OperatIng CyCle of a Pneumatic borer

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At the Institute of Mining of the Siberian Branch, Academy of Sciences of the USSR, we have developed a self-propelled pneumatic percussive machine (pneumatic borer) designed for drilling boreholes in soil for trenchless laying of underground pipelines and cables. The main advantages of these machines are simplicity of construction, ease of servicing, high productivity, reliability, and long service life.

Figure 1 shows a schematic diagram of the pneumatic borer. The frame is made of two components, a casing and an anvil. The cavity inside the casing contains striker with front and rear guide rings. The front guide ring has grooves to permit the passage of air. Sleeve which is integral with tail nut is inserted into the tail of the striker. Nut has a window for discharge of spent air. Elastic valve which protects the internal cavity of the machine from obstructions but does not hinder exhaust of spent air is fastened to the tube. Compressed air is fed to the machine by means of rubber-and-fabric hose. The rear working chamber, formed by the walls of the striker and sleeve, is always connected to the air-supply hose via an axial channel in the sleeve. The front chamber is periodically connected to the rear chamber or to the atmosphere via a window in the sides of the striker, as the machine operates. Window is automatically opened and closed as the striker moves relative to the sleeve.

When the machine operates, the striker, under the influence of the compressed air, executes reciprocatory motion and strikes the frame. The blows drive the frame into the ground; reverse motion is prevented by friction between the frame and ground. As a result of compaction of the soil, a borehole is formed.

Reverse travel, i.e., return of the machine, is achieved by changing the position of the air-distribution sleeve relative to the frame. Axial movement of the sleeve to a given position can be effected by various means, e.g., by means of a pair of screws. In this case the sleeve is moved by rotating the hose. The extreme forward position of the sleeve corresponds to forward motion, and the extreme rear position (shown in Fig. 1 by dashes) to reverse motion. When the sleeve is in the reverse-travel position, the striker inflicts blows on tail nut and the pneumatic borer moves back along the previously-made borehole.

The air-distribution system adopted for the pneumatic borer has recommended itself in practice. It is simple to construct, ensures reliable operation and sure starting of the machine, and permits a simple method of reversing the direction of motion. It was used in the IP4603 production-model pneumatic borers. Below we give the results of a study of the operating cycle of the borer, including the features of its air-distribution system.

In studying the operating cycle of the borer we made the following simplifications. The movement of the frame due to a single blow is small in comparison with the stroke of the striker; no account is taken of the frictional forces between the striker and frame and between the striker and sleeve, as these are small; no account is taken of air leaks through the gaps between the striker and frame and the striker and sleeve; the air pressure in the rear working chamber, which is always connected to the air mains, is regarded as constant; the pressure in the discharge chamber is regarded as constant and equal to that of the atmosphere; discharge of compressed air into the front working chamber and discharge of spent air from the front chamber occur, respectively, when the striker is in its extreme forward and back positions; and the durations of the intake and exhaust processes are small in comparison with the duration of the operating cycle.

The greatest error is introduced by the last of these assumptions, the error being greater, the shorter the stroke of the striker is. To compensate for this and the other errors, it is convenient to introduce experimentally-determined coefficients.
On the above assumptions, the equation of motion of the striker is as follows:

$$\frac{dA}{dx} - p_1 s_1 + p_2 s_2 - mg \sin \theta = 0,$$

where $A$ is the kinetic energy of the striker, $x$ the displacement of the striker (the origin being taken at its extreme forward position), $m$ the mass of the striker, $g$ the acceleration due to gravity, $\theta$ the angle of inclination of the borer to the horizontal, $p_1$ and $p_2$ the excess air pressures in the front and rear working chambers, respectively, and $s_1$ and $s_2$ the effective areas of the striker on the front and rear chamber sides, respectively.

The pressure in the front working chamber can be found from a multistage equation. For the forward and reverse strokes we find, respectively,

$$p_1 + p_a (W_0 + s_1 x)^\gamma = p_a (W_0 + s_1 x_0)^\gamma;$$

$$ (p_1 + p_a) (W_0 + s_1 x)^\gamma = x (p_2 + p_a) W_0^\gamma,$$

where $W_0$ is the volume of the front chamber in the extreme forward position of the striker, $x_0$ is the total working stroke of the striker, $p_a$ is the atmospheric pressure, $\gamma$ is the stage index, and $x$ is the filling factor of the front chamber, found experimentally.

Let us write (1) and (2) in dimensionless form:

$$\frac{da}{dz} - p_1 + \gamma p_2 - G = 0;$$

$$(P_1 + 1) (1 + z)^\gamma = (1 + z_0)^\gamma;$$

$$ (P_1 + 1) (1 + z)^\gamma = x (P_2 + 1),$$

where

$$a = \frac{A}{p_\alpha w_0}; \quad z = \frac{s_1 x}{w_0}; \quad z_0 = \frac{s_1 x_0}{w_0}; \quad P_1 = \frac{p_1}{p_\alpha};$$

$$P_2 = \frac{p_2}{p_\alpha}; \quad \gamma = \frac{s_2}{s_1}; \quad G = \frac{mg}{p_\alpha s_1} \sin \theta.$$

Eliminating $P_1$ from (3), for the forward and reverse strokes of the striker we get, respectively,

$$\frac{da}{dz} + 1 + \gamma P_2 - G - \left(1 + \frac{z_0}{1 + z}\right)^\gamma = 0;$$

$$\frac{da}{dz} + 1 + \gamma P_2 - G - \frac{x(1 + P_2)}{(1 + z)^\gamma} = 0.$$

Integrating, we get the following equations:

for the forward stroke of the striker,

$$a = \int_{z_0}^{z} \left[ G - 1 - \gamma P_2 + \left(1 + \frac{z_0}{1 + z}\right)^\gamma \right] dz$$

$$= (1 + \gamma P_2 - G) (z_0 - z) + \frac{1 + z_0}{\gamma - 1} \left[ 1 - \left(1 + \frac{z - z_0}{1 + z_0}\right)^{1 - \gamma} \right];$$