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RESEARCHES REGARDING THE CAPTOR REALIZATION FOR THE STUDY OF THE DYNAMIC LOADING OF THE 10¾″ STRING FOR MINE DRILLING

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Abstract: *In this work the results of the researches carried out for the making and gauging of the loading captors used in the frame of the drilling string for tension-resistive experimental study of the dynamic loading in case of drill pipes of 10¾" during the mine shaft drilling, having a diameter of 3.62 m, are presented. The experimental conditions imposed special prescriptions for the making of these captors, in order for the disturbing factors not to influence the measurements. The realized captors allowed to carry out recordings in real time of the specific deformation of the drilling string under separate and total/complex actions of the axial force, torsion and bending moments, and specific deformations of zones having stress concentrations, where cracks and breakages were produced. Also, they allowed the large diameter drilling process research, as a dynamic and vibratory process.*

Key words: *mine drilling string, dynamic loadings, captors.*

1. INTRODUCTION

The drilling string used for mine shaft sinking having a diameter of 3.62 m is carried out by means of a bit, a roller stabilizer, a „drill collar", drilling pipes of 10¾ in, with and without air tubes, and a kelly stem. In the frame of the drilling string, the drill pipes (Fig. 1) are the most sensible elements at dynamic actions performed during the drilling. This situation is pointed out by the different breakages and cracks which appeared. The breakages and cracks took place as a result of the disturbing caused by variable loadings of the drill pipes in zones with stress concentrators, which have a constructive nature (the section passing from the flange collar, with a thickness of 25 mm, to the drill pipe body, with a wall thickness of 15.11 mm) and a metallurgical nature (heat affected zone).

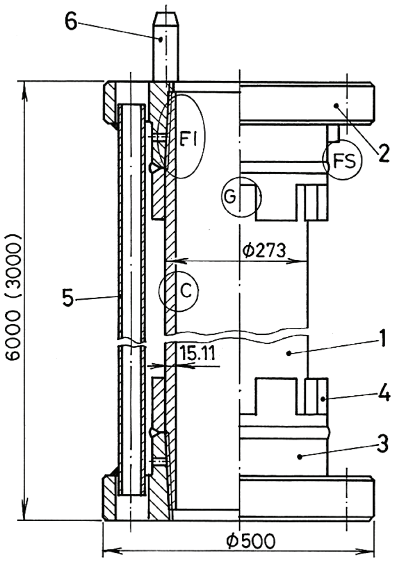

Fig. 1. Drilling pipe with air tubes: 1– body; 2 – upper flange; 3 – lower flange; 4 – collar with crenels; 5 – air tube; 6 – centre bolt.

The drilling process is characterized by a dynamic and a vibratory regime [1–3], determining the apparition of a complex loading state (of axial force, torsion moment and bending moment), which has a variable intensity.

Taking into account all these reasons, three experimental research directions of the tension state of the drill pipes of 10¾" in the frame of the drilling string were imposed: 1) determination of the weight and character of loading separately; 2) determination of the tension state in the section of the drilling pipe body (see Fig. 1, zone C); 3) determination of the tension state in zones with concentrators namely: a) zone of the flange shank in close proximity of the welding seam between this one and collar (Fig. 1, zone FS); b) the drill pipe body from the cut up part of the support collar, in close proximity of the welding seam between collar and body (Fig. 1, zone G); c) the threaded connection zone (Fig. 1, zone FI). These directions claimed an ample experimental research program generating a long and laborious preparation for the measurements.

2. REALIZATION OF LOADING CAPTORS

For the experimental research of the tension state of the drill pipes of 10¾" in the frame of drilling string the electrical stress analysis technique was chosen. The number of measurement points and their positions were improved by the proposed research direction. In this way three loading captors (CS1, CS2 and CS3) were realized. Three drill pipes represent all these captors, one of these having air tubes (CS1) and the other two without air tubes (CS2 and CS3), equipped with strain gauges protected by special sleeves. Each of the captors has possibility of separate measurement of the specific deformation due to the axial force (F), torsion moment (T) and bending moment and to the total complex deformations (C) of the drill pipe body. CS1 is endowed with rosettes for: measurement of total deformation in the part of the welding seam between the shank and the collar of the upper flange (rosette FS, of type "Δ", WA-06-250WY-120); measurement of total deformation in zone of the welding seam between the flange collar and the pipe body (rosette G, of the same type as rosette FS); measurement of total deformation in the zone of the threaded joint between the pipe body and the flange (rosette FI, of type 6/120RY11).

In order to eliminate the disturbing influences outside the points of measurement transducers were foreseen to compensate the hydrostatic and temperature effects, and connection electric circuits in semi-bridge or complete bridge were realized, corresponding to the specific deformation type to be measured, a special protection of the strain gauges was realized while at the same time using bridge pre-amplifiers and screened cables with 6 threads.

Finding an optimal solution for protection of strain gauges required more researches and experiments. Two technologies were experimented: the first relied on use of an epoxy resin and a felt made of glass fibre, as a reinforcing material, and the second relied on use of liquid rubber which reticulates in cold environment. The second technology was chosen.

This type of protection fulfils the following conditions: it is not chemically attacked by the drilling mud; it doesn't have influence on the stiffness of that part of the drill pipe; allows taking over the drill pipe deformation without damaging it; hinders the drilling mud penetration in the strain gauge zone by a very good adherence of rubber to metal; it has a sufficient mechanical resistance to the action of pressure and flow of the drilling mud; does not show a mechanical action on the strain gauges.

Protection of zone FI, of application of the rosettes on the drill pipe pin, inside, constituted also a difficult problem, because it had to satisfy the following demands: it should not allow the drilling mud penetration in the zone of strain gauges; to have a distinct mechanical resistance due to the fact that in this zone the drilling mud moves with a very high speed, carrying rock fragments having big sizes; it should not introduce measurement errors; to allow the external transmission of electric signals from the strain gauges applied on the inside surface of the drill pipe.

3. GAUGING OF THE LOADING CAPTORS

The process of measurement/recording in dynamic conditions during the drilling was carried out by means of a chain of electrical strain gauge complex measuring, made of strain gauges connected in semi-bridges or in complete bridges with a special protection, bridge pre-amplifier, screened bonding cable for depth having a large length (of tens or hundreds of meters), cable connectors, a collector with sliding contacts, another surface screened cable, a tensiometer and a recording device. This measurement chain can falsify the transmitted signal by the strain gauges. That is why it was intended to gauging the loading captors.

The gauging was carried out in two stages corresponding to the two different states wherein the captors could be found, namely: the first stage where the applying zones of the strain gauges on the three drill pipes were not covered by protection sleeves realized in accordance with the presented technology in the previous chapter, and without the collector in the measuring chain, a state called "WP" (without protection); the second where may be found the protection of the strain gauge application zones, and was used the collector inside the measuring chain, a state called "P" (with protection).

During both of these stages, a direct gauging by tensile loading of the drill pipes and an indirect gauging by electrical way with a "parallel resistance" were carried out.

The tensile loading of captors was carried out on a working stand whose scheme is presented in Fig. 2. The tensile force (*F*) was determined on the base of pressure measures (*p*) in the range [0; 31] MPa, which was read in the manometer M1 (Fig. 2), knowing the proportionality relation between F and p. Each of the experiments consisted of an increase, then a step-by-step decrease of pressure in the mentioned area, and measurements and recordings every time of the specific deformation indicated by the electronic tensiometer and recorder. In Fig. 3, as an example, the gauging diagrams for F1 (captor CS1, point F – axial force) in both of the states ("WP" and "P") and in Figs. 4 and 5 the gauging diagrams for the rosettes G and FS in the state "WP" (experiment III) are shown. As the welds on the crenels

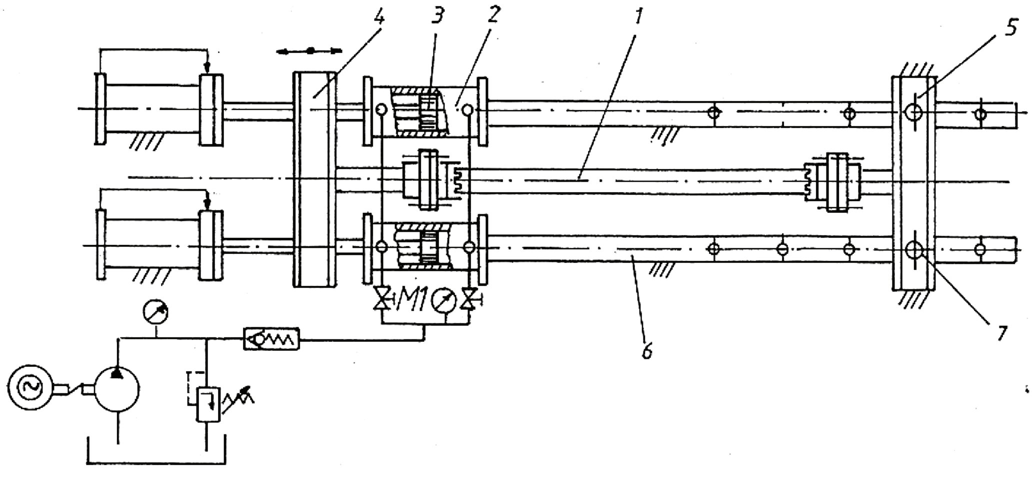

Fig. 2. Scheme of the working stand used for tensile loading of captors: 1 – loading captor; 2 – hydraulic cylinder; 3 – pi s-ton; 4 – mobile traverse; 5 – fixed traverse; 6 – guiding elements of the fixed traverse; 7 – fixing bolt.

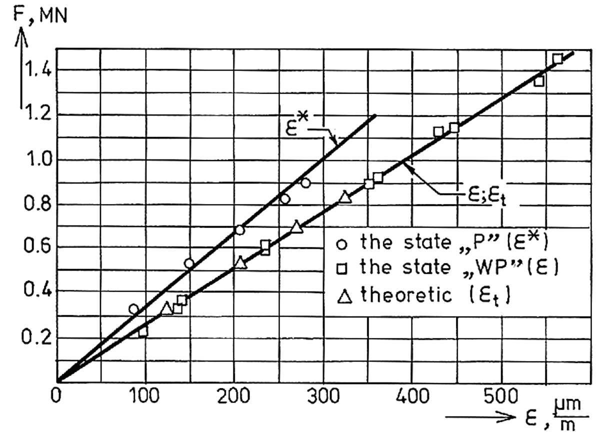

Fig. 3. Gauging diagrams of the captor F1.

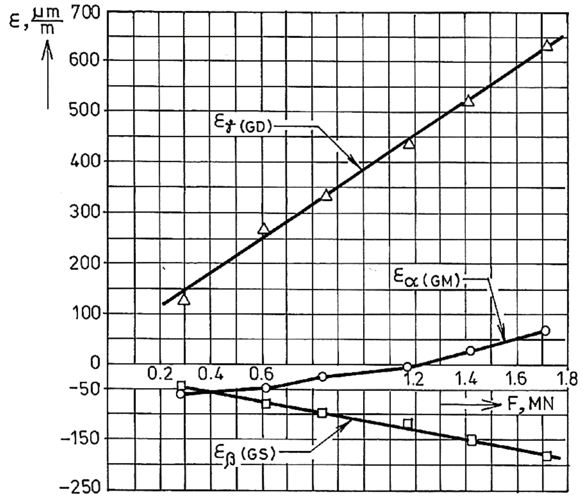

Fig. 4. Gauging diagram for rosette G in the state "WP", the third experiment.

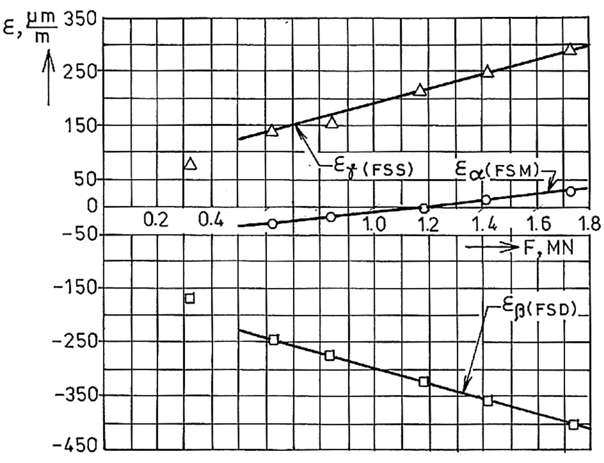

Fig. 5. Gauging diagram for rosette FS in the state "WP", the third experiment.

of the flange collar and on the pin top are realized after carrying out the threaded joint (therefore after application of a pre-stressing force) it was supposed that the first tensile test would result in a hysteresis effect, because some relaxations that occur by the conjugated action of the welding and the threaded joint determine the fact that the assembly does not come back in the initial state. Due to these reasons three experiments, each of them consisting of loading and unloading of the drill pipe, was foreseen in the measurement program. Because only in the case of the first experiment qualitative differences appear against those which follow, it was appreciated that the relaxations are especially produced under the first experiment conditions, so that the third experiment is already illustrating for established (repeatable) conditions. In keeping with the results obtained from the static measurements, the welded joints between the flange shank and the collar with crenels, and this and the drill pipe body participate effectively in taking over the axial forces, although only the threaded joint flange–body is destined to this purpose.

For indirect gauging an electrical resistance of 298.57 kΩ, paralleled to an arm of the Wheatstone bridge, was used.

From the analysis of the captor gauging diagrams F1 (Fig. 3) a very good concordance is to be found among ε_t values, theoretically determined on the basis of the measured force F, and of the specific deformation ε, determined in the state "WP" for the same measure of the force, the average error being 2.33%. Instead, the values of ε^*, obtained by measurement in state "P", are less, in average of 23%, than in state "WP", for the same tensile force. By the measurement of the gauging signal obtained by using the method of "paralleled resistance", the value $\varepsilon^* = 190.5$ μm/m, will result, which is very close to that determined by the same testing force (about 650 kN) effectively applied in the case of direct gauging in the state "P" of the captor F1, namely $\varepsilon^* = 191.3$ μm/m.

This fact demonstrates that errors obtained in case of the captor F1 gauging in the states "P" and "WP" are due to the existence of the protection and of the collector, which modify the characteristics of the measuring electric circuit, but they are not due to the mechanical actions of the protection on the strain gauges.

By using the gauging diagrams $F = f(\varepsilon)$ and $F = f(\varepsilon^*)$ belonging to the captors F1, F2 and F3, drawn for "WP" and "P" states, the ratio $\varepsilon/\varepsilon^* = 1.29$ was obtained. Therefore, the real values of the specific deformation ε is established by multiplication of 1.29 times of the values ε^*, obtained by means of measurements in dynamic conditions, in the field, for the respective loading captor.

4. CONCLUSIONS

In this work the research results realized for the construction of three captors with electrical strain gauges (called CS1, CS2 and CS3), used for the study the dynamic loading of the 10¾" drill string during the drilling of mining shafts having a diameter of 3.62 m, are presented.

The gauging of the captors and of the whole measuring chain impose a correction of the measurement results, determined by the effect of the protection and of the collector with sliding contacts on the measuring electric circuit.

The direct gauging showed the presence of a pretension state in the thread zone (FI) and zones with welds (FS and G), which has effects on the tensions due to the actions during the drilling and has an important role in yielding of the fatigue phenomenon.

The gauging allowed also the determination of the initial deformation state of the measure points for a certain static load from the hook. This fact was necessary because the measurements in dynamic conditions were carried out after the respective Wheatstone bridges had been equilibrated, the drilling column being suspended in the hook in that moment of equilibration. For example, for the captor CS1 mounted in the upper part of the drilling column, for a hook force of 1.315 MN, the initial specific deformations (ε_{x0}, $x = \alpha, \beta, \gamma$) in the measurement points FS and G are presented in Table 1. Thus, during the dynamic measurement the total specific deformation (ε'_x) represents, at a certain point, the algebraic sum between ε_{x0} and the specific deformation obtained by recording (ε_x).

For the hook force of 1.315 MN, the specific deformation of the drill pipe body obtained by gauging (Fig. 3) is $\varepsilon_{F0} = 510$ μm/m, yielding an axial tension of $\sigma_{F0} = 107.1$ MN/m^2. Of comparing this measure σ_{F0} with the equivalent tension measure $\sigma_{eqv.o}$ in the points FS and G in the Table 1, it may be found that the two welds participate effectively in overtaking the axial load, although they are not realized in this aim.

The realization of the three loading captors allowed the carrying out of the measurements in the field for research the large diameter drilling process [1, 2] and for the dynamic loading study of the 10¾" drill pipes in different zones of the body and its joint with flange with collar [4, 5]. As an example, in Figs. 6, 7 and 8, some recordings of specific deformations of the drill pipe (captor CS1) body due to the axial force (ε_F), to the torsion moment (ε_T) and bending moment (ε_B) are presented. All these were obtained during the drilling in case of a complete rotation of the drill pipe for different working regimes, characterized by the weight on bit (W_B) and the rotational speed of the bit (n_B).

Table 1

The initial specific deformations (ε_{x0}, x = α, β, γ) in the measurement points FS and G and the equivalent tensions

ε_{xo}; $\sigma_{eqv.o}$ Point of measur.	$\varepsilon_{\alpha o}$ μm/m	$\varepsilon_{\beta o}$ μm/m	$\varepsilon_{\gamma o}$ μm/m	$\sigma_{eqv.o}$ MN/m^2
FS	6	–343	238	102.7
G	–137	16	377	112.9

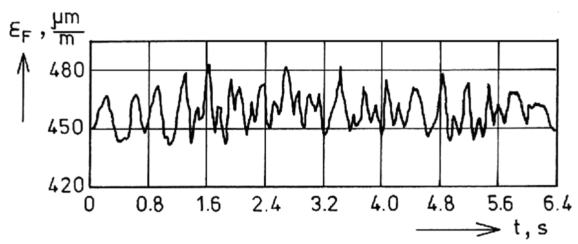

Fig. 6. Variation of deformation of the drill pipe body due to the tensile force (ε_F) for W_B = 120 kN and $n_B \approx 10$ rot/min.

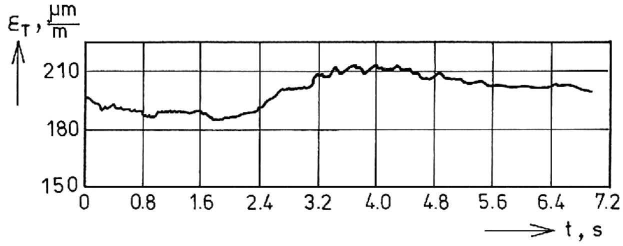

Fig. 7. Variation of deformation of the drill pipe body due to the torsion moment (ε_T) for W_B = 200 kN and $n_B \approx 10$ rot/min.

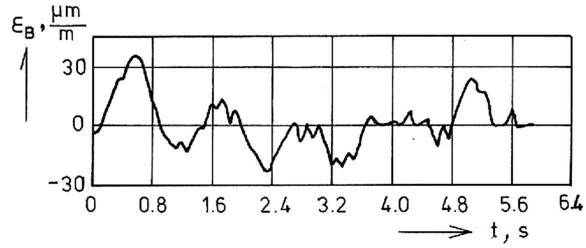

Fig. 8. Variation of deformation of the drill pipe body due to the bending moment (ε_B) for W_B = 140 kN and $n_B \approx 10$ rot/min.

Analyses of the recordings of this kind pointed out as to the character of each type of loading.

Also, with their help, by using the calculation relationships from the elasticity theory, diagrams of the tension variations, which load both the drill pipe body and the joint zones by thread and weld, were obtained.

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