Research of the aircraft dual-mode actuator with combined speed control during the transition from the main type of power supply to the backup

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Abstract. The paper presents the results of mathematical modelling and experimental research of a dual-mode electro-hydraulic actuator with combined speed control during the transition from the main type of power supply to the backup.

1. Introduction
In order to improve the fail-safety of the primary flight controls, the architecture of the integrated control system (ICS) of passenger aircraft involves the installation of several actuators to the flight control surface [1, 2]. At the same time, in the light of the concept of «more electric aircraft» (MEA), steering actuators with electric or dual-mode (electric and hydraulic) type of power supply are getting more and more use in modern passenger aircraft. These actuators include electro-hydrostatic and dual-mode electro-hydraulic types.

Dual-mode actuators constitute a special kind. Such actuators are capable of receiving power from both the on-board centralized hydraulic system of the aircraft (CHS) and the power electrical system. In this case, the main mode of operation of a dual-mode actuator is considered to be the mode in which it receives power from an external CHS (further «a main mode»).

2. Problem statement
There are various types of dual-mode actuators [3], those includes electric-backup hydraulic actuators (EBHA) [4,5], dual-mode electro-hydraulic actuators with combined speed control (EBHA-CSC) [6,7] and electro-hydraulic actuators with backup power source [8,9].

The functional diagram of a typical dual-mode electro-hydraulic actuator with combined speed control [7] is shown in figure 1. As it can be seen from the figure, the power supply modes in actuator are switched by a special pilot valve. This method of switching is also implemented in foreign electric-backup hydraulic actuators known to the authors [2, 3, 4].

The design feature mentioned above leads to the fact that the process of uncontrolled movement of the actuator rod and the associated spontaneous deflection of the flight control surface, at the moment of transition from one power supply mode to another, directly depends on a combination of factors, including:

- the delay of the built-in test system (BITS) to transfer the actuator from the main to backup power supply mode, introduced to prevent false failures;
- the type of switching a pilot valve: «hydraulically» by pressure in the external hydraulic system or «electrically» by an electrical command signal and the time that takes to changing the valve state;
- the time that needs to the backup power supply source to reach the operating mode (turning on the electric motor control unit, turning the electric motor to the required operation mode, etc);
- aerodynamic loads acting on the actuator and flight control.

In order to determine the influence of the above factors, a mathematical model of the EBHA-CSC was developed and an experimental study of the actuator work was conducted.

**Figure 1.** Schematic diagram of EBHA-CSC: LEM – linear electric motor, M – DC brushless motor, MSV – Mode selection valve, RV – Reversing valve, EHSV - Electrohydraulic servovalve, AFCV – spool of EHSV, EHA – Electro-hydrostatic actuator.

### 3. The object of study, research methods and main results

To study the switching modes of a dual-mode electro-hydraulic actuator with combined speed control (EBHA-CSC) a highly detailed mathematical model was developed in MatLab Simulink. The mathematical model of actuator, that was taken as a basis, is described in [7]. When EBHA-CSC operates from an external hydraulic system, it works as a typical electro-hydraulic servovalve actuator. The principal task in the compilation of the mathematical model was the correct description of the electro-hydraulic valve which switches actuator active modes. A prototype of a dual-mode electro-hydraulic actuator with combined speed control DRP-1 [7] was chosen as an object of study [7] and the logic of the operation of the mode selection valve (MSV) that was adopted in the actuator was implemented. The appearance of the test is shown in figure 2.
Figure 2. The appearance of EHA-1 actuator.

Structurally, the MSV consists of a spool valve, to one of the edge of which the high pressure hydraulic line is connected, which (high pressure hydraulic line) is cut off by the pilot valve (see figure 1). At the other edge, a compression spring and a contactless spool position sensor are installed. If a pilot valve is switched on, a high pressure fluid is supplied under the edge of the spool, the spring is compressed and the spool connects the hydraulic cylinder cavities to the EHSV, thereby transferring the actuator into power supply mode from the external hydraulic system («main mode»). The proximity sensor controls the position of spool. In the event of a pressure drop in the external hydraulic system, the MSV spool is moving to its basic state by a spring, the position sensor is triggered and a current is switched off from pilot valve coils, finally cutting off the high-pressure line from the edge of the spool. The MSV spool connects the cavities of the hydraulic cylinder with the reverse valve, thereby transferring the actuator to the backup operating mode from an external electrical system («autonomous operating mode» of the actuator).

It is worth noting that the forced disconnection of the high-pressure line from the edge of the MSV spool is made in order to avoid oscillations of the spool with an uneven or pulsating pressure drop in the external hydraulic system.

Preliminary verification of the mathematical model was carried out in the laboratory of department 702 of Moscow Aviation Institute on the test rig that was described in [10]. In the mathematical model of MSV the following issues were considered:

- the position of the valve and the opening area of the spool ports were depended on the pressure under the edge of the spool and the spring compression force. The valve was disconnected from the external hydraulic system when the supply pressure dropped to 12 MPa or according to the control signal (command to the pilot valve);
- the inclusion of the mechatronic actuator module (see figure 1 and [7]) was carried out simultaneously with the command to pilot valve, i.e. the electrical energy channel was in the «cold reserve».
- idle actuator was considered.

Figure 3a shows the results of mathematical modelling of EBHA-CSC operation when the actuator transits from the main operation mode to the autonomous one by a command signal. Figure 3b shows the simulation results with a smooth fall in supply pressure and EBHA-CSC switching to standalone mode by pressure level. As it can be seen from the figures, taking into account the adopted mechanical time constant ($T_m$) of the electric motor, the switching process lasts about 0.2 ... 0.3 seconds, and there are no uncontrolled oscillations of the actuator rod.
Figure 3. The graphs of moving of actuator output link and control signals when actuator transits from the main operation mode to the autonomous: a - by command signal; b - according to the level of discharge pressure.

Figure 4 shows the experimental graphs of the dual-mode electro-hydraulic actuator with combined speed control DRP-1 when actuator changes operation modes. As can be seen from figure 4a, when the actuator transits from the main to autonomous mode of operation, there is a drop in the speed of movement of the actuator stem related to the output of the mechatronic module and the pump to the nominal mode of operation from the «cold reserve».

During the reverse switching of the energy channels, an uncontrolled jump of the output link of the actuator is observed, caused by the operation of the valve.

Figure 4. The graphs of moving the output link of the actuator when switching energy channels: a - from the main to autonomous; b - from autonomous to main.
4. Conclusions
The obtained experimental graphs correspond to the results of mathematical modelling, which allows us to speak about the reliability of the accepted research methods. The developed mathematical model is well verified with the previously obtained results [7, 10], which allows it to be used to study various modes of operation of dual-mode electro-hydraulic actuators with combined speed control.

In addition, the developed mathematical model can be used in the educational process to train specialists in the field of actuators for ground, aviation and space technology.

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