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RELIABILITY OF KAROSA BUSES RUN BY A JOINT-STOCK COMPANY 'VILNIUS BUSES'

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Abstract. In the paper the data on operating reliability of KAROSA buses run by a joint-stock company 'Vilnius buses' are presented. The pneumatic front suspension and an automatic gearbox are investigated. The failures of these units and their causes are considered and some recommendations to increase the reliability of the equipment are provided. The need for using high-quality materials in maintaining the vehicles is demonstrated by the study of an actual case of highly corroded bearings.
Keywords: pneumatic front suspension, automatic gearbox, camshaft bearings, corrosion, reliability.

1. Introduction

In the analysis of major trends of transport system development in Vilnius the priority is usually given to public transport. Therefore, the main goal of enterprises engaged in passenger transportation is to ensure safe and timely provision of these services maintaining the required comfortability level. To achieve this aim enterprises should have completely reliable vehicles.

Vehicle reliability is specified at the design stage. Various methods of computer-aided mathematical modelling based on the application of software packages [1] are used. The required data are collected and updated in testing the particular models, equipment and units in modern well-equipped laboratories [2, 3]. New models of vehicles are also tested on the road [4].

Running a vehicle it is important to maintain the reliability rated by designers and manufacturers. However, actual conditions of operation are more complicated, with a number of various factors influencing the above vehicle characteristic. As a rule the designers cannot foresee or precisely evaluate all of them.

The existing problems show how important it is to determine the reliability of vehicles belonging to a particular company by testing them under operational conditions [5, 6]. The findings of such investigation and the recommendations based on them provide valuable information for improving methods and techniques of maintenance and repair as well as for taking account of spare parts, maintenance materials and determining the need for qualified personnel. The above data may also be useful for designers and manufacturers.

In 2002–2004 tests were carried out to determine the reliability of KAROSA buses belonging to a joint-stock company 'Vilnius buses' under operational conditions. The data on failure of the particular units of vehicles were collected under operational conditions, a survey of experts was conducted, causes of failures were identified and special literature was studied. Great attention was paid to the analysis of data on reliability and failures of the essential parts of city buses. In addition, a specific defect observed in the engine MIHR 06.20.45 A/3 of a bus KAROSA B-741 – heavy corrosion of the camshaft bearings was investigated. It was most probably caused by some accidental factor. Therefore, when identified and described it could provide some valuable information.

2. Analysis of front suspension reliability

Earlier the authors investigated the reliability of compressors of KAROSA buses [7]. A reliable pneumatic suspension secures safety and comfortability for passengers, while a faulty unit threatens their lives as well as changing the convergence angle of the wheels and accelerating the wear of the wheel tyres. This, in turn, increases the wear of the essential units of the vehicle. Therefore the analysis of the front suspension of KAROSA buses may be of great theoretical and practical value.

The performance and failures of the following units and parts of 104 buses were monitored under service conditions. They are: shock absorber, body height control valve, vertical axle swivel pin hub, horizontal cam hub and air cushions. The reliability of vehicle parts and units was determined by well-known methods of the reliability calculation theory [8, 9]. The data obtained are given in Tables 1, 2 and in Fig 1.

Table 1. The data on the expected average work-to-failure of suspension elements

$T_{p.vid.}$ thous. km	Shock absorber	Vehicle body height control valve	Vertical axle swivel pin hub	Horizontal cam hub	Air cushions
	88,3524	34,3923	57,6212	31,5570	130,44

Table 2. Failure rate

Length, thous. km		0-8,0	8,0-16,0	16,0-24,0	24,0-32,0	32,0-40,0	40,0-48,0	48,0-56,0	56,0-64,0
Midlength T_{vi}, thous. km.		4,0	12,0	20,0	28,0	36,0	44,0	52,0	60,0
Shock absorber	$f(T)$	0,0047	0,0145	0,0226	0,0261	0,0235	0,0165	0,0093	0,0046
	$F(T)$	0,0444	0,1500	0,3315	0,5400	0,7260	0,8587	0,9373	0,9755
	$\lambda(T)$	0,0049	0,0170	0,0338	0,0567	0,0856	0,1167	0,1492	0,1870
Vehicle body height control valve	$f(T)$	0,0054	0,0153	0,0219	0,0239	0,0214	0,0160	0,0102	0,0058
	$F(T)$	0,0462	0,1646	0,3389	0,5294	0,7001	0,8277	0,9111	0,9580
	$\lambda(T)$	0,0057	0,0183	0,0331	0,0508	0,0713	0,0929	0,1153	0,1381
Vertical axle swivel pin hub	$f(T)$	0,0067	0,0179	0,0240	0,0243	0,0203	0,0145	0,0090	0,0049
	$F(T)$	0,0545	0,1959	0,3853	0,5784	0,7402	0,8567	0,9286	0,9681
	$\lambda(T)$	0,0071	0,0222	0,0391	0,0577	0,0781	0,1011	0,1254	0,1529
Horizontal cam hub	$f(T)$	0,0069	0,0186	0,0256	0,0270	0,0237	0,0181	0,0121	0,0072
	$F(T)$	0,0478	0,1750	0,3490	0,5332	0,6961	0,8193	0,9028	0,9518
	$\lambda(T)$	0,0072	0,0226	0,0393	0,0578	0,0782	0,0999	0,1240	0,1486
Air cushions	$f(T)$	0,0034	0,0128	0,0800	0,2367	0,3397	0,2367	0,800	0,0128
	$F(T)$	0,0010	0,0170	0,1010	0,3350	0,6650	0,8990	0,9830	0,9990
	$\lambda(T)$	0,0034	0,0130	0,0890	0,3560	1,0141	2,3437	4,7081	12,772

$f(T)$ – differential distribution function; $F(T)$ – integral distribution function; $\lambda(T)$ – failure rate.

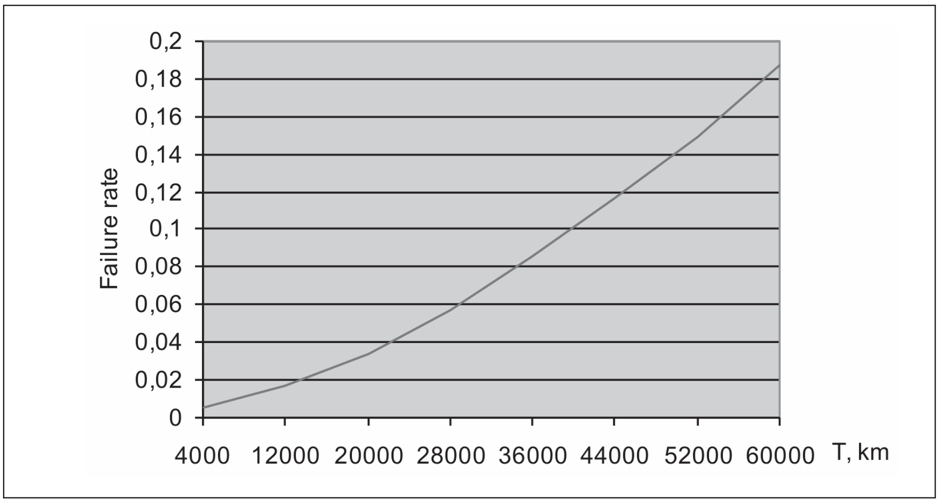

Fig 1. Shock absorber failure rate $\lambda(T)$

The testing has shown that the valve of vehicle body height control is the unit of front suspension which has the highest failure rate. Its average work-to-failure is 34.4 thous. km. In KAROSA buses run by 'Vilnius buses' Ltd this unit fails 3–4 times a year. When the front axle height regulator fails, the front of the vehicle body usually remains raised or lowered. In this case steering becomes complicated and the wearing of the pneumatic suspension air cushions and wheel tyres is increased. In this state a bus is not comfortable for passengers and the driver.

Body height regulator failures can be divided into two groups. The first group which is the largest embraces sudden failures caused by the control shaft jamming in the hub. The front of the bus body remains in the state in which it was when the above unit failed. When the faulty unit is dismantled, the corrosion is found.

The second group failures are associated with breaking down of the valve insulation. Such failures develop slowly due to the wear of the valve parts such as a rubber seal or insulator. The valve leaks air into other channels or in the atmosphere. All the above-mentioned failures of the body height control valve can be repaired at the enterprise. The rubber parts are replaced, while the products of corrosion and other pollutants are removed from the spaces. The repair is relatively cheap. The character of the failures discussed allows us to assume that the insulation of the unit in question is not adequate because of some drawbacks in its design.

Fast deterioration of the rubber parts of the valve indicates that the bus operational conditions are not favourable. To prove it, some other heavily loaded parts and units were investigated and their reliability was determined.

The only part less resistant than the body height regulating valve is a horizontal swivel pin hub. Its expected average work-to-failure is 31,6 thous. km. The part is made of polyamide. The intense wearing of the hub may be accounted for some design drawbacks. The part can be manufactured at the enterprise 'Vilnius Buses', however, a metal hub strengthening the unit is not used for economic reasons.

The reliability of shock absorber is higher with the average expected work-to-failure reaching 88,4 thous. km (Table 1). However, it is even more important to identify its failures and their causes because this unit plays an essential part in the suspension. The cases when piston rod lubricators leak oil are common for the parts of the second group. When rubber gaskets are aging their elasticity is reduced and cracks are formed. As a result the insulation of the unit is broken down.

The failures of this group largely depend on the type of the piston rod surface. It is usually chromium-plated to make it smooth and sleek. However, when the layer of chromium is damaged the part is affected by corrosion and gradually destroys the inner surface of the lubricator. As a result the oil is leaking. The amount of oil in shock absorber cavity gradually decreases thereby putting the unit out of action. The survey of bus drivers has revealed that one of the first signs of shock absorber disorder is more difficult driving because of vibration, shaking, knocking, etc. However, the driver gets used to it and this is dangerous because when it is necessary to stop or turn a bus quickly or to go to another traffic lane in an emergency situation, the vehicle may become uncontrollable.

Failures occurring due to the accumulation of some negative effects in a certain period of time include such cases as, for example, a shock absorber becoming less efficient because it has waste oil in its cavity or such oil was poured in it in repair, or the amount of oil was not properly measured. These failures may have the same grave consequences as described above. Therefore, this unit may be repaired only by highly-qualified workers. The maintenance procedures should meet the requirements including the examination of shock absorber oil as an essential structural element.

Another group embraces sudden failures of shock absorber, such as mechanical breakages occurring much more rarely. Springs, flexible plates and piston rings can fail. Usually it is the driver's fault when he drives on a rough road especially in freezing weather.

The data obtained prove that slowly developing shock absorber defects may remain unnoticed for a long time, but they may cause road accidents. Therefore, shock absorbers should be inspected every 20 thous. km of a bus run.

The results of testing concerning the types and causes of vehicle units failures and their reliability clearly show that the front pneumatic suspension operates under difficult conditions. This accounts for the fact that the average work-to-failure of air cushions hardly reaches 130 thous. km being much lower than that of 400 thous. km specified by the manufacturer.

3. Determining the reliability of automatic gearbox

Buses Karosa B-741 use automatic gearbox Voith Diwa D851.2/D863. Easy selection and changing of gears provided by this unit make it most suitable for city buses operating under the conditions when the distances between bus stations are short and traffic jams are rather common. The survey of drivers has shown that driving a bus with mechanical gearbox they make about 500 gear shiftings and other operations during eight working hours. It is evident that, in this case, the unit and its parts are subject to heavy wear thereby complicating the driver's work. The use of automatic gearbox facilitates this problem. Moreover, buses consume less fuel, while moving smoother and making less harm to the environment.

Monitoring of KAROSA B-741 buses in operation has revealed that major failures of automatic gearboxes are caused by:

1. Failure of control keys;
2. Breaking of contacts (power supply to the control unit);
3. Failure of electronic control system (microchips);
4. Failure of loading sensors;
5. Breakage of the main cable;
6. Damage of gearbox friction surfaces.

Based on the available data on gearbox failures, the reliability of its parts was calculated [8, 9]. The results obtained are given in Tables 3, 4 and in Fig 2.

The above data show that the main cause of gearbox failure is the failure of electronic control system.

The causes of the control keyboard failure identified during the repair are worn-out or oxidized contacts. These defects are easily removed by dismantling and cleaning the unit and replacing the faulty contacts. However, these seemingly slight defects may cause failure of gearbox resulting in friction surfaces damage and even causing accidents. The mechanical

Table 3. More accurate mathematical values of resource of parts of bus automatic transmission

$T_{p.vid.} \cdot 10^3$ km	Control keybord	Electronic control unit	The main control eable	Loading sensors	Damage of friction surfaces
	24,3989	29,3692	26,9961	23,7547	27,6670

Table 4. Results of failure rate calculations

Intervals, km		0-9000	9000-18000	18000-27000	27000-36000	36000-45000	45000-54000
Middle of interval T_{vi}, km		4500	13500	22500	31500	40500	49500
Control keybord	$f(T)$	0,01144	0,02792	0,03043	0,02248	0,01229	0,00515
	$F(T)$	0,10226	0,34711	0,61691	0,81855	0,93048	0,97863
	$\lambda(T)$	0,01274	0,04276	0,07943	0,12389	0,17678	0,24099
Electronic control unit	$f(T)$	0,01106	0,02488	0,02765	0,02221	0,01402	0,00723
	$F(T)$	0,09692	0,31775	0,56428	0,76301	0,89003	0,95595
	$\lambda(T)$	0,01225	0,03647	0,06346	0,09372	0,12749	0,16413
The main control eable	$f(T)$	0,01111	0,02414	0,02675	0,02187	0,01434	0,00780
	$F(T)$	0,09715	0,31165	0,55013	0,74561	0,87510	0,94635
	$\lambda(T)$	0,01231	0,03507	0,05946	0,08597	0,11481	0,14539
Loading sensors	$f(T)$	0,01615	0,02899	0,02753	0,01961	0,01770	0,00619
	$F(T)$	0,13890	0,39357	0,63928	0,81537	0,91818	0,96772
	$\lambda(T)$	0,01876	0,04780	0,07632	0,10621	0,21633	0,19176
Damage of friction surfaces	$f(T)$	0,00883	0,02271	0,02752	0,02359	0,01552	0,00816
	$F(T)$	0,07906	0,28045	0,52495	0,73523	0,87554	0,95027
	$\lambda(T)$	0,00959	0,03156	0,05793	0,08910	0,12470	0,16409

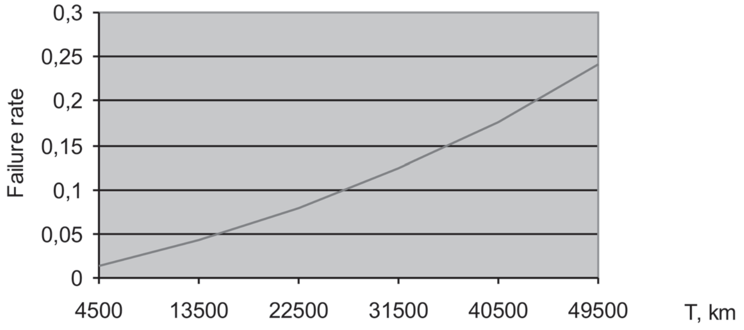

Fig 2. Failure rate of control keys $\lambda(T)$

damages of gearbox friction surfaces are often observed when dismantling the unit. Another influencing factor is the failure of gearbox electronic control system.

The most common cases are microchip failures, damages in electric insulation, oxidation and corrosion of contacts. The average work-to-failure of gearbox electronic control system is 30 thous. km. Failures are more often in cold weather. This may be accounted for higher humidity, temperature variations and bus vibration. Microchips often fail due to unstable voltage.

Gearbox should be inspected every ten thousand kilometers of travel. A bus runs about 9–10 thous. km a month in Vilnius. This means that preventive maintenance can be provided to meet the above requirements.

The detailed examination of the control cable when power supply is shut off and calculation of its reliability revealed some design errors. The cable may fail due to the damage of an insulating layer caused by its rubbing against the fixing elements. A faulty connection of two branches is often found. Its failure is caused by oxidation or corrosion. Failures due to damaged cable insulation are mainly observed in autumn and winter.

4. A case study of heavily corroded crankshaft bearings

In inspecting the above-mentioned units of buses KAROSA B-714 run by 'Vilnius buses' Ltd, a unique case of the engine MIHR 06.20.45 A/B failure caused by corrosion affecting the inner side of the crankshaft bearing inserts was observed. The maintenance staff of the enterprise workshop explained that, in general, such cases though encountered several times recently are extremely rare.

The inspection of all six pairs of inserts has shown that:

- both main and connecting rod bearings are affected by corrosion;
- corrosion affects only the inner side of the lower inserts;
- the largest areas affected by corrosion are in the main bearings.

It is clear that the observed defects were caused by a liquid which collected in bearings (on their lower inserts) because its unit weight was higher than that of the engine oil Statoil Max Way 15W–40 ($\rho \approx 0{,}885$ g/cm^3).

This state is more stable in the main bearings (because centrifugal forces are inactive). The data on corrosion-affected areas are given in Figs 3, 4.

Since the engine was filled with high quality fresh oil, it could be polluted only by a cooling liquid leaked

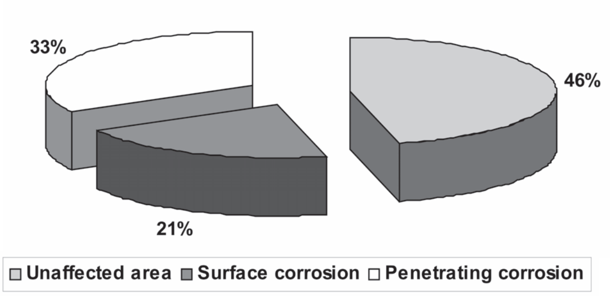

Fig 3. Inner surface damages of the lower insert of the crankshaft bearing

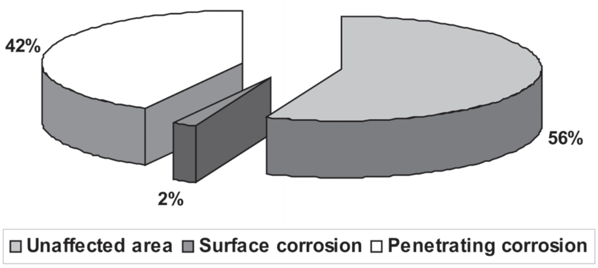

Fig 4. Inner surface damages of the lower insert of the connecting rod bearing

from a poorly insulated cooling system. Examining the oil remaining in the engine we could observe hardly any changes in its consistence (e.g. flakes, jelly). Since engine oil was discharged before dismantling the engine, it could not be properly examined and assessed.

The cooling liquid (ethylene glycol) was getting into the engine oil in small amounts because the cooling system was deteriorating and leaking it. However, it was not detected by any sensor or maintenance worker.

When examining cylinder hubs hardened and cracked rubber gaskets were detected and large areas damaged by cavitational erosion were found (Fig 5). These damages could be caused by the cooling liquid.

This occurs when a low grade or improper cooling liquid is used.

At the period of inspection TOSOL A diluted with distilled water (up to 50 %) was poured into the cooling system of KAROSA B-741 for economic purposes. Its boiling point is 108 °C.

However, MAXIGEL manufactured by the company 'Elf' which is recommended by the manufacturer starts boiling at +126 °C when diluted with water up to 56 %. The whole process having great negative effects may proceed as follows: the cooling liquid started boiling when heated up to ~100–180 °C, then the boiling ceased when it was cooled and after a certain time the liquid was heated and started boiling again. It is clear that a short time was needed for the cooling liquid to start boiling again and this was how it could

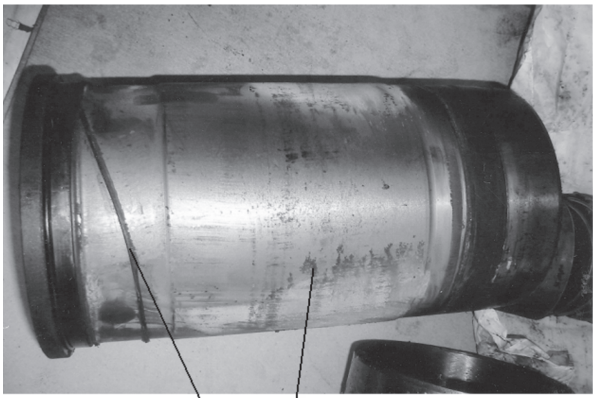

Fig 5. Surface damages of the cylinder hub: 1 – damaged rubbergasket; 2 – surface areas damaged by cavitational corrosion

damage cylinder hub surfaces and rubber gaskets. The use of a not suitable cooling liquid may be explained by inadequate evaluation of its negative effect on the engine and by the intention to cut expenses on maintenance materials.

Slow deterioration of an engine and its cooling system not detected by the enterprise sensors and other facilities could be observed by periodically checking oil and determining its operational characteristics [10].

5. Conclusions

1. The analysis of the data on the front suspension failures observed in a bus Karosa 104 and the calculation of the reliability of its units and parts by statistical models reveal that the body height control valve is its weakest element. Its average expected work-to-failure is 34,4 thous. km. This parameter of the connecting elements of the moving parts of suspension, e.g. that of a horizontal swivel pin hub is merely 31,6 thous. km. For air cushions it is 130.3 thous. km making only a third of the value specified by the manufacturer.

2. Units and parts of the pneumatic front suspension often fail indicating that service conditions of KAROSA buses are rather complicated.

3. It may be recommended to perform the routine maintenance of front suspension units and parts per 30–35 thous. km of the vehicle run.

4. Testing of the automatic gearbox of 71 buses KAROSA B-741 aimed at determining its reliability has shown that it is the electronic control system that fails most frequently. The failure rate $\lambda(T)$ of the units and parts tested reaches 0,06346-0,07943, while the corrected mathematical values of the specified safe operation range from 24,4 to 27,7 thous. km.

5. The observed failures of the automatic gearbox units such as burning out of microchips, corrosion of individual parts, oxidation and corrosion of contacting surfaces of power supply system and damages of a wire insulating layer at the connections show that some design errors were made in electronic control system. As a result, the system is nor properly insulated, this being the cause of more frequent failures in cold seasons.

6. The following preventive maintenance should be performed before the cold season: the contacts should be cleaned and lubricated with water-resistant oils.

7. Based on the data provided the preventive maintenance should be coordinated with the current maintenance performed per 10 thous. km of the vehicle run and the time of the routine maintenance of other units suggested in the present paper.

8. The case study of heavy corrosion of the crankshaft bearings and the analysis of its causes demonstrate the importance of high quality maintenance liquids and their proper application.

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