MECHANICAL DYNAMIC LOAD OF THE LHC ARC CRYO-MAGNETS DURING THE INSTALLATION

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Abstract

About 1700 LHC main superconducting dipoles and quadrupoles will have to be transported and handled between the assembly, the magnet measurements and the storage that precedes the final installation in the LHC tunnel. To ensure the required mechanic and geometric integrity of the cryo-magnets, transport specifications and allowed acceleration loads were defined after detailed dynamic analysis. A large number of cryo-magnets are now arriving at CERN on a regular basis. The logistics for the handling and transport are monitored with tri-axial acceleration monitoring devices that are installed on each cryo-magnet. Measurements are made to commission new equipment like overhead cranes, tunnel transport and handling devices to guarantee that the defined acceleration limits are respected. The results from the acceleration monitoring that are stored in the same quality assurance system as the cryo-magnets allowed to give a first idea of the level of the mechanical dynamic load on each magnet throughout the logistics chain and were used to detect details such as out-of-specification accelerations that needed improvement.

INTRODUCTION

About 1700 LHC main superconducting dipoles and quadrupoles will have to be transported and handled between the assembly, magnet measurements and storage [1] that precede final installation in the LHC tunnel. The dipole cold mass is 15 m long and has a mass of about 28 t. This heavy and flexible structure is assembled in a cryostat to reduce environmental heat in-leak to the magnets' super fluid helium bath. The cold mass is installed on three thin-walled support posts of glass fibre reinforced epoxy in its cryostat to form a cryo-dipole with a mass of 34 t. The Short Straight Sections (SSS) include the main quadrupoles together with their correctors and the beam position monitors. They are about 7 m long and have a mass of 8 t.

Maintaining the geometry of the cold mass inside its cryostat with a precision in the range of 0.1 mm, as well as the integrity of all its components is compulsory for a good performance of the future LHC. The cryo-magnets' dimensions and weight, the geometric constraints, as well as the fragile components, call for special attention during the handling and transport phases of the LHC installation.

Detailed engineering specifications were written to define the transport and handling procedures to be followed. To quantify the dynamic loads acceptable for the cryo-magnets, elaborate theoretical and experimental dynamic analyses were carried out [2]. Maximum permissible acceleration loads were determined. An acceleration monitoring device was selected and implemented. This monitoring system shows if the cryo-magnets were exposed to excessive accelerations (during possible incidents) and also gives information about the weak points of the transport logistics chain.

DYNAMIC BEHAVIOUR ANALYSIS

Finite element models of the cryo-dipole and the Short Straight Section were first built with estimated parameters. Modal analyses of the cryo-magnets under given boundary conditions were then performed.

In order to validate the theoretical model, several experimental modal analyses were carried out for the cryo-magnet under the same boundary conditions as considered for the calculations. The validated finite element model was used to perform several modal analyses of the cryo-magnet under different boundary conditions representing building, road and tunnel handling and transport equipment. The critical frequencies and their maximum admissible amplitudes were determined. The acceleration levels and excited frequencies were measured at some points of the cryo-magnets as well as the support posts' deformations during transport with different types of vehicles. Calculations and measurements were then combined to specify the maximum allowable accelerations within a certain frequency range for each different type of handling and transport. Table 1 gives the permissible accelerations to be measured at the cold mass extremity for cryo-dipole and SSS road transport.

Table 1: Maximum admissible accelerations (m/s^2) for cryo-dipole and Short Straight Section road transport.

	Lateral	Vertical	Longitudinal
Cryo-dipole	5	7	4
SSS	3	3	3

The document in [1] gives more details about the performed analyses.

CRYO-MAGNET TRANSPORT AND HANDLING SEQUENCES

The cryo-dipoles and the SSS pass through several sequences of handling and transport during their life between the cold mass arrival at CERN, their assembly and testing, until their installation on magnet support jacks in the LHC tunnel.

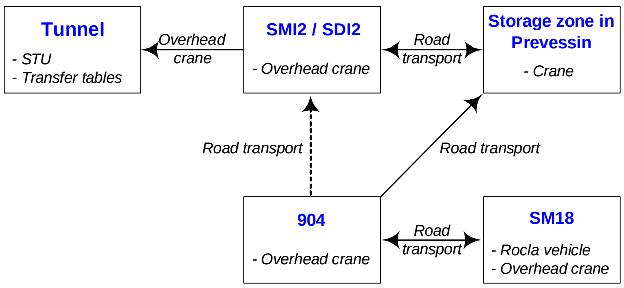

Figure 1: Short Straight Section handling and transport sequences

Figure 1 shows the significant number of transport and handling phases for a single SSS with different types of equipment, ranging from standard overhead cranes and road trailers to very special customised equipment [3].

ACCELERATION LOAD MONITORING FOR SERIAL TRANSPORT

About 1700 LHC main superconducting dipoles and quadrupoles will thus have to be transported and handled several times, with different vehicles and handling devices. All these operations are critical. Because of limited space and time, a detailed geometry and integrity check of the cryo-magnets is not possible in the tunnel prior to installation. Localizing and removing a damaged cryo-magnet installed in the tunnel, would be a difficult and time-consuming operation.

A detailed qualification of all the vehicles and handling devices that will be used during the LHC installation is hence needed. Each transported and handled cryo-magnet is monitored to ensure that the acceleration limits have not been exceeded. A tri-axial acceleration-monitoring device (Shocklog) is placed at the cold mass extremity of each transported cryo-magnet. The device records the event and the time it occurred.

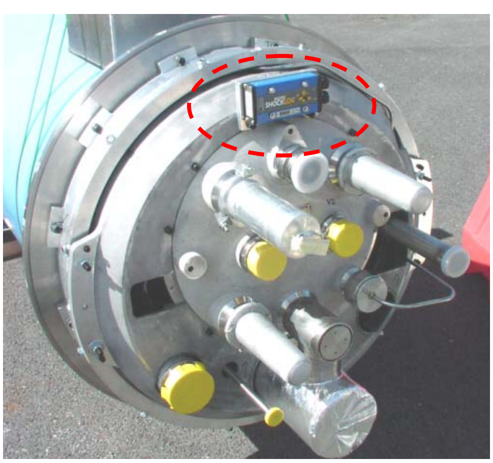

Figure 2: Acceleration monitoring device for cryo-magnet serial transport.

The results from the acceleration monitoring are stored in the same quality assurance system as used for the cryo-magnets, the Manufacturing and Test Folders Travellers [4]. This system includes an automatic notification procedure once a cryo-magnet is ready to be transported and a Shocklog™ has to be installed. It also includes automatic notification when a nonconformity is generated if the acceleration limits are exceeded.

RESULTS

Measured values during serial transport

A large number of cryo-magnets are now handled and transported at CERN on a regular basis. The results from the acceleration monitoring give a first idea of the level of the mechanical dynamic load on each magnet throughout the logistics chain.

Figure 3 and Figure 4 give an example of accelerations experienced in the vertical direction by some cryo-dipoles during road transport from the magnet assembly building to the storage zone and also from the storage zone to the LHC access shaft building.

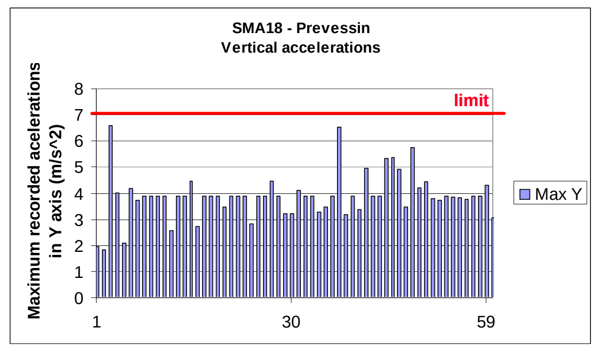

Figure 3: Vertical accelerations of the cryo-dipoles between assembly building and storage zone

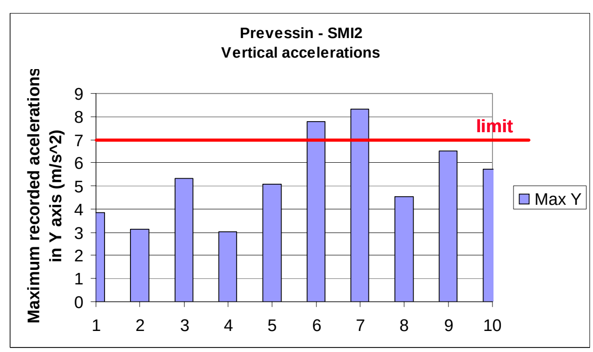

Figure 4: Vertical accelerations of the cryo-dipoles between storage zone and LHC access shaft

Analysis of events

This monitoring system shows if the cryo-magnets are exposed to excessive accelerations during possible incidents.

An interesting feature of this system is that the events are recorded. They can then be analysed to determine the frequency and shape of the out-of-specification acceleration recorded. It can be determined if a cryo-magnet's natural mode was excited and if there is a real risk that the cryo-magnet is damaged. Low frequencies, as for the event presented in Figure 5, are dangerous since the cryo-magnet components experience high deformations. The high acceleration measured for an event shown in Fig. 6 is a highly damped vibration at a high frequency, involving only low deformations. It is hence not dangerous for the cryo-magnet.

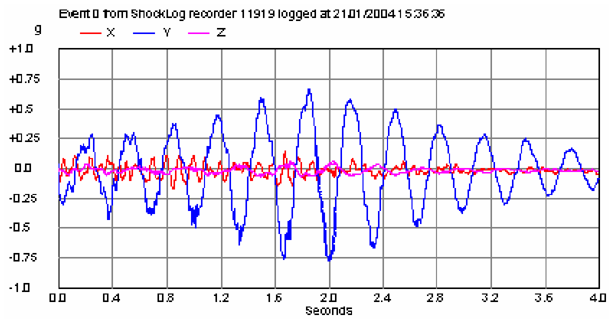

Figure 5: Accelerations (g) higher than the limit in vertical directions for a cryo-dipole during road transport; the event is critical with a real risk of damage

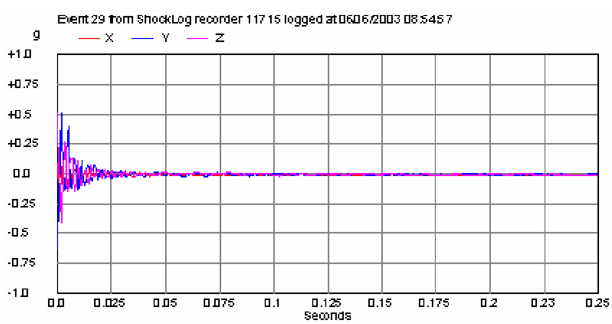

Figure 6: Accelerations (g) higher than the limit in vertical and longitudinal directions for a cryo-dipole during road transport; the event is not critical

The acceleration monitoring device also records the time when the events occur. This interesting feature allows identification of where in the logistics chain it happened and of the operator so that incidents can be investigated (and weak points rectified).

Improvement of the logistics chain

The results from the acceleration monitoring are also used to detect details such as out-of-specification accelerations that need improvement. The cryo-dipoles regularly experienced accelerations higher than the limits during the handling inside the LHC access shaft building. The same was detected for the SSS handling inside the SSS assembly building. The source of these accelerations was identified to be the cryo-magnet positioning on support jacks. These manipulations were not precise and required many iterations and attention from the operators. Improvements such as adjustment of the overhead crane movements and additional tooling were needed.

Other problems such as holes in the road asphalt were also traced back with the acceleration monitoring. On the other hand, accelerations recorded during most types of transport, such as cryo-dipole road transport from assembly building to the storage zone, are below the admissible limits.

CONCLUSIONS

To ensure the required mechanical and geometric integrity of the LHC cryo-magnets, transport specifications and permissible acceleration loads within a certain frequency range were defined, after detailed dynamic analysis, for each different type of handling and transport. Measurements are made to qualify new equipment like overhead cranes, tunnel transport and handling devices to guarantee that the defined acceleration limits are respected.

The logistics for the handling and transport are monitored with tri-axial acceleration monitoring devices that are installed on each cryo-magnet. The results from the acceleration monitoring are stored in the same quality assurance system as the cryo-magnets.

This monitoring system indicates when the cryo-magnets were exposed to excessive accelerations during possible incidents. It also allows detection of the weak points of the transport logistics chain that need improvement.

In general, the tri-axial acceleration monitoring devices showed that the qualified handling and transport equipment respect the specified acceleration limits.

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