9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF080

INVESTIGATION AND ESTIMATION OF THE LHC MAGNET VIBRATIONS INDUCED BY HL-LHC CIVIL ENGINEERING ACTIVITIES

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Abstract

The HL-LHC project requires major underground civil engineering, with the excavation of large underground structures in order to host new equipment. The tunnels construction and other civil engineering works will therefore take place in parallel with the LHC operation. The effect of vibrations induced by civil engineering activities needs to be evaluated in order to take required corrective actions.

For this purpose, experiments and measurements have been performed in order to characterize the vibration sources and to determine the vibration transfer path through the rock, the tunnel floor and the accelerator component structures. The transfer functions' amplitude and phase were determined with dedicated tools for molasses rock for both horizontal and vertical vibrations. An experimental modal analysis was carried on a LHC final focusing magnet.

The campaign of measurements has been performed to confirm the effect of the vibrations created on the surface on the circulating beam orbit at the resonance frequencies of the structure. This paper reviews the advanced technique of measurements, results and the conclusion about the impact of operating civil engineering machines (roadheader, hydraulic hammer) during beam exploitation.

MOTIVATION FOR THE STUDY

The Large Hadron Collider is situated underground on the border between Switzerland and France. The location of this precise, high performance, scientific machine in the underground tunnels, helps to reduce the influence from vibrations from the surface activities on the LHC machine.

However, in some cases, when heavy machinery works are performed in the close vicinity of the Large Hadron Collider, one could expect those disturbances to have an impact on its operation and in particular on the particle beam stability.

This concern is especially important in view of two large excavation projects scheduled for the coming years. One of the civil engineering worksites is in close proximity to the existing ATLAS detector. A new shaft will be excavated in 2018, during machine operation as a part of the HL-LHC Project [1]. The second project in collaboration with the Swiss authorities entitled "Géothermie 2020" [2], will perform multiple excavations within the canton of Geneva to exploit geothermal energy.

This paper presents the set of experiments and measurements that were made to estimate the level of beam's magnetic centre motion due to heavy machinery works in the close vicinity of LHC.

TRANSFER FUNCTION APPROACH

The key parameter to be monitored is the level of induced oscillation of the magnetic centre of the final focus magnets that are installed around the high luminosity experiments in LHC Point 1 and LHC Point 5

In order to estimate the vibration level due to the heavy machinery surface works, a vibration transfer function was determined between the point of excitation and the particle beam position (Figure 1).

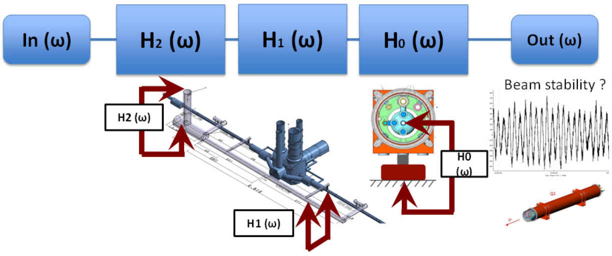

Figure 1: Combined Transfer Function Overview.

This transfer function is represented as a combination of three separate transfer functions:

$$H(\omega) = H_0(\omega) \cdot H_1(\omega) \cdot H_2(\omega)$$

where $H_0(\omega)$ is a transfer function between the magnet's magnetic centre and the slab on which the magnet is placed, while $H_1(\omega)$ and $H_2(\omega)$ correspond to the vibration transfer through molasses rock in horizontal and vertical direction respectively [3]. The visual representation of this transfer function chain is shown in Figure 1.

Examples of $H_0(\omega)$ transfer functions (Figure 2) were obtained by modal analysis on a spare LHC Q2 final focus magnet with vertical modal hammer excitation of the floor near the magnet. Figure 2 indicates $H_0(\omega)$ for both sides of the magnet measured in stand alone in a surface building. Several peaks visible in the graphs correspond to the natural frequencies of the magnet, with the highest one at 22 Hz (surpassing the magnitude of 100).

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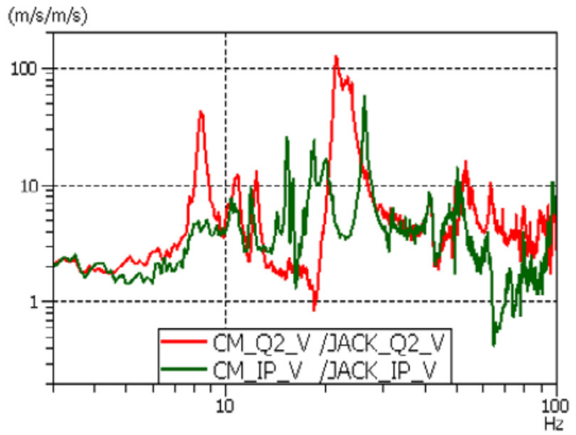

Figure 2: $H_0(\omega)$ Magnet Transfer Functions: Q2 side (red) and IP side (green).

In order to obtain the $H_1(\omega)$ transfer function a measurement was done between parallel tunnels at CERN (TT41-TAG41) at a distance of 40m from each other (horizontal plane). The vibrations generated in tunnel TT41 with a portable vertical electromagnetic shaker were measured in both tunnels using highly sensitive ground vibration sensors (seismometers). Based on this data the horizontal vibration attenuation curve through molasse rock was estimated (Figure 3).

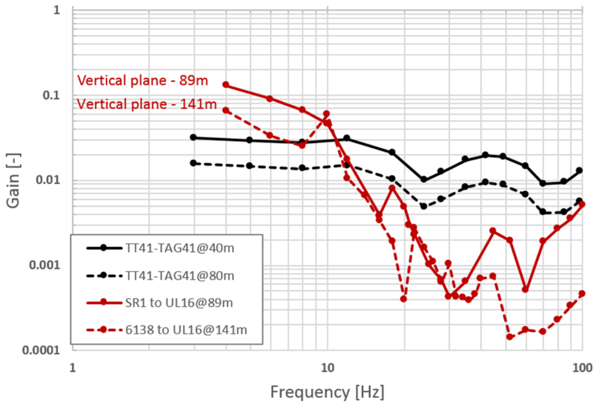

Figure 3: Vibration attenuation curves through molasses rock in horizontal (TT41-TAG41) and vertical (SR1/6138-UL16) direction.

Figure 4: Shaker Truck.

The $H_2(\omega)$ transfer function was acquired in a similar fashion as $H_1(\omega)$ – this time however with the excitation provided by a heavyweight shaker truck (Figure 4) placed on the surface at CERN P1 and the geophones located in the UL16 tunnel, 89 m below. Additional tests were also performed with the truck relocated to a further location, at a diagonal distance of 141 m from the underground sensors. The vibration attenuation curves obtained from those tests are also presented in Figure 3.

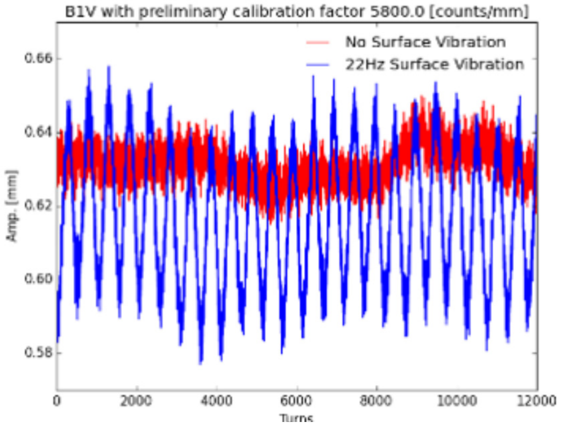

Figure 5: LHC Beam oscillation without excitation and with a 22Hz excitation (surface).

Figure 5 shows the beam vibration measured by BE-OP-LHC team during the shaker truck test for the excitation frequency of 22 Hz compared to the case without excitation. The large increase in beam vibration can be attributed to the natural frequency of the Q2 magnet as seen in Figure 2.

SOURCE CHARACTERIZATION

After the transfer function $H(\omega)$ has been determined, the next necessary step was to characterize the vibration levels $In(\omega)$ in relation to the type of the heavy machinery used. Figure 6 shows the source characterization for several different heavy machines along with the comparison to the vibration level of an extremely quiet space, in this case the underground tunnel of CMS detector (dark blue).

The source characterization for Volvo DD25w (orange) and CAT CB-434C (light blue) road rollers has been provided by Lawrence Berkeley National Laboratory [4].

The measurement for the hydraulic hammer (green) was performed on CERN premises during the concrete extraction operation on a building construction site. Of note is the fact that the operational frequency (8 Hz) of the hammer is visible as a peak in the curve along with its harmonic frequencies at 16 and 24 Hz.

The roadheader test (yellow) was performed in Thun, Switzerland, during the excavation of a tunnel for an underground parking space. The relatively low level of vibration excited by the roadheader, at least in comparison to the other tested machines, might be due to its continuous grinding action and its electrical power supply.

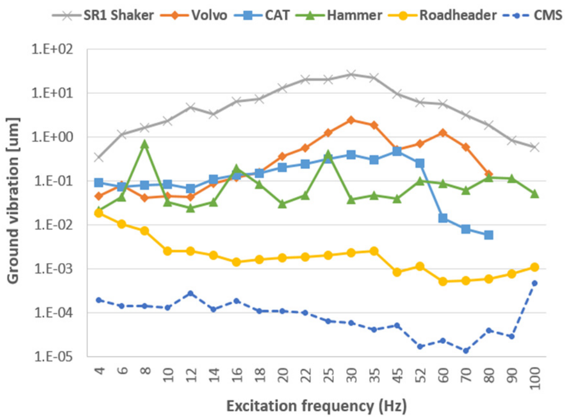

Figure 6: Ground vibration levels for heavy machinery in comparison to an extremely quiet place (CMS).

MAIN RESULTS

Figure 7 shows the surface motion level obtained from the shaker truck tests at CERN P1 along with the expected magnetic centre motion calculated through the acquired transfer function.

Although for most frequencies the level of expected magnetic centre motion stays below 1 µm, in the case of 22 Hz excitation (corresponding to the natural frequency of the magnet) the level exceeds 5 µm.

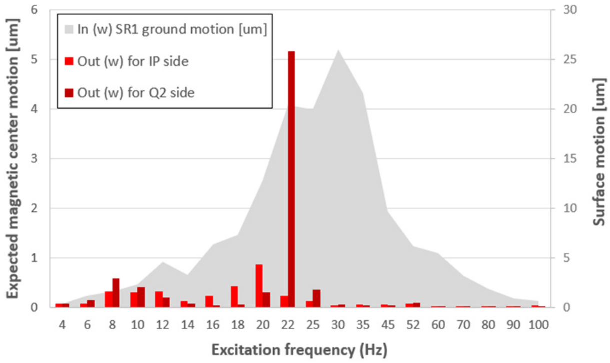

Figure 7: Surface motion and expected magnetic centre motion for the shaker truck input surface excitation.

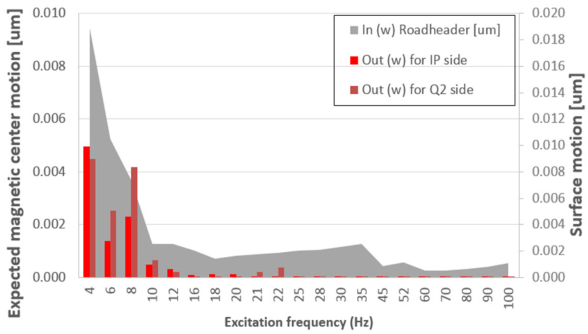

Figure 8: Surface motion and expected magnetic centre motion for the road header surface excitation.

Figure 8 shows a similar graph, this time calculated for the excitation by the road header.

ONLINE MONITORING

In March 2016 through a collaboration between the Swiss Seismological Service (SED) [5] and the CERN EN-MME and EN-SMM groups, an official CERN Seismic Network has started its operation [6, 7]. Consisting of three seismic stations (Figure 9) and equipped with both broadband and strong-motion seismometers, the aim of the network is to monitor the seismic activity in the close vicinity of the LHC. The seismic network provides the means of measuring the vibration in the tunnel and on surface, originating from the civil engineering activities and cultural noise.

The CERN seismic network is in continuous operation and the measured seismic data is directly accessible online under the FDSN network code "C4" [6]. The goal for the upcoming years is to expand this network with additional stations and sensors, in order to provide more detailed and precise information regarding the vibratory events in the area.

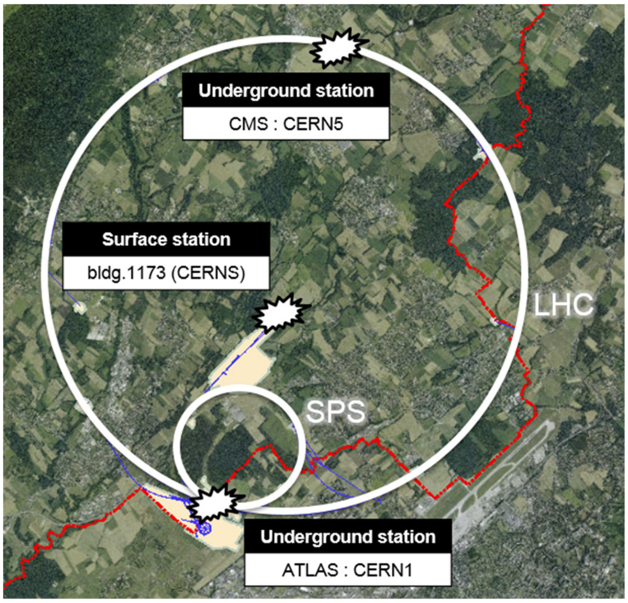

Figure 9: Location of CERN Seismic Stations.

SUMMARY & CONCLUSIONS

This paper explains the process and measurements performed in order to estimate the magnetic centre motion of the magnets in the LHC due to heavy civil engineering machinery works or seismic activity.

Monitoring, estimation and prediction of the vibration in the tunnel can provide information on the expected level of magnetic centre motion and the admissible levels. The presented seismic network will be a useful asset for this purpose, especially in light of the civil engineering activities planned in the area in the coming years.

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