Evaluation of the influence of the mode of movement of "Volgabus" buses on the performance of the clutch

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

*galina_vat@mail.ru

Abstract. The article gives evaluation of the clutch performance of "Volgabus-5270GH" MUE "Volzhskaya №1732 bus depot” based on bus removals with different mileage values. Scheduled maintenance and repair system implies the elimination of bus removals and repair works between MO1 (MO - Maintenance Operations) and MO2. Authors have carried out the analysis of clutch malfunctions. Based on many studies, it has been established that the service life of parts and components of vehicles in kilometers of run, under proper operation, obeys the law of normal distribution. It is defined that untimely bus removals with repair under condition of qualitative manufacturing and timely scheduled maintenance repair (SMR) are also possible under influence of operational factors of a route network of Volzhsky. The analysis of bus movement modes on the main routes and their possible connection with clutch malfunctions has been carried out. The article gives recommendations for increasing the efficiency of bus clutch.

1. Introduction
During the operation of “Volgabus-5270GH”, a large number of bus removals with clutch repairs were recorded. During the warranty period the manufacturer eliminated all faults. After the warranty is over, clutch faults occurred between the fulfillment of MO1 and MO2, which contradicts the requirements of scheduled maintenance and leads to additional costs. Therefore, it is necessary to find out the possible causes of malfunctions. In order to achieve this goal, it is necessary to analyze the nature of clutch malfunction, the influence of certain factors on them, in particular the conditions of bus traffic on the routes. The research of bus traffic modes on the main routes of Volzhsky has been conducted. The aim of the research is to evaluate the clutch performance of “Volgabus-5270GH” taking into account certain factors, in particular, bus traffic mode.

2. Defining the quantitative characteristics of the efficiency of bus clutch

2.1. Analysis removals with clutch repairs
“Volgabus-5270GH” (CityRhythm-10 GLE) buses manufactured by Holding “Bakulin Motors Group” (a division of “Volgabus Volzhsky”) are used in MUE “Volzhskaya №1732 bus depot”. The transport company received 50 buses powered by methane engine fuel in November 2017 as part of the Russian government's environmental program. Buses run on urban routes №1, №2u and №14.
During the period from November 2017 to December 2018 (warranty period) there were registered 53 clutch malfunctions. The manufacturer carried out repairs as part of warranty service. In 2019, 223 clutch malfunctions were recorded after the end of the warranty. Maintenance and repair work is carried out in the repair area of MUE “Volzhskaya №1732 bus depot”. Mileages before MO1 is 10000 km, before MO2 is 20000 km.

To evaluate the performance of the clutch of "Volgabus-5270GH", an analysis of bus removals in MUE “Volzhskaya №1732 bus depot” for the indicated period was carried out (table 1).

During the warranty period, the greatest number of bus removals with the clutch adjustment - 21, no clutch squeezing - 16. In 2019 the number of bus removals increased to 223. The greatest number of bus removals 130 - there is no clutch release, 39 bus removals with clutch adjustment.

| №  | Clutch malfunction nature     | During the warranty period (November 2017 - 2018) | In 2019 |
|----|-------------------------------|-----------------------------------------------|---------|
| 1  | Clutch Adjustment             | 21                                            | 39      |
| 2  | No clutch release             | 16                                            | 130     |
| 3  | Clutch slips                  | 10                                            | 37      |
| 4  | Clutch does not engage        | 2                                             | 11      |
| 5  | Clutch pedal                  | 2                                             | 2       |
| 6  | Clutch does not disengage.    | 2                                             | 4       |
|    | In total removals             | 53                                            | 223     |
|    | Average mileage before removals with repairs | 10394,2 | 11930,8 |

During the warranty period from November 11, 2017 up to December 31, 2018 the average mileage of buses before removals with clutch repairs was 10394 km, and in 2019 the average mileage was 11930.8 km (Table 1). Daily maintenance includes checking the free running of the clutch pedal and adjusting it if necessary. Maintenance includes checking the condition and tightness of the hydraulic drive clutch and checking the free running of the clutch pedal.

2.2. Research method choice

To provide the performance of vehicles and to maintain components and units in technically functional condition, it is necessary to know the laws governing the changes in the technical state of vehicles under the influence of various factors during operation. In other words, the management of vehicle performance is the effective use of scientific methods and standards to maintain vehicles in technically valid condition. [1].

Determining the quantitative characteristics of the performance of components and parts of rolling stock is possible with the help of mathematical methods based on the generalization of the accumulated statistical data on their work in real operating conditions. For the development of recommendations for the rational technical operation, improvement of the design of cars, information about regularity of changes in their technical condition is needed. The most important regularities of technical operation include changes in the technical condition of a vehicle, component, or parts by operating time (running time or mileage). It also includes the dispersion of the parameters of the technical state and other random variables that operate the technical operation, for example, the duration of the repair and maintenance work; the formation of the total flow of failures in vehicles (recovery process) [2].
To determine the performance of buses, removals due to ICE, clutch, gearbox, u-joint transmission are systemized. Based on many researches, it has been established that the resource of vehicles, as well as components and parts, under the correct operation, obeys the law of normal distribution.

"Operation of motor vehicles" chair of Volzhsky Polytechnic Institute constantly analyzes the performance of buses "Volzhanin", which consists in evaluation of removals with repair of components and parts with the determination of mileage from the moment of repair to the subsequent removal with repair. At the MUE «Volzhskaya № 1732 bus depot» enterprise, there is an automated “1C: Enterprise 8. Motor Vehicle Management Standard” program, which allows you to receive statistical data on removals with repair and to determine mileage before the next removal.

The plan for the collection of operating data provides the definition of buses removals with repair of engine, clutch and gearbox with the calculation of mileage to removal with repair.

Evaluation of the parameters of the vehicle mileage distribution to removal with the components repair, performed according to the method of Gmurman V.E., presented in [3].

The source data for calculating the number of objects of observation N:

The following indicators are used:
- confidence probability \( q = 0.95 \);
- marginal relative error \( E = 0.05 \);
- the coefficient of variation \( \nu = 0.20 \).

With these values, the size of selection should be at least 45.

The coefficient of variation is equal:
- with normal distribution (Gaussian) \( \nu = 0.3 \);
- with Weibull distribution \( \nu \) is from 0.3 to 0.9;
- with exponential distribution \( \nu \) is from 0.9 to 1.1.

The calculation is performed according to the following formulas [3]:

arithmetic mean \( \bar{x} \):

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \cdot n_i
\]  

(1)

standard deviation \( \sigma \):

\[
\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot n_i}
\]  

(2)

the coefficient of variation \( \nu \):

\[
\nu = \frac{\sigma}{\bar{x}}
\]  

(3)

confidence interval (interval value of mileage):

\[
\bar{x} - \frac{t \cdot \sigma}{\sqrt{n}} \leq x \leq \bar{x} + \frac{t \cdot \sigma}{\sqrt{n}},
\]  

(4)

where \( n \) – selection size; \( t \) – Laplace function argument, \( t = 1.96 \) when \( q = 0.95 \); \( \pm \frac{t \cdot \sigma}{\sqrt{n}} \) – measurement error.

Testing the hypothesis about the normal distribution is performed by the Pearson criterion [3]. As a criterion for testing hypothesis random value is taken \( x^2 \):

\[
x^2 = \sum \frac{(n_i - n_i')^2}{n_i}
\]  

(5)

where \( n_i \) and \( n_i' \) - are an empirical and theoretical frequencies.

The area of acceptance of the hypothesis is determined by the inequality:

\[
x^2 < x^2_{\alpha} (\alpha; k),
\]  

(6)

where \( \alpha \) – level of statistical significance, \( k \) – number of degrees of freedom.
The level of significance \(\alpha\) in the calculations is \(\alpha = 0.05\). Number of degrees of freedom \(k\) defined by equation: \(k = s - 1 - r\), where \(s\) – number of selection groups; \(r\) – the number of parameters of the intended distribution (for normal distribution \(r = 2\)), so \(k = s - 3\).

**Rule.** In order, at a given level of significance, to test the hypothesis about the distribution of the population according to the normal law, it is necessary to calculate the theoretical frequencies, and then the observed value of the criterion \(x^2\). According to the table of critical points of the distribution \(x^2\), given level of significance \(\alpha\) and number of degrees of freedom \(k = s - 3\) find the critical point \(x^2_{cr}\). If \(x^2_{observe} < x^2_{cr}\), then the hypothesis is approved. If \(x^2_{observe} > x^2_{cr}\), then the hypothesis is rejected.

2.3. Analysis of mileage distribution of buses before removals with clutch repairs

The analysis of removals with clutch repair of buses has been carried out and the regularity of distribution of runs before removals has been defined. Detection of quantitative characteristics of the clutch performance is carried out on the basis of the given method (item 1.2) on the basis of summary of accumulated statistical data of bus mileage before the clutch repair in real operating conditions.

Two periods of use of 50 buses “Volgabus-5270GH” are considered:
- 1st period - during the warranty period from November 11, 2017 up to December 31, 2018 [4];
- 2nd period - after the end of the warranty period from 1.01.2019 up to 31.01.2019.

The buses are operated on routes №1, №2u and №14 in Volzhsky. Operational properties of the transport facilities are determined by the technical characteristics of “Volgabus-5270GH”. The use of CNG motor fuel (methane) helps to improve the ecology of Volzhsky.

There has been carried out the calculation of parameters of bus mileage distribution before removals with the clutch repair according to formulas 1-3. The results of calculations are presented in Table 2. According to the initial assumptions, the distribution of bus mileage should be subject to the law of normal distribution. Calculations have shown that the distribution of mileage at clutch repairs does not correspond to the law of normal distribution. In the first period of operation the distribution of mileage before the removals with the clutch repairs corresponded to the exponential law of distribution - the coefficient of variation \(\nu =1, 14\) (12 sample groups with the interval of 4000 km of mileage are marked out). In the second period the distribution of mileage before the repair corresponded to the law of Weibull – the coefficient of variation \(\nu =0, 89\) (16 sample groups with the interval of 4000 km of mileage are marked out).

We tested the hypothesis of the Normal Law distribution of the assembly on the basis of Pearson’s criterion (Table 2). The test showed that the distribution of mileage with removals did not correspond to the law of normal distribution.

**Table 2. Test of mileage distribution with removals with clutch repair by Pearson criterion.**

| Removals with repair | Mileage distribution parameters | Compliance with normal law |
|----------------------|---------------------------------|---------------------------|
| &nbsp; | \(n\) | \(\bar{x}\) | \(\sigma\) | \(\nu\) | \(\chi^2_{observe}/\chi^2_{cr}\) | |
| " Volgabus-5270GH", warranty period, November 2017 - 2018. | &nbsp; | 53 | 11132 | 12800 | 1.14 | 18.01>16.9 | not complying |
| min. mileage before removals 179 km, max. mileage 44778 km. | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | |
| &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | |
| " Volgabus-5270GH", 2019 | &nbsp; | 223 | 10395 | 9228 | 0.89 | 106,012>22.4. | not complying |
| min. mileage before removals 161 km, max. mileage 61824 km. | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | |

The distribution diagrams of observed and theoretical bus runs before clutch repair are presented in Fig. 1-2.
As it can be seen from the presented graphs in Figures 1 and 2, the distribution of observed runs is subject to the exponential law, while the theoretical ones are subject to Weibull law. The exponential distribution of bus mileage before clutch malfunctions indicates possible failures in operation, repair and assembly technology, planned maintenance of the clutch.

According to [5] refusals (removals with repairs) characterize mainly the structural reliability, as well as the quality of production and assembly of vehicles and their units, and the subsequent ones characterize the operational reliability with the existing level of organization and production of maintenance and repair, and spare parts supply. In this regard, it can be concluded that starting from the moment of mileage of the unit or component after its repair, refusals appear like a sudden one and their distribution in most cases is subject to an exponential law, although their physical nature is mainly a joint manifestation of wear and fatigue constituents.

Using the method [5], we suppose that in the initial operating period of buses the repairs were carried out due to the quality of production and assembly of cars and their components and their
wearing-in. During the warranty period, the manufacturer provides service, repair and adjustment at its mechanical workshops.

Taking into account the fact that the bus depot carries out maintenance in accordance with the manufacturer's standards, let's analyze the impact of operational factors of the route network on removals with the repair.

3. Analysis of operational factors affecting clutch performance

3.1. Operational factors affecting the performance of buses
Factors affecting the performance of buses are divided into external and internal factors. Internal factors include bus performance, external factors include operating conditions and maintenance.

This paper considers the impact of operating conditions, which on urban routes are characterized by high traffic flow, reduced speed, increased engine speed, high mileage on the curvilinear trajectory, a large number of gear changes and can lead to a reduction in the life of both the clutch and the entire transmission.

The main operating conditions include road conditions, traffic conditions, driving conditions, driving mode, maintenance and driver's training.

Road conditions on routes №1, №2u and №14 are satisfactory. The asphalt coating determines the normal driving mode of the bus and the exclusion of removals with repairs.

Traffic conditions for public transport in the city of Volzhsky are unsatisfactory. The load of the city road network occurs due to the large motorization of citizens (407 cars per 1,000 inhabitants, with a SNiP norm of 247) and a large number of routed taxicabs — 344 city units and more than 200 suburban units, passing through the same streets as the bus routes. This can affect the decrease in buses speed, the frequency of maneuvering before bus stops, frequent gear changes, the increase friction of brake mechanisms, the frequency of maneuvering before bus stops, and an increase value of bus removals with malfunctions of engine, clutch, gearbox, brake and steering systems. The influence of traffic flow is considered in the paper [6]. Due to the large traffic flow on Mira street and Lenin avenue, where about 20 public transport routes pass, delays up to 60 seconds occur at traffic lights and pedestrian crossings.

Driving mode of the bus is to be set by the driver, depending on the road conditions, his qualification and the technical condition of the vehicle. The higher the driver's qualification, the more efficient the buses are and the fewer breakdowns and the more resources the vehicles have. Drivers of corresponding qualification work in MUE "Volzhskaya №1732 bus depot". Due to the difficult traffic conditions on the routes, drivers constantly have to consider the impact of operational factors on the technical condition of the buses.

Maintenance. The buses were under the warranty service of “Volgabus Volzhsky” Ltd. during 12 months. The bus depot carries out subsequent maintenance. Mileages before MO1 is up to 10000 km, before mileages MO2 is up to 20000 km.

3.2. Analysis of traffic modes on urban routes
To find out anticipated causes of clutch malfunctions, the analysis of traffic modes on routes №1 "32 micro district – Railway station", №2U "37 micro district–Karbysheva st.- HM Magnet", №14 "37 micro district - HM Magnet" was carried out. The study was conducted on weekdays in rush hours during the highest traffic flows. (fig. 3,4,5). The smartphone application «SpeedView: GPSS peedometer» was used to measure the speed and distance of a car.
Figure 3. Driving modes of buses on route № 1 in forward (a) and backward (b) directions

Figure 4. Driving modes of buses on route №2U in forward (a) and backward (b) directions

Figure 5. Driving modes of buses on route №14 in forward (a) and backward (b) directions
Table 3. Features of bus management on routes

| №  | Destination                      | Number of halting points | Number of bus stops | Number of maneuverings | Number of traffic lights / pedestrian crossings |
|----|----------------------------------|--------------------------|---------------------|------------------------|------------------------------------------------|
| 1  | 32 micro district – Railway station | forward 2, backwar 0     | 26                  | 29                     | 18/25                                         |
| 2U | 37 micro district - HM Magnet     | forward 2, backwar 1     | 25                  | 32                     | 18/26                                         |
| 14 | 37 micro district - HM Magnet     | forward 2, backwar 2     | 25                  | 40                     | 22/26                                         |

As it can be seen from the graphs of "Fig. 3,4,5" and Table 3, buses of routes № 1, № 2U and №14 operating in urban conditions in variable traffic mode with multiple acceleration and deceleration, with frequent changes of road resistance and traffic conditions, which is most typical for intensive urban traffic. The stability of the thermal regime and friction of the vehicle is disturbed in the components and engine when the vehicle is operated in a variable mode. It increases the wear rate of components and units and increases fuel consumption. [7]

Due to the high frequency of acceleration and deceleration, the vehicle is subjected to sinusoidal loads of completely different magnitude. So, for example, the engine, working in a mode of constantly changing loads, with change of weight influencing its traction-dynamic indexes very quickly breaks down, as a rule, because of strong wear of connecting rod-piston group. The result is an increase in fuel consumption and a deterioration in its environmental performance, in spite of the stated characteristics. Similar to gearbox and clutch have a limited resource due to their frequent use. Frequent starting and changing gears causes the clutch disc and gear synchronisers to wear out very quickly, which is a common cause of a faulty bus leaving the line. Moreover, the human factor must be taken into account. If the clutch is not fully engaged, a sudden release of the clutch will have a negative impact on the movement. [8].

4. Conclusions

1. Analysis of operational factors on the route network of the city of Volzhsky showed that deterioration in the performance of buses, causing premature removals with repair, is possible due to the high traffic flow, delays and maneuvering before traffic lights and pedestrian crossings, delays and maneuvering before stopping at the bus stop due to waiting for vacant space.

2. The factors considered lead to frequent maneuvering and variable bus operation, leading to a constant change in driving speed, an increase in engine speed, wear of brake linings, a large run during a curvilinear trajectory of movement, a large number of gear changes. In the components and in the engine, the stability of the thermal regime and friction is disturbed.

3. In the "Volgabus-5270GH" bus a manual gearbox is used, the reduction of the resource and clutch malfunctions of which is possible due to frequent gear changes because of changes in driving modes.
5. Suggestions

1. To reduce the number of buses with clutch repairs on urban routes, it is advisable to use automatic transmissions. Despite the significant difference in the cost of manual and automatic transmissions, automatic transmission allows to ensure smooth running during acceleration and braking, as well as reduce the number of removals with the repair of the clutch and operating costs for its repair.

2. To increase the performance of buses, it is necessary to reduce the influence of operational factors on the route network. To do this, it is necessary to reduce the traffic flow by redistribution of transit vehicles to other streets, making a separate lane for public transport, increasing the length of bus stops and the making of individual places for buses of medium and large capacity of MUE «Volzhskaya №1732 bus depot» to avoid maneuvering.

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