Anvilless hydraulic hammer with double-sided drive and increased lower ram mass

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Summary. The presented work determines dependencies for calculating values of ram motion when square of hydraulic unit plungers are proportional to masses of the rams. It is demonstrated that when equal forces are applied to the rams by the drive during direct idle stroke, the rams have equal momentum at any given time, which ensures minimum level of vibrations for the hammer.
Key words: hydraulic hammer, pressure, force, speed, acceleration.

INRODUCTION

Anvilless hammers constitute a part of the most powerful equipment used in die forging production. The main disadvantage of hammers with hydraulic connection of ram drive is the harmonic component present in the equations describing ram motion.

ANALYSIS OF PUBLICATIONS

Reference books on press-forging equipment [1, 6, 19, 20] consider anvilless vertical hammers with pneumatic drive and hydraulic connection between equal mass rams in terms of their functional action and impact energy; motion equations are not cited. Recently technical literature has started to include information on technical solutions for hammers with underhead [6] and overhead [7] drive, motion equations for overhead and underhead rams are presented in the works [13, 14]. According to researchers and specialists of forging workshops opinion no-anvil hammers are better than anvil hammers because of low vibration activity. This information can be found in [7, 10, 12], but the estimate of vibratory activity no-anvil vertical hammers was not made by experts until recently. Technical solutions for vertical no-anvil hydraulic hammers with one-way drive appeared recently , [2, 4, 5, 11, 18]. Kinematic analysis of the hammer head of this hammers is made in references [2, 9, 15, 17] it shows that in hydraulic anvilless hammers with single-side drive parabolic equations for motions of rams include harmonic components with cosine function. This results in fluctuating increase of the hydraulic pressure in the hydraulic reservoir in overdrive hammers and decrease of hydraulic pressure in underdrive hammers. These harmonic components of velocities which are out of phase lead to uncertainty of cooperative ram motion in the final stage of the load phase. Pressure ripple of aqua in hydraulic tank, as it's shown in [8], this leads to the excitation of vibrations in hydraulic unit of hammer heads. The pressure fluctuations are transmitted foundation hammer and a source of seismic tremors.

OBJECT AND TASKS OF RESEARCH

To formulate the ram motion equation for double-sided drive hammers with increased lower ram mass, to calculate conditions on which harmonic component is absent in motions and velocities of the rams in a double-sided drive hammer fig1.

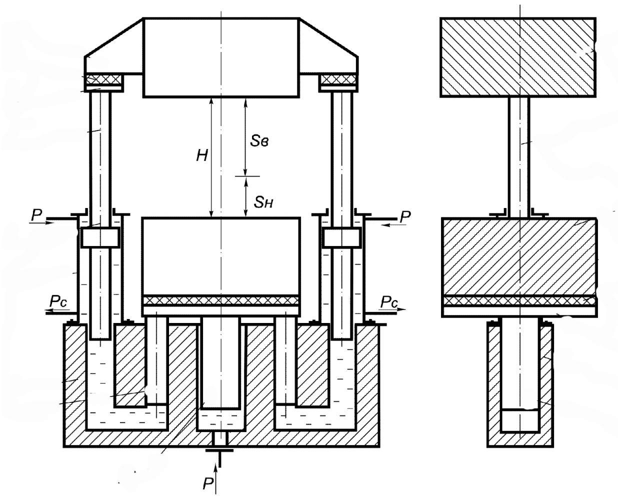

Fig. 1. Vertical hydraulic hammer with double-sided drive

MAIN PART WITH RESULT AND ANALYSYS

With increased lower ram mass, the plunger areas of the hydraulic connection unit are calculated according to the following dependence:

Total area of two side plungers:

$$S_1 = \frac{m_1 g}{p_{ст}}, \quad (1)$$

area of lower plunger

$$S_2 = \frac{m_2 g}{p_{ст}}, \quad (2)$$

where: m_1, m_2 - masses of upper and lower rams,

g - gravitational acceleration,

$p_{ст}$ - hydraulic pressure in the hydraulic reservoir with fixed rams.

The rigidity of hydraulic unit plungers of under the the liquid is calculated with the following dependence:

$$C_{в} = \frac{S^2{}_1 \cdot E}{V}, \; C_{н} = \frac{S^2{}_2 \cdot E}{V}, \quad (3)$$

where: $C_{в}$, $C_{н}$ - the rigidity of hydraulic under side and lower dampers,

S_1, S_2 - total area of side plungers of the upper ram and area of plunger of the lower ram, correspondingly,

E - coefficient of elasticity of the liquid in hydraulic reservoir,

V - the volume of liquid in hydraulic reservoir.

Reduced rigidity of the ram stroke hydraulic connection unit can be derived from the following dependence:

$$K_1 = \frac{C_1 \cdot C_{в} \cdot C_2 \cdot \frac{s_1}{s_2}}{C_1 \cdot C_{в} + C_{в} \cdot C_2 \cdot \frac{s_1}{s_2} + C_1 \cdot C_2 \cdot \frac{s_1}{s_2}},$$
$$K_2 = \frac{C_1 \cdot C_{н} \cdot C_2 \cdot \frac{s_2}{s_1}}{C_1 \cdot C_{н} \cdot \frac{s_2}{s_1} + C_{н} \cdot C_2 + C_1 \cdot C_{н} \cdot \frac{s_2}{s_1}}, \quad (4)$$

where: K_1 - upper ram support rigidity,

K_2 - lower ram support rigidity,

C_1, C_2 - rigidity of dampers of upper and lower rams.

Taking into account the jet continuity the motion equation for ram stroke can take the following form:

$$m_1 x_1'' + k_1 \cdot \left(x_1 - x_2 \cdot \frac{s_2}{s_1} \right) = F_1 \cdot \eta(t),$$
$$m_2 x_2'' + k_2 \cdot \left(x_2 - x_1 \cdot \frac{s_1}{s_2} \right) = F_2 \cdot \eta(t), \quad (5)$$

where: F_1, F_2 - upper and lower ram drive force;

$\eta(t)$ - Heavyside step function:

$$\eta(t) = \begin{cases} 1, t \geq 0, \\ 0, t < 0. \end{cases} \quad (6)$$

Transformation of this equation (6) into image space [Korn 1984] results in the following [3]:

$$X_1 \cdot \left(m_1 p^2 + k_1\right) - X_2 \cdot k_1 \cdot \frac{s_2}{s_1} = F_1 \cdot \frac{1}{p},$$
$$-X_1 \cdot k_2 \cdot \frac{s_1}{s_2} + X_2 \cdot \left(m_2 p^2 + k_2\right) = F_2 \cdot \frac{1}{p}. \quad (7)$$

Having solved the equation (7) in reference to X_1 and X_2 we receive the following values:

$$X_1 = \frac{\frac{F_1}{p}\left(m_2 \cdot p^2 + k_2\right) + \frac{F_2}{p} \cdot k_1 \cdot \frac{s_2}{s_1}}{m_1 \cdot m_2 \cdot p^2 + k_1 \cdot m_2 \cdot p^2 + k_2 \cdot m_1 \cdot p^2},$$
$$X_2 = \frac{\frac{F_1}{p} \cdot k_2 \cdot \frac{s_1}{s_2} + \frac{F_2}{p}\left(m_1 \cdot p^2 + k_1\right)}{m_1 \cdot m_2 \cdot p^2 + k_1 \cdot m_2 \cdot p^2 + k_2 \cdot m_1 \cdot p^2}. \quad (8)$$

Transforming the equation (8) into original function space allows us to receive ram stroke motion equation with a time variable.

$$X_1 = \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1} \cdot \frac{t^2}{2} + \\ + \frac{F_1 \cdot k_1 \cdot m_2^2 \cdot s_1 - F_2 \cdot k_1 \cdot m_2 \cdot m_1 \cdot s_2}{(k_1 \cdot m_2 + k_2 \cdot m_1)^2} \cdot (1 - \cos(\omega t)),$$

$$X_2 = \frac{s_1}{s_2} \cdot \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1} \cdot \frac{t^2}{2} + \\ + \frac{F_2 \cdot k_2 \cdot m_1^2 \cdot s_2 - F_1 \cdot k_2 \cdot m_2 \cdot m_1 \cdot s_1}{(k_1 \cdot m_2 + k_2 \cdot m_1)^2} \cdot (1 - \cos(\omega t)). \tag{9}$$

The harmonic component in the ram motion equations (9) will be absent when that $1 - \cos(\omega t)$ coefficients will be equal zero, i.e.:

$$\begin{cases} \dfrac{F_1 \cdot k_1 \cdot m_2^2 \cdot s_1 - F_2 \cdot k_1 \cdot m_2 \cdot m_1 \cdot s_2}{(k_1 \cdot m_2 + k_2 \cdot m_1)^2} = 0, \\ \dfrac{F_2 \cdot k_2 \cdot m_1^2 \cdot s_2 - F_1 \cdot k_2 \cdot m_2 \cdot m_1 \cdot s_1}{(k_1 \cdot m_2 + k_2 \cdot m_1)^2} = 0. \end{cases} \tag{10}$$

Simple mathematical transformations allow us to arrive at the following correlation:

$$\frac{F_1}{F_2} = \frac{m_1 \cdot s_2}{m_2 \cdot s_1}. \tag{11}$$

Juxtaposing (1) with (2) we see that $\frac{m_1}{s_1} = \frac{m_2}{s_2}$, taking into account values from (10) results $F_1 = F_2 = F$. This means that applying equal forces to the rams gives the rams equal momentum at any given movement time

$$F \cdot t = m_1 \cdot v_1 = m_2 \cdot v_2, \tag{12}$$

which ensures that the rams stop at impact regardless of their initial position and the height of forging.

With a double-sided drive and application of equal forces to the rams, the ram motion equation is the following:

$$X_1 = \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1} \cdot \frac{t^2}{2},$$

$$X_2 = \frac{s_1}{s_2} \cdot \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1} \cdot \frac{t^2}{2}. \tag{13}$$

Differentiating (13) by time the equation is derived to determine ram velocity:

$$X'_1 = \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1} \cdot t,$$

$$X'_2 = \frac{s_1}{s_2} \cdot \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1} \cdot t. \tag{14}$$

Differentiating (14) the equation is derived to determine ram acceleration

$$X''_1 = \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1},$$

$$X''_2 = \frac{s_1}{s_2} \cdot \frac{F_1 \cdot k_2 + F_2 \cdot k_1 \cdot \frac{s_2}{s_1}}{k_1 \cdot m_2 + k_2 \cdot m_1}. \tag{15}$$

Let us calculate several parameters of the hammer with the following entry conditions: upper ram mass m_1=20t, lower ram mass m_2 = 40t, coefficient of elasticity of the liquid E=2x10^9Pa. Because the upper ram moves downward (one stroke) in free fall mode, its maximum acceleration can not exceed 9,8 m/s^2; we take $j_в$ = 0,9g = 8,8 m/s^2. The rigidity of side and central dampers C_1 = C_2 = $3 \cdot 10^5$ N/m, upper ram stroke is 1.6m, lower ram stroke 0.8m, volume of hydraulic reservoir 1,0m^3.

Using the dependences stated above we can calculate the following values: rigidity of liquid support under side dampers C_d = $3 \cdot 10^5$ N/m, under lower damper damper C_u = $12 \cdot 10^5$ N/m. Reduced rigidity of hydraulic connection unit for upper ram K_1 = $1{,}2 \cdot 10^5$ N/m, for lower ram K_2 = $1{,}7 \cdot 10^5$ N/m. K_1 and K_2 substitution in (15) $X''_1 = 8{,}8 \mathrm{m/s^2}$ gives the force applied to each of the rams as F=176kN, idle stroke time t=0,6s, upper ram velocity on impact $X'_1 = 5{,}28 \mathrm{m/s}$, lower ram $X'_2 = 2{,}64 \mathrm{m/s}$. Impact energy is 418kJ, which corresponds to the impact energy generated by an anvil hammer with the mass of drop parts of approximately 25t and the mass of anvil not less than 500t. The total mass of impacting parts of an anvil hammer is not less than 525t, while the mass of these parts of a non-anvil hammer generating equal amount of energy is 60t. Moreover, the anvilless hammer does not generate post-impact vibrations unlike anvil hammers.

CONCLUSIONS

1. The article presents dependences for calculating ram motion values for a non-anvil hammer with increased lower ram mass, where areas of hydraulic unit plungers are proportional to ram masses.

2. It shows that when the drive applies equal forces to the rams at direct idle stroke, the rams have equal momentum at any given time of the stroke, the rams stop at impact, the hammer has minimum vibration activity.

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БЕСШАБОТНЫЙ ГИДРАВЛИЧЕСКИЙ МОЛОТ С ДВУСТОРОННИМ ПРИВОДОМ И УВЕЛИЧЕННОЙ МАССОЙ НИЖНЕЙ БАБЫ

Антон Рей, Юрий Гутько

Аннотация. В представленной работе определены зависимости для подсчета значения перемещения баб когда площади плунжеров пропорциональны массам баб. Показано что при приложении равных сил к бабам со стороны привода во время прямого холостого хода бабы будут иметь одинаковое количество движения в любой момент времени, что обеспечивает минимальный уровень виброактивности молота.

Ключевые слова: гидравлический молот, давление, сила, скорость, ускорение.