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Parameters of Motion for Hydraulic Vertical No-Anvil Hammers

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Abstract
an analytical solution for equations of motion for the head of no - anvil hydraulic hammer is achieved , dependence for determination the maximum value of force acting on the hammer head from the site of actuator is determined.

Theory
No-anvil hydraulic hammers are widely used in industry for forging the largest parts weighing up to 3000 kg, up to 4 meters length. Hammers with pneumatic actuators [1] have a complicated structure of their upper head parts, which reduces their durability. Idling the head within impact occurs by increasing the pressure of the liquid in the tank of hydro - connections, which reduces its efficiency.

In the Technical decision [2] the actuator is hydraulic type, and the motion of the hammer head during impact results in a reduction of fluid pressure in the hydraulic tank, to prevent this reduction to a level below the static value, that is fraught by formation of vacuum in the hydraulic tank site of hydro connections, by suction of atmospheric air, here it is necessary that the displacement of head not exceeded the allowable deformation of the head parts. A Schematic illustration of no-anvil vertical hydraulic hammer [2] is shown in Figure 1.

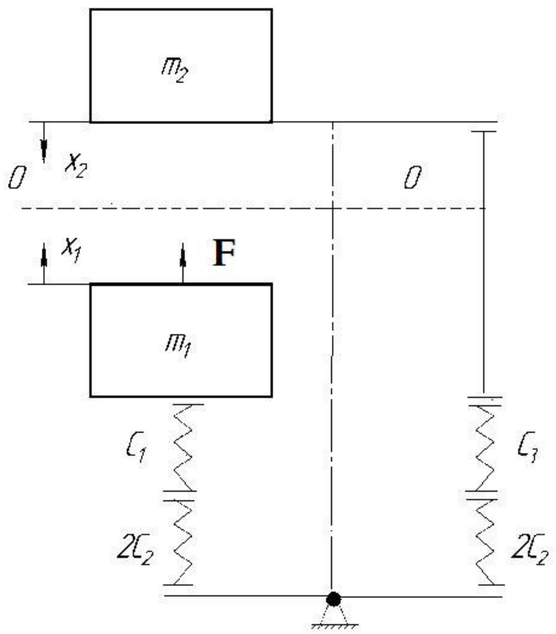

Fig.1. Schematic illustration of the mobile system of the hammer:
m2, m1 - masses of upper and lower heads; F - constant force exerted by the actuator, c1, c2, c3 - respectively, the rigidity of the upper shock absorbers, and shock absorbers of lower head.

Analysis:
Equivalent stiffness of the upper and lower connections is determined by the equation:

$$K = \frac{c_1 \cdot c_2 \cdot c_3}{c_1 \cdot c_2 + c_2 \cdot c_3 + c_3 \cdot c_1} \quad (1)$$

Equations of motion for the system have the form:

$$m_1 x_1'' + kx_1 - kx_2 = F\eta(t)$$

$$-kx_1 + m_2 x_2'' + kx_2 = 0 \quad (2)$$

Where: $\eta(t)$ -is the unit Heaviside function,

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

The initial displacement and velocity of the masses equal zero, transforming the equations of motion of the system (2) by Laplace transform [3] we obtain:

$$\left(m_1 s^2+k\right)X_1(s)-kX_2(s)=\frac{F}{s}$$

$$-kX_1(s)+\left(m_2 s^2+k\right)X_2(s)=0$$

Reactions $X_1(s)$ and $X_2(s)$ can be determined using crammers' rule:.

$$X_1(s)=\frac{\begin{vmatrix}\frac{F}{s} & -k\\ 0 & m_2 s^2+k\end{vmatrix}}{\Delta s}=\frac{F\left(m_2 s^2+k\right)}{s\Delta(s)},$$

(3)

$$X_2(s)=\frac{\begin{vmatrix}m_1 s^2+k & \frac{F}{s}\\ -k & 0\end{vmatrix}}{\Delta(s)}=\frac{kF}{s\Delta(s)},$$

Where:

$$\Delta(s)=\begin{vmatrix}m_1 s^2+k & -k\\ -k & m_2 s^2+k\end{vmatrix}=m_1 m_2\left[s^2+\omega^2\right]s^2$$

Here ω - is natural frequency of the system.

$$\omega=\sqrt{\frac{k(m_1+m_2)}{(m_1 m_2)}}$$

By substituting $\Delta(s)$ in equations of reactions (3) and providing simple algebraic manipulations, we obtain:

$$X_1(s)=\frac{F}{m_1+m_2}\left(\frac{1}{s^3}+\frac{m_2}{m_1}\cdot\frac{1}{s\left(s^2+\omega^2\right)}\right),$$

$$X_2(s)=\frac{F}{m_1+m_2}\left(\frac{1}{s^3}-\frac{1}{s\left(s^2+\omega^2\right)}\right) \qquad (4)$$

Inverse Laplace transform allows obtaining the system reactions as a function of time:

$$X_1=\frac{F}{m_1+m_2}\left[\frac{t^2}{2}+\frac{m_2}{m_1\omega^2}(1-\cos\ \ t)\right] \qquad \omega$$

(5)

$$X_2=\frac{F}{m_1+m_2}\left[\frac{t^2}{2}-\frac{1}{\omega^2}(1-\cos\omega t)\right]$$

To prevent formation of vacuum in the hydraulic tank of head hydro-connections site, the length of the stroke must not exceed the static deformation of the equivalent stiffness of the upper and lower connections (1).

$$x_1 - x_2 < \Delta l_{st} \tag{6}$$

By substituting (5) in (6) we obtain:

$$x_1 - x_2 = \frac{F}{\omega^2 (m_1 + m_2)} \left[\left(\frac{m_2}{m_1} + 1 \right) (1 - \cos \omega t) \right] < \Delta l_{st} \tag{7}$$

To determine the maximum difference of the stroke between upper and lower heads we equate to zero the first derivative

$$(x_1 - x_2)' = \frac{F}{\omega (m_1 + m_2)} \left(\frac{m_2}{m_1} + 1 \right) \sin \omega t = 0 \tag{8}$$

Solution of equation (8) is achieved when, n = 1, 2, 3 ... the maximum value of $(x_1 - x_2)$ by (7) corresponds to the condition of $\omega t = \pi + 2\pi n$ and after substituting the values of ωt (by solving (8)) in equation (7) and rearranging all we obtain:

$$(x_1 - x_2)_{\max} = \frac{2F}{\omega^2 m_1} < \Delta l_{st} \tag{9}$$

From (9) we find the maximum value of force acting on the lower head from the actuator site.

$$F < \Delta l_{st} \frac{m_1 \omega^2}{2} \tag{10}$$

In the known constructions to ensure a stable position of lower head in the lowermost position, its mass is taken as 5 ... 10% more than the mass of the upper head, the static deformation of the connection of the upper and lower heads is defined as:

$$\Delta l_{st} = \frac{m_2 g}{k} \tag{11}$$

by substituting (11) in (10) and rearranging we obtain the maximum value of force acting on the lower head from the site of actuator.

$$F < g \frac{m_1 + m_2}{2} \tag{12}$$

If to determine the equivalent stiffness by equation (1), the stiffness of the central and side dampers c1 and c3 depends on their design. Stiffness associated with the rigidity of the liquid located in the hydraulic tank, is defined as:

$$c_2 = \frac{EA}{V} \tag{13}$$

Where:
E - Modulus of elasticity of the liquid;
A - The total area of side plungers of the head, which can be determined by the relation:

$$A = \frac{m_2 g}{P_{st}} \tag{14}$$

P_{st} - Pressure of fluid in the hydraulic tank with fixed broads (static pressure);

V - Volume of liquid located in the hydraulic tank.

For no- anvil hydraulic hammer with m1 = $1{,}1\bullet10^5$ kg, m2 = 10^5 kg, the maximum force developed by the actuator is F = 1.03 Mn, if to consider that the acceleration of the head will be increased proportional to the force exerted by the actuator, with neglecting of friction forces acting on the seals of the plungers and guides of the upper and lower heads, the maximum calculated force can be taken as the basis for determining the parameters of the hammer actuator.

Conclusions

1. An analytical solution of the equations of motion for the mechanical system of no anvil hydraulic hammer, and the equations of motion of the hammer head are achieved.
2. An analytic relationship (formula) to determine the maximum allowable load acting on the hammer head in the direct no-load (idle) stroke, which ensures prevention of vacuum formation in the hydraulic tank connections, for the upper and lower hammer heads is achieved.

Literature

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