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EXPERIMENTAL LOAD DETERMINATION ON GEARBOX SHAFT

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Abstract

The load shaft of gearbox which drives the working wheel on a rotating excavator, or the driving shaft on the working wheel is from the resistance that overcomes in the process of digging with the excavator. Forces from the resistance are transmitted through the working wheel on its drive shaft and the gearbox. Loads on this shaft are torsion moments with a certain quantity. The values of those moments are very important because they represent the input values when analyzing the safety coefficient on the shaft and optimization of the gearbox. They are also indicators for the resistance of the digging processes in a particular mine. Theoretical load determination of this shaft is a difficult procedure and doesn't provide reliable results, because all influential factors in the work of the excavator can't be mathematically captured. For the purpose of an accurately determination of the load on the shaft it's necessary to conduct experimental research by measuring in real working conditions in previously established methodology.

This paper presented the methodology, measurement equipment and original approach to the application of tensiometric method for measuring the load of inaccessible shaft of working wheel on a specific rotating excavator and also to present the results from the conducted measurement.

Keywords: load determination, experiment, gearbox shaft

1. INTRODUCTION

The drive shaft of the rotating excavator working wheel obtains high loads, which are transmitted through the working on the wheel shaft and the gearbox for its driving. The loads are a result from the digging resistance that the excavator overcomes in the process of digging. Disposing of data on the amount of loads on the shaft and thus the size of the digging resistance for a given working regime of the excavator is essential because these data are input values in each process of optimization on the shaft and other structural elements of the gearbox.

Theoretical analysis of the loads on the shaft is a difficult procedure and does not give a realistic view of the magnitude of the digging resistance, so they preferred their experimental determination. Experimental determination of the load on the shaft requires a procedure that should be necessary performed together with experimental measurements of deformity-stress condition on the shaft during specific exploitation regimes of the excavator. The choice of equipment's and methodology of measuring influence the character of the test magnitudes, magnitudes measuring point, capabilities of the existing structure of which the measurement is realized, external influences and so on.

2. DESCRIPTION OF THE MEASURING OBJECT

The measured object, presented into the paper, is the drive shaft of the working wheel of the rotating excavator SRs-630 used in the coalmine "Suvodol" Bitola, Macedonia. The scheme of the drive gear of the excavator working wheel is shown in Figure 1, with a cross-section which is marked by the measuring point M. The scheme of the driving gear is represented into the following picture. The elements presented on the picture are the following: 1-electric motor, 2-gearbox (reducer) 3-output shaft of the gearbox, 4-working wheel, M-of cross section the drive shaft of the working wheel.

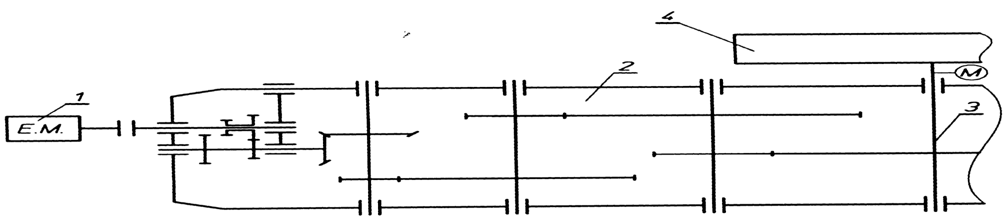
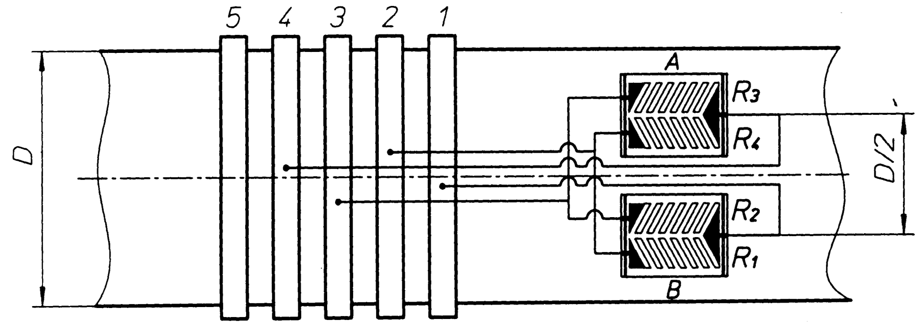


Figure 1 Scheme of the drive gear of excavator working wheel

The output shaft of the gearbox (marked with 3 in Figure 1) is designed as a hollow shaft, which allows the gearbox to put on the shaft on the working wheel. Rotational moment on the drive shaft of the working wheel is obtained with transferring rotating moment from the output shaft of the gearbox to the shaft of working wheel with cylindrical axle-pins that are involved in the development air gap between the two shafts.
On to the driving shaft on the working wheel the digging resistance occurring stresses. Experimental examination of the shaft determines the character and intensity of the stress state of the outer surface of the shaft, in a section thereof. Based on these data, determines the value of torsion moment of this shaft, at the intersection marked by M in Figure 1, which will get real value of its load.

3. METHODOLOGY OF MEASUREMENT

The basic aim of the measurement on the load shaft is to determine tangential stresses of outer surface fiber in the cross section M on to the shaft. This way determined deformations and actual torsion moment that loads the shaft, based on the known equations of strength of materials for relationship of tangential stresses with deformations and torsion moment. Measuring the mechanical magnitudes deformation on to the measuring point is conducted in tensiometric principles of conversion the measuring mechanical magnitude in adequate electrical, sensor for measuring magnitude, which for this purpose are two measuring strain gages for torsion stresses placed on the both opposite sides of the intersection M of the shaft. The way of installation of the measuring strain gages and their relationship with sliding rings is shown into Figure 2.



A B-measuring strain gages (rosettes for torsional deformation); 1, 2, 3, 4, 5-sliding rings

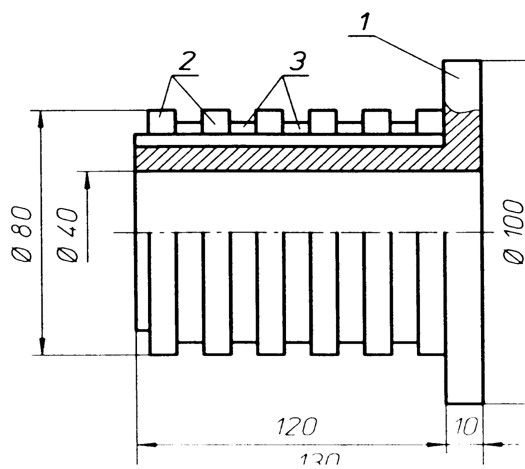
Figure 2 Connecting the measuring strain gages with the sliding rings

The transfer of electrical energy to and from the measuring stress gages are made through sliding rings with brushes. The electricity transmits on the rings with brushes, and from the rings with wires it is lead to the measuring gages (Figure 2). Turning electricity returns through the rings and brushes to measuring instruments such a turning signal. The sliding rings and brushes are shown in Figure 3 which is made for the purpose, for the unapproachable shaft of the working wheel of the excavator SRs-630.

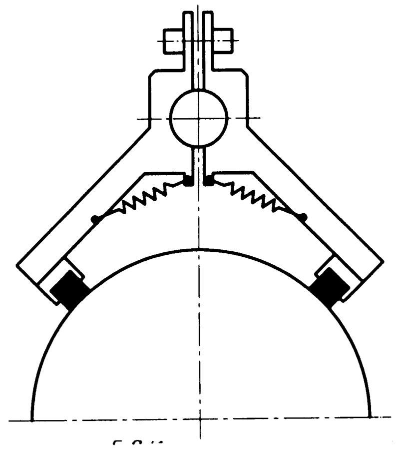
The sliding rings (Figure 3-a) are on the principle one-piece, made of brass and pulled on a bush of insulating material plastic. They are centered on the bush with distance rings between them, which are made out with the same material as the bush. Channel was engraved through the bush in the longitudinal direction in which are dragged through copper wires, which goes one to each ring where they are soldered. The second ends of these wires are joined with the wires coming from the measuring gages.

The sliding brushes (Figure 3-b) are made of an alloy of copper and graphite and brackets from brass. To achieve better contact between the brushes and rings, brushes are used into one ring. Brushes are placed on separate limb and the limbs are connected by springs to achieve a constant pressure between brushes and rings. These separate brackets of brushes are strung on a pin and they represent one whole.

Measuring strain gages, rings and brushes are connected in measurement installation shown in Figure 4, which includes measuring and amplifier bridge magnetic writer and paper writer - oscilloscope (or measuring and Amplifier Bridge, A/D converter and PC).



(a) sliding rings



(b) sliding brushes

Figure 3 Constructive view of the sliding rings and brushes

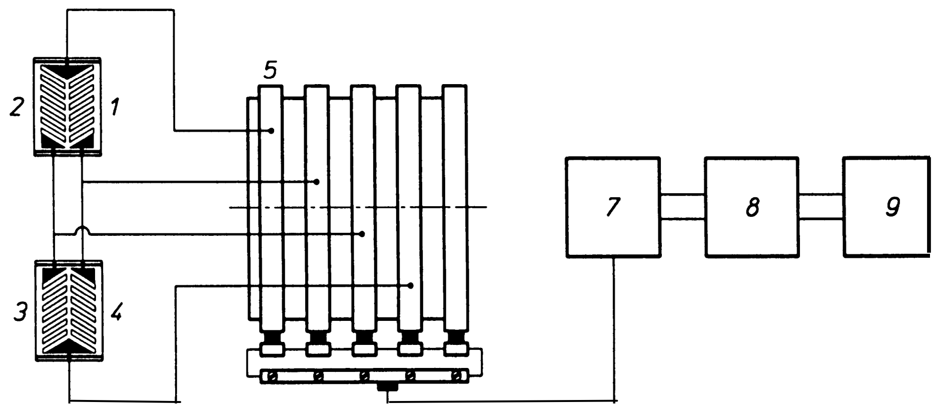


Figure 4 Presenting the measuring installation

On the presented figure number 4, we have marked the following:
1,2,3,4 - measuring strain gages placed at an angle of °45
5 - sliding rings with a ring for establishing grounding
6 - sliding brushes
7 - measuring and amplifier bridge
8 - magnetic writer (or A / D converter)
9 - paper writer-oscilloscope (or computer)

4. ORIGINALITY OF THE MEASUREMENT

Due to the inability to set the sliding rings to the shaft on the output of the gearbox, or on the entering of the working wheel (it’s not a possible physical approach from constructive reasons), proposed is a new way of setting, presented into this paper.
The measurement strain gages are glued to the shaft on to the working wheel at the place of its tilt during the annual overhaul of the excavator when the gearbox is drawn out with own output shaft from the shaft of the working wheel. In

their pull up, damages are not a common issue on to the measuring gages, because they are set up into a place where we have an air gap between the shafts. The wires that are soldered to the measuring gages are run through one of the holes for axle-pins, which transfers rotating moment from one to the other shaft (in this hole does not set axle-pin while repairing) and passing through the hole for this purpose on cover of the reducer (on the opposite side of the working wheel) out of its housing. Here the wires are connected with sliding rings.

The sliding rings with the axle-pin are placed on a pin with flange designed for this purpose. The pin with the flange is connected with screws on the output shaft top surface of the gearbox, through the cover of the gearbox. Such a constructive design the pin with the rings turns together with the output shaft of the gearbox or the shaft on to the working wheel. This constructive solution to output of the cover of the gearbox is shown in Figure 5.

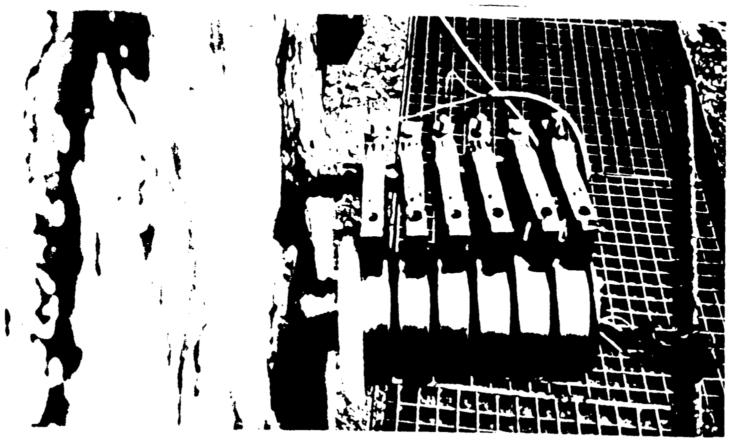


Figure 5 Representing the contact of sliding rings and brushes mounted on the output shaft on to the gearbox

5. PRESENTING THE MEASUREMENT RESULTS

Load of the drive shaft of the working wheel is measured during excavator work operations with horizontal carving and bigger rotation speed of the working wheel (7.2 min^{-1}) in each of the following defined working regimes:

- First regime - turning left by going down and maximum working load.
- Second regime - turning left by going down and normal working load.
- Third regime - turning left by going down and maximum working load at which safety couplings turn off the working wheel.
- Fourth regime - excavator working with advancing front (frontal bite).
- Fifth regime - turning right by going down and normal working load.
- Sixth regime - turning right by going down and maximum working load.

These different working regimes cover all of the working conditions on to the excavator over the total exploitation lifetime. The processed output results of the measurement, i.e. maximum deformations ε of the measuring point where are set measuring gages, for each of these working regimes, as well as the calculated magnitudes (torsion moment T_M, tangential stress of torsion τ , the power of drive shaft of the working wheel P_i and the power of input shaft of the gearbox P_v) are given into Table 1.

Table 1: Presenting systematical measuring results

Calculated magnitudes based on the measured magnitude ε					
Regimes	ε 10^{-6} [m]	T_M [Nmm]	τ [N/mm^2]	P_i [kW]	P_v [kW]
First	891.48	1286377308	144.01	960.61	1044.14
Second	629.28	908031041	101.65	678.08	737.04
Third	506.92	731469450	81.89	546.23	593.73
Fourth	122.36	176561591	19.66	131.84	143.30
Fifth	804.08	1160261886	129.89	866.43	941.77
Sixth	856.52	1230159266	137.71	916.63	996.34

The calculated magnitudes presented into Table 1 are obtained using the basic settings of the theory of strength of materials known characteristics of the gearbox, as shown below.

ε - relative elongation (dilatation) of the measuring point (for measuring gages) in μm,

$$\varepsilon = x \cdot 10^{-6} \quad (1)$$

where is:

x - deflection on the oscillogram of the measuring magnitude in mm multiplied by 17:48, which follows from calibration records of measuring magnitude.

T_M - torsion moment on the measuring point, calculated on the basis of the measuring deformation *ε*,

$$T_M = \frac{E}{1+\nu} \cdot W_o \cdot \varepsilon \quad (2)$$

where are:

E - modulus of elasticity of the material of the drive shaft of the gearbox, E = 0.21 x 10^6 N/mm^2,

ν - Poisson coefficient, $\nu = 0.3$,

W_o - polar moment resistance of the shaft of the gearbox, for the diameter *d* which are set the measuring gages,

d = 354.8 mm, $W_O = 0.2 \cdot d^3 = 0.2 \cdot 354.8^3 = 8932660.4$ mm^3

τ - tangential stress on the measuring point of the shaft,

$$\tau = \frac{T}{W_o} \quad (3)$$

P_i - power of the drive shaft of the working wheel (the output shaft of the gearbox), calculated on the basis of T_M ,

$$P_i = \frac{T_M \cdot n}{159155} \quad (4)$$

where is:

n - number of revolutions for for the shaft per second, n = 7.2 min^{-1} = 0.11885 s^{-1}

P_V - power of the input shaft of the gearbox,

$$P_V = \frac{P_i}{\eta_R} \quad (5)$$

where is:

η_R - efficiency coefficient of the gearbox.

6. CONCLUSION

The set measurement system in this paper is evaluated based on the experience of this kind of measurement as stable with a high safety coefficient. The error of measurement is estimated at about 1%.

The deformations and stresses on the drive shaft of the gearbox shown in Table 1 for different six working regimes of the excavator are the maximum in the separate regimes and suggest on impact short-term loads in those regimes which require high power of the gearbox for their mastering. But passing back from the output shaft of the reducer to the electric motor they are amortized so that the electric motor to reach smaller loads and require significantly less power for their master.

Such maximum stresses rarely occur in the daily work of the excavator, particularly those in both cases the overload (first and sixth working regime). The mentioned last loads are indicative of the possible maximum load on the drive shaft of the working wheel and authoritative for calculating the maximum torsion moments of the shaft, but not for the determination of dynamic durability of the gearbox because their occurrence is probable to less than 1% of total lifetime of the excavator.

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Elizabeta Hristovska had her Master and PhD degree on the Mechanical Faculty in Skopje, in the years 1997 and 2000. Since the year 1996 she is a part of the Faculty of Technical Sciences in Bitola, first of all as an assistant and the as well as a professor. Today she is a full time professor on the first, second and third cycle of studies. During the process of work at the faculty she has been mentor of numerous bachelor thesis as well as Master and PhD thesis. At the moment she is also a head of the Department for Industrial Engineering and Management – second cycle and a member of the University Senate. She has been in the past also a Vice Dean. During the process of work she has published 57 papers and 10 books in her home country, also 47 papers in foreign proceedings and journals from which some of them are with impact factor. She has been a part of 6 research projects, 6 applicative projects and also 6 TEMPUS projects. She's been a part of 12 study journeys in Europe and also a part of 4 guest lectures. Also she is a member of multiple scientific associations from where she has had more diplomas and awards.