Fuzzy Controllers for Position Control Electro-Hydraulic Actuators

Ruslan Sharipov
Faculty of aircraft engines, energy&transport
Ufa State Aviation Technical University
Ufa, Russia
obter@yandex.ru

Arsen Mesrpyan
Faculty of aircraft engines, energy&transport
Ufa State Aviation Technical University
Ufa, Russia
mesropyan@ugatu.ac.ru

Abstract—**This paper describes fuzzy controllers of an electro-hydraulic actuator in the control loop. The aim of research is to reduce steady-state error and a time response as short as possible. The electro-hydraulic actuator mathematical model is design taking into account the functional jet pipe servo-valve. This model is used to numerically simulate the functioning of the system. The model uses mass flow ratios to provide a more stable and realistic numerical simulation. Dynamic modeling provides to study the behavior of a servo with various controllers in the control loop. Through simulation, the proportional controller and the types of fuzzy controllers are tested. The controllers are implemented in MATLAB/SIMULINK. The fuzzy controllers are an intelligent technique to reduce steady-state error and time response.**

Keywords—servo-valve; numerical simulation; electro-hydraulic actuator, programmable logic controllers

I. INTRODUCTION

Modern aircraft control systems are complex loaded dynamic systems with a high level of reliability. Fuzzy control systems can improve the performance of the drive [1 - 8].

The use of fuzzy logic allows using the associative approach and obtaining the required control. Fuzzy logic controller processes incomplete information and provides informed solutions. All this determines the weighty benefits of applying this approach in the development of advanced intelligent control systems.

The hydraulic control systems play a very important roles in the aviation control systems owing to the following advantages—high power, accuracy, easy in power transfer, and so on [9-12].

Electro-hydraulic actuators are widely used in various fields of aerospace engineering. Steering hydraulic systems for aircraft and spacecraft for aircraft and spacecraft command surfaces, tilting the engine nozzle in the rocket are most responsible application of control systems. The steering behavior provides the necessary dynamic and static characteristics. Currently, there are modern techniques for improving dynamic and static parameters, such as hardware, software and design solutions. Fuzzy logic control with a electro-hydraulic servo-actuator is advanced technology.

Electronic systems are promising technologies for improving aircraft performance using valve-controlled electro-hydraulic actuators. These are modern control methods used to improve the behavior of electro-hydraulic actuators.

II. MATHEMATICAL MODEL OF SERVO-ACTUATOR

Fig. 1 shows a structural scheme of the electro-hydraulic servo-actuator considered in this paper. The electro-hydraulic actuator consists of electronic systems, hydraulic cylinder, the jet pipe servo valve. The purpose of the control is to generate an input current to control the position of the cylinder. Position control is controlled as follows: as soon as the input voltage corresponding to the input position is transmitted to the controller, the input current is generated in proportion to the error between the input voltage and the output voltage of the position sensor. Then, the jet pipe displacement is controlled according to the input current applied to the torque motor of the servo valve. Depending on the jet pipe position and the piston load conditions, the rate and the direction of the flows supplied to each cylinder chamber is determined. The movement of the piston is controlled by these flows.

Jet pipe position, piston position, loud position, hydraulic cylinder chambers pressure is controlled by electronic systems. The torque motor, controlled by the current of the electronic system, allows to adjust the piston position.
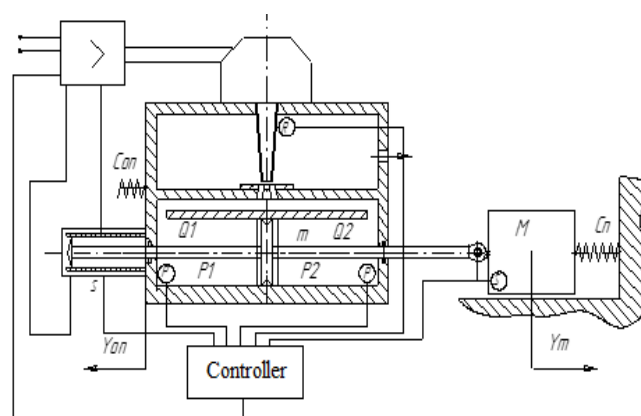

Fig. 1. Structural scheme of the electro-hydraulic servo-actuator

Actuators electronic control systems are based on the fuzzy controller. The fuzzy controller implements servoactuator control by porportional-integral-derivative.

Servo-actuator functioning equations were implemented in a MATLAB/SIMULINK scheme. A movement equation for the piston, flow ratios, a movement equation for the jet

pipe, a torque equation of the torque motor are used for the mathematical model of the servo-actuator.

From the assumption of a simple voltage loop we can conclude that the input voltage (V) is equal to the voltage drop across the coil resistance (R) and the inductor (L), with the back electromagnetic field produced by the torque motor in motion, i.e.:

$$\begin{cases} V = R \cdot I + L \cdot \frac{dx}{dt} + K_{ne} \cdot \frac{d\alpha}{dt}; \\ V = K_u \cdot (V_b - K_{oc} \cdot y(t)); \end{cases} \quad (1)$$

where V, V_b – the voltage of the; R – the resistance of voltage loop; I – the function of electric current in the voltage loop; L – the inductance; K_{ne}, K_u – the coefficient of back electromagnetic field in the voltage loop for the jet pipe servo valve; K_{oc} – the coefficient of feedback gain.

Movement equation for the jet pipe servo valve:

$$J \cdot \frac{d^2\alpha}{dt^2} = K_{mi} \cdot I - K_{ma} \cdot \alpha - b \cdot \frac{d\alpha}{dt} - C_n \cdot \alpha \quad (2)$$

where J is the rotational inertia of jet pipe; K_{mi} is torque motor constant, K_{ma} is coefficients of position loop gain; b – the coefficient of dinamic friction.

Basic valve equation for the jet pipe servo valve with saturation:

$$S\frac{dy}{dt} + \left(\frac{W_0 + A \cdot y}{E} + C_n\right)\frac{dP_d}{dt} =$$
$$\begin{cases} \frac{1}{2}\mu_Q^m \left[(1+\overline{z})\sqrt{1 - \frac{P_d}{\xi_P^m}} - (1-\overline{z})\sqrt{1 - \frac{P_d}{\xi_P^m}}\right], z \leq z_n \\ \mu_Q^m\sqrt{1 - \frac{P_d}{\xi_P^m}}, z_{max} > \overline{z} > z_n \end{cases} \quad (3)$$

where S – the effective area of the piston; W_0 – the volume of the hydraulic fluid in the chamber of cylinder; E – the elastic modulus of the hydraulic fluid; P_d – the pressure of the hydraulic fluid between the chambers of the cylinder; μ_Q^m – the coefficient of the fluid flow through the pipe; ξ_P^m – the coefficient of the fluid pressure through the pipe; z – the displacement of the pipe; z_n – the critical displacement of the pipe.

Piston motion equations:

$$M \cdot \frac{d^2y}{dt} = S \cdot P_d - F - C_n \cdot y - b\frac{dy}{dt} - F_{tr} \quad (4)$$

where S – the effective area of the piston; M – the mass of the loud; b – the coefficient of dinamic friction; F – the static load on the piston; C_n – the coefficient of position load.

When designing the following fuzzy controllers, one aim is to reach the desired improvements by using adjustment functions to vanish the stationary error and the saturation period of the converter. The following sections present two fuzzy controllers and the results obtained with these controllers.

The first targeted improvement in comparison with the proportional-plus-integral controller was to vanish the stationary error by the global translation of the output membership functions. The membership functions and the control surface are shown in figure 2.

For fuzzy controllers development one used Mamdani controllers with membership functions at the input and output. The linguistic terms used were: negative big – NB, negative medium – NM, negative small – NS, zero – Z, positive small – PS, positive medium – PM, and positive big – PB, both at the input and output (table 1). In general, a fuzzy control rule is a fuzzy relation, which is expressed as a fuzzy consequence. In fuzzy logic, there are many ways to define fuzzy implication. One of these methods can be expressed as a function of fuzzy implication. The choice of a fuzzy implication function reflects not only the intuitive criteria of implication, but also the effect of connectivity.
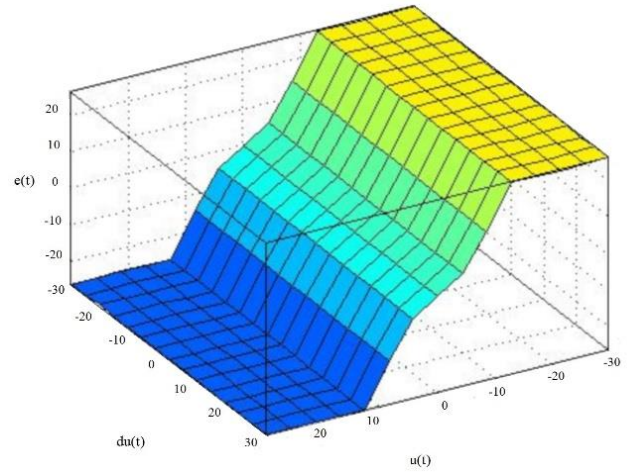

Fig. 2. Control surface of fuzzy control

The formation of the control signal in the fuzzy-regulator includes several stages (Fig. 3) based on the concepts of fuzzy logic: membership functions, linguistic variables, methods of fuzzy implication, etc. The method of fuzzy inference Mamdani is used.

TABLE I.   TABLE OF FUZZY LINGUISTIC TERMS

$du(t)$ \ $u(t)$	LN	SN	Z	SP	LP
LN	LP	LP	LP	LP	LP
SN	SP	SP	SP	SP	SP
Z	Z	Z	Z	Z	Z
SP	SN	SN	SN	SN	SN
LP	LN	LN	LN	LN	LN

The above methodologies, in which fuzzy logic is used to determine the proportional-plus-integral-plus-derivative controller parameters, were also compared with the fuzzy proportional-plus-integral-plus-derivative controller, in which the variable control is determined directly by means of a fuzzy inference system. The evaluated proportional-plus-integral-plus-derivative controller is the one proposed, in which the control variable is the sum of the outputs of a fuzzy proportional, proportional-plus-integral controller and a fuzzy proportional-plus-derivative controller (see Fig. 4). This choice allows you to save a small number of rules

(relative to the typical case of a fuzzy proportional-plus-integral-plus-derivative controller, in which three inputs must be taken into account) without compromising performance.

Two membership functions are used for two inputs e and 2, and three singletons for output, which is of the Takagi-Sugeno type. It turns out that two scale factors for two inputs and two for two outputs of the proportional-integral and proportional-derivative controllers must be selected by the user. In this case, typical practical rules can be adopted regarding fuzzy controllers, such as fuzzy weighting of a given value.
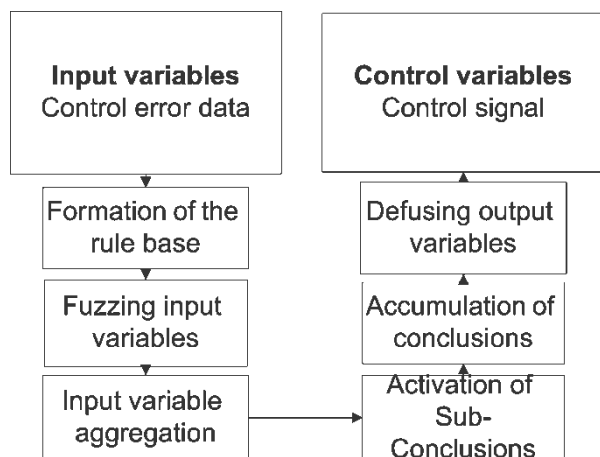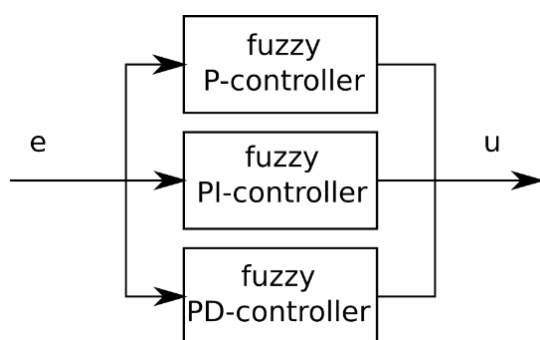
Fig. 3.   Control signal stage

Fig. 4.   Fuzzy controller

For the regulator adjustment a tuning peak of membership functions (fig. 5) is used.

Fuzzy modeling allows identification system parameters to obtain an adequate behavior. A fuzzy model is based on expert. Design a fuzzy model is difficult task when when the available knowledge is not complete, then the use of automatic views are recommended for the fuzzy model. A fuzzy modeling can be based on neural from networks, genetic algorithms and hybrid methods. Selection of relevant variables and adequate rules is critical for generating a good system.
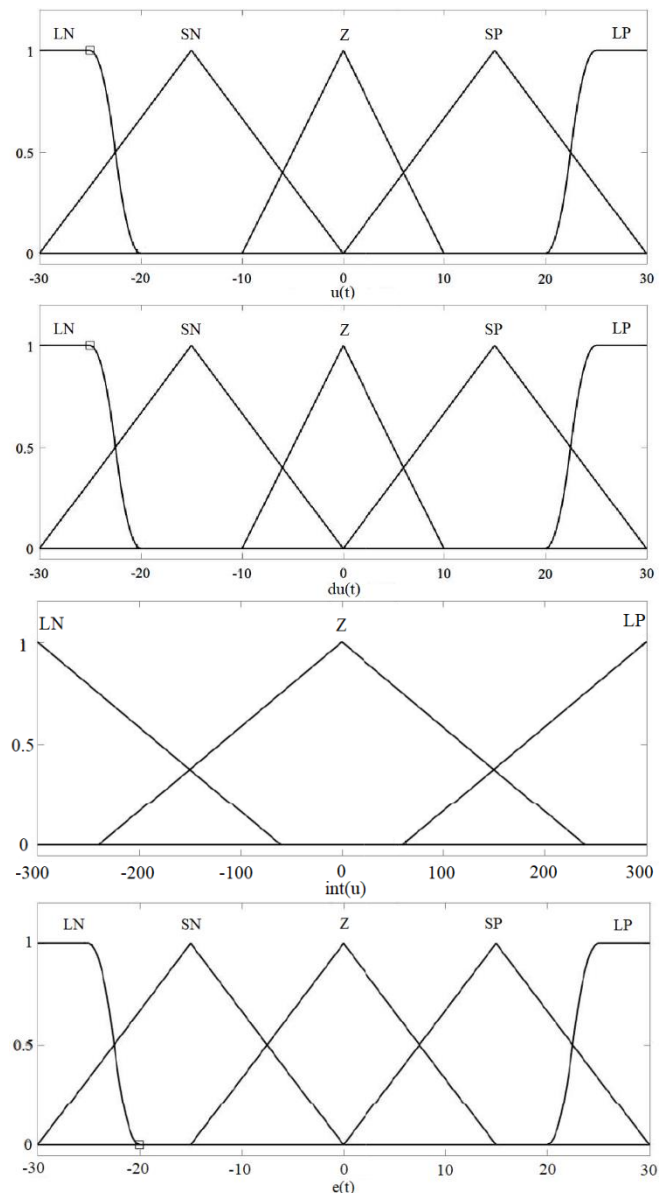
Fig. 5.   Tuning peak of membership functions

The fuzzy controller implementation used Type-1 FLS in the Matlab® Fuzzy Logic Toolbox, which allows an experienced user to easily adapt to use. Fig. 6 shows the main screen of the editor IT1FIS (Interval Type-1 Fuzzy Inference Systems).
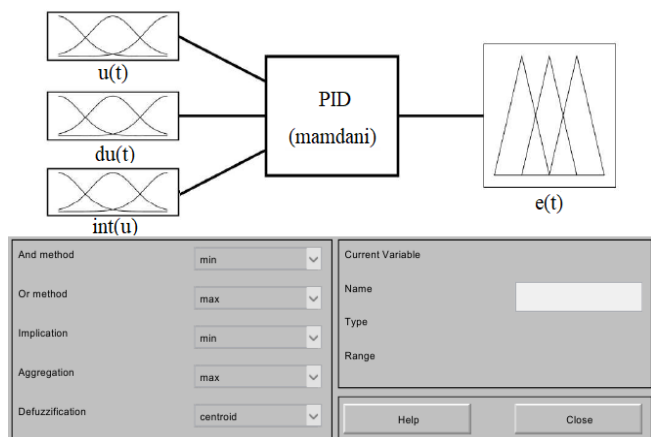
Fig. 6. Fuzzy editor of Matlab

III. COMPUTATIONAL EXPERIMENTS

A fuzzy controller implements motion control and a voltage to current converter. It also converts cylinder rod displacement to feedback voltage. The fuzzy controller operates in three modes: proportional, proportional-plus-integral and proportional-plus-integral-plus-derivative. The controller was developed in MATLAB / SIMULINK (Fig. 7.). The simulation results are shown in Fig. 8.
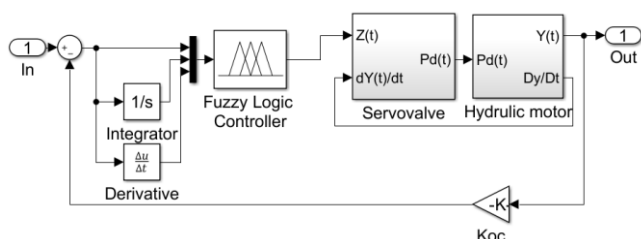

Fig. 7. Simulink block of the FLC controlled integrated in hydraulic actuator
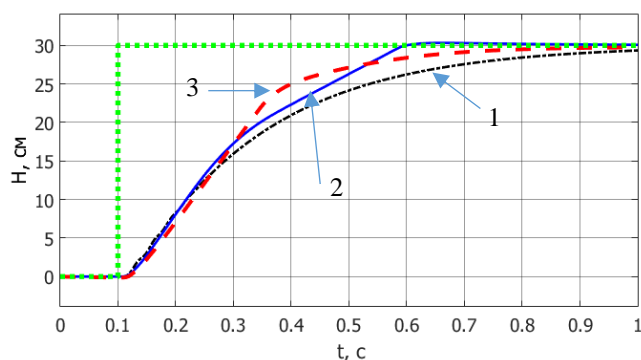

Fig. 8. The results of modeling of transient process in the jet pipe actuator 1 – with analog controller; 2 – with proportional fuzzy controller; 3 – with proportional-plus-integral fuzzy controller

From the results, it appears that, without an amplitude limit on the control variable, it is very difficult to improve the performances of an optimally tuned PID, even if we use a nonlinear (fuzzy-based) controller, The use of an additional parameter b is almost useless if the PID is optimally tuned. However, it has to be highlighted again that in practical cases it is very difficult to achieve an optimal tuning, so it is appropriate to compare the results obtained by using fuzzy-logic-based methodologies with those obtained with the Ziegler-Nichols tuning formula. In particular, the latter

appears to be the best method and it gives better step responses than in a standard nonlinear PID.

Fuzzy-logic-based tuning is more useful if saturations are significant in the process [13, 14]. In fact, it appears that in this case the performances of a classic PID can be improved using time-varying parameters, and the achieved results are difficult to improve by a standard fuzzy controller. Finally, one should consider the ease of tuning of the controllers (i.e. of the fuzzy module's parameters), since in practical industrial applications, the use of genetic algorithms is possible if a good process model is available. Many simulations (not reported here for the sake of brevity) have been performed for this purpose. It emerges that, for the fuzzy-logic-based tuning methods for which a technique for the selection of the parameters of the fuzzy its value has to be kept very low, otherwise the overall control system can be unstable. Finally, the evaluation of the load disturbance attenuation capabilities of the proposed schemes has been evaluated.

Specifically, a load disturbance step has been applied to the plant at steady-state initial conditions, without limits on the control variable. The controllers are the same as in the case of no saturation, i.e. tuned by the genetic algorithm to minimise the integrated absolute error on the set-point step response. Obviously, there is no difference in the results between two PID controllers in which only the fixed set-point weight value changes. Gaps in the table mean that the controlled system has become unstable. Hence it is apparent that, for some methodologies, great care has to be taken in the tuning of the overall controller, as highly undesirable effects might occur for some aspects of the control system. However, it is worth noting that the reported results about the following setpoint might not be achieved in practical cases; hence, it turns out that those controllers that present stability problems are less effective than previously thought.

IV. CONCLUSION

The developed mathematical model of an electro-hydraulic servo actuator with the fuzzy proportional-plus-integral-plus-derivative controller allows to identify the system parameters by solving the differential equations. The results of mathematical modeling show that when using the fuzzy controller, the main time of the transition process is reduced (up to 30%). The stationary error of overcoming the load by the electro-hydraulic servo actuator is reduced (by down to 3%). Fuzzy control is a universal and effective tool for achieving the required transient parameters when positioning an actuating hydraulic actuator.

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