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Study of an On-Off Control System with Lead Control Action

Alexandru Şahanschi, Alina-Simona Băieşu

Universitatea Petrol-Gaze din Ploieşti, Bd. Bucureşti 39, Ploieşti
e-mail: alex.saha91@yahoo.com, agutu@upg-ploiesti.ro

Abstract

In case of using a classical on-off controller, the control system response is characterized by continuous oscillations of the process output around the setpoint value. The amplitude of oscillations depends on the controller hysteresis value. A better dynamic performance of an on-off control system can be obtained when the controller hysteresis has a negative value, because the controller output will change the state before the process output crosses the setpoint value. This kind of behavior can also be obtained if the control system has a supplementary feedback lead which gives the controller a measure of the process output on a lead phase in comparison with the process output. The performance of the proposed on-off control system is tested in case of a process characterized by a second order with dead time transfer function and compared with the ones obtained with the classical on-off structure.

Key words: *on-off control, lead control action, hysteresis.*

Introduction

The classical control systems contain Proportional-Integral-Derivative (PID) controllers or on-off controllers. Between the two types of controllers, the on-off variant is the simplest, cheapest, effective and easy to implement variant, but it cannot be always used.

Usually, on-off control is used in some particular cases that do not require a precise control, or that can have energy turned on and off frequently, or where the mass of the system is so great that the process output changes extremely slowly [5].

In case of an on-off controller the control variable has only two states, is either on or off, having no middle state. An on-off controller will switch the output only when the process output (controlled variable) value crosses the setpoint value [4].

For example, in case of a heating process having an on-off controller, the control variable state is on when the temperature is below the setpoint value, and becomes off when the temperature crosses above the setpoint value.

In some on-off control applications, there are some considerations that need to be taken into account such the tear of control valves or other costs that can occur when power is reapplied each time the process output value drops. Therefore, practical on-off control systems are designed to include a deadband, named hysteresis, which is a region around the setpoint value in which there is no control action. The value of the hysteresis may be adjustable. This prevents rapid switching on and off as the process output value goes around the setpoint [6].

The process output value will oscillate around the setpoint value with amplitude that depends on the controller hysteresis. In order to obtain a better on-off control system response, having small amplitude of the process output oscillations, a negative value of the hysteresis has to be considered. That means that the controller output will switch the state from off to on when the controlled variable is below the setpoint value, and not above, as in the positive hysteresis value case [2].

This effect can be obtained also when on the control system feedback we use a lead element that gives a measure signal on a lead phase in comparison with the process output.

The objective of this paper is to present a study of an on-off control system having a supplementary feedback lead that implies a lead control action and offers good dynamic performance, in comparison with the standard on-off control system type.

On-Off Control Systems

The simplest type of a control system is the one that has an on-off controller, in which the control action has two-positions (on or off) or two-values (0 or 1). The on-off controller is a static nonlinear system, whose characteristic is presented in figures 1,a and b. In on-off control, the control signal c (controller output) takes only two distinct values (0 and 1), as in figure 1. Therefore, the controller runs like a switch and the final element is either fully open (on) or fully closed (off). The overall value of the control signal depends on the length of time when the signal is 0 and 1, respectively [2].

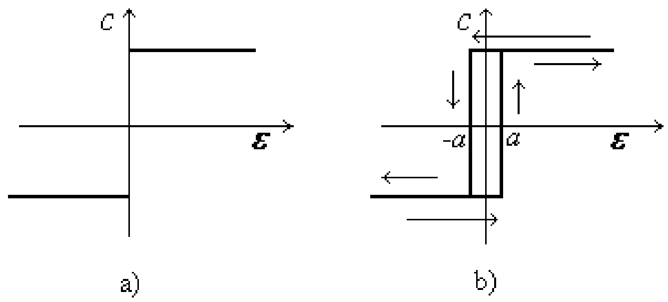

Fig. 1. On-off controller characteristic: a) without hysteresis, b) with hysteresis, c-controller output, ε-control system error, a-controller hysteresis.

The main disadvantage that occurs when an on-off controller is used is that the controlled variable y oscillates around the reference value r (figs. 2 and 3), and hence the quality of control is robust, but not very good [1].

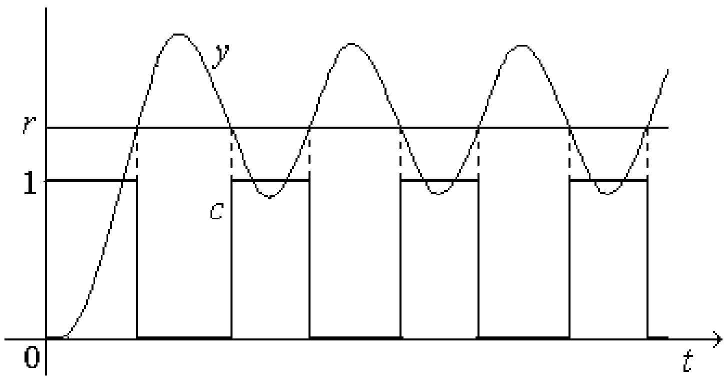

Fig. 2. On-off control without hysteresis: *c*-controller output, *y*-process output, *r*-setpoint.

Since the on-off controller will switch the output value only when the process output (y) crosses the setpoint (r), the process output will oscillate continuous, going from below setpoint to above, and back below. In some cases, when this cycling occurs rapidly, in order to prevent the damage of the final element, a hysteresis (a) is added to the controller output, as in fiure. 1b and figure 3 [1]. This hysteresis requires that the process output to exceed the setpoint by a certain value before the output will turn off or on again. The on-off controller hysteresis prevents the output to make rapid switches if the process output value oscillations above and below the setpoint occurs very rapidly [5].

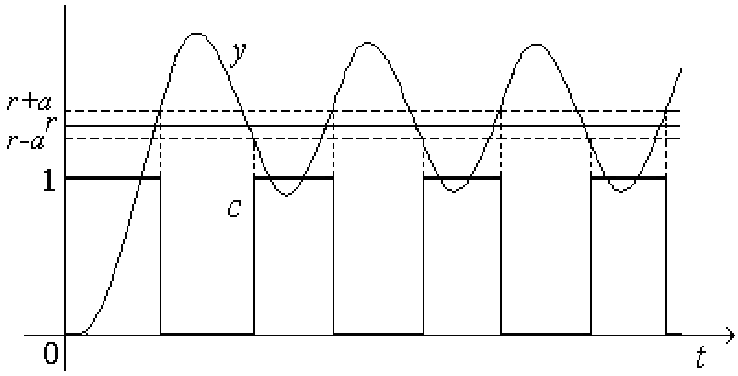

Fig. 3. On-off control with hysteresis: c-controller output, y-process output, r-setpoint, a-controller hysteresis.

The magnitude of the oscillations of the controlled variable (in percentage terms) is larger than or equal to the controller semi-hysteresis a. The equality occurs only for a static or sluggishness process (first order process). If the semi-hysteresis a is large, then the oscillation magnitude is greater than the semi-hysteresis value, as the system order increases, but the switching frequency of the control signal c is small [2].

An on-off control system is represented in figure 4.

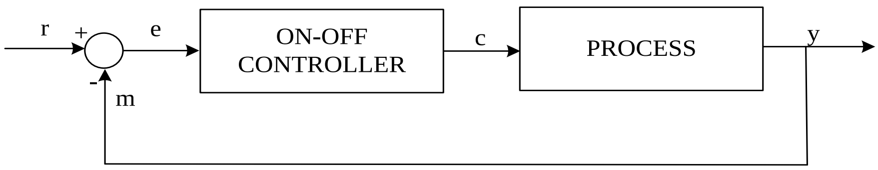

Fig. 4. On-off control system: c-controller output, y-process output, r-setpoint, m-measure, e-error.

The best response of an on-off control system can be obtained when the controller hysteresis is set to a negative value. In this case, the control action switch takes place before the process output reaches the setpoint value. Instead of using this negative hysteresis, we can use a variant that gives the same result, characterized by a supplementary feedback lead that gives the process output measure signal on a lead phase in comparison with the process output and implies a lead controller action.

The lead element is characterized by the following lead-lag transfer function [3]:

$$G_{LEAD}(s) = \frac{T_L \cdot s + 1}{T_0 \cdot s + 1}, \tag{1}$$

where T_L is the lead time constant and T_0 is the lag time constant.

Because the lead constant is much greater that the lag time constant, the dominant behavior is the lead behavior; that is the reason why this element is named lead element. The time constant T_0 is chosen small so that the measure signal do not be delayed to the controller input.

An on-off control system with lead control action is represented in figure 5.

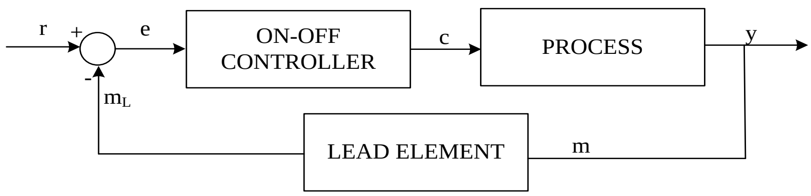

Fig. 5. On-off control system with lead control action: c-controller output, y-process output, r-setpoint, m-measure, m_L-lead measure, e-error.

The controller output switch takes place when the lead measure signal m_L reaches the setpoint value (r). Because the lead measure signal m_L is on a lead phase in comparison with the measure signal m, the control action switch takes place before the process output value reaches the setpoint value.

Simulation Results

In order to study the behavior of the on-off controller with or without the lead element, a process characterized by a second order transfer function with dead time was considered [3]:

$$G_p(s) = \frac{k \cdot e^{-\tau s}}{T_2 \cdot s^2 + T_1 \cdot s + 1} = \frac{1.3 \cdot e^{-2s}}{20 \cdot s^2 + 4 \cdot s + 1}. \tag{2}$$

In case of having the controller on manual, considering a step change of control variable from 0 to 1, we have the process step response from figure 6.

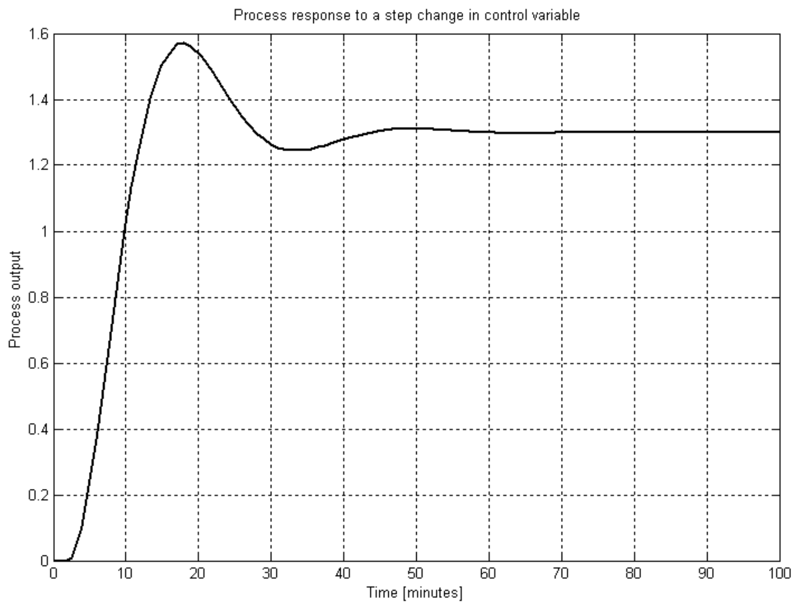

Fig. 6. Process output step response.

In case of a setpoint step change, considering the control system from figure 4, without the leading element, we have the following control system response. The hysteresis value is equal to 0.01.

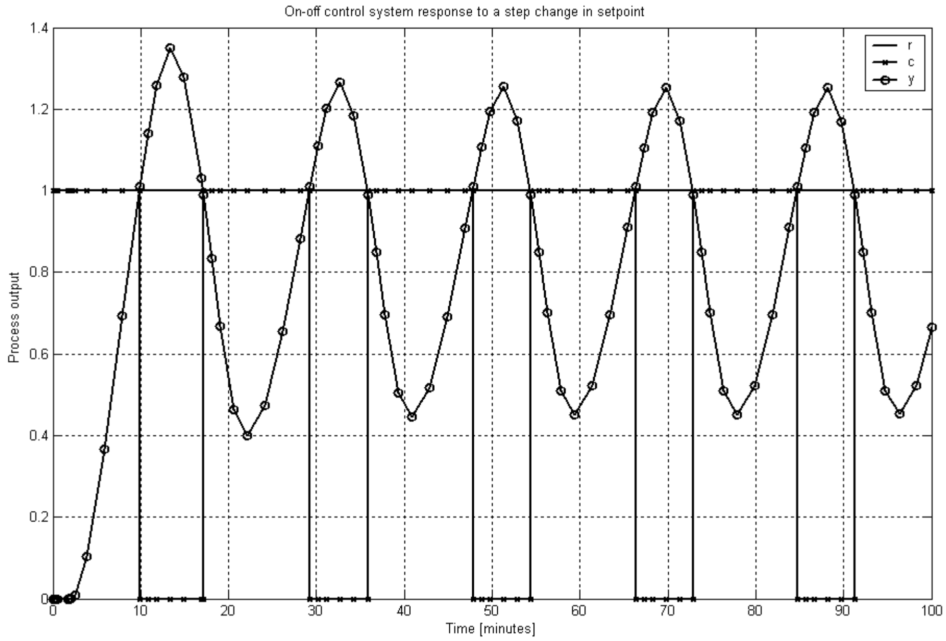

Fig. 7. On-off control system response to a setpoint step change, having hysteresis equal to 0.01.

In case of a setpoint step change for the control system from figure 4, without the leading element, we have the following control system response. The hysteresis value is set to 0.1.

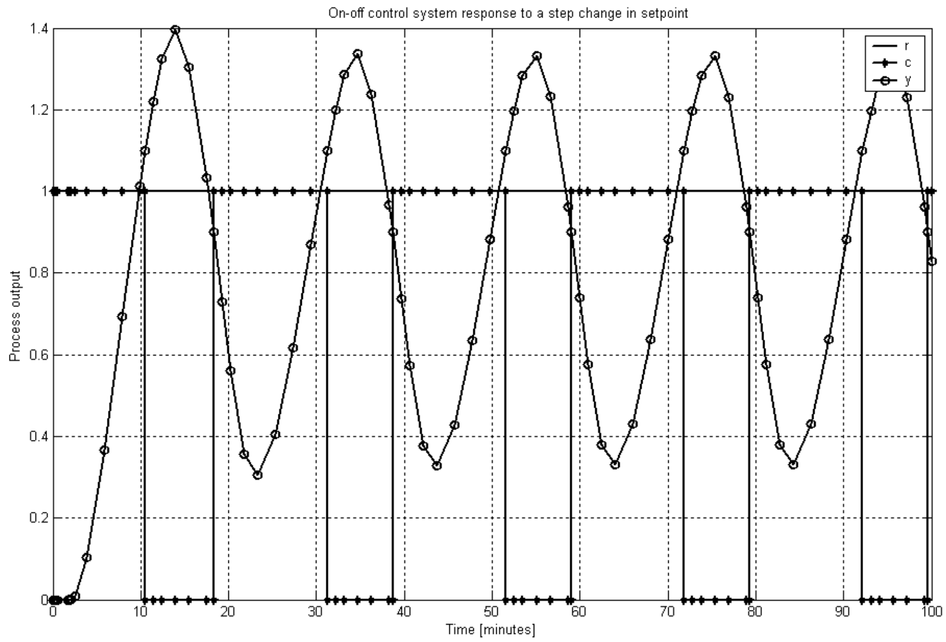

Fig. 8. On-off control system response to a setpoint step change, having hysteresis equal to 0.1.

Comparing the results from figures 7 and 8 we see that the process output oscillates with a small amplitude when the controller hysteresis has a small value (fig. 7).

In case of a setpoint step change for the control system from figure 4, without the leading element, we have the following control system response. The hysteresis value is equal to 0.5.

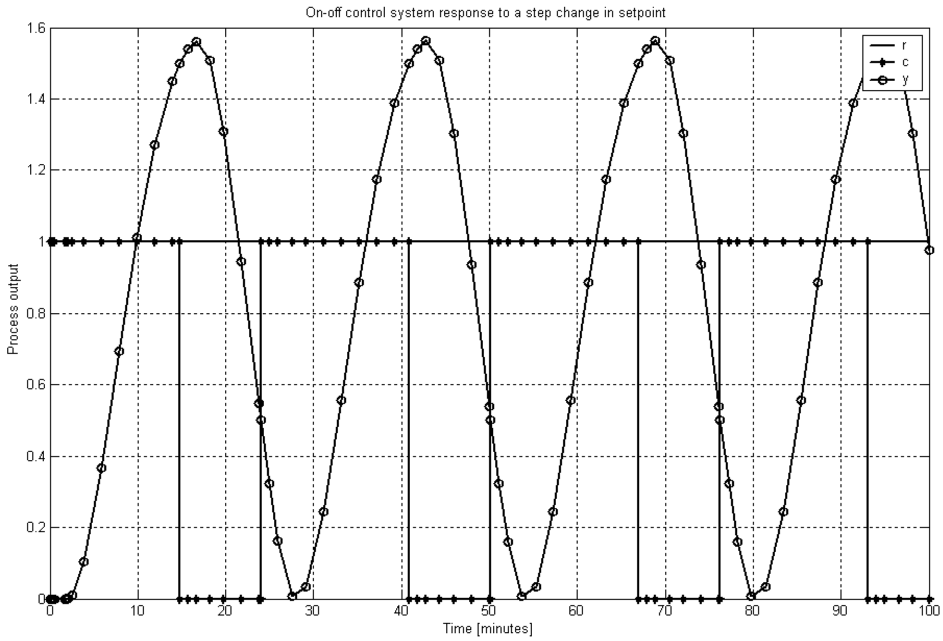

Fig. 9. On-off control system response to a setpoint step change, having hysteresis equal to 0.5.

In figure 9 the process output oscillations amplitude has a large value because the hysteresis value is also large, in comparison with figure 7.

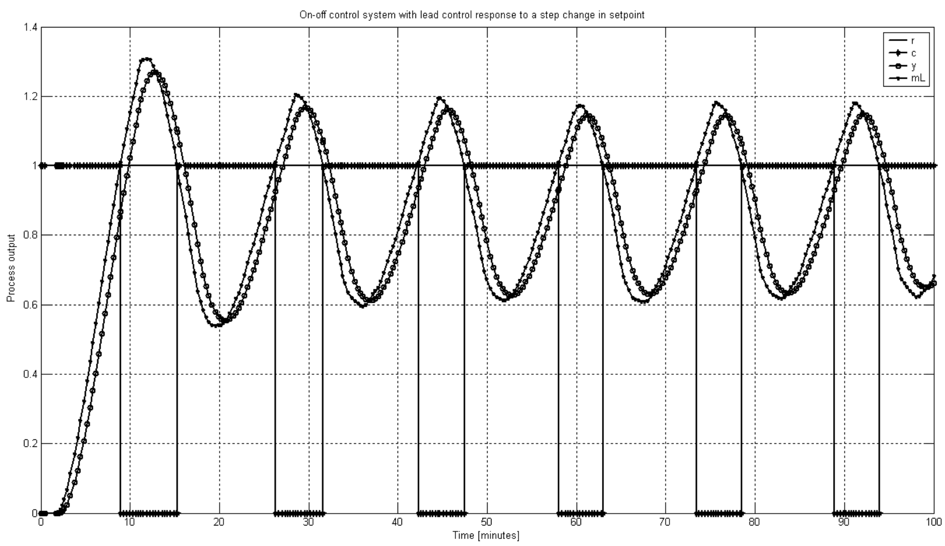

Fig. 10. On-off control system response to a setpoint step change, considering the lead element with T_L=1 min and having hysteresis equal to 0.01.

In case of using the on-off control system, with the lead element from figure 6, and considering the lead element (1) characterized by the following transfer function:

$$G_{LEAD}(s) = \frac{s+1}{0.1 \cdot s + 1}, \tag{3}$$

with the lag time constant T_0=0.1 min and the lead time constant T_1=1 min, we have the following control system response to a setpoint step change.

As we can see from figure 10 above, in comparison with the results from figure 7, the process output oscillates around the setpoint value with small amplitude because the controller output changes its state before the process output reaches the setpoint value. This is done due to the lead element that provides the measure of the process output on a lead phase.

Also, in case of using the on-off control system with the lead element from figure 6 but considering the lead element (1) characterized by the following transfer function

$$G_{LEAD}(s) = \frac{2 \cdot s+1}{0.1 \cdot s + 1}, \tag{4}$$

with the lag time constant T_0=0.1 min and the lead time constant T_L=2 min, we have the following control system response to a setpoint step change

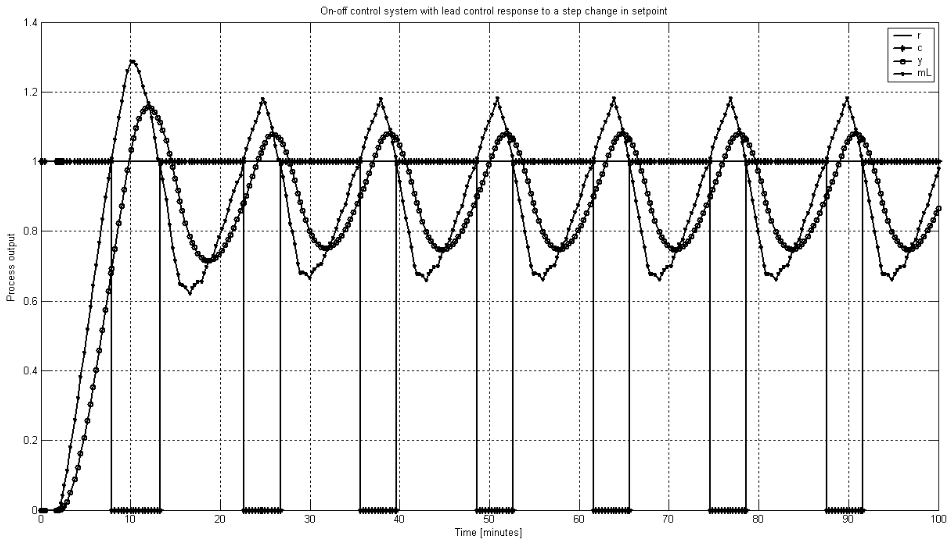

Fig. 11. On-off control system response to a setpoint step change, considering the lead element with T_L=2 min and having hysteresis equal to 0.01.

Also, in figure 11 in comparison with the results from figures 7 and 10, the process output oscillates around the setpoint value with a even smaller amplitude because the controller output changes its state long before the process output reaches the setpoint value.

In figure 12 are represented the cases from figure 7, considering the on-off controller without the lead element, and figure 11, considering the on-off controller with the lead element.

As we can see from figure 12, when the lead element is considered we obtain a better control system dynamic response, with small oscillations amplitude.

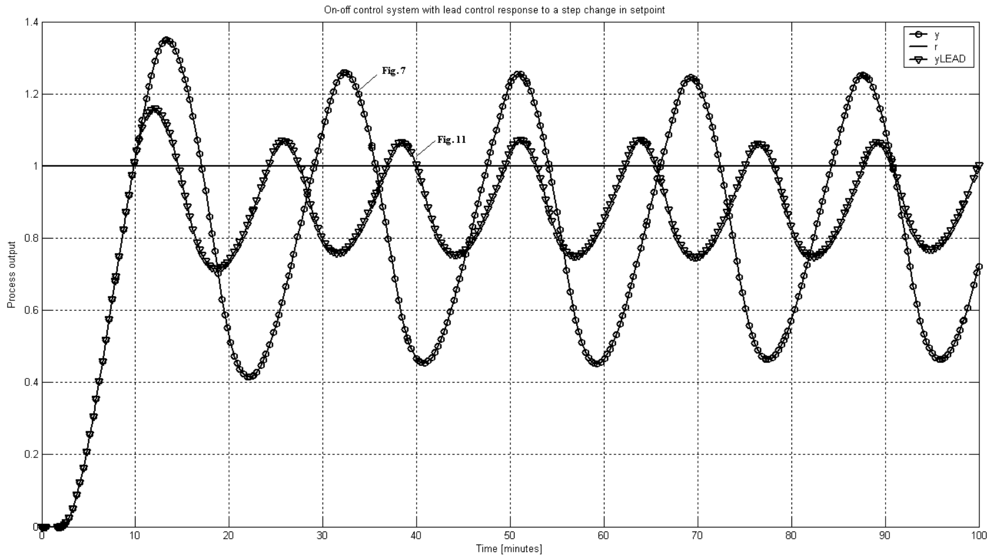

Fig. 12. On-off control system response to a setpoint step change, with and without the lead element, having hysteresis equal to 0.01.

Conclusions

This paper objective was to present the results that can be obtained when an on-off controller is used in order to control a linear process characterized by a second order with dead time transfer function.

Two cases are considered.

One is the case when the control system structure is a classical one, without a supplementary feedback lead.

The other case is the one that has a supplementary feedback lead, that provide a measure signal on a lead phase in comparison with the process output. In this case, the controller output switches before the process output crosses the setpoint value, when the lead measure signal becomes equal with the setpoint value. The controller has a lead control action that gives to the control system better performance characterized by oscillations with smaller amplitude.

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Studiul unui sistem de reglare bipoziţional cu comanda în avans

Rezumat

Răspunsul unui sistem clasic de reglare bipoziţională se caracterizează prin oscilatii continue ale mărimii de ieşire din proces în jurul valorii de referinţă. Amplitudinea oscilatiilor depinde de valoarea histerezisului regulatorului. În cazul sistemelor de reglare bipoziţională, o performantă dinamică mai bună, poate fi obtinută atunci când histerezisul regulatorului are o valoare negativă, deoarece iesirea regulatorului îşi va modifica starea înainte ca iesirea din proces să ajungă la valoarea de referintă. Acest tip de comportament poate fi obtinut dacă sistemul de reglare prezintă o reacţie în avans a măsurii mărimii de ieşire din proces. Performanta sistemului de reglare bipoziţional propus, cu comanda în avans, este testată în cazul unui proces caracterizat de o funcţie de transfer de ordinul doi cu timp mort si comparată cu performanţele structurii clasice bipoziţionale.