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DAMPING BUIDLING VIBRATIONS EXCITED BY SURFACE WAVE PROPAGATING IN THE GROUND

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Abstract

This paper presents anticipated results of reducing vibrations of a laboratory building by separating its foundation from the ground. In order to carry out a numerical analysis, the building and the foundation soil were modelled with the use of Multibody System Dynamics (MSD). In a real system, vibrations of walls and floors are caused by propagation of waves in the ground. Such waves are excited by cyclic impact of operating crushing elements of a roller-bowl mill located in the vicinity of the building. Energy carried by the waves is so high that they cause vibrations of the building when the waves encounter an obstacle in the form of the foundation. The vibrations have the velocity of several millimetres per second. This phenomenon has an adverse effect as far as the strength of elements made of brittle materials such as concrete and bricks is concerned, and it becomes critical when high-sensitivity measuring instruments are located in the rooms. Then, vibrations may cause incorrect readings of such instruments and damage of the elements, mainly electronic ones. In order to determine the extent of vibrations propagated from the mill to the laboratory building foundation, measurements of vibration parameters were carried out and amplitude-frequency responses of the investigated objects were obtained. The results of a simulation revealed that an expansion gap having a calculated effective height would allow reducing the level of vibrations in the building as well as in laboratory stations located inside.

Key words: *proper vibrations, minimisation of vibrations, resonance frequency values, propagation of disturbances in the ground, seismic and para-seismic actions*

1. Introduction

Civil structures are exposed to various types of dynamic loads among which seismic and para-seismic actions can be recognized. Seismic excitations occur due to earthquakes, whereas para-seismic excitations are caused by human activity such as vibrations of machines supported on own foundations, shooting in quarries, driving sheet piling, rail and road traffic, etc. Dynamic impact which is transferred by the ground to civil structures causes vibrations in them. Machines which are percussive in operation are usually located within a safe distance from buildings. However, it should be remembered that percussive-borne vibrations can propagate as disturbance in the soil medium over significantly long distances depending on the type of the base, depth of groundwater, above- and underground infrastructure, etc. [3]. As the distance from the source of vibrations increases, amplitudes of ground vibrations decrease, because the density of conveyed energy decreases, vibrations are damped and the energy is dissipated at the borders of ground layers [1]. Vibrations have an adverse impact on the strength of structures as well as the durability of elements of machines located inside. Therefore, actions are taken to devise the most effective methods of minimising vibrations for every case of such excitations [5, 7]. Three main types of methods for protection against vibrations such as passive, semi active and active ones can be distinguished [2]. Methods which involve direct interference with the source by eliminating the cause of vibrations lead to the best results. As an example, rotor balancing is a much simpler and effective solution than an attempt of limiting vibration levels by applying vibration insulation. A particularly important task from the viewpoint of engineering is to lower the level of vibrations in large structures and foundations of machines when the vibrations are caused by excitations which are resonant in nature [6]. In such cases, prior to corrective actions, there should be a numerical analysis so that results of applied solutions intended for minimisation of the level of vibrations can be anticipated [4].

This paper presents the concept of reducing the level of vibrations in a laboratory building caused by excitations from the system of a roller-bowl mill. The investigated object is located about 200 m away from the source of such vibrations. Surface waves which propagate in the ground in the form of shocks carry such a high amount of energy that vibrations having high amplitudes occur in the building due to the waves which reach the foundation, even though the source is located far away. The problem is quite serious as vibrating walls and floor make the laboratory tables and measuring instruments vibrate.

2. Measured parameters of vibrations in the structures

Measurements and analysis of vibration parameters were carried out *in situ* and aimed at determining the mechanism of how vibrations propagate from the ground to the laboratory building. The investigated structure is a two-storey building made of bricks. It was supported on strip footings and has a basement. The operating mill which is the source of vibrations is supported on reinforced-concrete foundations having dimensions of 10 m x 10 m x 3 m and is supported on Franki piles having the length of 12 m. The laboratory building is located about 200 m away from the milling station (the mill). A diagram of the roller-bowl mill in operation is presented in Fig. 1.

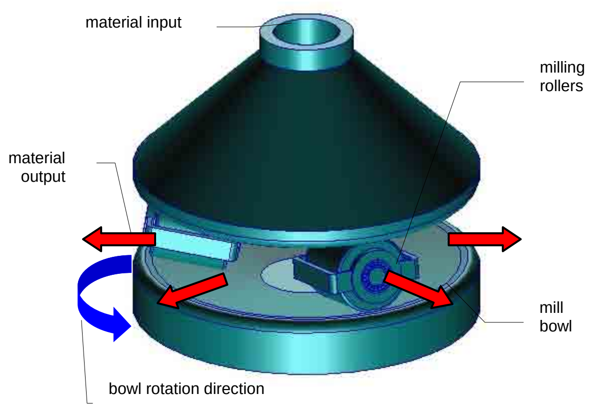


Fig. 1. A schematic view of the bowl with rollers as the element of the mill which excites vibrations

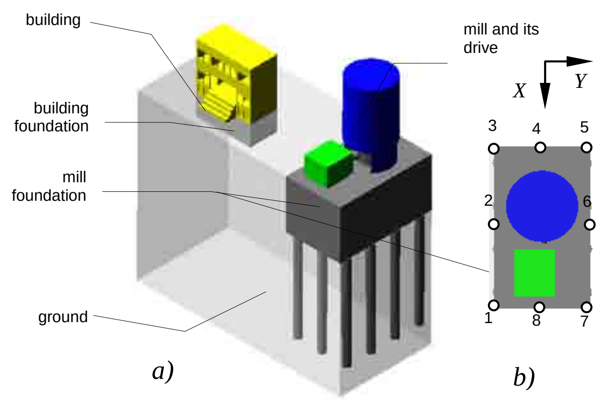


Fig. 2. A schematic view of the location of the mill with reference to the building (a) and location of measuring points at the foundation (b)

The material to be ground is fed from the top, and then it falls onto the bowl where it is ground down by three rollers moving on the bowl. The milling is removed by a system of fans, and then it is fed to separators so as to separate various grain sizes. The mill belongs to the group of machines which are percussive in operation. During the milling process rotation of the rollers is forced by the bowl rotating around the axis of the mill. The rollers can also move vertically. By falling onto the bowl the roller hits it and a quite significant amount of energy is transferred to the mill.

Measuring sensors were placed along the edge of the foundation of the mill (Fig. 2b) and at the bowl (Fig. 3a). Fig. 3 shows typical amplitude-frequency responses of vibration velocities of the mill bowl in the reduction gear axis (horizontally and vertically). Velocity amplitudes of bowl vibrations are considerable and equal to 3 to 4 mm·s^{-1}. The maximum RMS values measured in the axis of the reduction gear of the bowl driving system reached the value as high as 8.42 mm·s^{-1}. Instantaneous values reached even the level of 28 mm·s^{-1}. Frequency of vibration components in the measured band ranged from 3.5 to 11.5 Hz.

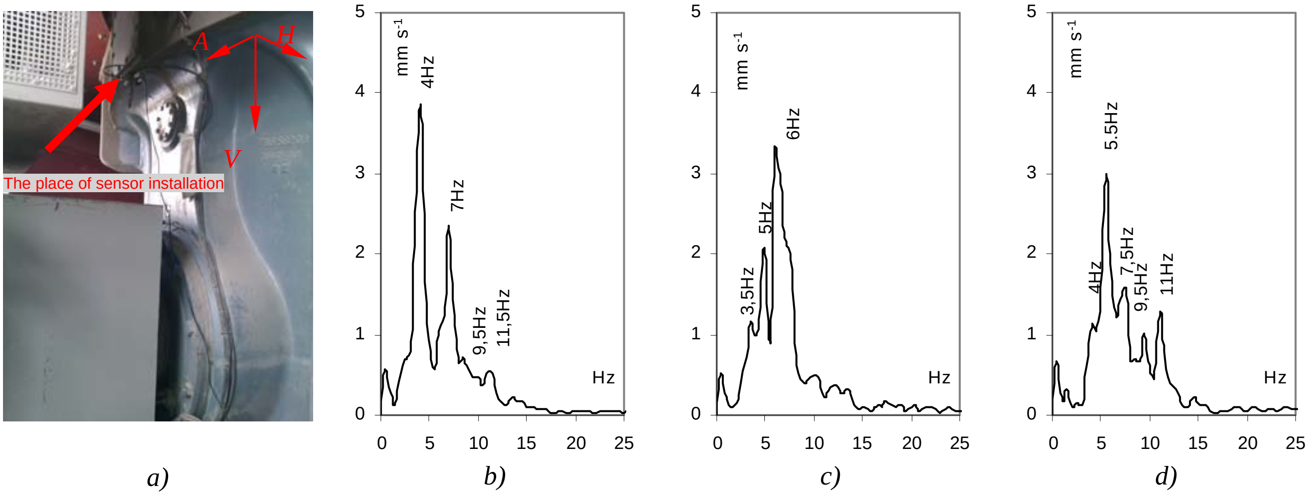


Fig. 3. Location of the measurement spot at the bowl a), an amplitude-frequency response of vibration velocity b) in the axis of the reduction gear, c) horizontally, d) vertically

Figs. 4 and 5 show amplitude-frequency responses of vibration acceleration values of the mill foundation in Y-axis, at point 1 and 3 respectively.

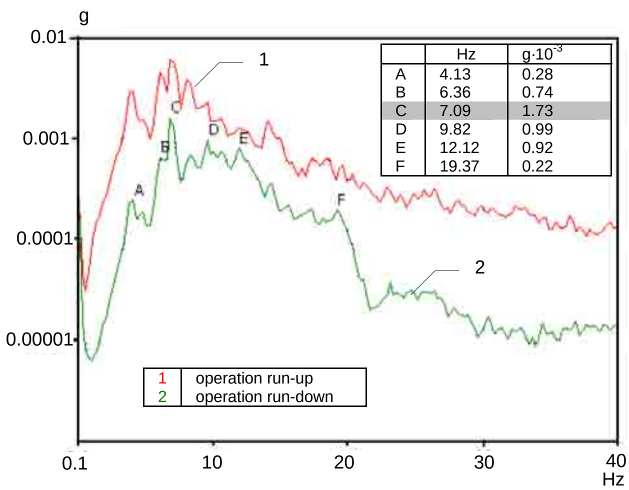


Fig. 4. An amplitude-frequency response of the vibration acceleration value of the mill foundation at point (1) in Y-axis

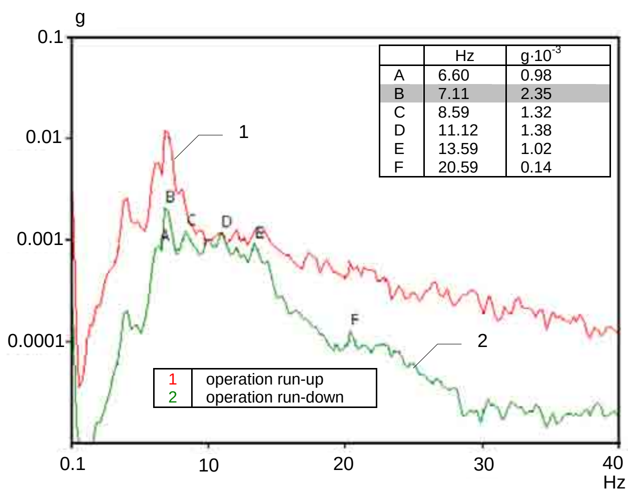
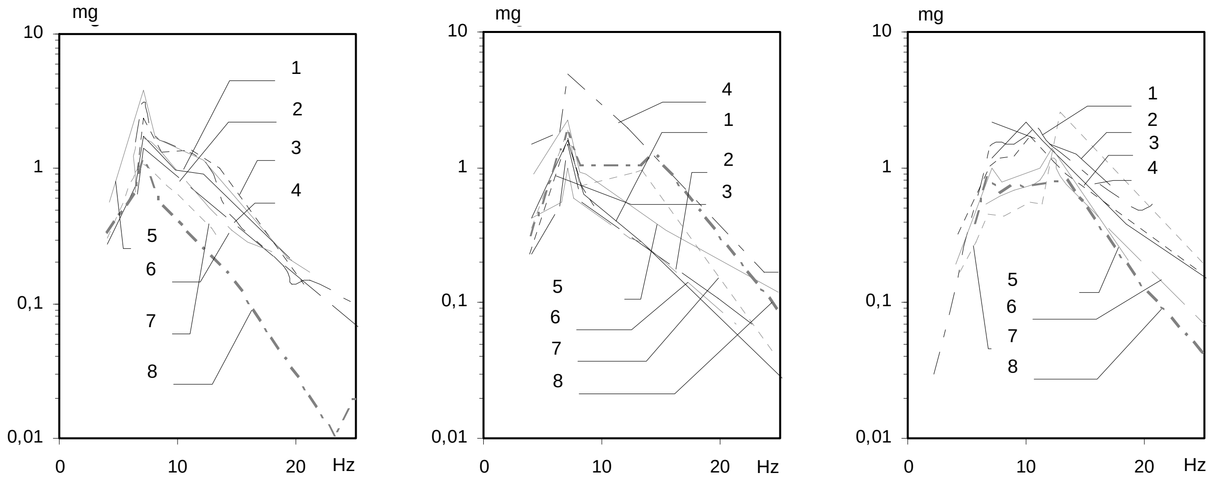


Fig. 5. An amplitude-frequency response of the vibration acceleration value of the mill foundation at point (3) in Y-axis

The responses were obtained on the basis of vibration acceleration values of the mill foundation in the function of time during mill operation run-up and run-down periods. By analysing the measurement results it can be observed that the area of foundation vibrations carrying lots of energy applies for the frequency ranging from 4 to 12 Hz. The recorded parameters of vibrations of the mill foundation prove that there are good conditions for applying insulation with the damping effect of 20 dB.

The maximum values of acceleration amplitudes for the mill foundation in Z-axis (vertical) correspond to higher frequency values than the maximum acceleration amplitudes of vibrations in the horizontal plane. For the frequency of ~13 Hz the value is 2.57 mg (0.025 $m \cdot s^{-2}$) (Fig. 6). The same effect can be observed in case of vibrations of the mill bowl.



a) *b)* *c)*

Fig. 6. Amplitude-frequency responses of vibration acceleration values of the mill foundation in a) X-axis, b) Y-axis, c) Z-axis

Changes of selected parameters of vibrations along time in the laboratory building were recorded as well. The sensors were placed in several places such as the laboratory on the working top of the table (point #1) and on the floor (point #2) (Fig. 7).

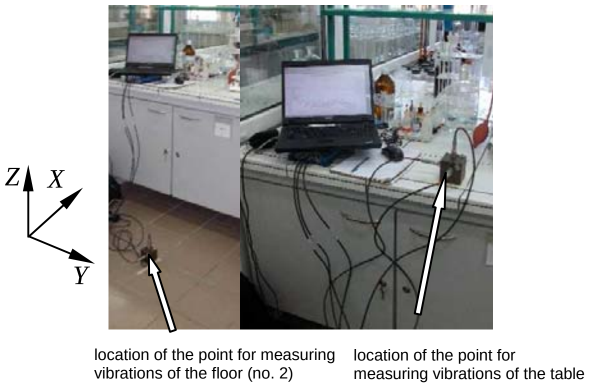


Fig. 7. A view of points for measuring vibrations of the table

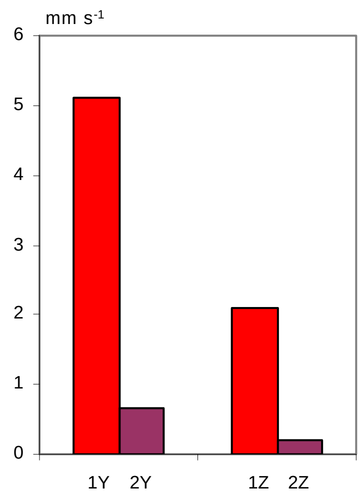


Fig. 8. Values of vibration velocity amplitudes at point 1 and 2 at the frequency of 7 Hz

Fig. 8 shows examples of vibration velocity amplitudes in the measuring points 1 (table) and 2 (floor) at 7 Hz, whereas Fig. 9 shows an amplitude-frequency response of a table vibration acceleration value in Y-axis.

By analysing the measurement results it can be observed that the value of table vibration velocity is higher in both horizontal and vertical plane when compared with vibrations of the floor. Resonant vibration can be observed in Y-axis.

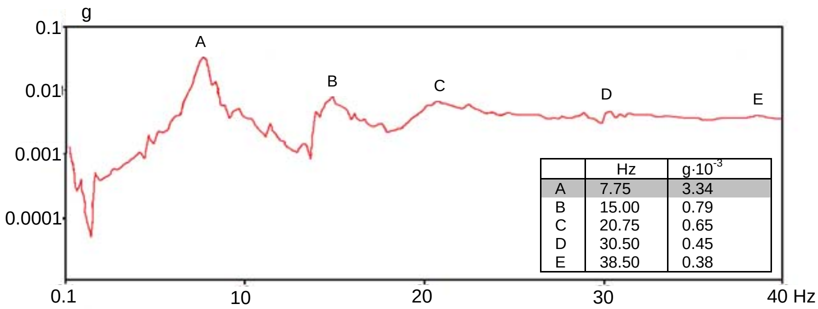


Fig. 9. An amplitude-frequency response of the vibration acceleration value of the table in Y-axis

The amplitude of floor vibration velocity in the horizontal plane is almost 8 times higher than the corresponding amplitude of table vibration velocity in the vertical plane (Figs. 10 and 11).

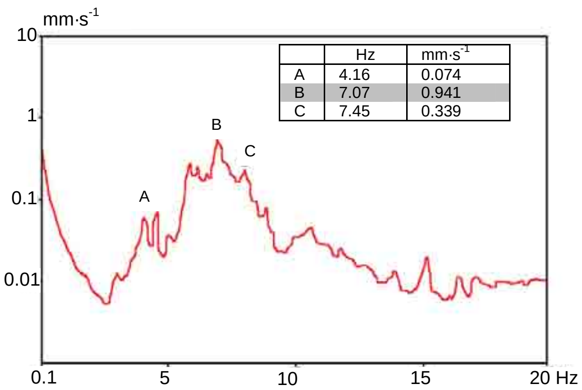


Fig. 10. An amplitude-frequency response of vibration velocity on the floor in Y-axis

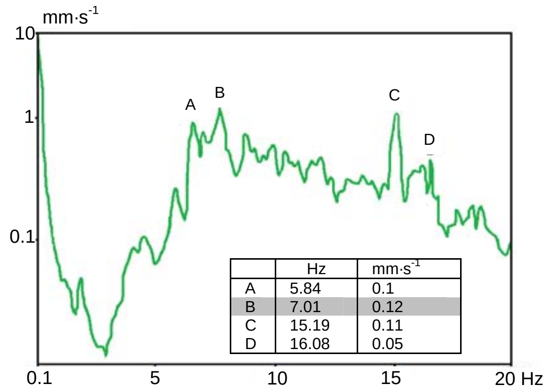
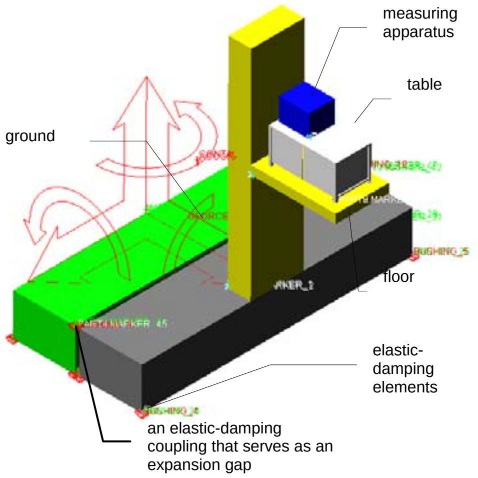


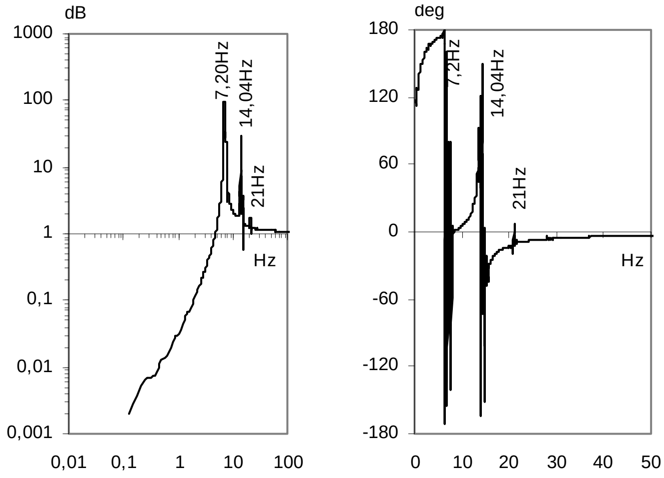
Fig. 11. An amplitude-frequency response of vibration velocity on the floor in Z-axis

3. Calculation model and numerical analysis

Multibody System Dynamics (MSD) was used for the purpose of a numerical analysis of vibrations propagating through the ground to the foundation of the building and the response of the system to the applied excitations with implemented damping insulation. The laboratory table where instruments are placed, as well as elements of the building such as the floor, walls, foundations and the ground, are modelled as rigid bodies (Fig. 12). Between the floor and the table there is a contact reaction. The contact between the foundation and the ground was modelled as an elastic-damping coupling for which parameters were selected in such a manner that proper vibration frequencies of the model would correspond approximately to the values obtained from the experiments.

Dynamic rigidity coefficients of the ground were determined by means of Savinov method in accordance to a standard. The coefficients depend on the type of ground, foundation pressure on the base as well the shape and dimensions of the foundation. For the purpose of calculations the following six discrete values of base rigidity coefficients $k_x = k_y = k_z = 10^6$ N/mm and $k_{\varphi x} = k_{\varphi y} = k_{\varphi z} = 10^8$ N mm were assumed. The analysis was carried out in the range of linear elasticity.



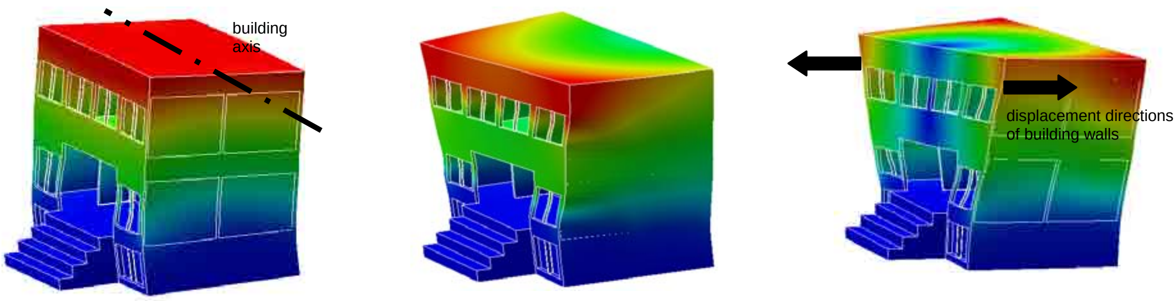


a) *b)*

Fig. 12. The model applied in the numerical analysis

Fig. 13. An amplitude-frequency response of vibration velocity of the table in Y-axis for the assumed model

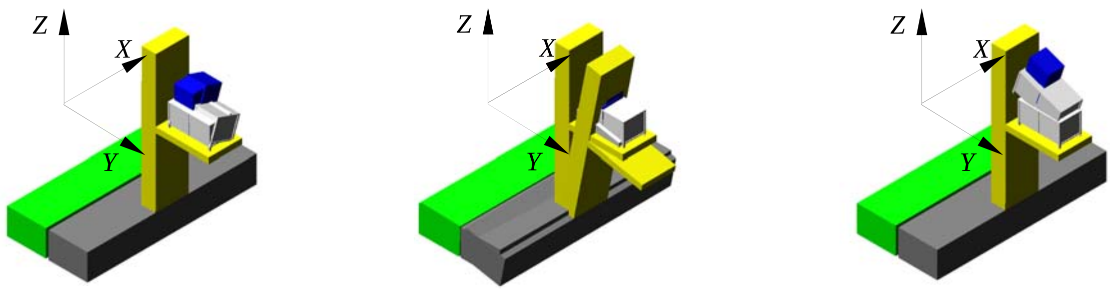
For a kinematic excitation assumed in the numerical analysis, determined at the foundation level, the horizontal component of ground vibration acceleration excited by the operating mill was assumed. Fig. 14 presents the first three forms of proper vibrations of the laboratory building. Deformation of the rigid body, here the building, at the frequency of 7.8 Hz corresponds to torsional vibrations.



a) *b)* *c)*

Fig. 14. Forms of building proper vibrations at the following frequencies: a) 4.1 Hz, b) 5.2 Hz and c) 7.8 Hz

The first three forms of proper vibrations of the 'table – floor – wall – foundation – ground' system are presented in Fig. 15. The first form of proper vibrations of the system being analysed corresponds to torsional vibrations around Y-axis, whereas the second one reflects the displacement along Y-axis. At the frequency of 18.8 Hz, the table vibrates in Z-axis and rotates simultaneously around X-axis.



f=7.28 Hz *f=7.76 Hz* *f=18.80 Hz*

Fig. 15. Forms corresponding to the first three frequency values of proper vibrations of the investigated system

Fig. 16 presents amplitude-frequency responses of floor vibration velocity in Y-axis and Z-axis respectively. Calculated floor vibration velocity amplitudes at ~7 Hz in Y-axis and in Z-axis have the respective values: 0.53 mm·s^{-1} and 0.044 mm·s^{-1} (Fig. 16). The values are lower than the measured values which were determined to be 0.65 mm·s^{-1} (Y-axis) and 0.2 mm·s^{-1} (Z-axis).

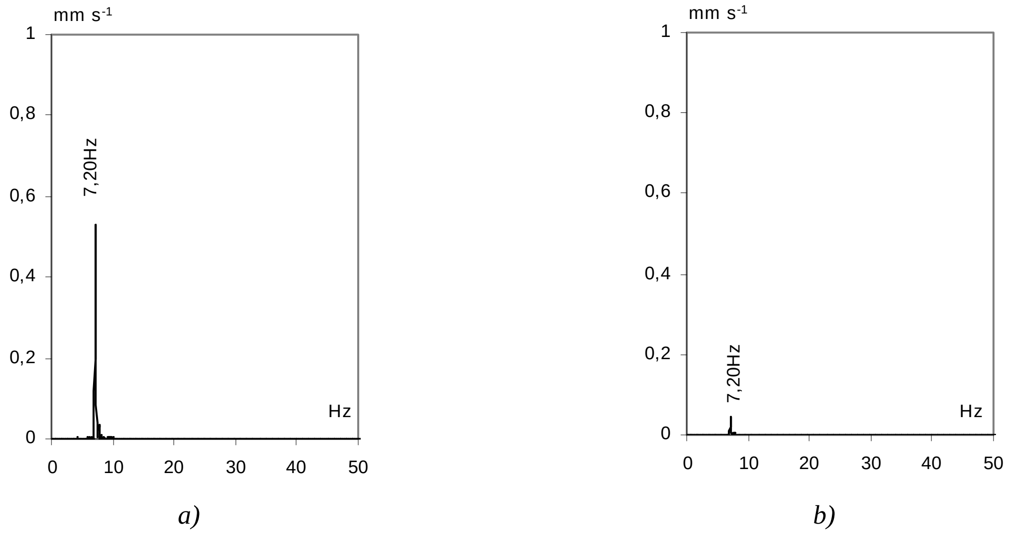


Fig. 16. An amplitude-frequency response of vibration velocity on the floor in a) Y-axis and b) Z-axis

The results obtained from the numerical analysis of table vibrations confirm that the table displaces with reference to the floor both horizontally and vertically. Vibration velocity of the table in Y-axis is much higher than in case of vibration velocity of the floor (Fig. 17).

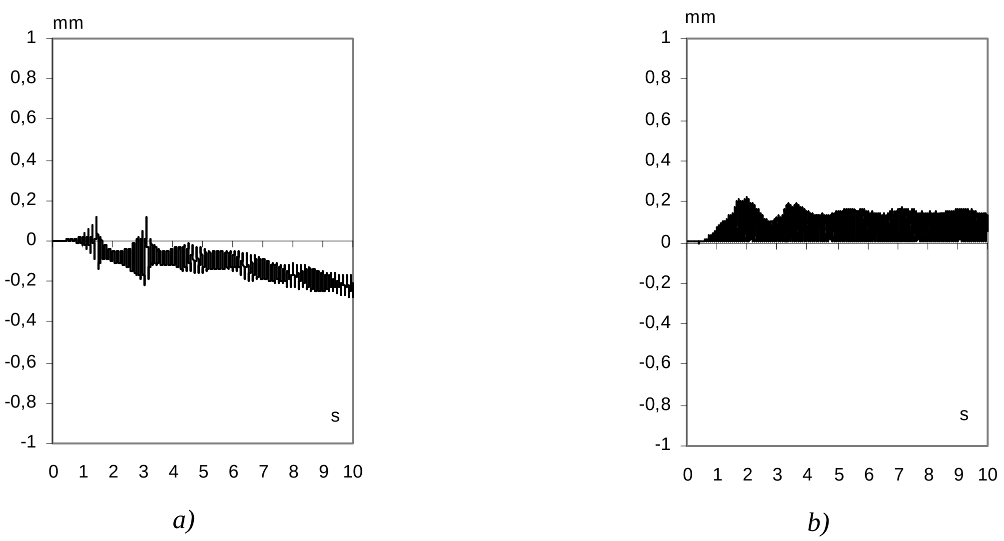
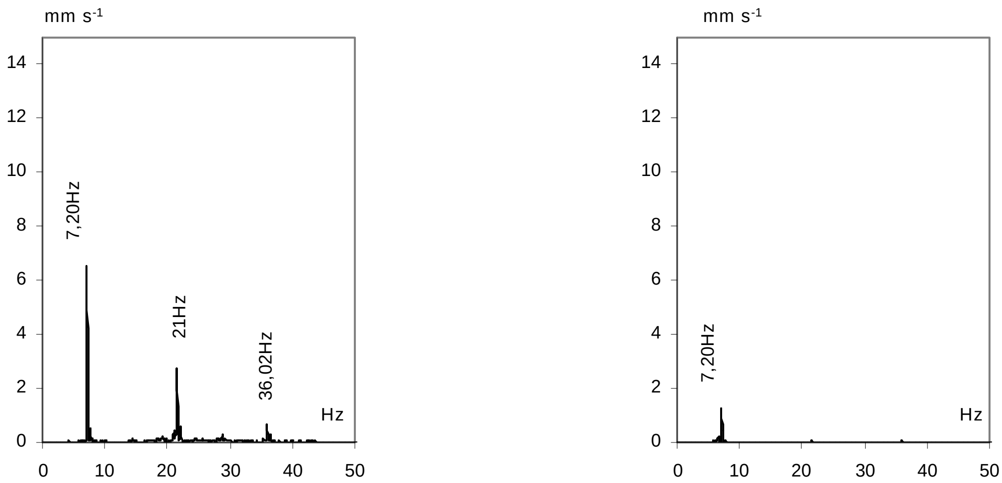


Fig. 17. Table displacement along the floor in a) Y-axis b) Z-axis in the function of time.

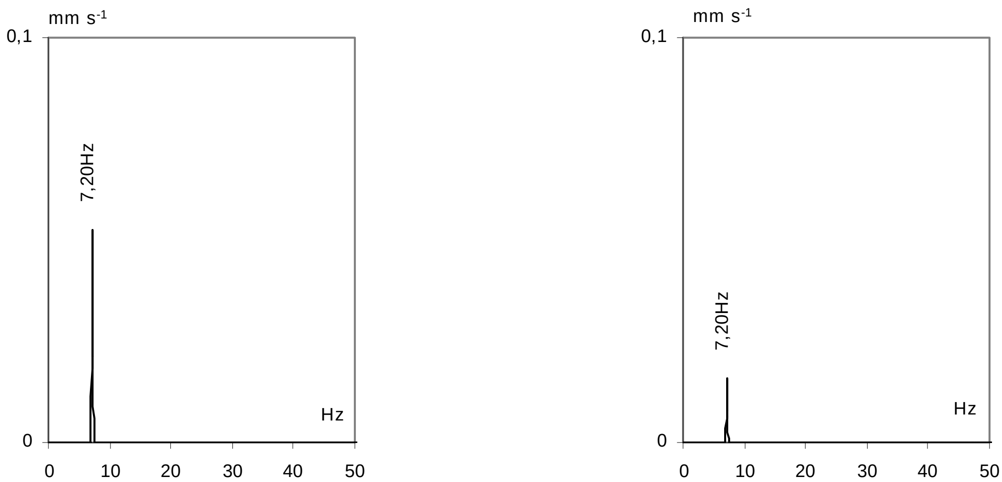
The vibrations are resonant in nature which is implied by the shape of spectrum containing ultraharmonic components of excitation frequency being 3× and 5× (Fig. 18). The values of table vibration velocity amplitudes obtained from the calculations at 7.20 Hz in Y and Z axes are as follows: 6.7 mm·s^{-1} and 1.26 mm·s^{-1}. In comparison, the values obtained from the measurements of table vibration velocity have the following values respectively: 5.1 mm·s^{-1} and 2.1 mm·s^{-1}.



a) *b)*

Fig. 18. An amplitude-frequency response of vibration velocity of the table in a) Y-axis and b) Z-axis

In order to damp the propagation of disturbances in the ground, excited by the operating mill, an expansion gap was simulated in the model within the foundation-ground plane. Fig. 19 presents the anticipated effect of reducing table vibrations in Y and Z axes when an expansion gap having the depth of 0.9 of the foundation block height is applied.



a) *b)*

Fig. 19. An amplitude-frequency response of vibration velocity of the table in a) Y-axis and b) Z-axis once an expansion gap at the building foundation has been applied

Once the separation gap has been added to the calculation model for the ‘table – floor – wall – foundation – ground’ system, a significant reduction of table vibration velocity amplitude was obtained. The value decreased from 6.7 mm·s^{-1} to 0.05 mm·s^{-1} in Y-axis, and from 1.26 mm·s^{-1} to 0.02 mm·s^{-1} in Z-axis at the excitation frequency of 7.2 Hz.

4. Conclusions

The main objective of this paper was to analyse the possibility of damping vibrations in a laboratory building where measuring equipment requiring high accuracy of indications is located. Experiments carried out for the object in a real scale confirmed that there were high-amplitude vibrations in the laboratory tables, and standard values were significantly exceeded. In order to anticipate how effective damping of the level of building vibrations would be, conditions assuming no contact between the ground and the foundation at some level were taken into consideration in the numerical analysis. As results from the analysis of the problem, application of an expansion gap considerably reduces vibrations in the laboratory building.

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