Expansion of application range of pneumatic hammers with adjustable impact effect

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Abstract. The author reviews briefly existing machines for trenchless laying of underground utilities and vertical driving of steel elements in soil. For a pneumatic hammer with ring and inertia valves for driving different diameter pipes, arrangement and operating principles are described. Powerful longitudinal forces generated by shocks ensure destruction of solid rocks or compaction of soil in the zone of hole-making. These forces can be used in implementation of other technologies as well. For instance, maintenance and rehabilitation of oil well centrifugal pumps, which requires complete disassembling of the machine. For taking of many parts (impellers and guide vanes) out of a hole (a pipe), a pneumatic hammer with piston weight of 40 kg was tested. Another application area of pneumatic hammers can be stimulation of caking material unloading from railway cars using a vibropercussion plant driven by pneumatic puncher. Replacement of the latter by a pneumatic hammer of the same size and performance can enhance efficiency of the process.

1. Introduction
One of the basic approaches to trenchless laying of underground utilities is driving of a steel pipe to act as a casing for higher protection of the utility lines from mechanical damage. Laying of steel pipes is carried out using a pneumatic hammer in ramming an open-ended or closed-ended pipe in soil. Such technologies reduce the cost of construction and have no alternatives in the conditions of a city [1–4].

Another application area of pneumatic hammers is vertical driving of pipes and other construction elements (I-beams, U-sections, L-steel, sheet piles) to make a blocking-off when retaining walls and protecting walls are constructed in soil in hard-to-reach places.

The pneumatic hammers are the simplest, reliable and highly effective machines for trenchless pipeline laying in soil. Vertical and horizontal driving of steel pipes can use a large pneumatic punch [5, 6].

2. Pneumatic hammers with adjustable impact effect
Based on the new principle of air distribution using elastic ring and inertia valves, the Institute of Mining designed a series of pneumatic hammers named Typhoon (Figure 1) [5–8]. The largest Typhoon hammer has a piston weight of 1000 kg. The specifications of the hammer models are compiled in Table 1.

These hammers provide higher power and economic performances as compared with Russian and foreign analogs at similar size and weight. For example Typhoon 740 hammer with piston weight of 740 kg and blow energy 1.5 times higher than the analogs have, at a low blowing rate of
(0.17...0.19)⋅10⁻⁴ m³/J, consumes 7 to 10 cubic meters of compressed air per minute [6]. The large air punch M400 (Institute of Mining, SB RAS) KOLOSS Hammer by Tracto-Technik (Germany) need 20 cubic meters of air per minute [5].

![Figure 1. Pipe driving by air hammer Typhoon: left—casing pipe; 2—power transmission line support.](image1)

**Table 1.** Specifications of pneumatic hammer models Typhoon.

| Description | Typhoon 40 | Typhoon 70 | Typhoon 130 | Typhoon 140 | Typhoon 190 | Typhoon 320 | Typhoon 300 | Typhoon 500 | Typhoon 740 | Typhoon 1000 |
|-------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|
| Blow energy at pressure 1.6 MPa, J (vertical) | 400 (450) | 700 (800) | 1300 (1450) | 1370 (1350) | 1800 (2150) | 2800 (3500) | 3000 (3500) | 4000 (5000) | 6000 (8000) | 8300 (11500) |
| Blow frequency², min⁻¹ | 126–350 | 150–250 | 180–228 | 220–336 | 120–175 | 65–125 | 114–174 | 60–115 | 60–90 | 42–65 |
| Air flow rate, m³/min | 3–6.3 | 4–6.3 | 6.5–8 | 6.5–9 | 5–7.5 | 5–9 | 5.7–10 | 6–11 | 8–12 | 11–18 |
| Piston weight, kg | 40 | 70 | 130 | 140 | 190 | 320 | 300 | 500 | 740 | 1000 |
| Machine weight, kg | 90 | 140 | 280 | 300 | 380 | 550 | 700 | 1300 | 1750 | 2500 |
| Machine size, mm | | | | | | | | | | |
| Length | 1000 | 1400 | 1350 | 1150 | 1680 | 1920 | 1380 | 1910 | 2620 | 2670 |
| Body diameter | 160 | 160 | 240 | 270 | 240 | 270 | 410 | 410 | 410 | 456 |
| Largest³ diameter of driven pipe, mm | 59 | 273 | 325 | 325 | 530 | 630 | 630 | 820 | 1020 | 1220 |

¹ Without inertia valve.
² The lowest value of the blow frequency corresponds to the lowest air flow rate.
³ The recommended diameters ensure driving of pipes not less than 40 m long.

The pneumatic hammer with elastic and inertia valves in the air distribution systems is composed of (Figure 2): 1—body; 2—piston; 3—anvil; 4—stem; 5—branch pipe; 6—elastic valve (ring); 7—air bleed; 8—inertia valve; 9—hose; 10—power stroke chamber; 11—back stroke chamber; 12—grooves; d—calibrated orifice diameter; d₁—main line diameter; D₁—power stroke chamber diameter; D₂—
back stroke chamber diameter; \( X \)—length of the power stroke of the piton; \( X_{\text{max}} \)—maximum travel length of the piston.

**Figure 2.** The pneumatic hammer with elastic and inertia valves.

Compressed air via hose 9 flows to power stroke chamber 10 and through air bleed 7 to back stroke chamber 11. Pressure grows in chamber 11. Under the increased pressure and due different areas of chamber 10 and 11, piston 2 is displaced backward (at the top in Figure 2).

At the same time, elastic valve 6 is stretched, pressed to inner surface of 3, slides over it and ensures sealing of chamber 11. When elastic valve 6 reaches grooves 12, air is exhausted and pressure drops in chamber 11. Under the action of the elastic forces, the ring valve or elastic valve 6 is constricted rapidly. Between anvil 3 and elastic valve 6, a wide circular clearance appears. Through this clearance, final exhaust and displacement of air to the atmosphere takes place during power strike of piston 2.

The air hammer generates great forces on the driven pipe at different blow frequencies—from 0.8 to 40 Hz. The blow frequency is governed by the power stroke \( X \) of the piston and the orifice diameter in air bleed 7 to feel back stroke chamber 11 with air. With shorter stroke of piston 2 and quicker fill of chamber 11 with air, the blow frequency increases. This property of air hammer Typhoon ensures adjustability of its impact effect.

The value of the blow-generated force depends on the blow energy and piston weight [9, 10]. The impact force can range a few to a few hundreds tons at the piston weight \( m \) from a few to a few hundreds kilograms. Figure 3 demonstrates the impact pulses generated in a pipe when it is driven in soil.
3. Rehabilitation of well centrifugal pumps

Lifting of highly corrosive liquids from an oil well is implemented using the well centrifugal pumps made of corrosion-resistive materials (Figure 4). Because of small size, the oil centrifugal pumps have their water export made in the form of guide vanes (GV) 1 in Figure 4.

A key function of the guide vanes is water export from impeller (I) 2, reduction in water flow velocity with simultaneous kinetic-to-potential energy conversion (pressure boost), and feed of water flow to the next impeller or to the discharge outlet. The impeller is to increase the kinetic and potential energy of water flow by means of its speedup in the blade system of the centrifugal pump impeller, and due to the pressure boost.

Repair and rehabilitation of an electric centrifugal pump (ECP) requires total removal of many alternate impellers and guide vanes from the body of the pump made of steel thickwalled tube [11]. After long-term operation, removal of parts from ECP body, especially GV arranged at minimized clearances along the interior of the thickwalled tube, is highly difficult due to sanding of the gaps. In this case, it is necessary to mill sand particles to finer size. In the meanwhile, it is anything but simple to apply considerable forces to each GV in order to mill sand particles and to take the parts out of the thickwalled tube.

One of the approaches to taking parts out of ECP body is vertically down drop of the assembled
pump until it hits a hard and rigid barrier. The hit-generated forces of inertial affect each internal part of ECP and promote removal of GV and I from the body. However, the hitting frequency in this case is limited to not more than one hit per second. Furthermore, it is necessary to construct a high metal-intensive pole equipped with a pull winch and a drop mechanism, and to arrange the pole in a high enclosed space for operation in winter. This requires high capital inputs.

Instead of dropping ECP from height, an alternative, convenient and efficient method to remove I and GV is using a pneumatic hammer with adjustable impact effect at minimum blow frequency [12]. In this case, it is possible to operate a compression plant with minimal air flow rate at a level of 3 cubic meters per minute.

Mostly ECP have three outward diameters of the body: 92.5, 102 and 103.5 mm. Driving of pipes with diameter of 100 mm to a length to 40 mm should uses pneumatic hammer Typhoon-40 (Т-40) with piston weight of 40 kg and unit blow energy of 400 J. In horizontally oriented operation, Т-40 has blow frequency of 2.5–5.8 Hz at air flow rate of 3.6–6.5 m³/min. Experiments show that the lower boundary of stable operation of hammer Т-40 is 1.8–2.1 Hz at air flow rate of 2.6–3 m³/min.

Disassembling of ECP should be carried out on a special bench (Figure 5a) equipped with blow energy absorber, which simulates self-discharging of the pipe from the inner parts. This process is similar to soil plug removal from a driven pipe (Figure 5b) [13, 14].

![Figure 5. Bench for ECP disassembling (a) and soil plug removal (b).](image)

The full-scale tests of disassembling of electric centrifugal parts using a pneumatic hammer meant for driving steel pipes in soil proved high efficiency of the process and maximum preservation of parts when removed from the steel pump body under the action of shock pulses.

### 4. Unloading of railway cars

Unloading of caking materials from railway cars can be stimulated by vibropercussion machines (Figure 6) driven by air punch SO-134 [1, 3] produced by the Odessa Construction and Finishing Machine Manufacturer, with blow energy of 50 J and blow frequency of 4 Hz at compressed air flow rate more than 10 cubic meter per minute.

Replacement of the punch by air hammer Typhoon-70 with piston weight of 70 kg ensures an increase in the blow energy by 40% at the same blow frequency and the decreased air flow rate by 40%. By adjusting the impact effect [6] by means of reducing the blow frequency 2.5 times, the air hammer will only need a compression plant with capacity of 4 cubic meters per minute (2.5 times less) purchased at lower cost.
5. Compaction of soil

Compaction improves load-bearing capacity of soil and its resistance to water permeability [15]. Technologically, soil compaction can be implemented on ground surface and at a depth. On the ground surface, soil is compacted by multiple rolling of a manual or power roller. Compaction at a depth is carried out by means of driving of a closed-ended pipe in soil. The pipe can be pulled out and re-used. These operations can involve a pneumatic hammer. Before driving a subsequent pipe, the nearby pre-made hole is filled with soil.

Soil compaction is necessary in construction of foundations and roads. Compaction is executed through the assistance of a plate placed on the ground surface and having sufficient weight to reach the wanted compaction. Vibration in combination with rolling is an efficient way of compacting loose and granular soil [16].

The vibro-rolling compaction is performed using a heavy and thick vibro-plate WACKER NEUSON DPU 130 manufactured in Germany (Figure 7). The drive of this machine can be the impact pulse generator—a pneumatic hammer with adjustable impact effect.

Alongside with pipe driving in soil, pneumatic hammers are usable as impact pulse generators in many technologies requiring application of huge forces.
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