EQUIPMENT FOR TUNNEL INSTALLATION OF MAIN AND INSERTION LHC-CRYOMAGNETS

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Abstract

The installation of about 1700 superconducting dipoles and quadrupoles in the Large Hadron Collider (LHC) is now well underway. The transport and installation of the LHC cryo-magnets in the LEP tunnels originally designed for smaller, lighter LEP magnets have required development of completely new handling solutions. The severe space constraints combined with the long, heavy loads have meant that solutions had to be very sophisticated. The paper describes the procedure of the installation of the main cryo-magnets in the arc as well as the more specific insertion cryo-magnets. The logistics for the handling and transport are monitored with tri-axial acceleration monitoring devices that are installed on each cryo-magnet to ensure their mechanical and geometric integrity. These dynamic results are commented. The paper includes conclusions and some lessons learned.

INTRODUCTION

The decision to re-use the LEP tunnel to house the LHC machine meant that the transport and installation of the much larger and heavier magnets needed for the LHC would be difficult to achieve because of severe space restrictions due to the tunnel designed for the much smaller and lighter LEP magnets. Additional difficulties for transport and installation arise since the superconducting cryo-magnets are relatively fragile as the cold mass is supported on insulating feet inside the outer vacuum vessel; this means that the choice of possible support and lifting points is restricted and that transport and handling equipment must not transmit shocks to the magnets. The interconnections at each end of the magnets overlap with those of adjacent magnets; this rules out a vertical lowering of the magnet into position and forces the final transfer of magnets onto their supports to follow a pre-defined trajectory which had to be developed to suit different interconnect layouts.

The main dipoles and main quadrupoles (SSS) in the arc and dispersion suppressors constitute about 94 % of the cryo-magnets to be installed. The remaining 6 % are the low-β triplets, the separation/ recombination dipoles and the matching quadrupoles Q4 to Q7 in the Long Straight Sections (LSS). The different lengths and support points of those magnets compared with the magnets in the arc imposed different installation equipment and procedures. Finally, the 16 connection cryostats in the dispersion suppressors are installed with the same equipment as the LSS cryo-magnets.

ARCS AND DISPERSION SUPPRESSORS

The main dipoles and quadrupoles for the arcs and the dispersion suppressors are lowered via the only access shaft large enough for the dipoles, onto the tunnel vehicles (BNN/MAFI, Germany) that transport the magnets to the installation point. The magnets are transported on a trailer or Magnet Transport Unit (MTU) that is connected at both ends to an Operator Transport Unit OTU. There are six such tunnel vehicles; four MTU for main cryo-dipoles, two of which are modified to be able to also transport LSS magnets (explained later). Two MTU are built to transport the main quadrupole cryo-magnets (SSS) and have three different support positions for the SSS arc, Q8, Q10, Q11 and finally Q9 of the dispersion suppressors that are longer than the SSS in the arc. The automatic, optically guided, hydraulic vehicles transport the magnets to the point of installation through the transfer tunnel, the 27 km long LHC ring and the bypass galleries around the experimental caverns. The speed of the loaded vehicles (total weight up to 54 t) is 3 km/h with most of the time not more than 10 cm clearance at the sides.

Figure 1: Limited space for the magnet transport in the LHC tunnel

At the installation point, the magnet is lifted by hydraulic cylinders in the trailer to allow positioning of two unloading equipment (UE) under the reinforced support cradles of the magnet. The UE lift the magnet off the trailer and the trailer is withdrawn from under the magnet.

A Transfer Equipment Set TES (ZTS VVU Kosice, Slovakia) composed of two transfer tables is then positioned under the magnet. The modular transfer tables which use stepper motors and harmonic drives handle the magnets with six degrees of freedom and high precision (0.1 mm). The TES lifts the cryo-magnet from the UE and automatically aligns the magnet with the magnet support jacks. After removal of the UE, the magnet is transferred following a predefined horizontal trajectory to pass the adjacent magnet interconnects and is then lowered onto the support jacks.

Figure 2: SSS with jumper transferred by the transfer tables between two cryo-dipoles

More information about the constraints in the tunnel infrastructure, cryo-magnets and installation interfaces and the features and maintenance of the tunnel vehicles and Transfer Equipment Set can be found in references [1], [2], [3].

LSS CRYO-MAGNETS

Because of the different functions and positions of the low-β triplets, the separation/ recombination dipoles and the matching quadrupoles Q4 to Q7 in the Long Straight Sections LSS, there are significant differences between those magnets which affect their transport and installation.

The design of two of the trailers for dipoles was modified and fixed support point sets were added to deal with six different support point distances (longitudinal and lateral). Six additional sets of support points were added to deal with an inversed magnet orientation. Lack of space and excessive cost imposed the use of non-hydraulic, fixed support points. A consequence of this was that the arc magnet UE could not be used.

A modular unloading equipment MUE was hence developed to lift the LSS magnets off the trailer. A MUE is a load carrying cradle with two lifting legs based on electrical jacks. Two MUE are assembled around the magnet during the installation. Two aluminium MUE cradles are strapped onto the magnet. Two MUE lifting legs are rolled in to position on spring loaded, retractable wheels by the operators and they are tightly fitted on the MUE cradle. Once the MUE legs are firmly put on the ground, two MUE can lift a 24 t magnet. An inclinometer synchronises the two legs of an MUE. After the trailer is removed, the procedure becomes similar to the procedure for the magnets in the arc. Although the assembly of the lifting equipment around the magnet seems more cumbersome, well trained operators can carry out an LSS installation in about two hours, practically the same time as the cryo-magnets in the arc.

Figure 3: MUE assembled around a magnet lifted off the trailer

With the MUE cradle directly in contact with the vacuum vessel, the magnet is not lifted as high as when a UE is used to allow the trailer to be withdrawn. This is an important advantage for some of the LSS magnets with a higher jumper (cryogenic connection between the magnets and the cryogenic supply ring QRL) where little space is left under the overhead rail.

Additional equipment is used for some of the low-β quadrupoles Q1 and Q2 that are installed in very confined dead-end tunnels through tunnel radiation shielding walls and even inside the forward experimental radiation shielding.

Figure 4: Q1 is moved with the motorised bogies into the ATLAS experimental radiation shielding

Since there is no space in these areas for vehicle or transfer tables to install directly on the magnet support jacks, the magnet is transferred onto two motorised bogies [4] that roll on two rails that are embedded in the floor.

The magnet is then transferred longitudinally along the rails towards the support jacks. The bogies are equipped with hydraulic jacks for vertical movements. Precise horizontal and some angular adjustments can be made to position the magnet precisely on the spherical bearings of the support jacks. After installation, the bogies are removed by passing them under a MUE support that holds the magnet on one end.

MECHANICAL DYNAMIC LOAD

The cold mass of a cryo- magnet is a heavy and flexible structure assembled on thin-walled fragile support posts in a cryostat to reduce the heat in-leak to the helium bath. To ensure the required mechanical and geometric integrity of the cryo-magnets, allowed acceleration loads were defined [5], [6]. Detailed tests were made to commission equipment like overhead cranes, spreader beams, tunnel vehicles, transfer equipment sets and modular unloading equipment. Each cryo-magnet that is transported and installed in the tunnel is equipped with tri-axial acceleration monitoring devices to verify that the defined acceleration limits are respected. The monitoring device also records with time and date the events that exceed warning or alarm acceleration levels. The out-of-specification accelerations that have occurred during only a few of the installations of almost half the LHC cryo-magnets could hence be analysed. The frequency and shape of the recorded acceleration indicates if a magnet's natural mode is excited and if there is a risk for the cryo-magnet.

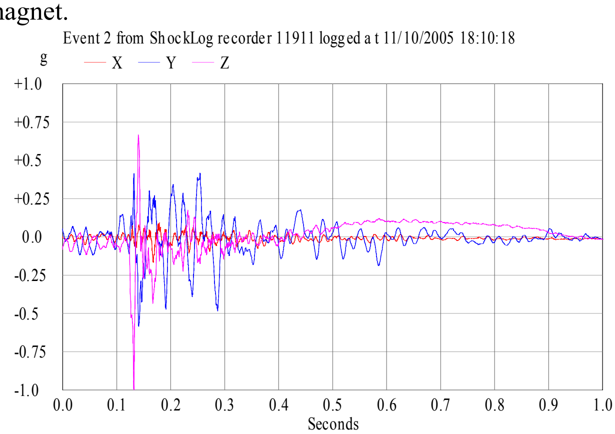

Figure 5: Recording showing an acceleration level exceeded in longitudinal direction

A typical type of event is shown in figure 5 where the alarm was triggered (1 g) in the longitudinal direction (Z, pink) and where a vertical mode was excited (Y, blue). The longitudinal acceleration is a highly damped event at high frequency followed by low frequency acceleration below the limits and is hence not dangerous for the magnet. The vertical acceleration is also smaller than the limits. This type of event appeared on one of the tunnel vehicles and was explained by wear in a bearing in the connection between the trailer and the operator transport unit. The problem disappeared when the bearing was replaced. Other events were traced back to the incorrect operation of the brakes of an overhead crane. The monitoring hence detects problems in the equipment before they become critical and is useful for preventive maintenance.

For some events where there was a doubt, the magnets were inspected in the tunnel and the position of the magnet ends was measured with respect to the vacuum vessel. However, no damage was found and the magnet geometry had not changed. To ensure traceability, the results of the acceleration monitoring are stored in the quality assurance system used for the cryo-magnets.

CONCLUSION

The installation equipment for all the different LHC cryo-magnets has been acquired and is operational. The installation of the LSS magnets required different equipment to the installation of the magnets in the arcs. The various methods and sophisticated equipment because of the severe space and weight constraints have been validated during the installation of about 50 % of the LHC cryo-magnets [7]. The mechanical dynamic loading of the magnets during tunnel transport and installation is followed with acceleration monitoring devices. The results from the monitoring show that the equipment is well adapted in order to preserve the mechanical and geometric cryo-magnet integrity.

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