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Compressive vacuum resistance to percussion hammer in downhole vibration source

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Abstract. The paper focuses on downhole vibration source used for wave generation in an oil stratum in order to increase oil recovery and stimulate hydrocarbon flow in a well. Simulation results of pre-shock compressive vacuum resistance to a hammer in an electromagnetic shock unit in a downhole vibration source are presented. The effect of axial hole in a hammer on induced compression is analyzed. Experimental data on changes in coil electromagnetic traction are presented depending on axial hole diameter in the hammer. Based on the effect of hammer hole diameter on compressive vacuum resistance and coil electromagnetic traction the present research findings can be of great use in designing an electromagnetic shock unit.

1. Introduction

The present-day problem of prime importance in the oil and gas industry concerns escalation of hydrocarbon production rates. The oil recovery factor for conventional oil and gas production technologies in Russia reaches 0.4, the essential portion of oil reserves remains in the interior of the Earth. The novel processes for oil recovery improvement (ORI) are in demand in order to involve the residual oil reserves into production. Since the 1970s the permanent research and pilot-full-scale tests on development of vibration-wave processes designed to improve oil recovery of wells have been advanced in Russia, the idea of the process rests on the application of the directed vibration-wave effect on the productive strata. The generated elastic oscillations cause variations in structure of macro- and micro-fractures in an oil reservoir and ways of repressuring medium percolation, thus involving the earlier intact oil reserves into active oil flow contour. Moreover, it is established appreciable acoustic wave influence on oil viscosity reduction, as well as suppressing capillary and adhesive forces hampering the displacement of hydrocarbons from porous structure of a stratum. At present the extensive many-years theoretical and experimental experience justifies the efficiency and promising perspectives of ORI wave process [1–5].

2. Numerical and experimental investigation results

At the Institute of Mining SB RAS the research and development work is conducted on investigation into a downhole electromagnetic impulse vibration source to generate the wave effect on oil reservoir for last three years. The research installation consists of electromagnetic reciprocating percussion motor and a hydraulic power unit, intended for transformation of axial hammer impacts into radial power impulses and their transmission to downhole production string.

In [6] the researchers prove the feasibility to design an electromagnetic drive based on long-stroke magnetic systems with ratio of magnetizing coil length to core radius of more than 15. Increase in this



ratio leads to increase in a stroke and hammer velocity; it seems the single way to higher impact energy in diametrically confined well space. However increase in motion velocity induces the compressive vacuum resistance because of air presence in hermetic volume. The laboratory tests of the pilot electromagnetic percussion unit at modes with/without sealed cases revealed that in operation with a one-piece hammer in a sealed case the compression generated under the bottom end of the hammer in a working stroke tends to reduce a hydraulic pressure impulse generated by a hammer impact in a power element by 15–20 % as compared to impulses generated in non-pressurized case. The similar test with a hammer with axial hole of 23 mm in diameter did not indicate the compression effect on pressure impulse in the power component. .

From above the necessity becomes obvious to establish interrelation between the axial channel diameter in the hammer and the magnitude of compression in a cavity under it, so the targets of the present research are:

- to study the effect of axial hole diameter in a hammer on compression induced under hammer in a working stroke;
- to determine the minimal diameter of hole in the hammer at which the stabilized pressure difference is reached between cavities under and over the hammer, when the hammer is moving at pre-impact velocity;
- to estimate the effect of axial hole in a hammer on electromagnetic coil thrust;
- to work out recommendations on designing an electromagnetic percussion unit with account for test results of the present research.

The virtual model describing the air pressure growth under the lower end at the final stage of the working stroke of the hammer was developed in software system SimulationX to study the effect of hole diameter in the hammer on compression. The computation scheme of the model is presented in Figure 1: hammer 1 of 14 kg in mass and 48 mm in external diameter, moving with a zero gap in guide 2; compression cavity 3, which volume is equal to a sum of volumes of air pockets of a real machine; pressure meter 4; pipe 5, connecting compression cavity 3 with cavity 6 over hammer. Pipe 5 has internal diameter equal to diameter of the hole in hammer and length equal to hammer length 1030 mm.

Assumptions made in the model are:

- under consideration is only pre-impact interval of hammer motion h_h , equal to 200 mm. Growth of compression in the initial hammer motion is not considered;
- by the moment when the hammer reaches the interval under consideration its pre-impact velocity v_h is 5 m/s. The hammer continues motion by inertia.

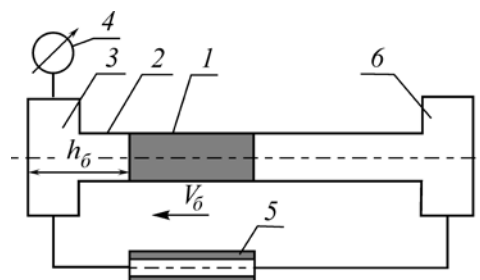


Figure 1. Calculation scheme to evaluate air resistance to hammer motion: 1—hammer; 2—guide; 3—compression capacity; 4—pressure meter; 5—pipe; 6—cavity over hammer.

In the numerical tests the internal diameter of pipe 5 was preset, the pressure growth in cavity 3 in the interval during which the hammer 1 advanced at distance h_h . Then the internal diameter of pipe 5 was increased stepwise with 4 mm stroke and the test was repeated. The initial diameter of the hole was preset at 4 mm and the cross-section is preset equivalent to a real gap in hammer–guide conjunction.

The oscillograms are obtained for different diameters of holes reduced to the same coordinate plane for illustration purposes (Figure 2a). Figure 2b demonstrates the relationship of the maximum pressure in the compression cavity versus hole diameter in a hammer.

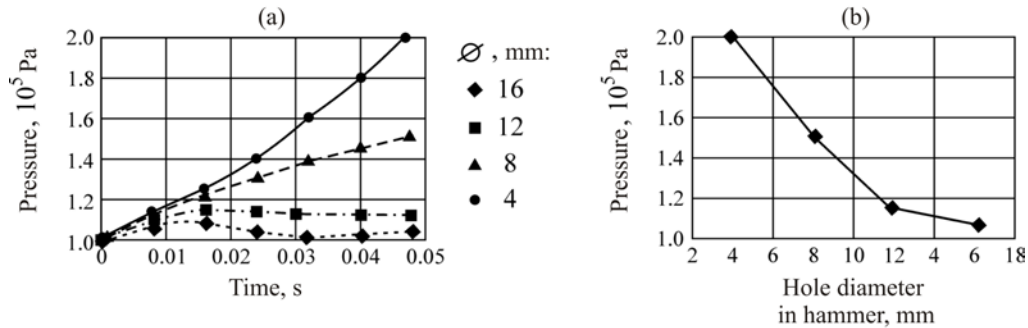


Figure 2. (a) Oscillograms for pressure in compression cavity and (b) dependence of the maximum pressure vs. hole diameter in the hammer.

By the analytical data on oscillograms the minimum 12 mm hole diameter in the hammer is sufficient to form a stable air flow from the compression cavity to a cavity over the hammer at constant difference in pressures. Thereto, difference in pressure is equal to $0.13\text{--}0.15 \cdot 10^5$ Pa, and the average resistance force is no more than 25.3 N.

Reduction in hole diameter (Figure 2b) leads to sharp growth of compression. In the case with one-piece hammer the average resistance at the calculation interval is 99 N. Furthermore, in the calculation interval it fails to gain the stable air flow under the constant pressure difference (oscillograms do not reach horizontal asymptote). This feature indicates that pressure will continue growing far to the beginning of the calculation interval during the entire working stroke of the hammer. Therefore, the model representation of these modes is not correct. Actual pressure values can be really higher than calculated ones.

Increase in hole diameter causes a cyclic air flow through it; this statement is proved by wave shape of pressure oscillogram. Thereupon, the time interval when difference in pressures between cavities is close to zero and accompanied with low or even zero air flow rate, thus indicating irrationality to make a hammer hole of more than 12 mm in diameter.

The hole diameter also affects the thrust of electromagnetic coil in addition to resistance acting on the hammer. This relationship relates to reduction in active cross-section of the anchor because of the hole [7].

The laboratory results of pilot electromagnetic hammer prototype tests give thrust characteristics of electromagnets operating with three hammer types: one-piece, with hole diameters of 13 and 22 mm. The thrust characteristics of the hammer having 48 mm external diameter at working current values of 20 A and 30 A are reported in Figure 3.

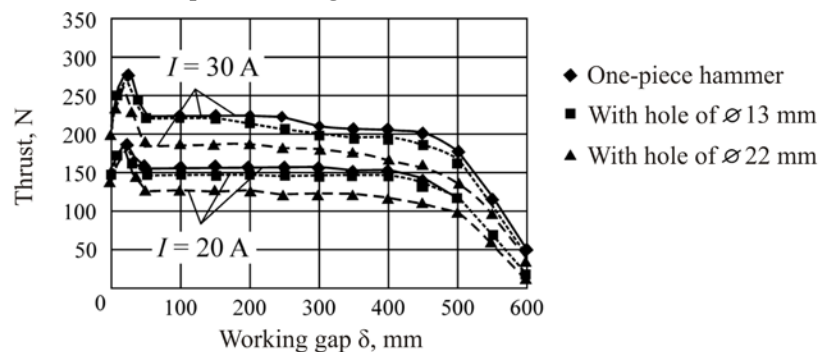


Figure 3. Experimental thrust characteristics of electromagnets in operation with different-type hammers.

By experimental data, the electromagnet thrust lowers with increase in hole diameter in the hammer. For hammer with 13 mm hole diameter the drop of the thrust amounts to no more than 3–6% in the complete working gap as compared to that for a one-piece hammer. This proves insufficient effect on the impact energy as compared to the compression resistance, when one-piece hammer is moving.

3. Conclusions

SimulationX modeling of hammer motion at pre-impact time moment was used to study the influence of axial hole diameter in a hammer on compression, generated below the hammer being in the working stroke.

It is established that the presence of 12 mm axial hole in hammer with 48 mm external diameter at 5 m/s motion velocity induces the formation of the stable air flow from the cavity under the hammer to the cavity over the hammer. In this case the pressure difference does not exceed $15 \cdot 10^5$ Pa, and head resistance is 25.3 N.

The electromagnet thrust in operation with hammer of 48 mm external diameter and 12 mm axial hole diameter is by 3–6% lower than that for a one-piece hammer. Such reduction in thrust is admissible with account for multiple reduction in compression in the cavity under the hammer.

When designing the percussion unit, it is recommended:

- to reduce volume of compression cavity;
- to provide overflow air chute between cavities over and under the hammer as a hole in the hammer of 12 mm in diameter or as specially made cuts on surface of coils; the cross-section area of a cut should be equivalent to cross-section area of the hole.

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