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Reciprocating Gas Engine with Auto-Triggering Intake Valve

V. S. Kalekin[1], D. V. Kalekin[2]

[1]Department of Engines, Omsk Branch of Khrulev Militari Academy of Logistics and Transport, Omsk, Voenny Gorodok, Russia
[2]Department of Computer Science and Engineering, Omsk State Technical University, Omsk, Mira, Russia

Email address
kalekinvc@mail.ru (V. S. Kalekin), kalekind@yandex.ru (D. V. Kalekin)

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Abstract
Results are shown of experimental research of reciprocating gas engine with auto-triggering intake valve and exhaust windows. Influence is estimated on indicatory power and specific gas usage of following parameters: relative dead space, spring rigidness of valve locking element and its maximum height and gas pressure on engine intake. Possibility of gas engine creation on industry standard unified piston compressor bases is proposed. Innovative reciprocating gas engines can be used in chemical and gas industries for purposes of energy recovery when pressure of gases is being reduced to match technological conditions, and also providing safety of work in environments where fire and explosion hazards exist.

1. Introduction

One of the main direction of the security work being done in fire-hazardous chemical, petrochemical, gas and mining industries, is the use of pneumatic drive instead of an electric actuator, allowing sparking.

Using of pneumatic actuator in mining machines and complexes in the development of deep mining is associated not only with increased risk of an explosion of gas or dust, but the presence of refrigeration effect, the role of which increases significantly with increasing depth development and rise in temperature in underground mines [1, 2].

The enterprises of the mining complex to drive the winches, hoists stem machines, drilling carriages, mucking machines and cargo transportation vehicles are widely used pneumatic piston engines. In comparison with other types of pneumatic piston pneumoengine possess good starting characteristics, allow overloading, have less leakage of compressed air.

For intensification of the work undertaken, implementation and use of high-performance pneumatic equipment require a further increase in air pressure at the inlet. However, the existence of forced slide timing does not help improve the efficiency of the pneumatic reciprocator at elevated pressure [3].

One of the ways to improve designs pneumatic reciprocator is forced replacement timing of a self acting valves. This will greatly simplify the design of pneumatic reciprocator, reduce and even eliminate leakage of the working environment, improve efficiency by reducing friction loss, ensure the effective operation with a slight change in performance factor at off-design regimes, increasing the frequency of rotation of the crankshaft [4].

In connection with the simplistic design pneumatic reciprocator can be expanded the range of applications in chemical and gas industry for energy conservation potential energy of the gaseous environments of high overpressure (waste by-products and intermediates), which leave the technical equipment before the subsequent stage of the use [5].

Reciprocating engines are a fundamentally new system of distribution of gas may also be used in the design and implementation of ecological drive motor transport through the use of energy pre-compressed or liquefied gas, inert with respect to the environment [6].

Work processes occurring in the cylinder of pneumatic (gas) reciprocator, connected with the scheme of motion of the working body in setting [7, 8].

Uniflow traffic pattern of the working body in a gas engine (expander) is provided by installing the intake valves normally open and performance exhaust windows in the wall of the cylinder at the end of the stroke [9].

2. Experimental Installation

For research were designed and created two experimental stand with annular self acting valves on the basis of reciprocating compressors: one in-line, vertical cylinder with a diameter – 60 mm and throw of piston – 38 mm, three in-line, Ш- shaped cylinders with diameters – 90 mm and throw of piston – 68 mm. In the lower parts of the pneumoengine cylinders in the vicinity of bottom dead center were made exhaust windows for exhaust air.

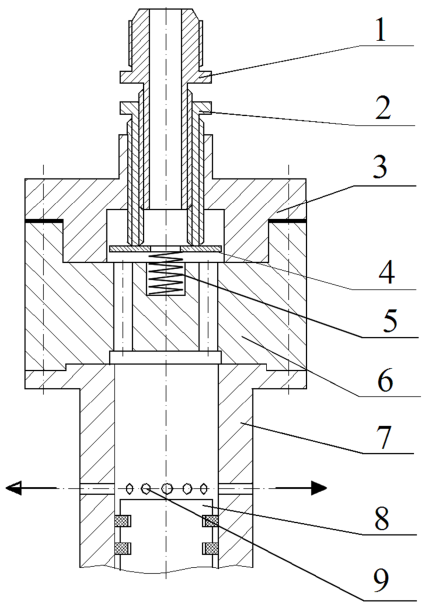

Fig. 1. *One in-line pneumatic actuator: 1-fitting of air, 2-lift stop, 3-valve cover, 4-annular locking element, 5-spring, 6 - cylinder head; 7-cylinder, 8-piston, 9-exhaust windows.*

One in-line pneumoengine is shown in Fig. 1. Upgraded valve head containing the lid 3 and 6, pins joined to the cylinder 7. At the head was placed normally open self acting inlet valve with an annular locking element 4, the compression spring 5 and the lift stop 2, able to navigate through the carving on the lid 3 to change the height locking element on the valve seat (lid 6). At the bottom of the pneumoengine cylinder were made exhaust windows 9. Compressed air supply to the engine was carried through the sleeve 1, screwed on the thread in the lift stop 2.

Principle of operation of a inlet self acting valve is as follows. When moving the piston from the top dead center, the gas pressure in the cylinder pc becomes lower than the valve head PH. When the pressure difference $\Delta p = (p_н - p_ц)$ reaches the value at which the gas force acting on the shutoff valve element 3 exceeds the force of the spring 4, the valve closes. In case of insufficient size of the gas power valve will remain open. To re-opening of the valve is necessary to force the gas from the cylinder and the force of the spring to overcome the gas force acting on the part of the valve head.

In the Ш- shaped pneumoengine been placed normally open annular inlet valves with three compression springs. In one in-line engine working processes were investigated with a annular self acting valve with a spring compression and leaf (elastic) a locking element [10].

Scheme of the experimental stand one in-line pneumoengine is shown in Fig. 2. Pneumoengine and motor part of the unit was put into rotation with compressed air from the compressor unit 1, consisting of two U-shaped compressors with a final pressure up to 1.0 MPa, output of 1 m3 per min each, mounted on the receiver 2.

As the external load one in-line pneumoengine electric generator used by the DC 12 with an adjustable unit rheostats 13 and autotransformer connected to the shaft of the engine belt drive.

Compressed air from the receiver 2 compressor unit in the cylinders of pneumoengine are fed through a gas pressure regulator 4, the pressure was controlled model gauge 3 class 0, 5. The temperature at the inlet and outlet of the cylinders was measured using a chromel-copel thermocouples. Register instantaneous volume flow was carried out float rotameter 5 (H250 company «KROHNE») with a measuring range of gas flow rate 12-250 m3 / h.

Measurement of the average volume flow of air is measuring complex, equipped with a rotating counters 7 (RVG-G-16 with a measuring range of gas flow in the working conditions of 8-160 m3 / h, maximum pressure up to 5,0 MPa) and an electronic corrector gas volume to the parameters of environmental environment EK260 with built-in absolute pressure sensors and platinum resistance thermometer.

On the oscilloscope recorded fast-changing pressure in the cylinders and valve cavities of pneumoengine, the angles of rotation of the crankshaft, the provisions in the TDC and BDC, the moments of angles close and reopen the shut-off valve elements.

To automate the experimental research used measurement set is compatible with computers, which were used in the data acquisition board with a frequency of collecting up to 100 MHz.

The software complex allows to configure the experiment script, storing and retrieving the script in the database, carry out measurements in real time with simultaneous archiving and visualization of experimental data. For the secondary processing and visualization of measurement results was developed special software.

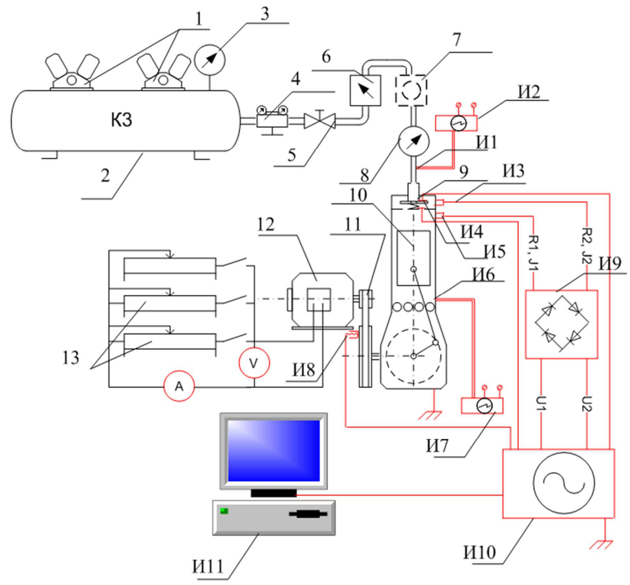

Fig. 2. Scheme of the experimental stand (the components of an automatic measuring system are highlighted and marked with the symbol И): 1 - Compressors 2 - Receiver, 3 - manometer, 4 - gas pressure regulator, 5 - Shut-off valve, 6 - flowmeter, 7 - Rotary counter; 8 - gauge pressure at the inlet, 9 - Locking element, 10 - cylinder and piston, 11 - Belt transmission; 12 - The electric motor (electric generator) DC; 13 - The load resistors; И1 - Thermocouple temperature input; И2 - meter inlet temperature; И3 - pressure in the suction cavity; И4 - Contact probe touches the limiter recovery; И5-pressure sensor in the cylinder; И6 - Thermocouple temperature at the outlet; И7-meter outlet temperature; И8 - Inductive timer TDC; И9 - Block converting current signals pressure sensors in the voltage differential signals to the ADC input; И10 – ADC; И11 – COMPUTER.

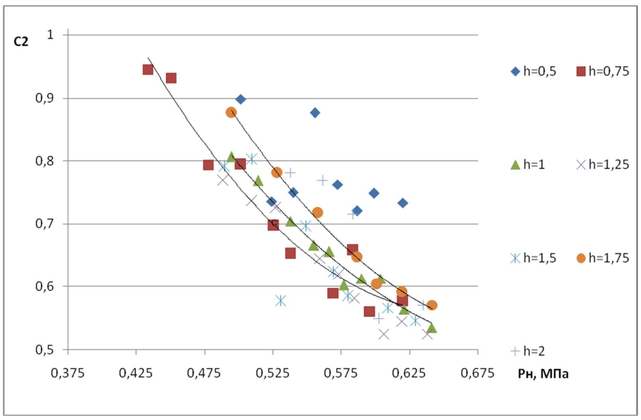

Fig. 3. Relative piston-stroke of the air pressure at the inlet to the engine when the rigidity Cpr = 1050 N / m, nominal relative dead space and variable height lift closures.

3. Results of Experiments

At a constant external load with an increase in inlet pressure pneumoengine for various lift height locking element closing the intake valve occurred closer to the middle of the piston-stroke ($C_2 \approx 0,55$) of TDC (Fig. 3), which is associated with an increase in the instantaneous piston velocity from zero to a maximum value of the crank mechanism.

When installed enough "hard" springs (Fig. 4) closing the valve, usually occurred after the opening of the piston exhaust windows ($C_2 \ge C_3 \approx 0,92$).

When you close the valve in the middle of the piston-stroke unit cost of compressed air for the operation of the engine at the corresponding external loads have minimum values (Fig. 5).

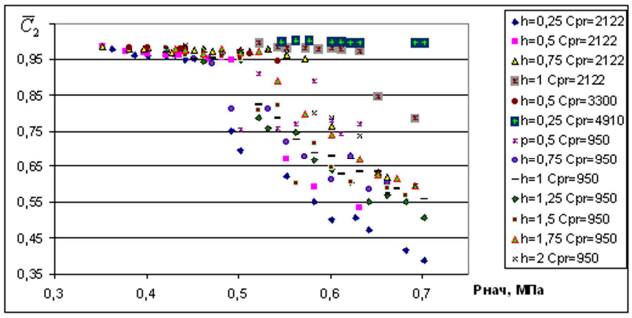

Fig. 4. The relative piston-stroke at the closing of the valve from the pressure of compressed air at the inlet of pneumoengine.

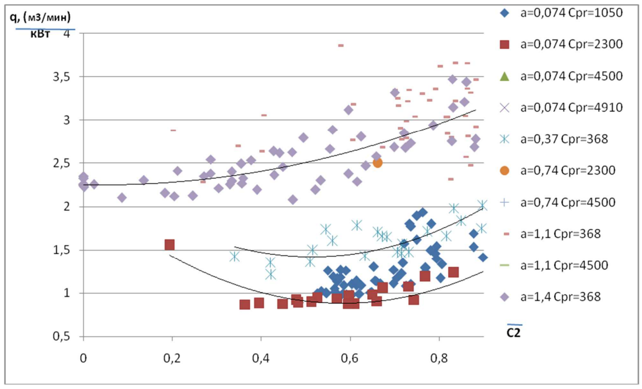

Fig. 5. Discharge intensity of air depending on the relative piston-stroke at the closing of the intake valve at a nominal relative dead space and variable height lift gate.

If the intake valve when $\bar{C}_2 \ge \bar{C}_3$ has not yet been closed, then open by the piston exhaust through the window there is a "parasitic slippage" of compressed air, which increased specific consumption of its pneumoengine.

In early reverse opening the intake valve before the arrival of the piston in TDC place filled with compressed gas cylinders, thus reducing the frequency of rotation of the shaft pneumoengine. As follows from Fig.6 decrease in the frequency of rotation of the motor shaft is also taking place with increasing spring stiffness especially at low altitudes lifting locking element ("little plus" in the Fig. 6). Have the same character depending on the indicator for power (Fig. 7).

The results have shown that appropriate choice of spring stiffness, regulation height gate at a constant external load and the lowest for a "dead" space, you can organize a working cycle, which can be achieved the best performance efficiency of pneumoengine (sufficiently high efficiency and lowest specific consumption of compressed air).

An analysis of the experimental curves of pressure in the cylinder from the angle of rotation of the crankshaft for various modes of operation scheme has been proposed submission cycles in the coordinates pressure – relative piston-stroke (Fig. 8).

For the origin of the the proposed schematization was adopted position by the piston at top dead center (TDC). As the dimensionless piston-stroke – the ratio of the current value of the piston-stroke Si to its full value of S, that is $C = S_i / S$. In the adopted notation, the dimensionless piston-stroke at the end of filling (closing the intake valve) - $C_2 = S_2 / S$, the expansion (opening piston exhaust windows) - $C_3 = S_3 / S$, ejection- $C_5 = S_5 / S$, compression (reverse of opening the intake valve) - $C_6 = S_6 / S$, in the position of the piston in the TDC and BDC, respectively equal- $C_1 = 0$, $C_4 = 1{,}0$.

At the point 1 cylinder volume equals the volume of dead space $V_м$ (the value of the relative dead space - $a = V_м / V_h = S_м / S$, the volume described by the piston in one revolution- V_h). With the valve open in the process of filling pressure in the cylinder varies along the line 1-2.

Depending on when the intake valve closing occurs, work cycles should be divided into two groups. When you close the valve to the passage of the piston exhaust windows (the first group of processes) at 2 begins the process of gas expansion (Fig. 8a), which ends at point 3 when the cavity of the cylinder through the exhaust windows connected with the atmosphere or the exhaust chamber. In the second group of processes after the closure of the valve is open the piston exhaust windows in the absence of the enlargement process (Fig. 8b).

Process exhaust 3-4 concludes with the arrival of the piston to BDC. Depending on the initial pressure, shape, number and size of window openings of exhaust gas pressure in the cylinder at the end of the process may, in one degree or another approach to the atmospheric or pressure in the exhaust chamber.

Processes 1-2, 2-3 and 3-4 occur when moving the piston from TDC to BDC under the effect of gas forces. Extrusion processes 4-5 and reverse compression 5-6-1 performed by the moment of inertia of the flywheel.

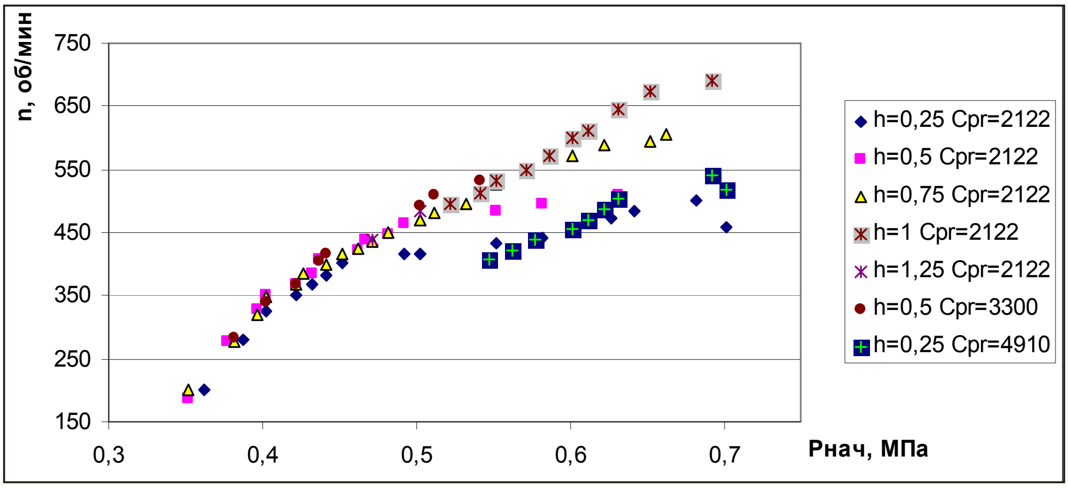

Fig. 6. *The dependence of the frequency of the shaft of the air pressure at the inlet at various altitudes lifting gate and spring stiffness.*

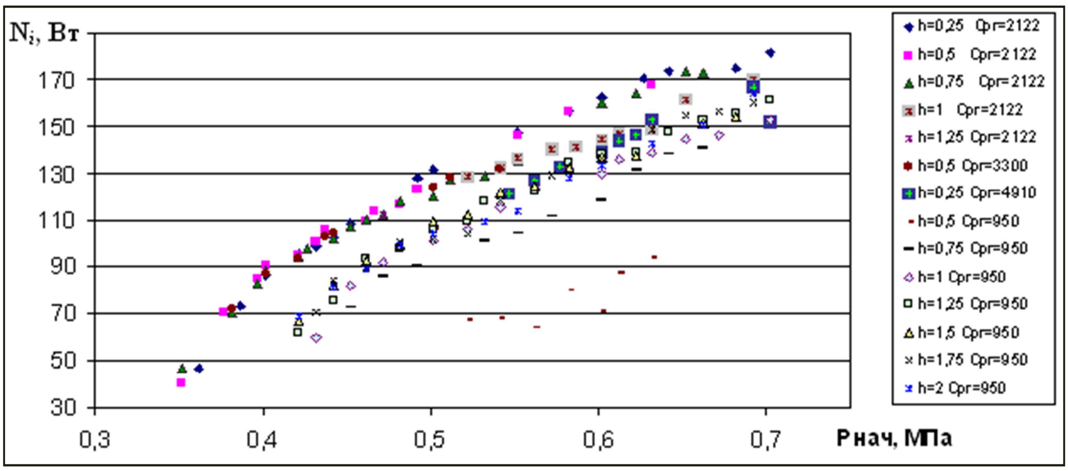

Fig. 7. *The dependence of the indicated power of the pneumoengine air pressure at the inlet for different spring stiffness and maximum altitude displacement gate.*

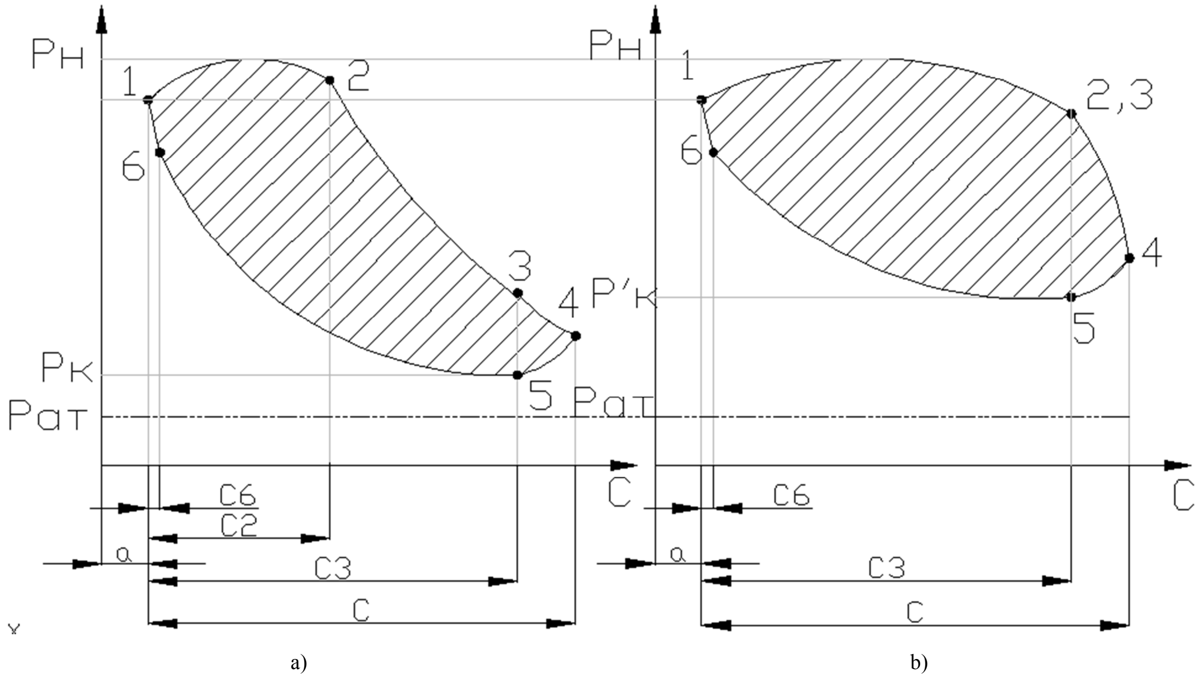

Fig. 8. *Schematized indicator diagrams of one in-line pneumatic actuator with a normally open a self acting valve: a) with the enlargement process (2-3), b) without the enlargement process; processes: 6-1-2 - filling; 3-4 - exhaust; 4-5 - pushing; 5-6 - reverse compression.*

4. Conclusions

Based on the results of experimental research one in-line pneumatic actuator found that:

- Moving the locking element on the valve seat (cylinder head) is the most structurally simple and economical means of regulation;
- The most efficient work process one in-line pneumatic actuator with the lowest unit costs can be achieved by adjusting the height locking element closing the intake valve a relative piston-stroke with a relative about 0.55;
- Accelerated mode of pneumoengine with hard springs achieved by increasing the height locking elements for closing the intake valves normally open at the time of passing of the piston exhaust windows;
- Indicated efficiency of one in-line pneumatic actuator is 0,40-0,43 of modes with an initial pressure of compressed air of about 0.65 MPa;
- For pneumoengine launch and operation without the use of additional devices is most expedient design with two opposed cylinders.
- It was also found that the pneumoengine could not succumb to specific factors of contemporary foreign and domestic models. Specific consumption of air under normal conditions for the indicated power, which is rather higher than the shaft pneumoengine, may be around 0, 8-1, 3 (m3 / min) / kW.

The accepted symbols

$a=V_м/V_h$ – size of relative dead space;

$V_м$ – dead space, m^3;

V_h – the volume described by the piston for one turn of a cranked shaft объём, m^3;

$C=S_i/S$ – a current relative piston stroke;

S_i - a current piston stroke, m;

S – a piston full speed, m;

C_1 – a relative piston stroke in position TDC;

C_2 – a relative piston stroke at the moment of closing of the inlet valve;

C_3 – a relative piston stroke at the moment of opening by the piston of exhaust windows;

C_4 – a relative piston stroke in position BDC;

C_6 – a relative piston stroke at the moment of opening of the inlet valve;

C_{pr} – rigidity of a spring of compression, H/m;

n – Frequency of rotation of a cranked shaft, mines^{-1};

h - the maximum height of lifting annular locking a valve element, mm;

N_i – display capacity of the pneumoengine, Vt, Вт;

p_{am} – atmospheric pressure of air, MPa;

$p_{нач}$ – pressure of air upon an input, MPa;

$p_ц$ – current pressure of air in the cylinder, MPa;

Δp – a difference of pressure, MPa;

q – the specific expense of compressed air, м3 minute/kw.

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