INSTALLATION OF A PARTICLE ACCELERATOR: FROM THEORY TO PRACTICE. THE LHC EXAMPLE.

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Abstract

Installing and commissioning the thousands of equipments constituting a Particle Accelerator is a lengthy and complex process. A large number of multidisciplinary teams are involved over a long period lasting usually many years. Diverse boundary constraints must be taken into account: space, a long and narrow tunnel with few accesses, time with milestones set many years in advance, and obviously budget.

A strict organisation associated with the management tools and the right people is the only way to success. The keywords are:

Knowledge: A unique and up-to-date database of all the elements and their location,

Integration: Study the physical position of the elements, suppress the interferences and define the installation methodology,

Prevision: Schedule all the activities and update on-line,

In-situ management and supervision: Teams dedicated to follow-up, corrective actions and orphan jobs,

Safety.

After presenting the planned overall organization, the paper will present practical achievements with the example of the LHC machine installation.

INTRODUCTION

The number of large research Particle Accelerator projects is fairly limited. Their design and construction are very long processes and, in consequence, good practices are often forgotten due to the delay which occurred between two subsequent projects. In any case, this is not a series production and the loss of knowledge and creativity often lead to new ideas aiming to a better organization. However, to achieve an efficient installation, the methodology of large industrial projects is a must, even when one claims for specificity of particle accelerators, research activities, and high technologies. Clearly a particle accelerator is unique and cannot straightforwardly be compared to large projects like factory premises, chemical plants, airplanes or rockets built on the basis of a quite well-established know-how. But, one should avoid completely reinventing everything and should aim at using widely known techniques.

Installing and commissioning the thousands of equipments constituting a Particle Accelerator is anyway a lengthy and complex process. Moreover, a large number of multidisciplinary teams are involved over a long period lasting usually many years. Established know-how must be used to guide and structure the creativity to reach the optimum use of the allocated resources.

After the survey of the diverse boundary constraints to be taken into account in the installation of a Particle Accelerator, the planned overall organization will be presented followed by the present practical achievements with the example of the LHC machine installation.

BOUNDARY CONSTRAINTS

An accelerator project has specific constraints in space, in time, and in money.

The space constraint is primarily a shape constraint defined by the long vacuum pipe(s) where particles will travel. The machine built around the vacuum pipe(s) is located in a narrow tunnel with few accesses and where one always tries to fit in as much equipment as possible.

The time constraint is inherent to the duration of an accelerator project: years and even decades with milestones set many years in advance. Installation is the last main step of the project and this activity is always put under the maximum pressure to finish faster than what is possible. An early and thorough preparation of this last phase is therefore advisable.

Obviously budget and resources are major constraints. The economical side has to be treated globally and not by only one team forgetting the consequences for the others. It is also often in conflict with the time constraint. The team coordinating the installation has to be created specifically for this task.

INSTALLATION: THE THEORY

In theory, the organisation of the installation could be summarized by some obvious but often forgotten keywords: knowledge, integration, prevision, in-situ management, and safety. What is behind these keywords is detailed below.

Knowledge

An accelerator is an assembly of thousands of parts to be installed at the right position. Managing this information, if not structured, becomes quickly a nightmare. A unique and up-to-date database of all the elements, their location and their interrelations is one cornerstone of the installation. But it is also a deliverable to be associated with the accelerator itself, allowing the operation crew to know what they have to handle.

It should also be added that all the protagonists have to speak the same language by using the same nomenclature for all the elements of the project.

Integration

The thousands of parts to be assembled in an accelerator are often closely intricate. Each team in charge of a family of components has the tendency to occupy more space than initially planned, leading to conflicts with the others. The integration process positions physically every element, detects and suppresses the interferences and finally defines the installation methodology.

Prevision

The installation of thousands of components means many activities largely interleaved, not only because of the location of these activities but also due to logistics interferences or safety constraints. A strong coordination is a must and this is done through the scheduling.

The planning process for accelerator project should be a multi-level scheduling based on: a Master Schedule taking into account the strategic goals and the major milestones of the project; a General Co-ordination Schedule aiming to implement and control the flow of installation that is most effective in term of resources and time; and a Detailed Installation Planning describing the installation scenario. The organisation of the installation is based on the splitting of the complete project in a series of work units, each with a clear and simply stated objective. The resulting Work Breakdown Structure (WBS) is also the basis for the progress and costs control.

The installation activities have to adapt through continuous feedback from the production sites and from the field. To this end, the detailed installation planning has to be permanently reviewed.

In-situ management and supervision

The diversity of the installation calls for a close supervision in the field. In relation with the detailed planning, work packages regrouping series of work units are defined for each installation phase and in a given zone. They give precise information on resources, logistics, environment, utilities, safety... and are the basis for the in-situ supervision of the protagonists.

Close supervision during all the installation work is an absolute necessity for an installation of good quality. However, mistakes cannot be entirely avoided and experience shows that the major types of non-conformities are poor workmanship, deviance from installation drawings as well as integration errors.

Safety

Ensuring the safety is always a difficult task: one often claims that safety measures slow down the work but they also help identifying incompatibilities between co-activities. Strict safety regulations are thus mandatory and their application needs supervision and control.

INSTALLATION: THE PRACTICE - THE LHC EXAMPLE

Applying the theory to the installation of the LHC was a major challenge, probably due to the large time gap between the LEP and the LHC projects that padded out the experience previously acquired. The present organization finally put in place, unfortunately after the start-up of the installation, is based on a strengthened coordination unit regrouping all the forces active in the fields of integration, configuration management, logistics, planning, site management, installation, and handling and transport. The ability to regroup personnel already experienced and knowledgeable in these fields has determined the success of this unit and its rapid running in despite its late creation. The role of the Installation Coordination Group is to ensure the smooth installation of the machine and its services, and to provide specific help when required.

Knowledge

The LHC Reference Database [1] is designed to store all data pertaining to the collider, its components, their layout, their manufacturing (under the responsibility of the equipment groups), and their installation as a large unified tool. The management of this data, the change control, and the release is handled using the now well-proven tools in Engineering Data Management System (EDMS). The LHC Reference Database is designed as an open system to be used for the LHC commissioning, controls and operation.

In order to speak the same simple language, an abbreviation system has been put in place both for the naming of equipment and its localisation. This is also the case for buildings: find a place is quite often a burden in such a large site as the LHC.

Integration

Integrating the large and complex LHC machine into the existing LEP tunnel is a major challenge. The cryostats of the LHC lattice are much larger than the LEP magnets and the external cryogenic line fills even more the tunnel. Space problems lead to small clearances and all conflicts between installed equipment or with transport must be solved beforehand in order to avoid unacceptable delays and extra costs during the installation.

Specific tools, based on the CAD software have been developed in the two dimensional domain for the longitudinal positioning of elements and in three-dimensional domain for the complete Digital Mock-up (DMU) of the LHC [2]. The 3-D studies are based on the software EUCLID from the company Matra-Datavision.

The integration process relies on the DMU and the LHC reference database to position the elements in the tunnel or the service areas. Very thorough representations of what will be installed in each are produced; the 110 non-standard underground areas are obtained by integrating the 3500 3-D models. In order to satisfy practical requirements, two types of coherent and consistent documents have been prepared on the basis of the 3-D scenes: 70 standard tunnel cross-sections and 514 2-D dimensioned drawings (two per LHC cell) [3].

Prevision

The size and the complexity of the LHC project call for a strong coordination of all installation activities. The strategy of a multi-level planning has been enforced: a Master Schedule, a General Co-ordination Schedule and a Detailed Installation Planning [4].

More than 2000 tasks have been identified and about 80’000 tons of materials have to be transported and installed down into the tunnel.

The time allocated to the LHC underground installation is about 5 years, excluding civil engineering. The sequencing of the various installations, often on the basis of different scenarios, has been studied in great detail in order to minimize interferences and consequently the amount of time lost. The installation of the machine elements in a single sector is expected to last three years.

The installation is subdivided in twelve steps occurring at different times in each sector regrouped in three main phases: General services, Cryogenic line and Machine.

The installation activities have to adapt through continuous feedback from the production sites and from the field. To this end, the detailed installation planning is actually reviewed, every 4 weeks, at the Short Term Planning Meetings in order to confirm the activities to be carried over the 3 coming months.

The installation has to take into account many constraints, in term of planning such as production rates, in term of logistics such as transport in a long and narrow tunnel, and in term of installation follow up.

Equipment can be lowered down into the tunnel through eleven shafts equipped with overhead cranes but only one of them is wide enough to lower down cryodipoles. The cryomagnets are then transported over many kilometres through the narrow tunnel to their final position.

The different contracts constraining the production and installation have been initially based on a "just in time" scheme. However the complexity of the construction and the time needed to fully test the cryomagnets required to uncouple as much as possible each contract from the others' evolutions and imposed large temporary storage between different assembly and test activities [5].

In-situ management and supervision

The co-ordination in the field requires a very good knowledge, updated on a day-to-day basis, of the situation in each worksite, of the possibility of co-activities and of the transport conditions in the underground areas. The LHC ring is subdivided into zones, each supervised by a Zone Coordinator who ensures that the installation activities are carried out as specified in the Work Package description. The aim is to stay aware of the advancement of every work site, and rapidly react to problems of all nature.

Zone Coordinators report to the Installation Follow-up Meeting that takes place every 4 weeks: this is a forum to share experiences and to check the homogeneity of the installation procedures on the different work sites.

After each installation phase, measures are taken to verify that the equipment was installed as foreseen. The survey is done either visually or, when needed, with sophisticated techniques like laser scanning; any anomaly is checked against the next layer of equipment.

An intervention team dedicated to rapid curing of in-the-field problems such as orphan works, ill-defined boundaries between work units or safety related interventions has been set up.

Safety during installation

The implementation of the safety rules is both a matter of organisation and a matter of application to the field. The organisation includes all the rules and regulations defined by CERN but also all those from the Host States (France and Switzerland). The responsibility in matter of safety is a hierarchical one. In the field, the application of safety is done via the safety coordinators (appointed by the project leader according to French law), the territorial safety officers, and the site managers. But the major effort is to convince people on the field that safety is a must.

CONCLUSION

Installing the LHC machine is an enterprise with a level of complexity that mirrors the high technology of the LHC project. Like for any other accelerator project, it is essential to start as soon as possible with the organisation of the installation. A dedicated team should coordinate the activities of all the equipment teams, with a view to solve all interferences and to insure a smooth installation which is the key to success. Finally, one should never forget that the quality of the equipment should be associated with the quality of the installation in order to succeed operating a highly sophisticated instrument.

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