

Ensuring vibration safety of megalopolises from influence of the subways

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Abstract. This article is presented analyse of the latest technical methods and their realization for decrease in vibration impact of the subway on the housing estate and recommendations about decrease in vibrations from train service of the subway are provided in the houses located along Marshall Biryuzov Street from No. 11 to No. 34.

1. The first section in your paper

Development of the latest technologies, one of the priority directions in the town-planning sphere during creation of the steady environment and full-fledged life of society. In big agglomerations the main place is taken by transport infrastructure.

Today the Government of the Russian Federation allocates the key place to extra street rail transport connections, such as railroads and subway. In turn the last is the difficult mechanism, at the same time the fastest and with big passenger traffic. The developed length of lines of the subway in Moscow contains about 801.3 km of a way passing under buildings and constructions.

We seldom pay attention to the vibration influence arising in buildings where we should be, work and live. Rather we pay attention to noise, that is to the air fluctuations coming to us directly from a source, either the so-called secondary or structural noise generated by the fluctuating elements of buildings under the influence of the getting vibration (for example, a ware ring in buffet).

However impact of vibration on the person can have negative consequences even in that case when we don't feel vibration.

In this regard there are rather rigid norms regulating vibration impact on the person who is in the building [1].

It is also possible to note that importance of fight against vibration has found reflection and in number of normative documents: 19 normative documents while to noise– only 8 are devoted to problems of measurement and decrease in vibration.

Expansion of network of the subways within the existing building, construction of housing within a technical zone of the subways, increases in social inquiries to comfort of residential zones I demand ensuring sanitary standards on vibration effect, and sometimes and more strict requirements, in a residential zone of megalopolises.



2. Another section of your paper

Any vibroprotection (or anti-vibration) construction provides dispersion of energy of vibration influence so that the energy which reached a securable object had the allowed level.

Any mechanical system can be considered as the system (set) of the masses connected among themselves by springs and dampers.

Each separate subsystem consisting of mass, a spring and a damper (figure 1), is called oscillator and is characterized by such parameter as natural frequency

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{c}{m}}, \quad (1)$$

where c – dynamic rigidity of a spring and m – corresponding weight.

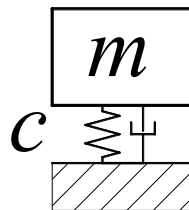


Figure 1. Elementary oscillator

Any oscillator works as the high pass filter, that is:

- 1) If the frequency of exciting influence is less than natural frequency, then this influence passes through oscillator practically without changes.
- 2) If exciting frequency is close or matches natural frequency, there is a resonance phenomenon which is characterized by sharp increase in a vibration amplitude.
- 3) The frequency of exciting influence is higher, the less there will be amplitude of forced oscillations. If the frequency of exciting influence is more, than $\sqrt{2} f_0$, then speak about efficiency of vibroblanking as with further increase in frequency the vibration amplitude of system will be less than amplitude of exciting influence.

Follows from told that in order that through the vibroextinguishing system there did not pass influence with f frequency, natural frequency of the f_0 system shall be at least twice lower.

The frequency is higher, the quicker energy of oscillations dissipates with distance in any environment (the high-frequency signal "whistle" dissipates to indiscernible level through several hundreds of meters, the low frequency signal "tyfon" is heard on several kilometers).

In the following subsection implementations vibroextinguishing (or anti-vibration) constructions are provided.

3. Another section of your paper

Methods of decrease vibrations in buildings near tunnels of the subway can be divided into two big groups: the events held in a tunnel and the events held in the building or near him.

Treat the events held in the building or near it:

- a wall in soil;
- vibration insulation of the building in base level;
- floating floor;
- anti-vibration partitions.

The following belongs to the actions which are carried out in a tunnel:

- laying of the increased elasticity in knots of intermediate fastenings;
- the special vibroextinguishing fastenings;
- undo sleeper laying;
- undo ballast mats;
- weight spring system.

The specified actions are given in a type of the organizational chart in the figure 4 and given in decreasing order of their efficiency.

Actions of the first group, as a rule, will execute at construction of buildings near the existing subway lines though there are cases of vibroprotection of already existing buildings.

The actions providing decrease in vibration in the tunnel can be provided both at construction, and on already operating lines. The truth in the latter case won't exceed efficiency of decrease in vibration 15–20 dB.

Further the actions which are carried out in designs of a way of the subways are considered.

3.1. The vibroextinguishing fastenings

For the system of fastening the role of mass will be executed by the fluctuating part of a rail with the associated neobressorennny mass of crew carried to a wheel. A spring will be one or several elastomer gaskets. The rigidity of elastomer gaskets, as a rule, cannot be lower than 50 kN/mm. In case of neobressorennny mass of the cart of 7500 kg natural frequency of system can be estimated at 30 Hz. I.e. the efficiency of elastic fastenings can begin from 55–60 Hz.

At the same time, than soft gasket of a node of fastening, subjects is more turn of rail section in case of influence of side forces [2]. At the same time the spacer contracts nonuniformly and the efficiency of vibroblanking decreases (figure 2).

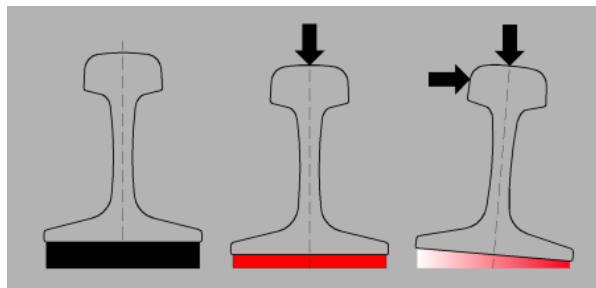


Figure 2. Operation of elastomer gaskets in a fastening node

Such decision was repeatedly realized in Moscow Metro: on a stage the October Field station – the Shchukinskaya station of the Krasnopresnensky line, from the PC 0113+00 to the PC 0116+00 rubber corrugated gaskets 10 and 20 mm thick under fastening like "subway" are laid down; on a stage the Krylatskoye station – the Strogino station of the Arbat and Pokrovsk line contact rail polyurethane spacers 14 mm thick (productions of the company Gettsner or NG-P) on the polimerbeton the korotyshakh of the KR and KRD type are laid down.

The efficiency of spacers on the Arbat and Pokrovsk line was 2–3 dB, and on the Krasnopresnensky line their efficiency so decreased that there was a need of their changeover.

3.2. Elastic laying in contact rail support (*podshpalny laying*)

Elastomer gaskets in contact rail support are most effective for constructions with cross ties (undo sleeper spacers). If contact rail support are not connected on the track width (units, lezhn), then there is the same restriction on rigidity of a spacer under the unit. And, the more unit height, the more will be influence of its turn on change of width of a track. For example, in case of service tests of the railroad switch on the Art. of Troparevo the turn of the units LVT in a lateral axis of a way of the plane is recorded in such a way that vertical relocation of an edge of the unit outside of a track is more than vertical relocation of a sole on a rail axis.

According to the vendor of the units LVT-HA their natural frequency makes 25 Hz, respectively the efficiency will begin approximately with 50 Hz.

In 1995–1996 in case of construction of a section of a section "Volga"– Maryino near the Lyublino station under Sovkhoznaya Street for lowering of vibrations under wooden cross ties laid down the special spacers consisting of two halves when superimposing which closed construction in the form of

a plane parallelepiped with a cavity was at each other created inside. Such construction was applied in the Minsk subway in case of construction of the second line on a stage the station Kupalovskaya– the Nyamiha station in 1990–1991.

However the efficiency of this construction turned out so insignificant that several houses on Sovkhoznaya Street had to be settled.

3.3. Weight spring system

The weight spring system is realized in several options in Moscow Metro (two options near the Art. of Sviblovo with rubber elastic elements) and two options on St. "Exhibition" in the form of the massive plates leaning on cylindrical steel springs of Gerb. Efficiency of vibroprotection on St. "Exhibition" is confirmed with measurements of SES of Moscow.

Schematically the design "weight spring" is presented in the figure 3.

Lack of the weight spring system is its considerable construction height and pointed transfer of load of a tunneling.

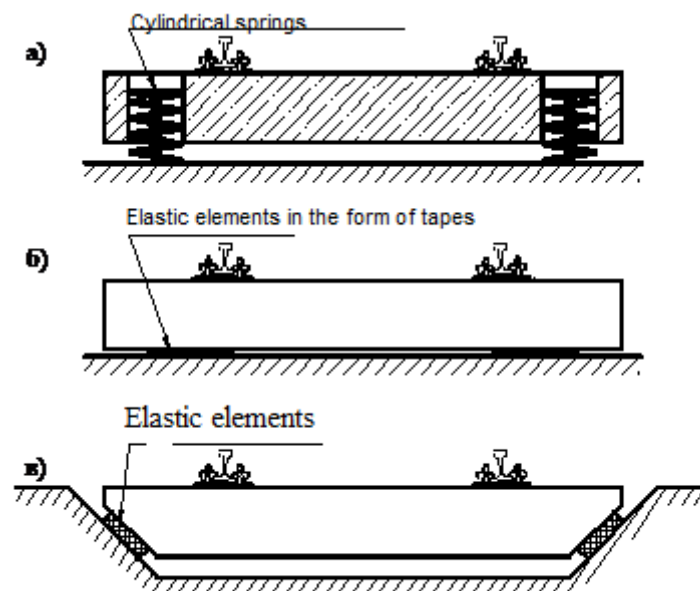


Figure 3. Designs of a way like "weight spring":

- a) A traveling plate on twisted cylindrical springs (it is realized on St. Exhibition (now– St. Business center); b) A traveling plate on elastic elements in the form of tapes (it is realized on the project of Metrogiprotrans on a stage of St. A botanical garden– the Art. of Sviblovo); c) A traveling plate in the form of the return trapeze on the elastic elements working for compression and for shift (it is realized on the project of the engineer Velichko on a stage of St. A botanical garden– the Art. of Sviblovo)

Application instead of springs of plates (up to a continuous supporting) creates drainage system problems from space under plates. Besides, from the weight spring systems more effective are systems with steel springs as in this case static and dynamic rigidity are equal among themselves while in the best polyurethane they differ by 1.3 times, and in rubbers, especially synthetic more than twice.

3.4. Continuous supporting of rails (ERS, Embedded Rail System)

This construction represents a concrete plate with two trenches for laying down of rails. Under a rail lay down a continuous spacer which provides necessary rigidity in the vertical plane. The space on each side of a rail or is flooded elastic material, or filled with different options of spacers. The efficiency is reached at the expense of a continuous supporting (there is no sag between contact rail support) and low rigidity of a contact rail spacer. Side spacers provide spatial stability of a rail.

Though developers declare efficiency to 20 dB in the medium octave frequencies of 16 and 31.5 Hz, nevertheless vertical relocation continuously of a supported rail remain in the range of 1.5–2.5 mm as even the most elastic materials of side spacers will not be able to provide a bigger sag without friction about walls of a trench and as a result of wear.

This technical solution is applied in the subways of Spain and the Warsaw subway (figure 4).

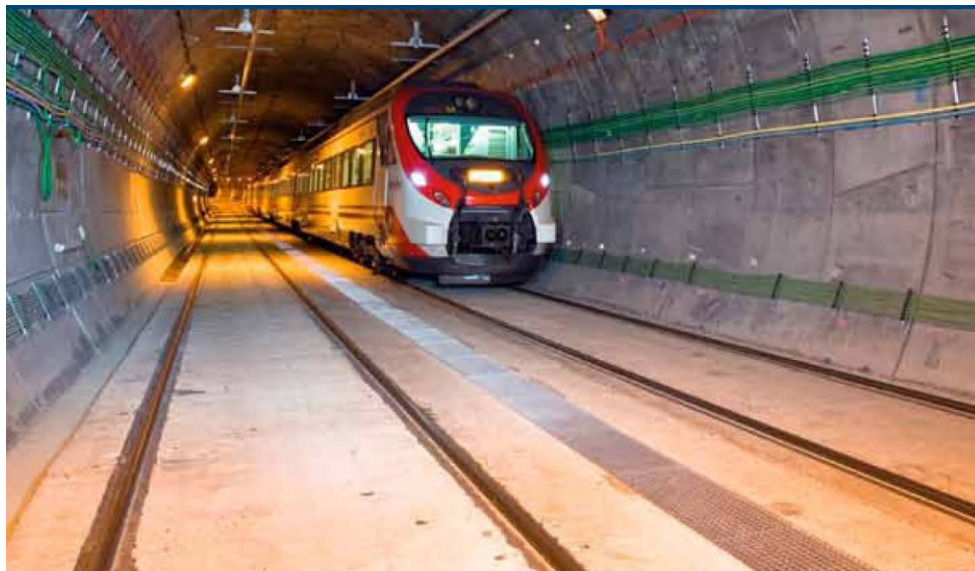


Figure 4. Way of the ERS system in a tunnel of the subway

3.5. VGS-10 system

The elastic system of fixing of VGS is created and patented in 2003 in Russia by ABV group of companies. It for the first time in world practice allowed to reduce vertical rigidity of a contact rail support to 2.5–4 kN/mm, when maintaining horizontal rigidity and resistance to stealing at the level of normal contact rail support.

As showed calculations, and then and practical laboratory tests, VGS has the considerable efficiency in the frequency of 31.5 Hz that does it comparable only to the mass spring systems as any other type of contact rail support and rail fastenings does not provide efficiency in this frequency. Hereinafter in this point the efficiency is considered only in relation to frequency 31.5.

The previous (earlier applied) VGS 2 and VGS 5 models were created with the maximum adaptation to the existing technologies of laying down of a way, tools and rail fastenings that considerably restricted possibilities of growth of their efficiency. Nevertheless, they reduced vibrations on different sections on values from 8 to 21 dB that SES [2] is confirmed by the full-scale measurements taken by different organizations including (and generally). Separately it is necessary to mark that having installation potential on operating sections in night windows, VGS 2 allowed to take measurements most correctly in the same points before its installation. The majority of vibroprotective constructions have no such potential that forces to determine their efficiency by measurements on "similar sections" that is always not absolutely correct because of different soil conditions, depths of tunnels, existence of joints of rails, etc.

The best measured results (comparative measurements on different sections with wooden cross ties and fastening of VGS 5 showed efficiency 18 dB) are received in case of new construction, however and here often the quality of laying down left much to be desired.

VGS 10 became low-detail, threadless (it is unified with ARS-4, see a figure 5), with a broad range of regulation of a rail in the plan and in a profile. Special constructive decisions reduce loads of traveling concrete and anchor bolts, allowing to reduce their cost.

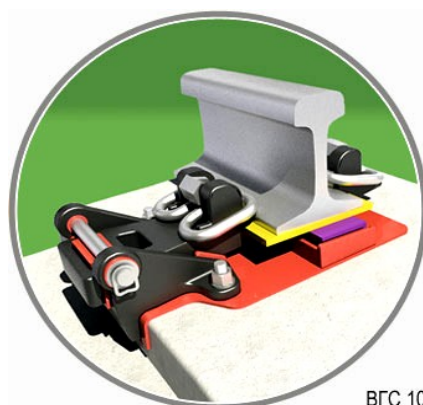


Figure 5. Fastening of VGS 10

The sleeperless design of a way has allowed to change essentially a rail supporting, having increased quantity of elastic contact rail support without changing the number of rail fastenings twice. Thus, the rail was evenly supported, having approached continuously supported rails in designs with the integrated rail (embedded rail).

Thanks to the high level of automation when laying with use of the 3D systems of navigation the probability of the construction marriage influencing efficiency is minimized. The efficiency of VGS 10 will be slightly higher, than at her predecessors. It will be reached at the expense of more evenly supported rail, and at the expense of the accuracy of laying of the rail without speakers on the level of contact rail support.

Besides it is necessary to consider that VGS 10 design (unlike the predecessors) can, in case of need, allow to increase vertical movement of a rail, for example, to 6 mm on those sites where it will be necessary. For this purpose it will be required to replace only material of elastic contact rail support. Installation of additional contact rail support directly on high-precision traveling concrete for providing a continuous supporting of a rail can become other option of the subsequent increase in efficiency.

Lack of VGS-10 is the lack of operating experience.

4. Another section of your paper

The approximate efficiency of the given actions, including by results of direct measurements before their carrying out is presented in table 1.

The data in table 2, values of efficiency, given in the table are received from reports of "Müller-BBM International"[3]; FBUZ "The Center of Hygiene and Epidemiology in the City of Moscow"[4], NO Ekogorod fund[5, 6] and other sources[7–9].

Table 1. Efficiency of actions for decrease in vibrations from a railway tunnel on nearby buildings

Action	Efficiency according to various sources	The efficiency confirmed (the place of realization)
System weight spring	up to 30 dB in the medium octave frequencies of 16 Hz and above	The measured values of vibration haven't exceeded settlement (the Art. Exhibition)*
Subballast mats	up to 25 dB in the medium octave frequencies of 31.5 Hz and above	8.3 dB (GABT)1)
Continuous bearing of a rail	up to 25 dB in the medium octave frequencies of 31.5 Hz and higher 2)	–
Podshpalny pokladka	up to 25 dB in the medium octave frequencies of 31.5 Hz and above	6–18 dB (23 on 1905 year St.) (VSP) 1)
LVT design (Low Vibration Track – a way of the lowered vibration)	5–10 dB is higher than 50 Gts3 of LVT HA)	according to JSC VNIIZhT

Action	Efficiency according to various sources	The efficiency confirmed (the place of realization)
The vibroextinguishing fastenings of VGS 02 and VGS 02MD	up to 12 dB in the octave frequencies of 31.5 Hz and above	11.3 dB (Museum of the Gun-on), 8.3 dB (Bolshoi Theatre) (VGS-02 and their modifications) 1)
VGS5	up to 8 dB in the medium octave frequency of 16 Hz and up to 14 dB–31.5 gts above	up to 3 dB in the medium octave frequency of 16 Hz and up to 18 dB – 31.5 gts and higher 1)
VGS 10	up to 8 dB in the medium octave frequency of 16 Hz and up to 14 dB–31.5 gts and higher 4)	–
Laying of the increased elasticity	up to 2 dB in the medium octave frequencies of 31.5 Hz and above	2 dB (Strogino)

Notes:

- 1) The efficiency is given on the measurements which are carried out on Moscow Metro [4–7];
- 2) According to the Edilon-Sedra company [8];
- 3) According to the Sonnevil AG company [9];
- 4) According to ABV group of companies [10].

Table 2. Comparison of characteristics and parameters of the vibroextinguishing systems

Design type	Efficiency, dB, in an medal octave strip, Gts		Need of concrete works	Approximate time for vibroprotection of the site during the work of 1 crew (2.8 km in single-line calculation), months	Need of polygon tests
	16	31,5			
1	2	3	4	5	6
VGS 02MD	0 (12)	12 (10)	no	6.5	no
LVT-M	-42) (16)	4 (18)	yes	17.5	yes
LVT-HA	-3)	-3)	yes	26.0	yes
VGS 5	3 (9)	18 (4)	yes	17.5	no
VGS 10	84) (4)	144) (8)	yes	10.0	yes

Notes:

- 1) The lack of efficiency, dB is given in brackets;
- 2) The negative value means growth of vibrations;
- 3) There are no data;
- 4) According to the producer.

4.1. Recommendations about decrease in vibrations from the subway

We will consider possible technical solutions on the example of a stage of St. "The October field" – the Art. Shchukinskaya.

From the provided analysis it is possible to draw the following conclusions and recommendations:

1) Ensuring the allowed vibration levels in houses down the street of the marshal Biryuzov requires decrease in vibrations by 12 dB in an medium octava strip of 16 Hz, on 23 dB in an medium octava strip of 31.5 Hz and on 22 dB in an medium octava strip of 63 Hz.

2) It is possible to apply the following designs to ensuring the required efficiency:

- VGS-10;
- continuously supporting rail;
- "weight spring".

However all these actions demand carrying out reconstruction of a way on the problem site.

For the purpose of cutting of costs for vibroprotective measures and reductions of terms of their realization it is possible to offer the following events:

- 1) Replacement of all defective cross ties on the site;
- 2) Fixing of all the shaken of cross ties for ensuring their dense contact with traveling concrete on the lower plate;
- 3) Replacement of all isolating joints on glue-bolt high-strength with metal-composite slips;
- 4) Replacement of intermediate fastenings like "subway" on fastenings of VGS2-50 MD (see table2).
- 5) Welding of all electro wire joints.

After performance of events of the specified actions repeated monitoring of a vibration situation in the buildings which are in a technical zone of the subway on the site of St is necessary. "The October field" – the Art. Shchukinskaya of the Tagansko-Krasnopresnenskaya Line in the volume specified in.

By results of monitoring to make the decision on further actions.

Follows from table 2 that the most effective solution for the operating line is installation of fastenings of VGS 10, however confirmation of their efficiency requires carrying out ground tests.

From the point of view of the smallest time for installation of vibroprotection installation of fastenings of VGS2-50MD is. In case of their installation carrying out concrete operations is not required. However before installation of fastenings of VGS2 it is necessary to revitalize sleepers economy completely: to replace unsuitable cross ties, to fix shaken cross ties for an exception of "keyboard" effect.

From table 2 it is visible that any of the proposed solutions does not provide 100% of lowering of the measured vibrations. Nevertheless it is necessary to consider that the shaken of cross ties ("keyboard" effect) and mechanical joints can make additional effect of elimination from 4 to 8 dB in the octave frequency of 16 Hz and above.

5. Conclusion

New technologies in the modern world allow to improve quality of life of the population, to do the world surrounding us safer and comfortable. Vibroprotection of a way – provides sustainable development of the cities and buildings. These measures will allow to level negative impacts from transport infrastructure on the housing estate and to improve quality of life of people

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