



The Property Comparison of Electromechanical and Electro-hydraulic Flight Control Actuators

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Abstract:

The paper is focused on the problems of modelling and simulation of aircraft electromechanical and electro-hydraulic actuators. The obtained results are used in a teaching process of this issue using their interactive displays for different activity modes.

Keywords:

Flight control actuator, modelling, simulation

1. Introduction

The utilization of modelling and computer simulation in teaching the system properties and their components brings higher quality and effectiveness of teaching and from the didactic point of view it also opens possibility for convenient interactive work. The merits of this method are especially significant in cases when it is necessary to simulate their action in various boundary work regimes that is not possible to induce in laboratory measurements of physical models because it could lead to their destruction. An aircraft flight control system is one of the systems that defines the flight characteristics and potential uses of the aircraft type. In modern aircraft, this system is composed of electric, hydraulic and mechanical components and must provide the necessary stability and control ability at different flight regimes. The servo-unit is an output component of the aircraft flight control system. It is necessary first to establish mathematical and simulation models before the behaviour analysis of the servo-unit and comparing it with the basic modes. Creating mathematical and computer models of an electromechanical and electro-hydraulic actuator is preferably based on its known principled schemes [1-4].

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2. Modelling of Flight Control Actuators

The electromechanical servo-drive is composed of an electromotor with a gear box, and consists of the feedback circuit with a mechanical converter (angular and linear) shifting to the electrical signal. The electro-hydraulic servo-drive generally consists of hydraulic power mechanism and electric or electro-hydraulic control circuits.

The solution of basic equations, describing the circuits of both compared actuators and adopting appropriate simplistic assumptions, can be obtained from the following block diagrams and transfer functions (see Fig. 1 and Fig. 2) of their computer simulation.

We used technical parameters for modelling of servo-drive units: electro-hydraulic servo-drive EGP and electromechanical servo-drive DPR-72 (with electromotor DV-200) [1].

2.1. Transfer Functions of the Electromechanical Actuators

The open-loop transfer function of the power electric drive is

$$W(p) = \frac{T_z p}{(T_K p + 1)(T_{za}^2 p^2 + 2\zeta_{za} T_{za} p + 1)} \quad (1)$$

$$T_{z1} = 0.1 \text{ s} \rightarrow \omega_{z1} = 10 \text{ s}^{-1}; T_K = 0.0007 \text{ s} \rightarrow \omega_k = 1430 \text{ s}^{-1}; \\ T_{za1} = 0.05 \text{ s} \rightarrow \omega_{za1} = 20 \text{ s}^{-1}; \zeta_{za1} = 0.2,$$

$$W_1(p) = \frac{0.1p}{(0.0007p + 1)(0.0025p^2 + 0.02p + 1)} \quad (2)$$

Assuming

$$K'_z = 0.5 K_z; T_{z2} = 0.2 \text{ s} \rightarrow \omega_{z2} = 5 \text{ s}^{-1}; T_K = 0.0007 \text{ s} \rightarrow \omega_k = 1430 \text{ s}^{-1}; \\ T_{za2} = 1.414 T_{za1} = 0.0707 \text{ s} \rightarrow \omega_{za2} = 14.14 \text{ s}^{-1}; \zeta_{za2} = 1.414 \zeta_{za1} = 0.2828,$$

$$W_2(p) = \frac{0.1p}{(0.0007p + 1)(0.005p^2 + 0.04p + 1)} \quad (3)$$

The closed-loop transfer function of the power electric drive is

$$\Phi_{\mathcal{K}}(p) \approx \frac{T_z p}{(T_z p + 1)(T_{mech} p + 1)(T_K p + 1)}. \quad (4)$$

Assuming

$$T_{z1} = 0.1 \text{ s} \rightarrow \omega_{z1} = 10 \text{ s}^{-1}; T_K = 0.0007 \text{ s} \rightarrow \omega_k = 1430 \text{ s}^{-1}; \\ T_{mech} = 0.025 \text{ s} \rightarrow \omega_{mech} = 40 \text{ s}^{-1},$$

$$\Phi_{\mathcal{K}1}(p) \approx \frac{0.1p}{(0.1p + 1)(0.025p + 1)(0.0007p + 1)} \quad (5)$$

$$\Phi_{\mathcal{K}2}(p) \approx \frac{0.2p}{(0.2p + 1)(0.025p + 1)(0.0007p + 1)} \quad (6)$$

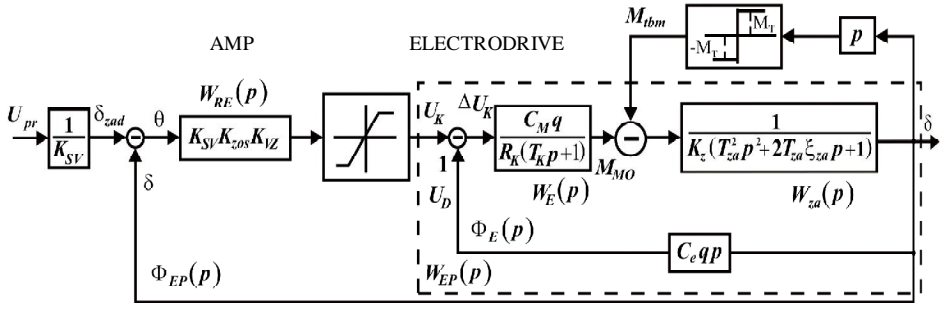


Fig. 1 Block scheme of electromechanical actuators

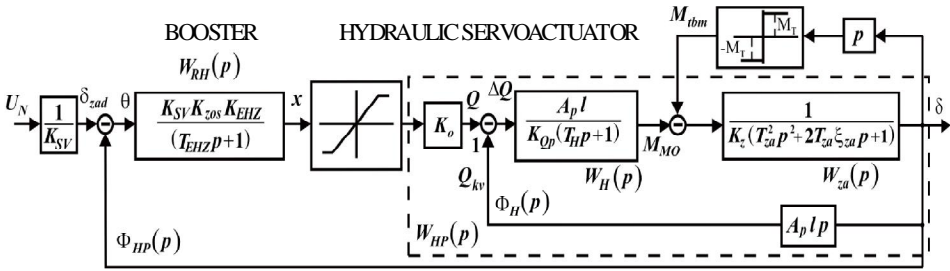


Fig. 2 Block scheme of electro-hydraulic actuators

The open-loop transfer functions of an actuator are

$$W_{PO}(p) = \frac{d(p)}{q(p)} = W_{zos}(p) \cdot W_{EP}(p) = \frac{K_{PO}}{(T_z p + 1)(T_{emch} p + 1)(T_K p + 1)} \quad (7)$$

$$W_{PO1}(p) = \frac{6}{(0.1p + 1)(0.025p + 1)(0.0007p + 1)} \quad (8)$$

$$W_{PO2}(p) = \frac{12}{(0.2p + 1)(0.025p + 1)(0.0007p + 1)} \quad (9)$$

The closed-loop transfer functions of an actuator are

$$\Phi_{P1}(p) = \frac{1}{(T_k p + 1)(T_{PO}^2 p^2 + 2T_{PO}x_{PO}p + 1)} \quad (10)$$

The closed-loop transfer function of an actuator can be approximately expressed by an oscillating circuit.

$$w \leq \frac{1}{T_{emch}}; \quad \Phi_{P2}(p) = \frac{d(p)}{d_{zad}(p)} \approx \frac{1}{T_{PO}^2 p^2 + 2x_{PO}T_{PO}p + 1}$$

Assuming

$T_K = 0.0007 \text{ s} \rightarrow \omega_k = 1430 \text{ s}^{-1}$; $T_{PO} \approx T_{emech} = 0.02 \text{ s} \rightarrow \omega_{PO} = 50 \text{ s}^{-1}$; $\zeta_{PO} = 0.4$,

$$\Phi_{P1}(p) = \frac{1}{(0.0007p+1)(0.0004p^2+0.016p+1)} \quad (11)$$

Assuming $K'_z = 0.5 K_z$; $T_{PO} \approx T_{emech} = 0.02 \text{ s} \rightarrow \omega_{PO} = 50 \text{ s}^{-1}$; $\zeta_{PO} = 0.4$,

$$\Phi_{P2}(p) = \frac{1}{0.0004p^2+0.016p+1} \quad (12)$$

2.2. Transfer Functions of the Electro-hydraulic Actuators

The open-loop transfer function is

$$W_{PO}(p) = \frac{d(p)}{q(p)} = \frac{K_{PO}}{(T_z p + 1)(T_{EHZ} p + 1)(T_{HP}^2 p^2 + 2T_{HP} x_{HP} p + 1)(T_r p + 1)} \quad (13)$$

Assuming

$T_r = 0$; $K_{PO} = 225$; $\zeta_{PO} = 0.4$; $T_z = 1.8 \text{ s} \rightarrow \omega_z = 0.55 \text{ s}^{-1}$;
 $T_{HP} = 0.0022 \text{ s} \rightarrow \omega_{HP} = 450 \text{ s}^{-1}$; $T_{EHZ} = 0.008 \text{ s} \rightarrow \omega_{EHZ} = 125 \text{ s}^{-1}$; $\zeta_{HP} = 0.3$,

$$W_{PO}(p) = \frac{225}{(1.8p+1)(0.008p+1)(0.000005p^2+0.00088p+1)} \quad (14)$$

The closed-loop transfer function is

$$\Phi_P(p) = \frac{d(p)}{d_{zad}(p)} = \frac{1}{(T_{PO}^2 p^2 + 2T_{PO} x_{PO} p + 1)(T_{HP}'^2 p^2 + 2T_{HP}' x_{HP}' p + 1)} \quad (15)$$

$\zeta'_{HP} \leq \zeta_{HP} = 0.2$; $T'_{HP} \approx T_{HP} = 0.0022 \text{ s} \rightarrow \omega'_{HP} = 450 \text{ s}^{-1}$;
 $T_{PO} = 0.008 \text{ s} \rightarrow \omega_{PO} = 125 \text{ s}^{-1}$; $\zeta_{PO} = 0.5$,

$$\Phi_P(p) = \frac{1}{(0.000064p^2+0.008p+1)(0.000005p^2+0.00088p+1)} \quad (16)$$

The power part transfer function is

$$W'_{HP}(p) = \frac{1}{(T_{HP}'^2 p^2 + 2T_{HP}' x_{HP}' p + 1)} \quad (17)$$

$T'_{HP} \approx T_{HP} = 0.0022 \text{ s} \rightarrow \omega'_{HP} = 450 \text{ s}^{-1}$; $\zeta'_{HP} \leq \zeta_{HP} = 0.2$,

$$W'_{HP}(p) = \frac{1}{(0.000005p^2+0.00088p+1)} \quad (18)$$

where ω – rotation speed, J – moment of inertia, M – torque, M_{fl} – friction torque, Q – flow quantity, δ – deflection angle, T_K – electromagnetic time constant, T_{emech} – electromechanical time constant of the drive, T_{za} – time constant of the load torque drive, ζ_{za} – damping coefficient of the load torque drive, ζ_{PO} – damping coefficient of an actuator, K_{PO} – amplification coefficient of open circuit electrical power, T_{HP} – time constant of the hydraulic drive, T_γ – converter electrical time constant of

electromechanical power control, T_{EHZ} – time constant of an electro-hydraulic amplifier, ζ_{HP} – damping coefficient of the hydraulic drive.

3. Simulating Models of Actuators

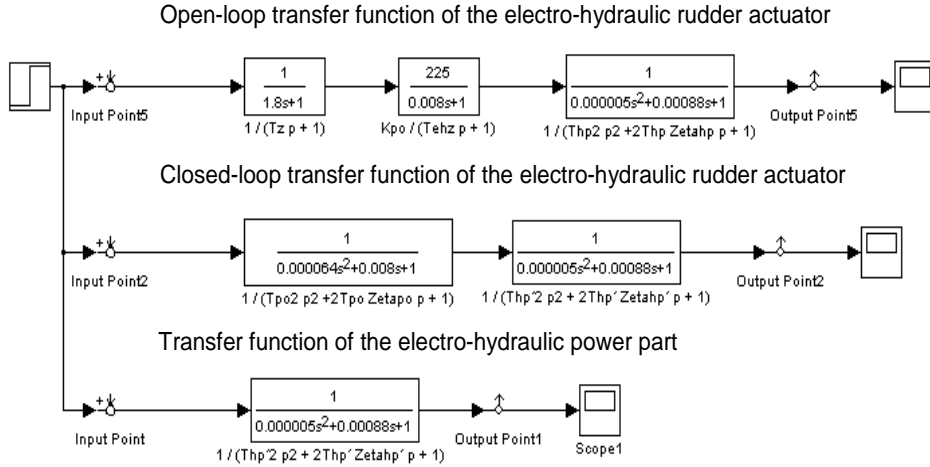


Fig. 3 Block scheme of electro-hydraulic actuators in Simulink environment

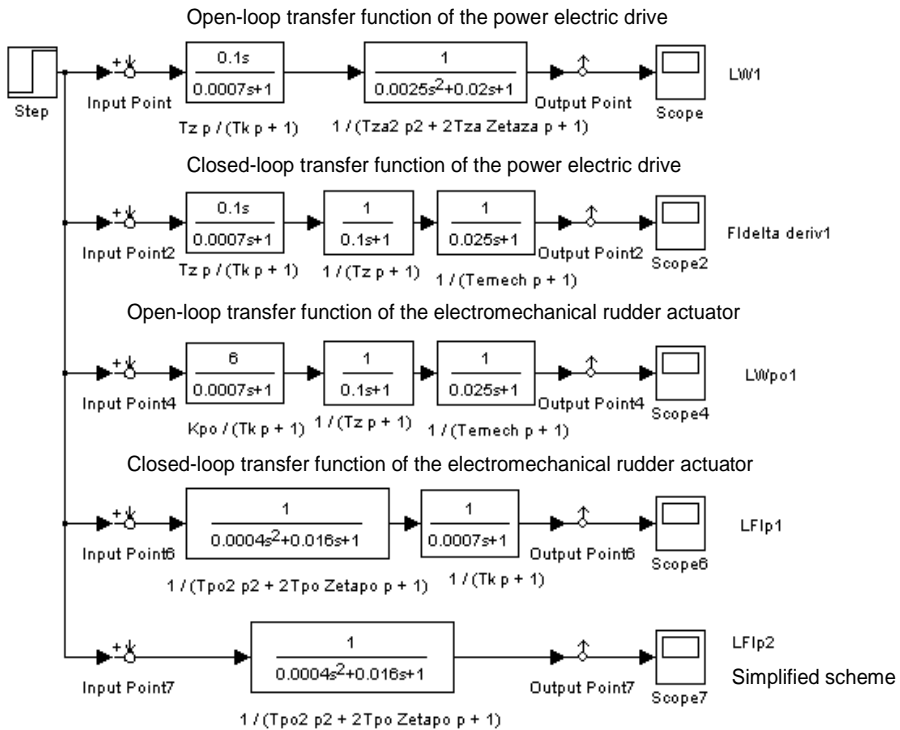


Fig. 4 Block scheme of electromechanical actuators in Simulink environment

Using the standard blocks in Simulink environment, it is possible to compile an adequate computer model of electro-hydraulic and electromechanical actuators according to Fig. 3 and Fig. 4.

4. Computer Simulation of Actuator Characteristics

It is possible to utilize the computer models for an analysis of actuator properties, evaluation of change affect of individual parameter values and determining their boundary values. The time courses of individual variables can be assigned to monitor changes in input parameters.

The time courses of individual variables can be assigned to monitor changes in input parameters. Behaviour of frequency response characteristics of electromechanical actuators is shown in Fig. 5. The basic way of expressing the dynamic properties of any closed automatic system is its transient response. Unit step responses of analysed actuators for small value of the input angle $\delta_{zad0} = 0.175$ rad, are given in Fig. 6.

Three parameters $\delta(t)$, $\delta'(t)$, $M_{MO}(t)$ define the changes – map curves of both types of flight control actuators. The electro-hydraulic power part (EHP) has a faster response and its transient action takes place in saturation velocity $\delta'_{HP}(t)$. EHP responds quickly and accurately to the changing input signal and in less than a hundredth of a second its speed exceeds the maximum speed δ'_{max} . EHP operates as an open loop system at intervals $\delta = 0 \div \delta_{zad0}$. Speed oscillating $\delta'_{HP}(t)$, and moment $M_{HP}(t)$ are caused by high frequency oscillating circuit. The analysed actuator is works as a closed-loop system after reaching the value of $\delta = \delta_{zad0}$. The moment created by EHP at start-up time is rapidly growing, reaching the value of 175 Nm, and simultaneously does not overpass the maximum allowable limit. The subsequent rapid decrease of the moment at the beginning of the operation is caused by rapid increase in moment of inertia of the rudder actuator. The electromechanical power part (EMP) transient characteristics are influenced by transient response of the electro actuator moment $M_{EP}(t)$.

EMP works as a non-linear system with moment saturation ($M_{EP} = M_{EProz}$) during the transient response. Transient response stabilization of EMP is slow, when $t = 0.2$ s, when it begins working as a normal closed-loop system, close to linear. The above-mentioned analysis shows, that the EMP is unable to satisfactorily handle the specified step change of an input angle. It has insufficient transient response, because of its own rotor moment of inertia. The comparison of dynamic actuators has been done for the same parameter values: $M_{za} = 200$ Nm; $\delta'_{max} = 2.62$ s⁻¹, $\delta_{max} = 0.35$ rad, $J_K = 2$ N m² rad⁻¹. These values are not the same for different types of control actuators. However, the parameter values are for EHP very low, load moment 200 Nm for EMP of 2.62 s⁻¹ speed is quite acceptable, but moment of inertia J_K is very low. Therefore, EMP is more advantageous when used in the cases where the load has a high inertia and required speed is low.

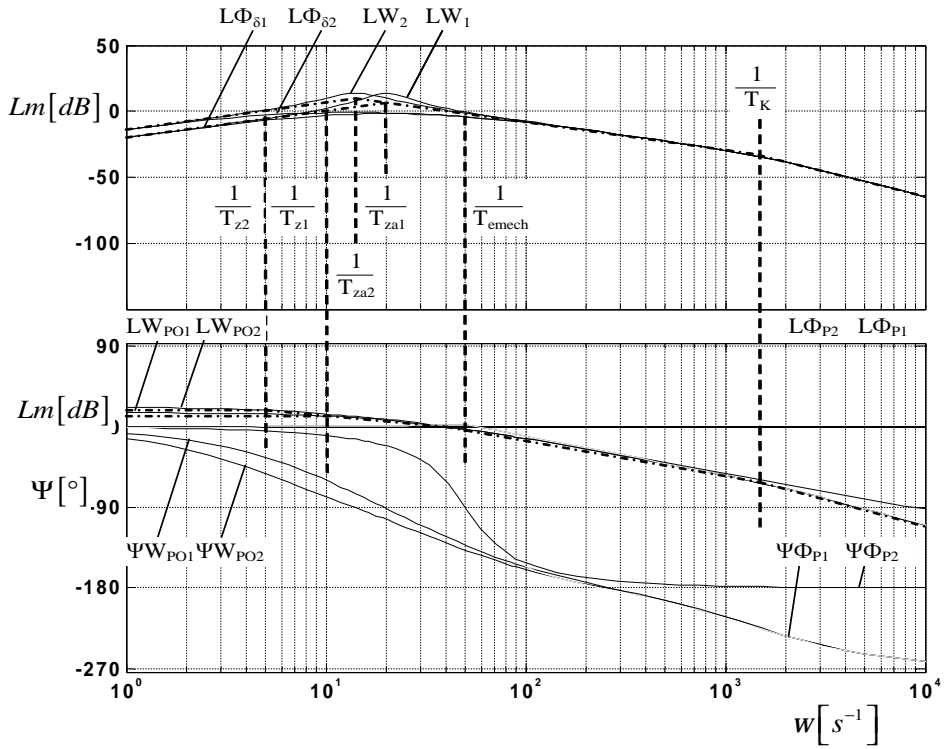


Fig. 5 Frequency characteristics of the electromechanical actuators

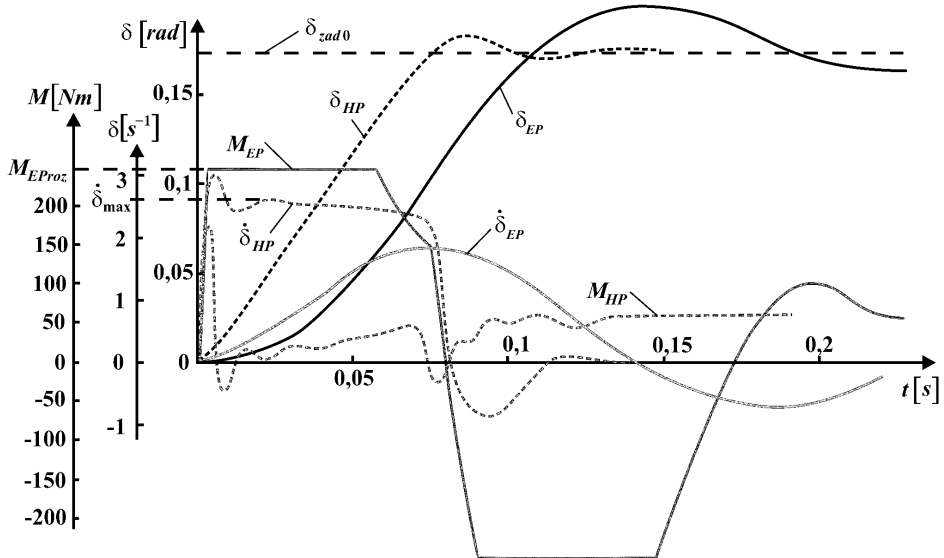


Fig. 6 Comparison of transient characteristics of the analyzed actuators

5. Conclusion

The designed models of electromechanical and electro-hydraulic actuators are adjusted to the teaching requirements of the problem. Comparison of dynamic properties of analyzed actuators, which are based on different physical principles in the environment of Matlab/Simulink, allows us to illustrate the analogy between various parameters. It is very important to have the final didactic elaboration in order to use the simulation experiment results effectively in teaching. Its purpose is to create an interactive environment for an optimal depiction of the obtained data according to the teaching requirements in a particular field [5].

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