EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-LEP-IM/89-31

ENGINEERING AND CONSTRUCTION EXPERIENCE AT LEP (CERN)

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Paper presented at the 1989 International Industrial Symposium on
the Super Collider (IISSC)

New Orleans February, 8-10 1989

Geneva, Switzerland

Avril 1989

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1. LEP IN THE EUROPEAN FRAMEWORK

CERN was born in 1953 in the centre of Europe - emerging weakened and impoverished from 6 years of war - as a cooperation between twelve Members states¹ with a goal of "nuclear research of a pure scientific and fundamental character". Since then, CERN has grown in terms of both facilities and personnel and now constitutes a community of some six thousand persons : physicists and engineers from Member and non-member states, designers, draughtsmen, electronics and computer experts etc.

The latest large facility presently under construction is LEP² which reflects the choice made in the 70's by the European physics community for investigating deeper the structure of matter and the forces which govern the Universe.

Figure 1. LEP underground work

2. LEP IN A FEW NUMBERS

LEP consists of a ring (see Figure 1), located in an underground tunnel, 26.6 km long, 3.8 m in diameter and excavated between 50 and 150 m below the surface. To minimize shaft depth, the tunnel is situated on an inclined plane (1.4%).

Three quarters of the ring lies in France and one quarter in Switzerland. Access shafts, 18 in total, with diameters between 5 and 24 m at eight points of the ring, link the LEP tunnel to the surface buildings. Four underground experimental areas are excavated and house the large detectors.

The ring is not a perfect circle but consists of eight curved sections, each 2800 m long, equipped with 1700 dipole pairs and linked by 500 m long straight sections. The particle beams are focused by 816 quadrupole magnets and 504 sextupole magnets. The bending magnets are of the low field type (0.1 T) to keep synchrotron-radiation within acceptable limits. In two of the eight long straight sections the particles are accelerated by 128 copper cavities, equipped with energy-saving storage spherical cavities, giving a maximum energy per beam of above 50 GEV. For the next step, called LEP 200, the copper cavities will be progressively supplemented with superconducting cavities to increase the machine energy above the W mass.

As far as the vacuum system is concerned, due to the synchrotron-radiation, the aluminium alloy extruded vacuum chamber is watercooled and covered by lead radiation shielding. For the first time the main pumping system is based on a non-evaporable getter (NEG) strip installed in the pumping channel part of the extrusion.

3. LEP IN A FEW DATES

The LEP project was approved in December 1981. Civil Engineering work started in September 1983. Installation at the surface started in June 1985 and underground installation in October 1985 at a very slow rate following building delivery by the civil engineering. 50% of the underground installation was performed during 1988. The aim is to "close" the machine mid-July 1989 and to proceed with the beam tests.

4. THE DESIGN STAGE

4.1 Design thoughts and principles

The LEP project involved about 4000 man years of indoor design, coordination, labwork and construction follow-up, about one third of which is design proper.

Before setting up the necessary task force for the design of such a large project, it is necessary to decide what has to be studied in-house and what should be subcontracted. Answers to this question are not always economically optimal as several pre-existing boundary conditions need to be taken into account, in particular presence of in-house specialists. The choice is more obvious for the design of the machine elements proper as the know-how in these fields (magnets, RF, vacuum ..) has for years been at a superior level in our type of research laboratory. In this case usage at CERN is to design, have a prototype built and tested inside and then send out a call for tenders for the production series. The economical choice in this case is more what to subcontract: subcomponents, components or complete systems. Experience shows that when a lot of different technologies are involved, a unique firm is seldom capable of doing the complete job but will subcontract several subassemblies. Money can usually be saved when subcontracting the various components and by having a special contract with another firm for assembly.

At LEP a typical case is illustrated by the 1740 dipole vacuum chambers. These aluminium alloy chambers were extruded in Germany then shipped to Austria for welding the various fittings and flanges, then shipped back to Germany for lead cladding and finally to CERN for testing before assembly in the dipoles. For this unique component 5 different firms were involved (see Figure 2).

Other reasons could lead to the same splitting principle: an example is transport as is the case for the dipole magnets of very special design (iron sheets imbedded into concrete). One dipole unit consists of a pair of 6 m cores. The sole "mechanical links" between the two cores are the vacuum chamber and the excitation bars, both having insufficient inertia for building a rigid structure out of the two cores. The assembly of the dipole subcomponents (cores, excitation bars and vacuum chamber) was thus performed at CERN, by a contractor in a hall directly located on top of an access pit to minimize the transport problems and optimize the installation sequence.

Figure 2. The round Europe trip of the dipole vacuum chambers

It has been found that at the design stage it is very important to consider not only the component itself, but to integrate it in its environment at the final stage, and to consider the complete installation sequence. From the beginning of the project an effort was made to design all components from their functionality to installation.

A different approach can be taken in the more classical fields, the so-called **conventional facilities**: civil engineering, cooling & ventilation and electrical distribution. The main in-house role here is to define the functions, the basic requirements, the performances, the environment and the boundary conditions.

The environment and boundary conditions were found to be of prime importance.

Two other aspects during the design phase which have important economical consequences are standardization and prefabrication.

Standardization minimizes the design costs as well as the construction costs. An attempt was made, for example to keep the type of buildings as few as possible.

Figure 3. A 6m metallic module being lowered into a LEP shaft

Prefabrication is a goal in itself. Great effort was made to minimize the work on-site, especially in the underground buildings where the hour cost is higher and the risks greater. For instance the equipment in the shafts was prefabricated into modules (either 6m metallic or 3m concrete - see Figure 3). This design enabled the complete metallic framework of a 100 m shaft to be erected in 3 days!

On the machine side, the same effort was made to avoid crowding in the tunnels.

For instance subassemblies consisting of a quadrupole, sextupole, correcting dipole, beam pick-up and a vacuum chamber were assembled and aligned on a common beam at the surface, on top of a pit directly linked to the machine tunnel.

These are just a few aspects at the design stage where we tried on one hand to avoid studying each element as an isolated item, and on the other hand to prefabricate the maximum possible beforehand.

4.2 Design tools (Reference 3)

A great deal of LEP design has been achieved using CAD. The main objective in the introduction of CAD from the beginning was the complete memorization of the whole machine. The modelisation of each component is not only used to produce standard production drawings, but also in the subsequent assemblies (see Figure. 4). Following LEP experience it is thought essential to keep in-house all the so-called general layout studies which summarize all the various systems on unique documents. In conjunction with CAD, a unique, controllable source of information is vital. In the LEP project the ORACLE Relational Database Management System was the unique source of information. This information, primarily used during the design and construction phase, will be of great help during the operation of the machine.

Figure 4. CAD representation of a short straight section assembly

5. THE INSTALLATION PHASE

5.1 LEP logistics (Reference 4)

The size of the LEP project, coupled with the tight construction schedule, called for organized planning, logistics and control. Considering the main tunnel alone, its 27 km's houses more than 50000 recorded different types of equipment of various dimensions and weight. In 1988, the most critical installation year for LEP, many activities were executed in parallel, spread over the 100 km² site, and performed by about 70 different contractors and subcontractors employing up to 700 people. Planning, follow-up and data feedback were essential to produce an accurate picture of the daily changes and to give a tool for immediate reaction. Conventional means were obviously out of the question for treating such an amount of information with the optimum response time. Again, all the data were managed with the Relational Database Management System, ORACLE. This powerful tool was used efficiently throughout the installation period, with the help of the various tables and application programs developed and simulated before the start of installation: POL (Planning using ORACLE for LEP), DICLEP (DICTIONARIES for LEP), LOI (Logistics Of Installation), Transport lists, follow-up of transport, follow-up of installation activities i.e work identified by its duration and resources, follow-up of magnetic components, feedback and statistics.

A general overview of the logistics behind LEP installation appears in Figure 5 .

Figure 5. General overview of the logistics behind LEP installation

Figure.6 shows the number of activities followed per month since the beginning of the project.

Figure 6. LEP activity follow-up.

5.2 Transport problems in underground tunnels

For the previous accelerators built at Cern (PS, ISR or even SPS) conventional ground transport means were adequate. However during the SPS installation it appeared that the speed of goods movement in the tunnel was considerably slowed down by the floor occupation of the various fitting teams. With LEP, the increase of size with the related increase of distance between pits (Reference 2) together with the very tight schedule called for an efficient means of underground transportation. The solution adopted comprises a monorail suspended from the concrete vault of the tunnel. This system has three main advantages :

- it travels off the ground which is very cluttered during the installation period

- it is self guided (a point of prime importance for safety)
 - it offers an unlimited range of operation since it is powered by electric bus-bars.
- The efficiency of the system was demonstrated when up to 12 Dipoles + 5 short straight section units were installed per day at distances of 18 km from the access shaft.
- Another advantage of this transportation system is the standardization of the containers for handling material such as cable trays, pipes, bus-bars, cable drums and vacuum equipment. These standard containers, made available to the installation firms, implied much easier material preparation, weekly material volume evaluation and transport organization (monorail and crane loading).
- In our opinion, the choice of underground transportation will be of utmost importance for the SSC installation.

6. CONCLUSION

The experience gained during the LEP project's engineering and construction / installation phase is multiple, but to relate everything in such a short paper is impossible. Nevertheless, the main features (all related to the size of the machine) appeared to us to be : a good analysis of contract splitting, minimization of costly underground work, maximization of prefabrication and standardization, use of a unique computerized source of information associated with modern CAD design tools, preparation of a management tool before the start of installation and a suitable choice of underground transport system. We certainly did not succeed in all aspects. However we tried!

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¹ Belgium, Denmark, France, Federal Republic of Germany, Greece, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom. Austria became a Member in 1959, and Spain in 1983

² Large Electron-Positron (Collider)