Evaluation of efficiency of buses "Volgabus" with determination of critical values of vibration acceleration of transmission

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Abstract. The article provides a rationale for diagnosing the condition of the driving shafts of buses "Volgabus". It is determined that the efficiency of the transmission depends not only on the influence of operational factors, but also on the quality of maintenance. The authors monitored the malfunctions of the driving shafts of buses and determined the task of diagnosing the transmission without removing the units and aggregates. The technique of fast diagnostics of the bus transmission by the instrumental method is offered. The article presents the results of a study of vibration acceleration of the buses "Volgabus" transmission with different mileage values. Critical values of vibration acceleration at which buses cannot be used are determined. The recommendations for the rapid diagnosis of the transmission of buses are given.

1 Introduction

The operative condition of units and aggregates of city buses is influenced by a large number of external operational factors: large cross-town traffic, maneuvering at stops, and the state of the road network. Trouble-free work of buses on the route is possible in case of prevention of transmission unit breakdown.

Preliminary forecasting of the state of bus units will allow excluding premature equipment malfunctions and failure of buses. However, currently, there is no diagnosis of the condition of the driving shaft. A malfunction of the driving shaft causes additional vibration, which can affect the performance of other transmission units. Vibration of the driving shaft leads to a disruption in tightening the bolted connections. And this leads to a break in the bolts of the flanges and the outboard bearing, the breakage of the engine mounting bolts. To maintain buses in working conditions and timely troubleshooting, there is a need to use methods for rapid assessment of technical condition without removing the units and aggregates.

The purpose of the study of the efficiency bus transmission is to find the critical value of the vibration acceleration of the transmission, in particular of the driving shafts.

The main task of the study is making the correct choice of vibration measurement tools and the definition of the methodology for conducting vibration acceleration studies of the bus's transmission.

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2 Choice of methodology and diagnostics

The analysis of the change in the kinematic (the angle of the driving shaft installation) and the dynamic (torque) parameters in connection with the change in the angle of rotation of the driving shaft is carried out. The calculations determine the operability of driving shaft while ensuring the requirements of technical operation [1]. During the monitoring, the causes of bus breakdowns were identified. The main causes of breakages are the following: wear of the splined connection of driving shafts; increased clearance (backlash) in the journals of driving shafts; break of bolts of flanges of a transmission and the rear axle; high levels of vibration driving shaft; breakage of the driving shaft [2].

It is determined that the performance of the transmission is directly related to the maintenance of the driving shaft, therefore it became necessary during the maintenance to determine the efficiency of the transmission by evaluating the condition of the driving shaft. At the moment, vibration diagnostics is a promising area for the development of technical diagnostics.

The values of the maximum permissible vibration levels are established by normative documents [3-5]. Such standards set general requirements for ensuring vibration safety in transport and other works related to the adverse effects of vibration on humans. In order to obtain the parameters of the vibration characteristic, vibration is measured at the intended places of contact of the machine with the human body; and at points where vibration is transmitted to a vehicle's supporting parts.

When evaluating the impact of vibration on a person, consider a general or local vibration. General vibration is a vibration transmitted to the human body at the points of its support (feet, buttocks, back, head). Local vibration is vibration transmitted through the hands of a person in contact with a controlled machine.

The main task of vibration monitoring of machines is to provide the necessary information about the technical condition of the working machine for subsequent maintenance. The normalized and measured value of vibration is vibration acceleration.

Methods of vibroacoustic diagnostics are presented in the works of Shchienko A. N., Barkova A. V., Boykin S. P. [6-8]. The disadvantage of using the method of vibroacoustic diagnostics is the lack of practical developments in norms and threshold levels, there is no generally accepted physical and spectral interpretation of the features of the manifestation of vibration acceleration. However, the study of the experience of using vibroacoustic diagnostics has shown its successful application in the diagnosis of defects having an impact nature - in rolling bearings, reducers.

The choice of the measuring instument of diagnosing the vibration characteristics of the driving shafts was made [9]. The investigations were carried out with the help of the measuring instrument "Algorithm-03 Vibration Analyzer". Algorithm-03 is a digital vibration analyzer of the 1st accuracy class (IEC 61672 and GOST 53188-1), a vibrometer (ISO 8041: 2005, GOST ISO 8041-2006), a spectrum analyzer (up to 20 kHz). The device meets the requirements of ISO 2204 for precision measurement.

"Algorithm-03" makes it possible to perform vibration measurements in three coordinate axes simultaneously with the recording of a signal on a digital medium. This makes it possible to perform multi-dimensional analysis of the measured signal. In practice, this allows you to simultaneously measure the current and energy parameters of vibration.

Current parameters the vibration are:

PEAK - peak value of vibration acceleration, measured by a peak detector; P-P - the range between the maximum and minimum peak values of vibration; MTVV is the maximum current value of vibration.

Energy parameters the vibration are:

RMS - root-mean-square value of vibration acceleration, measured by the rms detector; VDV is the dose of vibration.

The device is connected to a computer using the SvanPC ++ program via the USB port and through a wireless GPRS connection. The measurement results are also processed in the SvanPC ++ program.

The explored busses were in the repair area of the municipal passenger convoy No. 1732 in Volzhsky. The measurements were carried out with jack-lifted rear wheels at various engine speeds without load n = 600-900 rpm, with the load in the first gear with engine speed n = 1200-1500 rpm, in the second gear with engine speed of 2000-2500 rpm. Runs of buses are different, given in "Table 1".

The measurements were carried out in three axes X, Y, Z at control points, "Fig. 1". The directions of the measuring axes of the vibration sensor were adopted as follows. The X-axis is parallel to the axis of the rear axle in the horizontal plane, the Y-axis in the horizontal plane parallel to the longitudinal axis of the bus, and the Z-axis in the vertical plane perpendicular to the road.

The duration of the measurements for each axis was 10 seconds. The scheme of the sensor attachment points is shown in "Fig. 1". The vibration acceleration sensor was attached to the engine pallet, on the gearbox flanges and the main gear. On buses with a single driving shaft the sensor was fixed in the center of the frame. On buses with a divided driving shaft and a support bearing, the sensor was attached to the support bearing.
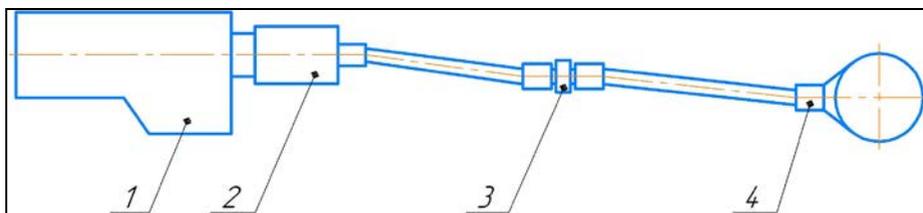

Fig. 1. Scheme of sensor attachment points for measuring vibration acceleration: 1 - engine pan; 2 - the gearbox housing; 3 - the support bearing (or the center of a frame); 4 - a flange of the main gear.

The "Fig. 2, 3, 4, 5" are the photos of the sensor attachment on the gearbox housing, on the engine pan, on the rear axle body, on the frame in the center.

Fig. 2. Attaching the sensor on the gearbox housing.

Fig. 3. Attaching the sensor on the engine pan.

Fig. 4. Attaching the sensor on the rear axle body.

Fig. 5. Attaching the sensor on the frame in the center.

3 Vibration acceleration study results

Measurements of vibration acceleration on buses "Volgabus-4298", "Volgabus-5270", "Volgabus-6270", "Volgabus-4298G8", "Volgabus-5270G2" with various runs to assess the efficiency of the transmission and determine the criteria for which a preventive or major repairs [10-12].

Vibration acceleration has a dimension of meter per second squared (m/sec^2) and characterizes the force dynamic interaction of elements inside the unit that cause vibration. The use of vibration acceleration values is very convenient for considering force interactions in mechanical constructions, since they do not need to be specially transformed for further interpretations. The disadvantage is that for vibration acceleration there are no practical developments in norms and threshold levels, there is no generally accepted physical and spectral interpretation of the main features of the manifestation of vibration acceleration. Therefore, the analysis of the state of the equipment by qualitative and quantitative parameters of vibration acceleration is a matter for future research.

Table 1. Maximum values of current values of vibration acceleration RMS, m/sec^2.

Sensor attaching location (Fig. 1)	Axis					
	X		y		Z	
	Engine speed					
	idle	gear	idle	gear	idle	gear
Bus "Volgabus-4298" run 15000 km, idle - 600 rpm, 1-st gear - 650 rpm						
engine pan	3,5	3,4	2,2	2,3	1,1	4,8
gearbox housing	2,4	3,6	5,9	0,1	2,6	5,5
frame in the center	4,8	5,7	3,0	3,5	5,8	5,7
rear axle body	5,7	3,6	1,7	3,6	5,6	3,6
Bus "Volgabus-4298G8" run 45000 km, idle - 900 rpm,2-nd gear – 2000-2500 rpm						
engine pan	0,23	0,27	0,6	4,7	0,2	0,6
gearbox housing	0,15	0,25	1,1	3,2	0,3	0,6
frame in the center	0,2	0,3	0,1	4,4	0,1	6,03
rear axle body	0,1	5,6	2,0	3,7	0,3	0,25
Bus "Volgabus-5270" run 826000 km, idle - 900 rpm, 1-st gear - 1200 rpm						
engine pan	2,6	5,9	4,2	43,2	45,7	48,4
gearbox housing	1,5	43,2	6,8	49,0	0,5	0,7
frame in the center	-	-	-	-	-	-
rear axle body	922,6	1318,3	922,6	716,1	1202,2	50,7
Bus "Volgabus-5270" run 82000 km, idle - 900 rpm, 1-st gear - 1200 rpm						
engine pan	2,4	2,3	43,7	42,2	17,2	6,2
gearbox housing	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 body	0,21	0,2	0,2	9,7	5,1	39,4
Bus "Volgabus-5270 G2" run 45000 km, idle - 650 rpm, 1-st gear - 1300 rpm						
engine pan	0,2	0,5	4,2	40,7	15,5	15,8
gearbox housing	0,2	0,2	27,2	42,7	0,2	18,8
frame in the center	-	-	-	-	-	-
rear axle body	0,1	0,15	3,8	38,0	0,1	16,8
Bus "Volgabus-6270" run 37000 km, idle - 900 rpm, 1-st gear - 1000 rpm						
engine pan	37,9	38,9	0,5	1,8	5,8	0,33
gearbox housing	6,5	0,6	43,2	19,1	0,9	6,8
frame in the center	0,2	1,2	0,4	42,7	6,0	0,2
rear axle body	0,2	3,8	0,2	0,1	0,2	4,5

During the analysis, the maximum and minimum values of vibration acceleration were sampled for each control point of the measurements. Peak values of vibration acceleration PEAK and RMS values of vibration acceleration have the same values and practically do not differ in order from the span between the maximum and minimum peak values of vibration P-P. The largest values are the range between the maximum and minimum peak values of vibration P-P. The maximum values of Max acceleration are less or equal to the Peak, R-P and RMS values, therefore further processing of the measurements is reduced to a sample of the rms values of the vibration acceleration and to the analysis of the acceleration at idle speed of the engine and the first gear. The results of the sample for all the investigated buses "Volzhanin" are presented in Table 1.

The analysis of root-mean-square deviations of vibration acceleration of buses "Volgabus-5270, 6270" is carried out. Comparative analysis showed that the maximal vibration acceleration of the driving transmission of buses occurs on the axes X, Y and Z depending on the bus run.

The "Fig. 6 - 11" are comparative diagrams of vibration acceleration in the standard deviation along the axes X, Y and Z, on the engine speed idle and on the first gear.
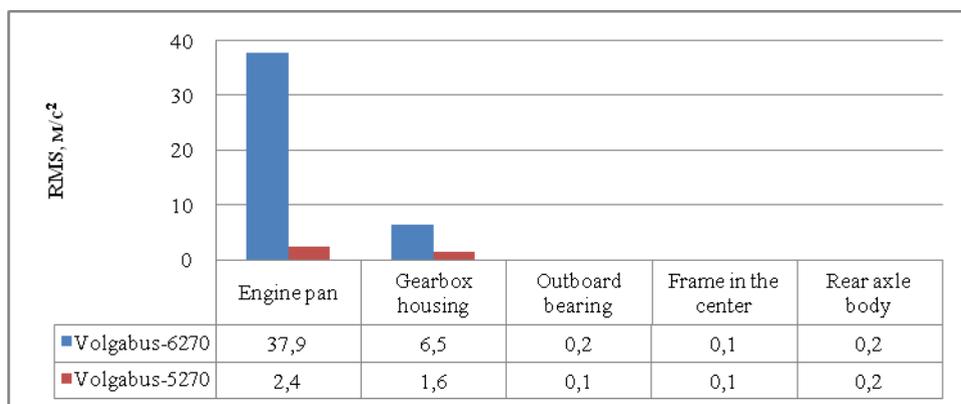

	Engine pan	Gearbox housing	Outboard bearing	Frame in the center	Rear axle body
■ Volgabus-6270	37,9	6,5	0,2	0,1	0,2
■ Volgabus-5270	2,4	1,6	0,1	0,1	0,2

Fig. 6. Root-mean-square deviation of vibration acceleration along the X-axis of the buses "Volgabus-5270, 6270" at idle speed of the engine.

At idle speed of the engine on both buses along the X axis, there are practically no vibrations, only on the engine pan of the Volgabus-6270 bus the high deviation value is 37.9 m/sec^2.
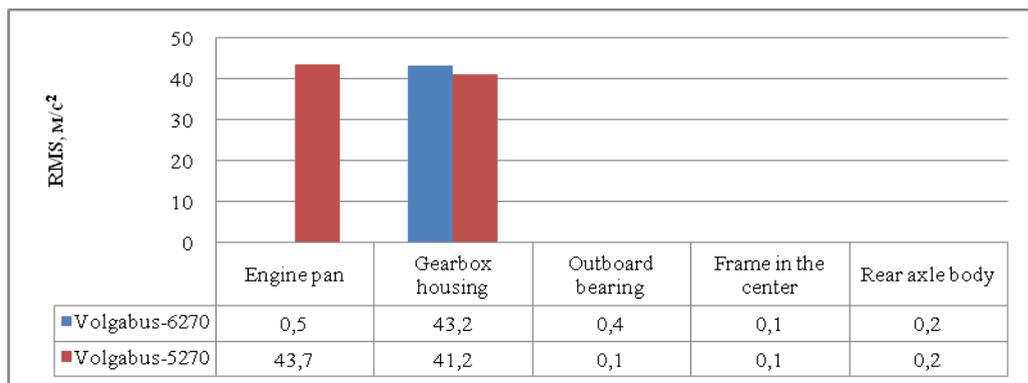

	Engine pan	Gearbox housing	Outboard bearing	Frame in the center	Rear axle body
■ Volgabus-6270	0,5	43,2	0,4	0,1	0,2
■ Volgabus-5270	43,7	41,2	0,1	0,1	0,2

Fig. 7. Mean-square deviations of vibration acceleration along the Y axis of the buses "Volgabus-5270, 6270" at idle speed of the engine.

On the Y axis at idle, the maximum values of vibration acceleration occur on the gearbox housing of both buses.
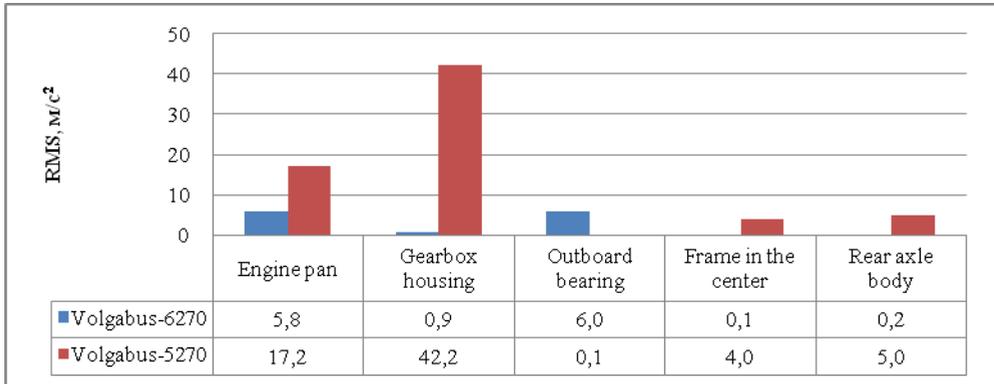

	Engine pan	Gearbox housing	Outboard bearing	Frame in the center	Rear axle body
Volgabus-6270	5,8	0,9	6,0	0,1	0,2
Volgabus-5270	17,2	42,2	0,1	4,0	5,0

Fig. 8. Root-mean-square deviations of vibration acceleration along the Z axis of the buses "Volgabus-5270, 6270" at idle speed of the engine.

As a result, at idle speed the maximum vibrations are available on engine pan and gearbox housing.
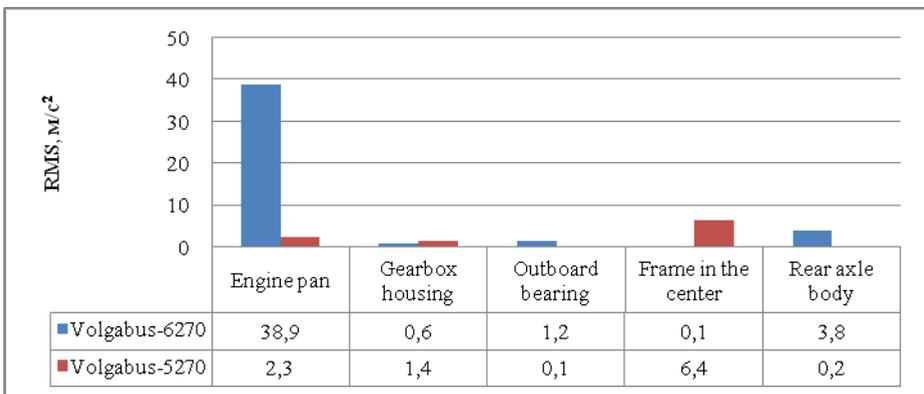

	Engine pan	Gearbox housing	Outboard bearing	Frame in the center	Rear axle body
Volgabus-6270	38,9	0,6	1,2	0,1	3,8
Volgabus-5270	2,3	1,4	0,1	6,4	0,2

Fig. 9. Root-mean-square deviations of vibration acceleration along the X axis of the buses "Volgabus-5270, -6270" at the first gear.

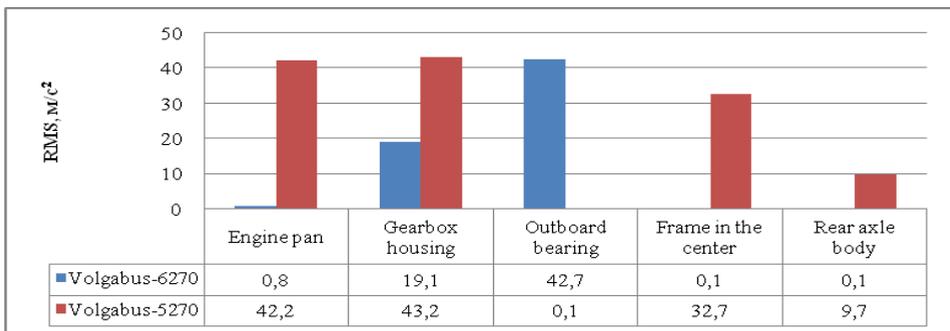From "Fig. 6 and 9" it is visible, that parameters at the first gear and idling did not change.

	Engine pan	Gearbox housing	Outboard bearing	Frame in the center	Rear axle body
Volgabus-6270	0,8	19,1	42,7	0,1	0,1
Volgabus-5270	42,2	43,2	0,1	32,7	9,7

Fig. 10. Root-mean-square deviation of the vibration acceleration along the Y axis of the buses "Volgabus-5270, 6270" at the first gear.

Under the load at the Y-axis, vibrations occur at the rear axle body of the bus "Volgabus-6270" and at the frame in the center of the bus "Volgabus-5270".
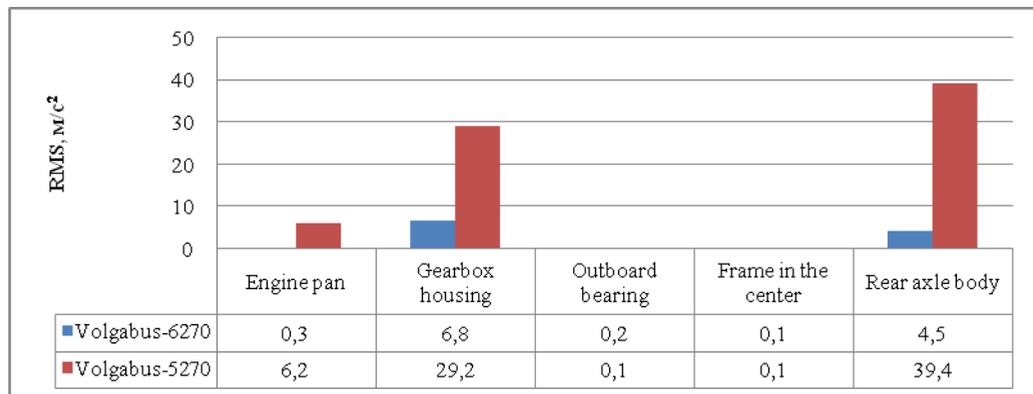

	Engine pan	Gearbox housing	Outboard bearing	Frame in the center	Rear axle body
■ Volgabus-6270	0,3	6,8	0,2	0,1	4,5
■ Volgabus-5270	6,2	29,2	0,1	0,1	39,4

Fig. 11. Root-mean-square deviations of vibration acceleration along the Z axis of buses "Volgabus-5270, 6270" at the first gear.

On the rear axle body of the bus "Volgabus-5270" the increased vibration along the Z axis is almost 40 m/sec^2 "Fig. 11".

A comparative analysis of all the diagrams at "Fig. 6 – 11" shows that the highest vibration acceleration occurs along the Y axis on both buses.

Studies of vibration acceleration made it possible to determine the critical vibration acceleration equal to 20 m/sec^2. At values greater than 20 m/sec^2, a weakening of the fastening of the bolts of the gearbox housing flanges and the rear axle and the breaking of the bolts of the support bearing were detected [13].

4 Conclusions

The investigations have determined the necessity of diagnostics of the transmission and the determination of the acceleration during the technical inspection, which will exclude the trips with driving gear failure.

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