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WAYS TO IMPROVE THE RELIABILITY AND OPERATING LIFE OF SMALL-SIZE ELECTROMAGNETIC VALVE

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Abstract. *This article considers the main ways of improving the reliability and durability of small-size electromagnetic valves. Major changes in the technical state of the valve components under dynamic operating loads were revealed using the results of resource tests of two-position valves with polarized electromagnetic actuator. An effective way for reducing the dynamic loads has proved to be the introduction of the damping element into the kinematic scheme of the electromagnetic valve actuator. Damping elements efficiency in reducing dynamic loads has been confirmed experimentally.*

Keywords: damping; operating life; reliability; solenoid valve.

1. Introduction

Pneumatic and hydraulic valves with a solenoid actuator, hereinafter – electromagnetic solenoid valves (EV), are technical devices designed to control the working medium flow in pneumatic and hydraulic systems of various purposes.

There is a separate class of EV which consists of small-size valves. They are widely used in space and aircraft systems, particularly in life-support systems, orientation and stabilization systems, in thruster control systems and other aircraft systems.

Structurally EV has two components: the actuator and the drive unit, which actually is an electromagnetic drive (ED). EDs are of various designs, and differ in activation modes and principle characteristics. Usually EDs working on direct current are used in aircraft systems. Among those two-position valves with polarized push-pull EDs are the most promising [1]. These devices are characterized by minimal energy consumption because they use it only for movement of the drive moving assembly at the moment of opening and closing of the valve. Retention of the valve slide in any position is made by permanent magnetic flux of constant magnet integrated into the valve structure. Another advantage of this valve group is greater operating speed: opening and closing time is about 8...12 ms. Such performance is provided by the high moving speed of the valve motion device. However this is one of the reasons of developing intensive periodic shock loads resulting in fatigue deformations and destructions of the valve mechanical elements. This is especially true for small-size EVs, which have relatively small contact areas. Similar problems occur during EV operation when they have the lock unit “metal to metal”. During closing there is shock interaction of the metallic valve saddle with metal sealing surface at the bottom part of the valve slide.

It should also be noted that nowadays one of the trends in the development of aviation and airspace techniques is enhancing the products resource. Therefore the issue of improving reliability and durability of small-size EVs for modern aircraft systems is currently relevant.

2. Analysis of the latest research and publication

Preliminary analysis of the existing information array about aircraft systems EV failures shows that high level of dynamic loads that occur during small-size valve operation causes degradation processes of high intensity on the contacting surfaces and in structural material [2]. Thus, the typical EV failures with push-pull ED at the operation are the destruction of the core elements (the rods), shut off unit, lock washers and other components [3, 4].

The principle ways for increasing the reliability and lifetime of the small-size EVs are further improvement of their design, reduction of dynamic loads on the valve components and units, which limit their resource, and rational choice of work reserves [5–7].

3. Aim of the work

The aim of the work is to develop scientifically-based recommendations for increasing the reliability and durability of small-size EVs, driven by the push-pull ED, as well as valves with “metal-to-metal” sealing as a result of additional damping in the valve moving assembly for reducing dynamic loads on components and units of the EV. To achieve this goal experimental research of serial and experimental valve samples, designed by PC «Kyiv Central Design Bureau of armature engineering» for use in aircraft systems, were conducted.

4. The results of the resource tests of EV with the push-pull ED

To determine the principle degradation processes, which occur in the elements and units of the EV with ED, five serial valves of this type, used in aircraft stabilization systems, were subjected to the resource tests. Structural scheme of such valve is shown in fig. 1.

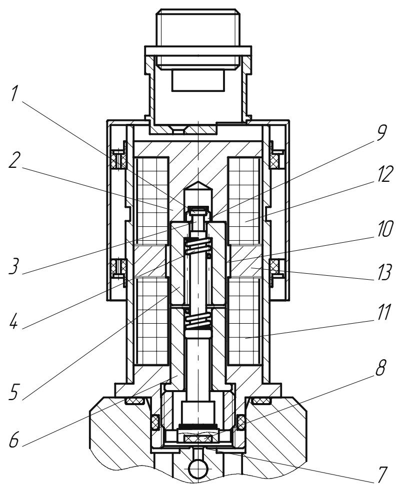


Fig. 1. Structural scheme of two-position valve with electromagnetic drive:
1 – rod head; *2* – electromagnet casing; *3* – rod; *4* – buffer spring; *5* – slider (armature); *6* – lower stop; *7* – saddle; *8* – slide; *9* – lock washer; *10* – distribution pipe; *11* – closing coil; *12* – opening coil; *13* – constant magnet

One of the design features of push-pull electromagnetic drive is the presence in its moving assembly of rod 3, which transfers executive force from the drive to the valve shut off unit.

During the test periodically every 20 000 cycles, which make up one block-cycle, the main parameters of the valve were checked (opening voltage U_{open} and time t_{open}, closing voltage U_{close} and time t_{close}), geometrical measurements were conducted and the slide travel distance x_{slide} was determined. Valve details were also photographed after the failure and subjected to the metallographic and the fractographic examination of the contact areas and the destruction zones of the valve mechanical elements.

The analysis of conducted resource tests has shown that during the valve operation the following changes occur in the valve technical state under the operation loads.

During the valve opening (when moving units travel away from the saddle) there are such effects as:

– shock cyclic contacting of the slider and locking washer, that leads to spalling as a result of fatigue of the contact end face surfaces (fig. 2) and changes in the relative position of these valve parts by the value c'' (fig. 3);

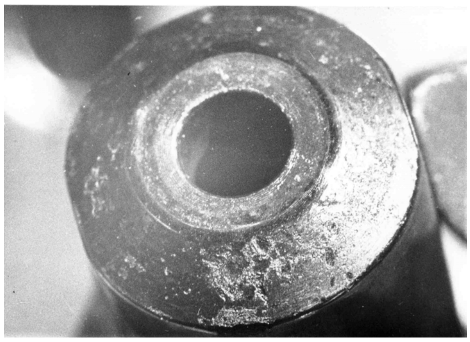


Fig. 2. Damage of the top end face surface of the slider (armature)

– cyclic application of distributed impulse force, which is normal to the contact plane of the washer and the rod head, that leads to changes in the configuration of parts 9 and 3 as a result of accumulation of one-sided plastic deformations, changes in the relative position of parts and accumulation of microdestructions in rod neck 3;

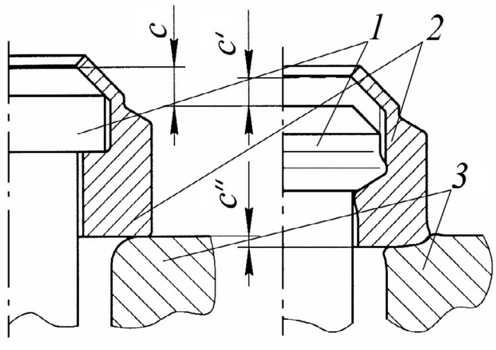


Fig. 3. Change in the relative position of locking washer (2), the head of the rod (1) and the slider (3).

– cyclic application of distributed shock force, which is normal to the contact area of the washer and rod head, which causes the change of the rod head configuration as well as lock washer (fig. 3) as a result of accumulation of the one-sided plastic deformations, change their mutual positions by value c' and accumulation of microdestructions in the rod neck material;

– shock cyclic contacting of the slider and upper stop, that leads to the degradation of the contact surfaces macrorelief of these parts (fig. 4).

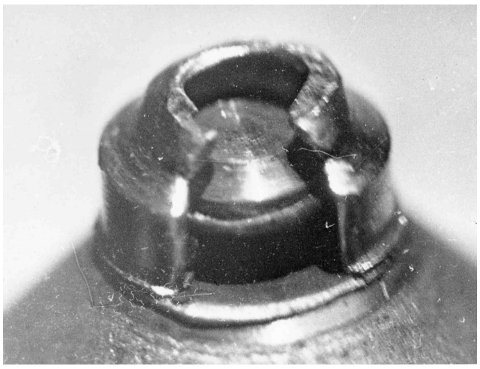


Рис. 4. Rod and slider mounting unite after valve lifetime end

At the valve closing (when moving assembly travels down to the saddle) there are such effects:

– shock cyclic contacting of the slide valve and saddle, that leads to the degradation of the contact surfaces macrorelief of the slide valve (fig. 5);

– shock cyclic contacting of the slider and lower stop, that leads to degradation of the contacting end face surfaces.

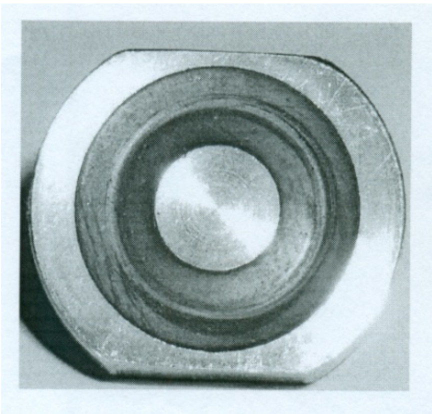


Fig. 5. Groove on the rubber surface of the rubber seal that is formed under the influence of operating loads

Deformation of the moving unit of EV results in significant changes in the relative position of the slider, the locking washer and the rod due to circular groove generation on the slider surface end face (c'') and plastic deformation of rod parts and locking washer by the value c' (fig. 3), which leads to the decreasing of slider travel distance by the value:

$$\Delta x_{зол} = c = c' + c'',$$

and that also increases the length of the chamber for buffer spring *4* (see fig. 1), which reduces the adjusting and operating force of the spring.

In addition, at the reciprocating motion of the valve moving unit the wearing process of the cylindrical surfaces of the slider and separation pipe occurs. As a result, there is a gradual degradation of friction surfaces microrelief and increase of friction forces.

The accumulation of microdeformations in the rod structural material leads, after a certain number of valve cycles, to the rod neck fracture (fig. 6) and complete EV failure.

Fig. 6. Fatigue destruction of rod neck

Under other equal conditions the intensity of the detected degradation processes is defined by the kinetic energy of the valve elements shock interaction that transforms into the deformation energy of these elements and accumulates in their structural material. The research conducted [6] shows that the condition of indestructibility of the core elements (rods) of the given EV type, is the inequality

$$E_k^{MU}(1 - K_{dis})n < E_{k_{cr}}^{\Sigma}, \quad (1)$$

where E_k^{MU} is the specific kinetic energy of a moving unit of the valve electromagnetic actuator; K_{dis} is the dispersion factor, which depends on the kinematic scheme of the valve moving unit and the presence of the damping element in it; n is the number of load cycles; $E_{к_{cr}}^{\Sigma}$ is the critical value of specific kinetic energy which transforms into the energy of structural material deformation and causes its destruction.

Analysis of the expression (1) shows that one of the effective ways to increase the number of valve operation cycles until the destruction of its rod is to increase coefficient K_{dis} by the installation of the damping element in the valve kinematic system, for example, rubber damping gasket *5* in the fastening unit of the slider and rod (fig. 7).

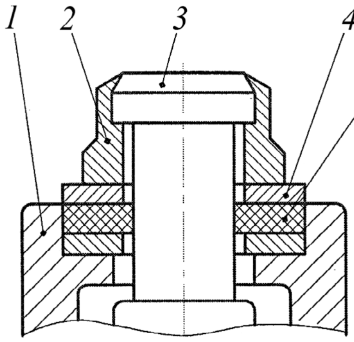


Fig. 7. Mounting unit of the rod and the slider with damping element:
1 – slider; *2* – lock washer; *3* – rod; *4* – washer; *5* – elastic element with low stiffness (damping gasket)

Experimental research of evaluating the effectiveness of such design decision has shown that the implementation of the damping element in the kinematic chain of the ED leads to the following effects:

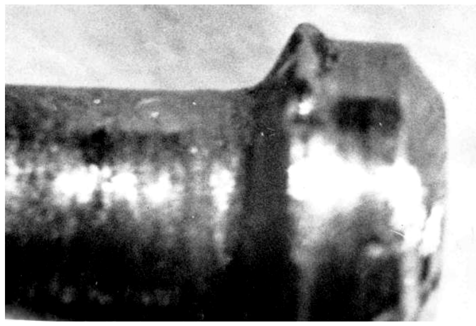
– increasing valve opening time from 32 ms to 44 ms and increasing valve closing time from 36 ms to 46 ms;

– appearance of fast damping oscillation process at the valve opening;

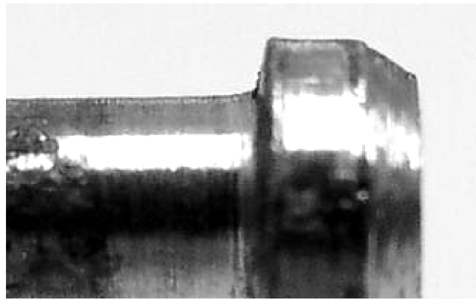
– significant reduction of changing the rod head and lock washer (fig. 8, as a typical example, shows the photos of the valve rod head after a certain number of cycles for the valve of usual design and with the damping element);

– significantly increased valve lifetime before the fatigue fracture of its rod (during comparative resource tests of the five usual design valves, the rod fracture occurred after respectively 6500, 6500, 10 000, 12 000 and 20 000 operational cycles, while two valves with the damping elements have worked 1000000 cycles without the rod destruction).

The positive impact of artificial damping on reducing the dynamic stresses and wear processes was also detected for the valves with the metal-to-metal lock unit (fig. 9), which have circuit groove in the structural material of the contact area of the slide and the saddle (fig. 10).



a



b

Fig. 8. Photos of valve drive rod head after resource loads: *a* – moving unit without damping device, operating time – 20 000 cycles; *b* – moving unit with the damping device, operating time – 1 000 000 cycles

As a damping element a rubber ring of 1 mm thickness was used.

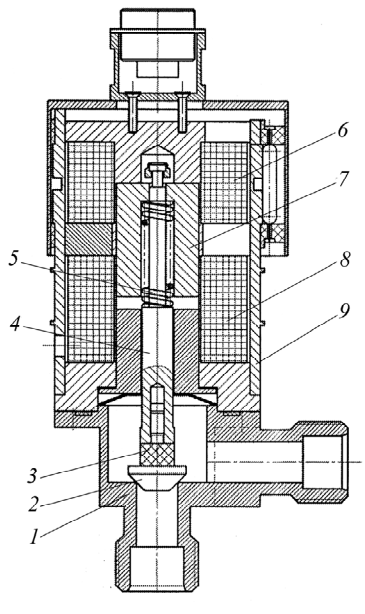


Fig. 9. Experimental prototype of the valve with metal-to-metal lock unit:
1– saddle, which is combined with the valve body; *2* – slide; *3* – damping element; *4* – rod, *5* – spring; *6* – opening coil; *7* – armature; *8* – closing coil; *9* – magnetic core

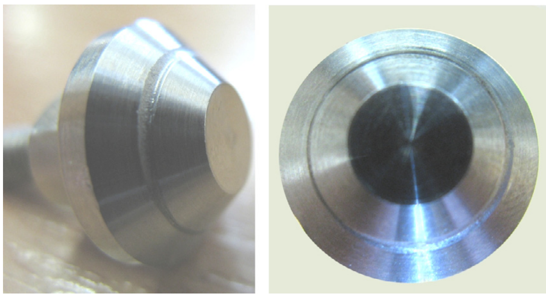


Fig. 10. Photos of the circular groove in the valve made of steel 08H18N10T after $3 \cdot 10^5$ cycles

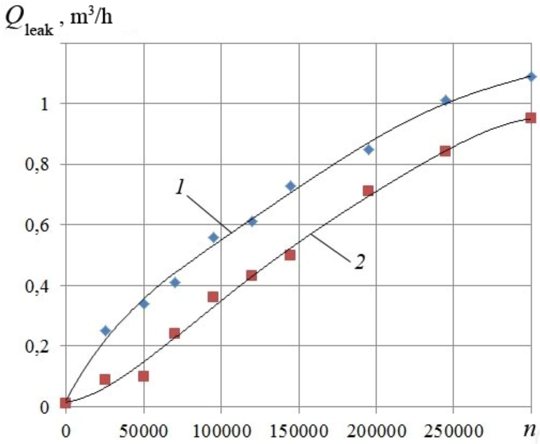
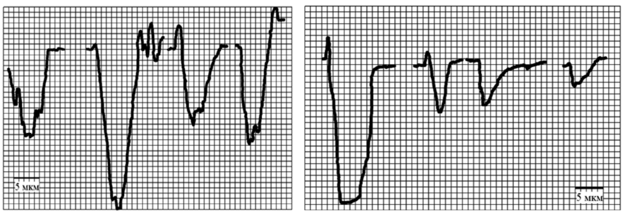


Fig. 11. Experimental dependencies of the leakage on the number of cycles:
1 – valve without damping element; *2* – valve with the damping element

The wear intensity reduction of the valve lock unit with damping element is confirmed by experimental dependencies of leakage change (fig. 11) and profile diagrams of the valve sealing elements after 300 000 cycles (fig. 12).



a *b*

Fig. 12. Profile diagrams of the slide and saddle contacting areas after 300 000 cycles:
a – without damping; *b* – with damping

5. Conclusion

Summarizing the results of conducted research on the reliability and durability of the small-size EVs allows make the following resume:

1. It was experimentally determined the typical changes in the valve elements and units technical state of small-size EV with push-pull ED under the working loads of the shock-impulse type. Such valves have a critical element – the rod, which has insufficient fatigue strength.

2. One of the ways to increase the reliability and durability of the small-size EV is the use of damping elements in kinematic scheme of the ED for reducing the intensiveness of the dynamical loads in valve elements and units.

3. Damping elements effectiveness in the reduction of dynamical loads is proven experimentally for the EV with two-positioned polarized ED and for the valves with the metal-to-metal sealing.

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Г. Й. Зайончковський[1], Є. І. Барилюк[2], Ю. С. Головко[3]. Шляхи підвищення надійності і довговічності малогабаритних електромагнітних клапанів
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Розглянуто основні шляхи підвищення надійності і довговічності малогабаритних електромагнітних клапанів. На підставі результатів ресурсних випробувань клапанів з двопозиційном поляризованим електромагнітним приводом виявлено основні зміни технічного стану деталей і вузлів клапана під дією динамічних експлуатаційних навантажень. Показано, що ефективним засобом зменшення динамічних навантажень є введення демпфірувального елемента в кінематичну схему електромагнітного приводу клапана. Ефективність використання демпфірувальних елементів для зниження динамічних навантажень підтверджена експериментально.

Ключові слова: демпфірування; довговічність; електромагнітний клапан; надійність.

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Рассмотрены основные пути повышения надежности и долговечности малогабаритных электромагнитных клапанов. На основании результатов ресурсных испытаний клапанов с двухпозиционным поляризованным электромагнитным приводом выявлены основные изменения технического состояния деталей и узлов клапана под действием динамических эксплуатационных нагрузок. Показано, что эффективным способом уменьшения динамических нагрузок является введения демпфирующего элемента в кинематическую схему электромагнитного привода клапана. Эффективность использования демпфирующих элементов для снижения динамических нагрузок подтверждена экспериментально.

Ключевые слова: демпфирование; долговечность; надежность; электромагнитный клапан.

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