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Investigation of Functional Diagrams of Step PID Controllers for Electric Actuators

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Abstract

This paper deals with analysis of main functional diagrams of step PID controllers for electric motor-driven actuators. The main formulae to calculate the parameters of the diagrams of step PID controllers are presented in the paper. The influence of these parameters on the transient processes in step controllers and on the output position of the actuator is analyzed. Transient processes in step controllers with motor-driven actuators are simulated in PI and PID control mode. These transient processes are compared to the transient processes in continuous controllers. The accuracy of step PID controllers is analyzed, and restrictions on the parameters of step PID controllers are presented. The diagrams of step PID controllers considered in this paper can be implemented in the up-to-date PLCs software for automatic control using the electric motor-driven actuators in the control loops.
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Keywords: step controller; diagram; actuator; PID control; transient process

1. Introduction

An automatic control loop (ACL) consists of the controlled system and the automatic controller. A simplified structural diagram of an ACL is presented in Fig. 1(a) and this diagram is taken as the basic diagram for theoretical calculation of the PID controller parameters (e.g. using the frequency response analysis and the Nyquist stability criterion) [1, 2]. However, in practice there are a number of other devices in the ACL besides the automatic controller (i.e. measuring transducer, actuator, valve etc., see Fig. 1(b)) and these devices influence the process of automatic control.

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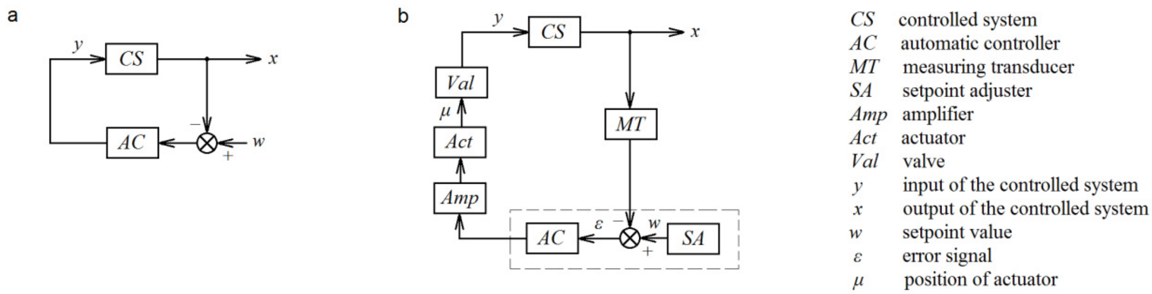

Fig. 1. (a) simplified structural diagram of an automatic control loop; (b) extended structural diagram of an automatic control loop.

The dynamic and static characteristics of each element in the ACL should be taken into account. The measuring transducer and the valve in many cases can be approximately represented by a proportional element. As far as the actuator is concerned, it can be of a proportional action (pneumatic actuator) or of an integral action (electric actuator with a drive with constant speed of rotation). The behavior of the electric actuator as an integral element needs to be taken into account during PID control in the ACL.

When the proportional action actuator is used, the continuous PID controller with a classical functional diagram is usually applied. In case of using the integral action electric actuator, the step PID controller is applied. The step controller can be built on the basis of the following diagrams:

- diagram of a step PID controller with double differentiation
- diagram with a continuous PID controller and a pulse-width modulator
- diagram with a continuous PID controller and a simulated positioner

One more option for the diagram of a step controller for an electric actuator is to apply the pulse generator. The diagram with the pulse generator is implemented in functional block FB42 "CONT_S" of SIMATIC S7 PLC software [3]. However, this diagram provides PI mode of control and does not provide PID mode of control.

2. Diagram of a step PID controller with double differentiation

A step PID controller can be built on the basis of the diagram of the R27 electronic controlling unit of "Cascade-2" complex of instrumentation [4]. The R27 controlling unit is meant for work with electric or hydraulic actuators having constant speed of movement. The unit can operate in PI and PID control modes.

According to the diagram of the R27 controlling unit the output step signal (pulses) is derived by means of a three-point switch with a first-order lag element (PT_1 element) in the negative feedback. The parameters of the PT_1 element are the proportional gain K_{NF} and the time constant T_{NF}. In order to introduce the differential component in the PID control law, the PT_1 element is transformed to an integral element with a negative feedback (see Fig. 2). The differentiated error signal is supplied to the sum block installed at the output of the integrator. There is double differentiation of the error signal in this diagram. The first differentiation takes place in the real differentiator block with the differentiation time T_D. The second differentiation takes place in the integrator which is located in the negative feedback to the differentiated error signal.

The diagram of the step PID controller presented in Fig. 2 provides processing of the input error signal according to PDD' function. And together with the actuator, which is an integral element, the PID control law is formed. In the PI control mode (when T_D=0) the diagram of the step controller provides processing of the input error signal according to PD function. And together with the actuator the PI control law is formed.

There are two main parameters of the three-point switch in the diagram of the step controller, i.e. the dead band Δ_{DB} and the hysteresis loop Δ_{HL}. The duration of steps (pulses) and breaks produced by the integral component of the PID control law is defined by the width of the hysteresis loop. There are two hysteresis loops in the three-point switch (one in the positive area and the other one in the negative area). And the widths of both of the loops are equal in order to provide the same pattern of movement of the actuator both in the positive direction and in the negative one.

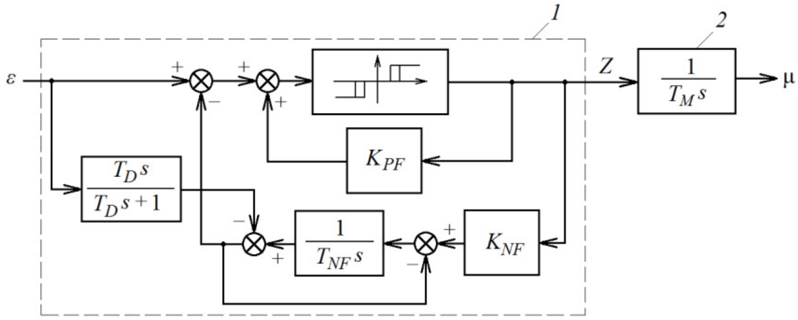

Fig. 2. Functional diagram of a step PID controller with double differentiation (*1*) and an actuator (*2*).

The range of the error signal within which the step controller does not produce any output signal is defined by the width of the dead band Δ_{DB}. On the other hand, the width of the dead band affects the angle of the step response curve at the output of the electric actuator with the step controller μ(*t*). The wider the dead band, the smaller the angle of the step response curve, which is caused by prolonging the duration of breaks between the steps.

It should be mentioned that there is no such parameter as "dead band" in continuous PI and PID controllers, because there is no three-point switch in the structure of these controllers [5]. However the "dead band" element is installed at the input of PID algorithm in many of up-to-date microprocessor controllers with the continuous output signal in order to "cut off" the insignificant changes in the error signal caused by the work of the analog-to-digital converters [3, 6].

In addition to the negative feedback to the three-point switch in the diagram in Fig. 2 there is a positive feedback with the coefficient K_{PF}. The positive feedback is introduced in order to prolong the duration of steps (pulses) at the output of the controller, which leads to an increase in the angle of the step response curve at the output of the electric actuator with the step controller μ(*t*). There is a restriction for the coefficient K_{PF}. If K_{PF} is greater than (Δ_{DB}–Δ_{HL}) then self-oscillation takes place in the diagram of the step PID controller which is an unacceptable phenomenon for the controller within the automatic control loop.

When the parameters of PID control law (K_P, T_I, T_D) and the motor time of the actuator (T_M) are known, the values of K_{NF}, T_{NF} and K_{PF} in the diagram in Fig. 2 can be calculated as follows:

$$\begin{cases} K_{NF} = T_I/(K_P T_M); \\ T_{NF} = T_I; \\ K_{PF} = \Delta_{DB} - \Delta_{HL} - 0.01. \end{cases} \tag{1}$$

The output signal of the step controller in the PI control mode consists of the first long pulse and a number of short pulses with breaks. During the first pulse the actuator will change its output position by the value approximately equal to the step change of the output signal of a continuous controller due to the action of the proportional component of the PI control law. All the next pulses with breaks lead to discrete changes in the actuator's output position due to the action of the integral component of the PI control law.

The principle of a step PID controller based on the diagram with double differentiation can be implemented in up-to-date PLCs by programming for motor-driven actuators in control loops.

3. Diagram with a continuous PID controller and a pulse-width modulator

Another principle of step PID controller for motor-driven actuators consists in applying a diagram with a continuous PID controller and a pulse-width modulator (PWM). This diagram is presented in Fig. 3. The output signal of the continuous PID controller (*Y* in Fig.3) passes through the differentiator (*2*) and thus the PDD' function is formed. The duty cycle of the output signal of PWM is set by the differentiated output signal of the continuous PID controller (γ=*Y*′).

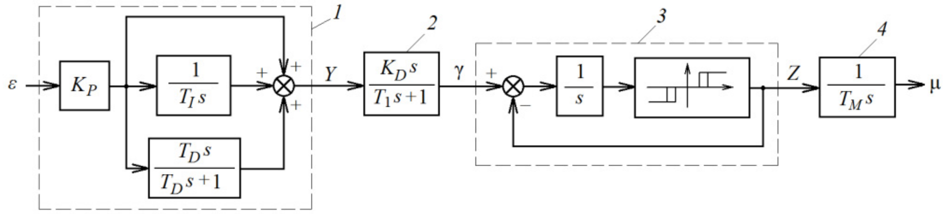

Fig. 3. Functional diagram of a continuous PID controller (*1*) with a differentiator (*2*), a pulse-width modulator (*3*) and an actuator (*4*).

The pulse-width modulator (*3* in Fig. 3) consists of an integrator and a three-point switch connected in series and covered by a negative feedback with a coefficient of unity. By means of such a connection the proportional conversion is implemented in PWM. So, the output signal of the continuous PID controller passes through the following conversions: differentiation (in the differentiator), proportional conversion (in PWM) and integration (in the actuator). Since the transfer function of PWM corresponds to the proportional element with the coefficient of unity, the differentiation coefficient K_D in the differentiator is set equal to the motor time of the actuator ($K_D=T_M$). Thus it is provided that the output position of the actuator μ is proportional to the output signal of the continuous PID controller *Y*. Time constant T_1 in the differentiator is set to a much smaller value than the motor time ($T_1 << T_M$, e.g. $T_1=0.01$ sec) in order to make the real differentiator as close to an ideal differentiator as possible.

The parameters of the three-point switch in PWM affect the transient processes at the output of the step controller with the actuator. In particular, the hysteresis loop Δ_{HL} influences the duration of steps (pulses) and breaks. The smaller the width of the hysteresis loop, the shorter the steps and breaks. And the dead band Δ_{DB} influences the shift of the step response curve at the output of the actuator with the step controller μ(*t*) relative to the output signal of the continuous controller *Y*(*t*).

The minimum width of the hysteresis loop of the three-point switch in PWM in Fig. 3 for a given minimum duration of control pulses $(\Delta t_s)_{\min}$ can be calculated by the following formula

$$(\Delta_{HL})_{\min} = (\Delta t_s)_{\min} \cdot \left(1 - \frac{\gamma_{\min}}{100}\right), \quad (2)$$

where γ_{min} is the duty cycle at the output of PWM at the minimum step change of the error signal $\Delta\varepsilon_{\min}$.

The value of γ_{min} can be calculated by the following formula

$$\gamma_{\min} = \frac{K_P \cdot \Delta\varepsilon_{min} \cdot 100}{T_I}. \quad (3)$$

The diagram with a continuous PID controller and a pulse-width modulator (Fig. 3) is implemented in the microprocessor controller PROTAR [7] for automatic control in the loops with motor-driven actuators.

If we take $T_1=0$ and make some structural transformations in Fig. 3 (i.e. move the sum block from the output to the input of the differentiator), then we will get an approximate version of the diagram with a continuous PID controller and a simulated positioner. This diagram is described below.

4. Diagram with a continuous PID controller and a simulated positioner

One more version of step PID controller for a motor-driven actuator is to apply the diagram with a continuous PID controller and a simulated positioner. This diagram is shown in Fig. 4. According to this diagram the output signal of the continuous PID controller goes to the simulated positioner which consists of a three-point switch covered by a negative feedback with an integrator. The integrator in the negative feedback simulates an actuator. The diagram of the positioner implements the differentiating action. Thus the output signal of the continuous PID controller passes through the following two inverse conversions: differentiation (in the positioner) and integration (in the actuator). As a consequence, there is proportional conversion of the output signal of the continuous PID controller *Y* to the output position of the actuator μ.

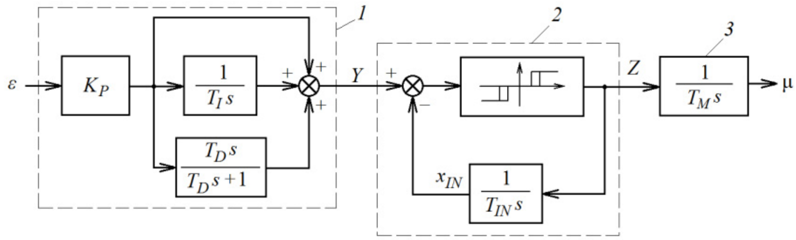

Fig. 4. Functional diagram of a continuous PID controller (*1*) with a simulated positioner (*2*) and an actuator (*3*).

The integration time of the integrator in the negative feedback is set equal to the motor time of the actuator ($T_{IN}=T_M$). That is why the output signal of the integrator represents the output position of the actuator ($x_{IN}=\mu$).

The parameters of the three-point switch in the simulated positioner (like in PWM in Fig.3) influence the transient processes at the output of the step controller with an actuator. The hysteresis loop Δ_{HL} influences the duration of steps (pulses) and breaks. And the dead band Δ_{DB} affects the shift of the step response curve at the output of the actuator with the step controller $\mu(t)$ relative to the output signal of the continuous controller $Y(t)$. If $\Delta_{DB}>2\cdot\Delta_{HL}$ the shift $(\mu(t)-Y(t))$ is negative (relative to the direction of output signal change) and its minimum current value is equal to $(\Delta_{DB}/2-\Delta_{HL})$. If $\Delta_{DB}=2\cdot\Delta_{HL}$ the minimum current value of the shift is equal to zero. If $\Delta_{DB}<2\cdot\Delta_{HL}$ the shift is positive and its maximum current value is equal to $(\Delta_{DB}/2-\Delta_{HL})$. However such a setting of the tree-point switch ($\Delta_{DB}<2\cdot\Delta_{HL}$) is not desirable, because the diagram of the positioner becomes less stable. If $\Delta_{DB}=\Delta_{HL}$ the tree-point switch transforms to a two-point switch and self-oscillation takes place in the diagram. In this case the diagram is unstable.

The minimum width of the hysteresis loop of the three-point switch in the simulated positioner in Fig. 4 for a given minimum duration of control pulses $(\Delta t_s)_{\min}$ can be calculated by the following formula

$$(\Delta_{HL})_{\min}=(\Delta t_s)_{\min}\cdot\left(\frac{100}{T_M}-\frac{\Delta\varepsilon_{\min}\cdot K_P}{T_I}\right). \tag{4}$$

By setting the minimum hysteresis loop $(\Delta_{HL})_{\min}$ in the simulated positioner, the duration of pulses due to the integral action of the PI control law will be equal to the given minimum duration of control pulses $(\Delta t_s)_{\min}$ when the input step change of the error signal is equal to $\Delta\varepsilon_{\min}$. For greater values of $\Delta\varepsilon$ and Δ_{HL} the duration of pulses will always be longer than $(\Delta t_s)_{\min}$.

The diagram with a continuous PID controller and a simulated positioner (Fig. 4) is implemented in SIPART DR20 controller of Siemens Company [8] for motor-driven actuators in control loops.

5. Diagram of a step PI controller with a pulse generator

To control the motor-driven actuators in the automatic control loops the abovementioned diagram of a step PI controller with a pulse generator can be applied. This diagram is shown in Fig. 5 and it is implemented in functional block FB42 “CONT_S” of SIMATIC S7 PLC software [3]. The diagram with a pulse generator is a modified version of the diagram with a continuous PID controller and a simulated positioner (Fig. 4). There are the following four distinctions between the diagrams in Fig. 4 and Fig. 5:

1. The differentiation block for the error signal ($T_Ds/(T_Ds+1)$) is present in Fig. 4, but it is not present in Fig. 5.
2. The pulse generator block is present in Fig. 5, but it is not present in Fig. 4.
3. Two integrators in Fig. 4 ($1/(T_Is)$ and $1/(T_{IN}s)$) are united into one integrator in Fig. 5 ($1/s$) and the coefficients $1/T_I$ and $1/T_{IN}$ are moved outside the sum block which is installed at the input of the integrator $1/s$.
4. There is a key in Fig. 5 at the output of the block with the coefficient $1/T_I$, but there is no key in Fig. 4.

If there were no key in the diagram of the step PI controller with a pulse generator (Fig. 5), then the transient processes at the output of this diagram would be the same as in the diagram in Fig.4 in the PI control mode ($T_D=0$).

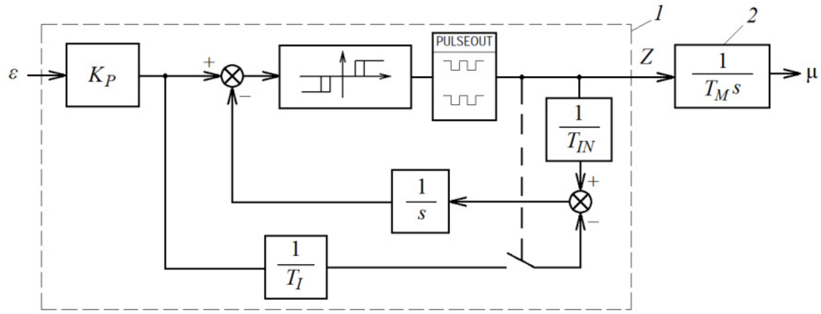

Fig. 5. Functional diagram of a step PI controller (*1*) with a pulse generator and an actuator (*2*).

The role of the key in Fig. 5 is to switch off the integral component of the PI control law when there are pulses at the output of the diagram. This leads to a shift in the step response curve at the output of the actuator with the step controller. The shift is negative relative to the output signal of the controller. The first pulse at the output of the step PI controller with a pulse generator (Fig. 5) provides movement of the actuator by the value equal to the proportional component of the PI control law. The integration time (T_{IN}) in the diagram in Fig. 5 is set equal to the motor time ($T_{IN}=T_M$) like in the diagram in Fig. 4. Calculation and setting of parameters of the three-point switch in the diagram in Fig. 5 is made the same way as it is done for the diagram in Fig. 4. The pulse generator together with the three-point switch in Fig. 5 generates pulses at the output of the diagram according to the given values of duration of pulses and breaks.

6. Accuracy of step controllers and restrictions on their parameters

Step controllers with actuators introduce shifts (by amplitude and by phase) to the transient processes in automatic control loops. The accuracy of the step PID controller with an actuator is defined by how close their step response curve is to the step response curve of the continuous PID controller. For quantitative estimation of the accuracy of a step PID controller with an actuator it is proposed to use the following three indexes (criteria): mean deviation (Δ), standard deviation (σ) and mean delay time (Δτ) of the step response curve of a step PID controller with an actuator from the step response curve of a continuous controller. The values of these indexes should be calculated by simulation using the diagrams presented above. Here the calculation should be done separately for the first step (pulse) and for the rest of the transient process. It is caused by significant distinction between the step response curve of a step PID controller with an actuator and the step response curve of a continuous PID controller during the first pulse. When a step change of error signal occurs, there is a step change in the output signal of a continuous controller but the output position of an actuator with a step controller varies gradually (in a linear manner). That is why the deviation of the step response curve of a step PID controller with an actuator from the step response curve of a continuous PID controller will be much greater during the first pulse than during the rest of the transient process. The values of the proposed indexes of accuracy depend on the type of the diagram and on the values of the set parameters in the diagram.

It is proposed to calculate the mean deviation, standard deviation and mean delay time according to the formulae:

$$\Delta = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} (\mu(t) - Y(t))dt \,; \tag{5}$$

$$\sigma = \sqrt{\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} (\mu(t) - Y(t))^2 dt} \,; \tag{6}$$

$$\Delta\tau = \frac{1}{\mu(t_2) - \mu(t_1)} \int_{\mu(t_1)}^{\mu(t_2)} (t(\mu) - t(Y))d\mu \,, \tag{7}$$

where μ(t) is variation of output position of actuator in time, $Y(t)$ is variation of output signal of continuous controller in time, t_1 and t_2 are limits of integration.

For calculation of the accuracy indexes during the first pulse, the limits of integration shall be set to the following values: t_1=0, t_2=Δt_{s1}. For the second part of the transient process after the first pulse, these values shall be set as follows: t_1=Δt_{s1}, t_2=t_{sim}, where t_{sim} is duration of simulation of the transient process.

It should be mentioned that the calculated values of the accuracy indexes (Δ, σ and $\Delta\tau$) according to formulae (5) to (7) represent deviation of the step response curve of a step PID controller with an actuator from the step response curve of a continuous PID controller derived by means of simulation. After implementation of the presented above diagrams of step PID controllers in specific devices (hardware), the accuracy indexes may assume greater values than those derived by simulation. There is also one more factor that leads to an increase in the values of the accuracy indexes, i.e. the distinction between an ideal integrating element and a real actuator. The inertia and hysteresis of a real actuator lead to an additional increase in the values of the accuracy indexes.

During application of a step PID controller in control loops there are some restrictions on the parameters of the control diagram and the actuator. Here are some of these restrictions:

- The rate of change of the integral component of the PID control law cannot be greater than the rate of change of the actuator position.
- Motor time of the actuator should be greater than the duration of the first pulse (Δt_{s1}).
- The step PID controller will behave like a step PI controller (there will be unipolar pulses at the output of the step controller and the duration of the first break will be longer than of the other breaks) for some settings of the integral and the differential components of the PID control law and for some values of hysteresis loop width Δ_{HL} and motor time of the actuator T_M.

These restrictions should be taken into account for correct application of step PI and PID controllers in automatic control loops.

7. Simulation of step response curves

In order to study the step response curves of various diagrams of step controllers with actuators in PI and PID control modes in detail and to compare them with the step response curves of continuous PI and PID controllers, a computer simulation was carried out using the numerical methods. The parameters of MEO-630/63-0,63-92K actuator [9] were taken for simulation. The input data for the simulation are: proportional gain K_P = 2, reset time T_I = 120 sec, differentiation time T_D = 10 sec, motor time of the actuator T_M = 63 sec, step change of the error signal $\Delta\varepsilon$ = 5%.

The parameters of the diagram of a step PID controller with double differentiation (Fig. 2) were calculated by means of formulae (1). The results of calculation are: K_{NF}=0.9524, T_{NF}=120, Δ_{HL}=0.2201, Δ_{DB}=0.6603, K_{PF}=0.4302. The simulation results for the PI control mode (T_D=0) are presented in Fig. 6 and for the PID control mode in Fig. 7.

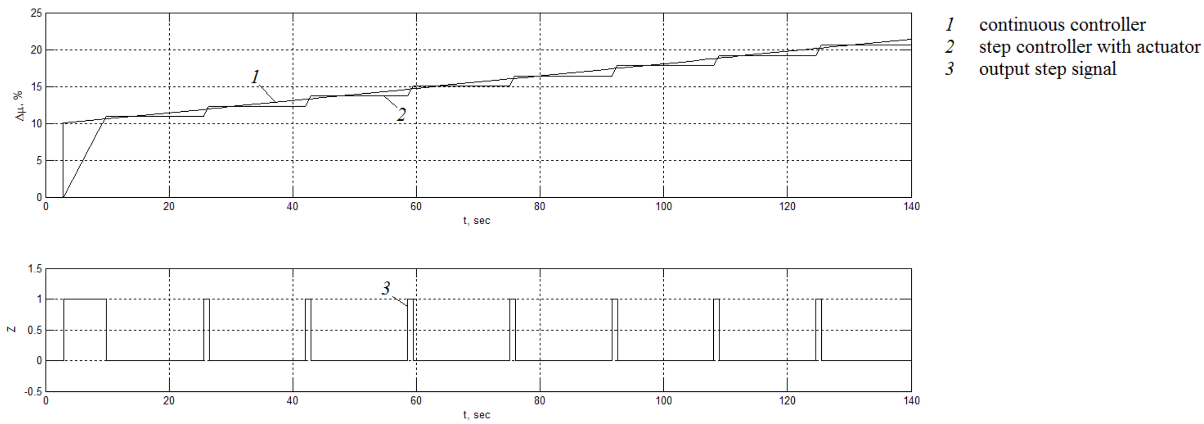

Fig. 6. Step response curves in PI control mode on the basis of the diagram in Fig. 2.

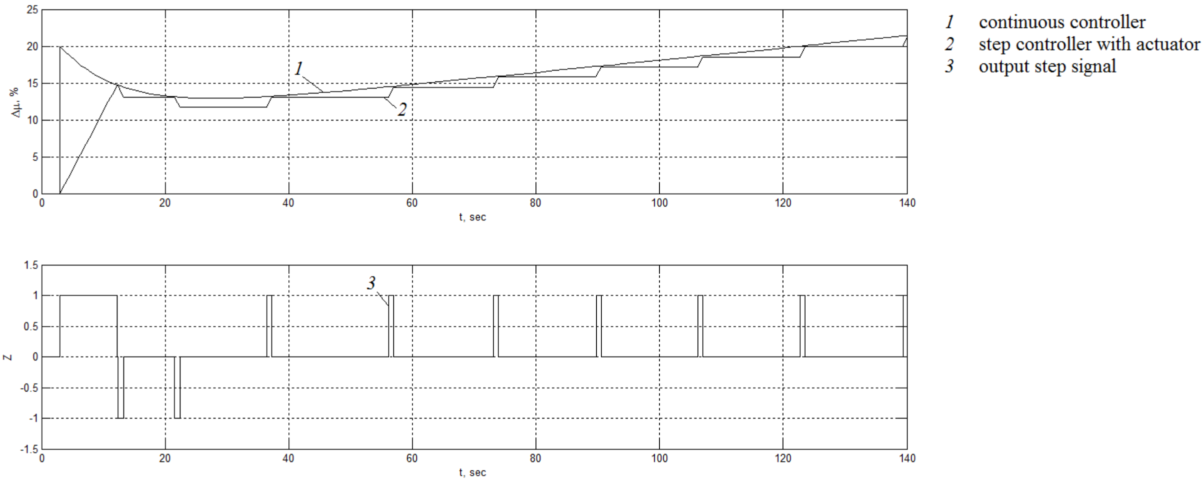

Fig. 7. Step response curves in PID control mode on the basis of the diagram in Fig. 2.

It can be seen from Fig. 6 that the angles of the step response curves of the continuous controller and of the step controller with an actuator are equal. The duration of the first pulse (Δt_{s1}) is 6.8979 sec. During the first pulse the actuator will move by a value of $\Delta\mu(\Delta t_{s1})$=6.8979/63×100=10.9490 (%), which corresponds to the action of the proportional component of the PI control law ($\Delta\mu(\Delta t_{s1})/\Delta\varepsilon$=2.1898≈$K_P$). The actual value of reset time (T_I) of the step controller with an actuator is 122.2 sec. The duration of the second pulse is 0.8647 sec. The values of the accuracy indexes during the first pulse are: Δ_1=-4.8129 %, σ_1=2.2413 %, $\Delta\tau_1$=3.0600 sec. The values of the accuracy indexes during the second part of the transient process are: Δ_2=-0.2836 %, σ_2=0.0429 %, $\Delta\tau_2$=3.3368 sec.

It can be seen from Fig. 7 that in the PID control mode there are both pulses “up” and “down” at the output of the step controller. The duration of the break between the first pulse (“up”) and the second pulse (“down”) is 0.0652 sec. The values of the accuracy indexes during the first pulse are: Δ_1=-9.5757 %, σ_1=3.6794 %, $\Delta\tau_1$=4.6233 sec. The values of the accuracy indexes during the second part of the transient process are: Δ_2=-0.7968 %, σ_2=0.0796 %, $\Delta\tau_2$=9.4432 sec.

To carry out a simulation for the diagram with a continuous PID controller and a simulated positioner (Fig. 4) the minimum width of hysteresis loop $(\Delta_{HL})_{\min}$ was calculated using formula (4). The result of calculation is $(\Delta_{HL})_{\min}$ = 0.4398. The input parameters for the simulation of the diagram in Fig. 4 are as follows: Δ_{HL}=0.8356, Δ_{DB}=1.6712, T_{IN}=63. The simulation results for the PI control mode (T_D=0) are presented in Fig. 8 and for the PID control mode in Fig. 9.

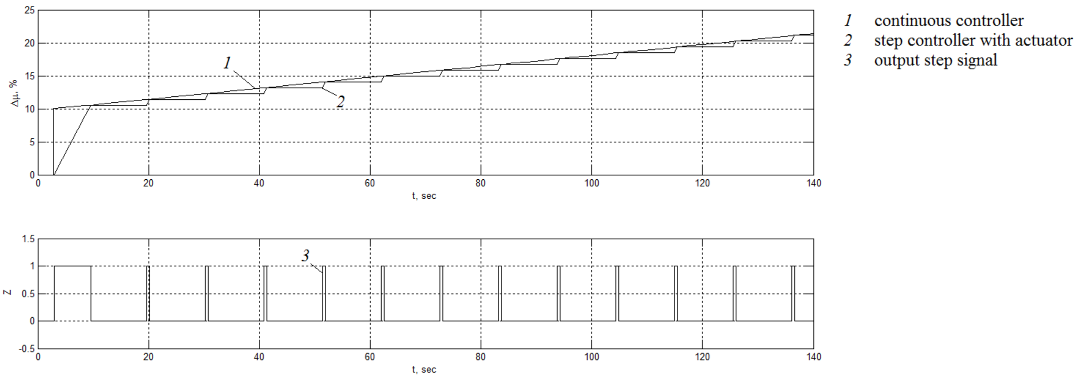

Fig. 8. Step response curves in PI control mode on the basis of the diagram in Fig. 4.

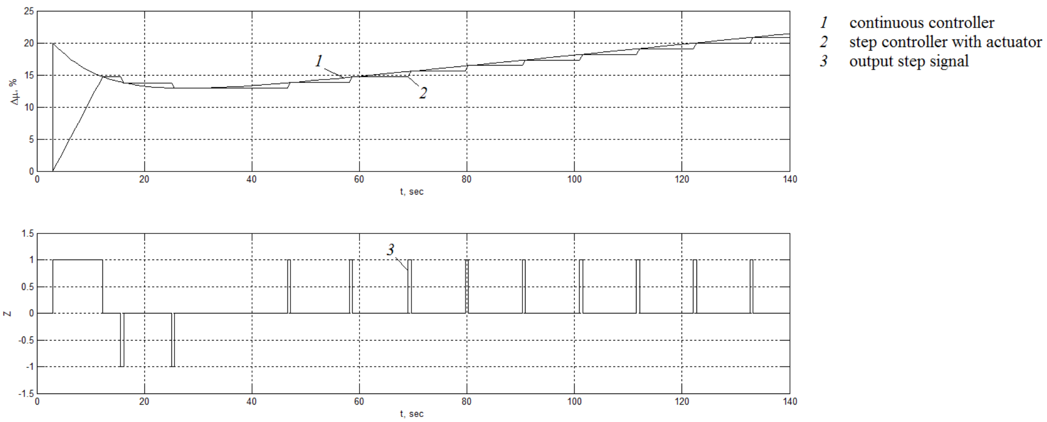

Fig. 9. Step response curves in PID control mode on the basis of the diagram in Fig. 4.

It can be seen from Fig. 8 that the angles of the step response curves of the continuous controller and of the step controller with an actuator are equal. The duration of the first pulse (Δt_{s1}) is 6.6491 sec. During the first pulse the actuator will move by a value of $\Delta\mu(\Delta t_{s1})$=6.6491/63×100=10.5541 (%), which corresponds to the action of the proportional component of the PI control law ($\Delta\mu(\Delta t_{s1})/\Delta\varepsilon$=2.1108≈$K_P$). The actual value of reset time (T_I) of the step controller with an actuator is 122.9 sec. The duration of the second pulse is 0.5556 sec. The values of the accuracy indexes during the first pulse are: Δ_1=-5.0 %, σ_1=2.3232 %, $\Delta\tau_1$=3.15 sec. The values of the accuracy indexes during the second part of the transient process are: Δ_2=-0.4107 %, σ_2=0.0429 %, $\Delta\tau_2$=4.9279 sec.

It can be seen from Fig. 9 that in the PID control mode there are both pulses "up" and "down" at the output of the step controller. The duration of the break between the first pulse ("up") and the second pulse ("down") is 3.2960 sec. The values of the accuracy indexes during the first pulse are: Δ_1=-9.5432 %, σ_1=3.6669 %, $\Delta\tau_1$=4.6391 sec. The values of the accuracy indexes during the second part of the transient process are: Δ_2=-0.2895 %, σ_2=0.0423 %, $\Delta\tau_2$=5.2396 sec.

The result of simulation of a step response curve for the diagram of the step PI controller with a pulse generator and an actuator (Fig. 5) is presented in Fig. 10. The input parameters for simulation of the diagram in Fig. 5 are as follows: Δ_{HL}=0.8356, Δ_{DB}=1.6712, T_{IN}=63.

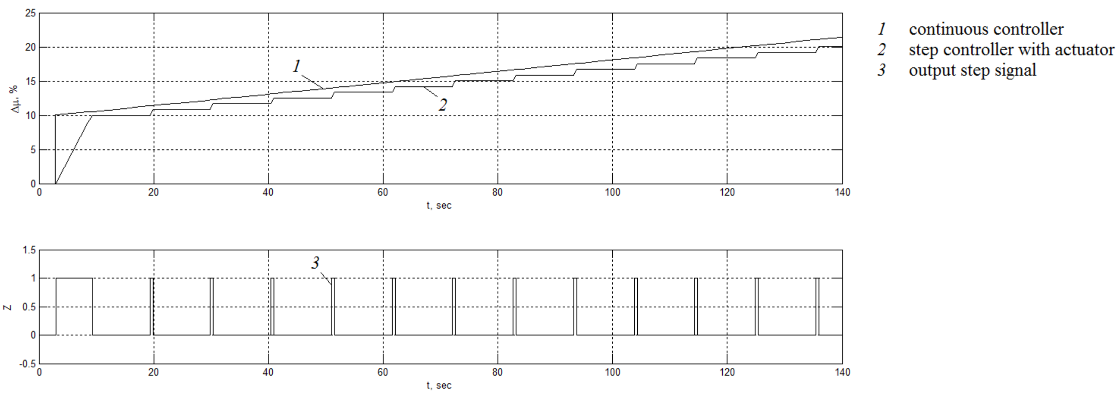

Fig. 10. Step response curves in PI control mode on the basis of the diagram in Fig. 5.

It can be seen from Fig. 10 that there is a negative deviation between the step response curve of the diagram in Fig. 5 and the step response curve of the continuous PI controller. This deviation becomes larger during the transient process which is caused by the existence of the key in the diagram in Fig. 5. The duration of the first pulse (Δt_{s1}) is 6.3 sec. During the first pulse the actuator will move by a value of $\Delta\mu(\Delta t_{s1})$=6.3/63×100=10.0 (%), which is equal to the action of the proportional component of the PI control law ($\Delta\mu(\Delta t_{s1})/\Delta\varepsilon=2.0=K_P$). The actual value of reset time (T_I) of the step controller with an actuator is 132.9 sec. The duration of the second pulse is 0.5265 sec. The values of the accuracy indexes during the first pulse are: Δ_1=-5.2625 %, σ_1=2.4502 %, $\Delta\tau_1$=3.15 sec. The values of the accuracy indexes during the second part of the transient process are: Δ_2=-1.1863 %, σ_2=0.1070 %, $\Delta\tau_2$=13.2803 sec.

On the basis of the calculated values of the accuracy indexes we can see that the largest deviation of the step response curve of a step controller with an actuator from the step response curve of a continuous controller in the PI control mode is present in the diagram of the step PI controller with a pulse generator (Fig. 5). The mean delay time introduced by this diagram is 13.2803 sec for the simulated example. And the largest deviation in the PID control mode is present in the diagram of the step PID controller with double differentiation (Fig. 2). The mean delay time introduced by this diagram is 9.4432 sec.

After simulation of step response curves for the diagram with a continuous PID controller and a pulse-width modulator (Fig. 3) in the PI and PID control modes it was defined that this diagram provides the same simulation results as the diagram with a continuous PID controller and a simulated positioner (Fig. 4).

Conclusion

A motor-driven actuator in the control loop affects transient processes during automatic control. The behavior of the motor-driven actuator as an integral element should be taken into account during PID control. The following diagrams of step controllers for motor-driven actuators have been analyzed: the diagram of a step PID controller with double differentiation, the diagram with a continuous PID controller and a pulse-width modulator, the diagram with a continuous PID controller and a simulated positioner and the diagram of a step PI controller with a pulse generator. The main formulae for calculation of the parameters of these diagrams are presented in the paper.

For quantitative estimation of the accuracy of step controllers with actuators it is proposed to use the accuracy indexes (criteria), i.e. mean deviation, standard deviation and mean delay time. Based on simulation results the accuracy of every diagram of step controller was analyzed. The largest mean delay time in the PI control mode is introduced by the diagram of a step PI controller with a pulse generator, and in the PID control mode by the diagram of a step PID controller with double differentiation. Restrictions on the parameters of the diagrams of step controllers and actuators have been defined in the paper. The diagrams of step PID controllers considered in this paper can be implemented in the up-to-date PLCs software for automatic control using electric motor-driven actuators in the control loops.

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