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**Mikalai Shepelevich,** PhD in Engineering Science, head of the scientific and research laboratory, Institute BelNIIS RUE, Minsk (Belarus)
**Aliaksei Kanaplitski,** Master of Technical Sciences, Research Assistant, Institute BelNIIS RUE, Minsk (Belarus)

**Шепелевич Николай Иосифович,** канд. техн. наук, доцент, заведующий научно-исследовательской лабораторией РУП «Институт БелНИИС», г. Минск (Беларусь)
**Коноплицкий Алексей Леонидович,** магистр технических наук, научный сотрудник РУП «Институт БелНИИС», г. Минск (Беларусь)

# EXPERIMENTAL STUDIES IN VIBRATION-INSULATING PROPERTIES OF BLOCKS IN RESILIENT FASTENING FOR METRO RAIL TRACK

# ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ВИБРОИЗОЛЯЦИОННЫХ СВОЙСТВ БЛОКОВ УПРУГОГО КРЕПЛЕНИЯ РЕЛЬСОВОГО ПУТИ МЕТРОПОЛИТЕНА

## ABSTRACT

*The results of experimental studies in vibration-insulating characteristics of a resilient rail track of metro are given. The studies were carried out on fragments of a rail track made of reinforced-concrete slabs with the dimensions 1.5 x 3 x 0.2 m, with the rail grid fragments installed on them (in concrete), made of: 1 – vibration-insulating blocks, EBS system; 2 – concrete blocks with the resilient fastening system, 300 UTS Vossloh; 3 – timber sleepers (the basic option). The static stiffness values of vibration-insulating blocks system were as follows: 17.9 kN/mm, for EBS type blocks (the vibration-insulating pad and the resilient insulation layer), and 17.2 kN/mm, for 300 UTS Vossloh type blocks (vibration-insulating pad stiffness). Tests were carried out by installing a vibration exciter on the rail track, with the weight 75 kN, provided with two industrial* *vibrators: 1 – with the exciting force 20 kN and frequency 50 Hz; 2 – with the exciting force 24.2 kN and frequency 25 Hz. The values of maximum root-mean-square vibration acceleration readings taken in test points of the concrete seat were used to assess the degree of vibration insulation for rail track systems. The vibration acceleration levels were measured in 31.5 Hz and 63 Hz frequency ranges; for this purpose, Oktava 101-VM three-channel vibration meter was used. The software, R110, version 1.20, was used to process the signals from vibration sensors.*

*It was found that, from two types of concrete blocks, the highest vibration insulation for the rail track seat is provided when EBS type blocks are used. In the root-mean-square frequency range 31.5 Hz, the vertical vibration level reduction to 4.3 dB was reached; in the frequency range 63 Hz, from 3.0 to 10.6 dB. The vibration level reduction in horizontal directions was, respectively, from 2.7 dB to 13.8 dB and from 3.1 to 11.4 dB.*

*As compared with the rail track on timber sleepers, EBS type blocks provide reduction of vertical vibration in 31.5 Hz frequency range from 3.2 dB to 11.1 dB. As for the vibration level in the rail track seat with EBS type blocks in the horizontal direction (longitudinal and transverse) at frequency 63 Hz, it is higher by 2.5–7.7 dB, that can be explained by damping effect of timber sleepers due to their large size including presence of cracks.*

## АННОТАЦИЯ

*Приведены результаты экспериментальных исследований виброизолирующих характеристик упругого рельсового пути метрополитена. Исследования проведены на фрагментах рельсового пути, состоящих из железобетонных плит размером 1,5 х 3 х 0,2 м, на которых были установлены (в бетоне) фрагменты рельсовой решетки, состоящей из: 1 – виброизоляционных блоков системы EBS; 2 – бетонных блоков с системой упругого скрепления «300 UTS Vossloh»; 3 – деревянных шпал (базовый вариант). Статические жесткости виброизоляционной системы блоков составляли 17,9 кН/мм – для блоков типа EBS (виброизоляционная прокладка и слой упругой изоляции) и 17,2 кН/мм – для блоков типа «300 UTS Vossloh» (жесткость виброизоляционной прокладки). Испытания выполнены путем установки на рельсовый путь* *вибровозбудителя весом 75 кН, снабженного двумя промышленными вибраторами: 1 – с вынуждающей силой 20 кН и частотой 50Гц; 2 – с вынуждающей силой 24,2 кН с частотой 25 Гц. О степени виброизоляции систем рельсового пути судили по величине максимальных среднеквадратичных виброускорений, измеренных в контрольных точках бетонного основания. Уровни виброускорений замеряли в частотных полосах 31,5 Гц и 63 Гц с помощью трехканального виброметра «Октава 101-ВМ». Обработка сигналов вибродатчиков производилась с использованием программного обеспечения – «R110 Version 1.20».*

*Установлено, что из двух типов бетонных блоков наибольшая виброизоляция основания рельсового пути достигается при применении блоков типа EBS. В среднеквадратичной частотной полосе 31,5 Гц достигается снижение уровня вертикальной вибрации до 4,3 дБ, а в частотной полосе 63 Гц – от 3,0 до 10,6 дБ. Уровень вибрации в горизонтальных направлениях снижен, соответственно, от 2,7 дБ до 13,8 дБ и от 3,1 до 11,4 дБ.*

*В сравнении с рельсовым путем на деревянных шпалах блоки типа EBS обеспечивают снижение вертикальной вибрации в частотной полосе 31,5 Гц от 3,2 дБ до 11,1 дБ. Уровень же вибрации в основании рельсового пути с блоками типа EBS в горизонтальном направлении (в продольном и поперечном) на частоте 63 Гц выше на 2,5–7,7 дБ, что можно объяснить демпферным эффектом деревянных шпал вследствие их большого объема, в т.ч. и наличием трещин.*

**Keywords:** vibration-insulating reinforced-concrete blocks, metro rail track fragments, vibration insulation tests, vibration accelerations.

**Ключевые слова:** виброизоляционные железобетонные блоки, фрагменты рельсового пути метрополитена, виброизоляционные испытания, виброускорения.

## INTRODUCTION

Until recent times, timber sleepers laid in track concrete were used as a rail seat. However, the experience of operation of these structures has demonstrated that they have several inherent disadvantages; the most significant are shorter service life and high maintenance expenses (sleepers must be replaced frequently).

As for the current world practice in construction of new metro lines and refurbishment of existing ones, widespread application is gained by the so-called resilient rail track fastening systems with reinforced-concrete blocks used in them; among these systems, the following are noteworthy:

– LowVibrationTreck (LVT) system consisting of a concrete block (a half tie), a vibration-insulating pad and a rubber cover embedded in track concrete;
– EBS, the insulated rail system where a concrete support block is set into a prepared tray (or a niche in concrete) with a resilient vibration-insulating pad laid on its bottom, and filling compound (resilient layer) is laid between the tray and the block;
– 300 UTS system including a concrete block and a rail fastening set, 300 UTS Vossloh, provided with a vibration-insulating pad.

Each of the aforementioned systems has its advantages and disadvantages (in terms of economic characteristics, manufacturing technology, specific features of application at a construction site, vibration reduction degree, operating costs etc.). When the designers choose one or another resilient fastening system for the metro rail track, they must carry out the comprehensive analysis covering all characteristics including considerations of location of the metro section to be designed [1–2].

For example, for Petrovshchina–Malinovka section in the second line of the Minsk Metro, EBS system vibration-insulating blocks made by *Tines* company were applied. Taking into consideration the experience (in general, positive) of operation of the test section, this this resilient fastening system for the rail track will also be used for construction of the third line of the Minsk Metro. For this purpose, production of vibration-insulating blocks will be arranged at the Reinforced-concrete Articles Plant, *Minskmetrostroi* OJSC, and the task of preparation of technical documentation for manufacturing of blocks was given to the *Institute BelNIIS* Republican Unitary Enterprise (RUE).

The goal of these studies is the determination of vibration insulation characteristics for various metro rail track systems and the selection of the most effective design (in terms of vibration insulation) of the resilient fastening for the metro rail track.

## DESIGNING VIBRATION-INSULATING BLOCKS

During the development of design solutions for blocks of the resilient fastening for the rail track, two design systems were taken by the *Institute BelNIIS* RUE as analogs:

- EBS, as having high vibration protection in vertical and horizontal directions;
- 300 UTS, as more cost-effective in manufacturing and operation of the rail track (vibration-insulating pads are easily replaceable). See Figure 1–2 for the design solution for blocks of the aforementioned systems.

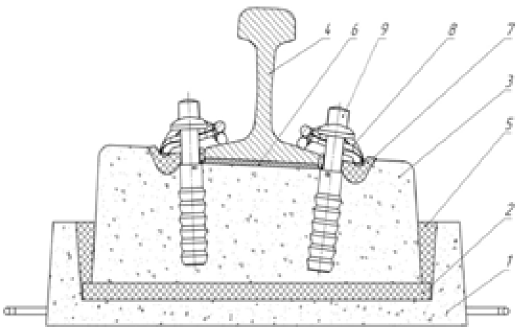



**Figure 1.** EBS type block design
1 – tray; 2 – cushion pad; 3 – support block; 4 – rail; 5 – insulation layer; 6 – rail pad; 7 – slab; 8 – clamp; 9 – screw

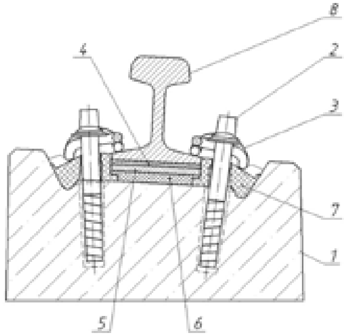



**Figure 2.** 300 UTS Vossloh type block design
1 – block; 2 – screw; 3 – clamp; 4 – rail pad; 5 – steel plate; 6 – cushion pad; 7 – angle unit; 8 – rail

After all necessary R&D and experimental activities, the Research Laboratory of Designs for Utilities in the *Institute BelNIIS* RUE has developed the working drawings and specifications for vibration-insulating blocks and has carried out the activities for their implementation in production. The major conditions for the development of block designs are: vibration insulation efficiency; operational reliability (interrepair time); cost. However, the first factor is critical for metro sections running in the direct vicinity of residential and public buildings.

## PROCEDURE FOR DETERMINATION OF VIBRATION INSULATION PARAMETERS

The procedure is based on determination (measurement) of maximum root-mean-square vibration accelerations in test points at a reinforced-concrete seat of the rail track fragments by bench tests.

The block-and-rail grid was tested by the combined impact of the static ($\mathbf{P}_{st}$) and dynamic ($\mathbf{P}_{dyn}$) vertical loads. Three types of rail track fragments were tested:

I – with vibration-insulating blocks, EBS type;

2 – with vibration-insulating blocks with 300 UTS Vossloh fastening;

3 – with standard timber sleepers.

The static stiffness of vibration-insulating blocks in vertical direction (according to the results of tests of reference specimens) was 17.9 kN/mm, for EBS blocks, and 17.2 kN/mm, for blocks with 300 UTS Vossloh fastening.

The rail track fragments are made by embedding the blocks in concrete on the seat made of reinforced-concrete slabs with the dimensions 1.5 x 3 x 0.2 m. The fragments were laid (on sand cushion, 30-50 mm thickness) horizontally on the earth foundation and buried by 100 -150. Each fragment contained four vibration-insulating blocks, with two rails, R50 type, 1.5 m length. The distance between block axles in transverse direction is 610 mm, the distance between rail heads is 1520 mm.

The static component of the load from the vibration exciter was made by four concrete blocks, FBS (foundation wall concrete) block type, laid on a support frame, with their main beams resting on a rail grid of a fragment at the level of vibration-insulating blocks. The total weight of blocks and the support frame was about 75 kN. The dynamic component was made by two industrial vibrators:

- IV-105, with the frequency 25 Hz and the exciting force $\mathbf{P}_{dyn} = 24.2$ kN;
- IV-107-A, with the frequency 50 Hz and the exciting force $\mathbf{P}_{dyn} = 20$ kN.

The blocks were set in a conductor and fastened on a support frame, prevented from shifting. The vibrators were rigidly fastened on intermediate beams (symmetrically at two sides) of a support frame at the level of a center of a rail head. Signal reading sensors were fastened on a concrete seat by studs installed in the concrete seat in three directions: X (across the rail), Y (along the rail) and Z (vertically). The sensor installation positions were located as follows: 1 – rail seat (between blocks); 2 – along the axle Z, on the concrete seat (near the block); 3 – along the axle Y, on the end surface of the fragment; 4 – along the axle Z, on the slab surface; 5 – along the axle X, on the end surface of the concrete seat (see Figure 3 for the fiagram).

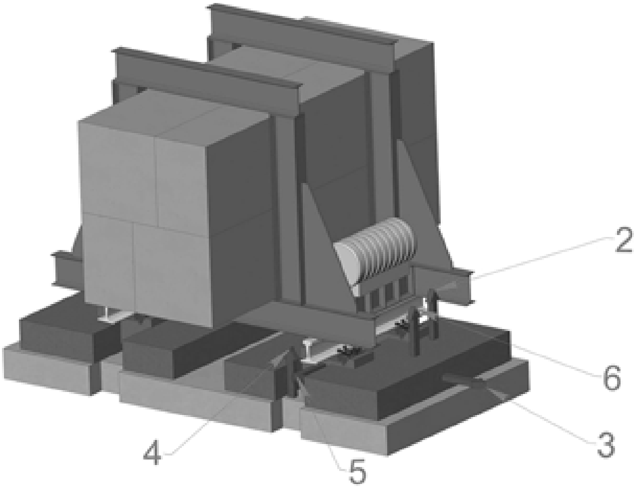



**Figure 3.** Diagram of arrangement of sensors on the rail grid fragment

See Figures 4 and 5 for the appearance of rail grid fragments and the testing equipment.

The three-channel vibration meter, Oktava 101-VM, with the reading ranges 1…1000 Hz for frequency and 80…183 dB for vibration (referred to $10^{-6}$ m/s$^2$), and the measurement error ±0.5 dB, was used to read the levels of vibration (vibration accelerations). The vibration meter was set 6 m apart from the vibration stand, and connecting wires were used to connect it to the notebook (for signal writing) and to the sensors; see Figure 6.

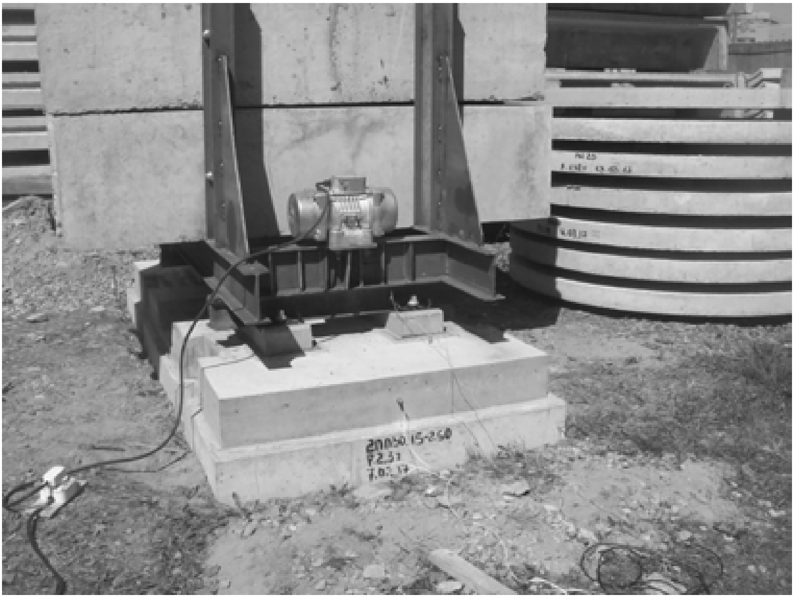


**Figure 4.** Appearance of a rail track fragment with EBS type blocks

**Figure 5.** Appearance of a vibration exciter when it is installed on the fragment made of sleepers

**Figure 6.** Appearance of a rail track fragment with 300 UTS Vossloh blocks and the testing equipment

The test was carried out in accordance with the procedure as follows:

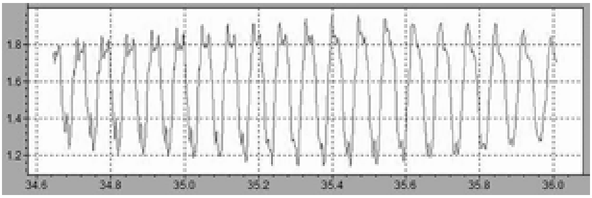
- switching on the vibrator IV-105 and writing the signal from sensors No.1–3;
- switching off the vibrator IV-105 and stopping the signal writing after 5 s;
- connecting the sensors No.4–6, switching on the vibrator IV-107-A and writing;
- switching off the vibrator IV-107-A and stopping the writing operation after 5 s.

The same was the test procedure with the vibrator IV-107-A-1,5 (50 Hz). Signals from vibration sensors were written after receiving the stable spectrum of vibration acceleration levels (on the notebook screen). The signal averaging time interval was 1 s. Measurements were repeated at each fragment of the rail grid. The software, R110, version 1.20 (used for OKTAVA type instruments), was used to process the records from vibration sensors.

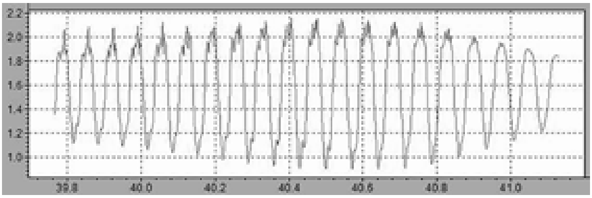
## VIBRATION TEST RESULTS

See Figures 7–8 for vibration records with root-mean-square values of vibration accelerations (in $m/s^2$) received from the sensor No.2 (vertical) for three types of fragments of the rail grid in time intervals (in seconds) before and after switching the vibrators off. The vibration record for the fragment No.1 (with EBS blocks) affected by the exciting force $\mathbf{P}_{dyn}$=24.2 kN with the frequency $\nu$ =25 Hz (the vibrator IV-105) demonstrates smaller amplitude values («peak-to-peak») of vibration accelerations as compared with similar vibration records for fragments No.2 (with blocks using the fastening 300 UTS Vossloh) and the fragment No.3 (with sleepers). When the fragments are affected by the exciting force $\mathbf{P}_{dyn}$=20 kN with the frequency $\nu$ =50 Hz (the vibrator IV-107-A), the vibration acceleration amplitudes are slightly reduced. Here, the fundamental mode in both cases corresponds to the natural (fundamental) oscillation frequency for fragments, ≈16–17 Hz.

a



b



c

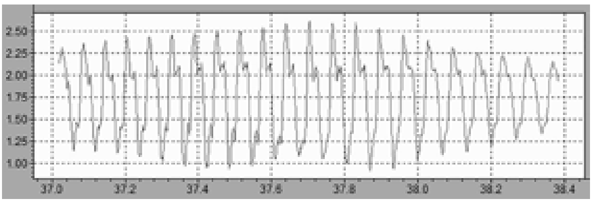


**Figure 7.** Vibration records from the sensor No.2 for $P_{dyn}$= 24.2 kN and v = 25 Hz
*a* – rail track fragment with EBS blocks; *b* – rail track fragment with 300 UTS Vossloh blocks; *c* – rail track fragment with timber sleepers

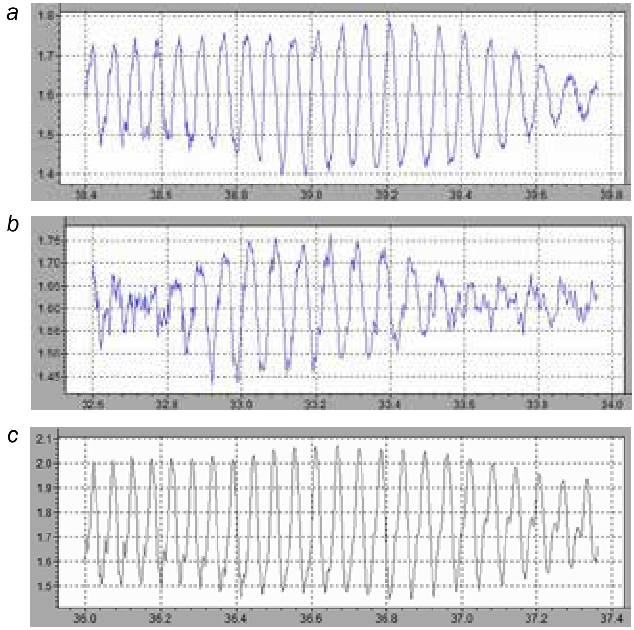



**Figure 8.** Vibration records from the sensor No.2 for $P_{dyn}$=20 kN and v = 50 Hz
a – rail track fragment with EBS blocks; b – rail track fragment with 300 UTS Vossloh blocks; c – rail track fragment with timber sleepers

In Sanitary Regulations, as a rule, root-mean-square values of the vibration speed (mm/s) or vibration acceleration ($mm^2/s$) measured in the specified frequency range, or their estimated levels (in decibels) referred to the specified (threshold) value [3], are used for assessment of the vibration impact. For comparative assessment of effectiveness of different vibration-insulating systems (as it is the case here), as a rule, vibration levels (in dB) are measured in specified frequency ranges.

Figures 9 and 10 demonstrate (for illustration) the diagrams of vibration acceleration levels derived from records of signals received from vibration sensors on the rail track fragment with EBS type blocks, for $\mathbf{P}_{dyn}$=24.2 kN and $\boldsymbol{\nu}$ =25 Hz, in 1/3 and 1 octave ranges.

Similar diagrams of vibration acceleration levels are plotted for rail track fragments with blocks 300 UTS Vossloh and for the fragment with timber sleepers including the cases with $\mathbf{P}_{\mathbf{dyn}}$=20 kN and $\boldsymbol{\nu}$ =50 Hz (not demonstrated here).

Root-mean-square levels of vibration acceleration values are derived (measured) as referred to the threshold value, $1x10^{-6}$ m/s$^2$ (it is preset in the signal decoding software). Permissible levels of vibration accelerations listed in sanitary regulations, as a rule, correspond to the threshold value $3x10^{-3}$ m/s$^2$, i.e. recalculation is necessary for comparison.

See Table 1 for comparative values (difference between readings of respective vibration sensors) of vibration acceleration levels for rail grid fragments made of EBS type blocks and blocks with 300 UTS Vossloh type fastening, and the fragment with the rail grid made of timber sleepers.

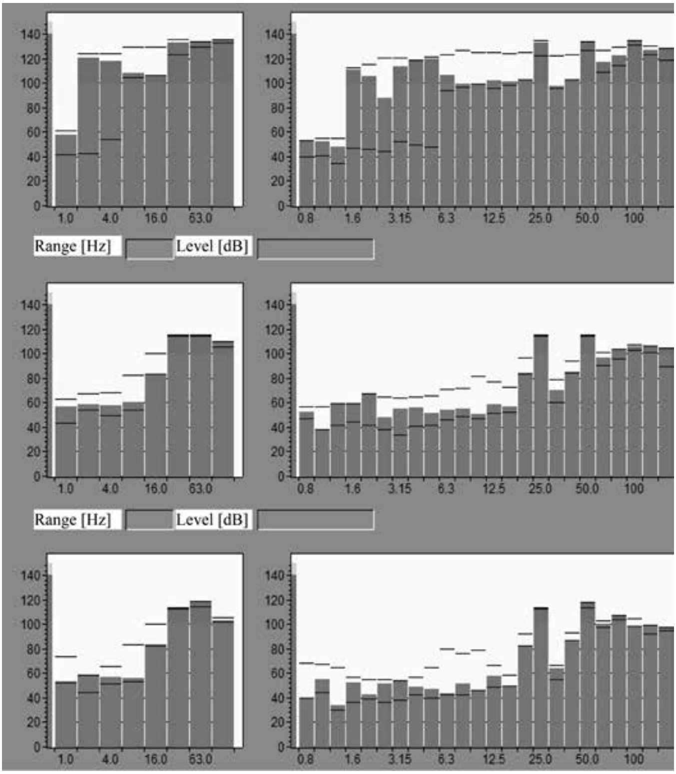



**Figure 9.** Vibration acceleration levels from sensors 1–3 on the rail track fragment with EBS blocks

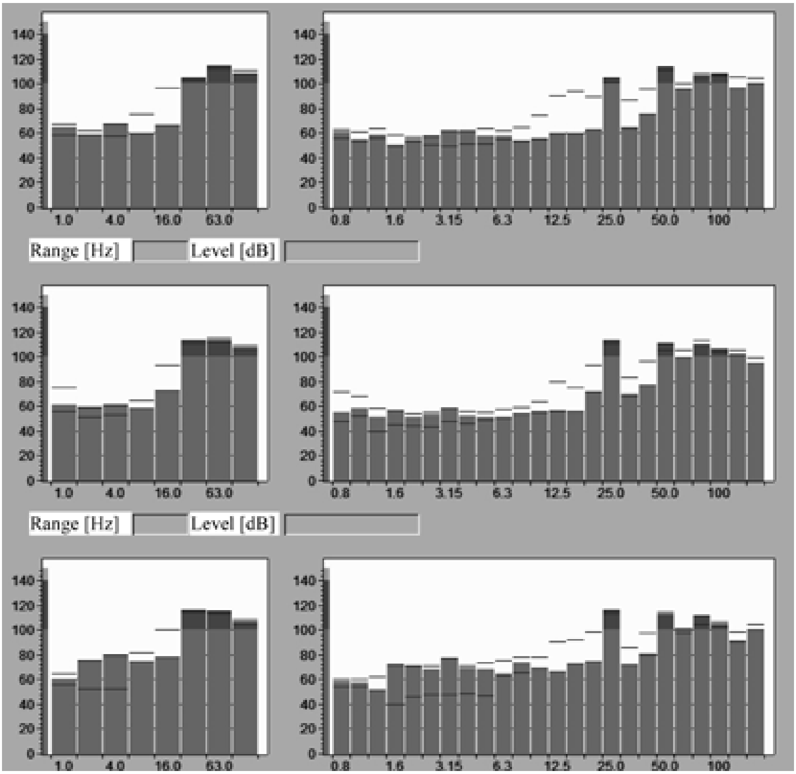



**Figure 10.** Vibration acceleration levels from sensors 4-6on the fragment No.1

*Table 1*

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBS and 300 UTS Vossloh blocks** | | | | | | **EBS blocks and sleepers** | | | | | |
| | **Vibrator IV-105 U2 (25 Hz)** | | | | | | | | | | | |
| Sensors, No. | 1 | 2 | 3hor. | 4 | 5hor. | 6 | 1 | 2 | 3hor. | 4 | 5hor. | 6 |
| Reduction (–) / rise (+), dB | 31.5 | | | | | | | | | | | |
| | | +1.2 | -2.7 | +3.6 | -5.5 | -2.6 | | -7.9 | -3.6 | -17.6 | -7.5 | -11.1 |
| | 63 | | | | | | | | | | | |
| | | -3.0 | -3.1 | -8.4 | -5.4 | -10.6 | | -0.7 | +8.5 | -15.8 | -9.7 | -12.0 |
| | **Vibrator IV-107A-1,5 U2 (50 Hz)** | | | | | | | | | | | |
| Reduction (–) / rise (+), dB | 31.5 | | | | | | | | | | | |
| | | +2.9 | -8.5 | -8.0 | -13.8 | -4.3 | | -10.7 | -10.5 | -2.9 | -5.6 | -3.2 |
| | 63 | | | | | | | | | | | |
| | | -9.8 | -11.4 | -5.8 | -6.2 | -7.6 | | -2.4 | +7.7 | +4.0 | +2.5 | -0.2 |

The analysis of results of vibration tests demonstrates that, from two types of reinforced-concrete blocks with resilient fastening, the maximum vibration insulation for the concrete seat of a rail track is provided when EBS type blocks are used.

In the frequency range 31.5 Hz, reduction is reached for levels of root-mean-square values of vertical vibration accelerations, from –2.9 dB (minus means negative value) to 4.3 dB; in the frequency range 63 Hz, from 3.0 to 10.6 dB. The vibration level reduction in horizontal directions (along and across the rail track) was, respectively, from 2.7 dB to 13.8 dB and from 3.1 to 11.4 dB.

It should be noted that the effectiveness of vibration insulation for the rail track depends significantly on stiffness (static and dynamic) of the resilient fastening. In vibration insulation systems under consideration, vibration-insulating pads are used to provide required stiffness in the vertical direction. In EBS system blocks, Sylodin type vibration-insulating pads with the static stiffness 8.2 kN/mm were installed. As a result, total vertical static stiffness of the system (including the resilient insulation layer) was ≈17.9 kN/mm.

Static stiffness of the rail fastening 300 UTS Vossloh was 17.2 kN/mm, i.e. static stiffness values in vertical direction are similar for both systems. However, EBS system blocks are fastened resiliently in horizontal directions (along and across a rail) also, while stiffness of the 300 UTS Vossloh system rail fastening in horizontal direction (e.g. perpendicular to the rail) is significant. Thus, EBS type blocks provide significant reduction of vibration in horizontal direction, while the levels of vertical vibration for fragments differ insignificantly (due to almost equal static stiffness).

As compared with timber sleepers, EBS type blocks provide reduction of the vertical vibration level from 3.2 dB to 11.1 dB in the frequency range 31.5 Hz. It should be noted that this frequency range covers natural oscillation frequencies for reinforced-concrete floors in residential and public buildings. This circumstance is the critical factor for application of one or another type of the resilient fastening system for metro rail track.

As for the horizontal vibrations (in longitudinal and transverse directions) in the frequency range 63 Hz, it is higher by 2.5–7.7 dB for a rail grid fragment with EBS type blocks than for a fragment with timber sleepers. This effect can be explained by damping effect of timber sleepers (embedded into concrete in the seat) demonstrated both along and across the rail track due to their large (as compared with blocks) size including presence of cracks.

It should be noted also that the rail track on timber sleepers does not provide the required reduction of the vertical vibration level in the frequency range 31.5 Hz and does not meet up-to-date requirements in terms of operational reliability due to short service life of timber sleepers.

## CONCLUSION

The results of vibration tests for rail track fragments have demonstrated that, for arrangement of the resilient metro rail track, preference in terms of vibration-insulating capacity shall be given to EBS type blocks providing significant reduction of vibration levels both in vertical and horizontal directions. The resilient rail fastening system 300 UTS Vossloh does not provide the rail track vibration insulation in horizontal direction (longitudinal and transverse), and application of this system is reasonable for sections where the level of impact of horizontal vibration waves is not critical.

Rail track fragments with timber sleepers, as compared with EBS type blocks, do not provide the required reduction of the vertical vibration level in the frequency range 31.5 Hz, while this range covers fundamental natural oscillation frequencies of reinforced-concrete floors in residential, administrative and industrial buildings.

The EBS type blocks for resilient fastening of the rail track will be used in the first starting-up section in the third line of the Minsk Metro. It is expected that not only reduction of the vibration level will be reached but also reduction of noise level at stations and in the tunnel during movement of trains. Further studies in effectiveness of application of vibration-insulating blocks will be carried out within the scope of commissioning (starting-up operation) of the first section in the third line.

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