

# The technology improvement and development of the new design-engineering principles of pilot bore directional drilling

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**Abstract.** This paper addresses the effectiveness of impact energy use in pilot bore directional drilling at pipe driving. We establish and develop new design-engineering principles for this method. These principles are based on a drill string construction with a new nipple thread connection and a generator construction of strain waves transferred through the drill string. The experiment was conducted on a test bench. Strain measurement is used to estimate compression, tensile, shear and bending stresses in the drill string during the propagation of elastic waves. Finally, the main directions of pilot bore directional drilling improvement during pipe driving are determined. The new engineering design, as components of the pilot bore directional drilling technology are presented.

## 1. Introduction

Large-scale application of trenchless technology in underground construction has motivated the proposed research. Generally, rotary well drilling rigs are used for these purposes [1-5].

The disadvantages of these drill rigs are as follows: firstly, the inefficiency of drill rigs in medium-hard and harder rocks, and secondly when drilling tools have to deal with similar hard materials, in particular concrete slabs or other construction debris.

In response to this problem, powerful percussive mechanisms are added in drill rigs used for pilot bores and for hardpan penetration [6].

The technologies using impact energy are promising. They allow influencing objects (rocks) with huge efforts. However, their efficiency can be maximised only by understanding the drill string dynamic process and by studying the regularities of strain waves propagating through the drill strings.

An elastic wave transfers the percussive energy and contributes to the penetration of the drilling tool into the rock.

The aim of research is to establish and develop a new design-engineering principle for the directional drilling of pilot bores during pipe driving, which is based on the application of a new drill pipe construction designed with a new nipple thread connection and the construction of a strain wave generator transferred through the drill string.



## 2. Methodology

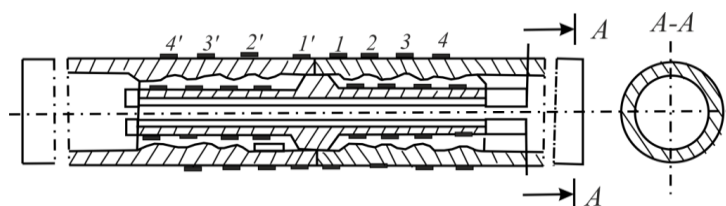
The experimental method allowed us to estimate the effectiveness of wave propagation along the drill string. Moreover, our experimental findings proved the effectiveness of the new nipple connections hidden inside the tube in load distribution during the operation [7].

The experiment was conducted on the test-bench developed by scientists of Tomsk Polytechnic University. It consisted of concrete blocks with through holes. These holes simulated an artificial borehole 42 mm in diameter. The drill string with new enclosed-type nipple connections was located in the artificial borehole.

Impact impulses in the drill string are generated by a pendulum impact machine with a fixed cylindrical hammer.

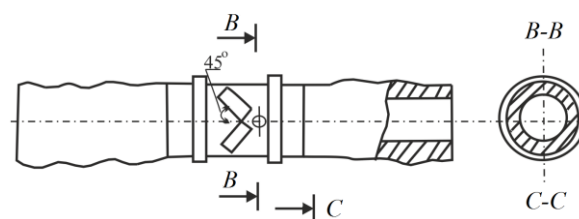
Furthermore, the drill string was loaded at a constant torque of 265 N·m by means of a lever with weight. The hammer pre-impact velocity was adjusted by changing its drop height. The percussive energy ranged from 31.25 to 207.35 J.

To measure the axial deformation in the new thread connection during static and dynamic loads, lateral grooves were formed in the surface of the nipple. Wire strain gauges with a nominal length of 10 mm and a resistance of 100 Ohm were bonded in these grooves (Fig. 2).



**Figure 2.** Schematic view of sticking resistance strain gauges for recording compression, tensile and bending stresses

To measure the bending and shear stresses, the same wire strain gauges were used, and stuck in the middle of the nipple (Fig. 3).



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

Finally, the power pulses were fixed by oscillograph S1 – 117 in five positions of the drill string. Furthermore, oscillograms of compression, tensile, bending and share stresses in elements of the thread connection were obtained and discussed.

The up-to-date hydraulically-driven drilling machines currently replace those with percussion mechanisms supplied by the pneumatic power.

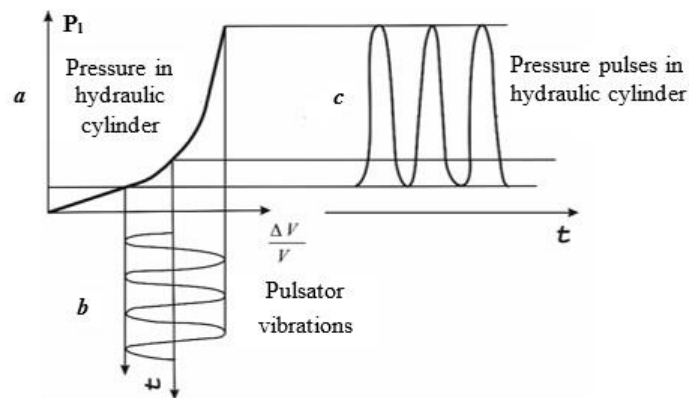
Hydraulic hammers used abroad possess the sufficient capacity, however require a powerful oil-pumping station allowing the hydraulic fluid to flow in high-pressure and drain hoses. The significant energy losses caused by the hammer reciprocal motion, and friction

losses caused by the fluid flow in high-pressure and drain hoses equal to approximately 10% of inertial losses. These energy losses are eliminated in the original hammerless hydraulic mechanism due to the formation of power pulses in a closed-loop system having a non-linear elastic element (a high-pressure hose) practically having no free fluid [8].

Power pulses are generated in a closed loop with a non-linear elastic element practically having no free fluid.

The proposed hydraulic mechanism includes two vibrating systems. The first is sinusoidal pressure fluctuations of the trapped fluid induced by the vibration generator. The fluid is pushed by the periodical movements of the plunger into the closed loop, thereby creating the pressure pulses. The second is a conventional vibrational contour, i.e. a mass with an elastic element.

The pressure pulse generator comprises the pulsator hydraulically connected to the driver, high-pressure hose, and hydraulic cylinder with a piston (Fig. 4).



**Figure 4.** Pressure pulses generated in hydraulic cylinder: *a* – non-linear behavior of fluid depending on the volume change  $\Delta P=f(\Delta V/V)$ , where  $\Delta V$  is trapped fluid pushed by the plunger into the closed loop;  $V$  is trapped fluid in the high-pressure hose and hydraulic cylinder; *b* – the diagram of relative volume change in the high-pressure hose; *c* – pressure pulses generated in the hollow hydraulic cylinder;  $P_l$  – initial pressure load induced by a feed thrust of the hydraulic mechanism with a drill string

### 3. Results and discussion

Widely used drill pipe joints, such as tool joints, sleeve joints refer to inefficient engineering designs for percussive drilling. Their cyclic tensile stresses have a low energy transfer coefficient.

Compared with other drill pipe joints, the suggested construction allows the transfer of the strain wave energy with minimum dissipation (Fig. 5).

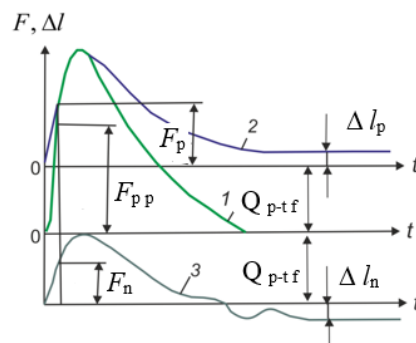
In the beginning, when the drill string was assembled, the nipple connection became deformed. This was due to the effect of normal force on the pipe joint. The tightening force acting on the enclosed-type nipple connection resulted in drill pipe compression and nipple tension.

An elastic impact produced by the interaction between the hammer of the percussive mechanism located outside the borehole and the drill string, resulted in strain wave propagation (Fig. 5, line 1). In this case the tightening force in the drill pipe is increased to

power pulse value (about 15-18 tons) (Fig. 5, line 2). Furthermore, tension force in the nipple is decreased (Fig. 5, line 3).

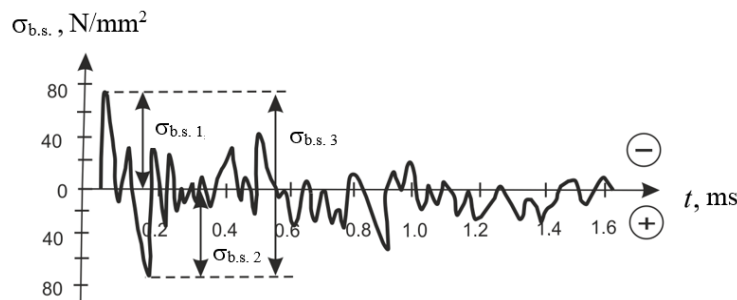
When the nipple is completely unloaded, a gap between adjacent threads is observed both in the drill pipes and the nipple. This results in additional nipple longitudinal displacement in relation to the drill pipe due to the torque. It also leads to additional and equivalent nipple tension ( $\Delta l_n$ ) and drill pipe compression ( $\Delta l_p$ ).

Nipple and drill pipes have different rigidity. Rigidity refers to the ability to resist deformation in response to an applied force. Rigidity extent is the stiffness. In our research the pipe stiffness was  $C_p = 1.6 \cdot 10^9$  N/m and the nipple stiffness was  $C_n = 0.44 \cdot 10^9$  N/m.



**Figure 5.** The influence of power pulse on the new nipple joint elements of drill pipes: 1 – power pulse propagation in enclosed-type nipple joint; 2 – the compressive force behavior in the drill pipes; 3 – the tension force behavior in the nipple;  $F_{p p}$  – power pulse value in the pipe segment before the thread;  $F_p$  – power pulse value at pipe end;  $F_n$  – the reduced tension force value in the middle of the nipple;  $F_{p p} = F_p + F_n$  – forces value at some instant;  $Q_{p-t f}$  – pre-tightening force

Note that in this case the thread segment of the drill pipe has repeated-load cycle, but the nipple has alternate asymmetric load.

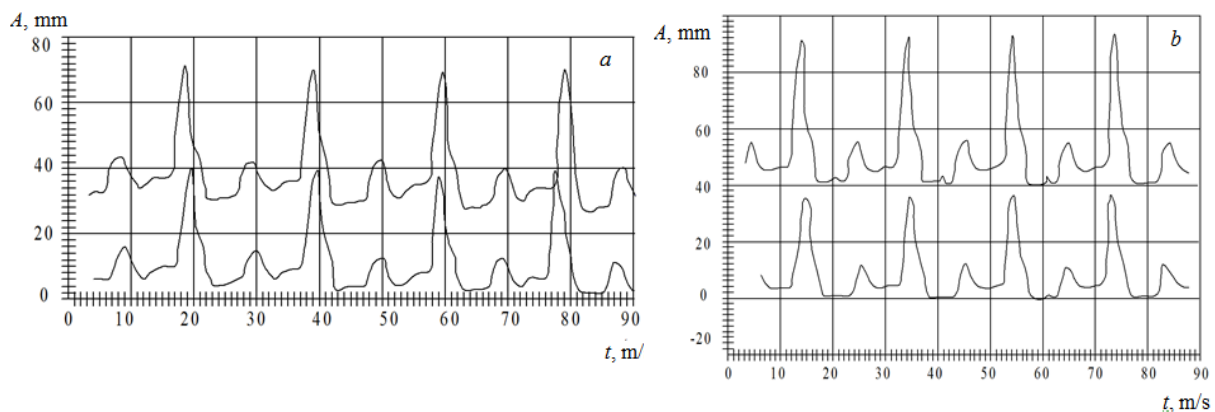


**Figure 7.** The bending waves propagation in the nipple  
 $\sigma_{и3.1}$ ,  $\sigma_{и3.2}$  – maximum of bending stress;  $\sigma_{и3.3}$  – variation range of bending stresses

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

The combined effect from the coupling torque and strain wave generated by the longitudinal impact, the drill pipes tightening occurred while in operation. It results in 2 or 3-fold reduction in the shear stress. 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. Experiments show that pressure pulses are formed due to the plunger strokes and inertial mass movements at the compression of trapped fluid. In turn, the formation of power pulses is oriented only towards the borehole. It does not necessitate protecting the drilling machine from power pulses reflected from the pipeline connections and the borehole.

The largest values of the strain wave amplitude and energy in the drill string are observed at the smallest length of the high-pressure hose and its largest diameter. The time dependences of the strain wave amplitude are presented in figure 8. This is due to the fact that a longer high-pressure hose connecting the hydraulic pulsator with the cylinder, provides the lower  $\Delta V/V$  ratio at the same parameters of hydropulsator. This results in lowering the pressure pulse amplitude in hydraulic cylinder and, as consequence, the power pulse in the drill string. Moreover, the decrease in the diameter of the high-pressure hose increases its rigidity. This also results in a decrease in the amplitude and energy of the power pulse.



**Figure 8.** Dependences between the power pulse amplitude and time at different geometry of high-pressure hose:  $a - d = 16$  mm,  $l = 2.5$  m;  $b - d = 20$  mm,  $l = 0.95$  m. The upper channel (beam) is the amplitude of power pulse in drill string; the lower channel (beam) is the pressure in hydraulic cylinder (20 mm corresponds to 36 kN); forcing frequency of pulsator  $\omega = 25$  Hz

#### 4. Conclusions

This study has proposed new engineering solutions as part of the pilot bore directional drilling technology. Using the new drill string construction and the hydropercussion device without a hammer, leads to the fact that power pulses with optimal parameters can be obtained and transferred to a downhole with minimum losses.

The enclosed-type nipple connection of drilling pipes is most efficient and durable as it takes into account wave processes in the drill string. The research has revealed the regularities of compression and tension stress changes in the elements of drill pipe joints.

The novel design solution proposed for the method of power pulse generation in a drill string is a promising research development. Hammerless hydromechanical systems having oil-pumping stations with pressure and drain pipelines simplify the flow chart of the drilling machine, considerably increase the efficiency of hammerless hydraulic mechanisms in comparison with all other up-to-date hydraulic percussion mechanisms.

## 5. References

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