ACTUATORS CONTROLLER FOR SMALL FWB AIRCRAFT

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This paper presents conception and practical realization of actuators controller. Actuators mounted on aircraft board are responsible for control surfaces deflection. They are critical elements of the fly-by-wire (FBW) control systems. Actuator should be precise, fast, powerful and reliable. Important part of this element is electronic controller. Electromechanical actuators can be improved by using appropriate control techniques, hardware and software structure.

Key words: *actuator, controller, FBW, aircraft.*

1. INTRODUCTION

FBW control systems have been used since the end of 1960's. In the beginning they were analog solutions. They allowed to overcome problems with conventional systems (for example Concorde) or they were experimental installations. First digital FBW was applied on F-8 Crusader and next on the Space Shutlle program, where it was a sheer necessity as task performance would have been impossible with conventional mechanically augmented configurations. The technology has been applied in industrial solutions over the last 15 years [1, 2]. Next, natural step seems to be using these systems in general aviation aircrafts [3]. This technique allows to extend possibilities of aircraft control, stabilization of flight parameters and better, flexible automatic control. Pilot can work as computer operator as well as he can control plane classically by using stick. FBW improving safety of flight and minimize pilot load.

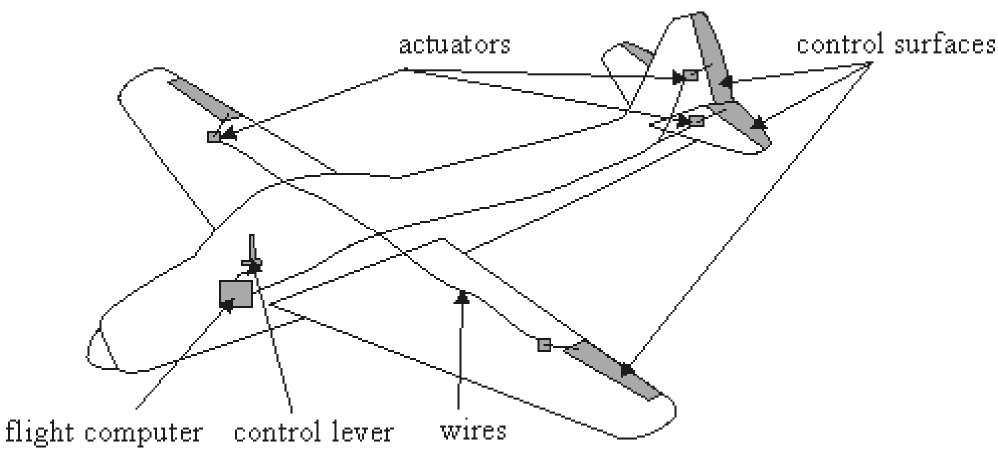

Fig. 1. Scheme of FBW control system

A principle of FBW is conversion of the pilot activity (stick movements) to electrical signals. These signals are sent to flight computers. They calculate them and provide the signals to adequate actuator controller where discrete information is changed into control surface deflection. This process is done without direct mechanical connections between the control-lever and the control surfaces [1, 4].

2. CONCEPTION

Actuators as critical elements of FBW system should perform strict criteria. They have to be reliable and work stably in every situation. It is very important because an actuator failure can cause a serious accident. The actuator controller should be reliable itself and independent from other equipment failures. The latter case can be achieved by multiplication superior control circuits (flight computers). Apart from it pilot should be able to deflect control surfaces directly by stick.

Adopted standard for input signals should make it possible to detect short circuit or contact gap in external circuit. In order to obtain this a pulse width modulation signal (PWM) with two constant zones: “0” and “1” has been applied. The full completion of input PWM is interpreted as short circuit and steady zero as a break. Control signals from flight computers are compared and the most believable is selected. This task is realized by software. If all signals from flight computers are wrong the control surface is set in neutral position and next the control can be switched by the pilot to stick. Pilot can switch the control to stick in every moment of flight.

The electromechanical unit is controlled throughout a power output block. The controller only sets *power control* and *direction* lines to a required state and the power output realizes powering of motor. The controller gets information about the load of the unit throughout *load* line. Information about deflection is providing to the controller directly from the electromechanical unit.

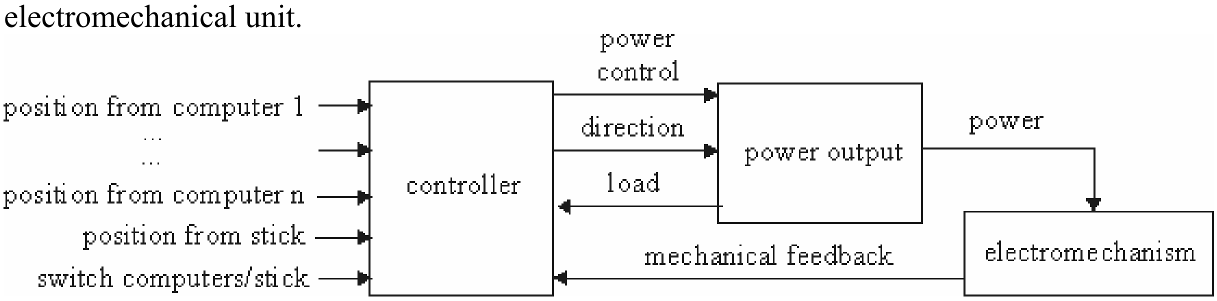

Fig. 2. Established actuator block scheme

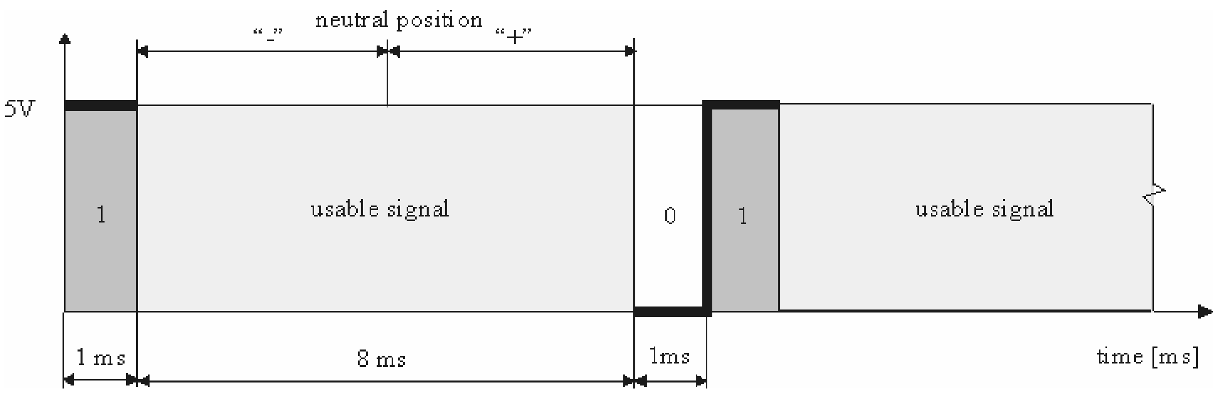

Fig. 3. PWM standard for actuator inputs

3. CONTROL ALGORITHM

The main task of the actuator controller is to position precisely the control surface [5]. Additionally this process should be as fast as possible. Obtaining a good quality of these two factors simultaneously is difficult in particular case and practically impossible in the general case. Compromising between precision and speed is necessary. The sufficient precision has to be established in the beginning and should be applied control algorithm maintaining it.

The electromechanical actuator without any load is a nonlinear element [5, 6]. During a normal flight it is burdened nonlinearly and nonstationarly by aerodynamic forces. Actuator cannot be represented as a linear element and we cannot use classical methods of analyses for it.

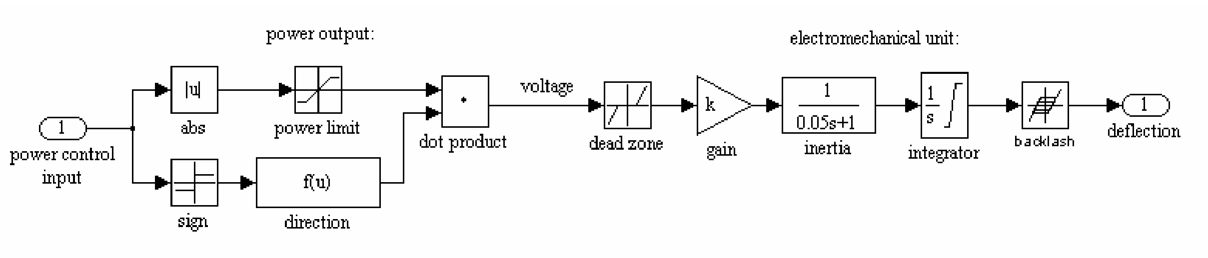

Fig. 4. Model of electromechanical unit and power output

There are also aspects of reliability and safety. A various and heavy load of the actuator, frequent changes of the control signal (especially direction) can cause quick amortization of electrical motor and the power driver. Control algorithm should prevent situations where the motor is load to much for a long time.

Dynamics of the actuator is very important. Quick and large changes of input function cause phase lag for output. This property is undesirable. It affects badly handling qualities of the aircraft and causes danger of appearing pilot induced oscillations (PIO) [6, 7]. Therefore phase compensator is necessary. It starts to work if maximum rate of the actuator is exceeded.

Choosing algorithm performing all this clauses is very hard. In the beginning at the research PID regulator was tested. Unfortunately changes of load value cause changes of PID parameters for regular work of this regulator. This type of regulator should have variable parameters but this is complicated due to many nonlinearities in system.
Next the synthesis of discrete Kalman regulator was done. This algorithm has after all better dynamic properties than PID: a less overshot, the shortest time of regulation and a less phase lag over rate saturation. During the tests this algorithm turn out to be very dangerous for mechanical structure because it causes hitches. These results dodn’t appear in a computer simulation. After tests on a laboratory stand this regulator was given up.
The two state (bang-bang) regulator seems to be a good solution. It doesn’t need many coefficients to find and it is simple for real application. Frequent inverts of motor powering signal are a problem. It can really shorten the time of motor life.

At last the heuristic regulator has been adopted [5]. It uses dependences between motor powering and actuating error established by expert. The heuristic regulator has very good static properties and good dynamics under rate saturation. Adding phase compensator is for it needed as well as for other algorithms over rate saturation. Practical realization of this algorithm is very simple.

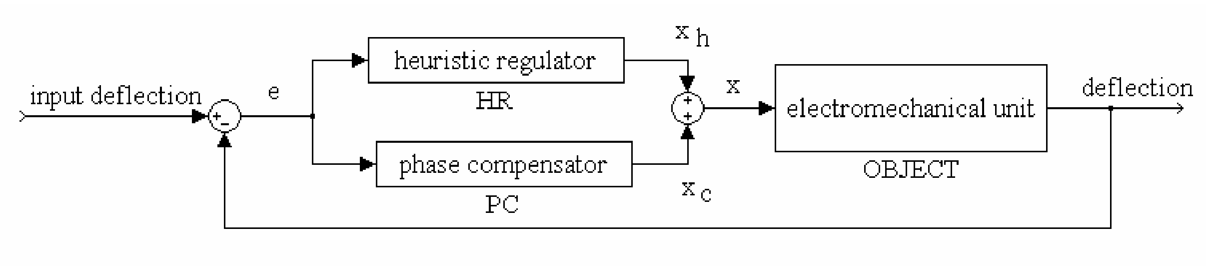

Fig. 5. Actuator deflection automatic control system

Dependence between motor powering and actuating error can be writing as:

$$x_h(t) = \begin{cases} 0 & \text{if } |e(t)| < |e_0| \\ |x_1| \cdot \mathrm{sign}(e(t)) & \text{if } |e_0| < |e(t)| < |e_1| \\ |x_2| \cdot \mathrm{sign}(e(t)) & \text{if } |e_1| < |e(t)| < |e_2| \\ \ldots & \\ |x_n| \cdot \mathrm{sign}(e(t)) & \text{if } |e_{n-1}| < |e(t)| < |e_n| \\ |x_{max}| \cdot \mathrm{sign}(e(t)) & \text{if } |e_n| < |e(t)| \end{cases} \quad (1)$$

$x_h(t)$ – heuristic regulator output signal
$e(t)$ – actuating error
$e_0 - e_n$, $x_1 - x_n$ – thresholds of actuating error and motor powering chosen by expert

Phase compensator can be realized as:

$$x_c(t) = \begin{cases} 0 & \text{if } \left|\frac{d}{dt}e(t)\right| < v_{max} \\ -\left[\left(\left|\frac{d}{dt}e(t)\right| - v_{max}\right) \cdot \mathrm{sign}\left(\frac{d}{dt}e(t)\right) \cdot k\right] & \text{otherwise} \end{cases} \quad (2)$$

$x_c(t)$ – phase compensator output signal
v_{max} – maximal rate of actuator
k – gain

Motor powering is equal:

$$x(t) = \begin{cases} x_h(t) + x_c(t) & \text{if } |x_h(t) + x_c(t)| \le x_{max} \\ |x_{max}| \cdot \mathrm{sign}\left(x_h(t) + x_c(t)\right) & \text{otherwise} \end{cases} \quad (3)$$

4. HARDWARE STRUCTURE

Controller is based on microprocessor equipped with watch-dog timer, A/D converter, three I/O ports and capture compare module used for catching PWM's. The microprocessor is galvanically isolated from input and output circuits by transoptors. Powering is from DC/DC converter. It ensures security chip powered from aircraft electric board installation. Feedback from deflection is realized by potentiometer powered from controller circuit and mounted in electromechanical unit.

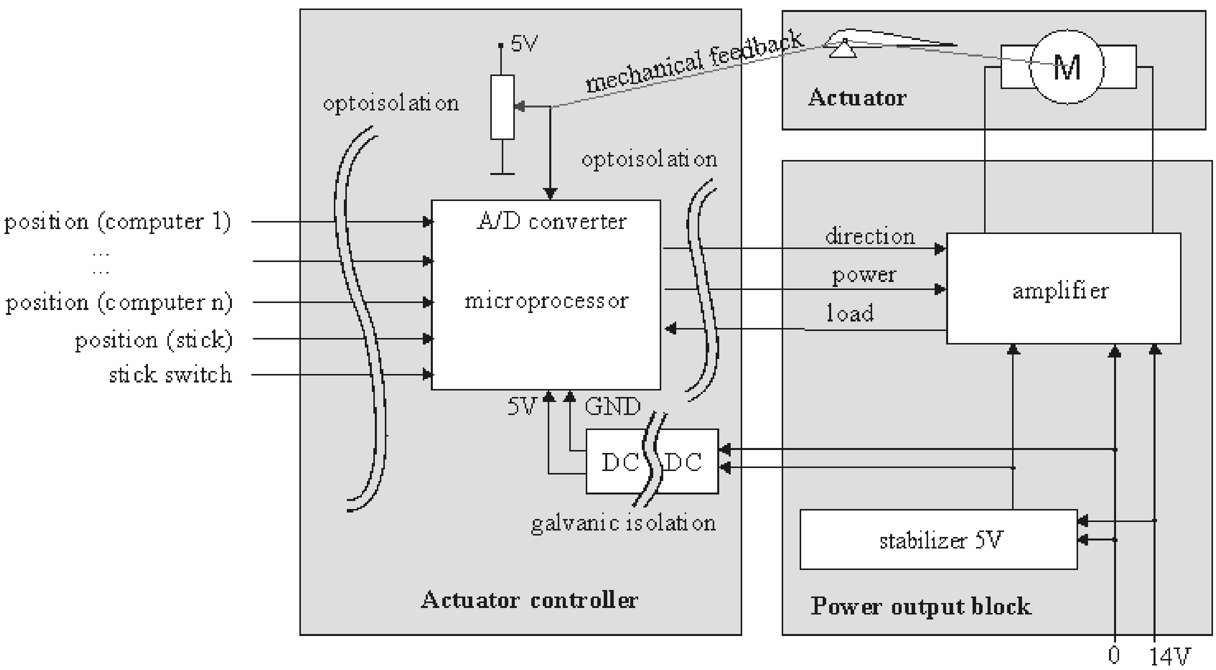

Fig. 6. Controller hardware structure

5. RESULTS OF LABORATORY STAND TESTS

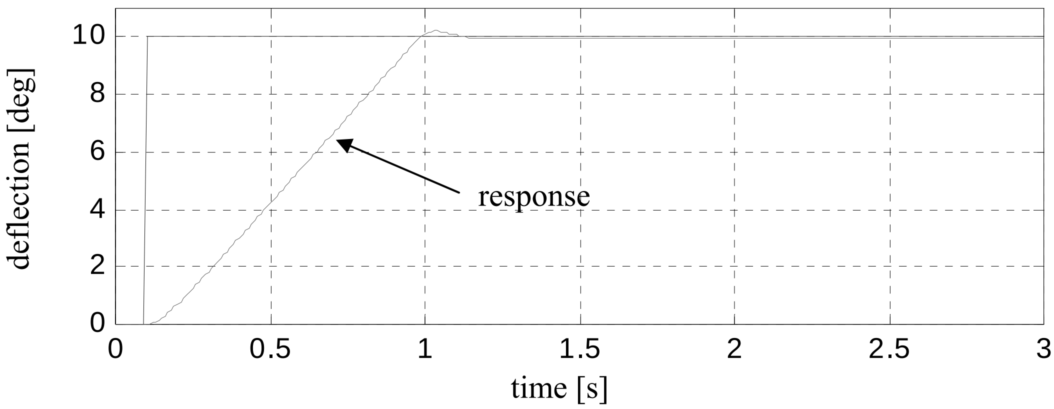

Fig. 7. Response for step function, PZL-110 rudder actuator, load 40[N]

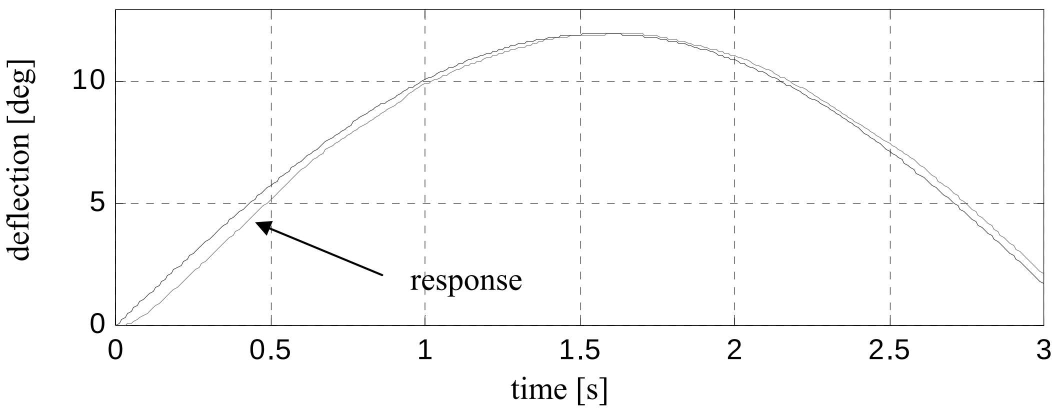

Fig. 8. Response for slow harmonic input function, PZL-110 rudder actuator, load 40[N]

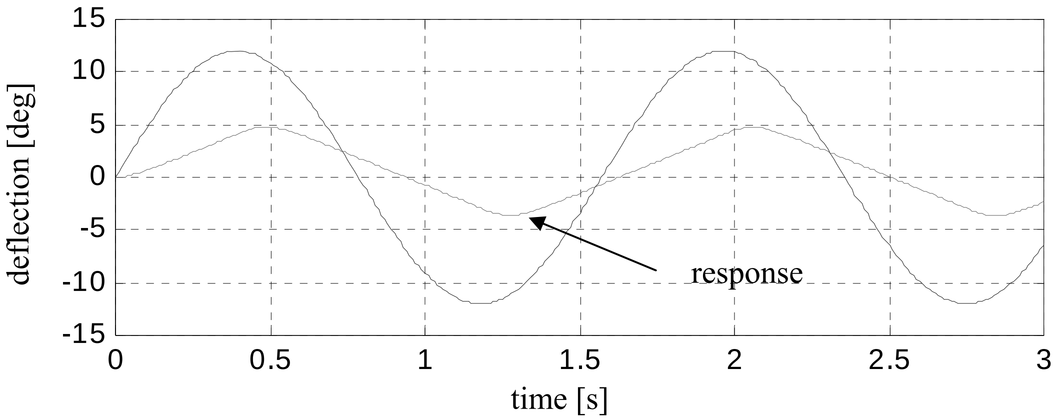

Fig. 9. Response for fast harmonic input function (max. rate of input function is over limit of actuator), PZL-110 rudder actuator, load 40[N]

6. CONCLUSIONS

Performed tests on laboratory stand showed actuator controller can positioning control surface with established static precision 0.1 deg (full range is ±20 deg). It has been also tested in admitted full load conditions positive as well as negative. Control algorithm permit to deflect surface with maximum power in wide range. Unfortunately speed is limited by electromechanical construction and over saturation we can only compensate phase lag. Amplitude of signal is suppressed.

Work of controller has been checked in many possible situations. Positive results of this test allow to build it on the board of PZL 110 "Koliber" as a part of the experimental FBW system. Planned the future test in flight (July 2003) will verify results of this work.

7. REFERENCES

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