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Analysis of Load Spectrums of Six-Speed Gearbox for Mountainous and Flat Terrains

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ABSTRACT: *The bearings, which are embedded in gearbox, are exposed to the varying work conditions and workloadsduring exploitation. The load and the frequency of rotation are changed in short intervals. The examination of the bearings, that are built into the gearbox, need to examine the entire gearbox. In order to obtain realistic loads during work of the bearing and forming load spectrum on the basis of experimental results in the exploitation, the measurement of load at the output of the gearbox has carried out. Based on these results, load spectrum for the bearings embedded in six-speed gearbox in the representative working conditions has been formed.*

Keywords: *bearing, gearbox, load spectrum*

I. INTRODUCTION

Bearings are exposed to the varying working conditions during the work of the gearbox. There is a change in load and the frequency of rotation in short intervals. The bearing testing are possible in the laboratory [1-4] or in the working conditions [5]. Bearing load testing is planned in a standard laboratory conditions under the corresponding force at a constant angular velocity [6-9]. Bearing testing results in laboratory conditions are compared with results which computer obtained [10].
Namely, the results obtained in laboratory conditions do not fully correspond to real working conditions and is necessary to transform them, with the appropriate calculations, in the fields close to working conditions of the gearbox. Further, it is possible to carry out measurements of torque [11, 12, 13, 14, 15] in real working conditions of the gearbox with embedded bearings.

As the gearbox working conditions vary depending on the exploitation conditions and the transmission speed, so is the dissipation of the number of revolutions until destruction large. The dynamic load rating of the bearing C is the load this bearing may submit during the 10^6 rev, it being does not occur damage of more than ten percent of the bearings (bearing failure probability 0,1). Value of failure probability 0.1 may be increased depending on the conditions of the exploitation. Taking into account the exploitation conditions, during testing comes to the changes of load, rotation frequency, inertial forces, lubrication etc. For the purpose of experimental tests in real working conditions when driving a truck at various road conditions a six-speed gearbox have been utilized (Figure 1). During the testing, next to road conditions, load on vehicle have been changed too.

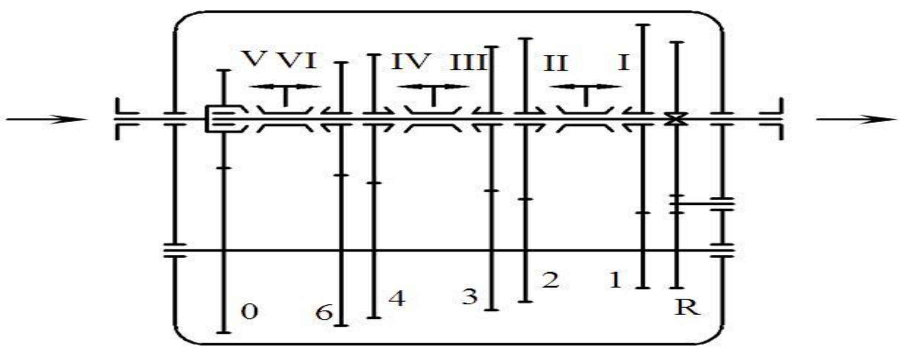

Fig.1. Bearings and gearsposition in the gearbox

II. GEARBOX TEST CONDITIONS

The six-speed gearbox is fitted to the freight motor vehicle, which position of the bearings is shown in figure 1.Five bearings are embedded in this gearbox, one of which is cylindrical roller bearing on the input shaft (B1), one ball bearing on the output shaft (B4), two tapered rolling bearings (B2 and B5) on the central shaft and another roller bearing on the output shaft (B3). Figure 2 shows a 3D view of the inner part of the gearbox with display of the bearings that are embedded in gearbox. During operation of gearbox working conditions are variable. Depending on the speed of the gear, as well as the conditions of exploitation, there are changes in: bearing load, rotation frequency, temperature, inertial forces and lubrication conditions. Taking this parameters into account, loads for different exploitation conditions are measured on the gearbox. Since the load is not the same, as well as participation of the gear speeds for laden and unladen motor vehicle and the operating conditions when driving on different terrains, in this case the measurement of the load for laden and unladen vehicle when driving on mountain and lowland terrains has been carried out. Figure 3 gives an overview of gearbox speed ratio when driving a truck in mountain and lowland terrain.

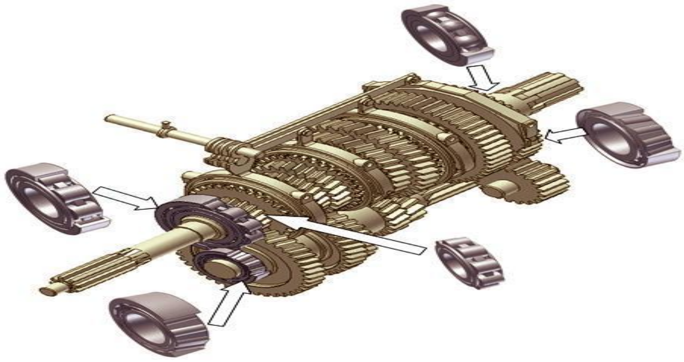

Fig.2. Six-speed gearbox with a 3D display of the interior of the gearbox

and down the slope. Figure 5 gives an overview of the results of one measurement when driving unladen freight motor vehicle on the flat ground using all gearbox speeds. It should be noted that when driving the vehicle at a different terrains, up and down the slope, all gearbox speedsare not used. The number and size of gearbox speeds, used for driving, depend on the road characteristics and vehicle load.

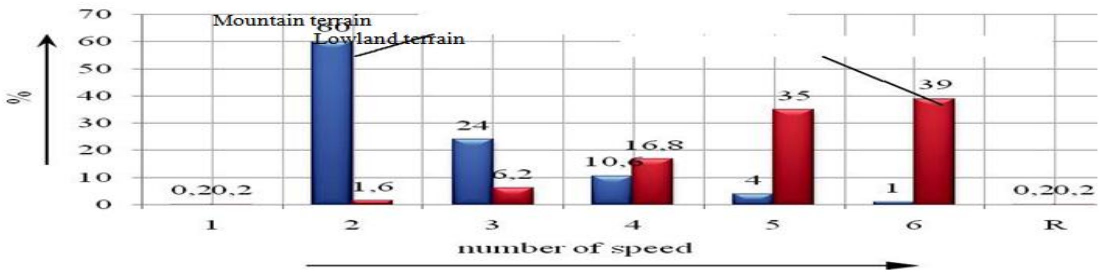

Fig.3. Gearbox speed ratio when driving on mountain and lowland terrain

Data are the result of the survey, which was conducted in long- term monitoring of freight motor vehicles, where were embedded manual gearboxes. The analysis results relate only to the gearboxes installed into freight motor vehicles and buses, and does not include results for passenger vehicles. For a given gearbox speed ratio the measurement of the torque on the output shaft was made, i.e. on the Cardan shaft, which is connected to the output shaft of the gearbox (Figure 4). The value of the load, which is measured on the Cardan shaft, greatly depends on the working conditions of the gearbox, so that the measurement was performed for representative working conditions, i.e. for a variety of terrain and gearbox speeds. The test drive was done on the flat ground, up the slope

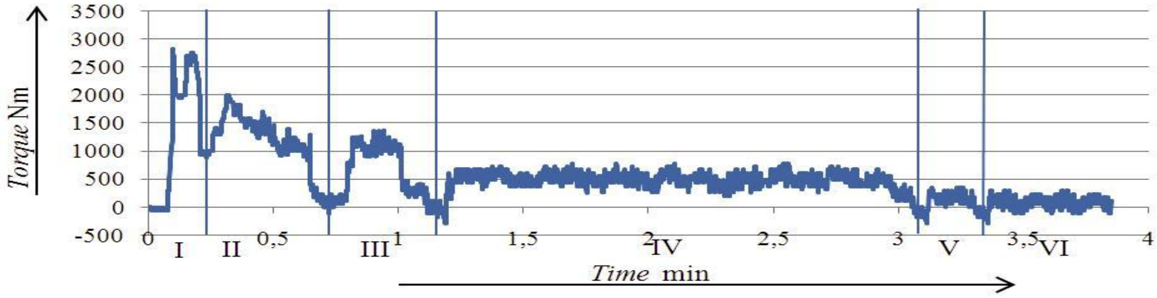

Fig.4. Measurement equipment installed on the Cardan shaft

In the same way the test results for other terrain, when driving loaded and unloaded vehicle, are obtained.

Fig.5. Torque diagram when driving unladen freight motor vehicle using all gearbox speeds on flat terrain

III. LOAD SPECTRUM OF THE BEARING

Roller bearingis embedded on the output shaft in the support B1 (figure 1). The bearing is exposed to variable load, depending on the running gearbox speed. In addition to these changes, the load changes depends on the change of the torque, which is transmitted through the gearbox. Fourteen force changes occurs in this support, i.e. the forces that occur when driving vehicles with all levels of transmission, except the fifth. On the other hand, the input shaft is supported on the output shaft. At the contact of the input and output shaft there is the bearing which transmits the forces at work of all gearbox speeds, except the fifth, so that the axial forces are balanced for the most part. The forces, which acting on the bearings, were calculated on the basis of the loads that is transmitted from the input to the output shaft using a certain gearbox speed. Based on the percentage share of gearbox speeds, the number of revolutions of the input shaft is calculated, so that percentage share of the bearing rpm on the input shaft for life time of 10^6 revolutions was obtained. Using the forces acting on the bearing, calculation for equivalent bearing loads for each gearbox speedis made (Table 1), on the basis of which the load spectrum for the ball bearings on the input shaft is formed (Figure 6).

The load is transferred from the input to the output shaft through the central shaft in all gearbox speeds except the fifth. Two tapered rolling bearings are embedded on the central shaft and distance between gears and bearings are fixed, so that loads transmitted through these bearings depend only on load changes. These changes are result of changing gearbox speed or driving conditions. Both bearings have the same rotation speed. The loads are transmitted over the output shaft during the work of all gearbox speeds. One side of output shaft is relies on the input shaft, and the other side is connected with Cardanshaft.There are two bearings on it, one of which is single row ball bearing at the outlet of the gearbox and the other is roller bearing which is located at the joint of the input and output shaft. The loads are calculated for both bearings for each gearbox speed, except the fifth, and they are different because of the distance between the gears and bearings where the load calculated.

Although both bearings are on the same shaft and rotating in the same direction, they won't have the same number of revolutions. The number of revolutions of the bearing (roller bearing) at the junction of the input and output shafts is equal to the difference between the number of revolutions of these two shafts.

	F N	$x_i=F_i/F$	n
1	19624	1	281097
2	17953	0,915	69896
3	16191	0,825	6884
5	14808	0,754	485175
6	14231	0,725	149624
7	8563	0,436	7324

Table 1. Equivalent loads of the bearing on the input shaft

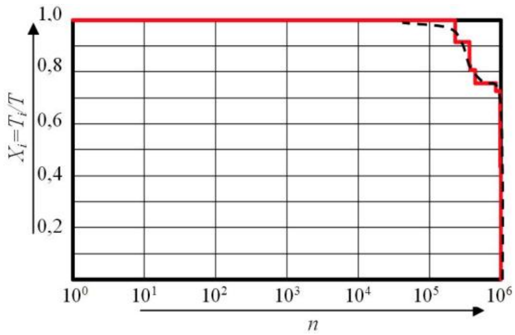

Fig.6. Load spectrum for the bearing on the input shaft

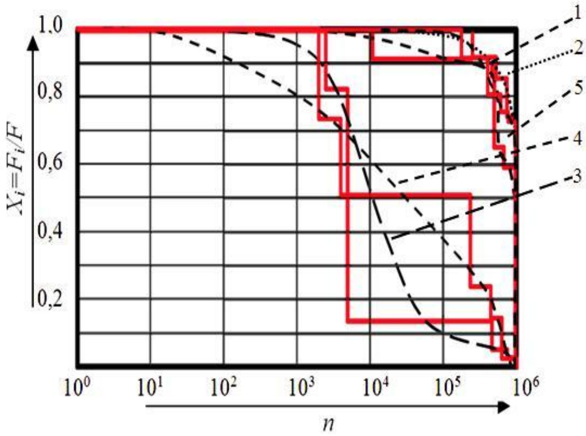

Fig.7. Load spectrum for all bearings in the six-speed gearbox

In the same way, as for the roller bearing on the input shaft, the load spectrum for the bearings on the central and output shaft are formed. Figure 7 shows the load spectrum for all bearings embedded in the gearbox.

1- roller bearing on the input shaft

2- tapered roller bearing on the central shaft on the side of the input shaft
3- tapered roller bearing on the central shaft on the side of the output shaft

4- ball bearing on the output shaft

5- roller bearing on the output shaft

Based on the analysis of the load spectrums for all bearings embedded in six-speed gearbox can be concluded that the bearings 1.2 and 5, i.e. roller bearing on the input shaft, tapered roller bearing on the central shaft on the side of the input shaft and roller bearing on the output shaft, have approximately equalized working conditions, i.e. heavy duty. The least loaded bearing, i.e. bearing exposed to middle duty, during the work, is the ball bearing on the output shaft.

IV. CONCLUSION

The bearings are exposed to variable loads during the work of the gearbox, which largely depend on the working conditions. To test bearing during the exploitation it is necessary to carry out tests on complete gearbox during various driving conditions. In the first place should be defined road conditions on which the testing carried out, as well as a percentage share of the gearbox speeds. The measurement was carried out using a strain gages on the Cardan shaft which is connected to the output shaft of the gearbox. The results are obtained for different road characteristics and different percentage share of the gearbox speeds. On the basis of these results, load spectrums for the bearings embedded in six-speed gearbox have been formed. By analyzing the results and load spectrums it can be concluded that the bearings embedded on the side of the input shaft may be critical.

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