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MEASUREMENT AND ESTIMATION OF UNDERGROUND TRAIN PASSING VIBRATION IN RESIDENTIAL AND ADMINISTRATIVE BUILDINGS

I.E. Tsukernikov*, S.A. Rybak, S.A. Kostarev**, I.A. Nekrasov*****

* JSC NIIpolygraphmash, 57, Profsoyznaya st., 117420, Moscow, Russia

** Vibro-acoustic laboratory, Tunnel Association of Russia, 21, Sadovaya-Spasskaya str., 107217, Moscow, Russia

*** JSC Algorithm-Acoustic, 48A, Otkritoe sh., 107370, Moscow, Russia

Tel.: 007 095 334 24 88 / Fax: 007 095 334 22 66 / Email: algoritm@lt.ru

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ABSTRACT

Based on temporal and spectral character of vibration generated by underground trains and requirements for vibration normalizing set up in residential and administrative buildings by Russian regulations, it is shown, that the most suitable parameter being measured is velocity, namely, its maximum and equivalent frequency weighted root-mean-squared values and the same values in three octave frequency bands with mid-frequencies 16 Hz, 31,5 Hz and 63 Hz. Features of vibration measuring are considered. Procedures for measurement data handling and guidelines for their estimation are described. Limited values for estimation of the frequency weighted velocities to meet the regulations are justified.

1 - INTRODUCTION

Russian Sanitary Norms (SN) 2.2.4/2.1.8.566-96 [1] and the methodical recommendations N° 2957-84 [2] regulate a measurement and estimation of vibration in inhabited and public locations. However because their provisions have a common character, they cannot reflect the complete specificity of the underground operation in modern cities and, accordingly, describe enough precisely and normalize vibration affecting a man from underground trains passing. The theoretical and practical substantiation of the modern approach to the problem of normalization, measurement estimation of the vibration caused by moving underground trains in buildings accommodations are given in papers [3,4]. This paper includes provisions which have been taken as principles of the Draft Russian Standard "Underground. Methods for measurement and estimation of underground train passing vibration in residential and administrative buildings".

2 - MEASUREMENT

Vibration generated in buildings during underground train passings is nonsteady intermittent in character with spectral components predominance at frequency range 11,3-90 Hz and recurred with a period determined by the timetable of the underground train passing. It is sufficient for its monitoring to be limited by measurement of one of the vibration variables: acceleration or velocity. [3]. The both parameters are equivalent with respect to using hardware, procedures of measurement and handling of data. But with relation to assessment of the controlled frequency weighted values the choice of the vibration velocity allows more organically agreeing the requirements to the underground with the requirements of SN [1].

The frequency weighted root-mean square (r.m.s.) value of vibration velocity and r.m.s. velocity values in octave frequency bands are accepted as the measured values describing vibration action. Therewith the last quantities should be registered only in three upper octave bands of the normalized range with the mid-frequencies 16 Hz, 31,5 Hz and 63 Hz. It is due to just as of the above-mentioned spectral composition of the vibration generated by underground trains, so also because the vibration registered in lower frequency bands is completely determined by a background vibration and the signal from underground train passing is practically not picked out [4].

One of the principal question which arises under vibration measurement is the choose of the integration time τ for running averaging the signal being measured when the r.m.s. value is determined (the device dynamic characteristics). The Russian document [2] require dynamic characteristics "slow" (τ=1 s) when a steady vibration is measured and "fast" (τ=0,125 s) by measuring a non-steady vibration. The German standard [5] employs τ=0,125 s independent of the type of the vibration being measured. GOST 12.1.012 [6] sets τ=10 s by measuring the whole-body vibration. In our opinion the deciding argument has to be the human response to vibration exposure. It has been found out the integration time to be required for the vibration perception is reduced from 2 s to 0,8 s at the frequency range 2-90 Hz [7]. This enables to recommend τ=1 s as the most optimum dynamic characteristics independent of the time pattern of the vibration to be assessed.

The measurement should be performed during time intervals marked by one schedule of train passing, for example by the most intensive train movement, which is realized for Moscow Metro from 7 to 9 and from 16 to 19 at day and from 6 to 7 at night.

The total measurement duration T is chosen to be long enough to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are been assessed. This duration is divided into the integer N of the partial time intervals with the duration 30 s (T=30 ×N s). During each thirty second partial time interval is recorded the maximum frequency weighted and octave r.m.s. velocity $\tilde{v}_i^l$, $\tilde{v}_{i,k}^l$, i=1, 2, …, N; k=1, 2,3; l is the number of a schedule during which the measurement is carried out.

3 - MEASUREMENT DATA HANDLING

On measurement evidence a maximum frequency weighted r.m.s. value of velocity is determined:

$$\tilde{v}_{\max}^l = \max_i \left\{\tilde{v}_i^l\right\}, \ i = 1, 2, \ldots, N \tag{1}$$

This value is taken as a value of the maximum frequency weighted r.m.s. velocity $\tilde{v}_{\max}$ in the duration of the reference time interval (complete time interval of the vibration exposure assessment) T_r: 16 hours at day and 8 hours at night, − which is one of the specific characteristics of human exposure to whole-body vibration. The another specific characteristic is the equivalent frequency weighted velocity, which is used to account the time of vibration exposure, and the value of which is calculated by the equation

$$\tilde{v}_{eq} = \begin{cases} B_l \tilde{v}_T^l & \text{if } 0,5 < \tilde{v}_T^{l(bac)} / \tilde{v}_T^l \leq 0,8 \\ C_l \tilde{v}_T^l & \text{if } \tilde{v}_T^{l(bac)} / \tilde{v}_T^l \leq 0,5 \end{cases} \tag{2}$$

where B_l=1 for the day assessment time and B_l=0,8 for the night assessment time; $\tilde{v}_T^l$ and $\tilde{v}_T^{l(bac)}$ are the effective frequency weighted velocities, which correspond to the total vibration during the measurement time interval T and to the background vibration existing during the time intervals between the successive trains passing, and are calculated by the equations

$$\tilde{v}_T^l = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\tilde{v}_i^l\right)^2} \quad ; \quad \tilde{v}_T^{l(bac)} = \sqrt{\frac{1}{N-n} \sum_{i=1}^{N-n'} \left(\tilde{v}_i^l\right)^2} \tag{3}$$

where $\tilde{v}_i^l$ and N are the same quantities as in Eq. (1); n is the number of the train passing events during the measurement time interval T; the stroke at the sum sign means that the only values $\tilde{v}_i^l$ are taken into account which have been recorded during the time intervals when train passing was absent.

The value of constant C_l in Eq. (2) depends on the timetable of the underground trains and the schedule l during which the measurements are carried out and is calculated by the equation

$$C_l = \sqrt{\frac{1}{T_r} \sum_j \frac{\tau_l}{\tau_j} T_j} \tag{4}$$

where T_j is the partial time interval of the vibration exposure when realizing the train movement schedule j; τ_j and τ_l are the train passing intervals in schedules j and l.

Eq. (4) is obtained from meeting the following conditions: the measurement time intervals T for different train schedules are chosen from the consideration that the number of train passing events is constant and the magnitudes of the background vibration effecting during the train absence are insignificant and may be neglected when the values of effective velocities $\tilde{v}_T^l$ are calculated by Eq. (3). The values of the constant C_l for lines of Moscow Metro by measurements being made in a period of the most intensity train moving are given in [3,4].

4 - VIBRATION EXPOSURE ESTIMATION

The following criterions are verified:

- if $\tilde{v}_{max} \leq \tilde{v}_{adm}$ and $\tilde{v}_{eq} \leq \tilde{v}_{eq,adm}$ the vibration is accepted to be admissible;
- if $\tilde{v}_{max} > 2,1\tilde{v}_{eq,adm}$ and $\tilde{v}_{eq} > 2,1\tilde{v}_{eq,adm}$ the vibration is accepted to be inadmissible;
- if $\tilde{v}_{adm} < \tilde{v}_{max} \leq \tilde{v}_{adm}$ or $\tilde{v}_{eq,adm} < \tilde{v}_{eq} \leq \tilde{v}_{eq,adm}$ the conclusion should be drawn from the verification of the spectral velocity values $v_{max,k}$ and $v_{eq,k}$ in three octave frequency bands with mid-frequencies 16 Hz (k=1), 31,5 Hz (k=2) and 63 Hz (k=3);
- if $v_{max,k} \leq v_{adm}$ and $v_{eq,k} \leq v_{eq,adm}$, $k = 1,\, 2,\, 3$ the vibration is accepted to be admissible;
- - if $v_{max,k} > v_{max,k}$ and $v_{eq,k} > v_{eq,adm}$ in any of three octave frequency bands the vibration is accepted to be inadmissible.

The admissible values are taken according to SN [1].

The necessity to set the range of the limit values for the frequency weighted velocities [$\tilde{v}_{adm}$,2,1 $\tilde{v}_{adm}$], [$\tilde{v}_{eq,adm}$,2,1 $\tilde{v}_{eq,adm}$] and to turn to estimation of spectral quantities stems of the fact that the admissible value of the frequency weighted velocity is not equal to the energetic sum of the weighted admissible values of velocity in six octave bands, but are established as the minimum of the admissible values in considered bands. As the result the paradoxical situation may arise: the determined spectral values of the maximum and/or equivalent velocities are less than their admissible values but the frequency weighted velocities are extended above their admissible values. Using the factor 2,1 in the upper limit value makes it possible to avoid this nonsense. This factor follows as result of the energetic sum of the admissible values of velocity in six octave bands of normalized range after frequency weighting them according to [1], [6].

REFERENCES

1. **SN 2.2.4/2.1.8.566-96**, *Industrial vibration, vibration in locations of inhabited and public buildings: Sanitary Norms*, Minzdrav of Russia, Moscow, 1997
2. **R 2957-84**, *Methodical recommendations for a measurement and hygienic evaluation of vibration in living accommodations*, Minzdrav USSR, Moscow, 1984
3. **I.E. Tsukernikov, S.A. Rybak, S.A. Kostarev**, Modern ideas of normalizing, measurement and estimation of vibration in buildings generated by underground trains, In *the 12-th International Symposium "Transport noise and vibration", St.-Petersburg, Russia*, pp. 71-74, 1996
4. **I.E. Tsukernikov, S.A. Kostarev, I.A. Nekrasov**, Choice of a normalized parameter when assessing underground train passing vibration in buildings, In *III All-Russia scientific - practical conference with international participation "New in an ecology and safety of habitability", 16-18 June, 1998, S.-Petersburg*, pp. 525-528, 1999
5. **DIN 4150, Teil 2**, *Erschütterungen in Bauwesen. Einwirkungen auf Menschen in Gebäuden. Deutsche Norm*, DIN Deutsches Institut für Normung e. V., Berlin, 1999
6. **GOST 12.1.012-90**, *OSSS. Vibrational safety. General requirements*, Standard edition, Moscow, 1990
7. **ISO 2631/1**, Evaluation of human exposure to whole-body vibration-Part 1: General requirements. International standard, *International Organization for Standardization, Geneva, Switzerland*, 1985