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Viewpoints on the Possibility to Use an Unbalanced Wheatstone Bridge to Measure the Bit Weight

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Abstract

Based on certain inconveniencies of the hydraulic load cells that are currently used on a broad scale to measure the load on the hoisting hook of the drilling rigs (and indirectly on the bit weight), the authors suggest that electronic measurement systems should be developed and used with the clear purpose of increasing the tensoresistive effect. A strain gauge MT applied on a circular section flexible metal rod that was inserted at the dead end of the calf wheel cable is positioned in one of the legs of the unbalanced Wheatstone bridge. The unbalance voltage of the bridge will be a dimension of the tensile stress on the measuring drum cable.

Key words: *bit weight, hook load, strain gauge, unbalanced Wheatstone bridge, resistance, elongation, stress, unbalance voltage.*

Introduction

The bit weight is one of the most important parameters in the drilling practice, mainly because it determines the drilling progress and indirectly the drilling time of a drilling rig. If the purpose is to minimise the drilling time, one of the conditions easily identified as necessary for fulfilling this purpose will be maximising the bit weight. Nevertheless, this is almost impossible due to certain restrictions imposed by:

- rock hardness in the penetrated layers
- the bit weight diameter and rate of wear;
- mechanical strength of the drilling string;
- the drilling rig depth;
- drilling type.

Depending on the abovementioned restrictions, the optimal bit weight operation for each drilling depth will be established whereby its current (measured) value will have to be known at all times. The problem resides in the impossibility of directly measuring the bit weight as a consequence of the harsh operating conditions from the bottom of the well for the measuring system and the impossibility of rendering the information to the surface free from any major disturbances. For these reasons, in order to determine the bit weight, most of the measuring systems prevalently used in well drilling measure the load on the crane hook and take into account the subjection to the inverse proportionality between the two values: the bit weight and the hook load.

Force Cell Measuring Systems for Measuring the Hook Load

The most frequently used measuring systems for the hook load of the drilling rig crane are those using force cells to measure the stress on the cable where the drilling string is suspended. The schematic diagram of this type of cells is presented in Fig. 1.

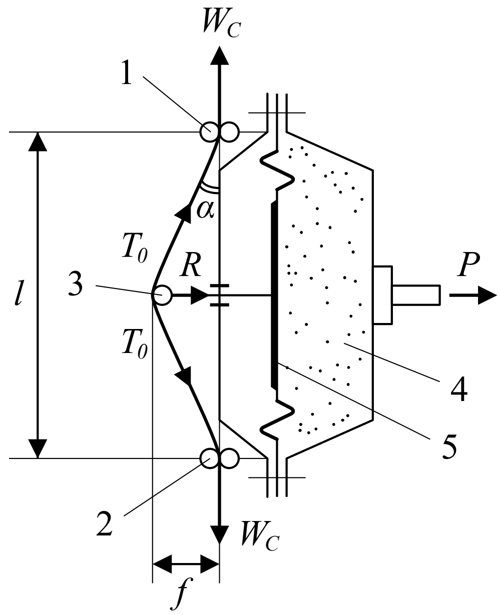

Fig. 1

The main component of the measuring system is the force cell (MARTIN DECKER or TOTCO recipient) that is mounted on the dead end of the calf wheel cable. The supporting elements 1, 2 and 3 enable the cable being flexed (pulled out from the collinearity with the 1, 2, 3 points) so that above the elastic membrane no. 5 of the force cell no. 4 there will be a force R directly proportional to the T_0 stress from the dead end of the crane cable:

$$R = 2T_0 \sin\alpha \tag{1}$$

where: T_0 is the stress on the dead end of the cable; α - the angle between the initial direction and the modified direction of the cable.

Whereas the α angle is very small, the value shall be approximated as:

$$\sin\alpha \cong tg\alpha = \frac{f}{\frac{l}{2}} = \frac{2f}{l} \tag{2}$$

where: f is the bending deflection and l is the distance between the supporting points 1 and 2.

If S_{ef} is the real surface of the elastic membrane and p is the pressure on the membrane, the relation may be written as follows:

$$R = p \cdot S_{ef} \text{ , so that:} \tag{3}$$

$$p = \frac{R}{S_{ef}} = \frac{4f}{l \cdot S_{ef}} \cdot T_0 \tag{4}$$

Assuming that the pulley block has m pulleys (equal to the number of crane pulleys) and the coefficient of efficiency of the crane – crown-block system isη, the T_0 voltage in the cable will be:

$$T_0 = \frac{W_c}{2m\eta} \tag{5}$$

and the voltage on the force cell output is:

$$p = \frac{2f}{m\eta \cdot l \cdot S_{ef}} \cdot W_c \tag{6}$$

1. The proposed electric measuring system

The proposed electric measuring system aims to increase the tensoresistive effect, namely to modify the resistance of a threadlike conductor when it is subject to mechanical stresses (elongation, compression, deflection, twisting) that elongate or compress it.

As a consequence, if a threadlike conductor with ρ resistivity, l length and A section is subject to a mechanical stress, the variation of its resistance under the alteration of its geometrical dimensions and its resistivity shall be:

$$\Delta R = \frac{\rho}{A} \cdot \Delta l + \frac{l}{A} \cdot \Delta\rho - \rho \frac{l}{A^2} \cdot \Delta l \tag{7}$$

By dividing the relation in (7) by $R = \rho \frac{l}{s}$, the result is:

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} + \frac{\Delta\rho}{\rho} - \frac{\Delta A}{A} \tag{8}$$

On the assumption that there is a linear variation of the ρ resistivity with a V volume expressed by:

$$\frac{\Delta\rho}{\rho} = k\frac{\Delta V}{V} = k\frac{\Delta l \cdot A + l \cdot \Delta A}{lA} = k\left(\frac{\Delta l}{l} + \frac{\Delta A}{A}\right) \tag{9}$$

and taking the following relation into account:

$$\frac{\Delta A}{A} = -2\mu\frac{\Delta l}{l} \tag{10}$$

where: μ is Poisson's ratio, the result will be:

$$\frac{\Delta R}{R}=\frac{\Delta l}{l}+k\frac{\Delta l}{l}+k\left(-2\mu\frac{\Delta l}{l}\right)+2\mu\frac{\Delta l}{l}$$
$$\frac{\Delta R}{R}=\frac{\Delta l}{l}\left[1+k(1-2\mu)-2\mu\right]+k\frac{\Delta l}{l} \tag{11}$$

To sum up, the relative regulation of the threadlike conductor resistance is directly proportional to the relative elongation.

The thermo-resistive element appears as a strain gauge and the k coefficient, where k = (1+k)(1-2μ), is called a/an ... factor which defines the sensitivity of the strain gauge.

The proposed measuring system to be used on load W from the crane hook (the load indirectly proportional to the bit weight) consists of using a strain gauge (MT) to be applied on a cylindrical section metal rod which is inserted on the dead end of the calf wheel cable as in Fig. 2.

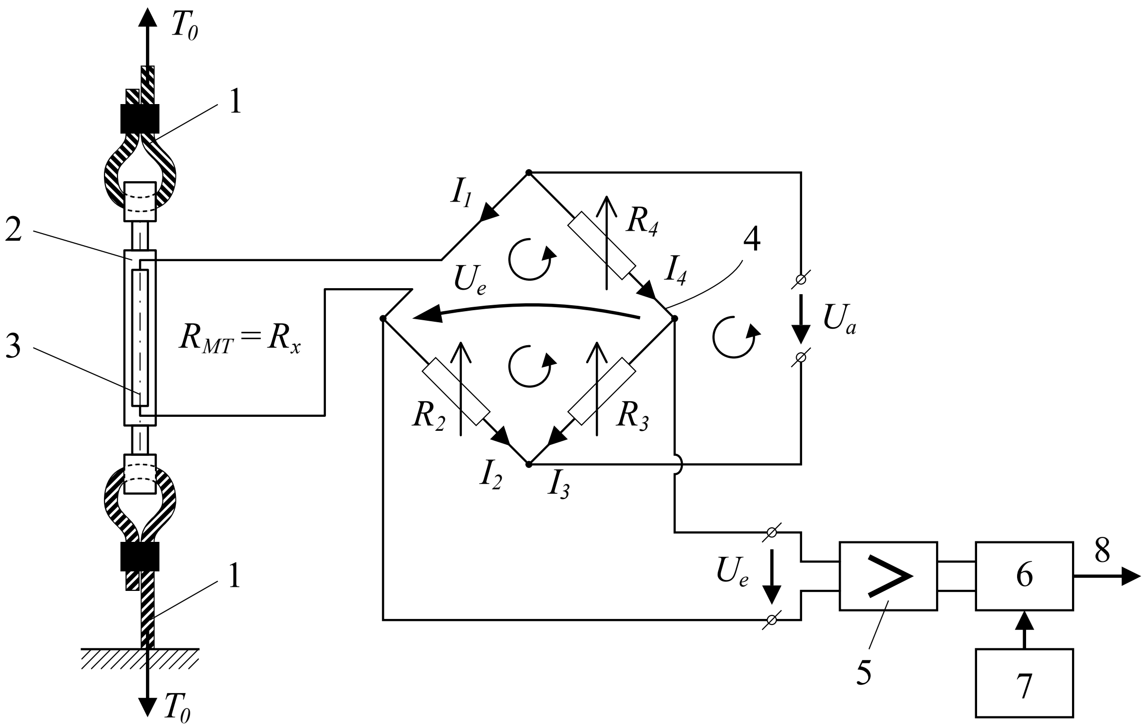

Fig. 2. Tensoresistive system for measuring the hook load
1. Dead end of the calf wheel cable; 2. Cylindrical metal rod (test rod);
3. Strain gauge; 4. Unbalanced Wheatstone bridge; 5. Direct current amplifier; 6. Adapter; 7. Reference supply; 8. Unified signal.

If we consider ΔT_0 the variation of the cable stress triggered by the variation ΔW of the crane hook load, S – the section of the rod, E – the rod elasticity module and l – the initial length of the flexible rod, when applying Hooke's law, we will have:

$$\frac{\Delta l}{l}=\frac{\Delta T_0}{E\cdot S} \tag{11}$$

But: $\Delta T_0 = \dfrac{\Delta W_c}{2m\eta}$, so that:

$$\frac{\Delta l}{l} = \frac{\Delta W_c}{2m \cdot \eta \cdot E \cdot S} \tag{12}$$

where *m* and η have the abovementioned values.

Assuming that the elongation of the flexible rod is equal to that of the strain gauge that is applied to it, the result will be as follows:

$$\frac{\Delta R}{R} = K \cdot \frac{\Delta l}{l} = K \cdot \frac{\Delta W_c}{2m \cdot \eta E \cdot S} \tag{13}$$

That means that the relative regulation of the resistance MT is directly proportional to the variation of the crane hook load.

The strain gauge MT whose nominal resistance (under no stress) equals $R_{MT_0} = R_{X_0}$ is introduced in one of the legs of an unbalanced Wheatstone bridge, which has calibrated resistors with known resistances R_1, R_2 and R_3 in the other three legs. At least one of the 3 resistors has a varying resistance in order to allow the bridge to be balanced for a strain gauge with $R_{MT_0} = R_{X_0}$. When the load W on the crane hook changes the cable voltage will also change, as well as the tensile stress of the flexible rod. These changes will modify the strain gauge resistance by $\Delta R_{MT_0} = R_{X_0} + \Delta R_{X_0} = R_x$ which will lead to the unbalancing of the Wheatstone bridge and to the generation of an unbalance voltage U_e.

The bridge balance equation– under no effort stress– will be established using Kirchoff's theorem and Ohm's law:

$$\begin{cases} (R_x + R_2) I_1 = U_a \\ (R_3 + R_4) I_4 = U_a \\ R_x \cdot I_1 - R_4 \cdot I_4 - U_e \end{cases} \tag{14}$$

$$I_1 = \frac{U_a}{R_x + R_2};\ I_4 = \frac{U_a}{R_3 + R_4}\ şi\ R_x \cdot \frac{U_a}{R_x + R_2} - R_4 \cdot \frac{U_a}{R_3 + R_4} = U_e\ ;$$

$$U_e = \left(\frac{R_x}{R_x + R_2} - \frac{R_4}{R_3 + R_4} \right) \cdot U_a$$

$$U_e = \frac{R_x \cdot R_3 + R_x R_4 \cancel{- R_4 R_x} \cancel{+ R_2 R_4}}{(R_x + R_2)(R_3 + R_4)} \cdot U_a$$

$$U_e = \frac{R_x \cdot R_3 - R_2 R_4}{(R_x + R_2)(R_3 + R_4)} \cdot U_a\ . \tag{15}$$

For the nominal value of the MT resistance (value of the strain gauge resistance under no stress) the varying calibrated resistances will be modified until the bridge is balanced: $U_e = 0$, meaning $R_x R_3 - R_2 R_4 = 0$.

If the flexible rod is subject to tensile stress, the bridge unbalance voltage is determined according to relation (14), which may as well be expressed as:

$$\frac{U_e}{V_a} = \frac{R_x}{R_x + R_2} - \frac{R_4}{R_3 + R_4} \tag{15'}$$

The degree of dependency $U_e = f(R_x)$, may be expressed as well as follows:

$$U_e = \left(\frac{R_x + R_2 - R_2}{R_x + R_2} \right) \cdot U_a - \frac{R_4}{R_3 + R_4} \cdot U_a \text{ , sau}$$

$$U_e = \left(1 - \frac{R_4}{R_3 + R_4} \right) \cdot U_a - \frac{R_2 \cdot U_a}{R_x + R_2}$$

$$U_e = K_1 - \frac{K_2}{R_x + R_2} \text{ ,} \tag{16}$$

Non-linear hyperbolic dependency.

If, when balanced, the resistances of the bridge legs are equal ($R_{x_0} = R_2 = R_3 = R_4$), the relation (15') may be written as follows:

$$\frac{U_e}{U_a} = \frac{R_{x_0} + \Delta R_{x_0}}{R_{x_0} + \Delta R_{x_0} + R_{x_0}} - \frac{R_{x_0}}{R_{x_0} + R_{x_0}}$$

$$\frac{U_e}{U_a} = \frac{R_{x_0} + \Delta R_{x_0}}{2R_{x_0} + \Delta R_{x_0}} - \frac{1}{2}$$

$$\frac{U_e}{U_a} = \frac{2R_{x_0} + 2\Delta R_{x_0} - 2R_{x_0} - \Delta R_{x_0}}{2\left(2R_{x_0} + \Delta R_{x_0}\right)} = \frac{\Delta R_{x_0}}{2\Delta R_{x_0} + 4R_{x_0}}$$

$$\frac{U_e}{U_a} = \frac{\frac{\Delta R_{x_0}}{R_{x_0}}}{4 + \frac{2\Delta R_{x_0}}{R_{x_0}}} = \frac{K \cdot \varepsilon}{4 + 2K \cdot \varepsilon} \text{ ,} \tag{17}$$

where ε is the relative elongation of MT determining the change in resistance R_{x_0} by ΔR_{x_0}.

Given that for supply voltages U_a expressed in volts the bridge unbalance voltage U_e is expressed in millivolts (mV), in order to amplify this signal (direct current amplifier marked with 5m....) certain final circuits and adaptors 6 must be used, that will enable the conversion to the unified signal, as shown in figure 2.

Conclusions

The hydraulic load cell shown in figure 1 currently used on a broad scale in drilling rigs has the disadvantage of a significant idleness, which renders it less effective should rapid variations of the bit weight arise. Furthermore, the change in time of the membrane elastic properties represents another important source of errors.

The proposed measuring system is characterised by a low speed of response and the change in time of the strain gauge (MT) characteristics can be dealt with successfully through the periodic rebalancing of the bridge.

The major inconvenience of the proposed system is the non-linearity of $U_e = f(R_x)$. This problem can be solved either by using more strain gauges that should be positioned in the bridge legs so that the linearity of this characteristic may be ensured, or by using some elements with a non-linear characteristic, but with an opposite non-linearity, that should be inserted so that their output would yield a linear characteristic $U_e = f(R_x)$.

The information regarding the measured value can be presented by means of analogical indicators and registering apparatuses whose scale is calibrated directly in power units.

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Considerații privind posibilitatea utilizării punții Wheatstone neechilibrate la măsurarea apăsării pe sapa

Rezumat

Pornind de la unele inconveniente prezentate de traductoarele hidraulice de efort utilizate in prezent pe scara larga pentru măsurarea sarcinii la cârligul macaralei instalațiilor de foraj (si in mod indirect a apăsării pe sapa) ,autorii propun in acest scop realizarea si utilizarea unor sisteme de măsurare electronica ce are in vedere valorificarea efectului tensorezistiv. O marca tensometrica MT aplicata pe o bara metalica elastica de secțiune circulara inseriată pe capătul mort al cablului tobei de manevra este amplasata intr-unul din brațele unei punți Wheatstone neechilibrate. Tensiunea de dezechilibru a punții va fi o măsura a solicitării la întindere la care este supus cablul tobei de măsura.