The behavior of enclosed-type connection of drill pipes during percussive drilling

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Abstract. Percussion drilling is the efficient method to drill small holes (≥ 70 mm) in medium-hard and harder rocks. The existing types of drill strings for geological explorations are not intended for strain wave energy transfer. The description of the improved design of the drill string having enclosed-type nipple connections is given in this paper presents. This nipple connection is designed to be used in drilling small exploration wells with formation sampling. Experimental findings prove the effectiveness of the enclosed nipple connection in relation to the load distribution in operation. The paper presents research results of the connection behavior under quasistatic loading (compression-tension). Loop diagrams are constructed and analyzed in force-displacement coordinates. Research results are obtained for shear stresses occurred in the nipple connection. A mechanism of shear stress distribution is described for the wave strain propagation over the connecting element. It is shown that in the course of operation the drill pipe tightening reduces the shear stress three times.

1. Introduction
During the percussive drilling, the pipe connection is exposed to the axial load, impacts produced by percussive mechanisms, and coupling torque [1]. The study of the nature of these loads, their estimation and consideration in the drill string design allow improving the durability of thread connections.

Such types of connections as pipe-in-pipe, coupling, coupling-and-tool refer to inefficient design methods of the percussive drilling because cyclic tensile stresses and a low rate of power pulse propagation are observed.

A safe operation of the thread connection is provided, first of all, by the reduction of the strain wave energy loss. The strain wave energy dispersed in thread connections is determined by the multiple reversed strains, thread frictions and, as consequence, heating of thread connections rather than by longitudinal movement of the drill string [3-8].

The nipple connection hidden inside the drill pipe is the alternative to the thread connection which lack most of the above stated disadvantages [9].

2. Experiment technique
The behavior of the suggested nipple connection presented in figure 1 was studied on the test bench under the quasistatic loading (compression-tension), the schematic view of which is shown in figure 2. The properties of dissipative forces were obtained.

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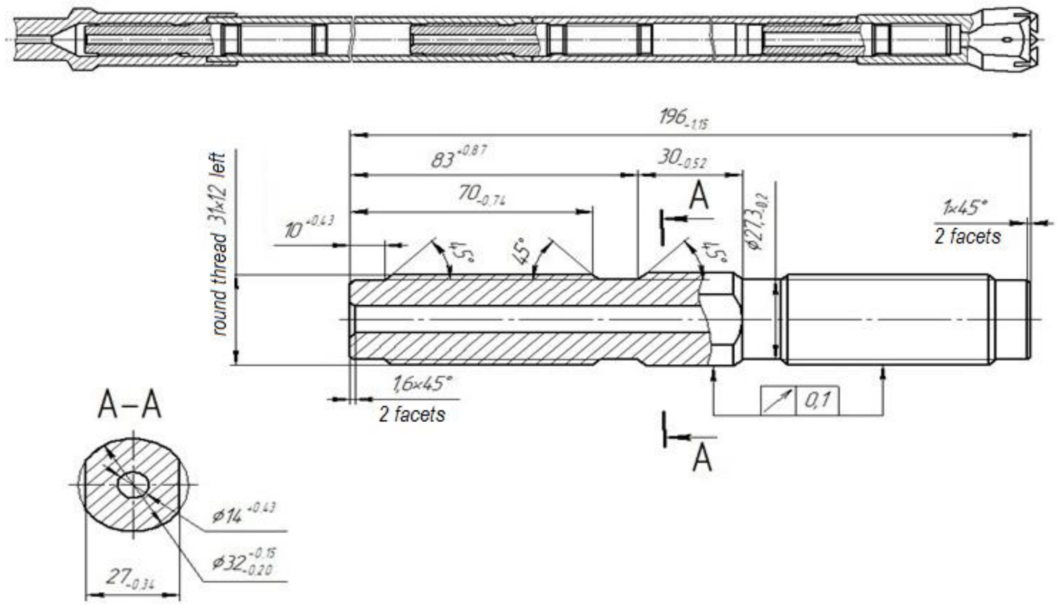

Figure 1. Cross-sectional view of enclosed-type nipple connection.

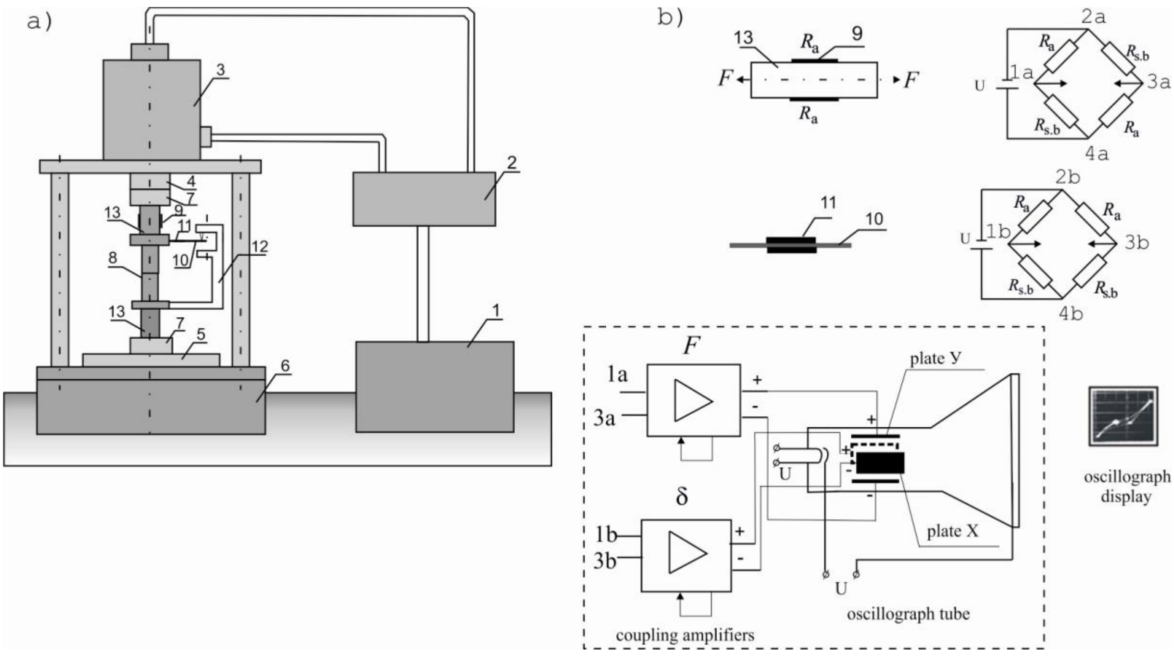

Figure 2. Schematic view of the test bench for hysteresis diagram construction at thread connection loading: a) test bench components: *1* – oil-pumping station; *2* – distribution device; *3* – hydraulic press; *4* – hydraulic press shaft; *5* – cellar floor; *6* – foundation; *7* – clamper; *8* – thread connection (coupler); *9* – strain gauges; *10* – displacement measuring elastic plate; *11* – displacement transducers; *12* – clamp; *13* – pony drill collar; b) circuitry: R_a, $R_{s.b}$ – active and self-balancing strain gauges respectively; *Y* and *X* – vertical and horizontal oscilloscope beam deviation plates, respectively; δ – drill pipe displacement relative to coupling element; *F* – longitudinal force.

Loop diagrams were obtained by the following way. A segment of the drill pipe was fixed by clampers, a clamp being mounted.

The coupling torque was applied to the thread connection. Balancing was performed for the bridge joint and oscilloscope S1–117.

The pulse and relative displacement signals were displayed on the oscilloscope by the *x* and *y* axes. The beam scanning was switched-off. The loop diagram obtained on the oscilloscope display was then photoed.

Shear stresses were studied on the drop-hammer test bench. The axial load was created by the air-feed mechanism and ranged from 3.4 to 11.3 kN. The rate of load application was controlled by the compressed air pressure supplied to the percussive mechanism. The coupling torque of the drill string was obtained using the weight lever and ranged from 49 to 245 Nm. Pulses obtained on the oscilloscope display were photoed. Resistance strain gauges were stuck in the centre of the nipple as shown in figure 3, since shear stresses achieve their maximum in the given section under static and dynamic loads.

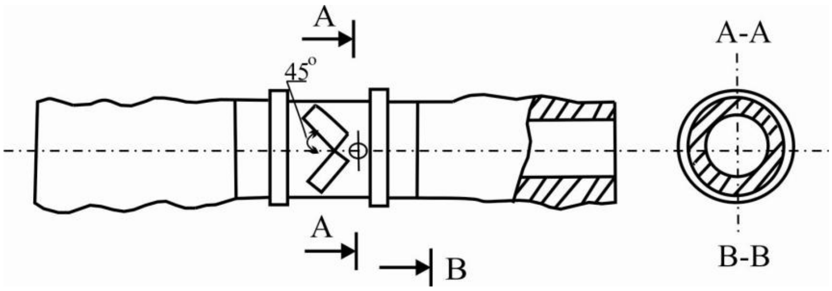

Figure 3. Schematic view of sticking resistance strain gauges for recording shear stresses.

The obtained data were then processed using the mathematical statistics techniques.

3. Results and discussion

The analysis of the curves shown in figure 4, shows the deformation properties of the nipple thread connection.

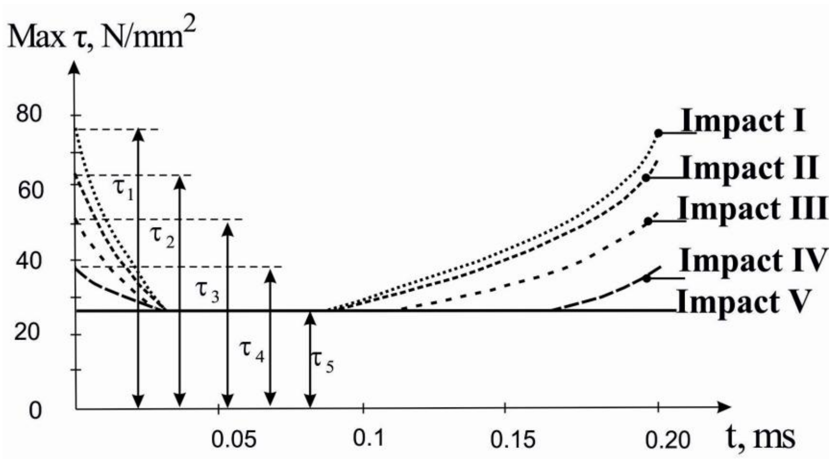

Figure 4. Shear stress distribution in the nipple at combined action of coupling torque and power pulses.

The area of the hysteresis loop represents the behavior of inelastic resistance force or the dissipated strain wave energy at the applied cyclic compressive and tensile loads.

A mechanism of deformation of the enclosed-type nipple connection during the quasistatic loading is given in the table below.

Table. Deformation mechanism of the enclosed-type nipple connection during the quasistatic loading.

Diagram sectors	Description
I–II	Thread connection is pre-tightened: the value of the applied coupling torque defines deformation of the drill pipe and nipple threads. The tightening force in drill pipes and nipple is larger than the compressive force. Further compression of the connection increases the compressive force in the drill pipe joint and unloads the nipple. Static friction is transformed to sliding friction. In sector *II* friction is absent, and the nipple is completely unloaded; a gap between the adjacent threads is observed both in the drill pipe and nipple. This sector corresponds to the pipe stiffness.
II–I	At the compressive load removal (down to *I* point), the nipple returns to its original position. This sector corresponds to the connection stiffness.
I–III	Tensile force applied to the thread connection causes a larger nipple tension and increases friction over the contact area between threads in drill pile and nipple. The total thread stiffness increases.
III-IV	Further decrease of tensile force results in insignificant relative displacements in drill pipe and nipple threads due to the high stiffness contact between these threads.
IV–V	The decrease of tensile force results in the decrease of friction in drill pipe and nipple threads.
Interval V–I	Tensile force is absent in *V* point. The significant friction is observed between the adjacent threads of drill pipe and nipple. This sector corresponds to inelastic deformation in the nipple connection.
V–VI	The total stiffness of the nipple connection is considerably lower than that in sector *I–II,* since the reversed friction is observed in the drill pipe thread.

The external coupling torque affecting the drill string evokes shear stresses in the connecting elements. At the same time, the coupling torque can be transmitted through the nipple threads and the drill pipe joints.

The modification of shear stresses is observed in the nipple as a result of a series of percussions generated by the hammer at constant pre-impact velocity of 5.1 m/c (figure 4).

The behavior of these dependencies can be explained by the coupling torque fractions redistributed between the nipple thread and the drill pipe joint. This complex wave process occurring in the pipe connection can be described as follows.

1. The tightening force acting on the thread connection at the beginning (some 3 t) results in the drill pipe compression and the nipple tension.
2. During the strain wave propagation, the compressive force increases in drill pipes up to the its peak values (15-18 t), while the tensile force in the nipple decreases. The contact deformation of adjacent threads in connecting elements is considerably reduced resulting in the nipple threading into the pipe due to the external coupling torque.
3. In the ending of strain wave propagation, the drill pipe acts on the nipple thread as a compressed spring, thereby causing its larger tension than before the strain wave propagation. Contact forces, friction, and shear stresses in threads are increased.
4. By the direct pulse propagation, shear stresses turn to be lower than the preceding ones. This is because the increase of the external coupling torque fraction in the pipe joint, and the decrease of that one in the nipple.

This wave process is repeated until about 70-75% of the coupling torque in the connection is transmitted through the drill pipe joint. The transmission of the coupling torque is then stabilized. In this experiment, the transmission of 70-75% of the coupling torque was observed after 5 impacts.

4. Conclusions

1. Experimental research is connected with the understanding of the process dynamics occurred in the drilling tool.
2. The new design of the coupling element allowed minimization of strain wave energy losses at its propagation over the drill string, providing the sufficient strength of coupling elements.
3. The combined effect from the coupling torque and strain waves generated by the longitudinal impact, the drill pipe tightening occurred while in operation that reduced the shear stress 2-3 times. Being located inside the drill pipe, the nipple was unloaded from the most of transverse and longitudinal loads, while 70% of coupling torque was transmitted through the drill pipe joints.

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