where the concept of a DG master was introduced: an assembly that combines the different DG1/2/3 models, each a separate CAD item, into a single assembly. We use the NX "reference set" mechanism to select dynamically at which level of detail a module should be shown. NX provides assembly load options to define rules which reference sets shall be loaded preferentially; loading only DG1 or DG2 models initially and selectively loading DG3 models in regions of interest ensures that even a model of the complete PETRA-IV program can be opened and manipulated.

With modularisation comes a design process that proceeds from coarse layout with space allocation (DG1) go conceptual design with interface definition (DG2) to a full engineering design (DG3). Where this approach is followed, integration of higher-level systems can be performed based on DG2 models. Particularly collision checks, which are invaluable in detecting and removing overlaps between components at an early stage, can be performed efficiently at DG2 level, which was extensively done at E-XFEL [2]. Providing a well-defined interface to the outside world ensures that results of collision checks remain valid as long as the DG2 space allocation does not change. This interface can even be frozen by releasing the DG2 model, while work on the DG3 engineering design continues or even before it has started. In addition, separation of DG2 and DG3 offers to protect proprietary or confidential design details by restricting access to DG3 models without compromising the ability to integrate the full system.

Placement of Components from Lattice Files

The number, size, and placement of accelerator components, such as magnets, RF cavities, and instrumentation, is designed with dedicated programs such as MAD-X [4]. It is of highest importance to faithfully implement the placement of all these components in the engineering model and support design iterations with a fast and efficient turn–around, so

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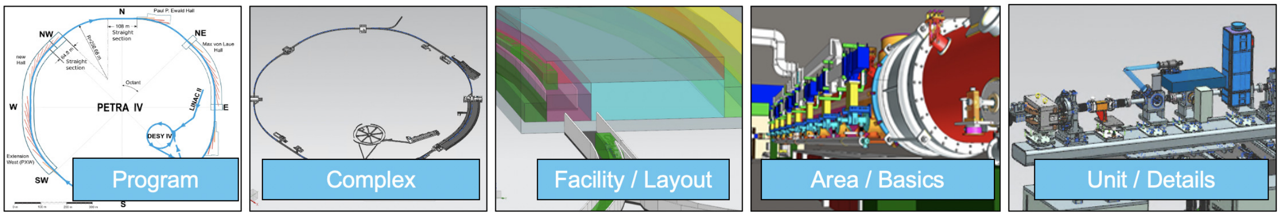

Figure 3: Hierarchical structure of CAD integration model: Top-level summarizes the entire PETRA IV program; complex separates accelerators, experiments and civil infrastructure facility defines major functional installations like (pre-) accelerators and beamlines, which are sub-divided into spatial and technical areas, which in turn are made from assembly and installation units.

that the lattice can be promptly updated and validated when additional components such as absorbers, pumps, shutters etc. are added to the design.

In our approach, special parts are employed that contain only coordinate systems at the calculated positions of components; these coordinate systems serve as anchors for constraints that position all lattice components such as magnets, RF cavities, or beam instrumentation. Because these parts contain no geometric volumes that represent tangible components, they may be included in the CAD model wherever necessary and do not lead to double–counting of components. These lattice parts are also used to position support structures, reducing the need for constraints on geometric features such as surfaces or bores that depend on the detailed design of the components and may change as the design evolves.

The coordinate systems are generated automatically with a set of Python scripts in NX. Their placement is parametrised by expressions which read their values from spreadsheets that are directly generated from the lattice program. Also, placing components into the assembly and constraining them to the coordinate systems has been automated. This offers a reliable and rapid way to generate realistic CAD geometries from lattice files already in early design stages and helps to adapt the lattice to space constraints. This is of particular importance in the PETRA-IV project, where existing tunnels and experimental halls pose stringent constraints on the geometry of the new accelerator.

CONFIGURATION MANAGEMENT

An accelerator facility undergoes constant change, ranging from adaption of specimen holders to the installation of whole new photon beamlines or the complete refurbishment of an accelerator. Representing the exact configuration of the whole facility for every given time is next to impossible, but also unnecessary, when changes remain local and do not affect the space requirements or interfaces to the surroundings. Nonetheless, at each level of the model, configuration changes need to be tracked and modeled.

We use configurations to represent an entity in a specific constellation, e.g. at a specific point in time, or a design variant. Distinct configurations are modelled by one assembly per configuration, such that the assembly represents the entity's state completely, without double counting, observing a 100 %–rule. All configurations are combined in a configuration master assembly that collects all states of the given entity that are present in the model.

RESULTS AND BENEFITS

Based on the techniques discussed above, we have set up an integration model of the PETRA-IV program, with a spatial extent of 1 km^2. The model comprises more than 70 buildings relevant for the construction project. The model includes configurations for the present (PETRA-III) state as well as design variants for PETRA-IV based on several lattice variants currently under study.

Using different levels of detail at several levels, we ensure that even the top level assembly encompassing the complete model can still be opened efficiently, with the possibility to successively load more and more details where needed. These levels of detail support a design process based on a progression from layout via concept to detailed design, decoupling these design phases to a large extent.

Alignment of the model structure with the product breakdown structure facilitates review and sign-off processes, with a product item that has a well-defined scope, purpose and requirements. Teams from separate groups or project work packages have assemblies that they own exclusively, ensuring clear responsibilities and preventing unauthorised or accidental changes by others.

Automation tools that generate geometry from accelerator lattice calculations enables fast and efficient design iterations, such that the accelerator makes optimal use of the scarce available space.

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