Research of the Effectiveness of Use of New Mechanism in Reciprocating Compressors

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“Research of the effectiveness of use of new mechanism in reciprocating compressors”

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1. General

Basic optional advantages of the reciprocating compressors with controlled law of piston motion in comparison with regular crank reciprocating compressors (RC) were stipulated in Article [1] and [2]. For example, Konjukhov’s mechanism [3] permits to control the law of piston motion during operation of the compressor.

Control of the piston motion law ensures a number of new possibilities. For example, Konjukhov’s motion mechanism permits:

• shift the top and/or bottom dead centers;
• reduce the piston stroke from 4R to 2R due to the shift of the upper and/or bottom dead centers;
• stop the piston in the upper or bottom dead centers or any other position during rotation of the crankshaft;
• reduce the piston speed at specified crankshaft turning angles;
• increase the piston speed at specified crankshaft turning angles.

Object of the research – show that there are laws of piston motion different from the regular crank mechanism laws and that are more effective from the power point of view.

The research included mathematical modeling of the working processes of the real reciprocating compressor with controlled law of piston motion and regular crank mechanism and further comparison of energy (power) characteristics (power losses in the suction valves, power losses in the delivery valves, indicated power) of the reciprocating compressors with traditional crank mechanism and compressors in which the law of piston motion differs from the law of piston motion in traditional crank mechanism.

Selection of law of piston displacement

We studied the influence of the law of piston motion on major characteristics of the reciprocating compressor – energy losses in the suction and delivery valves, indicated power. Due to the complexity of determining the optimal law of piston motion the research was conducted in the conditions of conventional laws of piston motion.

Since the losses of pressure (energy) in the valves depend on the speed of gases in the valves, that is on instant piston speed \( C_n \), it is feasible that the piston motion law is determined by the law that changes its speed. Preliminary research showed that losses of...
pressure in the valve which value is smaller than in the crank-shaft mechanism take place at the piston motion constant speed (best results) and constant acceleration.

Having analyzed the physics of the processes of suction and delivery we proposed a generalized conventional law of piston motion -trapezoidal (figure 1).

![Generalized conventional law of piston motion](image1)

Figure 1

In picture 1 angles $\Delta \varphi_i$ correspond to the delays (stops) of the piston in the vicinity of the dead centers and angles $\alpha_i$ determine the law of piston motion.

In the present research we studied operation of the reciprocating compressor under the simplified trapezoidal law of piston motion (figure 2) because it was necessary to determine whether the law of piston motion effected compressor efficiency characteristics and indexes. Effect of piston stops in the vicinity of the dead centers at this stage of research was not studied.

2. **Mathematical model**

Basic principles of mathematical model creation are given in [4]. Pressure in front of the suction and delivery valves is constant. All coefficients in the equation of the valve motion are borrowed from [4, 5, 6, 7].

**Experimental data.** Boundary conditions (temperature of the walls of the cylinder), coefficients of discharge of self-acting valves depending on the elevation height, coefficient of pressure on the valve's plate depending on the elevation height, coefficients in the equation for determining coefficient of heat release between the gas and the walls...
of the cylinder, conditional clearances (gaps) in the piston packing and the valves, and other experimental data necessary for the mathematical model are borrowed from [4, 8].

Additional information. During mathematical modeling of the working processes flap (as in the prototype) and ring type valves were used. Use of two types of valves increases trustworthiness of the achieved results. Analyzing the modeling results, reference is made with respect to the type of the valve.

![Simplified trapezoidal law of piston motion](image)

Figure 2

Object of Research

As nominal 1st stage of the well known in Russia and CIS countries K-5 air compressor (without crosshead) that makes part of the PKS-5 portable compressor station manufactured by Melitopol Compressor Factory was chosen for the research. Selection of the research object is conditioned by existing indicator’s diagrams received experimentally. Need for such experimental diagrams is determined by checking whether mathematical model is adequate or not.

Calculation experiment was conducted when the compressor operated with two types of valves: flap and ring valves. Ring valves are standard valves selected in accordance with OST 26-12-2005-78 standard for the nominal regime of 750 r.p.m. (average piston speed $C_m = 3 \text{ m/s}$).
Research has been made for nominal r.p.m. and double nominal, that is for 750 r.p.m. \((C_m = 3 \text{ m/s})\) and 1500 r.p.m. \((C_m = 6 \text{ m/s})\). For purity of the calculation experiment at 1500 r.p.m. we used valves chosen for the regime of the 750 r.p.m.

Calculation experiment for compressors with controlled law of piston displacement and for compressors with crank mechanism was conducted at piston stroke equal to 120 mm, suction pressure \(10^5 \text{ Pa}\) and delivery pressure \(2.9\times10^6 \text{ Pa}\).

**Main Results of the Research**

First stage of the calculation experiment with ring valves installed was conducted at nominal 750 r.p.m.. Results are presented in table 1.

<table>
<thead>
<tr>
<th>Regime</th>
<th>(N_{\text{ind}}) kW</th>
<th>(\Delta N_{\text{suc.valve}}) kW</th>
<th>(\Delta N_{\text{del.valve}}) kW</th>
<th>(\eta_{\text{isot.ind}}) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>K5 (750 rpm)</td>
<td>8,13</td>
<td>1,03</td>
<td>1,21</td>
<td>68,3</td>
</tr>
<tr>
<td>Compressor with new mechanism (750 rpm)</td>
<td>6,696</td>
<td>0,64</td>
<td>0,77</td>
<td>82,22</td>
</tr>
</tbody>
</table>

Adopted symbols:

- \(N_{\text{ind}}\) – indicated power, kW;
- \(\Delta N_{\text{s,v}}\) – power losses in suction valves, kW;
- \(\Delta N_{\text{d,v}}\) – power losses in delivery valves, kW;
- \(\eta_{\text{isot.ind}}\) – isothermal-indicated productivity coefficient.

Second stage of the calculation experiment was conducted at 1500 r.p.m. (at double nominal). The results are presented in table 2.

<table>
<thead>
<tr>
<th>Regime</th>
<th>(N_{\text{ind}}) kW</th>
<th>(\Delta N_{\text{suc.valve}}) kW</th>
<th>(\Delta N_{\text{del.valve}}) kW</th>
<th>(\eta_{\text{isot.ind}}) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>K5 (1500 rpm)</td>
<td>18,64</td>
<td>4,071</td>
<td>5,591</td>
<td>59,35</td>
</tr>
<tr>
<td>Compressor with new mechanism (1500 rpm)</td>
<td>14,69</td>
<td>3,057</td>
<td>3,035</td>
<td>75,3</td>
</tr>
</tbody>
</table>

Symbols given in table 2 are the same as in table 1.

Similar results were received for flap valves.
Discussion of the results of the numerical experiment

Analysis of the results of numerical experiments showed that employment of mechanism with controlled law of piston motion in reciprocating compressors at the expense of the random (not optimal!) selection of laws of motion for different processes with respect to their physical peculiarities permitted to drastically increase the effectiveness of the compressor without changing the design of both the cylinder and the valves:

- indicated-isothermal efficiency coefficient increased by 15%;
- losses of energy (power) in the suction valves decreased by 38%;
- losses of energy (power) in the delivery valves decreased by 36%;
- indicated power (energy consumption on compression and gas transfer) decreased by 18%.

Analysis of the results of numerical experiments showed that employment of mechanism with controlled law of piston motion in reciprocating compressors at the expense of the random (not optimal!) selection of laws of motion for different processes with respect to their physical peculiarities permitted to drastically increase the compressor’s specific speed (without changing the design of both the cylinder and the valves) and increase the indicated-isothermal efficiency coefficient.

- Increasing the r.p.m. two times (average speed of the piston) we got 7% increase of the indicated-isothermal efficiency coefficient.
- It has been proved that tuning of the piston motion law for every shaft r.p.m. value should be done separately and individually.

We revealed complicated interrelated effect of angles $\alpha_1$, $\alpha_2$, $\alpha_3$ и $\alpha_4$ on operating efficiency of the compressor. Selecting law of piston motion it is necessary take into consideration that angles $\alpha_1$, $\alpha_2$, $\alpha_3$ и $\alpha_4$ cannot be considered as independent variables.

We brought out in principle a new proposition: in reciprocating compressor fitted with mechanism that controls the law of piston motion, during delay of closure of suction or delivery valve it is possible to gain indicated power due to smaller losses of power in the processes of suction and delivery thanks to more rational law of piston motion in
these processes. In reciprocating compressors with crank mechanism delays of valve closure lead to deterioration of the effectiveness of the compressor.

It has been determined that law of piston motion should be selected for every shaft r.p.m. value separately.

**Conclusion**

Preliminary research demonstrated that:

1. It is possible to reduce the energy (power) losses in the suction valves by 40% at nominal r.p.m. of the crankshaft in reciprocating compressors with controlled law of piston motion by selecting a law of piston motion during suction process.
2. It is possible to reduce indicated power by 15% and more at nominal r.p.m. of the crankshaft in reciprocating compressors with controlled law of piston motion by selecting a law of piston motion.
3. Mechanism with controlled law of piston motion permits to double the piston average speed and achieve higher efficiency coefficient of the compressor.
4. In reciprocating compressors with controlled law of piston motion power performance improvements due to selection of respective law of piston motion are considerably (several times) higher than friction losses in additional vapor of friction.

**Literature:**
