Methodology for evaluating energy-saving technical solutions of impact machines and equipment

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Abstract. The paper proposes a method of sequential exclusion at the stage of designing feature elements in known and synthesized pneumatic impact mechanisms in order to select preferred constructive solution of machine mechanism for destruction of mountain ranges in preparing the bases for construction of buildings and structures. The method involves a phased analysis of several variants of mechanisms at the same time with exception of the same structural features, elements that have the same effect on the work process and resource mechanisms. Thus, only original compositions remain that characterize distinctive qualities of technical solution of the pneumatic impact mechanism variant corresponding to its intended purpose.

1. Introduction
Creation of new pneumatic impact mechanisms (PIM) is predetermined by their classification with proposal of possible structural features, elements, with known properties.

Such features-elements must be unambiguous and causal, allowing creation of their unknown combinations, but with the expected desired properties. Among the well-known classifications, one can name a detailed classification of impact machines [1] and descriptions of combinations of well-known PIM solutions with brief description of their operation and purpose [2]. However, the use [1, 2] is associated with difficulty of choosing individual features, elements to obtain a given technical solution at the design stage.

In [3], a classification of feature elements is presented, which can be used in combinations of design solutions for PIM, by performing their set with desired properties, to analyze combinations and ability to replace individual features, elements to obtain a given technical solution at the design stage.

In [3], methods for analysis and synthesis of PIM with only one moving attribute-element in form of a striker were also proposed.

However, proposal of classification features-elements [3] does not seem sufficient for PIM air distribution systems, since they are ambiguous and make it difficult to create combinations with specific means determined by their properties.
The classification of features-elements with specific constructive and dynamic means and properties was proposed in [4]. This classification significantly expands the number of design features, elements and their combinations, which allow creating PIM with wide possibilities for their appointment.

The methodology of applying the proposals [3, 4] for a more reasonable choice of constructive solution of PIM, from a number of known technical solutions at the same time, is carried out on the example of analysis of widely known solutions [5-7] and synthesized [8-10] without their materialization, which will significantly reduce time to obtain a qualitative assessment, which should be supplemented by a quantitative one, taken into account by physical and mathematical description of PIM workflow.

Let's consider the sequence of descriptions of working process on the example of PIM [10], for sinking of underground wells in soil environments. The work program and the results of its implementation with the analysis of quantitative indicators are not considered in this paper due to well-known methods for implementing such tasks.

2. Scheme of pneumatic impact mechanisms

2.1. The first stage of the study

A brief description of device and operation selected to compare the PIM scheme is presented by the first stage of proposed method. Figure 1a, b, c, d, e, show the schemes of PIM, and their descriptions are given in the text with notation and source.

Figure 1a shows the PIM scheme [5].

Compressed air from the network through channel A enters the annular flow chamber B of cylinder body 1, from where, depending on the position of drummer 2 through the flat channel, into the undercut of the ring controlled chamber G of idling or into the undercut of the controlled chamber D of working stroke.

The chambers G and D are emptied into surrounding space alternately: chambers G - through the exhaust annular channel E of the chamber Zh of atmospheric pressure located in the cavity of hammer 2, and the exhaust channel I of tube 3; chamber D - through the annular channel-recess K of tube and its channel I.

Under the influence of difference of power pulses from the side of chambers G and D, the striker makes a reciprocating motion and periodically strikes the shank of tool 4.

Figure 1b presents the scheme of PIM [6].

Compressed air from the network enters pre-chamber A of cylinder body 1, from where it enters chamber B through channel W in tube 2, of network air (also known as working chamber) located in hammer 3, from where, depending on its position along radial channel D - in recesses D with a groove E in the idle control chamber W or partially when intake channels I and K are combined into annular chamber A of pneumatic buffer in cylinder body.

Chambers G and L are emptied alternately: chamber G — through groove E, groove D when channel G is combined with exhaust channel H in the tube; chambers A - directly through channels I and N.

Under the influence of difference of power pulses from the side of chambers G, Zh and L, drummer makes reciprocating movements and strikes the shank of tool 4.

Figure 1c, presents the PIM scheme [7].

Compressed air from the network through channel A in cylinder-case I enters annular pre-chamber B of network pressure (it is working inlet chamber), whence depending on position of hammer 2 relative to inlet channel G in form of a flat on stepped tube 3, through channel D, scrum E, groove F on the drummer in a controlled camera And idle entrance. The annular chamber K of pneumatic buffer periodically communicates with atmosphere through the lateral outlet channel L and central channel M in the tube.

Chamber I is emptied periodically through channels L and M in the tube.
Under the influence of difference of power pulses from chambers I, K and G, striker makes reciprocating movements and strikes the shank of tool 4.

Figure 1g presents the scheme of PIM [8].

![Figure 1. Schemes of PIM.](image)

Compressed air from the network through inlet channel A enters pre-chamber B in glass 1, from where it passes through bypass channel B in side wall of flange 2 into the annular accumulation chamber G, forming between the glass and cylinder body 3 and through afterburner channels D to distribution chamber E, as well as an annular isthmus 4 divided with it, into chamber Zh of pneumatic buffer, brake chamber I, and at the same time, along overflow channel-flat H on the side surface of tube 5 into idle chamber K.

Chambers E, I, G are emptied into the atmosphere through chamber K, depending on the position of hammer 6, interacting with the radial outlet channel A in tube with its longitudinal extension in form of channel M.

Under the influence of difference of power pulses, air pressure from the side of chambers K, E, I, Zh, striker makes a reciprocating motion and periodically strikes the shank of tool 7.

Figure 1d, presents the PIM scheme [9].

Compressed air from the network through inlet channel A enters chamber B in flange 1, from where it simultaneously passes through inlet channel W in flange wall to annular accumulation chamber G formed between cup 2 and cylinder 3 and through inlet channels D in cylinder wall to distribution and brake chambers, and through channel G in flange cover into brake chamber and stroke. From distribution and brake chambers, air enters through bypass channel-groove K (or channel-flat) on the side surface of hammer 4 into idle chamber.

Between chambers I and E separated by an isthmus 5, an annular boost chamber M is formed, which is in connection with accumulation chamber G by boost channel N.

The idle chamber L is divided by an isthmus O to the front chamber L from the side of tool shank 6 and rear chamber T from the side of distribution chamber E. The bypass channel-groove on the side surface of striker periodically communicates between chamber T and L.

Chambers H, M, E, and L are emptied depending on the position of striker through the radial exhaust channel Y in the wall of blind tube 7 and then along its longitudinal channel F, through the exhaust channel X into the atmosphere.

Under the influence of difference of power pulses, air pressure from the side of chambers I, M, E and L drummer makes a reciprocating motion and periodically strikes the shank of tool 6.

Drummer is provided with a through hole for passage of tube, which is fixed relative to glass 2.
Figure 1e, presents the PIM scheme [10].

Compressed air from the network through inlet channel A enters pre-chamber B in flange 1, from where it simultaneously passes through inlet channel W of flange wall into annular accumulation chamber G formed between cup 2 and cylinder 3 and through afterburner channels D to distribution chamber E, as well as separate with it annular flange 4 into chamber G of pneumatic buffer and simultaneously along radial inlet channel I on the side surface of tube 5 and its extension into idle chamber L.

Between chambers I and E separated by an isthmus 5, annular boost chamber M is formed, which is in communication with accumulation chamber G by boost channel N.

Chambers E and G are emptied into the atmosphere only through chamber A, depending on the position of hammer 6, interacting with radial outlet channel M in tube with its longitudinal extension in form of channel N.

Under the influence of difference of power pulses, air pressure from the side of chambers L, E and Zh drummer makes a reciprocating motion and periodically strikes the shank of tool 7.

Chamber F of pneumatic buffer comprises throttle channel O of boost in annular flange and intake channel C in the chamber wall.

2.2. The second stage of the study

It involves description of structural formula of PIM device using designations of feature elements [3, 4], presented in table. 1.

Structural formulas of compared PIM are presented in form of a record [3, 4], where feature elements are arranged in tiers, from top to bottom, vertically from the beginning of work process to its end, in one cycle. Consistently on each tier along the horizons - from the source of formation of power impulse to the end of working process in one cycle, in accordance with their classification features, elements and table. 1.

Description of structural formula with a record of additional qualifying features-elements of constructive means is presented in the order of their consideration at the first stage.

Structurally, all PIMs have pre-chambers of network air that perform functions of receiver and, according to classifications [3, 4], are indicated by letter B of Russian alphabet and are defined as means for stabilizing parameters of the air supplied from the network to the PIM.

On the scheme of the PIM, structurally, chambers of network air of means B may not be shown, but their presence is implied. This is explained by the fact that chambers of means B (In) do not directly generate pressure impulses from the side of working or idle chambers, and provide the necessary and sufficient amount of compressed air to the air distribution system.

Features-elements of boosting means K can also be ignored, since they are close in design to the intake means. However, if the objective function is assigned to the process of pressurizing working chamber, then the availability of these pressurization means and their location in the PIM design should be indicated.

When evaluating the PIM, in case of sufficiency of passage sections of channels, it is possible not to consider characteristic elements L of the exhaust air. However, if the task is to assess stabilization means B or release means L, then to simplify the procedure, their structural features-elements should be considered separately or with a smaller number of PIM options.

At the second stage of PIM study, we write a complete code description of its structural formulas (Table 2). At the same time, means A - formation of a power impulse and related dynamic and structural features-elements are adopted according to [3] with addition of additional design features according to [4]:

In (D *) and (E *), characteristic elements are indicated, provided for by possible variants of dynamic signs (a), (f), (i) according to [3].
Table 1. Classification of signs, elements clarifying (supplementing) design of the means ensuring the operation of PIM.

| Dynamic feature elements | Design feature elements |
|--------------------------|-------------------------|
| Code | Basic on [3, 4] | Code | Basic on [3, 4] | Code | Additional on [3, 4] |
| C | Intake means | 1 | In (on) the rod, motionless | a | Channel of circular cross section |
| | | 2 | In (on) the rod, movable | | |
| | | 3 | In (on) the tube, stationary | | |
| | | 4 | In (on) the tube, stationary | | |
| | | 5 | In (on) the case for drummer | | |
| | | 6 | In (on) the drummer | | |
| | | 7 | In (on) the drummer stock | | |
| | | 8 | In (on) the piston of hammer | | |
| | | 9 | In (on) coupling | | |
| | | 01 | In (on) sleeve | | |
| | | 02 | In (on) a glass | | |
| | | 03 | In the (on) anvil | | |
| | | 04 | In (on) a guide | | |
| | | 05 | In (on) the lid | | |
| | | 06 | In (on) flange | | |
| | | 07 | In (on) another kinematic link | | |
| | Also 1 - 07 | b | Slot channel | | |
| | Also 1 - 07 | c | Groove channel | | |
| | Also 1 - 07 | d | Scrum channel | | |
| | Also 1 - 07 | e | Cranked Channel | | |
| | Also 1 - 07 | f | Tier channel | | |
| | Also 1 - 07 | g | Recess Channel | | |
| | Also 1 - 07 | h | Groove channel | | |
| | Also 1 - 07 | i | Screw channel | | |
| | Also 1 - 07 | j | Ring channel | | |
| | Also 1 - 07 | k | Stepped channel | | |
| | Also 1 - 07 | l | Composite channel | | |
| | Also 1 - 07 | m | Another kinematic link | | |
| B | Stabilization tools | Also 1 - 07 | Also a - m | | |
| D | Launcher | Also 1 - 07 | Also a - m | | |
| E | Bypass tool | Also 1 - 07 | Also a - m | | |
| F | Delay tool | Also 1 - 07 | Also a - m | | |
| G | Extrusion Tool | Also 1 - 07 | Also a - m | | |
| H | Afterburner | Also 1 - 07 | Also a - m | | |
| I | Purge tool | Also 1 - 07 | Also a - m | | |
| K | Supercharging | Also 1 - 07 | Also a - m | | |
| L | Release tool | Also 1 - 07 | Also a - m | | |

Table 2. Code description of structural formulas.

| Figure | PIM scheme | PIM structural formulas | Designation |
|--------|------------|-------------------------|-------------|
| 1a     | Figure 1a  | B58d, A2h2C58de83g3l31, A2g1h2C58de803k3l31 | A*          |
| 1b     | Figure 1b  | B5a, A2h2C3aL6g3c, A2g1h2C3aE6a56g56cL6g3c | B*          |
| 1c     | Figure 1c  | B02a, A1h2C05aE3d6k6dc, A2g1h2C3d6k6dcL6agl | C*          |
| 1g     | Figure 1g  | B0205a, Ba3C0506aE5ag, A2g1h2C3d6k | G*          |
| 1d     | Figure 1d  | B0205a, Ba3C036aE5ag + E5ag, A2C5gaE65k5cL6f3a | D*          |
2.3. The third stage of the study

To simplify structural formulas, we do not consider description of means of the first lines and means L.

In this case, combination groups (A *), (B *), and (C *) are not divided into subgroups, since this will lead to an increase in the number of steps, and it suffices to choose the combination (B *) as the simplest one by the number of additional specifying design features -elements and differences in means of E.

At this stage, consideration of PIM in the second group and, given the similarity of the second and third lines, are not considered.

We obtain following records of structural formulas of PIM of the first and second groups with exception of the same features, elements (table. 3).

| PIM scheme | PIM structural formulas | Designation |
|------------|-------------------------|-------------|
| Figure 1e  | B0205a, Ba3C0306aE5ag + E06a + E3a, A2(a)(f)(i)D5a + A2h2C5ga + A2hc5gaE63klcL6k3a, A2g1h2/D3aC5l6d3aL6k3a | E*         |

Table 3. Code Description of Structural Formulas.

| PIM scheme | PIM structural formulas | Designation |
|------------|-------------------------|-------------|
| Figure 1a  | A2h2C58dE83d, A2g1h2C58dE803k | A**         |
| Figure 1b  | A2h2C3a, A2g1h2C3aE6a56g56C | B**         |
| Figure 1c  | A1h2C0SaE3d6k6dc, A2g1h2C0SaE3d6k6dc | C**         |
| Figure 1g  | Ba3C0506aE5ag, A2h2C0506aE3d6k, A2g1h2C0506aE3d6k, Ba3C0306aE5ag+E5ag, | G**         |
| Figure 1d  | A2(a)(f)h2D5ag+A2h2E5ga+ A2C5gaE6sk5c, A2g1h2E516c, Ba3C0306aE5ag + E06a + E3a, | D**         |
| Figure 1e  | A2(a)(f)(i)d5a +A2h2C5ga+A2h2C5gaE03klc, A2g1h2C5l6d3a | E**         |

2.4. The fourth stage of the study

Analysis of structural formulas (A ** - B **) confirms minimum amount of funds E in the variant (A **).

In the group of formulas (G ** - E **) the minimum amount of funds is E in the variant (G **), but the variant (L **) contains means (D) - for launching the chambers for working and idling of drummer. Since the option (G **) does not have the means (D), and the option (D) has it only for travel cameras, it is natural to adopt option (E). Omitted features-elements are canceled:

--- E5ag + --- E5ag, (A***)
--- D5a + --- D5a + --- + --- E65k5c;

--- E5l6c
--- E5ag + --- E06a + --- E3a,
--- D5a + --- + --- E03klc, (E***)
--- D3a
In addition, we note that the appearance in the third line (E ***) of new control functions of intake-exhaust and bypass, as well as the absence of direct (into the atmosphere) exhaust air from the exhaust chambers, exhaust is carried out only through the idle chamber. This implies its repeated use in the idle chamber and reduction of air consumption from the network.

Implementation of additional chambers in the PIM from working and idle side of drummer with constantly open intake channels with calculated areas of their bore sections allows getting a smooth nature of change in air pressure in the chambers, which improves vibration and noise characteristics of the PIM [11, 13, 19-22, 24].

Given the guaranteed launch of the PIM in operation, we accept the design option (E ^ *), for example, if the purpose of the machine is underground drilling in soil media.

Disadvantage of combination of PIM (V *) is the presence of an atmospheric pressure chamber in the hammer, which does not participate in formation of a pressure pulse from the side of working and idle chambers, and complicates the design solution of the PIM, reduces its strength and service life.

Construction of a step-shaped tube with an exhaust and air inlet and by-pass control channel makes the tube more complex, as can be seen from the presence in (B *) [7] of additional specifying structural features-elements. In addition to the noted drawbacks, we note in (B *) execution of shank of working tool with the channel in which the tube is placed, which reduces the strength and resource of the shank of working tool.

Conclusions on the structural formulas (A ***) and (E ***)

Attributes-elements of the first lines are the same. Since the structural properties of features-elements are known from table. 1, we restrict to counting only their number.

So, for (A ***): the second and third lines contain the number of feature elements in E and L, respectively 6-4 units and for (E ***), in E and L, respectively 12 and 8 units, but in addition elements D contain 4 units, which are means of guaranteed launching of the PIM into operation, and which are absent in (A ***).

3. Physic-mathematical description of pneumatic impact mechanisms

Designations in the design scheme of PIM and its description (see Figure 2) [10]:

\[
V_{tp}, V_{cp}, V_{pb}, V_{tc}, V_{ct}, V_{ac}, V_{ca}, V_{cx}, V_{px}, V_{tx}, V_{vt}, V_{vi} - \text{volumes of: end chamber, annular chamber, pneumatic buffer chamber, brake chamber and its cylindrical part, accumulation chamber and its cylindrical part, rear and front idle chambers, chamber in the hammer between the tube and the tool shank, exhaust chamber in the tube;}
\]

\[
\omega_{tp}, \omega_{cp}, \omega_{pb}, \omega_{tc}, \omega_{ct}, \omega_{ac}, \omega_{ca}, \omega_{cx}, \omega_{px}, \omega_{tx}, \omega_{vt} - \text{geometric cross-sectional areas of the air supply channels to chambers with a volume } V_{tp}, V_{cp}, V_{pb}, V_{tc}, V_{ct}, V_{ac}, V_{ca}, V_{cx}, V_{px}, V_{tx}, V_{vt};
\]

\[
P_{tp}, P_{cp}, P_{pb}, P_{tc}, P_{ct}, P_{ac}, P_{ca}, P_{cx}, P_{px}, P_{tx}, P_{vt} - \text{air pressure in chambers with volumes } V_{tp}, V_{cp}, V_{pb}, V_{tc}, V_{ct}, V_{ac}, V_{ca}, V_{cx}, V_{px}, V_{tx}, V_{vt}.
\]
\(\phi_{tp}, \phi_{pb}, \phi_{tc}, \phi_{ac}, \phi_{ca}, \phi_{cs}, \phi_{px}, \phi_{st}\) – coefficients of the barodynamic component of working process in chambers with volumes \(V_{tp}, V_{pb}, V_{tc}, V_{ac}, V_{ca}, V_{cs}, V_{px}, V_{st}\);
\(\theta_{tp}, \theta_{pb}, \theta_{tc}, \theta_{ac}, \theta_{ca}, \theta_{cs}, \theta_{px}, \theta_{st}\) – air temperature in chambers with volumes \(V_{tp}, V_{pb}, V_{tc}, V_{ac}, V_{ca}, V_{cs}, V_{px}, V_{st}\);
\(\Omega_{tp}, \Omega_{pb}, \Omega_{tc}, \Omega_{ac}, \Omega_{ca}, \Omega_{cs}, \Omega_{px}, \Omega_{st}\) – coefficient of thermodynamic component of working process in chambers with volumes \(V_{tp}, V_{pb}, V_{tc}, V_{ac}, V_{ca}, V_{cs}, V_{px}, V_{st}\);
\(a_{c}\) – geometric cross-sectional area of cylinder and tube;
\(a_{nc}\) – cross section area of bypass channel on the side surface of hammer;
\(a_{a}\) – sectional area of air outlet channel from the chamber with volume \(V_{st}\);
\(p_a\) – air pressure in the atmosphere and air supply network;
\(\varphi_{a}, \varphi_{th}\) – coefficients of barodynamic component in the atmosphere and network;
\(\Theta_{a}, \Theta_{th}\) – air temperature in the atmosphere and air supply network;
\(\Omega_{a}, \Omega_{th}\) – coefficients of thermodynamic component in the atmosphere and network;
\(a, b, c, d, e, f, h, i, j, z, n, m, r, s, y\) – length between the cutting edges along the length of cylinder.

Differences in intake control (quantitatively and qualitatively) are carried out by continuously open throttles depending on the ratios \(p_i, p_j = x_{ij}\) and the laws of Saint-Venant and Wantzel. When changing \(x_{ij}\) due to the process of compression-expansion of air in the chamber, and, consequently, coordinate of position of the hammer \(x_h\), air consumption should be taken into account by dependence \(Q_{ij} = Q(x_{ij}, x_h)\). Thus, the control of the air inlet in the chamber volume depending on \(x_h > 0.5288\) or \(x_h \leq 0.5288\) by \(x_h = 0\) or \(x_h > 0\), or \(x_h < 0\), which occur when the intake throttle is always open. This constraint management situation of \(\varphi_{ij}\) and \(\Omega_{ij}\), which take into account conditions of baro- and thermodynamic process, and in case \(V_i \neq \text{const}\) and chorodynamic component of the process in form \((V_i \pm x_i Sy)\), where \(V_i\) – volume of the working and idle drummer chamber; \(Sy\) – Working diametrical sectional area of the drummer.

It should be noted that in case of airless PIM (APIM) and valveless PIM (VIPIM), the air inlet to the chambers is controlled when the drummer blocks the inlet channel. In this case, the firing pin in the APIM performs the functions of a valve, and in the VIPIM - the functions of the spool, which is how they fundamentally differ from the DPIM. In [3], the definitions and differences of inkjet (IPIM) from valve (VPIM) and spool (SPIM), as well as APIM and VIPIM from DPIM are given.

Assumptions and limitations for the equations describing the PIM workflow take into account the experience of previous studies [11-26].

1. For the barodynamic and thermodynamic components of the process, an indicator of the process is taken when air flows from the network into the end chamber is \(k = 1,4\); \(P_c = p_{tp} = \text{const}\) and \(\theta_c = \theta_{tp} = \text{const}\). At the same time, the laws of Saint-Venant and Wantzel work for \((P_i / P_j) < 0.5283\) and \((P_i / P_j) > 0.5283\). In the polytropic process of air bypass between the chambers at \(\varphi_{0i} = \text{const}\) it is accepted that \(k = 1\) m for \(\varphi_{0i}\) amendments are introduced \(\Omega_{i}, \varphi_{i}\) as: for a barodynamic process \(\varphi_{i}, \varphi_{ij}\) and for the thermodynamic process \(\varphi_{ij}, \Omega_{ij}\) [11-14].

2. For the components of barodynamic and thermodynamic processes, the condition remains constant of coordinate of position of the body of working tool supported on the shoulder and, therefore, of impactor in contact with working tool shank in each cycle of working process, i.e. at \(x_s > 0, x_s \leq 0\) and \(x_s > 0, x_s \leq 0\), which are taken into account by rebound coefficients \(k_s\) and \(k_e\) [15-26].

3. The equality of air pressure in the annular grooves of accumulation and brake chambers and annular precamera when overlapping the annular grooves of the side surface of striker is accepted [11-14].

4. In the equations of physical and mathematical description of the PIM workflow, coefficients of air consumption by the throttle inlet, bypass and exhaust channels are taken equal to unity \((\mu_k = 1)\), which should be specified by calculation [27, 28] or by blowing and taken into account when assigning design values of geometric cross-sectional areas of each throttle channel.

Limitations when changing the direction of cross section of the air flow.

We introduce notation for coefficients of barodynamic components \(\varphi_{ij}\) and \(\varphi_{pi}\), where indices \(ij\) – are direct flow and \(ji\) – reverse flow:
ties expressed through rebound coefficients \( \Omega_{ij} \) and \( \Omega_{ji} \), where the indices \( i \) and \( j \) are similar to \( \varphi_i \) and \( \varphi_j \) and depend on them:

\[
\Omega_j \equiv \Omega_i = \begin{cases} 
\varphi_i < 0 & k-1 \\
\varphi_i = 0 & k-\varphi_i / \varphi_j \\
\varphi_i > 0 & k-1 \\
\end{cases} 
\]

Restrictions for moving the drummer \( x_y \) and body \( x_e \) depending on collision and rebound velocities expressed through rebound coefficients \( (dx_y/dt)_o \), \( (dx_e/dt)_o \):

\[
(dx_y/dt)_o = \kappa_y (dx_y/dt)_j \quad \text{by } x_y \leq 0
\]

where \( \kappa_y \) – impactor rebound coefficient from the tool shank and

\[
(dx_e/dt)_o = - \kappa_e (dx_e/dt)_y \quad \text{by } x_e \leq 0
\]

where \( \kappa_e \) – bounce coefficient of the tool flange.

Restrictions on the area of geometric cross sections of throttle channels:

\[
\omega_{bc}(x_y) = \begin{cases} 
x_y = 0 & \omega_{bc} \\
0 < x_y < b & \omega_{bc} \\
b < (x_y + L_y) < (c-g) & 0 \\
(c-g) < (x_y + L_y) < i & \omega_{bc} \\
i < (x_y + L_y) < f & 0 \\
f < (x_y + L_y) < h & \omega_{bc} \\
h < (x_y + L_y) < j & 0 \\
\end{cases}
\]

\( \omega_{bc} = a_{bc} \cdot b_{bc} \), where \( a_{bc} \) and \( b_{bc} \) – width and depth of the channel-groove or cross-sectional area of the channel-scrum.

\[
\omega_y(x_y) = \begin{cases} 
x_y = 0 & \omega_{ac} \\
0 < (x_y + L_y) < i & \omega_{ac} \\
i < (x_y + L_y) < f & 0 \\
j < (x_y + L_y) < z & \omega_{ac} \\
\end{cases}
\]

\[
\omega_{ac}(x_y) = \begin{cases} 
x_y = 0 & \omega_{ac} \\
0 < (x_y + L_y) < s & \omega_{ac} \\
s < (x_y + L_y) < f & 0 \\
f < (x_y + L_y) < h & \omega_{ac} \\
h < (x_y + L_y) < i & 0 \\
\end{cases}
\]
\[
\begin{align*}
\omega_{vt}(x_y) = & \begin{cases} 
  x_y = 0 & 0 \\
  0 < x_y < m & 0.5 \omega_{vt} \\
  m < x_y < s & \omega_{vt} \\
  x < x_y < f & \omega_{vt}
\end{cases} 
\end{align*}
\]

(8)

Air intake chokes with constant geometric cross-sectional areas:
\(\Omega_{dp}, \omega_{pb}, \omega_{as}, \omega_{cp}, \omega_{tx}\).

The equations of barodynamic component of the PIM [10] workflow:

\[
\frac{dp_{tp}}{dt} = k \left[ W(\omega_{tp}\varphi_{tp} - \omega_{at}\varphi_{at} - \omega_{pb}\varphi_{pb} - \omega_{cp}\varphi_{cp}) \right] / V_{tp} 
\]

(9)

\[
\frac{dp_{cp}}{dt} = k \left[ W(\omega_{cp}\varphi_{cp} - \omega_{at}\varphi_{at} - \omega_{ac}\varphi_{ac}) \right] / V_{cp} 
\]

(10)

\[
\frac{dp_{ix}}{dt} = k \left[ W(\omega_{ix}\varphi_{ix} - \omega_{px}\varphi_{px}) \right] / V_{ix} 
\]

(11)

\[
\frac{dp_{px}}{dt} = k \left[ W(\omega_{px}(x_y)\varphi_{px} + \omega_{tx}(x_y)\varphi_{tx} - \omega_{vt}(x_y)\varphi_{vt}) - px(dx_y/dt)S_y \right] / \left( V_{px} + V_{tx} + x_y S_y \right) 
\]

(12)

\[
\frac{dp_{sx}}{dt} = k \left[ W(\omega_{sx}(x_y)\varphi_{sx} + \omega_{px}(x_y)\varphi_{px} + \omega_{ca}(x_y)\varphi_{ca} - \omega_{vt}(x_y)\varphi_{vt}) - px(dx_y/dt)S_y \right] / \left( V_{sx} + V_{px} + V_{ac} + x_y S_y \right) 
\]

(13)

\[
\frac{dp_{ca}}{dt} = k \left[ W(\omega_{ca}(x_y)\varphi_{ca} + \omega_{at}(x_y)\varphi_{at} + \omega_{ct}(x_y)\varphi_{ct} + \omega_{st}(x_y)\varphi_{st} + \omega_{pb}(x_y)\varphi_{pb} + px(dx_y/dt)S_y \right] / \left( V_{ca} + V_{at} + V_{ct} + V_{st} + V_{pb} + x_y S_y \right) 
\]

(14)

\[
\frac{dp_{ac}}{dt} = k \left[ W(\omega_{ac}(x_y)\varphi_{ac} + \omega_{ct}(x_y)\varphi_{ct} + \omega_{ac}(x_y)\varphi_{ac} + \omega_{pb}(x_y)\varphi_{pb} + px(dx_y/dt)S_y \right] / \left( V_{ac} + V_{ct} + V_{ac} + V_{pb} + x_y S_y \right) 
\]

(15)

\[
\frac{dp_{lc}}{dt} = k \left[ W(\omega_{lc}(x_y)\varphi_{lc} + \omega_{pb}(x_y)\varphi_{pb} + px(dx_y/dt)S_y \right] / \left( V_{lc} + V_{pb} - x_y S_y \right) 
\]

(16)

\[
\frac{dp_{pc}}{dt} = k \left[ W(\omega_{pc}(x_y)\varphi_{pc} + \omega_{pb}(x_y)\varphi_{pb} + px(dx_y/dt)S_y \right] / \left( V_{pc} + V_{pb} - x_y S_y \right) 
\]

(17)

\[
\frac{dp_{pb}}{dt} = k \left[ W(\omega_{pb}(x_y)\varphi_{pb} + px(dx_y/dt)S_y \right] / \left( V_{pc} + V_{pb} - x_y S_y \right) 
\]

(18)

In (9) – (19) \(S_y = S_c - S_t\); restrictions for \(p_1\) using (1);

\(W = (2R_k/(k-1))^1/2\), where \(k\) and \(R_k\) process indicator and gas constant.

In (9) \(\omega_{tc} = \omega_{t} - \) sectional area of the inlet channel into the end chamber from the network.

In (11) and (12) \(\omega_{px} = \omega_{t} - \) tube diamicentric area.

In (14) and (15) \(\omega_{ca} = \omega_{t} - \); In (16) and (17) \(\omega_{ct} = \omega_{t} - \).

To simplify solutions of equations (9) - (19), the hydraulic resistance coefficients for all \(\omega_t\) is equal to one. Actual geometric dimensions of cross-sectional areas \(\omega_{gti} = \) const, as well as \(\omega_{gtt}, \omega_{gtx}, \omega_{gty}\) are determined using the methods of calculating air flow [27, 28] or by purging the channels with specification of flow coefficients \(\mu_{gti}\) and calculation \(\omega_{gti} = \omega_{gti} \mu_{gti}\).

The equation of the baromechanical component of the PIM workflow:

\[
\frac{d^2x_y}{dt^2} - (P_x-P_p)S_y/m_y \text{ by } x_y > 0
\]

(20)

where \(d^2x_y/dt^2 - \) drummer acceleration; \(P_x, P_p - \) total air pressure from the side of idling chambers and working chamber; \(S_y - \) drummer end ring area;

\(m_y - \) drummer mass.
\[
d^2 x_c/dt^2 = [\(P_x - P_p\)S_y + F_r]/m_c \quad \text{by} \quad x_c > 0,
\]
where \(d^2 x_c/dt^2\) – acceleration of the movement of the body; \(F_r\) – pressure on the body; \(m_c\) – body mass, consisting of all masses rigidly connected to the cylinder.

Equations of thermodynamic component of the PIM workflow [10]:

\[
D\theta tp/dt = [W(\omega_c\phi_p\Omega_p - \omega_c\phi_a\Omega_a - \omega_p\phi_p\Omega_p - \omega_p\phi_a\Omega_a)](p_p V_p)^{-1}
\]

\[
D\theta tp/dt = \theta_c[p(\omega_c\phi_a\Omega_a - \omega_c\phi_p\Omega_p - \omega_c\phi_p\Omega_p - \omega_c\phi_a\Omega_a)](p_p V_p)^{-1}
\]

\[
D\theta p/dt = \theta_p[p(\omega_p(\phi_a, x_p)\Omega_p + \omega_c(\phi_a, x_p)\Omega_c - \omega_c(\phi_a, x_p)\Omega_c - (k-1)p_p(dx/dt)S_y)](p_p ((V_p + V_c) - x_Sy))^1
\]

\[
\theta_{tc}/dt = \theta_{tc}[W(\omega_c(\phi_a, x_p)\Omega_c + \omega_c(\phi_c, x_c)\Omega_c + \omega_c(\phi_a, x_c)\Omega_c - \omega_a(\phi_a, x_p)\Omega_a - \omega_a(\phi_a, x_c)\Omega_c + \omega_p(\phi_a, x_p)\Omega_p)] -
\]

\[
(k-1)p_p(dx/dt)S_y](p_p ((V_a + V_c + V_p) + x_Sy))^1
\]

\[
\theta_{tp}/dt = \theta_{tp}[W(\omega_p(\phi_p, x_p)\Omega_p + \omega_c(\phi_p, x_c)\Omega_c + \omega_c(\phi_p, x_c)\Omega_c - \omega_a(\phi_p, x_p)\Omega_a + \omega_a(\phi_p, x_c)\Omega_c + \omega_p(\phi_p, x_p)\Omega_p) -
\]

\[
(k-1)p_p(dx/dt)S_y](p_p ((V_c + V_p + V_c + V_p) - x_Sy))^1
\]

\[
\theta_{tc}/dt = \theta_{tc}[W(\omega_a(\phi_a, x_p)\Omega_a + \omega_a(\phi_a, x_c)\Omega_c + \omega_a(\phi_a, x_c)\Omega_c - \omega_a(\phi_a, x_p)\Omega_a + \omega_a(\phi_a, x_c)\Omega_c + \omega_p(\phi_a, x_p)\Omega_p)] -
\]

\[
(k-1)p_p(dx/dt)S_y](p_p ((V_a + V_c + V_p) - x_Sy))^1
\]

\[
\theta_{tp}/dt = \theta_{tp}[W(\omega_p(\phi_p, x_p)\Omega_p + \omega_p(\phi_p, x_c)\Omega_p + \omega_p(\phi_p, x_c)\Omega_p + (k-1)p_p(dx/dt)S_y)](p_p ((V_c + V_p + V_c) - x_Sy))^1
\]

\[
\theta_{tp}/dt = \theta_{tp}[W(\omega_p(\phi_p, x_p)\Omega_p + (k-1)p_p(dx/dt)S_y)]/p_p (V_p - x_Sy)
\]

Given the notes on the use of values \((d\theta/dt)\) about control and compliance \((dp/dt)\), in preliminary studies, the solution of equations (22) - (32) can be omitted.

In this paper, the authors limited themselves to the presentation of a physical and mathematical description of workflow of considered PIM and its qualitative assessment.

4. Conclusions

The proposed method of comparative assessment allows making an informed choice of preferred constructive solution for PIM for one or more types of tools (A - L), which the designer proposes to accept in design for a specific purpose.

The use of structural formulas to describe the design features of PIM allows evaluating simultaneously several mechanisms selected for comparison, without their materialization, and give preference to one of them on the basis of informed decision-making.

From the experience of creating and using PIM in shock machines at the initial stages of comparison, it is enough to apply for a quantitative assessment of dependence \((dp/dt)\), without considering \((dQ/dt)\).

Application of well-founded restrictions to \(p(t)\) and \(\theta(t)\) can give a compact physical and mathematical description of the concept and workflow of PIM.

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