Experimental studies of a valveless non spool-type pneumatic percussion mechanism of a hammer

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Abstract. Performing different kinds of activities, both in mining companies and in construction of industrial, housing and civil facilities requires specialized equipment provided with attached active operating elements, for example, pneumatic hammers. The analysis and selection of a schematic diagram of a pneumatic percussion mechanism are performed using known elements-features and structural additional expanding elements-features. This allowed a development of a new design of a valveless non spool-type pneumatic percussion mechanism of a hammer, for which analytical studies of its operating modes using a mathematical model were conducted. Experimental studies were carried out with an experimental sample of a pneumatic percussion mechanism to specify the reliability of parameters for the proposed mathematical model.

1. Introduction
In the process of mining and at construction facilities if drilling and blasting operations are impossible, percussion mechanisms are used for labor-intensive technological operations\cite{1-6}, such as:
\begin{itemize}
  \item crushing and destruction of oversize rock and frozen soils;
  \item penetration, roof and sides wall scaling of mine workings;
  \item hole drilling, formation of recesses and holes in rock masses;
  \item disassembly of a certain structural elements of industrial buildings and engineering structures.
\end{itemize}

Currently, the Russian Federation as well as countries of the former Soviet Union and beyond have been widely used pneumatic, hydraulic, hydro pneumatic and other percussion mechanisms, unitized with various sizes of basic carrier machines to carry out the above-mentioned work. Pneumatic hammers are preferred due to \cite{7}:
\begin{itemize}
  \item a reliable operation in hard natural climatic and technological conditions;
  \item air usage as a working medium to ensure a steady operation and low requirements for thermal operation modes of moving system elements;
  \item providing required percussion power of machine function elements during various technological operations;
  \item meeting environmental and safety requirements.
\end{itemize}

In view of the above, the issues of creating new structures of pneumatic percussion mechanisms (PPM), determining their rational geometric characteristics, providing the required percussion power
and minimum air consumption during technological processes at mining enterprises and construction facilities are relevant.

A mathematical model of operation of a valveless non spool-type pneumatic percussion mechanism (VINsPPM) of the hammer was previously developed in order to find rational parameters of its operation [8, 9]. Experimental studies of working processes of the examined VINsPPM of a hammer were conducted to estimate correctness of accepted limitations and assumptions in previously performed analytical studies [10-12].

2. Methodology, hardware and software to carry out experimental studies

The design of VINsPPM of a hammer with elements-features of a combined air distribution with a required percussion power and low air consumption is the subject of the experimental study. Components of VINsPPM of a hammer and its general view are shown in Fig. 1.

![Figure 1. VINsPPM of a hammer: a) components, b) general view. 1 - idling chamber housing; 2 - cylindrical housing of power stroke chamber; 3 - distribution chamber housing; 4 – supply pressure chamber housing; 5 - shank end; 6 – stepped striker; 7 - sleeve; 8 - pins; 9 - rod; 10 – spring.](image-url)

The experimental research program was focused on identification of the following parameters in a work process of VINsPPM of a hammer such as pressures in chambers under working and idle operations, energy and percussion frequency; vibration and noise characteristics. A high-speed digital video camera TMC-6740GE with a Navitar DO-5095 lens was used in the course of experimental study of dynamics (energy and percussion frequency) of the work process of a hammer’s VINsPPM. Technical characteristics of this video camera and its lens provided for 1250 frames/s shooting of the
work process and required linear resolution in the field of view about $10^{-4}$ m [13]. Assistant V3 vibrometer and Testo 815 noise level meter were used to measure vibration and noise characteristics.

3. **Technique for results processing of experimental studies of VlNsPPM of a hammer**

   Special software product Frame Analyzer has been developed to process obtained video frames [14]. Video frames processing consists of two stages: a preparatory stage and a frame processing stage. The preparatory stage includes the determination of parameters for viewing and frames processing of high-speed video recording:
   1) a video frame viewing scale is set in order to reduce the effect of pixel discreteness of a screen on data processing results;
   2) loading of the first frame of high-speed video recording;
   3) performing of sequential numbering of all frames;
   4) determining of the scale of exposed image in order to ensure a correct calculation of values obtained during the experiment;
   5) setting of a frame exposure rate;
   6) setting of the analysis mode of obtained experimental data (constant or discrete mode).

   A constant analysis mode allows sequentially observation of the dynamics of one selected point, defining its motion and speed by successive clicks on each analyzed frame. A discrete mode allows observation of the dynamics of different points on each two consecutive frames. Statistical processing of the results of experimental studies was carried out using Direct repeated measurements software product [15].

4. **Comparative analysis of integrated study results**

   Recording of operating process parameters in chambers of hammer’s VlNsPPM was carried out in series of eight measurements for various pressures in the network (0.4; 0.5; 0.6 and 0.7 MPa) after the mechanism began operating in a steady mode.

   Processing of obtained video frames made it possible to get data about the speed change of a hammer’s VlNsPPM shank end when it is stricken with a stepped striker, taking into account the impact coefficient between them. Option settings of the pneumatic hammer were carried out according to the preliminary calculation of VlNsPPM using the Program for calculating barodynamic characteristics of the pneumatic percussion mechanism [16]. Air pressure supplied from $p_0$, network, rebound coefficients of striker $k_y$ and casing $k_c$ from the tool; flow coefficients of intake throttles of chambers of working $\mu_p$ and idle $\mu_i$ strokes and exhaust air discharge channels $\mu_{1a1}$, $\mu_{2a2}$ are initial data for preliminary calculation. Values of flow coefficients $\mu_i$ are calculated according to dependencies given in a reference book [17], and rebound coefficients are calculated according to recommendations [18]. As a result of experiments, flow coefficient values $\mu_i$, rebound coefficients $k_y$, $k_c$, as well as air pressure $p_0$ in a prechamber were refined and used to perform a repeated specified calculation on a computer. Flow coefficient values were specified according to the method of identification by pressure diagrams.

   Working processes in chambers of experimental model of VlNsPPM with $p_0=0.6$ MPa, $k_y=0.2$ and $k_c=0.1$ are represented by oscillogram of pressure change in chambers of working and idle operation modes $p_i=p(t)$ (Fig. 2).
As the study of oscillograms shows, the nature of the change in air pressure in VINsPPM chambers of a hammer at steady operation modes indicates the stability of operating cycles for each of the modes. The results of experimental studies are presented with a dashed line, the results obtained by means of a mathematical model are given with a solid line in fig. 3.

Figure 2. Oscillogram of working processes in chambers of working and idle operation modes of hammer’s VINsPPM.

Figure 3. Research results of parameters of hammer’s VINsPPM.

A – percussion energy; i – percussion frequency; Gv – air flow

The measurement of vibration and noise characteristics of percussion pneumatic hammer with VINsPPM was conducted on a bench with a press force on the housing Fp = (2250…2400) N (fig. 4).
5. Conclusion

A sample of hammer’s VlNsPPM containing combined air distribution facility at inlets to working and idle operation mode chambers was manufactured for experimental studies. The air distribution facility was constructed in a form of overlapping calibrated channels controlling air flow. A procedure to conduct complex research using modern information technology, hardware and software was developed. Experimental studies of VlNsPPM of a hammer were performed for network pressure 0.4; 0.5; 0.6 and 0.7 MPa. Data on percussion energy, percussion frequency, air flow rate and the effect of design parameters of VlNsPPM were obtained. For this design of VlNsPPM of a hammer, the percussion energy of experimental model varied from 413.8 to 669 J, the percussion frequency changed from 7.8 to 10.5 Hz, the air flow altered from 0.08 to 0.20 m³/s if the network pressure changed from 0.4 to 0.7 MPa. The results of the studies showed a disagreement between experimental data and numerical simulation data on percussion energy up to 3.84%, on percussion frequency up to 3.96%, on air flow up to 6.87%, which is within the range of possible error of measurement results and their processing, performed by means of mathematical statistics methods.

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