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MEASUREMENT OF TORQUE ON THE CARDAN SHAFT EMBEDDED IN THE FREIGHT VEHICLE

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Abstract: *Before analysis, development or improvement of existing structure of drive unit or gearboxes, the load that appearing in exploitation must be known. This paper presents a method of load (torque) measurement, on the cardan shaft embedded in the freight vehicle, using strain gages. The aim of the study is to determine torque variation depending on the exploitation conditions (road surface, speed transmission, vehicle load, etc). The measurement was performed for different road characteristics (vehicle movement on flat terrain, up and down the slope). Results are presented using tables and diagrams, and percentage utilization of the power drive unit, embedded into freight vehicle, was calculated based on obtained values of torque. Obtained results have an important role for designers because they give a general insight in the load on the cardan shaft , which represent the basis for future development or redesign of power unit or gearboxes and basis for forming of specter of gear load and bearing embedded into gearbox.*
Keywords: *torque, cardan shaft, strain gages, freight vehicle*

INTRODUCTION

Experimental and scientific researches that precede the development or reconstruction of gearboxes are very significant in terms of improving and complementing the existing results, in order to achieve robustness of the structure. The research may be carried out immediately before the process of development or reconstruction of the product, or it can be carried out later and optionally used for reconstruction. Such an experimental research, was performed in this paper and refers to the measurement of torque on the cardan shaft of the freight vehicle using strain gages.

Measurement of the torque by experimental methods in the vehicles may be performed on the basis of speed measurements of vehicle movement [1], and using sensors embedded in the motor without changing the structure during assembly [2]. In order to define a method of torque measurement that realizes synchronous motors, there are two different methods [3].

Besides the tests on engines, torque measurements on the manual gearboxes [4] and vehicle shafts can be performed [5, 6]. Strains gages are often applied for torque measurement on the shafts and they are very suitable for this use. They are glued to the appropriate places on the shaft so the corresponding stress can be measured. The measured value are transmitted to the sensor circuit where they are compared with calibration data, on which basis torque values are calculated. Strain gages are connected in Wheatstone bridge in order to obtain accurate results of the torques [6]. This paper is a extension of the research started in [7] and [8], through which the model of the gearbox was developed, and which is the basis for analysis of gearboxes.

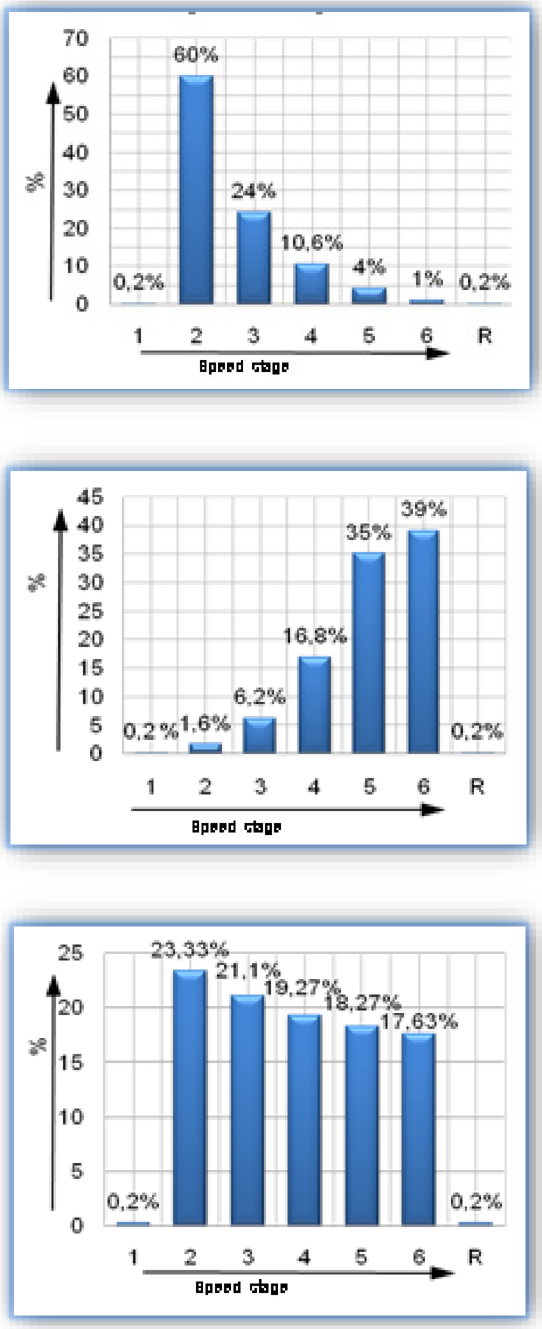
Freight vehicles are applied in almost all parts of the world. This form of transport is at the service of many companies for decades, especially those in mountainous and woods abounding areas. When driving a freight vehicle in different conditions, the driver has a very important role throughout the process. The manner in which he performs the vehicle operation depends on his ability, and therefore use of certain gearbox speeds. It should be noted that the vehicle driving in the same road conditions may not be the same.

ANALYSIS OF WORKING CONDITIONS AND TORQUE MEASUREMENT METHODS

Freight vehicles operate under different working conditions. During the exploitation, the road characteristics and loads are varying, and freight vehicle drivers are also very important. To determine how is changing the torque under different driving conditions and different gearbox speeds, the torque measurement on the Cardan shaft, which is embedded in the freight vehicle FAP 1620, was carried out.

As the freight vehicles used under various road characteristics, the test was made while driving the vehicle on plain terrain as a representative of lowland terrain, up and down the slope as a representative of mountainous terrain, using of appropriate gearbox speeds. For given test, using the method of interview the percentage share of gearbox speeds was obtained (Figure 1).

By analyzing the diagrams of percentage share of gearbox speeds for trucks, we can confirm the assumption that the driving over mountainous terrain mostly uses the lower gearbox speeds, while driving over flat terrain mostly uses the higher gearbox speed.



a)

b)

c)

Figure 1. Participation of gearbox speeds in truck drives under various operation conditions: a) mountain conditions, b) flat ground conditions, c) combination conditions

The vehicle (Figure 2) is equipped with six-speed gearbox 6MS-80 and FAMOS engine. The vehicle has been upgraded with vehicle-mounted grapple device for wood transport.

The basic parameters of the engine and gearbox are:

Engine

- *Type: FAMOS 2F 131 B*
- *Maximum power – Output: 147 kW/2200 min^{-1}*
- *Maximum torque: 668Nm/1400-1600 min^{-1}*

Gearbox

- *Type: FAMOS 6MS-80*
- *Construction: Synchronous Gearbox, six forward gears and one reverse*
- *Ratio 6,7; 3,86; 2,34; 1,44; 1,00; 0,73, reverse 6,31*

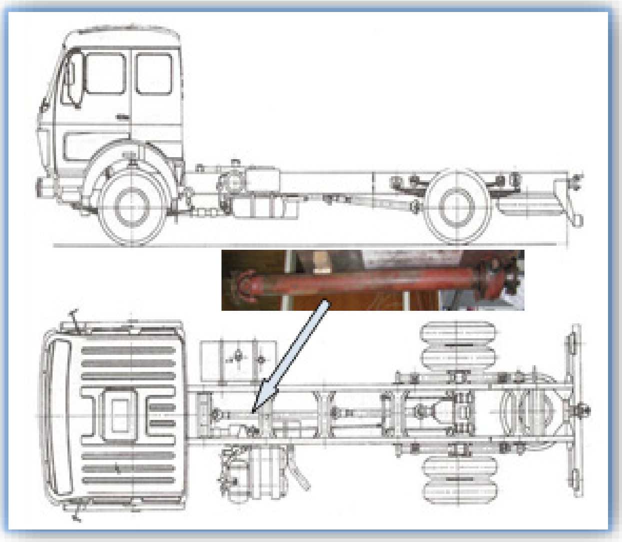
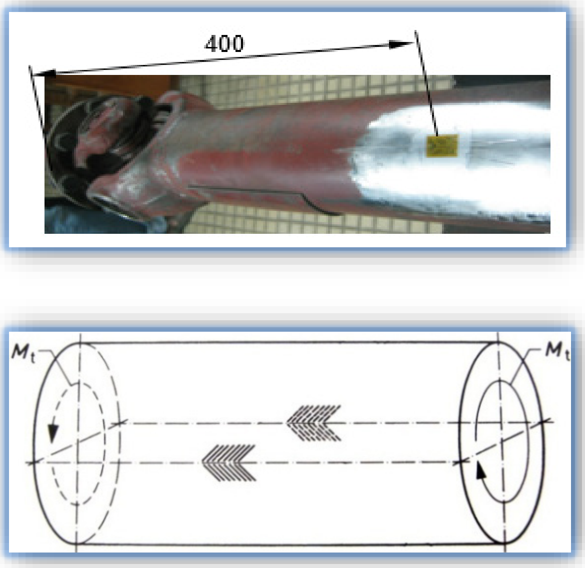


Figure 2. The vehicle for measuring torque brands FAP 1620

Based on a detailed analysis and observing of the possibility for realization torque measurement in all gears speeds for representative driving conditions, the most suitable place on the Cardan shaft was determined. The torque is transmitted via two cardan shafts from the gearbox to the drive shaft, one of which is directly connected to the gearbox output shaft, while on the other side relies on the bearing, whose length is fixed. The other shaft is telescopic and it is connected to the first Cardan shaft on the one side and to the differential transmission on the other side. For reasons of simpler and easier installation of measuring devices to the first shaft, the measurement is performed on it. The measurement was made with strain gages, which were glued on Cardan shaft at a distance of 400 mm from its beginning, i.e. on the side of gearbox (Figure 3a).



a)

b)

Figure 3. Location of glued strain gage a) glued strain gage on the shaft; b) schematic view of strain gage

Tensiometers (strain gages) are most suitable for this purpose, so that the two strain gages were glued on cardan shaft in the form of herringbone at an angle of 180 degrees (Figure 3b). The strain gage technical data:

» Tolerance of Temp Compensation $\alpha=11\cdot10^{-6}/^{\circ}K$,
» Gage Resistance 120,0 ±0,2%,
» K-factor 2,05 ± 1,0 %,
» Gage Factor Change with Temperature $95\cdot10^{-6}/^{\circ}K$.

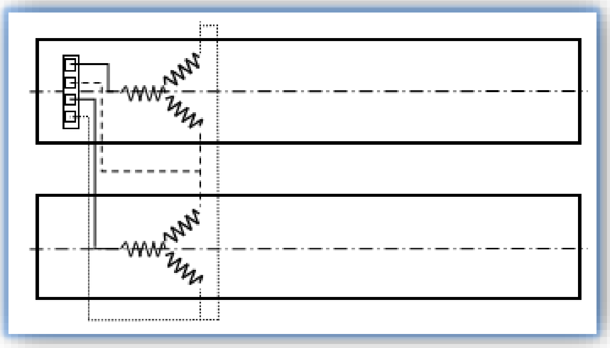


Figure 4. Method of connection strain gages with connectors

Glued strain gages are connected in Wheatstone bridge and the corresponding connectors on which are connected the device for contactless data transfer.

Figure 4 shows method of connection strain gages with connectors.

As a support to the torque measurement, communication module RN41 was used (bluetooth). The connection between the communication module RN41 and strain gages was made using a PIC 16 F 887 which transforms measured values from strain gages in a signal suitable for contactless data transfer to the receiver. Transmitted signals are recorded by a suitable device (Bluetooth for PC) on computer, and then in a suitable form shown. The computer was used for monitoring certain changes that take place on the shaft, and as a basis for visual display and recording of data served a software form Data Logger II v7.0 which is reprogrammed and adjusted for torque measurement. Before of each measurement the value of compensation was entered to avoid possible temperature changes.

The maximum theoretical output torque of the gearbox is less than 6000 Nm, and calibration was performed so that the maximum values that may occur at the output of the gearbox are set on determined value. In addition, the scale where the display range is set, is divided into two parts, so that one part of the bar shows a positive values for the forward movement of a truck, while the second part of the scale is set for showing and recording negative values for reverse movement of the vehicle.

TORQUE MEASUREMENT

Based on the obtained percentage participation of the gear pairs and set the measuring device to Cardan shaft, we have measured torque for unloaded and loaded vehicle for an representative working condition.

The movement of unloaded vehicles on the flat ground

When examining the truck on flat ground,, as a representative for plains driving conditions, were used all gears. From the idle state was launched vehicle first stage of transmission and measured the value of torque in the amount of 2820 Nm (Figure 5).

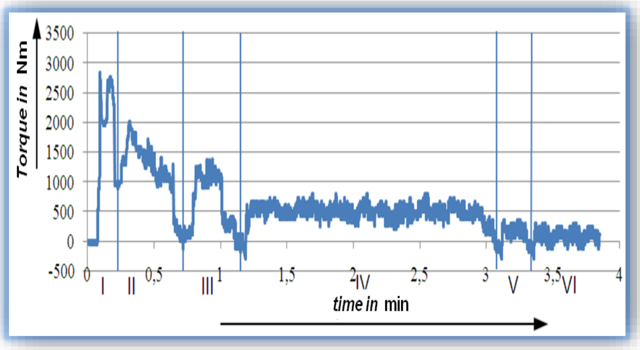


Figure 5. Diagram of the measured torque when driving unburdened freight vehicles using all gear pairs on flat terrain

On the diagram of the measured torque, sudden changes the intensity of the measured values show moments of switching from one gear pairs to another. The diagram also shows that the increase of gear reduces the value of the measured torque. The values of torque on the Cardan shaft were measured in terms of driving unloaded a truck at normal driving conditions (no overload). With the diagram (Figure 5) can be seen that during the long driving one stage of transmission can appearing several times the maximum torques, which shows stochastics driving conditions.

Based on the measured results can be seen that the maximum engine power is used in the driving fourth gear around 83%, while the lowest utilization of engine power when using sixth gear (Table 1). The values of maximum torque for all gears and percentage utilization of engine power when driving unburdened truck using all gears on flat terrain are given in Table 1.

Table 1. The values of maximum torque and the percentage of power utilization using all gears for driving unburdened a truck on flat terrain

Speed stage	Maximum torque on Cardan shaft [Nm]	Engine power efficiency [%]
First	2820	62.93
Second	1940	75.15
Third	1250	82.95
Fourth	770	83.08
Fifth	351	54.83
Sixth	292	53.25

When switching from one to another gear pairs can see a clear decrease in torque because at that point due to inertia of the vehicle does not appear torque by transmission than by the drive shaft.

The movement of unburdened vehicles up the slope

During freight vehicles driving up the slope it is important to notice that only three transmission stages are used and measured results are shown in Fig. 6.

During driving in second transmission stage, different values of torque were measured. Right side of diagram (Fig. 6) shows torque variation because of ride over rough terrain. Maximum of torque is 2800Nm and it is measured for the first transmission stage.

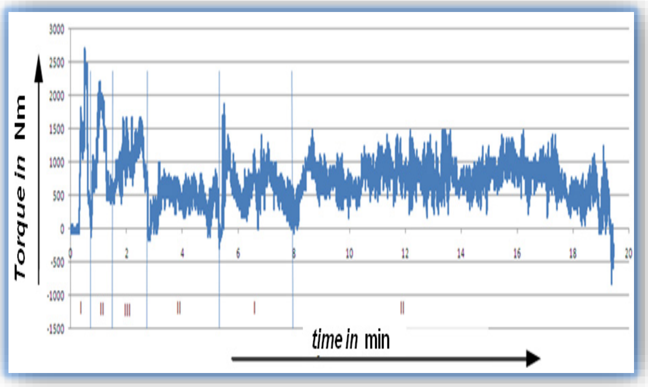


Figure 6. Diagram of measured torques during unloaded freight vehicles ride up the slope

Based on results in table 2, maximum engine power efficiency (cca. 87,33%) is during ride in third gear and minimum engine power efficiency is during ride in second gear.

Table 2. Maximum torques and engine power efficiency percentage values during unloaded truck ride up the slope

Speed stage	Maximum torque on Cardan shaft [Nm]	Engine power efficiency [%]
First	2800	63.56
Second	2200	85.22
Third	1609	87.33
Second	995	38.54
First	1870	42.45
Second	1450	56.17

The movement of unburdened vehicles down the slope

During riding down the slope truck accelerates because of inertial forces, so Caradan shaft is loaded in different way in order to truck riding up the slope. In this case, loads are same as loads using gear pair for reverse. Diagram of torque mesured results for two transmission stages and reverse is shown in Figure 7.

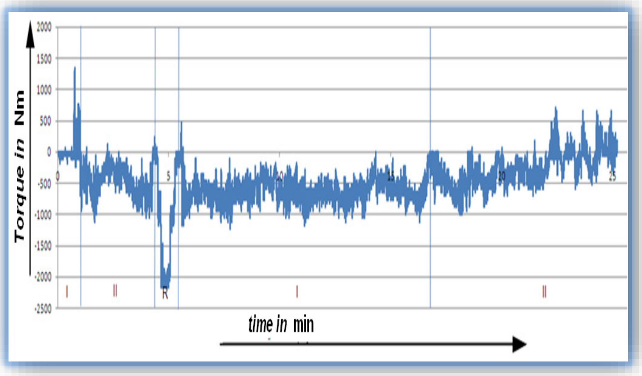


Figure 7. Diagram of measured torques during unloaded freight vehicles ride down the slope

On the same road both torque for riding in second gear and reverse was measured. Maximum torque of 2170 Nm on Cardan shaft was measured for reverse. Also, maximum engine power efficiency is for reverse (Table 3).

Table 3. Maximum torques and engine power efficiency percentage values during unloaded truck ride up the slope

Speed stage	Maximum torque on Cardan shaft [Nm]	Engine power efficiency [%]
First	1346	30,55
Second	-1053	41,50
Reverse	-2170	47,99
First	-1170	26,33
Second	-995	38,54

In the same manner and under the same road characteristics was measured the torque for laded truck whose weight was 15980 kg. During the loaded truck ride on the flat ground was obtained diagram of the measured maximum torque (Figure 8) with a percentage of engine power efficiency (Figure 9) for the respective transmission stage.

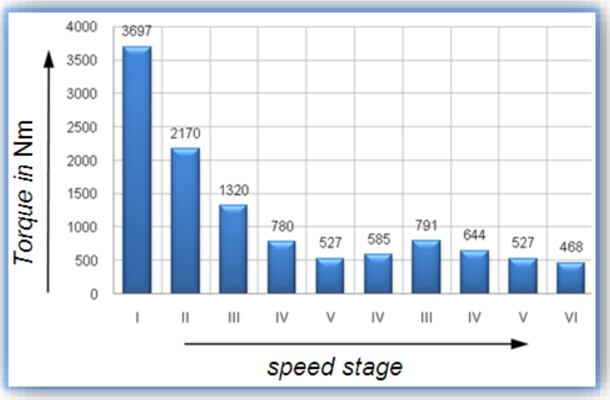


Figure 8. Diagram of maximum measured torques during loaded truck ride on the flat tertain

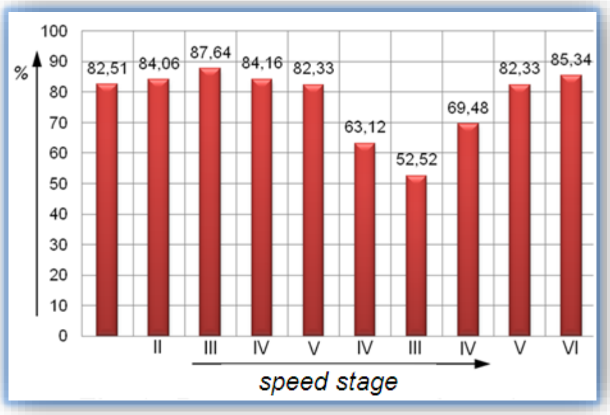


Figure 9. Percentage utilization of power engine when loaded truck driving on flat tertain

In addition, the measured values are not always the same and vary depending on driving conditions. During repeated measurements were obtained different values of torque when using some of transmissions stage. This suggests a stochastics change of the torque values. The measured values are only representative indicator of the state of working conditions. During the loaded truck ride on the flat ground in first gear was measured torque more than 870 Nm (23% more using engine power) truck unloaded ride for the same road *characteristics. During the unloaded truck ride in third gear was measured the highest engine power efficiency. During the truck loaded ride in the same transmission stage the engine power efficiency was 5% more then unloaded truck ride.*

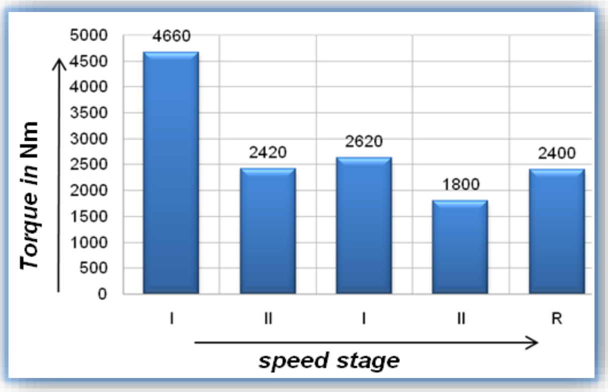


Figure 10. Diagram of maximum measured torques during loaded truck ride up the slope

Torque of 4660 Nm was measured during the loaded truck ride up the slope and this torque is higher for 1830 Nm than measured during the unloaded truck ride up the slope (Figure 10).

Engine power efficiency (over 92%) is during ride in first gear up the slope and this is 30% more than truck unloaded ride up the slope (Figure 11). Engine power efficiency is more than 9% in second gear.

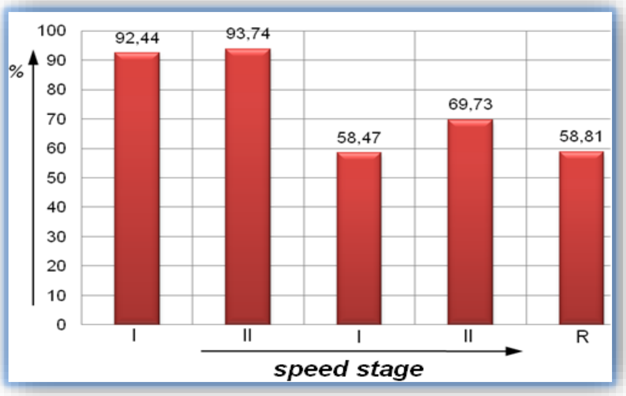


Figure 11. Percentage utilization of power engine when loaded truck ride up the slope

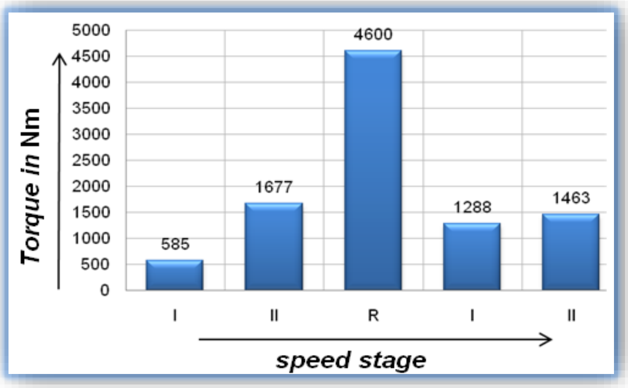


Figure 12. Diagram of maximum measured torques during loaded truck ride down the slope

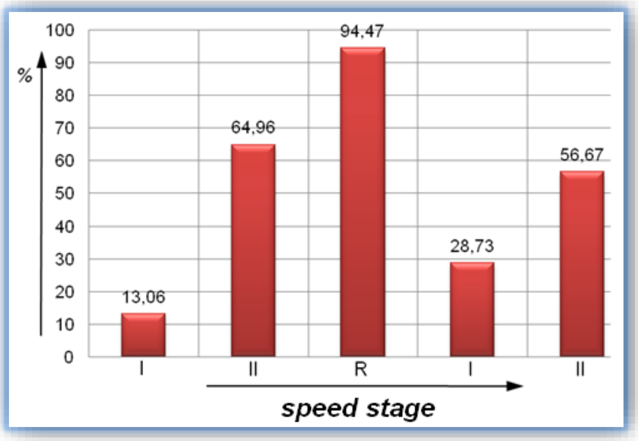


Figure 13. Percentage utilization of power engine when loaded truck ride down the slope

In the case, during the truck ride down the slope maximum torque of 4660 Nm on Cardan shaft was measured for loaded truck reverse (Figure 12). This torque is for 2430 more then unloaded truck reverse. Such an increase in torque resulting in increase efficiency of engine power unit for over 49%. Maximum engine power efficiency (over 94%) is during loaded truck reverse (Figure 13).

CONCLUSION

Before analysis, development or improvement of existing structure of drive unit or gearboxes, the load that appearing in exploitation must be known. This paper presents a method of measuring torque of Cardan shaft during exploitation. Through the paper shows a method of setting the strain gage on the shaft, as well as one of the possible contactless measurements methods. Torque was measured for different representative, different road characteristic and driving conditions. Small differences torque that occur in the experiment are due to changes in travel characteristics (substrate etc.).

The overall conclusion is that the torque will be higher for the loaded truck for the same road characteristics, was expected, but how will torque in which case increase and how will change engine power efficiency it was not possible to assume.

The paper also presents the percentage of engine power efficiency when loaded or unloaded truck ride in specific gear on same road characteristic. It is possible to expect similar behavior of Cardan shaft torque on other commercial truck similar purposes.

In accordance with the foregoing it can be said that the results of this study are important for mehanical constructors engineer and engineers who are engaged in developing, analyzing and reconstructing of powertrain, gear box, Cardan shaft for trucks. Also, the results are the basis for the formation of load spectrums of gears, bearings and gear boxes, as well as possibilities for simulation of real working conditions in Laboratory conditions for appropriate tests.

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