Assessment of the Vibrations Effects Caused by Technical Seismicity Due to the Railway traffic on High-sensitivity Machinery

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Abstract. The numerical and experimental approach in structural dynamics problems is more and more current nowadays. This approach is applied and solved in many research and developing institutions of the all the world. Vibrations effect caused by passing trains used in manufacturing facilities can affect the quality of the production activity. This effect is possible to be solved by a numerical or an experimental way. Numerical solution is not so financially and time demanding. The main aim of this article is to focus on just experimental measurement of this problem. In this paper, the case study with measurement due to cramped conditions realized in situ is presented. The case study is located close to railway. The vibration effect caused by passing trains on the high-sensitivity machinery contained in this object were observed. The structure was a high-sensitivity machine that was placed in a construction process. For the measurements, the high-sensitivity standard vibrations equipment was used. The assessments of measurements’ results were performed for the technological conditions and Slovak Standard Criteria. Both of these assessments were divided to amplitude and frequency domain. The amplitude criterion is also divided to peak particle velocity and RMS (Root Mean Square). Frequency domain assessment were realised using the frequency response curves obtained from high-sensitivity machinery manufacturer. The frequency limits are established for each axis of triaxle system. The measurement results can be predicted if the vibration have to be reduced. Measurement implemented in the production hall should obtain materials to determine the seismic loading and response of production machinery caused by technical seismicity.

1. Introduction
The main aim of this article is to clarify the approach to assessing the impact of technical seismicity caused by railway traffic on high-sensitivity machinery. The requirements of producers of machinery are now placed on the conditions in which it will operate a specific device. One of the most important requirements is the aspect of vibration. For determining or predicting conditions due to the vibration can be used either FEM (Finite Element Method) simulation or experimental measurements. Simulation of a FEM computation model is indeed less financially demanding, but it requires complex inputs. The inputs can be generated or also obtained by experiment. The dynamic response of subgrade of the CONTURA G2 Measuring Center (Carl Zeiss IMT Corporation) was assessed applied the experimental
way in production hall SEJONG Slovakia. The impact of vibration on the hall and its subsoil under the existing normative legislation was also assessed [1].

2. Information about the investigated object
Monitored newly built hall SEJONG Slovakia Extension is located in the area of SEJONG Slovakia, in Lietavská Lúčka (district Žilina) on parcel No. 1182/3. The hall is located in the protection zone of ZSR (Slovak Railways) by the minimum distance from the rail axis being 23 m. The rear wall of the hall is approximately parallel to the axis of the rail. At a distance of about 50 m from the SW corner of the hall, the railway crossing on the road III. class to the village Lietavská Svinná – Babkov is located. The structure of the hall is under construction. The hall will be used for the production and control of automotive industry products in the future. The hall is founded on large diameter piles. The piles are situated under the supporting structure in the form of assembled reinforced concrete skeleton and flat roof lying on prestressed concrete beams. The two floors building part (southern edge of the hall) will be used as a quality control after completion of the hall. The production hall part (situated in the middle) consist of the single floor. The administrative section (on the northern border) consist of the three floors. After the finishing, the hall will have external walls with sandwich thermal and sound insulation panels. At the time of measurements, foundation structures, main vertical and horizontal structural members, some construction a roof, one part of cladding were completed, and the floor was drawn to the stage of compacted gravel sub-base with a sprinkling sand-gravel protective layer. Area construction site is originally located on the sample weight of waste material.

3. Description of the measuring techniques
Measuring the level of vibrations was performed by the A/D card National Instruments enabling to load data with a sampling frequency of 1000 Hz. The five inputs assigned to vibration velocity sensors SM6 B04 were plugged in to this card. With the use of an amplifier INVEL 300 B3, signal to detect noise ratio has been modified. The two pieces of the vibration velocity sensors SM6 B04 are constructed with built-in amplifier INSENS 100. Measuring office was installed in the SW corner of the hall at the pillar 1C. Vibration velocity sensors were placed in the measuring profile, which is about a line perpendicular to the axis of the railway line passing through the nearest point on the structure of the hall (column 1C). The sensors were placed around the south wall directly on the ground. One of the sensors was installed directly on the pillar hall 1C. The scheme of the measuring line is displayed in Figure 2 and Table 1 contains information about distances of each measuring point from the axis of the railway line. The measuring line has been designed to obtain values of vibration in the subsoil, in particular the place of the area of quality control, where the high-sensitivity measuring equipment will be placed. All vibration velocity sensors were fitted so that their horizontal longitudinal axes (x-axis) pointed to the source of vibration (railways). The horizontal transverse axis (y-axis) faced parallel to the railway line. The vertical axis is in the direction of gravity.

Figure 1. (a) situation, (b) view of the building
The railway line distance to the investigated object is 23 m. The dispatchers train services of stations L. Lucka, Rajec were contacted before and during measurement. Based on information from them, the approximate time of passage, the direction of the passage, type of train and freight trains on whether they are empty or loaded, were determined. Speed at passage was estimated as the ratio between the passing of the two marks and their distance (50 m). The subgrade vibration was monitored during normal construction activity in the hall too. The construction process of the hall was excluded during the vibration measurement due to train passage. The identified parameters are shown in Table 2.

**Table 1.** Distance of sensors from the axis railway line

| sensor | VIB01 | VIB02 | VIB03 | VIB04 | VIB05 | VIB06 | VIB07 |
|--------|-------|-------|-------|-------|-------|-------|-------|
| L [m]  | 1.50  | 6.00  | 12.20 | 23.30 | 23.30 | 29.60 | 42.10 |
| comment | yard  | embankment terrain | terrain | column(h=0.2m) terrain | terrain |

The registered source vibrations were passages of trains, the passage of vehicles through the railroad crossing and construction works in the hall. Measurement was carried out under the Roll mode when
record runs through breaks. After each recording was processed graphics exports and a preliminary evaluation of the record. After the finish of measurement, the data was transferred from the laboratory to the measuring computer by LAN connection to a secure server. The measured values of vibration velocity were continuously evaluated. Signal analysis of the dynamic vibration velocity sensor records included an evaluation of all three components $v_x, v_y, v_z$.

They consist of finding the maximum amplitude vibration rate, space velocity, acceleration and displacement, obtaining a spectrum of the time signal, the time course of finding space velocity and the dominant frequency [2, 3].

Table 3.

| record | sensor No. | $V_x$ [mms$^{-1}$] | $V_{xy}$ [mms$^{-1}$] | $V_p$ [mms$^{-1}$] | $V_{z,ef}$ [mms$^{-1}$] | $V_{xy,ef}$ [mms$^{-1}$] | $V_{p,ef}$ [mms$^{-1}$] |
|--------|------------|---------------------|----------------------|---------------------|------------------------|------------------------|------------------------|
| 01 VIB01 | 16.700     | 15.700              | 22.400               | 1.800               | 2.100                  | 3.200                  |
| VIB02  | 1.600      | 2.300               | 2.400                | 0.250               | 0.380                  | 0.560                  |
| VIB03  | 0.800      | 1.300               | 1.400                | 0.150               | 0.250                  | 0.350                  |
| VIB04  | 0.094      | 0.210               | 0.210                | 0.025               | 0.044                  | 0.060                  |
| VIB05  | 0.057      | 0.200               | 0.210                | 0.016               | 0.040                  | 0.053                  |
| VIB06  | 0.083      | 0.170               | 0.180                | 0.016               | 0.033                  | 0.044                  |
| VIB07  | 0.033      | 0.100               | 0.110                | 0.007               | 0.017                  | 0.024                  |
| 05 VIB01 | 17.100     | 16.900              | 21.500               | 2.200               | 2.700                  | 4.100                  |
| VIB02  | 1.700      | 1.900               | 2.400                | 0.260               | 0.440                  | 0.650                  |
| VIB03  | 0.720      | 1.300               | 1.400                | 0.170               | 0.260                  | 0.400                  |
| VIB04  | 0.120      | 0.280               | 0.280                | 0.026               | 0.058                  | 0.071                  |
| VIB05  | 0.085      | 0.260               | 0.270                | 0.018               | 0.052                  | 0.063                  |
| VIB06  | 0.095      | 0.200               | 0.210                | 0.020               | 0.040                  | 0.053                  |
| VIB07  | 0.039      | 0.085               | 0.088                | 0.009               | 0.020                  | 0.032                  |
| 11 VIB01 | 19.100     | 13.300              | 20.900               | 2.300               | 2.300                  | 3.700                  |
| VIB02  | 1.400      | 2.300               | 2.400                | 0.260               | 0.390                  | 0.570                  |
| VIB03  | 0.560      | 1.100               | 1.300                | 0.120               | 0.190                  | 0.290                  |
| VIB04  | 0.110      | 0.160               | 0.180                | 0.021               | 0.041                  | 0.055                  |
| VIB05  | 0.068      | 0.140               | 0.150                | 0.014               | 0.039                  | 0.050                  |
| VIB06  | 0.059      | 0.120               | 0.130                | 0.014               | 0.033                  | 0.044                  |
| VIB07  | 0.024      | 0.086               | 0.089                | 0.006               | 0.021                  | 0.028                  |

Table 3 shows the maximum value of the effective amplitude and speed of vibration components. There is also a record highlighted passage that sparked the greatest seismic effect. Figure 4 shows a sample record speed of vibrations at the point of passage VIB1 with maximum dynamic effect. Figure 3 shows the dependence of changing its velocity amplitude vibrations at the distance from the source. In the representation were used only consistent records and sensors. Based on this graph, it is possible to interpolate or extrapolate values of speed of oscillation in locations where the measurement was not carried out. The maximum velocity amplitude of vibration in the vertical direction ($v_z$), horizontal ($v_{xy}$, greater of $v_x$ and $v_y$), spatial vectors ($v_p$) and their effective values ($V_{z,ef}$, $V_{xy,ef}$ and $V_{p,ef}$) were evaluated in the records with dominant effect on structure. The maximum values for each sensor are bold in text.
**Figure 3.** Dependence of the RMS amplitude vibration rate on the distance from the source (attenuation curve) for "maximum alert" in a logarithmic scale

**Figure 4.** The vibration velocity time histories, measuring on the sensor VIB01
4. Analysis of the measurement data for assessing the effects on high-sensitivity machinery

The sensitive frequency characteristic of the CONTURA G2 Measuring Center was performed. The traffic seismicity load effects on machineries are evaluated in vibration acceleration domain (deformation wave propagation [3]). It is necessary to transform the velocity vibration data to acceleration vibration using the numerical integration. The sensitive characteristics are given by manufacturer and it is performed in acceleration vibration magnitude spectra [4] [5].

The vibration velocities measuring sensors were used because they are more sensitive in frequency band lower than 10 Hz. The sensitive characteristics performed by manufacturer of the machinery signify that this frequency band is the most important. For the main analysis number 5, empty freight train, direction LL – RA average travel speed 45 km.h⁻¹ were used. The measured records were processed in system SigView analysing system. The frequency analysis of the vibration acceleration records for each points and directions were realised via Signal tools/FFT spectrum analysis in SigView. Before spectral analysis, the Hanning window was applied for the records without smoothing. As an example, the results from measurement number 5 are presented in Figure 5, 6 and 7. Within these results frequency-amplitude criteria are also displayed.

Figure 5. The comparison of the measured and criterial frequency characteristics in point VIB04

Figure 6. The comparison of the measured and criterial frequency characteristics in point VIB06
The investigation of the seismic response effect on structures was realised for three axial vibration velocities records according “STN EN 1998-1 Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings” and the national annex “STN EN 1998-1/NA” and its change “STN EN 1998-1/NA/Z1”. The basic criterial parameters in these standards are directly depending on seismic load and the degree of damage. Some important limits from the “STN EN 1998-1 Eurocode 8” standard of the effective vibration velocities (vz,ef, vx,ef, vy,ef) for the resistance class and the significance class are:

- If there is no component over 3,0 mms-1, there is no seismic risk.
- If there is no component over 12,0 mms-1, no dynamic calculation is needed.
- The damage possibility if any component is over 60 mms-1.
- The cracks 1 mm width if any component is over 100 mms-1.

5. Conclusion

For the assessment of impact of technical seismicity on the high-sensitivity machine Contura G2 serve the digitized data supplied by the client in the form of a document Technical Services - Instalation Instructions CONTURA G2 Measuring Center (Carl Zeiss IMT Corporation). Assessment and limit values are shown in graphic form in Figure 5, 6 and 7. All the measurements were analysed in detail in terms of the level of technical seismicity from sources that are actually occur and could affect the assessment of the object. On the basis of the measurements, calculations and evaluations can be concluded. Construction of buildings need not be analysed in terms of I limit state for dynamic response caused by technical seismicity: vef = (0.063 ± 0.001) mms\(^{-1}\) <3.0 mms\(^{-1}\).

- No need to calculate the dynamic construction halls: vef = (0.063 ± 0.001) mms\(^{-1}\) <6.0 mms-1.
- There is no possibility of faults with the construction of buildings by technical seismicity: vef = (0.063 ± 0.001) mms\(^{-1}\) <60.0 mms -1.
- No property damage has Stage 1: vef = (0.063 ± 0.001) mms\(^{-1}\) <100.0 mms-1.
- In none of the measured points in the hall (VIB04, VIB06, VIB07) does no component spectrum of the vibration acceleration limit values specified by the manufacturer (Figure 5, 6 and 7).

From the interpretation of measurement results it shows that transport has on the building structure such adverse effects, in order to make the necessary conservation measures, since identified data is several orders of magnitude lower than the limit - standardized. The results also show that there is no need to take any protective measures when installing the machine, since the data are detected at least an order of magnitude lower than the limit, specified by the manufacturer.
The measurement is performed on the field and not on the floor, so after completing the floor layers and insertion machines can actually figures differ slightly from those detected by measuring, as the made-up state and interacts with the ground floor and the machine itself [6] [7].

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