Effect of general and local vibration of workplace on driver's work process and traffic safety of busses «Volgabus»

A V Popov, G A Chernova*, M V Velikanova and N S Khvan
Volzhsky Polytechnic Institute (branch) of FSBEI of Higher Education Volgograd State Technical University, Volzhsky, Russia

*galina_vat@mail.ru

Abstract. In the article there are given results of research of influence of vibration accelerations of a transmission of buses of Municipal Unitarian Enterprise "Volzhskaya №1732 bus depot" on change of vibration of a workplace of the driver. It is determined that the increased vibration in the workplace of the bus driver may depend not only on external facts in the operating conditions on the route, but also on an internal factor - the vibration of the bus transmission elements. These factors worsen the work conditions of drivers and the tension of the work process, cause fatigue and increase the risk of road accidents. Recommendations are given to reduce vibration acceleration in bus transmissions.

1. Introduction
Vibration in the driver's workplace is one of the most important factors in increasing the difficulty and tension of the work process. Exposure to vibration increases physical and mental fatigue reduces attention and worsens concentration. To establish a possible relationship between vibrations in the driver's workplace and vibroaccelerations of transmission elements, an analysis of the results was made and additional measurements were taken. It has been established that there is a connection between the vibration acceleration of the elements of the transmission, engine, running gear and vibrations in the driver's workplace.

Modern diagnostics and maintenance of transmission components and units can not only increase the life of the vehicle, but also provide the necessary level of vibration for protection of the driver of the vehicle, reduce stress and fatigue, the risk of musculoskeletal system diseases, improve traffic safety.

The aim of the study is to establish a link between increased vibration in the bus driver's workplace and the vibration acceleration of transmission components.

The main task of the work is to determine the influence of general and local vibrations in the driver's seat on the work process and on the safety of driving.

2. Indicators of severity and tension of the driver's work process
The main indicators of the severity and tension of the work process are presented in the normative document "Guidance R 2.2.2006-05 "Guidance on hygienic assessment of factors in the working environment and work process. Criteria and classification of work conditions"[1].

Severity is a characteristic of the work process, reflecting the predominant load on the musculoskeletal system and functional systems of the body (cardiovascular, respiratory, etc.),
providing its activity. Severity is characterized by physical, dynamic activity, weight of lifted and moved items, total number of stereotypical working movements, size of static activity, nature of working position, depth and frequency of inclination of the body, movements in area.

The permitted work conditions (2nd class) are characterized by such levels of environmental factors. The work process that do not exceed the established hygienic standards for workplaces, and possible changes in the functional state of the body are restored during a regulated rest or by the beginning of the next shift and do not have an adverse effect in the nearest and distant period on the health of workers and their descendants. The permitted work conditions are conditionally considered to be safe. Work conditions of drivers refer to the 2nd class, under which all standards and requirements to a workplace are observed.

Harmful work conditions (3rd class) are characterized by the existence of harmful factors that exceed hygienic standards and have an unfavourable effect on the employee's body and/or his descendants.

Harmful work conditions according to the degree of exceedance of hygienic norms and changes in the organism of workers are classified into 4 degrees of harmfulness:

1. level 3 class (3.1) - work conditions are characterized by such deviations of levels of harmful factors from hygienic standards, which cause functional changes, which are usually restored at a longer (than by the beginning of the next shift) interruption of contact with harmful factors and increase the risk of health damage;

2. level 3 class (3.2) - levels of harmful factors that cause persistent functional changes. They lead in most cases to an increase in occupation-related disease. (It can be expressed by an increase in the rate of illness with temporary disability and, above all, those diseases that reflect the condition of the organs and systems most vulnerable to these factors), the appearance of initial signs or minor forms of occupation-related diseases (without loss of professional capability to work) that develop after continuous work.

The tension of the driver's work process corresponds to class 3.3 - level 3 of class 3 as per [1]. This class is characterized by such levels of factors of the working environment, the impact of which leads to the development, as a rule, of professional diseases of light and medium degree of severity (with loss of professional ability to work) in the period of employment, the growth of chronic (professionally caused) pathology.

Vibration at the driver's workplace is one of the most important factors in increasing the severity and tension of the work process. Vibration is high frequency and low amplitude fluctuation. The main sources of vibration in the vehicle are the condition and type of road surface, the work of the engine and transmission units. Vibration accelerations arising in the process of movement increase with increasing speed, deteriorating quality of the road surface, as well as with reducing the useful load. Vibrations can occur in longitudinal, transverse and vertical directions. [2] Studies show that the impact of vibration increases physical and mental fatigue, reduces attention and worsens perception. [3] Vibration has also been shown to affect heart rate, blood pressure and respiration. [4] Prolonged exposure to low-frequency vibration negatively affects the human lumbar spine and increases the risk of pain in this part. [5, 6] Bus drivers are also at risk for musculoskeletal diseases. [7]

The purpose of this research is to establish a connection between the increased vibration in the bus driver's workplace and the vibration acceleration of transmission components, to determine the severity of the bus driver's work process.
3. Vibration research methodology

Buses manufactured by Holding "Bakulin Motors Group" (Volgabus brand) are operated at the Municipal Unitarian Enterprise «Volzhskaya №1732 bus depot» in Volzhsky. Compliance with occupational health and safety standards is one of the priorities of the company's policy; therefore, on request of the carrier, the level of general and local vibration was measured in the bus driver's seat of the following models: "Volgabus-4298G8", "Volgabus-5270GH", "Volgabus-6270". Measurements were carried out by LLC "Test Laboratory "Trud" using the following equipment: Noise meter-vibrometer, spectrum analyzer "Ecophysics-110A", noise and vibration analyzer "Assistant". Local and general vibration have been measured. The unit of vibration measurement is decibel (dB).

Local vibration is classified as operating along the orthogonal system of X, Y, Z-axes. The X axis is parallel to the axis of the source of vibration (steering wheel), the Y axis is perpendicular to the palm, and the Z axis is in the plane formed by the X axis and the direction of supply or force application (or forearm axis when no force is applied). General vibration is classified as acting along the axes of the orthogonal system of coordinates X, Y, Z, where X and Y- horizontal axes are directed parallel to the supporting surfaces; Z - vertical axis perpendicular to the supporting surfaces of the body in places of its contact with the seat, floor, etc., "Fig.1". [8]

Figure 1. Coordinate system of vibration in the driver's workplace.

The department of «Automobile transport» of the Volzhsky Polytechnic Institute (branch) Volgograd State Technical University carried out measurements of vibration accelerations of transmission elements with the help of the device "Algorithm-03" in m/s². When taking measurements, the vibrating instrument sensor was placed in 4 points: in the horizontal plane in the checkpoints on the engine tray (point 1) and gear-box casing (point 2); the suspension bearing housing (point 3) and main gear (point 4).

Measurements in each checkpoint were taken on the three axes X, Y, Z. The direction of the axes in each checkpoint is the same. On the X-axis, the device fixes transmission units' vibrations in the horizontal plane parallel to the bus axis; on the Y-axis, it fixes vibrations parallel to the bridge axis; on the Z-axis, it fixes vibrations in the vertical plane, perpendicular to the site or road. The duration of measurements on each axis was 30 seconds.

To establish the relationship between the vibration acceleration of transmission components and vibrations in the driver's workplace, the data obtained are analyzed, for which the conversion of transmission vibration acceleration measurements is made from m/s² to dB.

4. Results of vibration research

In accordance with [9, 10, 11, 12], the standard values for general (Table 1) and local vibration (Table 2) in the driver's workplace are established.
Table 1. Standard value of general vibration in the driver's workplace.

| The title of the measurable parameters of the working area (bus driver's cab, seat) | Standard value, dB | Work conditions class of [13] |
|---|---|---|
| Equivalent adjusted level: | | |
| X-axis | 112 | 2 |
| Y-axis | 112 | 2 |
| Z-axis | 115 | 2 |

Table 2. Standard value of local vibration in the driver's workplace.

| The title of the measurable parameters of the working area (bus driver's cab, seat) | Standard value, dB | Work conditions class of [13] |
|---|---|---|
| Equivalent adjusted level: | | |
| X-axis | 126 | 2 |
| Y-axis | 126 | 2 |
| Z-axis | 126 | 2 |

According to the Russian State Standard 31319-2006, measurements of general vibration in the workplace of vehicle drivers should be made in real daily conditions of the employee's location in the workplace. According to the requirements of the Russian State Standard R 55855-2013, a number of conditions must be fulfilled, such as: the tires at the vehicle must be without damage, the pressure must be in accordance with the manufacturer's instructions, permissible wear must not exceed 20% of the original height of the protector drawing. The movable adjustable seat where measurements are taken should be adjusted so that it is convenient for the driver to handle the vehicle and drive. In the case of adjustable seat suspension, it shall be adjusted by the weight of the driver to avoid hitting the lower and upper restraints. The weight of the driver should be within the range of 70 to 90 kg. The engine and other vehicle units are heated to operating temperature before testing. The tests are carried out under meteorological conditions: no precipitation; outside temperature from minus 10 °C to +40 °C; wind speed measured at the control section at an altitude of approximately 1.2 m, not exceeding 5 m/s. All requirements have been observed during the measurement.

Based on the results of the study of the vibration of the bus driver's workplace of LLC "Test Laboratory "Trud", the charts are presented in Fig.2,3,4,5.

Based on the actual values of the general and local vibration "Fig.2" at the workplace of the bus driver of the "Volgabus-4298G8", we can draw the following conclusion - the real level of the harmful influence does not match the hygienic standards and work conditions correspond to class 3.

![Figure 2](image-url)
Based on the actual values of general and local vibration "Fig.3" in the workplace of the driver of "Volgabus-5270GH", we can come to the following conclusion - the actual level of harmful influence corresponds to hygienic standards and work conditions correspond to class 2.

![Figure 3. General and local vibration in the workplace of the driver of the Volgabus-5270GH.](image)

Based on the actual values of general and local vibration "Fig. 4" in the workplace of the bus driver of "Volgabus-6270", we can come to the following conclusion - the actual level of the harmful influence does not correspond to hygienic standards and work conditions correspond to class 3.

![Figure 4. General and local vibration in the workplace of the driver of the Volgabus-6270.](image)

Based on the actual values of general and local vibration "Fig.5" in the workplace of the driver of "Volgabus-5270", we can come to the following conclusion - the actual level of the harmful influence does not correspond to hygienic standards and work conditions correspond to class 3.
Figure 5. General and local vibration in the workplace of the driver of the Volgabus-5270.

Combined graphs of general and local vibration are shown in Fig.6. According to the diagrams, it can be concluded that the vibrations in the driver's workplace in the Volgabus-5270GH bus are the smallest in all three axles and do not exceed the standard values, therefore, they correspond to hygienic standards, unlike other studied models of Volgabus buses.

Figure 6. Summary graphs of general and local vibration.
Table 3. Vibration value in the driver's workplace according to bus brands, dB.

| Axis                  | Volgabus-4298G8 | Volgabus-5270GH | Volgabus-6270 | Volgabus-5270 | Norm  |
|-----------------------|----------------|----------------|---------------|---------------|-------|
|                       | actual value   | Class of labor value | actual value | Class of labor value | actual value | Class of labor value | actual value | Class of labor value | actual value | Class of labor value |
| X-axis                | 120            | 3.2            | 98            | 2             | 113            | 3.1            | 116            | 3.1            | 112            |                  |
| Y-axis                | 123            | 3.2            | 101           | 2             | 112            | 2             | 115            | 3.1            | 112            |                  |
| Z-axis                | 126            | 3.2            | 104           | 2             | 111            | 2             | 110            | 2             | 115            |                  |

General vibration in the driver's workplace (driver's seat)

| Axis                  | 118            | 2             | 100           | 2             | 115            | 2             | 118            | 2             | 126            |                  |
| Local vibrations in the workplace (driver's seat)

| Axis                  | 110            | 2             | 102           | 2             | 109            | 2             | 110            | 2             | 112            |                  |
| Local vibrations in the workplace (steering wheel)

| Axis                  | 113            | 2             | 110           | 2             | 118            | 2             | 121            | 2             | 126            |                  |

Considering the measurements of general and local vibrations in the driver's workplace, it can be concluded that out of all four Volgabus brand buses tested, only in the model Volgabus-5270GH, the vibrations in the driver's workplace do not exceed the standard values and fully correspond to hygienic norms, work conditions of class 2. Three out of four investigated buses of Volgabus brand do not correspond to the hygienic norms of work "Fig. 6, Table 3". The reason for this can be the increased vibration acceleration in the elements of the transmission, chassis and engine.

As a result of measurements, the relationship between increased vibration in the workplace of the bus driver and the vibration acceleration of transmission components has been established. Transmission vibration acceleration measurements were taken at idling speed without load (w/l) and under load (l) at several points (engine tray, gearbox flange, rear axle and frame in the center). The measured root mean square (RMS) values of vibration acceleration (m/s²) are shown in Table 4 [13].

The vibration acceleration measurements are in m/s². In order to compare the obtained values with the values of vibration accelerations in the workplace of the bus driver, which have the measurement in decibels (dB) and to analyze the obtained data, it is necessary to convert the bus vibration accelerations from m/s² to dB. Vibrations of bus transmission elements in decibels are shown in Fig. 7. [14].

The following formula is used to transfer from m/s² to dB:

$$A_{dB} = 20 \cdot \log_{10} A + 120,$$

where $$A_{dB}$$ – vibration acceleration in decibels, $$A$$ – vibration acceleration in m/s², 120 dB – level 1 m/s².
### Table 4. Maximum values of current vibration acceleration RMS, m/s²

| Place of sensor installation (Figure 1) | Axes X | Axes Y | Axes Z | Engine rpm speed |
|----------------------------------------|--------|--------|--------|------------------|
| «Volgabus-4298» mileage 15000 km, w/l 600 rpm, 1 gear 650 rpm | 3.5 | 3.4 | 2.2 | 2.3 | 1.1 | 4.8 |
| Gearbox flange | 2.4 | 3.6 | 5.9 | 0.1 | 2.6 | 5.5 |
| Pillar in the center | 4.8 | 5.7 | 3.0 | 3.5 | 5.8 | 5.7 |
| Rear axle | 5.7 | 3.6 | 1.7 | 3.6 | 5.6 | 3.6 |
| «Volgabus-4298G8», mileage 45000 km, w/l 900 rpm, 2 gear 2000-2500 rpm | 0.23 | 0.27 | 0.6 | 4.7 | 0.2 | 0.6 |
| Gearbox flange | 0.15 | 0.25 | 1.1 | 3.2 | 0.3 | 0.6 |
| Pillar in the center | 0.2 | 0.3 | 0.1 | 4.4 | 0.1 | 6.03 |
| Rear axle | 0.1 | 0.6 | 2.0 | 3.7 | 0.3 | 0.25 |
| Bus «Volgabus-5270», mileage 820000 km, w/l 900 rpm, 1 gear 1200 rpm | 2.6 | 5.9 | 4.2 | 43.2 | 45.7 | 48.4 |
| Gearbox flange | 1.5 | 43.2 | 6.8 | 49.0 | 0.5 | 0.7 |
| Frame in the center | - | - | - | - | - | - |
| Rear axle | 922.6 | 1318.3 | 922.6 | 716.1 | 1202.2 | 50.7 |
| «Volgabus-5270», mileage 82000 km, w/l 900 rpm, 1 gear 1200 rpm | 2.4 | 2.3 | 43.7 | 42.2 | 17.2 | 6.2 |
| Gearbox flange | 1.6 | 1.4 | 41.2 | 43.2 | 42.2 | 29.2 |
| Frame in the center | 0.12 | 6.4 | 0.14 | 32.7 | 4.0 | 0.14 |
| Rear axle | 0.21 | 0.2 | 0.2 | 9.7 | 5.1 | 39.4 |
| «Volgabus-5270 G2», mileage 45000 km, w/l 650 rpm, 1 gear 1300 rpm | 0.2 | 0.5 | 4.2 | 40.7 | 15.5 | 15.8 |
| Gearbox flange | 0.2 | 0.2 | 27.2 | 42.7 | 0.2 | 18.8 |
| Frame in the center | - | - | - | - | - | - |
| Rear axle | 0.1 | 0.15 | 3.8 | 38.0 | 0.1 | 16.8 |
| «Volgabus-6270», mileage 370000 km, w/l 900 rpm, 1 gear 1000 rpm | 37.9 | 38.9 | 0.5 | 1.8 | 5.8 | 0.33 |
| Gearbox flange | 6.5 | 0.6 | 43.2 | 19.1 | 0.9 | 6.8 |
| Pillar in the center | 0.2 | 1.2 | 0.4 | 42.7 | 6.0 | 0.2 |
| Rear axle | 0.2 | 3.8 | 0.2 | 0.1 | 0.2 | 4.5 |

Note: w/l - engine speed without load; l - engine speed with load.
Figure 7. Vibrations of transmission elements.

On the Volgabus-5270GH model, the vibration acceleration of transmission components is the smallest in three axes and does not exceed 137dB. On the Volgabus-4298G8, Volgabus-5270 and Volgabus-6270 models, vibration acceleration reaches 153 dB on certain components and units. General and local vibrations in the driver's workplace in the Volgabus-5270GH bus are also the lowest, do not exceed the standard values in the axes X, Y, Z and correspond to the hygienic standards, while in other tested buses the general and local vibrations exceed the standard values, which do not correspond to the hygienic standards.

5. Conclusions
The driver's work is estimated by the tension and severity of the work. The tension of work is related to the factors of the working environment affecting the driver. The severity’s due to the physical activity of the driver.

General assessment of tension of driver's work corresponds to class 3.3 - 3 degree 3 (3.3). Work conditions characterized by such levels of factors of working environment, the impact of which leads to the development of, as a rule, professional diseases of light and medium degree of the seriousness (with loss of professional ability to work) in the period of working activity, the growth of chronic (professionally caused) disease.

According to the results of the study, it can be concluded that there is a certain connection between the vibration acceleration of the transmission, engine, chassis and vibrations in the driver's workplace.

Only Volgabus-5270GH bus drivers have acceptable work conditions (class 2). On the other buses, the standard vibration values are higher. Improper wheel balancing, loose bolts and loose fasteners, excessive play in mating parts etc, can cause increased vibrations of transmission, chassis and engine components. This in turn leads to increased vibrations in the driver's workplace, both local and general. The class of work conditions for drivers of Volgabus by the severity can be set 3.1-3.2.
6. Proposals
In order to improve work conditions for bus drivers, it is necessary to diagnose and maintain these transmission components and units in a proper way. It can not only increase the service life of the vehicle, but also provide the necessary level of vibration protection for the driver, reduce tension and fatigue, the risk of musculoskeletal diseases therefore increase traffic safety, reduce the risk of getting the bus into a traffic accident and save lives and health of not only the bus driver but also the passengers inside the vehicle.

Acknowledgement
The authors are grateful to the specialists of Municipal Unitarian Enterprise “Volzhskaya №1732 bus depot” for the opportunity to carry out bus diagnostics and use the data of vibration research in the workplace of the driver LLC "Test Laboratory "Trud".

References
[1] 2.2.2006-05 «Guidelines for the hygienic assessment of working environment and labor factors. Criteria and classification of working conditions».
[2] V. M. Mishurin, A. N. Romanov Driver Reliability and Traffic Safety: M.: Transport, 1990. – 167 p.
[3] Du B. B., Bigelow P. L., Wells R. P., Davies H. W., Hall P. & Johnson P. W., The impact of different seats and whole-body vibration exposures on truck driver vigilance and discomfort, Ergonomics, 61(4), pp. 528–537 (2017).
[4] Kubo Mitsunori, Fumio Terauchi, Hiroyuki Aoki and Yoshiyuki Matsuoka. 2001. An Investigation into a Synthetic Vibration Model for Humans: An Investigation into a Mechanical Vibration Human Model Constructed according to the Relations between the Physical, Psychological and Physiological Reactions of Humans Exposed to Vibration, International Journal of Industrial Ergonomics, 27 (4), pp. 219–232 (2001).
[5] M. R. McCann, M. A.Veras, C. Yeung et al., Whole-body vibration of mice induces progressive degeneration of intervertebral discs associated with increased expression of Il-1βand multiple matrix degrading enzymes, Osteoarthritis and Cartilage, vol. 25, no. 5, pp. 779–789 (2017).
[6] Fan R., Liu J., Li Y., Liu J. & Gao J., Finite Element Investigation of the Effects of the Low-Frequency Vibration Generated by Vehicle Driving on the Human Lumbar Mechanical Properties, Bio Med Research International, 2018, pp. 1–9 (2018).
[7] Thamsuwon O., Blood R.P., Ching R. P., Boyle L. & Johnson P. W., Whole body vibration exposures in bus drivers: A comparison between a high-floor coach and a low-floor city bus, International Journal of Industrial Ergonomics, 43(1), pp. 9–17 (2013).
[8] GOST R 55855-2013 Automotive vehicles. Methods for measuring and evaluating total vibration.
[9] GOST 31319-2006 (EN 14253:2003) Vibration. Measurement of general vibration and assessment of its impact on humans. Workplace measurement requirements
[10] GOST 31191.1-2004 (ISO 2631-1:1997) Vibration and shock. Measurement of general vibration and assessment of its impact on humans. Part 1. General requirements.
[11] GOST 31192.1-2004 (ISO 5349-1:2001) Vibration. Measurement of local vibration and assessment of its impact on humans. Part 1. General requirements.
[12] GOST 31192.2-2005 (ISO 5349-2:2001) Vibration. Measurement of local vibration and assessment of its impact on humans. Part 2. Requirements for measurements at the workplace.
[13] Chernova G.A., Sinkov A.V., Moiseev Yu.I. Valuation of efficiency of buses «Volgabus» with determination of critical values of vibration acceleration of transmission, MATEC Web of Conferences. Vol. 224 : International Conference on Modern Trends in Manufacturing Technologies and Equipment 2018 (ICMTME 2018) (Sevastopol, Russia, 10-14 September, 2018) : conference proceedings / ed. by S. Bratan [et al.]; – [Publisher: EDP Sciences] – 9 p. (2018)
[14] Chernova G. A., Ryazankin A. E., *Assessment of the impact of vibration acceleration of the Volgabus bus transmission on driver labor intensity*, Internauka: electron.scientific. journal, № 23(105). URL: http://internauka.org/journal/science/internauka/105 (2019).