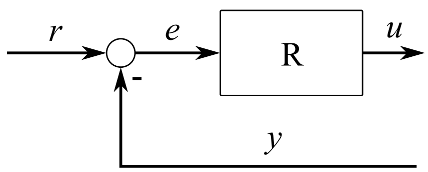
1 Discontinuous controllers

Step Control

- Two position or multi-position controller;
- Work with several objects.



Finite set of output states $u = \{u_1, u_2, \ldots, u_n\}$ - simple!

Control law: $u = F(e)$ - is strongly nonlinear.

If the corresponding time constants are large enough, good control results at small errors can even be reached with discontinuous controllers and simple control elements.

Types of controllers:

- Two position mode,
- Three position mode,
- Multiposition mode.

1.1 Two position mode/ON-OFF Controller

Output: $u = \{u_1, u_2\}$

This is a discontinuous form of control action, and is also referred to as two-position control. This type of control does not actually hold the variable at set point, but keeps the variable within proximity of set point Fig. 1. The term dead band or neutral zone is used for the values between the on and off values [1, 2].

The indicators of self-oscillating mode are the oscillation amplitude A and period of the oscillations T_{osc}, see Fig.1.

The frequency and amplitude of the oscillations depend and determined by the following values:

✓ Delay θ,

✓ Time constant τ_o of object (defines the object's inertia),

✓ Value of **hysteresis** H / hüsterees / гистерезис.

- The larger $H, \theta/\tau_o$ - the greater the amplitude A is.

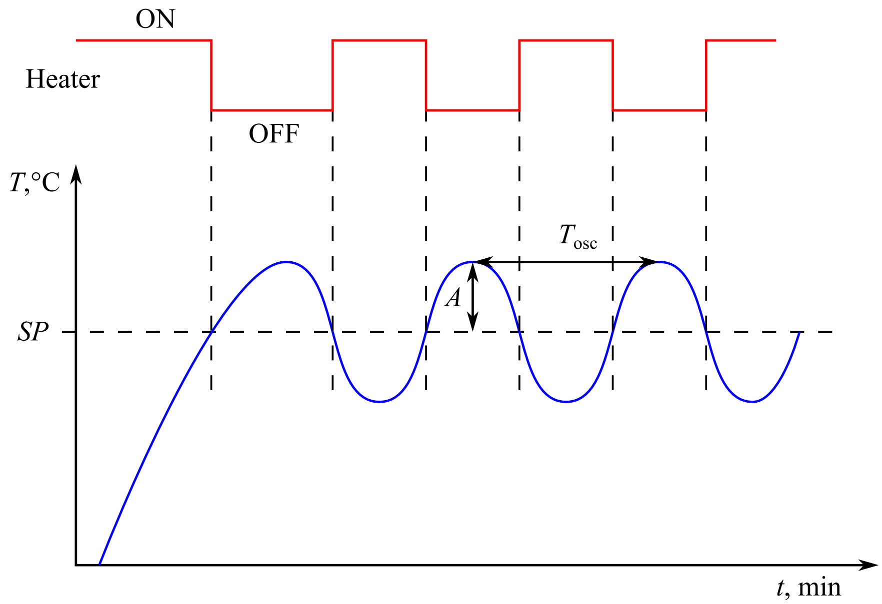


Figure 1: Response on the control action

- The larger τ_o and θ - the longer oscillation period T_{osc}.

On-off control is common for simple, non-critical applications.

At home: cooker, iron, refrigerator, etc.

Industry: compressors, fans (engine), heaters, valves, etc.

The ideal on-off controller Fig. 2 is not practical: processes disturbances and electrical interference [3].

Good points	Bad points
✓ Does not require tuning, suitable for all objects	✓ Actuator's frequent cycling ⇒ to premature failure (mechanical wear)
✓ Simple, low-cost: output contact $0, 1$	✓ Precision problem
✓ Max response to deviations: reacts the same way on different inputs $r = 1, 10, \ldots$	✓ Waste of energy: heated to a grater $T,^{\circ}C$ than necessary

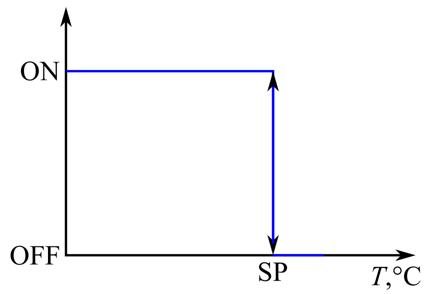


Figure 2: Ideal ON-OFF controller

Hysteresis H

Hysteresis / hüsterees / зона неоднозначности

- Separates changes $u_1 \to u_2$ and $u_2 \to u_1$;
- Positive value $H > 0$;

Representation method:

✓ Symmetrical $\pm H/2$ with respect to error $e = 0$;

✓ Asymmetrical.

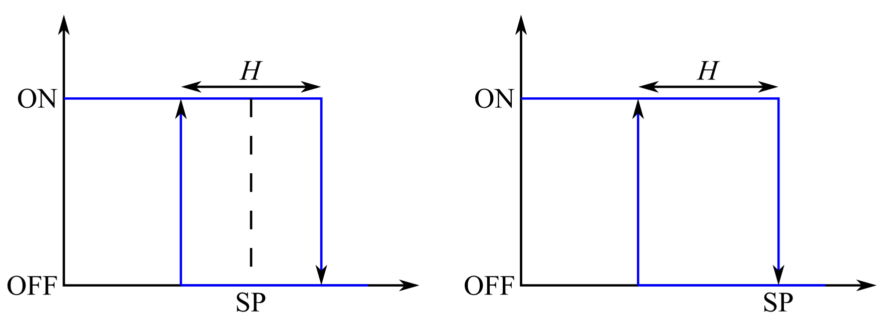


Figure 3: Types of hysteresis

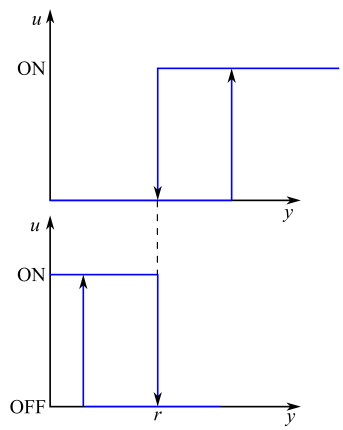
Nowadays value of the hysteresis is the only programmable parameter in such type of the controllers. Representation of the hysteresis is described in the manual of the controller or control system.

The controller's input/output characteristic $u(y)$

Measured value $y = (r - e)$.

Error characteristic is inverted $(\ldots - e)$ and shifted (by r).

Two types of characteristics:



direct characteristics

pärikarakteristik

регулятор прямого действия

$K_o < 0$ object: freezer

reverse characteristics

pöördkarakteristik

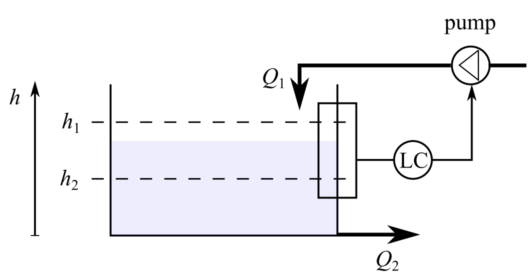
регулятор обратного действия

$K_o > 0$ object: iron

Consider three control cases with

1. Integrating,
2. Inertial,
3. and object with a delay.

Integrating object (liquid level of the tank)



$W_0 = K_0 \frac{1}{s} = \frac{1}{T_0 s}$

$Q_1 - Q_2 = \frac{dV}{dt}; \quad V = \int (Q_1 - Q_2) dt = A \cdot h$

$h = \frac{1}{A} \int (Q_1 - Q_2) dt \qquad W_0(s) = \frac{H(s)}{Q_1(s)} = K \cdot \frac{1}{s}$

Q_2: output flow $(0 \ldots Q_{2_{\max}})$ - disturbance

Block-diagram: controller, disturbance, tank

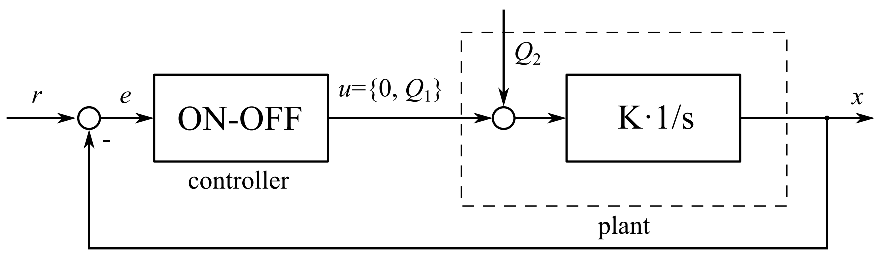


Figure 4: Intergrating object

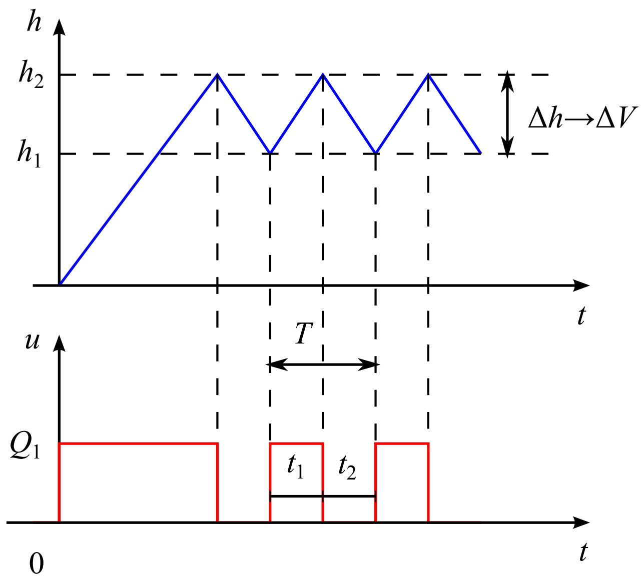
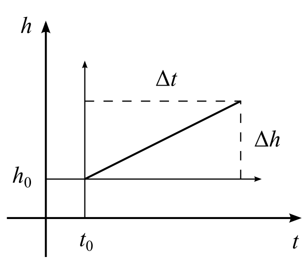


Figure 5: ON-OFF control of integrating object



If IN - Q_1 and OUT - Q_2 do not change
$\Delta V = A \cdot \Delta h = (Q_1 - Q_2) \cdot \Delta t$,
then level h - linear
$h(t) = [(Q_1 - Q_2)/A)] \cdot (t - t_0) + h_0$

NB! Inflow and outflow pumps have different control characteristics (direct and reverse), see Fig. 6.

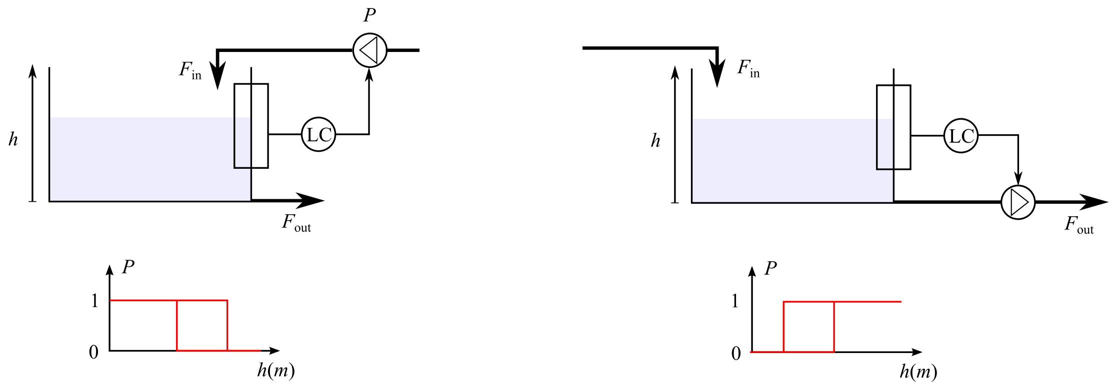
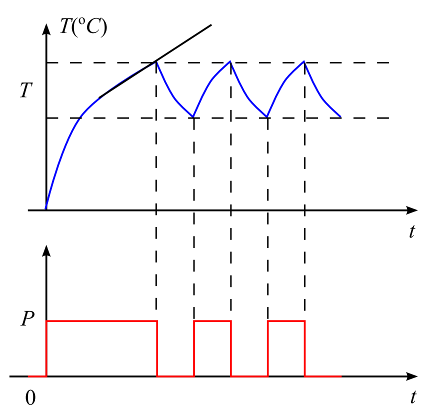


Figure 6: Pumps characteristics

Aperiodic or inertial objects



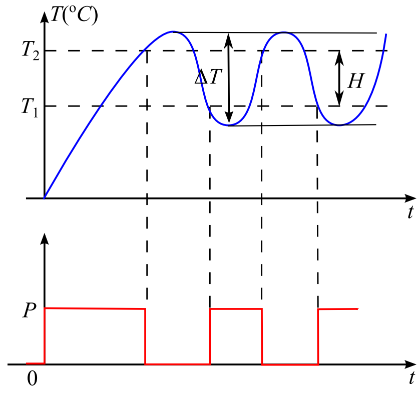
$$W = \frac{K}{1 + \tau_o s}$$

inertial process

Control error $\Delta T > H$ (ΔT is min if $H = 0$). Error depends on delay and time constant ratio θ/τ_o.

θ/τ_o	0.1	0.5
$\Delta T/T$	$\pm 5\%$	$\pm 20\%$

$\Rightarrow \quad 80\ ^\circ C \pm 16\ ^\circ C = 64\ ^\circ C \ldots 96\ ^\circ C$



$$W = \frac{K}{1+\tau_o s} \cdot e^{-s\theta}$$

process with delay

Step controller is not suitable for objects with delay!

Realization of On-Off Controller

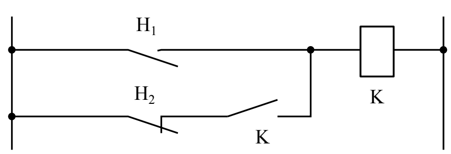
1. **Controller**

   PID controllers have ON-OFF mode

2. **Wiring diagram** (relays)

   using two sensors H_1, H_2

   $$\left.\begin{array}{ll} H_1 = \text{ON} & h > h_1 \\ H_2 = \text{OFF} & h > h_2 \end{array}\right. \text{inflow}$$



electrical diagram:

relay K launching the pump

3. **PLC**

   algorithm pump $= H_1 \vee \overline{H_2}\&$pump

1.2 Three position mode/Floating Control

Floating control is a variation of On/Off control that requires a fast responding sensor and a slow-moving actuator connected to the final controlled device (valve or damper). Floating control is not a common control mode, but it is available in the most microprocessor-based control systems.

Three-position controllers provide good quality of control for inertial objects with a small delay: control of the motors (rotation of direction), heating/cooling/0. Floating control keeps the control point near the set point at any load level, and can only be used on systems with minimal lag between the controlled medium and the control sensor. Floating control is used primarily for discharge control systems where the sensor is placed immediately downstream from the coil, damper, or device that it controls [4].

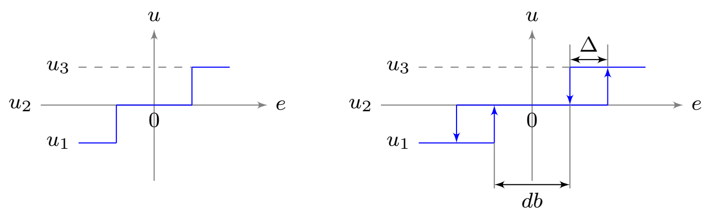


Figure 7: Three point controller without and with hysteresis

Three point controller is depicted in Fig. 7 , where output: $u = \{u_1, u_2, u_3\}$, db - is **dead band** / tundetuse tsoon / зона нечувствительности, Δ - open/close hysteresis.

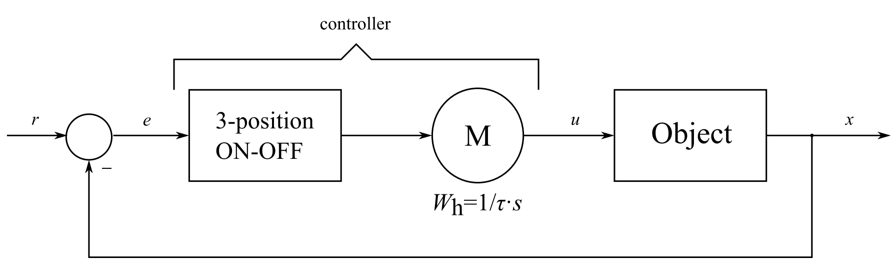
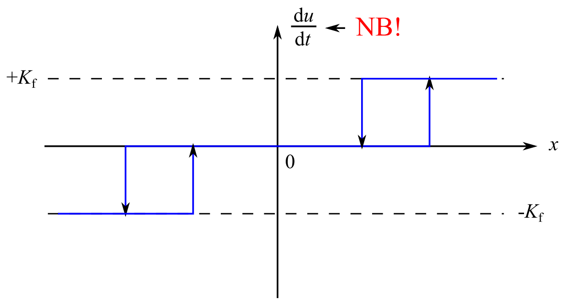


Figure 8: Floating Control diagram

In a typical application, the control point moves in and out of the dead band, crossing the switch differential. A negative change between a present value and the set point causes the actuator working. The narrow differential of the controller stops the actuator after it has moved a short distance. On a rise in Present Value above the set point, the reverse occurs. Thus, the control point can float between open and closed limits and the actuator does not move. When the control point moves out of the dead band, the controller moves the actuator toward open or closed until the control point moves into the dead band again.



$du/dt = \{-K_f, 0, K_f\}$
$u = \pm K_f \cdot t + u(0)$

The control process with floating controller is presented in Fig. 9.

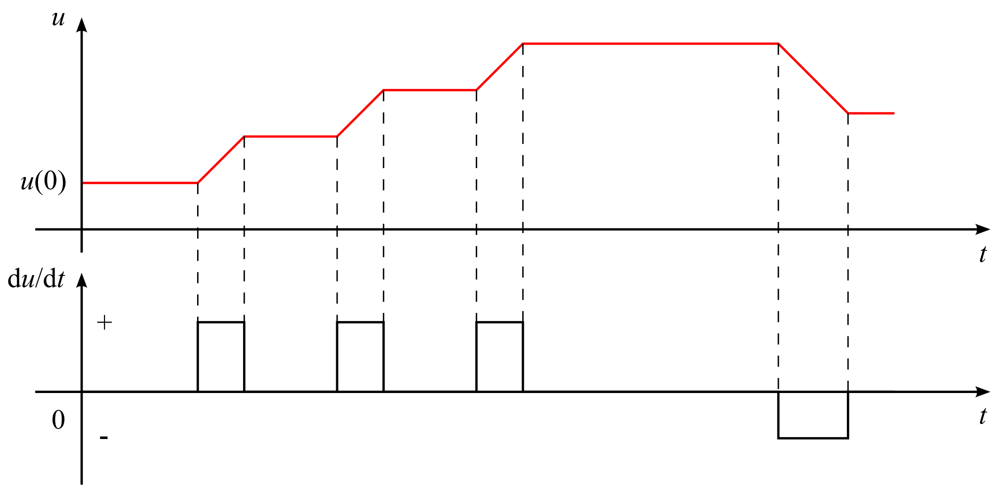


Figure 9: Control process using 3-point controller (floating)

1.3 Multi-position controllers

Multi-position controllers can manage multiple loads, such as group of heaters, fans, dampers, etc. In that case controller works as the selector .

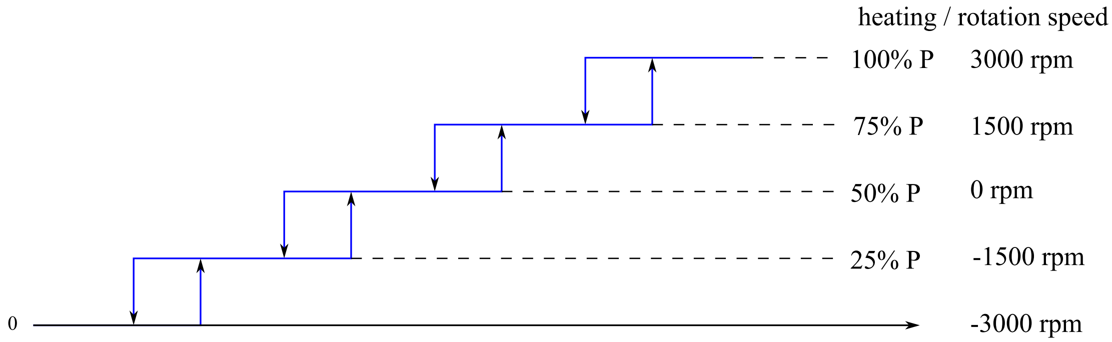


Figure 10: Multi-position control system

Controller output $u = \{u_1, u_2, \ldots, u_5\}$.
Multi-position controllers are used to:

✓ Improve the accuracy of control.

✓ Reduce the time of control.

✓ Improve the quality of control.

- Reduces the oscillatory behavior of two position controllers;
- Reduces undershoot and overshoot.

Bibliography

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