EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — SL DIVISION

CERN SL-98-044 DI

The Effects of LHC Civil Engineering on the SPS and LEP Machines

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Abstract

The LHC will utilise much of the existing LEP infrastructure but will require many new surface buildings and several smaller underground structures, two new transfer tunnels from the SPS to the LHC and two huge cavern complexes to house the ATLAS and CMS experiments. Excavation for the underground structures will start while LEP and SPS are running, causig the existing tunnels in close proximity to move. The predicted movements are of sufficient amplitude to prevent machine oepration if no precautions are taken.

Presented at EPAC-98, 6th European Particle Accelerator Conference
Stockholm
22-26 June 1998

Geneva, Switzerland
June, 1998

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1 INTRODUCTION

The LHC will utilise much of the existing LEP infrastructure but will require many new surface buildings and several smaller underground structures, two new transfer tunnels from the SPS to the LHC and two huge cavern complexes to house the ATLAS and CMS experiments. Excavation for the underground structures will start while LEP and SPS are running, causing the existing tunnels in close proximity to move. The predicted movements are of sufficient amplitude to prevent machine operation if no precautions are taken.

2 ATLAS, CMS AND TRANSFER LINES

At LEP Point 1 two new shafts (18m and 12.6m in diameter) will provide access to the new experimental cavern (UX15) for ATLAS. The cavern (30m wide, 35m high and 53m long) will be built with its axis parallel to the LEP/LHC beam tunnel. The service cavern USA15 (20m diameter, 62m long) will be constructed perpendicular to UX15.

The excavation of the access shafts, USA15 and the vault of UX15 will be carried out while LEP operates. The remainder of the works, i.e. the bulk of the experimental cavern, connection galleries and tunnel enlargements, will be completed after the final LEP shutdown in October 2000.

The underground works for the CMS experiment at Point 5 consist of two new shafts, two new caverns, a number of smaller connection and service galleries and enlargements of the existing LEP tunnel. The new experimental cavern UX55 (26.5m wide and 24.0m high) and the service cavern US55 (18.0m wide and 11.5m high) are parallel and in close proximity to each other. Prior to any excavation work on the caverns, a 7m thick concrete pillar will be constructed between the two caverns to take the load of the rock mass above. Once this pillar is completed, the excavation of the caverns will commence. The excavation of the service cavern and the crown of the experimental cavern will be completed before October 2000.

The two transfer tunnels from the SPS, TI2 to Point 2 of the LHC and TI8 to Point 8, are both about 2.5 km long. They will be excavated outwards from mid point access shafts towards the SPS and LEP up to a limit determined by radiation safety. In the region close to the SPS, the extension of the tunnels beyond this limit will be done during SPS shutdown periods. At the LEP/LHC end the breakthrough will be after LEP has stopped running.

2.1 Finite element analysis

Numerical analyses of underground structures require that meaningful geo-technical ground models are developed and that behaviour laws and failure criteria, matching the prevailing ground conditions, are defined. In addition, the rock support system and other design criteria must be defined and formulated to be incorporated into the numerical model.

Different two-dimensional and three-dimensional finite element and boundary element programs have been employed. The overall stress development in the rock mass and in the primary and secondary linings during and after excavation has been studied, taking into consideration a wide range of loads and the three-dimensional interactions.

The output of the analyses has been used to predict movements of the existing structures. Displacement values for the affected tunnels have been determined as a function of the construction sequence and the distance from the excavation area. Details of the predicted movements of the SPS and the LEP are given in [1] and [2].

2.2 Predicted Tunnel Movements

The SPS will be affected mainly by the excavations of the ATLAS caverns at Point 1. The displacement of the SPS/TI12 tunnels will occur in two steps and could total $\sim$10mm downwards. Since the excavation of the transfer tunnels TI2 and TI8 will stop at the radiation limit and the breakthrough will be done during shutdown periods, their effects on operation are considered to be of lesser importance.

The LEP tunnel will be affected at both Points 1 and 5 by the excavation of the ATLAS and CMS caverns, and at Points 2 and 8 where the transfer lines will be connected to the LEP/LHC tunnel. The cavern excavations will affect the tunnel over the length of the new caverns plus approximately half their length on either side. Outside of these areas no movements should occur. The amplitude of the displacements at the longitudinal limits of the new caverns should be $<$40% of the maximum values. The maximum displacements will occur at the centre of the excavations (for ATLAS 30mm up and for CMS 20mm up and 10mm radially).

In the region of the radiation limit near LEP, the excavation of the TI2 tunnel may cause the LEP tunnel to move by up to 2mm. The same effect may occur in the case of TI8 approaching LEP near Point 8. In addition, where TI8 crosses over LEP, $\sim$700m from Point 8, up to 4mm vertical displacement of the LEP tunnel may occur. Finally, there may be some vibration (up to $\pm$1mm) of the LEP and SPS tunnels when the boring machines are very close to the existing facilities.

3 BEAM DYNAMICS

3.1 LEP

Displacement of the quadrupoles in LEP introduces orbit distortions and vertical dispersion. Displacing the first quadrupole doublets (QL1) on either side of the interaction point (IP) by 1mm introduces a vertical dispersion which is an order of magnitude too large (note that the predicted maximum displacement of QL1 in Point 1 is $\sim$10mm).

19% of the predicted displacements in Point 1 can be compensated at top energy with the standard optics using the single corrector adjacent to each of the QL1's. If one uses a special detuned optics in the odd numbered points, where there are no experiments, up to 40% of the displacement can be compensated. A side effect of the detuned optics is a small increase in the parasitic beam-beam tune shift.

The vibration from the excavation of TI2 and TI8 makes an oscillation of the position of some insertion quadrupoles in points 2 and 8 of LEP. A 1mm displacement of one of these quadrupoles introduces an orbit distortion $\sim 1\sigma$ in the transverse planes. Other consequences are tune and chromaticity shifts and an increase in the vertical emittance. Effects of similar amplitude are expected from the displacements associated with the cross-over of the TI8 tunnel. The orbit distortions and tune shifts are at, or beyond, the acceptable limits for background and luminosity performance. Unfortunately, it is not possible to reduce the effects by modifying the optics because of the low-β experimental insertions in these areas.

3.2 SPS

A displacement of quadrupoles in the SPS causes a degradation of the orbit which can not be corrected at high energy (450 GeV). A vertical displacement by more than 2mm of one quadrupole at the predicted location will cause unacceptable orbit distortions.

It has been shown for the SPS-LEP electron transfer line (TI12) that using all available vertical correctors plus two large strings of vertical bending magnets which are powered in series, it is possible to correct the trajectory errors induced by vertical displacements of 5mm. The predicted displacements (two steps of 5mm) of the tunnel can therefore be accommodated during continued operation and the transfer line can be realigned during the shutdown following the USA15 excavation in 1999.

4 HARDWARE MODIFICATIONS

4.1 Vacuum Equipment

In the SPS and TI12, the vacuum chambers are supported in the magnets and the limiting factor is the acceptable distortion across a bellows. The limiting amplitude of 4mm is not expected to occur, since this would mean a differential movement of 4mm over a short length of the machine or transfer line.

In LEP it is also the vacuum bellows that is the critical element and in this case the displacement limit is 2mm. The vacuum chamber supports have been modified to accommodate realignment over a large range ($\leq$40mm).

4.2 Beam Instrumentation

The beam instrumentation affected by the tunnel movements in Point 1 will be the two polarimeter mirror boxes situated at $\pm$12m around the IP and the mirror box at the IP which feeds the streak camera in the optical laboratory by means of two beryllium mirrors. In Point 5 the collimator installed at the IP will be affected. The mirror box is connected via two telescopes to light pipes which pass through 15m of rock to the optical laboratory. The bellows at the bottom ends of the telescopes will have to compensate for the full extent of the floor movement since it has been predicted that the optical laboratory, which is installed in the US15 area, will not move during the excavations. Appropriate modifications to the equipment will be made during the 1998-99 shutdown.

The optical paths for the laser beam (polarimeter) and the synchrotron light (streak camera) can be retuned to accommodate movements of up to 5mm before physical realignment is necessary.

The mirror boxes and collimator are supported on normal supports, like the vacuum chambers, and these will be modified to accommodate the required realignment.

4.3 Magnets

In LEP, the magnets concerned by the movements are the first 2 doublets on both sides of IP1 and IP5 and the first bunch train sextupole. Each doublet is positioned on a girder supported on three mechanical jacks. The sextupoles are supported by a single foot which can be adjusted over a range of about 10mm using 3 screws.

The mechanical jacks allow a total movement of about 40mm but they were originally installed with a 25mm retraction so insufficient adjustment was possible. The jacks are now positioned in holes in the floor which are 30mm deep and wide enough to allow access to the adjuster. No modification was required for the sextupoles since the adjustment available was adequate to allow realignment over the predicted range.

In the SPS, the range of vertical movement with the jacks is sufficient to cope with the predicted tunnel floor movements. In the transverse direction, a small modification is required to the parts which limit the movement.

In the transfer line from SPS to LEP the magnet jacks can accommodate the predicted tunnel floor movements.

4.4 Separators

It will be necessary to lower the two separators (ZL1L and ZL1R) installed either side of IP1 and IP5 as the tunnel floor rises. The range of adjustment on the separators is more than adequate but in order to allow high voltage conditioning of the separators at the largest gap (160mm, with the electrodes retracted) it was necessary to make two small circular excavations per separator in the tunnel floor to accommodate the tubes carrying N_2 gas to the electrodes. The realignment will be done manually by operators equipped with special tools.

With the separators installed and under vacuum only orthogonal movements limited to the vertical, transverse and longitudinal plane are possible. Corrections of tilt must be avoided entirely, as they could lead to failure of the bellows installed at the extremities of the separator. To avoid any possible error with the double separator supports, the drive axes of the two screw jacks are linked rigidly by a transmission bar, connected after realignment and reconnection of the adjacent vacuum chambers. This will simplify the correction - a single action moves both screw jacks - and avoids the risk of twisting the bellows by mistake.

5 SURVEY SYSTEM

The intense synchrotron radiation environment in LEP is particularly hostile and therefore a radiation resistant monitoring system, based on a stretched wire and capacitative detectors, was chosen. In Points 1 and 5, wires have been mounted in the plane of the beam suspended from posts about 130m apart. The suspension points are in stable areas and the tension of 150N is derived from weights and a frictionless suspension system which guarantees a constant position of the wire at all temperatures. The wire therefore provides a fixed reference across the affected area for the detection of both horizontal (X) and vertical (Y) movement.

The wire is made from carbon fibre and kevlar and is installed in an aluminium channel which protects it from the air currents in the tunnel. The position of the wire is monitored at eleven double detectors per Point. Each detector is mounted on a small translation table which allows fine adjustment of the detector position in X and Y and also compensation for movement of the tunnel floor.

The position of the wire is measured to an accuracy of $\pm$0.1mm over a range of $\pm$5mm. The signals from the detector are treated in electronics located away from the radiation area and are connected via a Siemens processor to the CERN control system where the data is logged.

In the SPS the overall displacements are expected to be smaller than those in LEP. The areas affected are exposed to intense radiation since they are close to the extraction areas. No permanent monitoring system has been installed in these areas because they are in the curved sections of the machine, there are many elements concerned and it is cheaper to monitor the movements using classical methods. In many cases the machine elements themselves can be checked for displacements and for each area the measurements can be made in a relatively short time ($\sim$4 hours).

During the 1997/98 shutdown reference measurements were made in the affected areas in the SPS and TI12 and the vertical positions of all SPS quadrupoles were also checked. In the region of the TI8 works the radial position of all elements was checked and reference measurements recorded. In the affected area of the LEP transfer line, direct measurements on the machine elements are not possible because of the nature of the installation. A system of fixed fiducial points has been established in this area so that rapid checks can be made with respect to these references.

6 CONCLUSIONS

The nature of the geological problem (looking for very small movements in enormous inhomogeneous structures) makes the uncertainty on the predicted movements very large but but even relatively small displacements could cause performance degradation and ultimately vacuum failures. The risk that the machine performance is degraded is unacceptable and therefore the predicted movements have been treated as an upper limit and the necessary precautions have been determined.

The detuned optics will be used in LEP to minimise the beam dynamics effects and all the necessary modifications to allow realignment over the full extent of the displacements of the machines will be made. The position monitoring system which has been installed in LEP will allow continuous monitoring of the situation and interventions for realignment can be scheduled at a convenient time. In the SPS, regular checks of the affected areas will be made throughout the coming years. For the most part, the latter can be scheduled during planned interruptions to the physics programme.

The civil works have already started and will continue throughout the remainder of LEP operation, affecting different areas at different times. According to the current schedule for the civil engineering it has been estimated that the access for realignment in the accelerators will take up to about 40 hours in the SPS and around 100 hours in LEP.

7 REFERENCES

[1] B. Goddard et al., “Preliminary Report on the Consequences of LHC Civil Engineering for the SPS and LEP”, CERN-SL-96-73 DI and CERN-ST 96-02, December 1996.

[2] B. Goddard et al., “Final Report on the Consequences of LHC Civil Engineering for the SPS and LEP”, CERN-SL-97-66 DI and CERN-ST/97-01, December 1997.