УДК 621.646.4

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EXPERIMENTAL RESEARCH OF WEARING PROCESSES IN METAL-METAL SEALING UNITS OF PNEUMATIC ELECTROMAGNETIC VALVES

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ПРОЦЕССОВ ИЗНОСА В ЗАПОРНЫХ УЗЛАХ ТИПА «МЕТАЛЛ-МЕТАЛЛ» ПНЕВМАТИЧЕСКИХ ЭЛЕКТРОМАГНИТНЫХ КЛАПАНОВ

Purpose. Experimental research of technical state change in metal-metal sealing units of pneumatic valve with two-positioned polarized electromagnetic drive.
Design/methodology/approach. It has been shown that the work peculiarity of pneumatic valves with two-positioned electromagnetic drive and with metal-metal sealing is shock loads during its closure and opening. Such loads lead to intensive wearing process and increasing of gas leakage through the sealing units of different design and made of different materials. It has been experimentally confirmed, that the effective way of wear intensiveness decreasing in metal-metal sealing units is the use of special damping units in the valve
Findings. As a result of experimental research it was concluded that including in the valve design of special damping device reduces the stress in the sealing unit elements, which occurs in the sealing units elements during the valve closing, and, as a result, the wear intensiveness of the sealing unit decreases. Usage of less wear-resisting, comparatively to the stainless steel 08X18H10T materials leads to the increase of wear intensiveness of the sealing unit contact surfaces.
Originality/value. Comparative analysis of the obtained experimental dependencies shows, that including of the damping device decreases the intensiveness of gas leakage increase through the closed valve, which occurs with the increase of the operational cycles. Damping element provides the kinetic energy dissipation that decreases the wear speed of the sealing surfaces of the valve slide and the saddle.
Keywords: electromagnetic valve, metal seal, shock loads, wear processes, gas leakage, damping device

Introduction

The electromagnetic valves with the metal-metal sealing unit are widely used in systems that work at high temperatures, in the aggressive environment or working liquid. Use of hard metal sealing leads to the shock loads on the valve elements during its closing and thus increases the processes of wear. That has a direct influence on the valve lifelength and operational reliability of the electromagnetic valve. For the resource evaluation of such valves it is important to evaluate the level of the dynamic loads, which are present on the valve sealing unit and are characterized by the dynamic coefficient. As it is shown in the work [4], the processes of closing in the valves with hard metal-metal sealing are characterized with the periodic shock loads with high dynamic coefficient that leads to fast destruction of the valve elements. It has been revealed, that dynamic coefficient highly depends on the hardness of kinematic links of the electromagnetic valve and the damping properties of the valve design [7].

The literature sources [5] give many examples of wear processes decreasing for the metal sealing unit of the electromagnetic valve with the use of damping properties of the valve assembly. In most cases that is achieved by including in the assembly a special element, which has less rigidness, than the valve slide or saddle. But this method has significant limitations by the damping factor, because the deformation of included spring damping element should be reversible. The most popular designs of the valve sealing units are shown on the Fig. 1.

The valve sealing that is shown on the fig. 1, *c* has normal rigidity, and the property of elastic deformation. It's a traditional design of valve metal sealing units, which requires careful surfaced job. In other designs the valve elements can be protected from the high loads with the help of the saddle with the spring bounding ring (Fig. 1, *d*). Sealing unit also can use the saddle with the spring properties that is made as thin bush (Fig. 1, *a, b*). For the high vacuum systems the valves can be made as it is shown on the Fig. 1, g, *e*. Such design has great sealing during the work at high temperatures, and has lifelength up to $3 \cdot 10^3$ cycles.

In present time there is a tendency at increasing the valve work time, so it is necessary to decrease the dynamic loads on the elements of the metal-metal sealing unit. This can be achieved by optimizing the sealing units, giving to it damping properties, and using special damping devices, that are implemented in the valve.

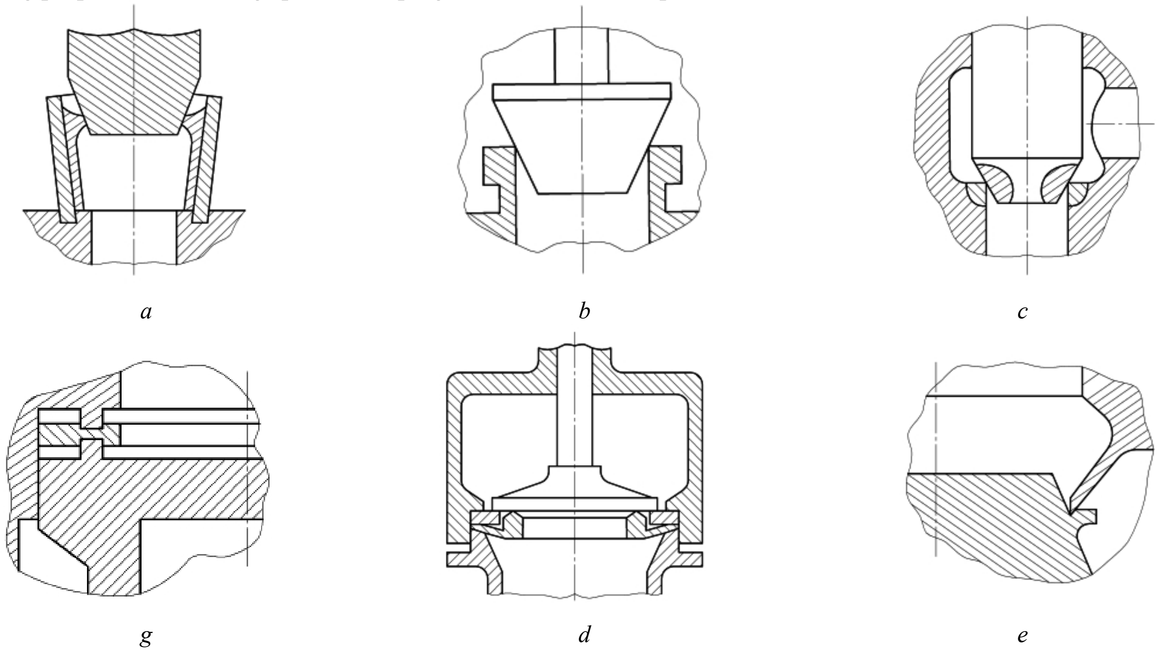


Fig. 1. Typical examples of the valve design with metal-metal sealing, which have damping properties

Aims of the research

Experimental research was conducted for solving next problems:

- determining the influence of cyclic shock loads on the change of the sealing element's geometry.
- studying the transition processes of the valve sealing into the non-working condition under the influence of long cyclic shock loads.
- evaluating the effectiveness of using special damping devices as the part of the electromagnetic valve.

Research

Object of the research. For the object of study it was chosen the serial pneumatic valves with two-positioned polarized electromagnetic drive, which were designed in PC «Kiev Central Design Bureau of Valves», and experimental modifications of those valves with the sealing units of different design:

– EMV with the cone valve slide and saddle;
– EMV with the cone valve slide and rectangular saddle;
– EMV with the spherical valve slide and rectangular saddle.

The experimental units were made of steel 08X18H10T, CT45, and BT1-0

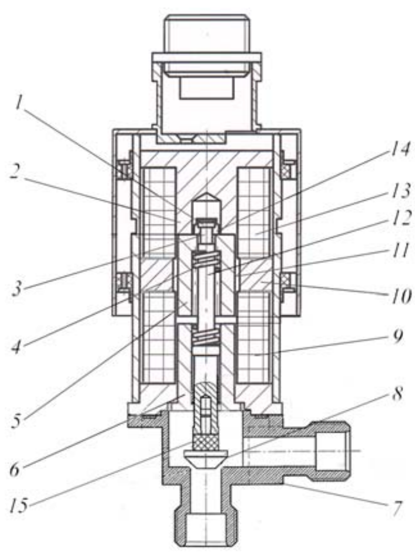
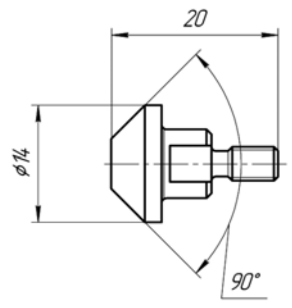
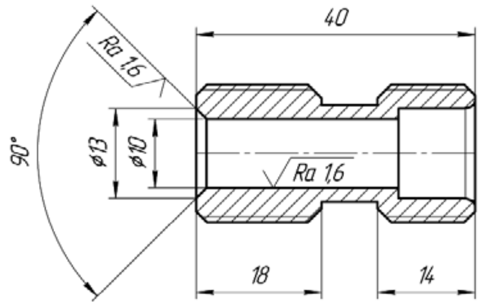


Fig. 2. Pneumatic electromagnetic valve with «metal-metal» sealing unit:
1 – rod head; *2* – case of the electromagnet (upper stop); *3* – rod neck; *4* – buffer spring; *5* – armature; *6* – bottom stop; *7* – saddle; *8* – valve slide; *9* – closing coil; *10* – constant magnet; *11* – separaion tube; *12* – rod; *13* – opening coil; *14* – lock washer, *15* – damping spacer

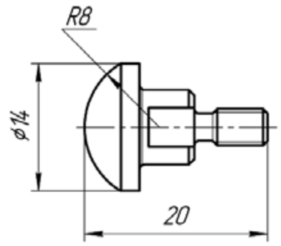
Types of used experimental sealing units of electromagnetic valve with metal-metal sealing unit are given on the fig. 3. Such designs of the sealing unit were chosen because of their wide use in the practical designing.



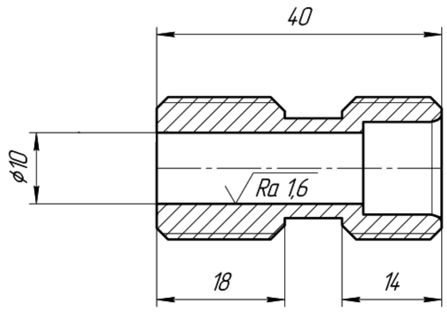
Valve slide, type 1



Saddle, type 1



Valve slide, type 2



Saddle, type 2

Fig. 3. Types of used experimental sealing units of electromagnetic valve with metal-metal sealing unit

With the purposes of the damping element the elastic nitril-butadien rubber ring was used. It was installed between the valve slide and the rod (see Fig. 2). For the effectiveness evaluation of this damping device the results obtained for the experimental units with and without damping were compared.

One loading cycle for the experimental unit of metal-metal sealing of the valve was conducted in the next way.

In the beginning position the valve is closed, and its opening coil *13* and closing coil *9* of the electromagnetic system are shut off from the electrical supply. Valve retaining in the closed position is provided by the force of the constant magnet *10,* and buffer spring *4*. In this position the valve slide *8* is pressed against the sealing surface of the saddle *7*. The spring *4* is compressed to its setting force N_{set} .

After the turning on the power supply to the coil *13* of the valve electromagnetic system, the armature *5* starts going upwards, and in the same time its compressing the buffer spring tarts going upwards, and in the same time its compressing the buffer spring *4* to the working force N_{work} . During this the armature *5* through the rod *12* transfers its motion to the valve slide *8*. During the armature movement, when the air gap between the armature and the upper stop *2* of the electromagnet decreases to the value, that is less than the air gap between the armature and the bottom stop *6*, the constant magnet is magnetically switched to the retaining of the armature in the open position. After the armature moves to its full path h , it collides with the upper stop of the electromagnet, and is retained in the upper position by the electromagnetic forces of the opening coil, and the constant magnet.

The closing process happens due to the armature movement in the reverse direction after the electric impulse in the closing coil *9*. During the movement of the armature with the rod, the constant magnet is reversed, and from that moment it creates the electromagnetic force, which retains the valve slide in the closed position.

The shock load onto the surfaces of the saddle and the valve slide is created during the closure, when the valve slide reaches the sealing surface of the saddle. The kinetic energy of the valve slide movement is transformed into the potential energy of deformation of contacting surfaces of the valve slide and saddle.

Observation of the technical condition changes of the metal-metal sealing was conducted as the gas leakage measurement through the sealing unit. Measuring of leakage was conducted during the increasing number of working cycles. The measurements were conducted for the experimental valves with and without the damping device in its design.

The obtained results of the gas leakage measurements for the closed valve made of stainless steel 08X18H10T, are given on the Fig. 4.

Given dependencies show, that use of the special damping device in the valve design decreases the speed of the gas leakage increase through the closed valve with the rising number of work cycles. The speed of leakage increasing for the sealing unit made of the valve slide type 1, and saddle type 2, has the average rate at $2,2 \cdot 10^{-6}$ m^3/hour for the one cycle. And the same parameter for the sealing unit made of valve slide type 1, and saddle type 1 is in average $2{,}0 \cdot 10^{-6}$ m^3/hour for the one cycle.

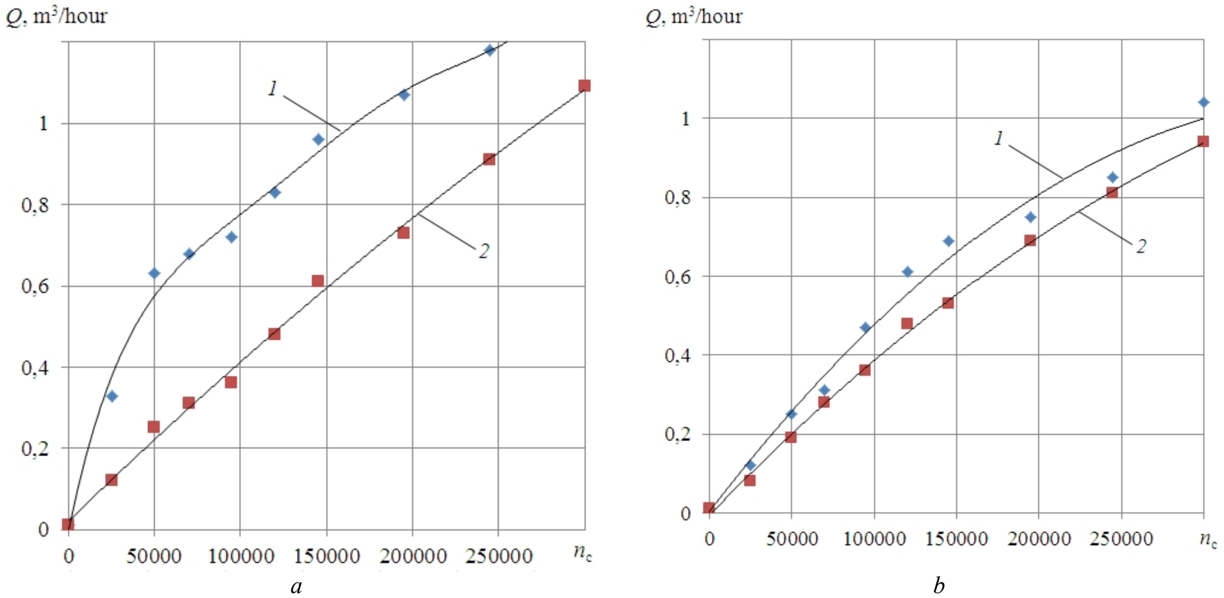


Fig. 4. Dependency of the gas leakage through the sealing unit, which is made of stainless steel, from the amount of the operating cycles:
a **– sealing unit made from valve slide type 1 and saddle type 2;** ***b*** **– sealing unit made from valve slide type 1 and saddle type 1;** *1* **– without the damper, 2 – with the damper**

Given dependencies show, that use of the special damping device in the valve design decreases the speed of the gas leakage increase through the closed valve with the rising number of work cycles. The speed of leakage increasing for the sealing unit made of the valve slide type 1, and saddle type 2, has the average rate at $2{,}2 \cdot 10^{-6}$ m^3/hour for the one cycle. And the same parameter for the sealing unit made of valve slide type 1, and saddle type 1 is in average $2{,}0 \cdot 10^{-6}$ m^3/hour for the one cycle.

Pair of valve slide type 1 and saddle type 2 is modeling the sealing unit, which is shown on the fig. 1*c*. Such design allows to simplify the sealing unit design without decreasing its sealing ability. That is achieved because of the sharp edge of the saddle, which is made with an angle of 90^o, and it creates high contact pressure on the valve slide. In this case the valve slide is damped as if it was made from the soft material, as it is shown on the fig. 1*g*. The stress, which occurs during closure inside the sealing unit elements made from valve slide type 1 and saddle type 2, are shown on the Fig. 5.

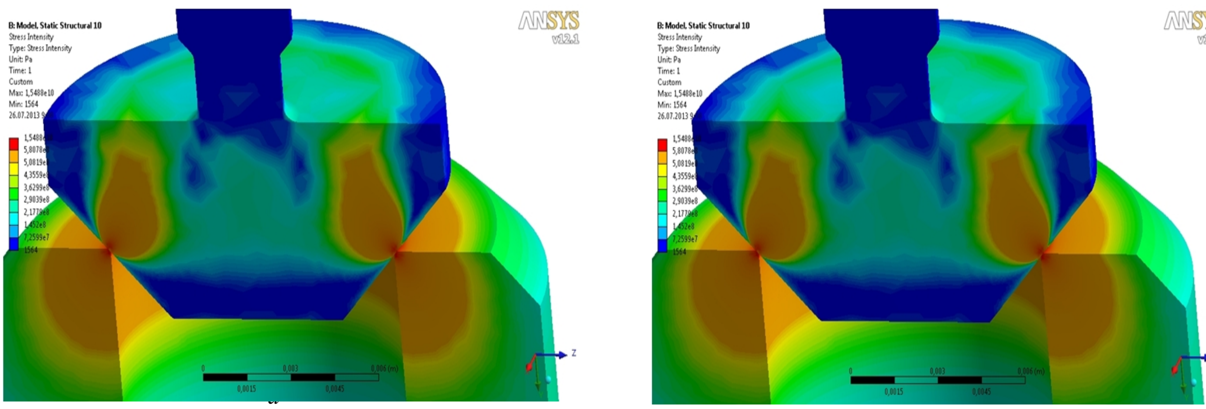


Fig. 5. Visualization of stress during the valve closing in the elements of the valve sealing units, which were made of stainless steel 08X18H10T for the valve slide type 1 and saddle type 2:
a **– without damper;** ***b*** **– with the damper**

The presented picture of stress disperse, which was obtained using the finite-elements method [4], correlates with the real picture of deformation for the valve slide, which is shown on the Fig. 6.

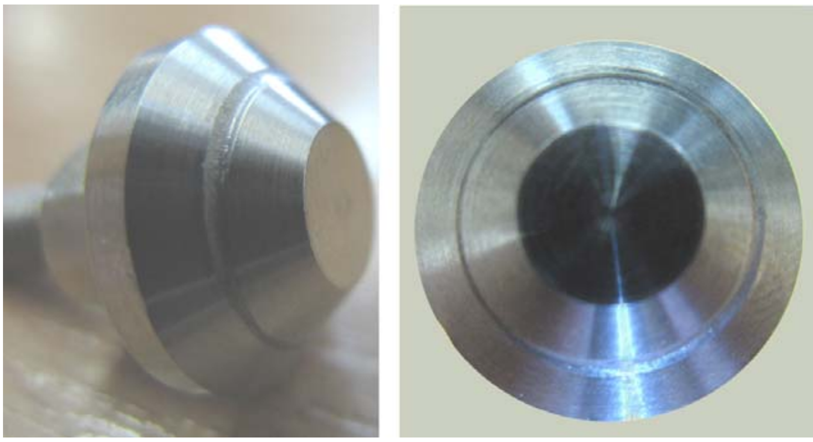


Fig. 6. Photos of the valve slide, which is made of stainless steel 08X18H10T, after the 300000 operation cycles without damping

Conducted calculations show, that in the sealing unit elements, which consists of valve slide type 1 and saddle type 1, in the moment of closing, there is slightly less level of stress (4,5% in average), that in the pair made of valve slide type 1 and saddle type 2. The reason for that is bigger area of the contact zone. Distribution of the stress, which occurs in the elements of the sealing unit made of valve slide type 1 and saddle type 2 in the moment of closing, are shown on the Fig. 7. Such valve design has less intensiveness of the gas leakage increase during operational cycles, because its elements receive less plastic deformation per one operational cycle. But the valves, which use the pair of valve slide type 1 and saddle type 1 require higher sealing force, which is generated by the electromagnet. That leads to the increase of mass of the whole valve, and increases energy consumption.

Experimental research has also shown that with the equal sealing force generated by the electromagnet, valves with the sealing unit made of valve slide type 1 and saddle 1 have slightly higher starting leakage in the closed position at zero working cycles, than the valve made of valve slide type 1 and type 2.

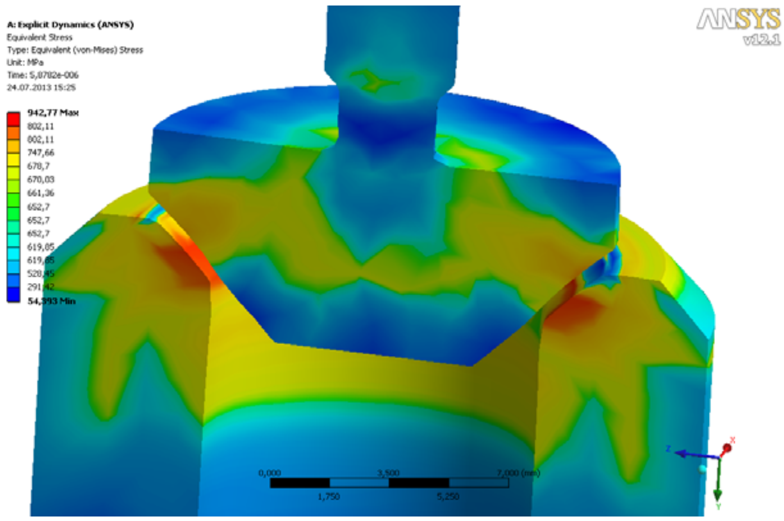


Fig. 7. Stress distribution in the elements of the valve sealing units, which has no damper, and that are made of stainless steel 08X18H10T, in the moment of closing for the valve slide type 1 and saddle type 2

The conducted valve operation research with the use of different sealing units design, which were made of stainless steel also show, that including in the valve design of special damping element reduces the stress, which occurs in the sealing units elements during the valve closing (см. рис. 5), and, as a result, the wear intensiveness of the sealing unit decreases.

Usage of less wear-resisting, comparatively to the stainless steel 08X18H10T materials, such as steel CT45 and titanium alloy BT1-0, leads to the increase of wear intensiveness of the sealing unit contact surfaces.

The experimental dependencies of the gas leakage change for the closed valve of the different valve slide and saddle design made of steel CT45 is shown on the Fig. 8.

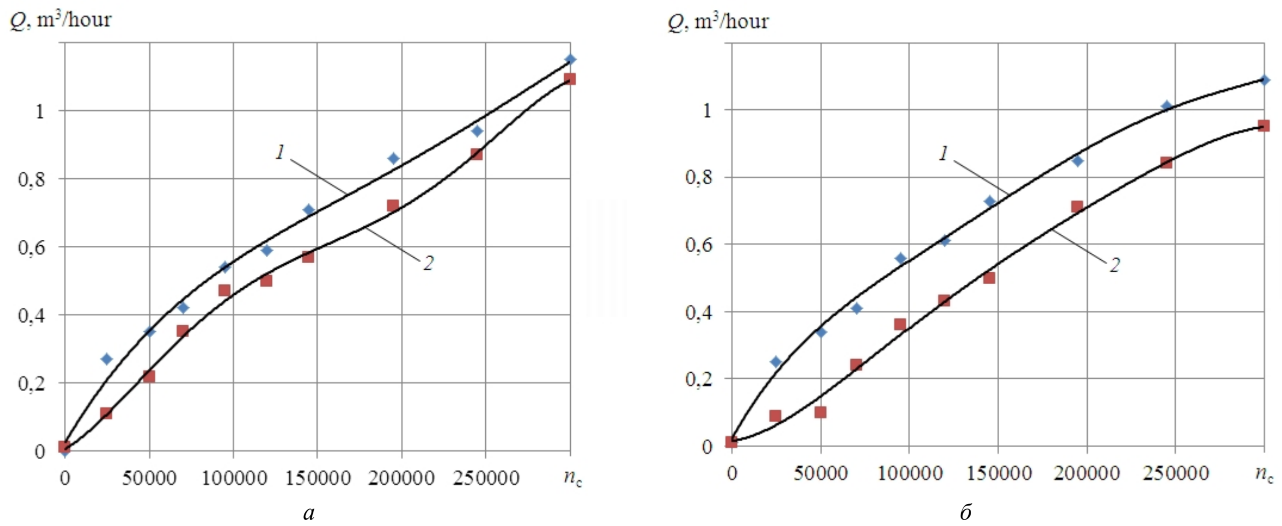


Fig. 8. Dependency of the gas leakage through the sealing, unit made of steel CT45, from the number of the operational cycles:
a **– sealing unit consists of the valve slide type 1 and saddle type 2;**
b **– sealing unit consists of the valve slide type 2 and saddle type 2;** ***1*** **– without damping,** ***2*** **– with the damping**

For the valve sealing unit, which consists of the valve slide type 1 and the saddle type 2, the average speed of the leakage increase in the closed position is $3,0 \cdot 10^{-6}$ m³/hour for the one operational cycle without the damper, and $2,9 \cdot 10^{-6}$ m³/hour for the one operating cycle with the presence of damper. For the sealing unit made of valve slide type 2 and saddle type 2 – correspondingly $5,33 \cdot 10^{-6}$ m³/hour for one operational cycle without the damper, and $3,96 \cdot 10^{-6}$ m³/hour for the one operational cycle with the presence of the damper.

The Fig. 9 shows experimental dependencies of the gas leakage change in the closed position if the valve for the different sealing unit design made of titanium alloy BT1-0.

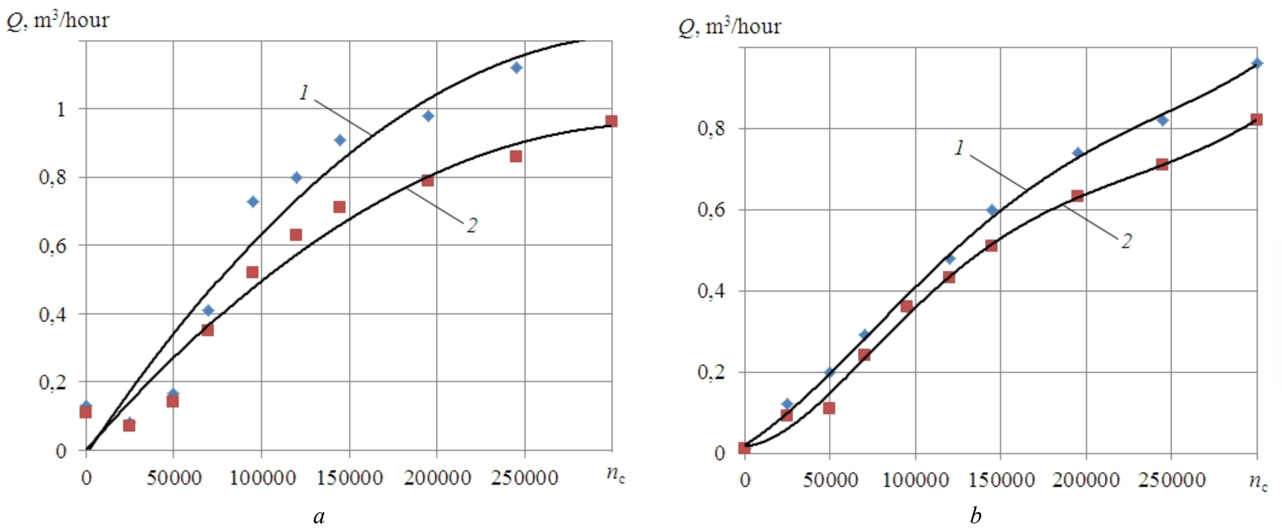
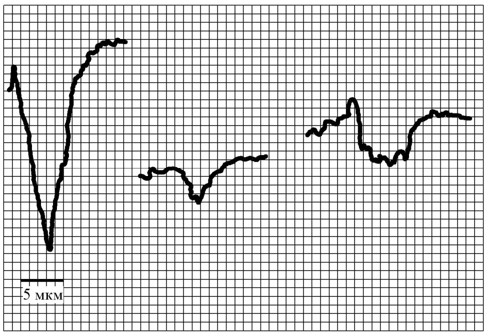


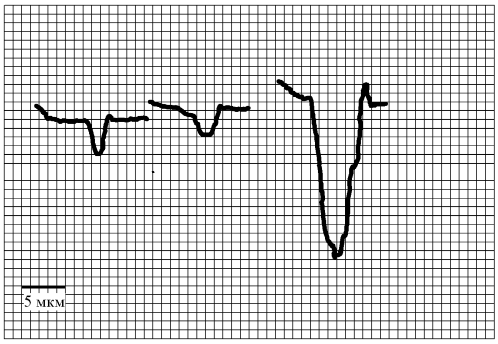
Fig. 9. Dependency of the gas leakage through the valve sealing unit made of titanium alloy BT1-0,
from the number of the operational cycles:
a **– sealing unit consists of the valve slide type 1 and saddle type 2;**
b **– sealing unit consists of the valve slide type 2 and saddle type 2;** ***1*** **– without damping,** ***2*** **– with the damping**

Installed sealing unit made of titanium alloy BT1-0 with the valve slide type 1 and saddle type 2 had an average increment of the gas leakage in closed position per operational cycle $4,4 \cdot 10^{-6}$ m³/hour without the damping device, and $3,2 \cdot 10^{-6}$ m³/hour per one cycle with the damping device. For the sealing unit made of the valve slide type 2 and saddle type 2 – correspondingly $4,8 \cdot 10^{-6}$ m³/hour per operational cycle without damper and $2,8 \cdot 10^{-6}$ m³/hour per one operational cycle with the damper.

Comparative analysis of the obtained experimental dependencies shows, that including of the damping device decreases the intensiveness of gas leakage increase through the closed valve, which occurs with the increase of the operational cycles. Damping element provides the kinetic energy dissipation, when the valve slide shocks at the saddle. That decreases the wear speed of the sealing surfaces of the valve slide and the saddle. It has been confirmed by the conducted scanning for surface profilograms for the experimental speciment made of stainless steel after the 300000 operational cycles (Fig. 10).



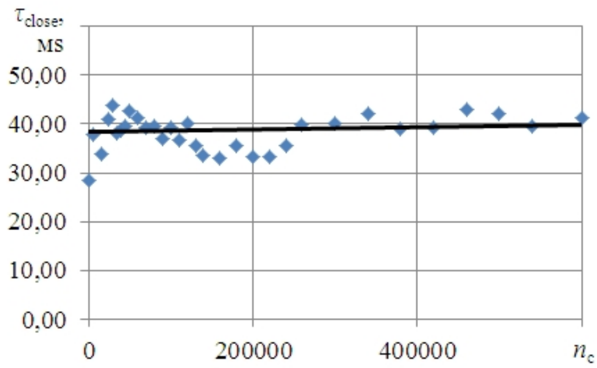
a



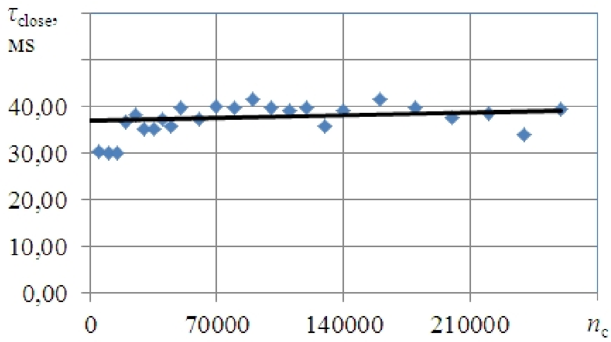
b

Fig. 10. Profilograms of the sealing surfaces of the valve slides type 1, made of stainless steel 08X18H10T, after 300000 operational cycles:
***a* – without damper; *b* – with the damper**

It is necessary to note, that including the damping device in the kinematic scheme of the valve in certain manner changes the character of the transient processes in the valve during its closing and opening [5]. There is an increase of the oscillation process. Fig. 11 shows experimentally obtained dependencies for the valve closing time τ, which increases with the number of the operational cycles. Including the damping element in the kinematic scheme of such electromagnetic drive only slightly increased the opening time τ, and its change intensiveness during operation.



a



b

Fig. 11. Changes of the closing time with the increasing of the operational cycles:
***a* – without damper; *b* – with the damper**

Summary

1. It has been experimentally confirmed, that the peculiarity of work of pneumatic drive with two-positioned polarized electromagnetic drive with the rigid metal-metal sealing unit is the occurrence of shock loads onto the surfaces of the sealing unit, which leads to the intensive wear processes of sealing surfaces of the valve slide and saddle during operation.

2. Experimentally obtained dependencies of the gas leakage increase trough the closed valve, with the operational cycles, for the different sealing elements design and different used materials (stainless steel 08X18H10T, steel CT45, titanium alloy BT1-0).

3. It has been shown the reasonability to use the cone valve slide and a saddle with a sharp edge in the sealing unit with metal-metal work surfaces. Usage of the cone valve slide with the cone saddle slightly decreases the level of stress inside the sealing unit elements under the shock loads, but it requires increasing of the sealing fors during the valve closing, which is created by the electromagnetic system of the valve.

4. For the electromagnetic valve lifelength increase it is reasonable to use as the constructive material for the sealing units with the metal-metal sealing surfaces the stainless steel 08X18H10T, which is more resistant to the shock loads comparatively to steel CT45 and titanium alloy BT1-0.

5. For decreasing the dynamic stress and wear intensiveness for the valve sealing surfaces with the meta-metal valve slide and saddle, it is effective to use special damping devices, which are implemented into the valve design.

Анотація. *В статті наведені результати експериментальних досліджень зміни технічного стану запірних вузлів типу «метал – метал» пневматичних клапанів з двопозиційним поляризованим електромагнітним приводом. Підтверджено, що особливістю функціонування таких електромагнітних клапанів є виникнення ударних навантажень на елементи запірного вузла клапана під час його закриття, що призводить до інтенсивним процесам зносу та збільшення протічки газа через клапана в його закритому положенні. Представлені експериментальні залежності збільшення протічки газа через запірний вузол клапана різного конструктивного виконання з використанням різних конструкційних матеріалів. Експериментально підтверджено, що ефективним засобом зменшення інтенсивності зносу елементів запірного вузла клапана типу «метал – метал» є застосування спеціальних демпфіруючи пристроїв в конструкції клапана.*

Ключові слова: електромагнітний клапан; металеве ущільнення, ударні навантаження, процеси зносу, протічка газу, демпфуючий пристрій.

Аннотация. *В статье приведены экспериментальных исследований изменений технического состояния запорных узлов типа «металл – металл» пневматических клапанов с двухпозиционным поляризованным электромагнитным приводом. Подтверждено, что особенностью функционирования таких электромагнитных клапанов является возникновение ударных нагрузок на элементы запорного узла клапана при его закрытии, что приводит к интенсивным процессам износа и увеличения протечки газа через клапан в закрытом положении. Представлены экспериментальные зависимости увеличение протечки газа через запорный узел клапана различного конструктивного исполнения с использованием различных конструкционных материалов. Экспериментально подтверждено, что эффективным способом уменьшения интенсивности износа элементов запорного узла клапана типа «металл – металл» является применение специальных демпфирующих устройств в конструкции клапана.*

Ключевые слова: электромагнитный клапан; металлическое уплотнение, ударные нагрузки; процессы износа; протечка газа; демпфирующее устройство

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Подана до редакції 07.11.2015