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Jiří FRIES[*], František HELEBRANT[**], Petr KLOUDA[***]

TORSIONAL MOMENT MEASUREMENT ON BUCKET WHEEL SHAFT OF GIANT MACHINE

MĚŘENÍ TOČIVÉHO MOMENTU NA HŘÍDELI KOLESA VELKOSTROJE

Abstract

Bucket wheel loading at the present time (torsional moment on wheel shaft, peripheral cutting force) is determined from electromotor incoming power or reaction force measured on gearbox hinge. Both methods together are weighted by steel construction absorption of driving units and by inertial forces of motor rotating parts. In the article is described direct method of the torsional moment measurement, which eliminates mentioned unfavourable impacts except absorption of steel construction of bucket wheel itself.

Abstrakt

V současnosti se zatížení dobývacího orgánu (točivý moment na hřídeli kolesa, obvodová síla kolesa) určuje z příkonu pohonu kolesa nebo z reakce pohonu měřené na reakčním závěsu převodovky. Oba dva způsoby jsou zatíženy vlivy tlumení ocelové konstrukce pohonu a setrvačnými silami rotačních částí pohonu. V článku dále uváděná přímá metoda měření tyto vlivy eliminuje s výjimkou útlumu v ocelové konstrukci samotného kolesa.

1 INTRODUCTION

The principle of direct measurement of the torque of a giant excavator wheel is the tensometric measurement of torsional deformation of that part of wheel shaft or hub of final output gear of the drive that transmits the torsional effect from the drive gearbox to the excavator wheel. A signal from a sensor for this deformation (tensometer) is processed by highly-accurate digital microelectronic circuits and stored in a recording device (Flash type memory). From there, it is transferred as needed in on-line or off-line mode by using the wireless computer network technology into a PC. There it is stored on a disc for the needs of further processing and analyses.

On the basis of theory of elasticity and of strength it can be proved that in a case of a circular cross-section beam that is subject to a torque M_k, the maximum relative deformation of its surface fibre making with the longitudinal beam axis the angle of 45° is proportional to the tangential stress according to the following relation:

$$\tau = 2G \cdot \varepsilon_{45} \qquad (1)$$

where:

τ - shearing stress [$N \cdot mm^{-2}$],

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[*] doc. Ing. Jiří FRIES, Ph.D., VSB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Production Machines and Design and Institute of clean technologies for mining and utilization of raw materials for energy use, Faculty of Mining and Geology, 17. listopadu 15/2172, Ostrava-Poruba, tel. (+420) 59 732 4207, e-mail jiri.fries@vsb.cz

[**] doc. Ing. František HELEBRANT, CSc., VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Production Machines and Designing. 17. listopadu 15, Ostrava-Poruba 708 00, Czech Republic, Europe (Europe Union). Tel.: ++420 59 699 4388, email: frantisek.helebrant@vsb.cz

[***] Ing. Petr KLOUDA, Research institute of brown coal, Most, Budovatelů 2830, + 420 476 208 664, e-mail klouda@vuhu.cz

G - coefficient of elasticity [$N.mm^{-2}$] (for steel G = 80000 $N.mm^{-2}$),
ε_{45} - torsion deformation – relative prolongation of fibre under 45° angle [$m.m^{-1}$].

Shaft loading – torsional moment we are able determine from relation:

$$M_t = 2G \cdot \varepsilon_{45} \cdot W_t \cdot 10^{-12} \quad (2)$$

where:
M_t - torsional moment [kNm],
W_t - modulus of elasticity in torsion [mm^3],
ε_{45} - relative prolongation of fibre [$\mu m.m^{-1}$].

Quantities G and W_t reflect material and geometrical – dimensional properties and are known in advance. *The quantity that is both unknown and subject to measurement is the relative elongation of surface fibre ε_{45}.* The relative elongation of fibre can be measured by means of a tensometric sensor.

The practical installation of tensometers on the surface of shaft can be performed in the following two manners: using a tensometric rosette and using stand-alone tensometers; the latter being used here. The use of this manner is supported above all by influences affecting the accuracy of measurement in case of its long-term application. The influences are as follows:

Accuracy of gluing the tensometers: deviation from the direction of 45° by an angle α gives the error of measurement $f = (\cos 2\alpha - 1) \cdot 100\%$. For real $\alpha \leq 5°$ and connection of four tensometers into a full bridge, the error of measurement is $\frac{f}{4} = -0.4\%$.

Influence of change in ambient temperature: by gluing all four tensometers on one part (shaft, hub) and by connecting them into a full bridge, the influence of temperature is sufficiently compensated. Error is of the order of hundredths of one percent as a maximum.

Time drift of measuring chain: in modern electronic systems, a change in set parameters is small in time. On the assumption of drift values of the same order in all the measuring channels, this drift can be compensated by an additional tensometer on the part that is not exposed.

Simultaneous (tension – compression) bending stress acting on the shaft – hub: by gluing all four tensometers on one part (shaft, hub) and by connecting them into a full bridge, the influence of additional bending or tension-compression stress is perfectly compensated as well.

2 MEASUREMENT

2.1 Measurement Object

As an example of method for the direct measurement of a torque on the wheel of wheel excavator, an excavator of series KU800 was selected. The reason was the fact that on this giant machine, this measurement had already been carried out. However, the wheel radius of similar design appears increasingly frequently in giant machines of type series KU300 and K2000, and modified also in giant machines SchRs1320.

The wheel radius of excavators of series SchRs1320 consists of a cell-less, single-walled bucket wheel, equipped with a 2×1,000 kW drive. Its technical specifications are stated in Table No. 1 given below.

2.2 Measuring Chain

The measuring chain on the wheel excavator consists of: sensors - tensometers; shielded cables; a measuring unit (unit), equipped with an internal memory, and a module for wireless data transmission, shock-proof and resistant to climatic effects, and a control module - personal computer (notebook).

It is necessary to connect the sensors to the measuring unit by means of shielded cables. In practice, the measuring unit EMS DV 803 has proved to be used advantageously. The whole chain is supplemented by the control module equipped with control software for measuring unit control and by the wireless data transmission module.

The measuring chain can work independently in off-line mode. The control module is absolutely essential merely for the adjustment of the measuring unit, the commencement and the end of measurement and the download of data from the internal memory of the unit to the control module for subsequent processing. Naturally the control module can work in on-line mode of monitoring the measuring process.

Tab. 1 Technical parameters of boom of bucket wheel excavator SchRs 1320.

Parameter	Units	Value
Wheel diameter	[m]	12.5
Number of buckets	[pc]	26
Bucket volume	[m^3]	0.71
Bucket wheel running speed	[min^{-1}]	5.5
Bucket wheel drive power	[kW]	2×1000
Circumference. Wheel speed	[$m \cdot s^{-1}$]	3.6
Discharge quantity	[min^{-1}]	143
Theoretical capacity	[$m^3 \cdot h^{-1} \cdot$s·z.]	5500
Specific digging force (by ČSN 27 7013)	[$kN \cdot m^{-1}$]	157
Peripheral digging force	[kN]	500
Peripheral digging force	[kN]	max
Type of bucket wheel	[-]	cellular

From mentioned parameters it is possible for drive efficiency η=0.95 expect maximal torsion moment on bucket wheel shaft $M_k \leq$ 5,000 kNm.

2.3 Installation of the Measuring Chain on the Wheel

The proper installation of the measuring chain on the wheel of excavator took place in the following steps: the selection of locations of sensors and measuring unit on the wheel; the manufacture of holders for mounting the measuring unit on the wheel wall; the gluing of tensometric sensors; the installation of required cables and holders on the wheel wall; the connection of measuring unit and the verification of functionality of measuring chain in specific conditions at a standstill of excavator, and the calibration of measuring chain.

The construction of wheel radius is very compact and as a consequence approximately 83% of torque is transferred from the gearbox of drive to the wheel by the hub of final output gear of gearbox and the shaft surface is practically inaccessible (hidden inside the hub of final output gear). The straight part of the hub itself is concealed with the gearbox housing as well. For the installation of tensometric sensors, only a conical transient surface between the straight part of hub and its flange that serves the connection of the wheel to the final output gear of gearbox is left. There, required tensometers were glued on the diameter of 1000 mm. On the wheel of excavator SchRs1320, the tensometers were glued very close to the transient rounded part of wheel flange on the shaft.

For the installation of the measuring unit, a location was selected on the rather small conical wall of the wheel, where relatively the smallest threat due to the falling of material from buckets in the course of operation of the excavator could be expected. In the case of wheel of excavator SchRs1320, the location for the installation of measuring unit and its feeding should be selected on the shaft closer to the sensors, and the units should be fastened with a tape.

2.4 Gluing of Tensometric Sensors and Calibration

The gluing of tensometric sensors was carried out during the preventive downtime of excavator. The tensometers were glued in a usual way and treated with the top cement SG250 in the first layer and the cement ABM 75 in the second layer.

The load acting on the shaft – the acting torque or peripheral force on the wheel can be determined from relation (2). The resultant value of M_t is affected by the ignorance of accurate values of quantities G and W_t for specific wheel versions. That is why it is necessary to perform the calibration of measuring chain by means of known magnitude of peripheral force and the known radius of action of this tangential force. The peripheral force is formed in a way known from the process of adjustment of excavator couplings. Between a bucket of braked wheel and the lower structure of excavator, a rope with a tensometric sensor is put tangentially to the wheel. By a microtelescoping member of the bucket-wheel boom, the required peripheral force is induced. The radius of its action is determined. In our case, the force acts approximately within the radius R_k = 6.025 m.

Values of the force are read from the measuring bridge and simultaneously a record of relative elongation is performed by the recorder EMS DV 803 (Fig. 1). By means of mathematical regression, relations between the measured relative elongation of torque sensors and the peripheral force on the wheel and the torque are then determined.

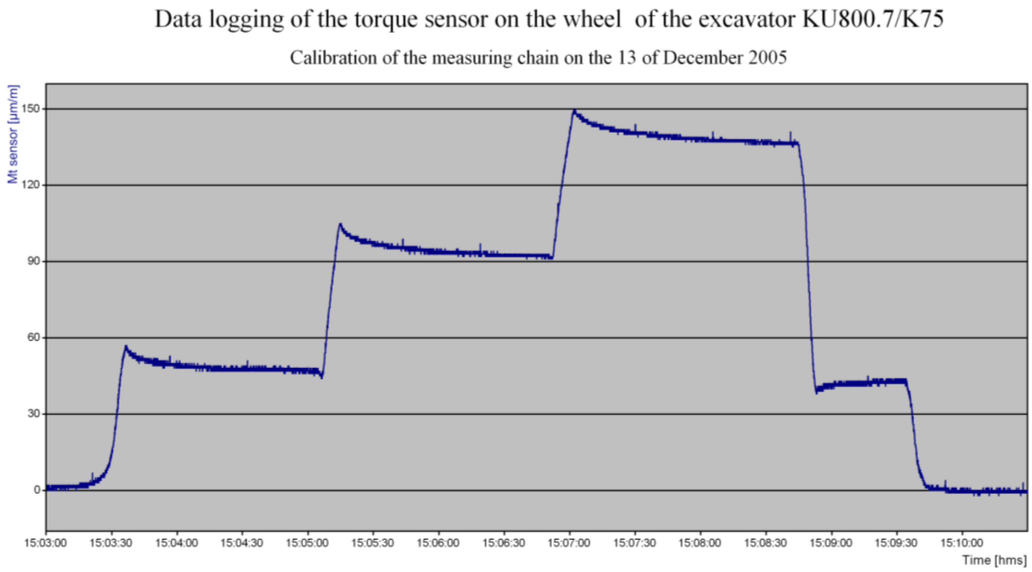

Fig. 1 Measuring chain calibration.

2.5 Authenticity measurement

Functionality authentication of direct measurement method of loading excavator's bucket wheel in operational conditions was performed by comparing and analysis of contemporary results of direct torque measurement by mentioned method and measurement drive power requirement of bucket wheel.

Tongue moment from measured data we will determine:

- from comparative shear – torque deformation by calculation by the help of calibration meter relation,
- from comparative shear – torque deformation by calculation by the help of theoretical relation,
- from power unit input; for possibility of acquired results comparison.

In table No. 2 and 3 are mentioned values examples of particular parameters after basic statistical characteristics application on acquired results.

Tab. 2 Torsion moment evaluating.

Torsion moment	Mean value [kNm]	Variance [kNm]	Peak value [kNm]	Amplitude factor [-]	Effective value [kNm]	K [%]
From input	506	14.7	1131	2.13	595	-
From measurement	418	17.5	1825	4.37	519	87.3
From measurement after smoothing out	418	-	1539	3.68	500	84.1

Tab. 3 Power input evaluating

Magnitude / Units	Mean value	Variance	Peak value	Effective value	Amplitude factor
Relative prolongation [$\mu m \cdot m^{-1}$]	64	6.85	280	80	4.37
Power input [kW]	352	11.7	719	378	2.13

Factor amplitude is given like ratio of peak / middle values. Ratio K is effective values of torque moment given from mark and defined from power requirement – column K in table. After the fact, real torque actuating on bucket wheel excavator is given by relation:

$$M_t = \frac{M_{tm}}{K} = \frac{0{,}5G \cdot \varepsilon \cdot W_t \cdot 10^{-12}}{K} \tag{3}$$

Factor K could be determines either by theoretical analysis of torque moment transmission from gear - box of bucket wheel drive to bucket wheel, alternatively from measured variable data by progress resulting from last column above - mentioned tables.

Theoretical determination of K coefficient is in virtue of relation:

$$K = 1 - \left(\frac{b}{l} \cdot \frac{J_{p2}}{J_{p1} + J_{p2}} \right) = 0{,}874 \tag{4}$$

where:

b - distance from centre of output gear to ringlet DOBICON below bucket wheel (b = 1100 mm),

l - distance between DOBICON ringlets of output gear hub PVD (*l* = 1100 mm),

J_{p1} - torsion moment of inertia in cross - section of output gear hub at point where strain-gauge bridge sensors are glued-on (J_{p1} = 7,1.1010 mm^4),

J_{p2} - torsion moment of inertia in cross - section of bucket wheel shaft between DOBICON ringlets (J_{p12} =1,686.1010 mm^4).

On the bucket wheel excavator SchRs1320 for measurement directly on shaft is K = 0,9 ÷ 1 (drive effectivity).

3 CONCLUSIONS

At present, loads on an excavating element (torque on the wheel shaft, wheel peripheral force) are determined from the power input of wheel drive or from the reaction of drive measured on the gearbox shackle. In both the manners, the effects of absorption of steel construction of drive as well as the inertial forces of rotational parts of drive manifested themselves. The direct method of measurement eliminates these effects with the exception of absorption in the steel construction of the wheel itself.

However, the direct method of measurement also makes it possible to acquire detailed knowledge of relation between the real load on the excavator unit and the character of well measurable wheel drive input, especially in the area of dynamic transient processes. The acquired knowledge then will contribute certainly to the specification of design of excavator unit construction and the design of its drive from the point of view of strength, life and control.

The direct method of measurement of excavator wheel load can also be used for the determination of transfer properties to determine the size and the character of stress applied to the steel construction of giant machine in critical points, which is necessary for the evaluation of residual life of the steel construction.

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