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3D INTEGRATION METHODOLOGIES OF THE ACCELERATORS AT CERN

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Abstract

The 3D design of large accelerators like the Large Hadron Collider (LHC) requires coordination among equipment, services, and infrastructure. As numerous systems are designed, procured and installed, 3D integration studies are important steps at any stages of a project, starting from the conceptual phase with space reservations, envelopes, and interfaces, followed by the technical design phase managing the detailed and simplified 3D models, and finishing by the installation phase with follow-up of discrepancies. While the first phases serve to validate the accelerator configuration and design, the installation phase is followed by a reverse engineering process to verify the 'as-built' configuration, representing the final actual setup of the accelerator. At CERN, the 3D Integration Office for the accelerators assumes responsibility for collecting, aggregating, centralizing, and checking the 3D models provided by CERN design offices such as equipment owners, electrical, civil engineering, metallic structure, transport, handling, cooling, and ventilation services. This office manages 3D space, avoiding mechanical interferences before and during the installation phase. This paper describes the CAD, PDM and PLM methodologies used for 3D integration of the accelerators at CERN, highlighting their critical aspects and specificities.

INTRODUCTION

The 3D design of a large complex like the CERN accelerator complex [1] requires coordination between different services and infrastructure. Various components must be designed, procured, and integrated together. Thus, the role of the Integration Office is crucial. The Integration Office is responsible to provide an overall model of the accelerators at CERN. Complete 3D integration models represent the installation and serve to guarantee that there is no physical interference between different systems, services, and components. The applied methodology plays an essential role. The use of skeletons and referential systems ensure an accurate positioning and orientation of every element in the machine which is significant for the entire functionality and achievement of global scientific goals. Furthermore, it is important to share a common referential for all concerned infrastructures and services such as civil engineering constructions, cooling, ventilation, electrical, survey services, transport equipment etc.

Considering the total number of components installed in the accelerators complex, loading a whole assembly model is time consuming and can even be impossible with the during the loading process. This paper highlights another essential part of the integration methodology – the simplification of the components 3D models.

Lifecycle of the integration model in the Product Data Management (PDM) system is critical. Different design lifecycles of the models are covered. Apart from the 3D modelling, another important side of the process for organising data in the PLM/PDM system is the naming and referencing of this information. The use of defined naming rules allows to find a desired 3D model and to work correctly on it.

Therefore, the methodology used for the accelerator complex integration at CERN is important and its key aspects and particularities are described hereafter.

METHODOLOGY

The 3D Integration Office for the accelerators is responsible for collecting, centralizing, and checking the 3D models provided by design offices such as mechanical, electrical, civil, and handling engineering, cooling, and ventilation services. The Integration Office manages 3D space and prevents any interference before the installation phase.

The accelerators integration process is continuous along the whole lifecycle of the machine until its decommissioning, but even after decommissioning, some old infrastructures could be used to house future experiments. A good example of this situation is how LEP infrastructure was the basis for the LHC.

To provide a centralised source of documentation and to ensure a high-quality management process of accelerators at CERN, the Integration Section works in close collaboration with Configuration and Coordination teams [2,3]. A collaboration through knowledge, and technology exchange on the methodology and tools with other laboratories around the world remains important.

Integration Process during the different phases of the project

The integration process starts with collecting space requirements from all concerned stakeholders for initial space reservation which permits to have a first idea of the infrastructure size. The size is being adjusted with the changing requirement along the integration process and can be altered comparing to an initial estimation. At this

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stage, communication between diverse services is crucial. The space reservation is communicated to specialists in charge of the equipment engineering design. Once the mechanical concept is developed, a simplified model is required to be used in the integration model. The moment the integration of the requested configuration of the machine is completed, an approval process starts. The approval process is important to track all the changes in the configuration made during the study phase. By using a change status lifecycle, system integration can ensure the traceability of the past, present and future configurations. As soon as an infrastructure is built and equipment is installed, the integration process is finalised by generating an 'as-built' configuration. The latter involves the 3D scanning of the installed environment of the configuration so that it can be reverse engineered. Hereafter, the role of the Integration Office during the different phases of the project is explained.

Initial – Data gathering

At the initial stage of a project, the integrator must bring together numerous resources from multiple services for ensuring the required space for the equipment, and the proper positioning of the diverse systems to avoid interferences between them. Collecting 3D resources from stakeholders from the diverse services and infrastructure at this stage represents a challenge for the Integration Office. Measurements on site and visual checking are the main principles for on-site data gathering. If the information of an environment is lacking, meaning there is not enough 3D data to start the integration study, a 3D scanning of the area may be needed so that it can be reverse engineered. The goal is to produce a 3D integration model with all the relevant information, as detailed as possible. These steps constitute the main activity for the integration section to proceed to the study phase.

Study & Iterations

During the study phase, the integration office is in charge of two main activities. The first being the gathering of the up-to-date 3D models of the services involved in the study, and the second one is the search for finding solutions and proposals to the problem at hand. One situation may be solved in different ways, so the integrator analyses different possibilities and generates different configurations and solutions in collaboration with the stakeholders. This is an iterative sequence, where proposals evolve into the right direction after multiple meetings and discussions with the services involved, and project leaders. These iterations take place until the final validation of the Integration Scene by all the stakeholders.

Manufacturing & Installation

Once the proposal has been approved, the different services proceed to the manufacturing of the components. This situation may vary with the mechanical components of the machine since they can evolve simultaneously with the Integration study. To properly complete the installation in the machine, all components arrive in consecutive phases [2] to sequentially control the correct installation of the elements added into the tunnel. At this stage the challenge of the Integration Office is the real-time follow up of the different installations taking place at the same time.

Non-conformities

Non-conformities can be discovered during different stages of installation. There are two types of non-conformities described in the earlier related publications [4]: critical and "use as is". The former generates a major impact on the field and the rest of installations cannot be carried out, furthermore new integration studies are required, and installation has to be updated. The latter generates a minor impact. Installation remains as installed but 3D models have to be updated. Early identification of the non-conformities is important to avoid critical situations and detrimental impact on the installation.

As-built - Reverse Engineering

After treatment of the non-conformities, the installation is completed. At this stage, it is important to gather again all the latest information in 3D to consolidate the Integration Scene. Thus, an "as-built" 3D model is required. This model can be obtained by reverse engineering the installed environment collecting the latest situation by 3D scanning [5]. The Integration team is responsible for scheduling the 3D scanning and requesting geolocalised scans via the CERN survey team.

Because of the long history of the organisation and the use of different CAD systems along the years, some integration data is missing, therefore there are several campaigns at CERN of reverse engineering to reconstruct missing beam lines and technical building data in 3D [6].

CAD methodologies

The following chapter provides an overview of main CAD tools used for a successful and correct integration.

Coordinate system and local referential

CERN Coordination System (CCS) and local referential are necessary for correct positioning and accurate assembly of accelerators, transfer lines and overall CERN infrastructure [7]. CCS is used to define the relative position of all the accelerators and experiments at CERN [8]. A local referential system is linked to the CCS. The local referential is defined by codes allowing an easy operation, transformation, and recognition of corresponding referential of the machine. The code has four digits, the first digit represents the concerned accelerator ring. Digit '1' corresponds to LHC, '2'- SPS and '3' – PS, and so on. The three other digits identify the associated point of the selected machine ant its orientation. In the currently CAD Tools used at CERN – CATIA v5 R27 is the one used by the Integration Office, – a special macro is used to be able to migrate the 3D models from one referential system to another.

Skeleton

Another tool often used by integrators is the Skeleton. The Skeleton is a positioning support for core machine

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components based on theoretical and experimental data, and on-site survey measurements turn into a combination of 3D reference points. Skeleton consists of simple geometrical elements such as points, lines, and planes, and represents positions and orientation of components in the machine. Points and planes represent important interfaces of related equipment in the beam line as a key aspect for the correct orientation of components throughout the 3D integration. The concept is to fix a related component to its corresponding reference element in the Skeleton during the integration.

Naming

Naming is one of the most important parts of methodology required to ensure a correct storage in the Product Data Management system (PDM). A special naming code was developed by the Integration Office and is used for the CERN accelerators complex. The code reflects (1) the project title, (2) the referential where the project is housed, (3) the service title, and (4) the year of the configuration. Respecting the naming code allows an efficient search of the desired model in the PDM system when needed. Correct naming provides an important information from the first glance and without spending time to open the model.

3D Simplification

Integration accelerators models require simplified models of equipment since the use of mechanical engineering ones makes the full assembly heavy and hard to operate. Therefore, simplification is an important process in the integration workflow. Different tools have been recently tested and the simplification procedure is being established. The simplification workflow can use manual or semi-automatic processes. Depending on the chosen approach the procedure involves different software. There are many questions to be answered concerning which method is the best to be applied by the Integration Office – Who is responsible for providing the simplified models? Is it the mechanical engineer in charge of the engineering model or is it reasonable to create a simplification team dedicated to the delivery of all simplification models? Is there a balance between manual and automatic tools? A special working group at CERN was created in 2023 to provide a professional judgment on this topic.

Drawings & Layouts

A consolidated 3D model is one of the principal outcomes from an integration. Production of detailed drawings of accelerator machines is time and resources consuming but is a mandatory result for the validation of the configuration of the machine. Consolidated layouts must be provided for the approval of the corresponding configuration. However, while tunnel and shaft cross-sections drawings have a spread and important application at CERN, they do not go through the same approval process as the layouts.

PDM and PLM

Storage and easy access to the models is one of the goals of PLM/PDM systems. Hereafter, the lifecycle stages, and organisation of the 3D models in the system is described.

SmarTeam is currently used at CERN as PLM/PDM system. All models must be organised and saved there. Integration models are divided and stored by systems: Electrical, Cooling, Ventilation, Handling, Cryogenics, Civil Engineering, etc. Furthermore, the division of the models is structured by desired infrastructures and locations, such as having services designed and stored separately if they are meant to be used for a cavern, a shaft, a tunnel, or a surface building, even if it will require the sectioning of the service models accordingly.

The current PDM/PLM system at CERN allows to have several statuses of a model during its lifecycle:

In work – shows that the model is still in progress and cannot be considered as the final one.

Ready For Check/In reviewing – a contributor launches the validation process through a drawing or layout. This documentation goes through two different controls to be approved.

Released – once both controls have been done by the corresponding person in charge, and the document has been signed, the CAD document is approved and its status changed to Released. The release demonstrates the maturity of the model and its readiness for installation.

It is essential that the naming code is implemented which indicates the year of the released configuration. Once the model is Released, the integration is consolidated, and any further updates derive to a new version of the model.

Depending on the Integration phases described previously in this document, the status will determine which model to be used.

CONCLUSION

The integration process is defined from study to installation at the CERN Accelerators Complex [9]. However, the methodology is still under development considering breakthrough technologies, and new management and communication skills among its members. The Integration Office is always exploring the use of groundbreaking tools and technologies to improve or implement better and easier procedures, like new 3D laser scans for better reverse engineering, VR glasses for “on-site” verification while the machine is not accessible, visualisation software so that the 3D data could be shared much easier with the stakeholders, etc. Moreover, to have newcomers abide to the developing and continuously improving methodology of the Integration Office, a special training is organised to ensure the respect of the best practices procedures.

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