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Research of the industrial facility underground structures settlement caused by its machinery dynamic loads

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The article is devoted to the issue of research of the soil basement vibrocreep negative impact, which takes place under dynamic loads. The results of on-site measurements of industrial facility underground structures forced dynamic vibrations parameters have been presented. The influence of the dynamic vibrations value on the development of underground cable channel precast concrete units uneven settlement has been analyzed. The interrelation between the value of the channel built-up construction settlement at the point of measurement and the amplitude of forced vibrations at this point has been determined.

Keywords: vibrocreep, soil base, foundation, uneven settlement, dynamic load, vibration amplitude.

Дослідження осідань підземних конструкцій промислового цеху від дії динамічних навантажень його обладнання

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Стаття присвячена питанню досліджень негативного явища віброповзучості ґрунтової основи, що має місце при динамічних навантаженнях. Дослідження проводилися на заводі з виробництва металопрокату з приводу триваючих нерівномірних осідань повнопрохідного двоповерхового кабельного тунелю розташованого в підземній частині виробничого цеху. Як було встановлено даний кабельний тунель піддається динамічному впливу при роботі двох пілігримових станів, на яких виробляються безшовні гарячекатані труби великого діаметра. Серйозність питання осідання кабельного тунеля для виробництва полягає в можливому ушкодженні прокладених у ньому комунікацій внаслідок нерівномірного й нестабілізованого осідання його збірних залізобетонних конструкцій. Установлене, що із двох розташованих у зоні проходження кабельного тунелю пілігримових станів один з них, позначений у статті під №2, спричиняє суттєвіший вплив на величину амплітуди коливань у всіх його точках у яких проводилися виміри. У статті викладені результати натурних вимірів параметрів вимушених динамічних коливань підземних конструкцій кабельного тунелю промислового цеху, які були зроблені на відмітці -5,200 від рівня чистої підлоги. Серед іншого було встановлено, що максимальна амплітуда коливань кабельного каналу перебуває в точці №4 найбільш наближеної до пілігримового стану №2. У районі зазначеної точки також перебуває й зона з максимальним осіданням конструкцій тунелю. Проаналізовано вплив величини динамічних коливань на розвиток нерівномірного осідання збірних залізобетонних секцій підземного кабельного тунелю. Встановлено взаємозв'язок величини осідання збірної конструкції каналу в точці виміру від величини амплітуди вимушених коливань у даній точці.

Ключові слова: віброповзучість, ґрунтова основа, фундамент, нерівномірне осідання, динамічне навантаження, амплітуда коливань.

Introduction

The increase in the productivity of metallurgical machines (new machines and the ones which are in operation for a long time), is caused by a significant intensification of their operation modes. At the same time, both static and dynamic loads within machines increase, which are fully or partially transferred to the foundations and "absorbed" by the base on which this machinery is installed. Due to acting loads, metallurgical machines are unparalleled among other heavy machines.

One of the main methods of producing seamless pipes of large and medium diameters with wall thickness from 7 to 100 mm is rolling on pilger mills. A wide range of pipes for almost any purpose is produced on pilger mills: oil pipes, casing pipes, boiler pipes made of special steels and alloys, bimetallic pipes. Seamless pipes of large diameter (up to 630 mm) with different wall thickness without using mill expanders can be made only on pilger mills.

The pilgrim method is one of the most economical and versatile methods for producing seamless pipes, since switching to a different size of pipes on pilger mills takes much less time than, for example, on a continuous multistand mill. Therefore, despite the demand for new rolling technologies, the production of pipes on pilger assemblies continues to be one of the most common in the world for producing hot-rolled pipes of a wide range of sizes and steel grades [1].

Technological loads of pilger mills are characterized by short duration (less than 0.8 s.) and a pronounced peak character, as well as significant amplitudes of vibrations transmitted to the base.

The values of the mechanical properties of soils of different composition, structure and state in general decrease depending on the mode of dynamic loads on them. Vibration, shocks and other oscillating movements typical for urban conditions, adversely affect the geotechnical properties of foundations of buildings and structures. Incoherent (sandy) soils are the most sensitive to such impacts, especially in the water-saturated state [2-4].

Review of research sources and publications

Geotechnics [5–7], by analogy with statics [8], distinguish three phases of base deformation depending on the intensity of the combined static and dynamic loads on it. The first phase takes place under small static and dynamic loads, the settlement of the base within it occurs due to a decrease in the soil porosityl. The second phase is characterized by the development of significant areas of plastic deformations in the massif (even under small dynamic loads, significant precipitation occurs with a tendency to their growth and lengthening of the stabilization time [2–4]). These settlements occur in sandy soils (including dense ones) and clayey soils. In the third phase, the settlements are destructive and have high speed – loss of stability or immersion of the foundation in the ground as in a viscous fluid [9 - 14].

Definition of unsolved aspects of the problem

When designing foundations for machinery with dynamic loads, the influence of vibration transmitted through the base of the foundation on the ground should be considered. It reduces their strength, increases compressibility and, as a result, causes cracks in structures when their strength limit is exceeded due to a combination of static and dynamic loads. In addition to the frequency and amplitude of forced vibrations of the machinery, the type and size of the foundations, as well as the natural vibration frequencies of structures and their elements affect the level of vibration.

Problem statement

It should be noted that if the structures of foundations for heavy machines (in this case, pilger mills) are often correctly designed for the perception and distribution of significant dynamic loads, then with other underground structures located in the zone of propagation of vibrations, the phenomena known as vibrocreep can occur. The purpose of this paper is to identify the influence of amplitudes and frequencies of the dynamic load on the value of the underground structure settlement, which is in the range of vibrations transmitted by the foundations of heavy metallurgical machines.

Basic material and results

Research of the parameters of dynamic vibrations in the active industrial facility of the metallurgical plant has been carried out in cable channels under the facility (mark -5,200) under pilger mills No.1 and No.2 in connection with complaints of cable channels geometry violation in the zone of the dynamic loads on the foundation grounds during operation of these pilger mills. The scheme of the vibration parameters measurement points is shown in Fig. 1.

To determine the vibration parameters, a set of equipment has been used, which consists of a vibrometer VIP-2 that includes a displacement sensor D21A and a digital oscilloscope Oscill connected to the vibrometer for spectral and visual analysis of the vibration nature and recording of the oscillogram of vibrations. The vibration parameters along the vertical axis, perpendicular to the earth surface have been recorded as the most significant component in the case of the base vibrocreep.

Next, the measured parameters of vibrations at the points indicated in Fig. 1 have been considered.

Point No.1

At point No.1 with the operating pilger mill No.1, the following vibration parameters have been recorded: the maximum vibration amplitude has been recorded at 30 μm at a frequency of a pulsed load of 1.2 Hz (see Fig. 2).

With inoperative pilger mills No.1 and 2, at point No.1, "background" vibration is observed at a level of ≈ 10 μm at a frequency of 15 Hz (between the pulse peaks in Fig. 2 and 3).

At point No.1 with the running piliger mill No.2, the following vibration parameters have been recorded: the maximum vibration amplitude has been recorded at 15 µm at a frequency of a pulsed load of 1.2 Hz (see Fig. 3).

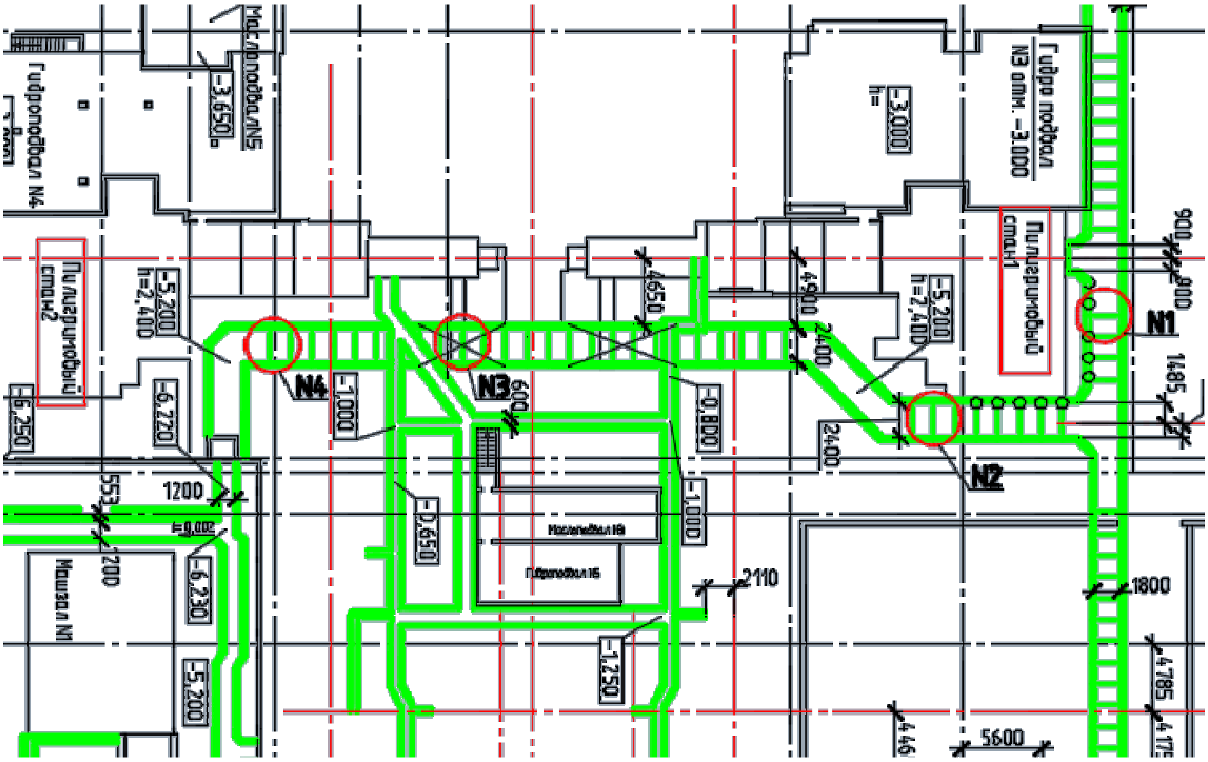

Figure 1 – The scheme of the points of measurement of vibration parameters on a fragment of the plan of cable channels

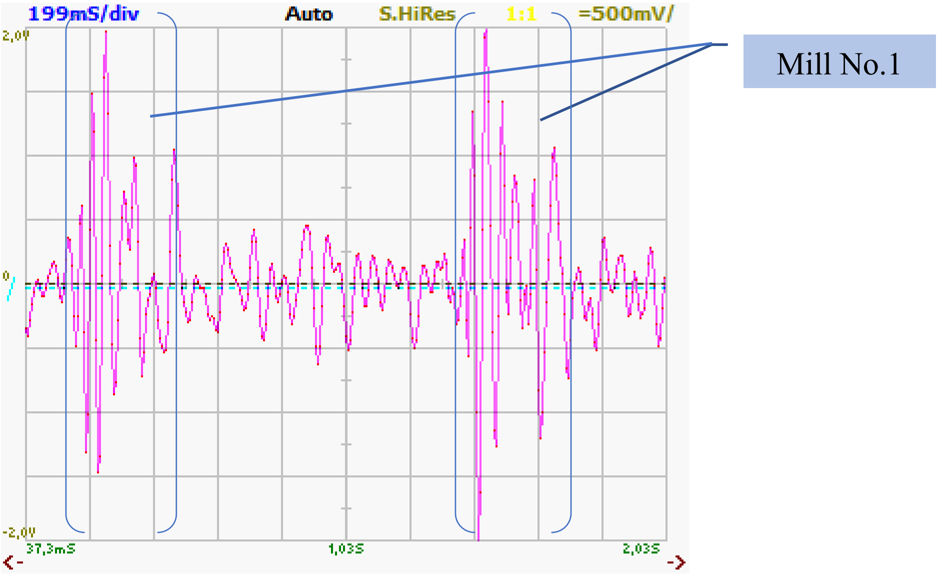

Figure 2 – Oscillogram of vibrations. Point No.1
Pilger mill No.1 is in operation. (1 div. Y axis = 3.75 µm, 1 div. X axis = 0.2 s)

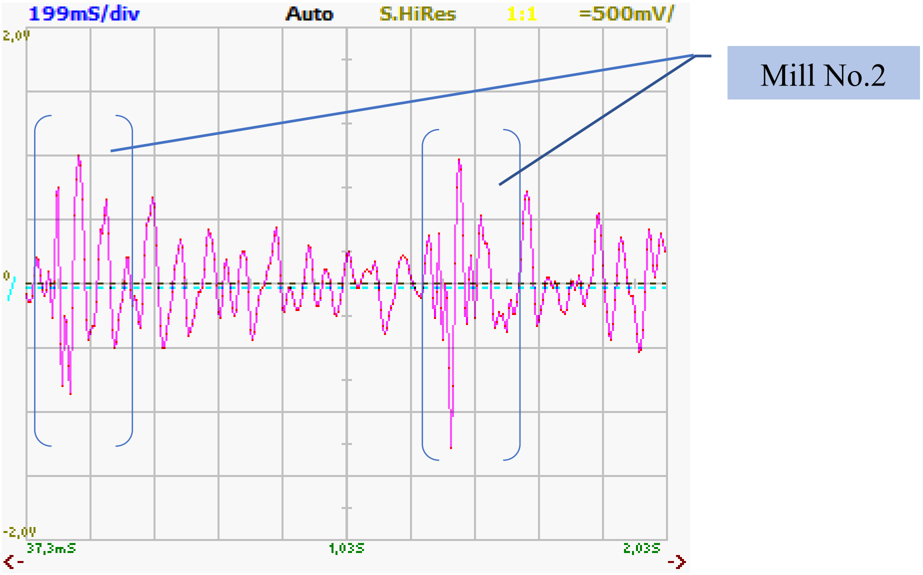

Figure 3 – Oscillogram of vibrations. Point No.1
Pilger mill No.2 is in operation. (1 div. Y axis = 3.75 µm, 1 div. X axis = 0.2 s)

Point No.2

At point No.2, the following vibration parameters have been recorded for operating pilger mills No.1 and No.2: the maximum vibration amplitude has been fixed at the level of 90 µm (mill No.1) and 50 µm (mill No.2) at a pulse frequency of 1.2 Hz (each of the mills separately) (see Fig. 4).

At point No.2 with the operating piliger mill No.1, the following vibration parameters have been recorded: the maximum vibration amplitude has been recorded at 100 µm at a frequency of a pulsed load of 1.2 Hz (see Fig. 5).

With non-operating pilgrim mills No.1 and 2 at point No.2, as well as at point No.1, “background” vibration is observed at a level of ≈ 10 µm at a frequency of 15 Hz (see the spectrogram in Fig. 6).

Point No.3

At point No.3 with the operating pilger mill No.2, the following vibration parameters have been recorded: the maximum vibration amplitude has been recorded at 100 µm at a frequency of a pulsed load of 1.2 Hz (see Fig. 7).

At point No.3, the following vibration parameters have been recorded for operating pilger mills No.1 and No.2: the maximum vibration amplitude has been recorded at 100 µm (mill No.1) and 25 µm (mill No.2) at a pulse frequency of 1.2 Hz (each of the mills separately) (see Fig. 8).

With inoperative pilger mills No.1 and 2 at point No.3, as well as in other currents, there is a “background” vibration at the level of ≈ 20 µm at a frequency of 15 Hz (see Fig. 9).

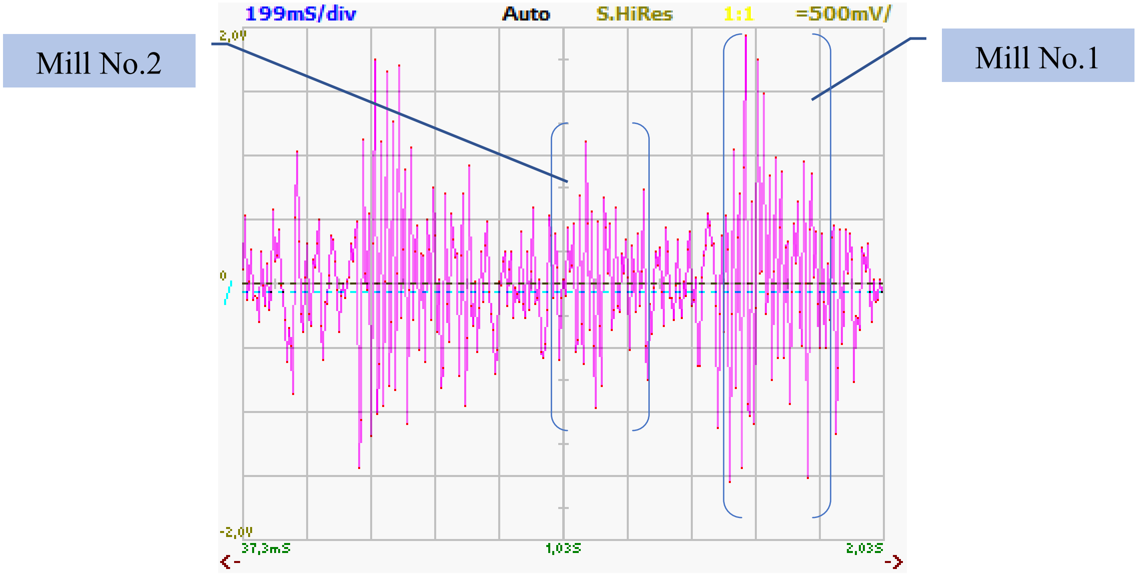

Figure 4 – Oscillogram of vibrations. Point No.2
Pilger mills No.1 и No.2. are in operation (1 div. Y axis = 12.5 µm, 1 div. X axis =0.2 s)

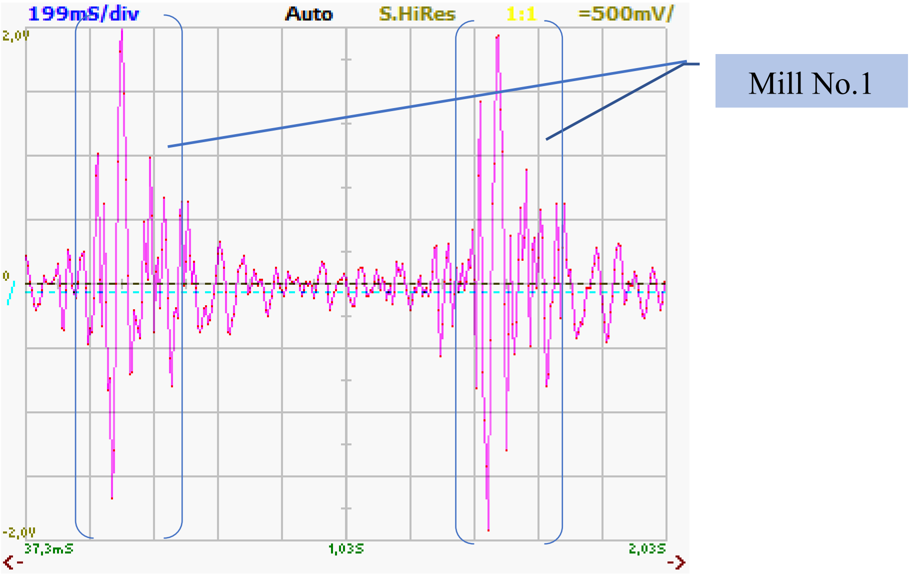

Figure 5 – Oscillogram of vibrations. Point No.2.
Pilger mill No.1 is in operation. (1 div. Y axis = 12.5 µm, 1 div. X axis = 0.2 s)

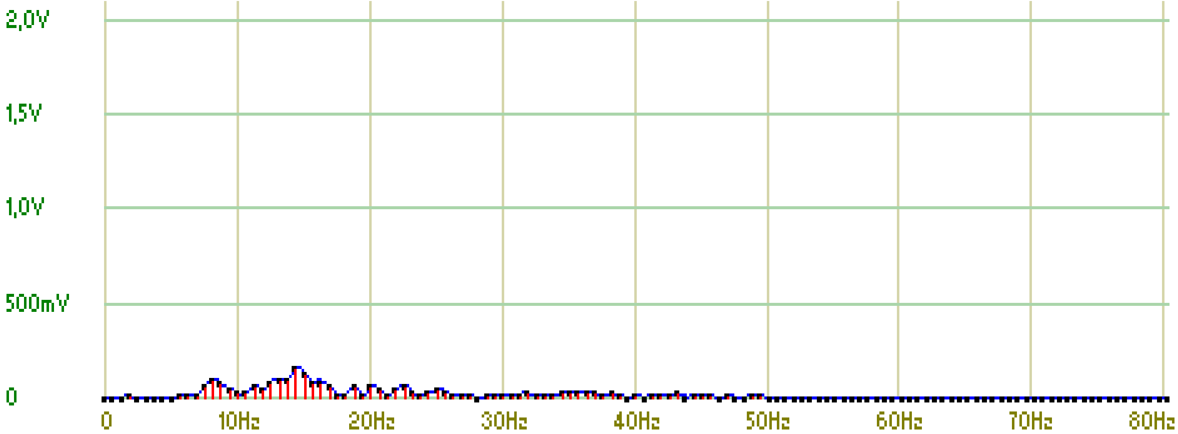

Figure 6 – Spectrogram of the "background" amplitude of vibrations with inoperative mills No.1 and No. 2. Point No.2.

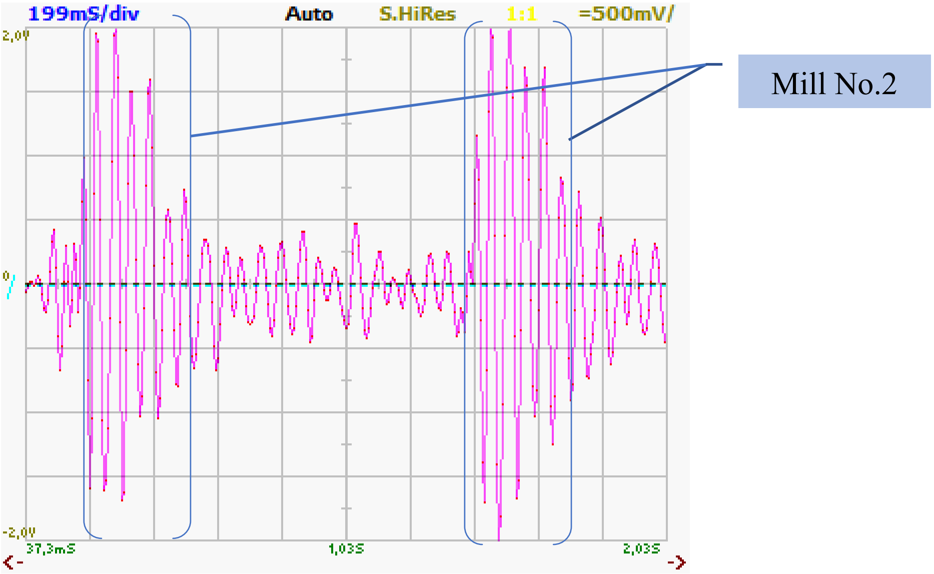

Figure 7 – Oscillogram of vibrations. Point No.3.
Pilger mill No.2 is in operation. (1 div. Yaxis =12.5 µm, 1 div. X= 0.2 s)

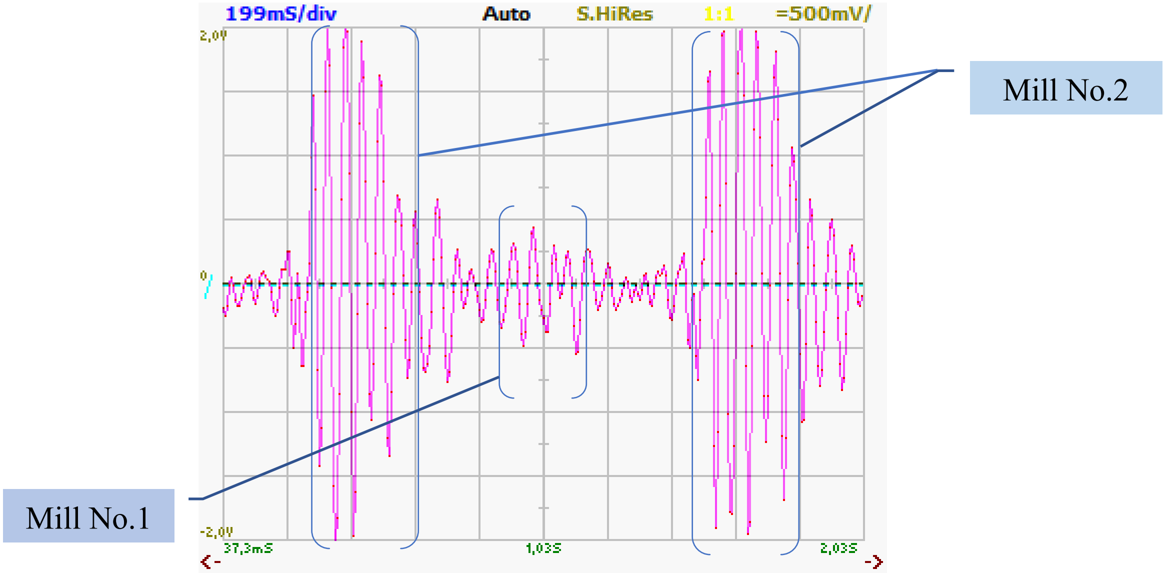

Figure 8 – Oscillogram of vibrations. Point No.3.
Pilger mill No.2 is in operation. (1 div. Y axis = 1.5 μm, 1 div. X axis = 0.2 s)

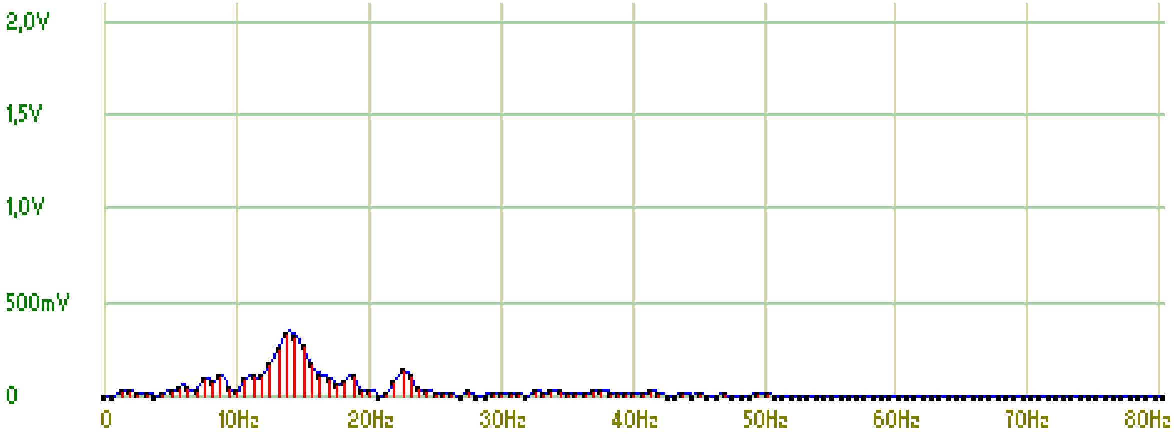

Figure 9 – Spectrogram of the “background” amplitude of vibrations when the mills No.1 and 2 are inoperative. Point No.3.

Point No.4

At point No.4 with the operating pilger mill No.2, the following vibration parameters have been recorded: the maximum vibration amplitude has been recorded at 250 μm at a frequency of a pulsed load of 1.2 Hz (see Fig. 10).

At point No.4, a “background” vibration at a level of ≈ 30 μm at a frequency of 15 Hz is observed, which is somewhat higher than at other points and is probably related to the approach to the source of these vibrations while moving from point No.1 to point No.4 (see Fig. 11).

Thus, in the process of measuring the parameters of vibrations in the pass-through cable tunnel under the industrial facility at the mark -5,200 under the pilger mills No.1 and No.2, the following has been established:

– The maximum amplitude of vibrations from the operation of pilger mills has been determined when pilger mill No.2 was operating at point 4 and is equal to 250 μm at a frequency of a pulsed load of 1.2 Hz.

– High values of vibrations from mill No.2 at points No.1 and No.2 (located under mill No.1); the vibrations from mill No.1 at points No.3 and No.4 (being under mill No.2) practically do not exceed background vibrations. And also, the fact that the maximum recorded value of the vibration amplitude of the cable tunnel when pilger mill No.2 is operating is 2.5 times larger than the amplitude of vibrations when pilger No.1 is operating suggests that the machine No.2 has more influence on the dynamic picture of the cable tunnel.

– With inoperative pilgrim mills No.1 and No.2, the amplitude of forced vibrations of the sections of the pass-through cable tunnel is also non-zero and increases from 10 to 30 μm as it moves from point No.1 to point No.4 (apparently in the direction to the source of vibrations), the frequency of this type of forced vibrations (called “background” in the article) is 15 Hz. Despite their relatively small amplitude, these vibrations can also contribute to the base deformation, compared to the amplitude of vibrations from impulses during the operation of pilger mills, however they have a greater number of effective impulses at a higher frequency.

Apparently, the structure of the foundations of pilger mill No.2 may have a zone of direct transmission of dynamic loads on the structures of the cable channel. This assumption is also supported by the fact that the greatest local violation of the geometry of the tunnel (displacement of sections of prefabricated cable tunnels in a vertical plane relative to each other about 20 cm) is also located in the area of point No.4.

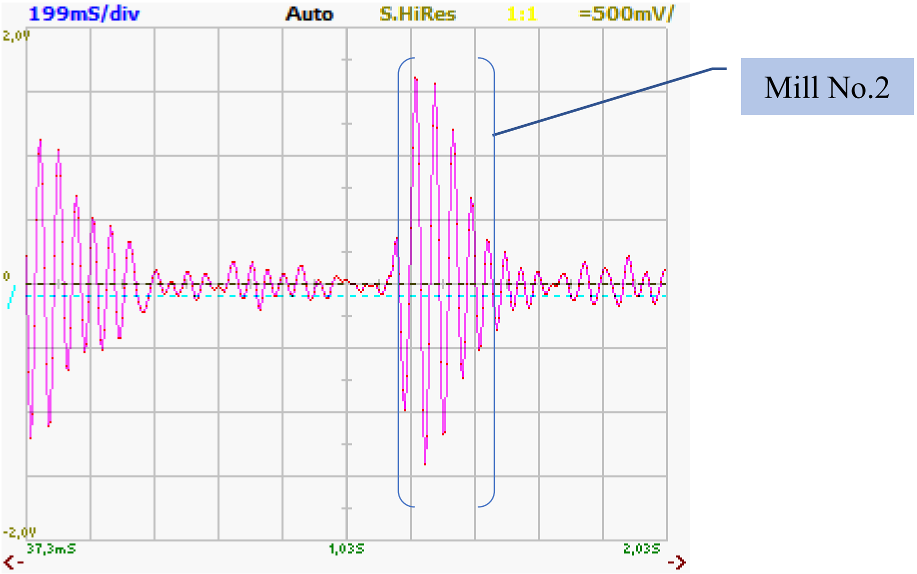

Figure 10 – Oscillogram of vibrations. Point No.4.
Pilger mill No.2. is in operation (1 div. Y axis = 37.5 µm, 1 div. X axis = 0.2 s)

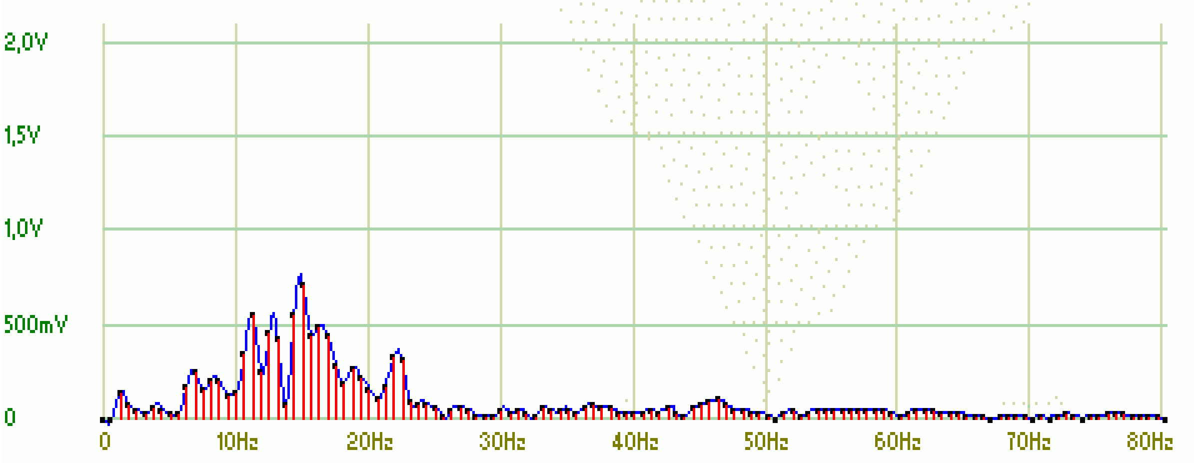

Figure 11 – Spectrogram of the “background” vibration amplitude when mills №1 and №2 are inoperative. Point No.4

Conclusions

The research of vibration parameters at various points along the length of the cable tunnel in the range of vibrations from pilger mills indicates a tendency for increase of vibrations from point No.1 to point No.4. On the plan of an industrial facility, point No.1 is the closest to pilger mill No.1, and point No. 4 is the closest to pilger mill No.2. Based on the nature of the violation of the tunnel geometry, its uneven settlement is observed from point No.1 to point No.4 with an extremum near point No.4. By the nature of the measured parameters of dynamic loads, pilger mill No.2 makes a greater contribution to the dynamic load on the cable tunnel structure with the maximum value near point No.4, which led to the maximum displacement of the cable channel sections near this point. The current situation directly indicates the need for a detailed account of dynamic loads not only when designing foundations for metallurgical machines, but also when constructing other underground structures located in the zone of vibrations propagation.

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