A VIRTUAL CAD MODEL OF THE LHC

S. Chemli, C. Hauviller, R. Messerli, Y. Muttoni, H. Prin*, E. Van Uytvinck
CERN, Geneva, Switzerland
*Kraftanlagen Nukleartechnik GmbH, Heidelberg, Germany

Abstract

Integrating the large and complex LHC machine into the existing LEP tunnel is a major challenge. Space was not really a problem to fit the LEP machine into its tunnel, but LHC cryostats are much larger than the LEP quadrupoles and the external cryogenic line fills even more the tunnel. Space problems lead to small clearances. Possible conflicts, or at least the most penalising ones, between installed equipment or with transport, must be solved beforehand in order to avoid unacceptable delays and extra costs during the installation. Experience gained with LEP has already shown the help that Computer-Aided Engineering tools could provide for the integration.

A virtual model of the LHC is presently prepared. The actual LEP tunnel, known with a quite good accuracy (centimetre level), has been modelled and all the elements of the machine constructed as 3D objects with the CAD system are positioned accurately on the basis of data generated from the theoretical definition. These layouts are used to generate the reference sections and to check the clearances.

Examples of this powerful approach applied to engineering for accelerators are given.

1 INTRODUCTION

Building the LHC and all its high-technology elements is a challenge, but integrating the LHC machine in the existing LEP tunnel will also be a challenge. The difficulties are due to dimensional problems of two types:

- the machine is very long (27 km) and the precise longitudinal positioning of the numerous elements is a must;
- the transverse dimensions of the machine and its services must fit into the tunnel.

The thousands of magnetic elements are housed in large cryostats, which look like 15 m long tubes, 1 m in diameter, assembled together. The external cryogenic line, a 0.6 m diameter tube with a lot of protuberances, also occupies a fair amount of space. What is left in the tunnel section is occupied by a lot of services: water and helium tubes, cable trays, pumps, racks, transport system, and a possible future electron machine to be installed above the LHC.

Even if it was a challenge to integrate the LEP machine in its tunnel, the quadrupoles being the widest elements with a transverse section of about 0.7 m^2, the LHC cryostats and its cryogenic line occupy four times more transverse space.

If space inside the tunnel is a problem, clearances become a major concern, especially since the tunnel accuracy is not at the same level as the mechanical parts: it is a very large civil engineering work with centimetre and even decimetre offsets.

Experience gained with LEP [1] has already shown the help that Computer-Aided Engineering (CAE) tools could provide for the integration. LHC integration is more complex and use of CAE tools is then heavily required.

This paper presents the tools, which have been developed in the two dimensional domain, mainly for the longitudinal positioning of elements, and in three-dimensional domain, the Digital Mock-Up (DMU) of the LHC. Results achieved so far are outlined together with the work underway in the framework of Computer Aided Design (CAD) and Engineering Data Management System (EDMS).

2 2D SCHEMATIC LAYOUT

The basic approach in the two dimensional domain are the 2D schematic layouts. These layouts show the longitudinal arrangement of the magnets and other equipment in the LHC tunnel. Three types of schematic layouts have been developed: general, conceptual and mechanical, depending on the level of detail.

The general schematic layout shows only the magnetic lengths of the main magnets (dipoles and quadrupoles) and their operating temperatures. The various corrector families and the beam instrumentation are added in the conceptual layout that reflects the machine optics as generated from the accelerator design package MAD[1]. These two types of layout present the LHC from an optics point of view, and allow rapid finding of all optic elements in any given area of the machine.

The operating parameters of the magnets (magnetic lengths and position of their centres) and the mechanical parameters of cryogenic assemblies are shown to scale in the mechanical layout. The mechanical references for the cryo-assemblies are the virtual interconnection planes (VIP, drawn in 2D by a line perpendicular to the beam axis) and the fixed support post of the cold mass. The description of cryogenic assemblies is given in an

[1] Computer package developed at CERN

AutoCAD™ library and is stored in an Oracle™ database (Fig. 1).

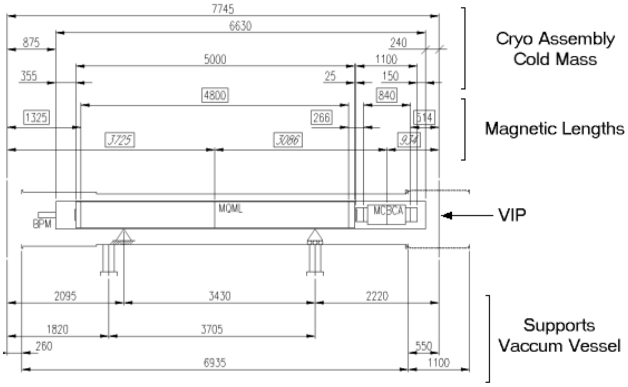

Figure 1: An element and its parameters

The “s” co-ordinate (cumulative magnetic length) of its VIP gives the position of each assembly in the machine from the machine origin (Interaction Point 1). The sequence of VIPs thus defined is stored in the database, and a cryogenic assembly from the library associated to every entry. This set of data links the description of the cryogenic assemblies to the magnet parameters, which makes possible an automatic generation of the MAD input.

A navigation interface (Fig. 2) is available on the Web for viewing the layout. For easier viewing, the machine is split into three main areas: arcs, dispersion suppressors and long straight sections, and in half-cells. To ensure the validity of the information given in the navigator, the drawings archived in the CERN Drawing Directory[1] (CDD) are transformed in a format suitable for the Web.

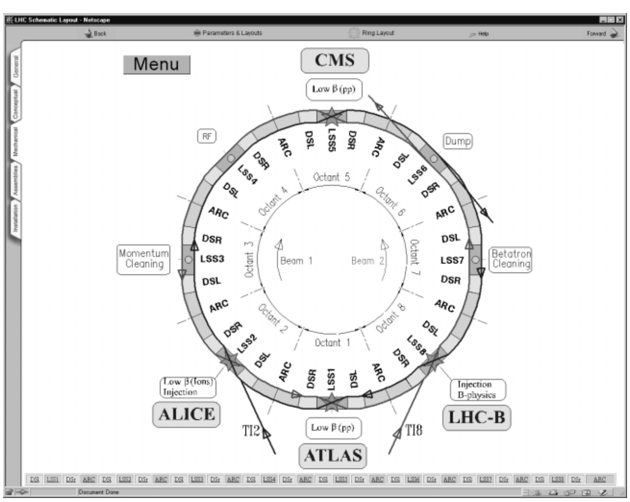

Figure 2: 2D Web Navigation Interface

3 CONTEXTUAL 3D DESIGN AND RELATED PROBLEMS

The contextual design of a collider such as the LHC consists in the integration, in a given environment, of 3D mock-ups. Those virtual objects (surface buildings, underground tunnels, caves, LHC accelerator equipments and large detectors) are modelled as close to the reality as possible using the EUCLID™ package. Such a Digital Mock-Up is essential in order to minimise the cost impact of the modifications in the construction, installation and exploitation phases of the LHC project.

As most of the 3D elements exist in the design offices databases, building a DMU of the LHC machine using the 2D schematic layout could be considered as a Lego game. This is not the case. Several factors are required to achieve a good DMU.

The clearance between the elements is a lot tighter for LHC than it was for LEP. Therefore, major simplifications introduced in LEP 3D toolbox are unacceptable for LHC.

Quite complex aspects have also to be considered:

- the tunnel does not respect the accuracy initially expected;
- the machine is curved and tilted;
- the vertical direction changes along the tunnel because of the accelerator plane slope and because of earth curvature.

As a matter of fact, integration will put together the models coming from all involved corporations. Designers have their own methodology of creating the equipments or the elements that will be assembled in the machine. This methodology is adapted to the element they are considering during the design process. They do not always keep the same referential from one designed part to another, for a better comfort (the LHC is tilted but all the elements are drawn with a vertical Z co-ordinate) and a higher accuracy (integration of small elements far from the CAD origin may generate strange algorithmic and topological results). To achieve the integration, it is then necessary to compute the position of the element in a unique co-ordinate system covering the whole CERN area.

It is clear that our virtual prototyping project has to cope with the following complex fields:

- LHC accelerator systems database of equipment positions;
- very large modelling (many equipments and buildings);
- geodetic calculations;
- high precision calculation of components positions in more than hundred co-ordinates systems;
- measurements of the as built LEP tunnels.

4 MODELS COLLECTION AND INTEGRATION

The LHC DMU is made of two parts. The periodic part consisting of the "standard" tunnel sections and the repetitive cells of the machine, automatically generated. The non-periodic one, typically the surface buildings and the various experimental and ring caves, manually integrated.

4.1 Automatic integration

The LHC DMU will dynamically be generated as much as possible from a set of models provided by the design offices (3D standards under change control), the Survey databases, the EDMS and the 2D layout.

The main tunnel has been measured and a dedicated application has been developed to build automatically any area of the tunnel from the measurements.

Other tunnels can be a few kilometres long and quite difficult to model because of their changing orientation combined with the variation of the vertical direction. Specific developments are needed.

The machine elements are generated and located longitudinally with the 2D schematic layouts and positioned in the 3D space using the Survey co-ordinates database. Periodic or semi-periodic systems, which can be located in a digital manner, will be generated also automatically.

4.2 Manual integration

All activity sectors are concerned by this DMU: civil engineering, handling, transport, piping, cable trays, etc. Each field of work acts first sequentially to find the best trajectory of a pipe line or a cable tray and then iteratively in order to solve the interferences detected between cryogenic equipments, electrical boxes, etc. This process proceeds from the largest equipment to the smallest ones.

The LHC domain is covered by a unique co-ordinate system. This domain is split in geographical zones with their local referential in such a way that co-ordinates inside a zone does not exceed one kilometre.

The models are stored in this local referential.

Nevertheless, each area has also a set of secondary co-ordinate systems aimed to ease the modelling phase. Each designer has to clearly identify the system that he uses.

This information gathered at the time the models are released, allows the CAD system to store data in the local referential of the zone. This process is kept under the control of an approval tool (CDD).

4.3 Some examples

Figure 3 shows an example of the LHC DMU with all the elements integrated inside the actual standard tunnel. This DMU is used by the engineers, but also with the help of ROBCAD/DYNAMO™ package, to detect the interferences between elements or to study installation and transport sequences.

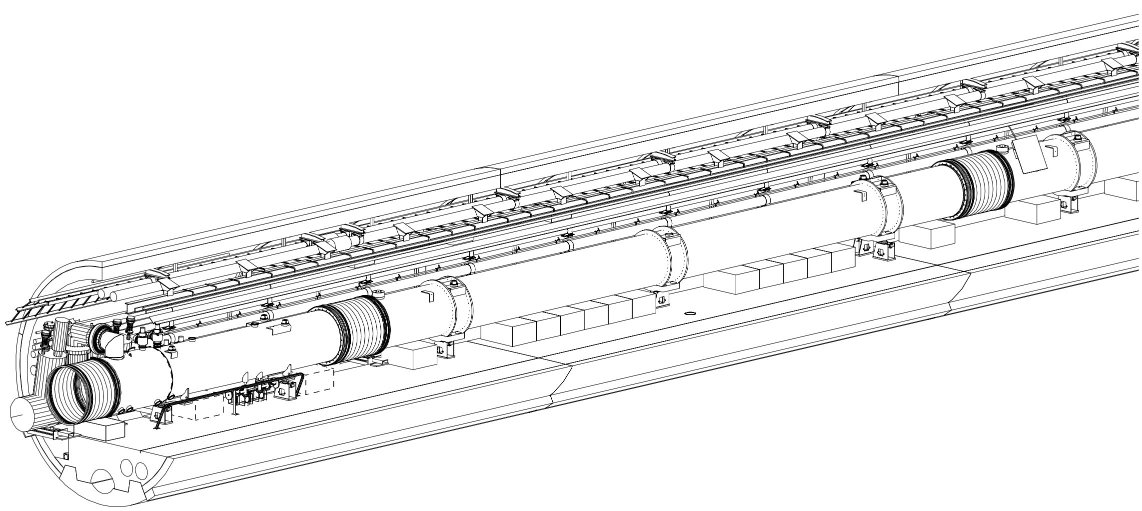

Figure 3: The LHC machine integrated into its tunnel - Partial view of a standard zone

5 CONCLUSION

CAE tools are extensively used to understand and ease the integration work of the LHC machine and the related services. The 2D layouts are accessed on a daily basis by most of the collaborators. The 3D Digital Mock-Up is under development but already used to solve tricky engineering problems.

ACKNOWLEDGMENTS

The authors would like to thank J-P. Quesnel and his Survey team for providing measurements and alignment databases and F. Soriano for the artistic contributions.

REFERENCES

[1] G. Bachy, C. Hauviller, R. Messerli, M. Mottier, "Computer-Aided Engineering in High Energy Physics", 1988 European Particle Accelerator Conference, Rome, June 1988.