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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.

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1 INTRODUCTION

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. The arc dipoles installed into their cryostats, hereafter called cryo-dipoles, are 15 m long and have a mass of about 33 t. The so-called Short Straight Sections (SSS) include main quadrupoles together with their correctors and the beam position monitors. The Arc SSS are about 7 m long and have a mass of about 8 t.

All those cryo-magnets contain fragile components, such as the thin-walled support posts made of glass fiber reinforced epoxy, to reduce environmental heat in-leak to the magnets super fluid helium bath. The correct position of the magnet inside its cryostat (precision in the range of 0.1 mm) as well as the integrity of all its components are compulsory factors for a good functioning of the future LHC. The cryo-magnets dimensions and weight, the geometric constraints, as well as the fragile components, make them very difficult to handle and transport.

The cryo-dipoles and the SSS pass through several sequences of handling and transport during their life between the assembly locations to their installation on jacks.

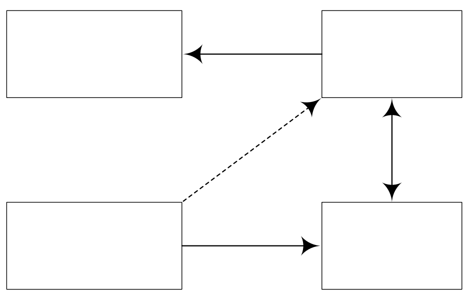


Figure 1: Cryo-dipole handling and transport sequences.

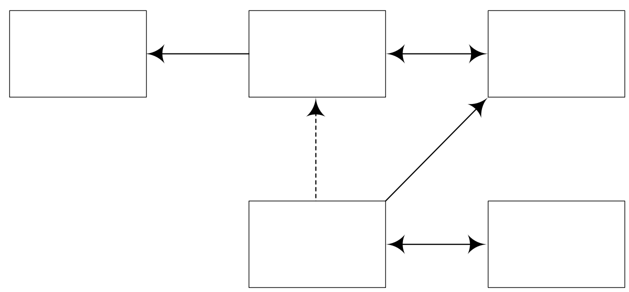


Figure 2: Short Straight Section handling and transport sequences.

Understanding the cryo-magnets dynamic behavior is needed to avoid potential malfunctions provoked by vibrations during transport and handling.

A detailed dynamic analysis was performed to determine the behavior of the cryo-magnets under all the handling and transport conditions and to choose the related optimum parameters. Finite element modal calculations as well as experimental modal analyses were carried out. The maximum accelerations admissible during transport with several types of vehicle were computed. The accelerations experienced by both types of cryo-magnet were measured during real transport with different vehicles. The dynamic deformation of the support posts in the cryo-dipole was also measured. The methodologies of these analyses and their results are reported in this note as well as the resulting specification for the transport during the LHC installation.

2 GENERAL ANALYSIS METHODOLOGY

Finite elements models of the cryo-dipole and the Short Straight Section were first built with estimated parameters. Modal analysis of the cryo-magnet 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 surface, road and tunnel handling and transport equipments. The critical frequencies as well as their maximum admissible amplitudes were determined.

Cryo-magnet dynamic behavior during transport with different types of vehicles was then measured. The acceleration levels at some points of the cryo-magnets as well as support posts deformations were measured during several transports.

Calculations and measurements were then combined to specify the maximum allowable accelerations within a certain frequency range during different types of handling and transport.

3 CALCULATIONS

The cryo-magnets were modeled with the finite element code Ansys™. Components significant for the vibration behavior, i.e. cold mass, support posts, vacuum vessel and transport restraints, were detailed to a sufficient level.

The finite element model was used to determine the natural frequencies and corresponding shape of the cryo-magnet installed under different boundary conditions corresponding to the several handling and transport sequences. Figure 3 shows a result example:

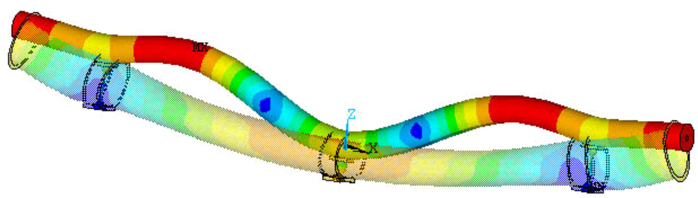


Figure 3: Example of cryo-dipole finite element modal analysis result.

The critical frequencies as well as their maximum admissible amplitudes were then determined for the different surface, road and tunnel handling and transport equipments.

4 TESTS

Modal analyses of cryo-magnets on concrete blocks (boundary conditions during storage) were carried out and compared to the calculation result. The natural modes were measured up to 50 Hz for three directions (lateral, vertical and longitudinal).

The natural frequencies and the mode shapes of the cryo-magnets were determined with free (impact) and forced vibration. The harmonic and random forced excitation was applied by an electrodynamic shaker (see Figure 5) via an impedance head. Tri-axial PCB-ICP™ accelerometers measured the accelerations of the cryo-magnet components during the modal analysis.

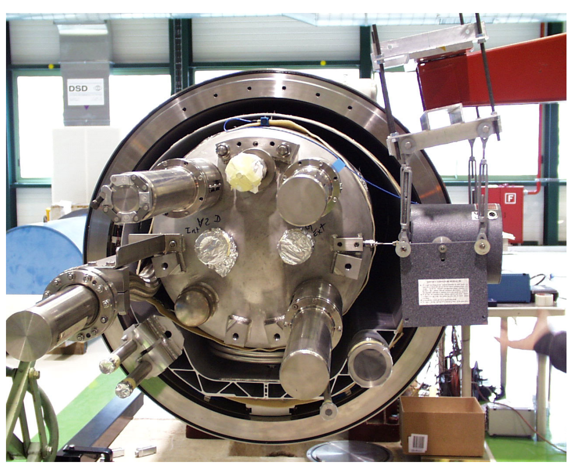
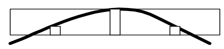
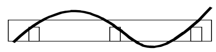
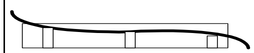
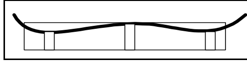


Figure 4: Short Straight Section experimental modal analysis.

The natural frequencies and the modal shapes obtained permitted to validate the finite element models. Table 1 gives an example of the comparison between tests and calculations, for the first four vertical modal shapes and natural frequencies of the cryo-dipoles installed on concrete blocks.

Table 1: Example of cryo-dipole on concrete blocks modal analysis results - comparison tests/calculations.

Cryo-dipole vertical modal shape	Frequency	
	Tests	Calculations
	8 Hz	10 Hz
	16 Hz	17 Hz
	28 Hz	32 Hz
	36 Hz	34.6 Hz

Tri-axial PCB-ICP™ accelerometers and LVDT gauges were then used during cryo-magnet transport with different types of vehicles to measure the accelerations and tri-axial dynamic deformations of the support posts.

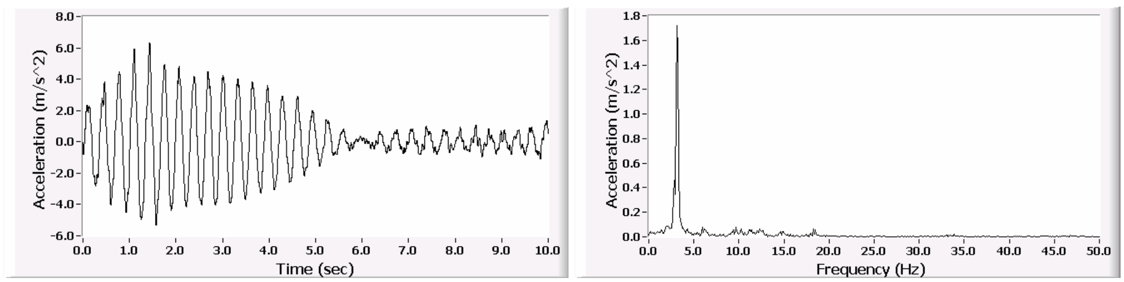


Figure 5: Example of acceleration measurement during cryo-dipole transport with road trailer.

The most important vibration amplitudes and the corresponding frequency values were recorded during cryo-magnet transports with surface, road and tunnel vehicles. It was also checked that the measured accelerations and support post deformations were coherent.

5 SPECIFIED ACCELERATIONS LIMITS

Calculations and measurements were combined to specify the maximum allowable accelerations within a certain frequency range during different types of handling and transport.

The theoretical model allowed the calculation of the cryo-magnet modal scheme under several transport conditions. For each identified modal shape, the maximum admissible acceleration at a specific point of the cryo-magnet was calculated from its components specified maximum deformations. This specific point is the one where accelerometers are installed during the transport.

Tests allowed to validate the theoretical model and to identify which modes are excited during a transport. Knowing the modes that are excited during a given type of transport, and knowing the corresponding acceleration limits at a given point of the cryo-magnet, global acceleration limits were defined for several types of transport.

Table 2: Maximum admissible accelerations to be measured at the cold mass extremity for cryo-dipole and Short Straight Section road transport.

		Lateral	Vertical	Longitudinal
Accelerations (m/s^2)	Cryo-dipole	5	7	4
	SSS	2.9	2.9	2.9

6 DYNAMIC LOADS DURING SERIAL TRANSPORT

6.1 Accelerations monitoring device

More than 1200 cryo-dipoles and more than 350 SSS will have to be transported and handled several times, and with different vehicles and handling devices. All these operations are critical. 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 an important 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 also monitored to ensure that the acceleration limits have not been exceeded. A tri-axial acceleration-monitoring device is placed at the cold mass extremity of each transported cryo-magnet.

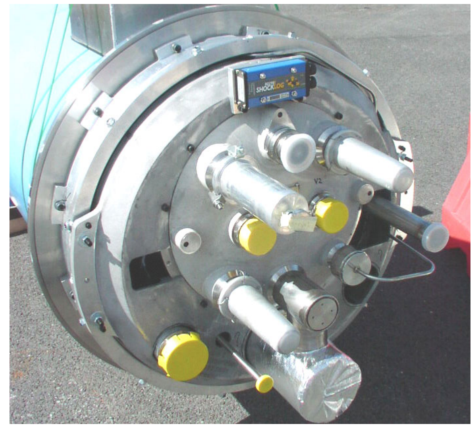


Figure 6: Acceleration monitor device for cryo-magnets serial transport.

6.2 Measured accelerations during serial transport

A large number of cryo-magnets are now arriving at CERN on a regular basis. The results from the acceleration monitoring that are stored in the same quality assurance system (MTF) as the cryo-magnets allowed giving a first idea of the level of the mechanical dynamic load on each magnet throughout the logistics chain.

Figure 7 and Figure 8 give an example of accelerations experienced by some cryo-dipoles during road transports from the SMA18 building to the storage zone in Prevessin, respectively from the storage zone to the SMI2 building.

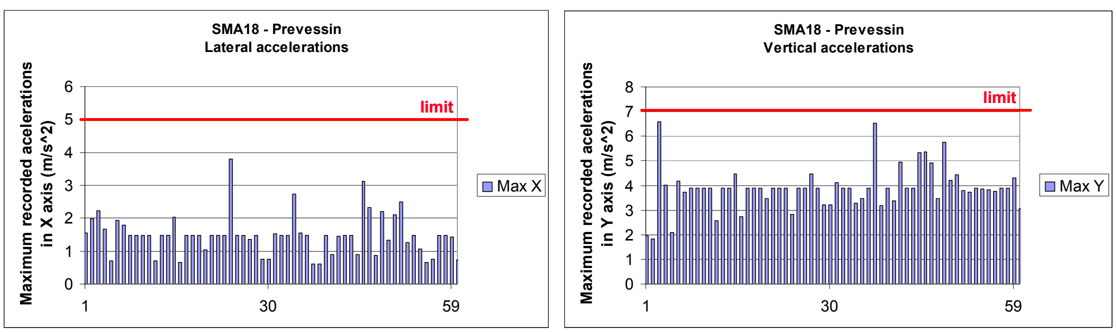


Figure 7: Lateral and vertical accelerations experienced by the cryo-dipoles between SMA18 and Prevessin.

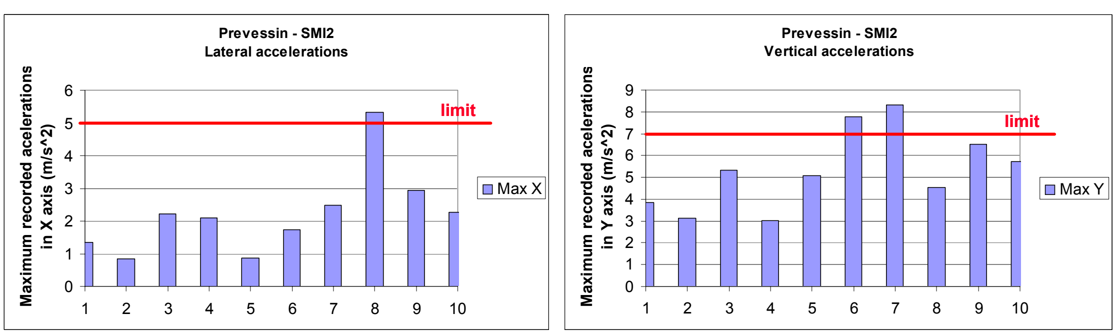


Figure 8: Lateral and vertical accelerations experienced by the cryo-dipoles between Prevessin and SMI2.

The results from the acceleration monitoring are also used to detect details such as out-of-specification accelerations that needed improvement. It was detected that the cryo-dipoles regularly experienced accelerations higher than the limits during the handling inside SMI2 building. The same was detected for SSS handling inside building 904. The source of these accelerations was identified to be the cryo-magnet positioning on jacks. These manipulations are not precise and require many iterations and attention from the operators. They need improvement such as adjustment of the overhead crane movements, additional tooling etc... The measured accelerations also allow the detection of other high accelerations sources such as holes in the road asphalt.

On the other hand, accelerations recorded during some types of transport, such as cryo-dipole road transport from SMA18 to the storage zone in Prevessin, are almost always under the admissible limits. In the future, for these types of transport it might be acceptable to monitor the accelerations only on some randomly-chosen cryo-magnets.

7 CONCLUSIONS

A detailed dynamic analysis was performed to determine the behavior of the cryo-magnets under several handling and transport conditions.

Calculations and measurements were combined to specify the maximum allowable accelerations within a certain frequency range during different types of handling and transport. Measurements are made to commission new equipment like overhead cranes, tunnel transport and handling devices to guarantee that the defined acceleration limits are respected.

To ensure the required mechanic and geometric integrity of the cryo-magnets, a tri-axial acceleration monitoring devices is installed on each transported cryo-magnet. 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.

8 REFERENCES

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