

Development of small diameter pilot hole directional drilling for trenchless utility installation

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Abstract. The paper overviews trenchless utility installation techniques and prospects of further development of horizontal directional drilling technology to drill small diameter pilot holes. The improved design is suggested for the thread connection of drill pipes and hydraulic system to generate power pulses.

1. Introduction

Infrastructure and housing development led to the increase in construction of underground utility and transport systems. Trenchless installation of utility systems is a predominant technology in developed countries. The trenchless technology used for the underground utility systems is based on the formation of subsurface pilot holes drilled in soil with the possibility of further extension up to the required diameter.

So far, worldwide experience has been accumulated in laying pipelines and installing utility systems using both controlled and uncontrolled methods.

Uncontrolled method is based on horizontal directional penetration of pipelines or sheathing pipes due to static or impact loads. The end of a sheathing pipe can be either open or closed. Pipe pushing is one of the first and simple methods of trenchless technology. Originally, the pipe pushing method was mechanical. Later, the invention of hydraulic pipe pushing machines and vibratory hammers allowed improving it greatly. The former implies a high-pressure water-jet to washout soil before using a rock cutting tool; the latter uses spinning counter-weights to create vibration to the pile, which allows it to "cut" soil into the ground.

It should be noted that the pipe pushing can be performed using a pneumatic percussive machine, comprising a hollow casing in which a piston is in reciprocating motion; and a valve assembly through which compressed air is supplied to the piston face. Pipe pushing is limited to 500 mm maximum diameter and 100 mm length of the pipe.

Pipe ramming differs from the pipe pushing by directing the soil into the pipe interior instead of compacting it outside the pipe.

Controlled method of trenchless utility installation is performed by drilling machines and relates to horizontal directional drilling that includes several stages such as pilot hole drilling, hole reaming, and pipeline laying.

The main properties of drilling machines are the drag force, torque, and performance of reciprocating piston pump.

The drilling machines are divided into rotary, percussive, vibratory, and vibratory-rotary drilling machines.



The modern percussive drilling machines provide significant increase in their drilling capacity and drilling rate in severe conditions. The main parameters of the efficient installation of utilities in complicated urban conditions are the unit capacity and its dimensions. The unit capacity is important for the drive in hard rock, while the unit dimensions influence its mobility and operating capacity in restrained urban conditions.

2. Thread connections of drill pipes

During the percussive drilling of small diameter pilot holes, the thread connections of drill pipes are subjected to the axial load, torque, and transient load. The information on loading effects on thread connections at the design stage, allows increasing their service life.

The practical experience shows that the break of thread connections during the percussive drilling occurs due to their imperfect design revealed under the transient loads.

The insufficient operating capacity of drill pipes and their connections leads to the increase in drill-steel production and consumption and results in great loss of time spent to replace the damaged pipes. Therefore, the pipe connection should be designed to increase the operating capacity of the drill string and the labour capacity while drilling holes.

During the power pulse propagation over the drill string, the strain waveform is changed and the strain wave energy is dissipated. The literature review shows that a safe operation of thread connection is associated, first of all, with the decrease in the strain wave energy when the power pulse travels through it. The strain wave energy is dissipated in thread connections rather than directed to the longitudinal movement of the drill string and rock cutting tool. It is induced by the multiple alternating strains, thread friction, and heating of thread connections [1, 2, 4].

Nowadays, internal upset drill-pipes and pipe-in-pipe system connection are used for directional drilling of a small diameter pilot hole (fig. 1).

In addition to the elastic forces occurring during the power pulse propagation through this type of thread connection, dissipative forces also arise, which requires additional energy.

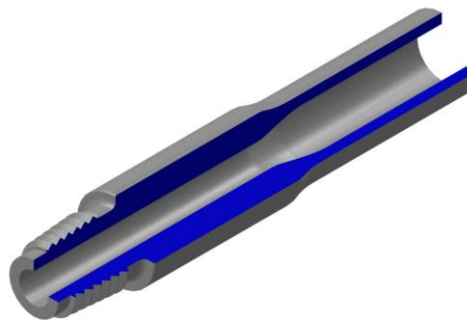


Figure 1. Pipe-in-pipe system connection.

While drilling, the thread connections are subjected to different loads that considerably complicate the analytical determination of dissipative forces induced by the dynamic loads. The quasistatic loading of thread connection is used to investigate the behavior of elastic and dissipative forces observed in thread connections.

The suggested design [3, 6, 7] of nipple thread connection shown in figure 2, is more efficient and allows improving the drill string reliability and cutting transport as well as ensuring the automation of making-up and breaking-out drill pipes.

The nipple connection comprises two drill pipes having a female straight thread and a nipple having a continuous male thread. The nipple has a collar with two annular grooves on its both sides. Collar grooves are cut on the internal side of the drill pipe ends. Non-threaded segment of one of the nipple ends is rigidly fixed in the drill pipe and has longitudinal cuts that divide the non-threaded segment into elastic plates. Elastic plates have collars with a bevel front face which are fixed in the

annular groove after the achievement of strain tolerance in the tapered groove. Wrench flats are cut on another non-threaded segment of the nipple end.

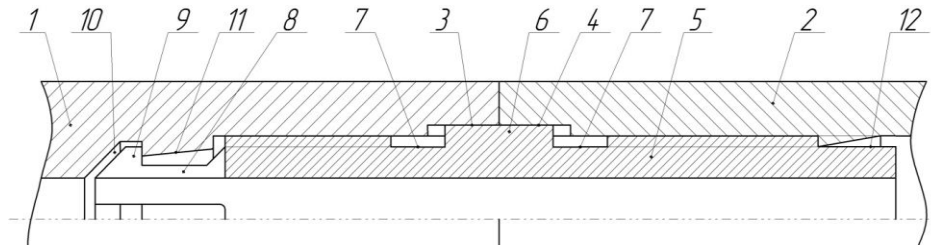


Figure 2. Cross-sectional view of nipple thread connection: 1, 2 – drill pipes; 3, 4 – grooves; 5 – nipple thread; 6 – collar; 7, 10 – annular groove; 8 – elastic plates; 9 – collar with bevel front face; 11 – tapered groove; 12 – wrench flat

The suggested design of the nipple connection [10] has the following advantages:

- Nipple locates inside two butt-coupling pipes providing the minimum energy loss at strain wave transmission;
- In strain wave propagating through the connection, pipe sections are compressed, while the nipple is unloaded from normal tensile and deformation stresses produced by the pre-tightening force;
- The collar and annular grooves cut in the nipple improve the connection durability at bending strain;
- The automation of making-up and breaking-out drill pipes is possible due to the nipple fixation in one of the drill pipes;
- The nipple connection hidden inside the drill pipe provides the consistency of the outer diameter of the drill string, which improves the cutting transport and eliminates the possible drill string jamming in the well.

The suggested nipple thread connection can be used in percussion drilling of medium-hard and harder rocks ($f=6\dots 14$). The transmission rate of strain wave energy along the drill string increases due to the increase in contact stiffness between thread connections and decrease in the nipple stiffness.

3. Hydraulic system of pulse shaping

The literature review on power pulse generation by horizontal drilling machines reveals the availability of well-developed theoretical foundation of pneumatic equipment. It has facilitated the development and production of effective percussive drilling machines. It should be noted that pneumatic percussion mechanisms has lower efficiency in comparison with hydraulic or electric machines. Electric percussion mechanisms have a number of limitations that impair the invention of more powerful mechanisms. New technical decision is patented by Shadrina *et al.* [8]. It relates to the percussion mechanism that generates power pulses in a drill string. Hammerless hydromechanical system with no oil-pumping stations simplifies the flow chart of the drilling machine and considerably increases the efficiency of the mechanisms in comparison with all other hydraulic percussion mechanisms. However, the hydraulic power cylinder of the suggested percussion mechanism has an imperfect design, which has negative impact on the capacity and efficiency of the mechanism.

The improved design of percussion mechanism is suggested for the percussive drilling machine comprising the hydraulic pulsator connected with the drive; the fluid-pulse shape correcting device; hydraulic power cylinder with piston contacting with the drill string shank. The hydraulic pulsator is represented by cylinder and plunger, while the fluid-pulse shape correcting device is represented by a hollow elastic element with non-linear characteristic. It is filled with a fluid and characterized by a bellows installed in the hydraulic power cylinder and connected to the hydraulic pulsator by means of the hollow elastic element. Thereby, a closed cavity is formed filled with fluid. On one side, the

bellows is rigidly fixed to the spring loaded piston, and on the other, with the spring-loaded inertial mass. The cross-sectional view of percussion mechanism is presented in figure 3.

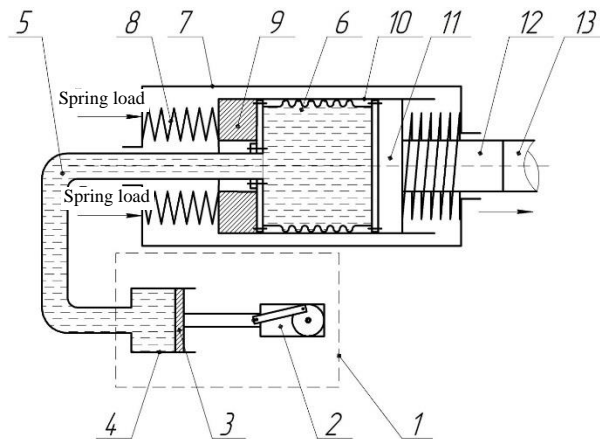


Figure 3. Cross-sectional view of percussion mechanism: 1 – hydraulic pulsator; 2 – drive; 3 – plunger; 4 – hydraulic power cylinder; 5 – elastic element; 6 – bellows; 7 – protective case; 8 – spring; 9 – inertial mass; 10 – end of hydraulic power cylinder; 11 – spring-loaded piston; 12 – shank; 13 – drill string

The hydraulic pulsator is connected with the drive and plunger located inside the hydraulic power cylinder. Its cavities are connected to the bellows by an elastic element and filled with fluid. The protective case is equipped with a spring supported by inertial mass. The inertial mass is fixed to the end of the hydraulic power cylinder connected to the bellows cavity. The bellows cavity is rigidly connected with the spring-loaded piston supported by a drill string shank.

In switching the drive of hydraulic pulsator, plunger starts a reciprocating motion in hydraulic power cylinder. The reciprocating motion produces the fluid pulses the shape of which is characterized by a gradual pulse rise. In turn, these fluid pulses induce forced oscillations of hydraulic fluid in the elastic element. The shaped fluid pulse travels then in the bellows and acts on the spring-loaded piston. Then it passes through the shank and achieves the drill bit having propagated over the drill string [9].

The pressure pulses, generated in the closed volume, propagate in hydraulic power cylinder through the piston in the capacity of the longitudinal elastic strain wave and transfer to the drill string shank. Further, the strain wave propagates at the velocity of sound in the material of the drill string and then travels to the rock cutting tool. Owing to the power pulses, the cutting tool intensifies the rock disintegration, thereby, increasing the drilling penetration rate.

It is worth noting that the suggested percussion mechanism also includes the automated control for the power pulses. In drilling soft rock, the amplitude of power pulses is not high, since it exhibits no resistance to the cutting tool. On the contrary, in hard rocks the amplitude of the power pulse generated by the plunger pair is high, which increases the power capacity of the percussion mechanism.

4. Conclusions

The equipment of drilling facilities with percussion mechanisms is the prospective way of engineering and technological development of small diameter pilot hole directional drilling used for trenchless utility installation. In its turn, the percussion mechanism equipment requires the improved design of the drill string, in particular, the pipe connections that provide the pulse propagation from the percussion mechanism to the rock cutting tool.

The early investigations of the dynamic processes occurring in a drill string during the percussive drilling of small diameter pilot holes have shown that nipple pipe connections have a range of advantages over the pipe-in-pipe or coupling connections. The suggested design of the nipple

connection ensures the automation of making-up and breaking-out drill pipes due to the nipple retention in one pipe and its constrained movement inside the thread connection. It led to the decrease in the dynamic loads and stresses in the nipple during the pulse transfer from the thread connection to the cutting tool.

The suggested hydraulic system of pulse generating is a hammerless percussion mechanism that has higher efficiency than those with conventional hydraulic hammers. In the latter ones, the reciprocating motion of a hammer in hydraulic cylinder consumes most of the energy. The experiments showed that power pulses can be generated with a gradual rising edge and longer duration, which will ensure the efficient use of energy. This hydraulic system includes the automated control of the pulse amplitude depending on the rock resistance. With the increase of the rock hardness, the pulse amplitude will be automatically increased.

The implementation of the suggested design solutions patented by the Russian Federation will considerably increase the productivity and reliability of the equipment used for the horizontal directional drilling of small diameter pilot holes.

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