Background for engineering a continuous-operation soil drifter

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Abstract. The paper discusses the feasibility of combining compaction and excavation processes in hole making. The continuous loop of hole-making and soil removal from hole pipe by compressed air return flow is proposed. Usability of an air hammer drill with elastic valve in the air distribution system in capacity of a drifter motor is examined. Using a physical dimension model with piston 4 kg in weight, the author refines energy and frequency performance of the pulse generator given the backpressure in the exhaust chamber. The experimental curves of the percussion capacity parameters are obtained.

1. Introduction
Trenchless technologies of laying utility services enjoys increasingly wider application in underground construction owing to their undeniable advantages as well as due to essential strengthening of standards and regulations in the sphere of anthropogenic load in natural landscapes and maximum possible preservation of surface transport infrastructure [1–5]. Amidst such technologies, a certain place on the market can belong to the combination hole-making method proposed by the Institute of Mining. In this method, the hole-making process is combined with radial compaction of soil, which promotes stability of hole walls, and removal of soil off the hole. Research shows that with this method, the hole-making process consumes less energy and becomes simplified owing to withdrawal of fixative solutions, elimination of over-compaction of soil and avoidance of full cross-sectional development of the hole bottom [6–8].

All tools available by now for making holes with partial soil compaction and removal can be divided into continuous and cyclic action. In the former case, breaking of hole bottom and advance of a drifter takes place simultaneously with portioning and removal of soil off the hole; in the latter case, these operations are implemented at different time.

2. Operation principle of underground tools
The continuous action equipment is, for instance, the tool with a cutting ring actuated by a pneumatic impulse-generating mechanism, with soil plug removal by compressed air flow from a compression plant [9]. The percussion unit of this tool (Figure 1) uses air hammering device 1, at the front of which sleeve 2 with transverse ribs 3 is mounted for attachment of bit 4 with outside cylindrical barrel 5 and tilted cutting cutting rings 6. Nozzle 7 at the front serves for catching fine soil particles by compressed air flow fed to the bottom hole through the hole in flange 8 with safety valve 9. The operating process of the tool includes cutting of pilot guide and transportation channel 11 with its axis coincident with the project path of the hole. When the drifter operates, the ribs divide soil into sectors, and the cutters
make ring-shaped chips suitable for removal by air flow. Advance of the drifter is accompanied by making final hole 11. The field tests of the equipment revealed some shortages, namely:
—high air flow rate to ensure sufficient air velocity in the cavity of the reamer;
—possible cutting of the hole wall by the leading edge and deflection of the tool from the project path;
—low efficiency in compact and clayey soil.

![Figure 1. Drifter with soil removal by air: 1—air hammering device; 2—sleeve; 3—rib; 4—bit; 5—barrel; 6—cutting rings; 7—nozzle; 8—flange; 9—safety valve; 10—pilot channel; 11—hole.](image1)

The principle of cyclic action is implemented in equipment which applies integrated loading of soil by dynamic impulses generated by drifter and by static force from traction equipment [10, 11]. Such hole-making assembly is shown in Figure 2. It consists of air percussion mechanism 1 with ring-type bit 2, which are the main functional elements of the drifter delivered to the bottom of hole 3 by two-way traction facility 4 from pit 5 using pull-in 6 and pull-out 7 steel cables via wind-up drum placed in outlet pit 9. The reamer is made as barrel 10 with transverse ribs 11 and central sleeve 12. The front of the bit has compacting cone 11 meant to shape walls of the hole. The operating mode of this tool involves recurrent intermitted cycles, including delivery of the drifter to the bottom hole, bottom hole cutting and pull-put of the device together with removal of soil.

![Figure 2. Cyclic action drifter: 1—air percussion mechanism; 2—bit; 3—hole; 4—traction facility; 5—operating pit; 6—pull-in cable; 7—pull-out cable; 8—wind-up drum; 9—outlet pit; 10—barrel; 11—rib; 13—sleeve; 13—compacting cone.](image2)
3. Prototype test results

The preproduction model of such drifter has been trialed at full scale on the test ground of the Institute of Mining, and at various construction site of the city of Novosibirsk. The drifter made more than 200 m of holes with diameter of 325–426 mm intended for various utility services. The trials proved that the equipment met most of technical and operating requirements. A major drawback appeared to be impossibility of casing while hole-making, or pulling of a product pipeline, which limits the application of this equipment in soft and clayey soil.

It was decided to improve the combination hole-making method. To this effect, a series of studies was carried out, and the basic diagram of the continuous-action drifter was developed and proposed as a result [12] (Figure 3)

Preparatory operations include making of a guide connection channel between inlet 1 and outlet 2 pits. In this channel, flexible coupling 3 is arranged to connect traction device 4 and air hammering device 5. The latter makes hole and simultaneously pulls pipeline 6 in it. The cutting ring of the drifter is additionally equipped with diffuser 9 for portioning of soil.

![Figure 3](image_url)

Figure 3. Block diagram of continuous-action drifter: (a) bottom hole cutting; (b) portioning of soil and (c) removal of soil from hole: 1—inlet pit; 2—outlet pit; 3—cable; 4—traction mechanism; 5—air hammering unit; 6—pipeline; 7—soil; 8—soil plug; 9—diffuser.

During heading, the bottom hole is cut, and soil enters the pipe interior for further removal (Figure 3a). As the drifter advances, soil accumulates and compacts, which is contributed to by a narrowing section in the form of an elastic hose. In this fashion, a soil plug is formed and prevents discharge of compressed air return to the atmosphere (Figure 3b). In the resultant void, a backpressure grows up to a critical value and creates the required static force for removal of the soil plug from the hole (Figure 3c). This technological sequence recurs many times during the hole-making process.
As a driving unit, it is expedient to use a generator based on the air hammer with elastic valve in the air distribution system. Such machines are designed by the Institute of Mining, are known under the trade mark Typhoon and have proved their efficiency in special construction in the wide range of climatic and industrial conditions of operation [13].

The main elements of the air hammer (Figure 4) are piston 1, anvil 2 mounted on cylindrical body 3 and back nut with air outlet 4. The forward $A_1$ and back stroke chambers $A_2$ are connected via throttle channel 5. Exhaust is controlled by ring-shaped elastic valve 6. The exhaust compressed air is fed to the chamber $A_3$ connected to the atmosphere.

Figure 4. Air hammer: 1—piston; 2—anvil; 3—body; 4—back nut; 5—throttle channel; 6—elastic valve; $A_1$, $A_2$—forward and back stroke chambers; $A_3$—exhaust chamber.

One of the specific requirements imposed on this machine is efficient operation of the air percussion drive under backpressure from the side of the exhaust channel. The critical modes of the working cycle of this mechanism were studied in a series of laboratory tests. The test object was selected to be air hammer model Typhoon 4 with piston mass $m = 4$ kg [14].

The tests were carried out on a special bench (Figure 5). Its mechanics consisted of front cylinder 1 with percussion device. Exhaust air was fed to sealed cavity 2 and accumulated there to simulate operating conditions of additional resistance in exhaust channel of the machine. The back pressure value was adjusted using the air tap T and visually monitored by readings of the manometer M. the measurement chain was composed of the pressure sensors S1–S3, block of electric signal amplifiers BA and the analog-to-digital converter ADC connected to a portable computer. The data were processed in the standard environment of Power Graph Professional and Exel.

Figure 5. Test bench: 1—cylinder; 2—cavity; S1–S3—pressure sensors; BA—block of amplifiers; ADC—analog-to-digital converter; T—air tap; M—manometer.
The obtained results made it possible to specify the behavior of the operating cycle of the percussion machine with elastic valve in the air distribution system given additional resistance to exhaust air flow from the side of the exhaust chamber. During the tests, the air flow resistance was evaluated by the backpressure varied in the range of $p_b = 0–0.5$ MPa. As the result, in the test interval, the machine performed stable operation at the fed compressed air pressure of 0.6 MPa. As seen in the resultant plot (Figure 6), accumulation of exhaust compressed air is accompanied by gradual decrease in the energy of the impulse input from the initial value $E = 40$ J at $p_b = 0$ to $E = 1.5$ J at the maximum backpressure $p_b = 0.5$ MPa. A different picture is observed under variation in the frequency component of the percussion capacity, $f(p_b)$. There is an increasing trend in the function from $f = 14.2$ Hz ($p_b = 0$) to $f = 26$ Hz ($p_b = 0.5$ MPa). The maximum growth of this parameter is observed at $p_b = 0.3–0.4$ MPa when the frequency is varied from 17.4 to 24 Hz.

Figure 6. Output parameters of air hammer Typhoon 4 with backpressure in exhaust chamber.

The above indicated features are explained by the shortened travel of the piston (Figure 4) when its back end is affected by addition backpressure from the side of the exhaust chamber. In this case, the kinetic energy of the piston is reduced owing to the drop in the pre-blow velocity of the speedup, and the period of the working cycle of the machine is shortened with the simultaneous increase in the blows per unit time.

The changed behavior of the impulse generator fits the operating mode of the drifter. As the drifter advances in the hole, soil intake persistently grows and the accumulated soil plug prevents the compressed air exhaust. The backpressure in the exhaust chamber increases, and the energy of the percussion drive drops, which is accompanied by the deceleration of the bottom hole cutting and the decrease in intensity of soil accumulation in the annulus. This trend keeps on until the pressure of compressed air on the soil plug reaches a critical value sufficient for separation of the plug from the reamer and its removal along the pipe to the inlet pit. In the meanwhile, the observed increase in the blow frequency adds to better cleaning of the tool and to the decrease in the soil friction on the inner pipe surface during removal (vibratory displacement effect) [15, 16]. Then, after removal of a soil batch, resistance at exhaust lower to zero, and the drifter operates in the normal mode at the totally recovered performance. The rate of penetration increases, and a new soil plug starts forming.

4. Conclusions
1. The known engineering solutions on the technology and equipment of horizontal hole-making in soil in combination with soil compaction and removal are reviewed.
2. The alternative method with continuous cutting of bottom hole by pneumatic percussion tool with cutting ring, batch-wise removal of soil plug by exhaust compressed air and simultaneous pulling of pipe sections in the made hole is proposed.

3. Using the physical model with piston mass of 4 kg, the nature of the change in the operating mode of the pneumatic hammer with elastic valve in the air distribution system under the backpressure in the exhaust chamber in the range of 0–0.4 MPa is determined. It is found that the energy input is reduced more than 20 times at the concurrent increase in the frequency component of the percussion capacity by 1.8 times. The applicability of such devices as drives for drifters is illustrated.

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