SELECTION OF PARAMETERS FOR A PNEUMATIC IMPACT MECHANISM WITH VALVE AIR DISTRIBUTION

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By parameters of the pneumatic impact mechanism (PIM) with a valve air distribution device we understand the volumes of the working chambers, and the area and reducing length of the striker.

The reduced length of the striker is the distance between the cut-off edges of the striker represented by a straight cylinder coinciding with the flat ends of the cylinder, and weight of the striker is not governed by cylinder geometry.

Presented in Fig. 1a is a diagram of the pneumatic impact mechanism used for analyzing the operating processes: a cylinder 1 with radial holes separating the volume of the cylinder into the power stroke and idling chambers, and an axial hole for introducing the working tool 3; the longitudinal dimensions of the radial holes compared with the chamber dimensions and also the transverse size of the axial hole compared with the longitudinal dimensions will be ignored for simplicity. Within the cylinder there is a striker piston 2 periodically applying impacts to the end of the tool. The reciprocating movement of the striker is due to alternate supply by the valve air distribution device 4 of compressed to the working chambers and the exhaust provided by the striker.

The following assumptions are made: 1) the body of the PIM is stationary; 2) the volume occupied by the end of the tool and the volume of the channels for supplying compressed air do not affect the chamber volumes; 3) frictional forces equal zero; 4) there is no overflow of compressed air from one chamber to the other or outflow from the chambers into the atmosphere; 5) admission of compressed air into the working chamber and exhaust from the opposite chamber occurs instantaneously and simultaneously; 6) heat exchange with the surrounding atmosphere and between the chambers is negligibly small; 7) the working substance (compressed air) is an ideal gas.

The assumptions distort the real picture of the process but they markedly simplify the calculations and this is justified in the outline planning stage. The problem is to determine to a first approximation the main structural dimensions of the PIM which would guarantee obtaining the required impact energy and frequency with the least possible consumption of compressed air, the smallest dimensions, pressure force, and vibration.

Shown in Fig. 1b are curves for the resultant force $R(s)$ and striker energy $E(s)$ in relation to the striker position. The following notations are introduced: $U_B$, $U_H$ are the power stroke and idling chamber volumes respectively; $F$ is striker area; $s_B$, $s_H$ are the reduced length of the power stroke and idling chambers respectively ($U_B = F \cdot s_B$, $U_H = F \cdot s_H$); $s_{BK}$, $s_{HK}$ are final ('idling') reduced length of the power stroke and idling chambers respectively; $l_y$ is reduced striker length; $s_{\text{max}}$ is striker travel; $p_a$ is atmospheric pressure or pressure in the chamber connected by the exhaust ports with the atmosphere; $p_B$, $p_H$ are absolute air pressure in the power stroke and idling chambers respectively; $m_y$ is striker weight; $A_y$ is striker energy; $V_y$ is striker pre-impact velocity; $T_{ij}$ is the time for movement of the striker in the interval of the path from $i$ to $j$; $T_c$ is cycle duration; $\nu = 1/T_c$ is striker frequency; $E_i$ is striker energy in the $i$-th interval of the path, and also dimensionless parameters:

$$ \frac{p_a}{p_a} = \frac{\bar{p}_a}{\bar{p}_a}; \frac{p_a}{p_a} = \frac{\bar{p}_a}{\bar{p}_a}; \frac{s}{s} = \frac{s}{s}; \frac{\bar{s}}{\bar{s}} = \frac{\bar{s}}{\bar{s}}; $$

$$ \frac{s_{\text{max}}}{l_y} = \frac{s_{\text{max}}}{l_y}; \frac{s_{\text{max}}}{l_y} = \frac{s_{\text{max}}}{l_y}; $$

\[
\frac{\bar{s}_{max}}{l_f} = \frac{s_{max}}{s_u} = \frac{1}{z_u} = \frac{1}{z_a}; \quad \bar{s}_a = \frac{1}{z_a};
\]

\[
\frac{\bar{E}_i}{p_B l_f} = \frac{E_i}{p_B T_f} = \frac{T_y}{\sqrt{\frac{m_{f_y}}{2\rho F}}};
\]

\[k_f\] is striker recoil factor; \(k = 1.4\) (adiabatic exponent); \(L = \bar{s}_H + \bar{s}_B\) is total reduced dimensionless cylinder length; \(\lambda\) is a dimensionless coefficient which depends on absolute air pressure in the working chambers of the PIM and reduced lengths of these chambers*:

\[
\lambda = \frac{\bar{p}_u + \bar{p}_a - \frac{\bar{s}_u}{k - 1} \left[ \left( \frac{1}{\bar{s}_u} \right)^{1-k} - 1 \right] - \frac{\bar{s}_a}{k - 1} \left[ \left( \frac{1}{\bar{s}_a} \right)^{1-k} - 1 \right]}{\bar{p}_u \frac{k - 1}{k} \cdot \bar{s}_u (\bar{p}_u^{1k} - 1) + \bar{p}_a \frac{k - 1}{k} \cdot \bar{s}_a (\bar{p}_a^{1k} - 1)}.
\]

Taking account of the notations adopted expression (1) may be presented somewhat differently:

\[
\lambda = \frac{\bar{p}_u + \bar{p}_a - \frac{\bar{z}_u}{k - 1} \left[ \left( 1 - \bar{z}_u \right)^{1-k} - 1 \right] - \frac{\bar{z}_a}{k - 1} \left[ \left( 1 - \bar{z}_a \right)^{1-k} - 1 \right]}{\bar{p}_u \frac{k - 1}{k} \cdot \bar{z}_u (\bar{p}_u^{1k} - 1) + \bar{p}_a \frac{k - 1}{k} \cdot \bar{z}_a (\bar{p}_a^{1k} - 1)}.
\]

The specific compressed air consumption \(q\) is expressed in terms of \(\lambda\) and \(k_f\):

\[
q = \frac{0.6(1 - k_f^2)}{\lambda},
\]

whence it follows that in order to achieve the least specific compressed air consumption it is necessary to provide the greatest value of \(\lambda\).

Since the efficiency criterion for a PIM most frequently encountered in practice is specific consumption we dwell in detail on selecting the rational PIM parameters from the position of providing the least \(q\) (which is equivalent to providing the greatest \(\lambda\)).

As follows from (1) and (2), \(\lambda\) is a function of four arguments: \(\bar{s}_H, \bar{s}_B, \bar{p}_H, \bar{p}_B\) or \(z_H, z_B, \bar{p}_H, \bar{p}_B\). The five-dimensional space for parameters may be shown in three-dimensional space using the method of sections, i.e., fixing two of the four arguments.

The numerical method of analysis showed that function \(\lambda\) is convex and it has a global maximum. In studying \(\lambda\) it is desirable simultaneously to watch the sum \((\bar{s}_H + \bar{s}_B)\) which equals \(L\) and which it is desirable to be the smallest, or in other words to give preference to the greatest value of \(\lambda\) for which \(L\) is the least.

Taking account of the notations adopted previously we have

\[
L = \frac{L}{l_f} = \bar{s}_u + \bar{s}_a = \frac{1}{z_u} + \frac{1}{z_a}.
\]

From (4) we determine

\[
z_a = \frac{z_u}{L \cdot z_u - 1}.
\]

A change in \(\bar{s}_H\) and \(\bar{s}_B\) from 1 to \(\infty\) corresponds to a change in \(z_H\) and \(z_B\) in the range from 1 to 0.

In order to observe the change in \(\lambda\) it is sufficient by varying \(L, z_B, \bar{p}_H, \bar{p}_B\) to solve the set from (2) and (5) numerically.