



The study of hydraulic hammer device in drilling tool assembly in hydraulical rotary drilling

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Abstract

The article presents the study of a hydraulic hammer device for rotary well drilling. The mathematical model of the hydraulic hammer device has been described and studied, the relation of the dynamic load changes on the rock-destruction tool from the principal parameters of the hydraulic hammer device have been obtained. The trial rotary boring with the use of a hydraulic hammer device in drill tool assembly has been carried out, an increase in the drilling penetration rate has been achieved by 47%.

Keywords: Hydraulic Hammer Device, Hydraulical Rotary Drilling, Drill Tool Assembly, Piston, Near-Bit Hydraulic Hammer.

1. Introduction

The increase in the drilling penetration rate of deep wells at the present stage of the well construction development is realized by placing the equipment, generating additional impulse force actions at the bottom of the drilling tool assembly [1-4]. Optimization of parameters of such devices boosts the quality of the well construction and drilling performance [5-7]. For this purpose the mathematical model of hydraulic hammer device has been developed (Figure 1).

2. Material and Methods

In order to reveal the basic parameters of the hydraulic hammer device, taking into account their optimal values and to assess their impact on the performance of the entire drilling tool, it is necessary to develop a mathematical model of hydraulic hammer device, which reflects the performance of the drilling tool elements individually. In the development of the mathematical model of drilling string assembly with the hydraulic hammer device, set over the rock-destruction tool (Fig. 1), the following arrangements are introduced:

- drill string is considered as a homogeneous rod;
- piston of the near-bit hydraulic hammer hitched to the bit is considered as a discrete mass;
- hydraulic hammer body hitched to the drilling string is also considered as a discrete mass;
- drill string is considered as infinitely long, i.e. the resonance phenomena in the column are not considered;
- contacting of the bit with the bottom-hole is considered viscoelastic.

The greatest effect of the near-bit hydraulic hammer, along with the drilling tool, is achieved when creating the maximum impact on the bit during well drilling.

The axial vibration of the drill string is expressed in the differential equation [3, 4]:

$$\frac{\partial^2 U}{\partial t^2} + 2\nu \frac{\partial U}{\partial t} - a^2 \frac{\partial^2 U}{\partial x^2} = 0, \quad (1)$$

where U is the cross section deviation of the drill string comparative to the position of static equilibrium;

v - resistivity factor;

a - velocity of sound wave in the material of drill pipes;

t - time interval; x is the level of the design cross-section.

The axial float equation of the piston represents the dependence:

$$M \frac{\partial^2 Y}{\partial t^2} = -C_2 Y - \mu_2 \frac{\partial Y}{\partial t} + C_1 (Z - Y) + \mu_1 \left(\frac{\partial Z}{\partial t} - \frac{\partial Y}{\partial t} \right) - C_3 (Y - U|_{x=0}) - \mu_3 \left(\frac{\partial Y}{\partial t} - \frac{\partial U}{\partial t} \Big|_{x=0} \right), \quad (2)$$

where C1, C2, C3 - spring stiffness, bottom-hole rigidity, disconnector stiffness respectively;

μ1, μ2, μ3 is the viscous resistance coefficient of the spring, of the bottom-hole, of the disconnector respectively;

M - mass of drilling tool elements, perceived by the impact interaction;

Y - level of element position, perceiving the shock action;

U is the level of the drill string position.

The axial hydropercussion unit displacement represents the following dependence:

$$m \frac{\partial^2 Z}{\partial t^2} = P \sin(\omega t) - C_1 (Z - Y) - \mu_1 \left(\frac{\partial Z}{\partial t} - \frac{\partial Y}{\partial t} \right), \quad (3)$$

where Z is the level of the coordinate position of the hydropercussion unit;

m - mass of the hydropercussion unit;

P - amplitude of hydraulic action;

ω is the circular frequency in hydraulic action change,

$$\omega = 2\pi f; \tag{4}$$

where f is the frequency of the hydraulic hammer device
The boundary conditions for the drill string are selected:

a) displacement of the drill string lower section is represented by the expression

$$EF \frac{\partial U}{\partial x} \Big|_{x=0} = -C_3(Y - U|_{x=0}) - \mu_3 \left(\frac{\partial Y}{\partial t} - \frac{\partial U}{\partial t} \Big|_{x=0} \right), \tag{5}$$

where E is the drill material modulus of elasticity;

F - cross-sectional area of drill pipes;

b) oscillations of the pipe string are damped at infinity, the drill string is considered to be infinitely long

$$U|_{x \rightarrow \infty} = 0. \tag{6}$$

The axial oscillating motion of the drill tool together with the hydraulic hammer device in the final form is expressed by the following differential equation system:

$$\begin{aligned} \frac{\partial^2 U}{\partial t^2} + 2v \frac{\partial U}{\partial t} - a^2 \frac{\partial^2 U}{\partial x^2} &= 0; \\ m \frac{\partial^2 Z}{\partial t^2} &= P \sin(\omega t) - C_1(Z - Y) - \mu_1 \left(\frac{\partial Z}{\partial t} - \frac{\partial Y}{\partial t} \right); \\ M \frac{\partial^2 Y}{\partial t^2} &= -C_2 Y - \mu_2 \frac{\partial Y}{\partial t} + C_1(Z - Y) + \mu_1 \left(\frac{\partial Z}{\partial t} - \frac{\partial Y}{\partial t} \right) - \\ &- C_3(Y - U|_{x=0}) - \mu_3 \left(\frac{\partial Y}{\partial t} - \frac{\partial U}{\partial t} \Big|_{x=0} \right); \\ EF \frac{\partial U}{\partial x} \Big|_{x=0} &= -C_3(Y - U|_{x=0}) - \mu_3 \left(\frac{\partial Y}{\partial t} - \frac{\partial U}{\partial t} \Big|_{x=0} \right); \end{aligned} \tag{7}$$

$$U|_{x \rightarrow \infty} = 0.$$

To simplify the solution of the question, the perturbing hydraulic power $P \cdot \sin(\omega \cdot t)$ is substituted for $P \cdot e^{i\omega t}$.

In view of the fact that this system of equations is linear, its solution can be represented in the following form:

$$\begin{aligned} U &= X e^{i\omega t}; \\ Y &= C e^{i\omega t}; \\ Z &= D e^{i\omega t}. \end{aligned} \tag{8}$$

In solving these equations, we obtain the following result:

The formula for determining the dynamic face output is found in the following way:

$$F_{\text{д}} = (C_2 + \mu_2 i \omega) \frac{P R_1 a}{c(ab - R_3^2) - R_1^2 a}, \tag{9}$$

where $a = (R_3 - EFk)$;

$b = R_1 + R_2 + R_3 - M\omega^2$;

$c = R_1 - m\omega^2$;

$$R1=C1+\mu1 i\omega ; R2=C2+\mu2 i\omega ; R3=C3+\mu3 i\omega .$$

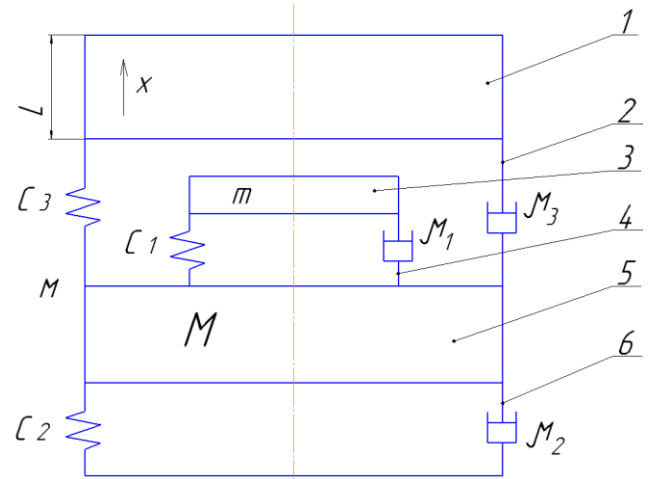


Fig. 1: Chart of a drilling tool with a hydraulic hammer device: 1 - drill string; 2 - disconnector; 3 - hydropercussion unit with valve unit; 4 - spring; 5 - drilling tool elements, perceiving impact interaction; 6 - bore-hole bottom; L is the drill string length

In drill tool performance, it is also important to determine the force action transmitted by the near-bit hydraulic hammer to the drill string, which is determined by the following expression:

$$P_{kol} = B \cdot k \cdot E \cdot F$$

$$\text{where } B = \frac{P R_1 R_2}{c(ab - R_3^2) - R_1^2 a}. \tag{10}$$

3. Results and discussions

The force action of the hydraulic hammer device on the drill string depends much on the cross-sectional stiffness of drill strings.

The efficient operation of a drill tool with a hydraulic hammer device is implemented when creating maximum dynamic loads on the well bore [7].

The analytical study of the mathematical model showed the following results. The dynamic load on the rock-destruction tool increases from 10600 to 20700 N at a mud flow rate of 0.015 m³ / s, when spring force increases from 10,000 to 100,000 N / m (Fig. 2). When spring stiffness is 30000 N/m, when circulation rate increases from 0,005 to 0,018 m³ the dynamic load on the rock-destruction tool increases from 8200 to 11200 N (Fig. 3). When the weight of the hydropercussion unit increases from 6 to 10 kg, the dynamic load on the rock-destruction tool increases from 21700 to 22800 N, and when the weight of the hydropercussion unit is increased from 10 to 20 kg, the dynamic load on the bit decreases from 22,800 to 16,200 N (Fig. 4).

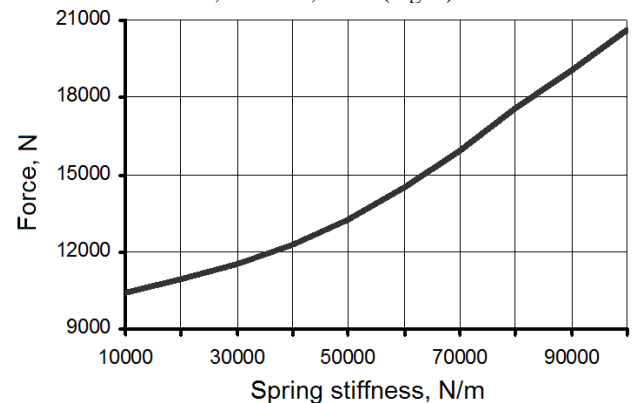


Fig. 2: The graphical chart of the face output dependence on the spring stiffness

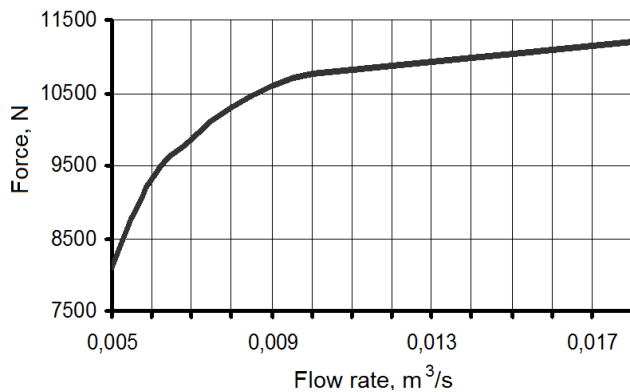


Fig. 3: The graphical chart of the dynamic bottom-hole load dependence on the flow rate

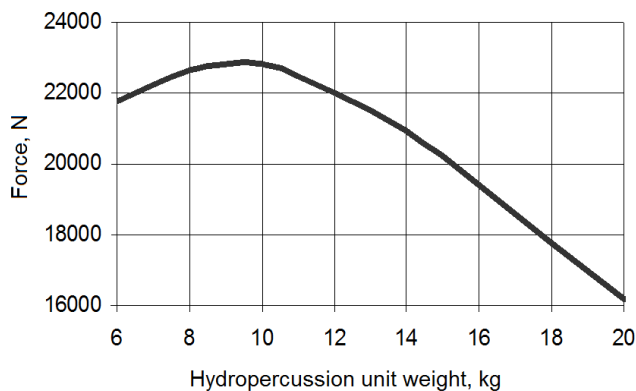


Figure 4: The graphical chart of the dynamic bottom-hole load dependence on the hydropercussion unit weight

A test specimen of the hydraulic hammer device was designed. Well drilling was performed on Tuymazinskaya area of the category 2, No. 1900 «C» with the use of a hydraulic hammer device. During the performance, the influence of the hydraulic hammer device on the boring, on the bit and the drilling penetration rate were studied. The drilling rig A- 60/80 is equipped with positive piston-type mud pump 375. During the hole drilling, the following parameters were monitored: mud circulation rate, drilling penetration rate, drilling weight, stand pipe pressure. The axial drilling weight was maintained in the range of 35 ... 45 kN, the drilling mud density was 1250 kg / m³, the stand pipe pressure from 6 ... 8 MPa, the fluid loss 8.5 cm³ in 30 minutes. The drilling mud delivery was 0.012 ... 0.013 m³/s. A rotary drilling was used with drill string rotation at rotational speed of 80 rpm using the rotary table of make P400/80. The drilling tool had the following assembly: the bit 123.8 EHP53AK, the stabilizer KL123, the vibrator, DC-108 mm in length of 24 m, the rest - HWDP-73 mm. The hole drilling was carried out on the Kynovskiy horizon, represented by hard formations, with an average drilling rate of 1.28 m/h. The drilling has shown the effectiveness of the use of hydraulic hammer device of this design, which was confirmed by drilling results. The hydraulic hammer device has shown reliability and efficiency during the side hole drilling. The speed of mechanical drilling at the well No. 1900 is 25.5% higher in comparison with the wells drilled with similar characteristics.

The side hole drilling of category 2 No. 1314 «C» on Tuymazinskaya area was carried out. A rotary drilling was used. The influence of the hydraulic hammer device on the speed of mechanical drilling was studied, drilling parameter checkout was exercised: mud circulation rate, stand pipe pressure, drilling weight, speed of mechanical drilling.

The combination of the drilling tool assembly is as follows: bit 142.93TK-ZOD, hydraulic hammer device, drill-collar string-108

mm, its length is 28 m, HWDP-73 mm. Drill string rotation was carried out with a rotor of the make P400 / 80 with a frequency of 68 rpm. Drilling was carried out with a drilling rig A-60/80, equipped with one positive piston-type mud pump-375. The diameter of the pump liner is 90 mm, the standpipe pressure is 9.0 MPa. The pressure on the bit was maintained at 55 kN, the mud flow rate was 0.009 ... 0.011 m³/s. The curvature of the horizontal rat hole is 29.9°. Mud properties: viscosity 55 s, density 1.21 kg / m³, filtration 3 cm³/ min. The cutting was carried out while tapping the Domanikovyi horizon, consisted from solid rock formations. The average penetration rate was 0.993 m / h.

4. Conclusion

The speed of mechanical drilling with the use of a hydraulic hammer device is 47% higher than the drilling of wells with similar parameters. The hydraulic hammer device has shown reliability and operability in side hole drilling.

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