Lecture 1 **Classification of Automatic Control Systems**

1.1 Fundamental terms of the Control Theory

Control is a process of purposeful impact upon an object of regulation forcing it to achieve the predefined target if there are some disturbances that prevent the object from doing that.

The term *"control"* is more general than the term *"regulation" and* we will use him.

Control Object (CO) is *a dynamic system* in the course "Linear Automatic Control Systems". *Dynamic system* is a system the current state of which depends not only on current inputs but also on its previous states.

Control Object will be depicted as the following:

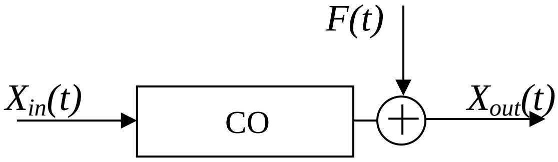

Fig. 1.1.a. Denotation of Control Object

Here (Fig.1.1a, 1.1b, 1.1c) are introduced the following symbols: perturbation action as $F(t)$, input and output variables as $x_{in}(t)$ and $x_{out}(t)$ respectively, output target as X_{target}; plus "+" denotes algebraic sum of signals.

If the point of application of external disturbance is not defined then Control Object is depicted in the following way:

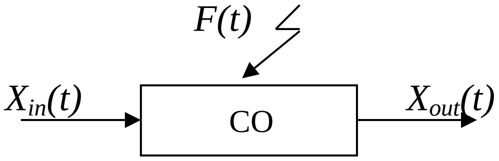

Fig. 1.1.b. Control Object with undefined point of application of external disturbance

The questions arise: "How can the dynamic control system are presented?" and "What are the goals of control?"

Goals of Control (GC) can be different: to achieve the maximization of productivity of an ore mining machine or minimization of petrol consumption can serve as examples of GC. It is essential to define GC clearly first and then to develop ways of its achievement.

When GCs are defined we can work out a structure of *Automatic Control System.* For the purpose we have to carry out the following steps:

1) to depict the Control Object as it is shown in fig.1.1b.

2) to define clearly the goal (X_{target} in fig. 1.1.c).

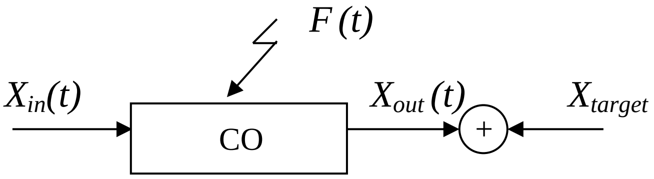

Fig. 1.1.c. Control Object with a defined goal

3) to choose the *Control Action* $\delta u(t)$, which takes into account the difference between x_{out} and x_{target} at every instant of time:
$e(t) = x_{out}(t) - x_{target}$; $\delta u(t) = ke(t)$.

4) to apply $\delta u(t)$ to control input (fig. 1.2):

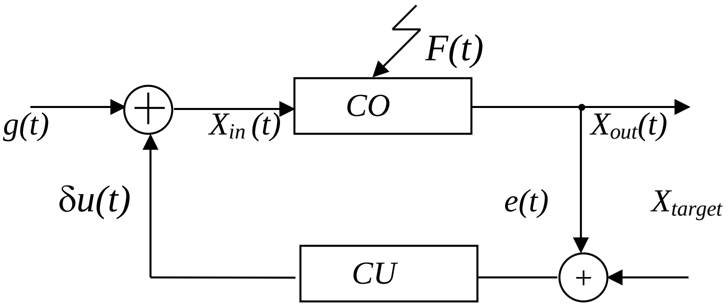

Fig. 1.2. Structure of Automatic Control System

Here *CU* is a *Control Unit (or Controller)*. So the description of control process is the following: to produce such a control action $\delta u(t)$ that a system would react on it by minimizing the difference between an actual output value and a target value, that is by minimizing *the deviation* $e(t)$. Minimization of deviation means that system output gets closer and closer to a desired target value; hence adjustment of control value occurs.

A very important question is: “Is control always possible?” It is necessary to evaluate the problem. There are such conceptions as: full controllability and observability, partial controllability and observability.

Common classification includes Automatic and Automatized (automated) Control Systems.

Automatic Control Systems operates providing needed regulation or maintenance of some physical variables (voltage, temperature, pressure etc.) during sufficiently long time period in the control process.

On the other hand, if a human is somehow involved in the control process (e.g. assigns voltage value to be maintained) the system is called *Automatized Control System.*

Some more terms for the Control System should be added. They are *Feedforward* and *Feedback*. Linkage between elements is called *Feedforward* if its direction coincides with the direction of forward (input-to-output) distribution of a signal in Control Object. Reverse linkage is called *Feedback* (fig. 1.3). Feedback plays significant role in control process and will be described in details later.

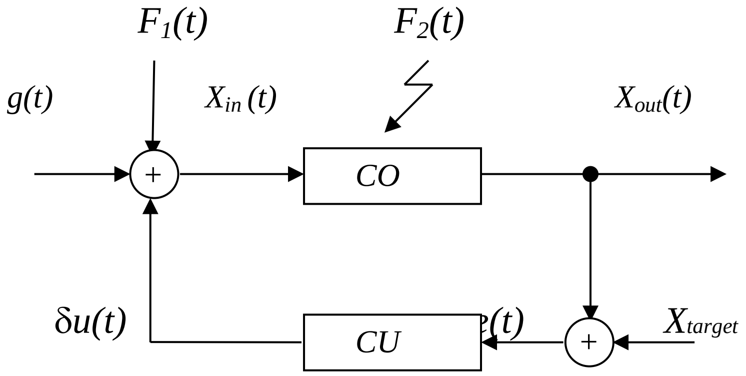

Fig. 1.3. Conventional Control System with feedback

Here (Fig. 1.3) $X_{out}(t)$ is a controlled variable, $X_{in}(t)$ is a controlling variable, X_{target} is a goal, $\delta U(t)$ is a *Controlling Action*; F_1, F_2 are *Disturbing Actions, CU* is a *Control Unit (or Controller)*; $e(t)$ is an error (deviation).

The Controller can be realized software (on an electronic computer) or it can be realized by hardware. On the figure below (Fig. 1.4) the general hardware realization is shown.

The controller consists of a measuring unit, a transducer amplifier and an executive unit. Measuring unit is a sensitive device which reacts in some way on the measuring value deviation. The purpose of transducer amplifier is to transform signal to the form accepted by executive unit, which in turn produces control action $\delta u(t)$. Altogether these units serve for accurate object controlling if an external perturbation action $F(t)$ is really present.

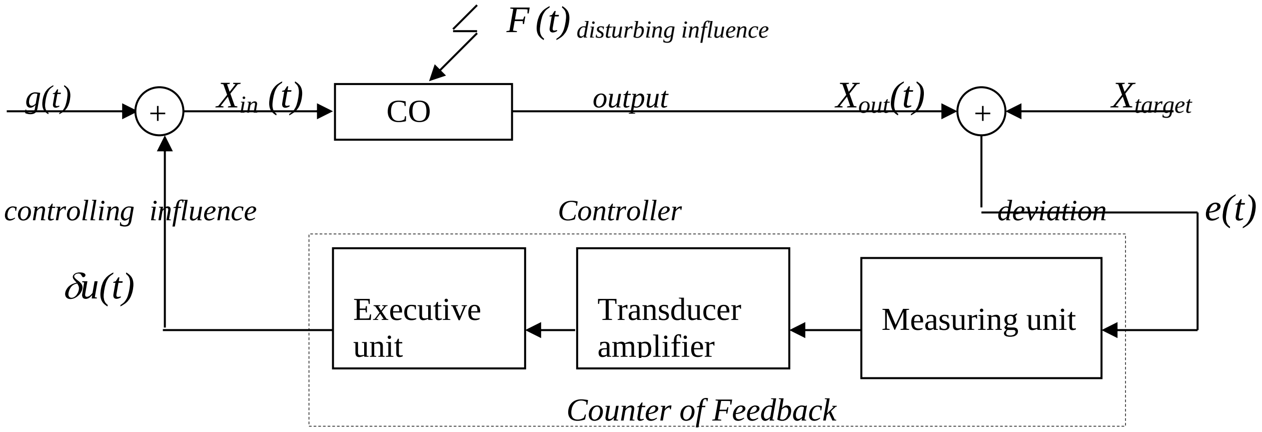

Fig. 1.4. Automatic Control System with a hardware controller

For mathematical description of dynamic systems and its physical properties differential equations are used, both exact and partial.

If a dynamic system description relies on an assumption that a disturbance signal spreads from input to output *immediately* such system is described by exact differential equations and is called *System with Lumped Parameters*. Examples: engine control system, chemical reactor control system, flight-control system etc.

In contrast, systems assuming that the speed of disturbance distribution is finite are described by the means *of partial differential equations*. They are called *Systems with Distributed Parameters*, examples are: water flowing in pipes, heat conduction in reactors and oil pipelines etc.

In addition to differential equations algebraic and integral equations find their use in Control Theory. In particular, algebraic equations allow describing state of combinative (static) systems, and integral equations help us to solve many problems of mathematical physics e.g. the *Wiener-Hopf equation.*

However, it is necessary to note that integral and differential equations are in general difficult to solve directly except rare special cases. Therefore Laplace transformation (direct and reverse) is widely used in Control Theory as an instrument for finding these solutions.

1.2 Classification of ACS according to the nature of their internal dynamic processes

Each Automatic Control System (ACS) consists of a set of links interconnected with each other in different ways. A particular link has his (unique) input and output corresponding to its input and output variables. The variables can have different physical origin such as voltage, time, temperature, pressure etc. *The set of all links' equations and characteristics forms a description of dynamic control processes in the whole system.*

Every classification is relative.

Below there is presented one of the variants of ACS classifications based on the character of inner dynamic peculiarities.

Dynamic ACS can be divided into big classes according to the following attributes of internal dynamic processes:

- continuity or discreteness in time;
- linearity or nonlinearity of equations describing these processes.

The first criterion suggests three types of ACS: *continuous***,** *discrete (impulsive or digital)* and *on-off (relay) systems***.**

According to the second criterion continuous and discrete systems are both divided into linear and nonlinear subclasses, while relay systems are all nonlinear. Here we will define all ACS classes given in fig. 1.5.

Continuous System is a system in which all links produce continuous output according to continuous input.

Hence, for an automatic system to be continuous it is necessary first of all that

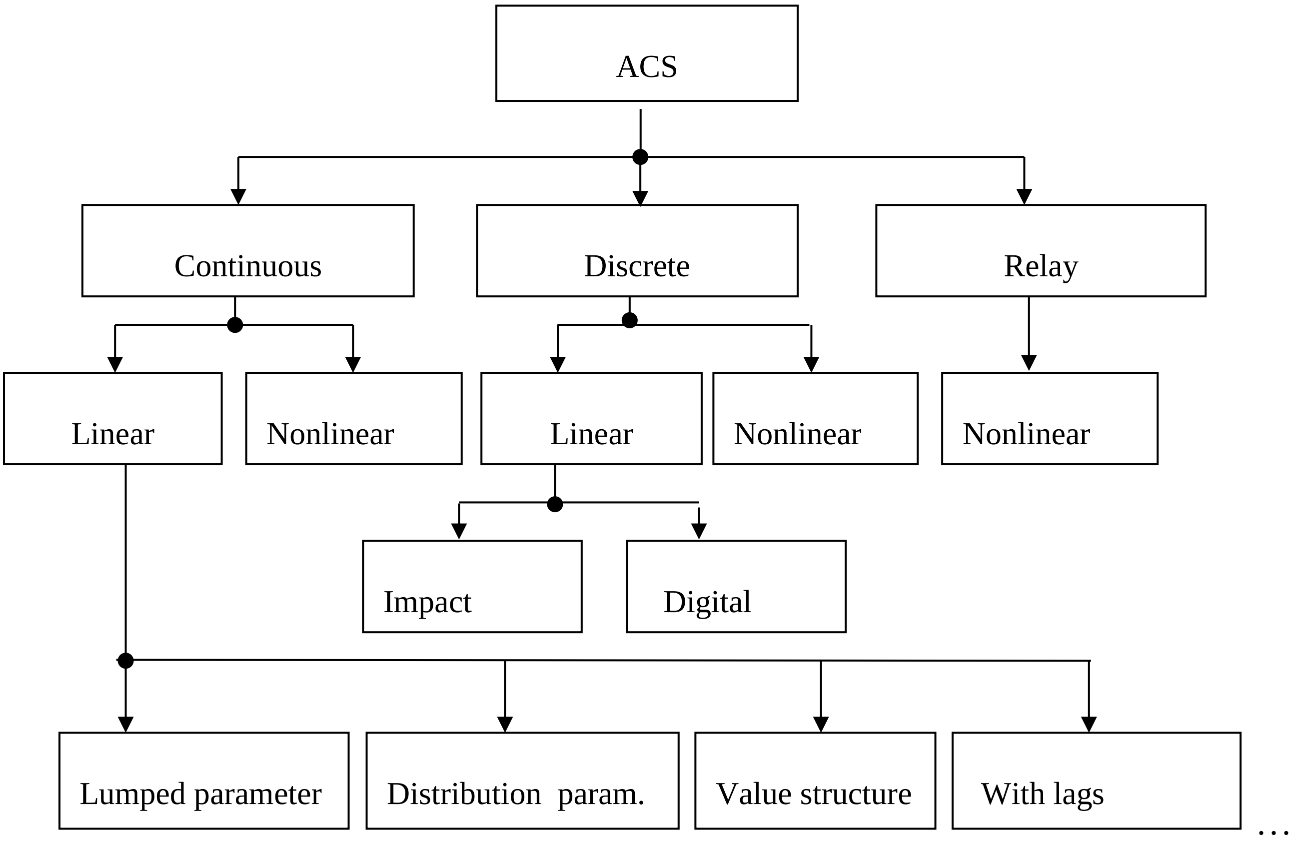

Fig. 1.5. Classification of Automatic Control Systems

steady-state characteristics of all links should be continuous as well (Fig. 1.6).

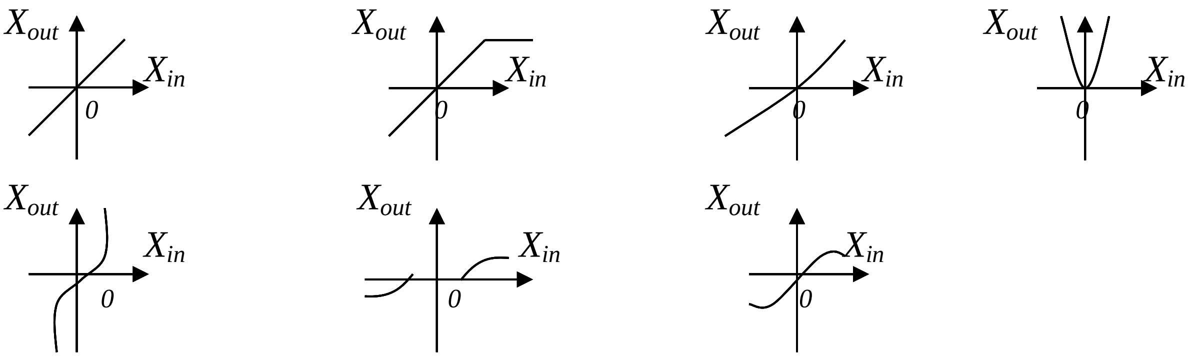

Fig. 1.6. Examples of steady-state characteristics

Let us examine some examples of continuous dynamic systems. One of automatic control pioneers was Russian scientist I.I. Polzunov (И.И. Ползунов). In

1765 he invented (*Barnaul, Russia*) a water level regulator in a boiler of a steam-engine (Fig. 1.7).

In this case the boiler is a control object; a floater is a measuring device which senses regulated value *H* (the water level). The float is able to act directly on a regulating device (water valve in the case). Changes in steam consumption from the boiler by the engine are the main perturbation action on the control object. If steam consumption increases vaporization occurs more intensively and as a result water level decreases. As a consequence the float's downward movement causes the valve to open out wider and entering water flux increases total amount of water in the boiler and helps to maintain the water level at the desired value. Another kind of perturbation action in this system is a change in thermal conditions of the boiler (furnace fire intensity, supply water and environment temperatures etc.). Anyhow the regulator eliminates an undesirable water level deflection regardless of the exact reason causing it.

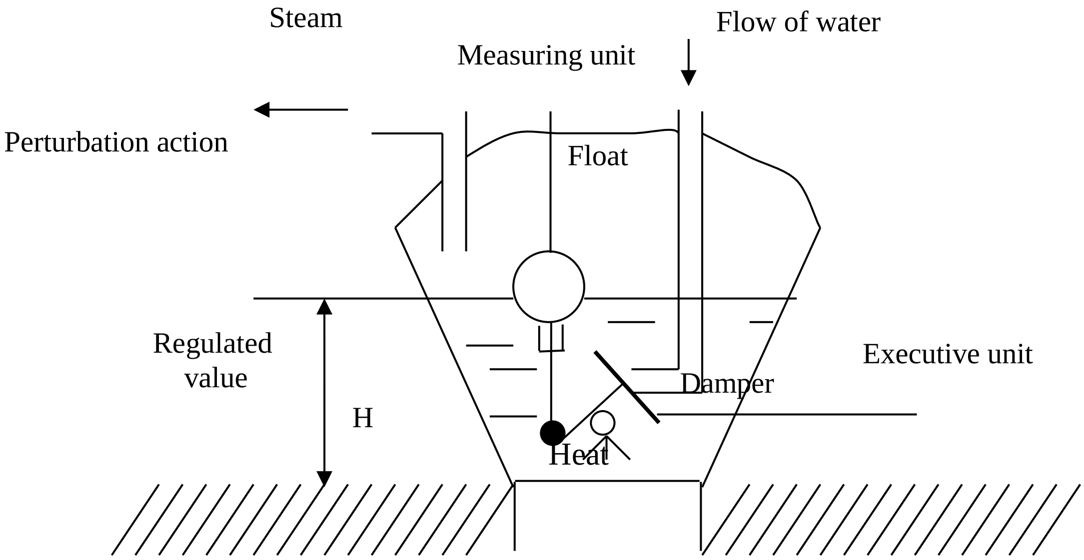

Fig. 1.7. Polzunov's water level regulator

The scheme in fig 1.7 is transformed into Control Theory diagram and is shown in fig. 1.8.

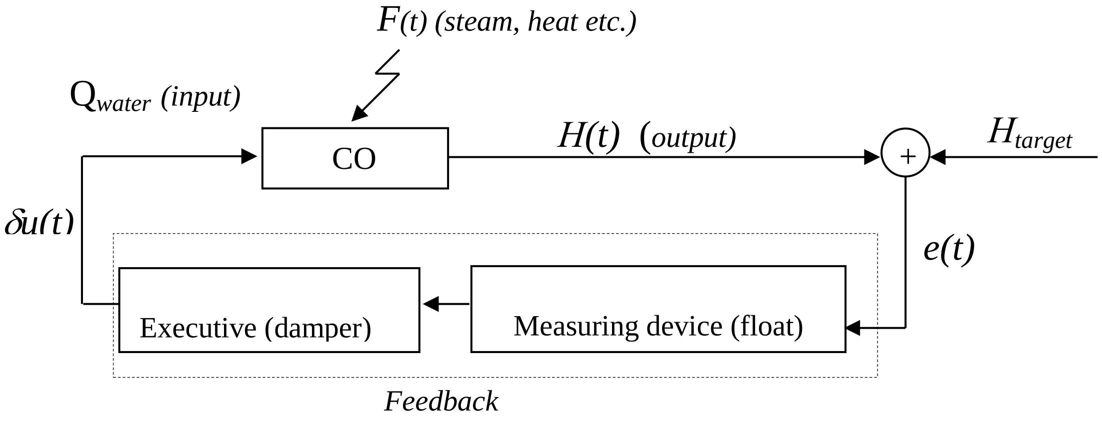

Fig. 1.8. Polzunov's water level regulator as a control theory diagram

The next historically well-known and widely-spread automatic regulator was Watt's (Уатт) steam-engine shaft centrifugal governor (England, 1784). Later in 1808 Frenchman Jacquard (Жаккар) designed the first programmatic loom control system (punch card-based).

In 1881 Russian scientist K.E. Tciolkowsky (К.Э. Циолковский) constructed automatic elevator used in dirigibles. Eight decades later, in 1961 Y.A. Gagarin (Ю.А. Гагарин) was the first man performed space flight. Nowadays contemporary Automatic Control Systems are developed. They allow controlling nuclear reactors, space ships and other extremely sophisticated devices.

In the XX century the development of automatics followed the path of electrification of control systems for machinery, thermal, chemical and other systems. In the XXI century development of automatic equipment follows nanotechnologies; the robot technique uses an artificial intelligence, etc.

In *Discrete Systems* at least one link produces discrete output according to continuous input. As a rule a discrete output forms a series of pulses appearing periodically as in fig. 1.10.

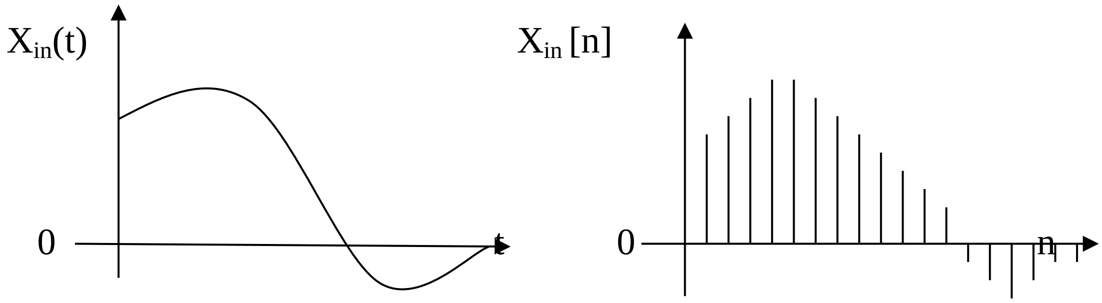

Fig. 1.10. An example of continuous and discrete signals

A link that transforms a continuous input signal to a series of pulses is called *Impact part* **(***Pulse Link*). If the following link is discrete also then in addition to discrete output signal it has discrete (pulsating) input signal too. Discrete ACS class includes pulse control systems (systems containing pulse links) and systems containing digital computers as internal parts.

Digital Computing produces output discretely per some period of time in the form of figures for separate output discrete digital value. An example of a discrete system with continuous control object is given below.

In this case a latch transforms discrete control pulses into a step function (by fixing a pulse value during the period of time when the discrete input is not present, fig. 1.11, 1.12). Generally the latch is not a part of the control object but it is closely related to the object so their combination was called *Generalized Control Object***.** It is necessary to note however that a latch is needed only if a digital to analog converter

(*DAC, ADC* – analog to digital converter) is not presented in the system, which is not the case in the example.

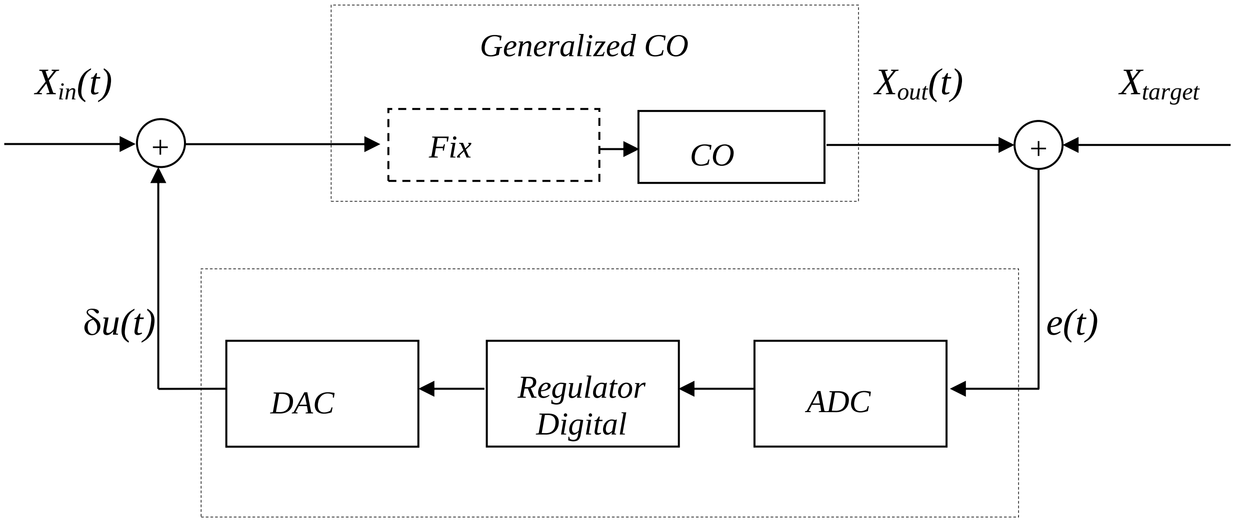

Fig. 1.11. A discrete system with continuous control object

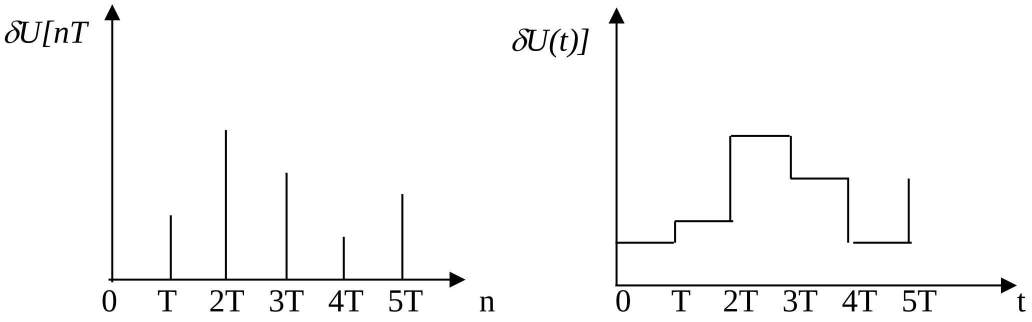

Fig. 1.12. Input and output signals of a latch

In whole the system is a discrete one since it contains an impact (pulse) element, a digital computer. But what is the need to introduce *ADC* and *DAC* in the system? The answer is as simple as the question: to provide embedding of a digital computer. It cannot accept continuous analog input; neither can its discrete digital output be consumed by the control object (except cases when using a latch). A digital computer improves a particular system by providing such benefits as:

- usage of only one control station to control many devices;
- ability to realize complicated control rules (optimal, adaptive etc.);
- ability to standardize and unify control tasks, provided by programmatic adjustments of control rules to match new control objects.

Next systems under consideration are *Relay Systems***.** *Relay (On-off) Systems* are nonlinear systems, in which at least one link’s output discontinuously jumps according to continuous input. Such link is called *a Relay part*. As we can see (Fig. 1.13) a relay steady-state characteristic has a point of discontinuity.

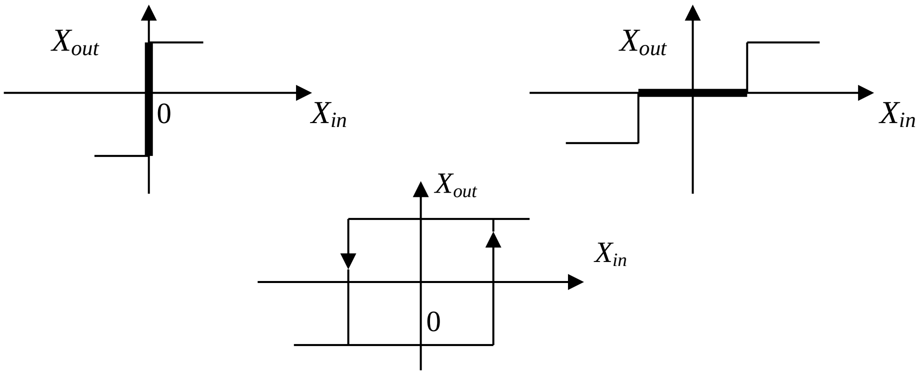

Fig. 1.13. Relay steady-state characteristics

One can think that relay systems are much alike discrete ones. But there is one significant difference: moments of time when a system opens or closes are unknown in general, they are defined by the system internal structure and the current state of its variables. This is completely different from the discrete systems behavior where signals exist at predefined moment of times or appear periodically.

Consider an example of relay system in the figure 1.15.

It is a temperature regulator; the task is to maintain constant predefined temperature of the object cooled by the air. A regulating device in this case is a ventilating louver which blades' angle of deflection dictates cooling airflow intensity. A relay element here is polarized relay 3 (Fig. 1.14).

Its middle contact closes to the left or right contacts correspondingly to the sign of current in bridge's diagonal 2 (i.e. correspondingly to the sign of regulating value displacement) thus directs current to different drive windings; as a result louver blades deflect at needed angle in both directions.

Voltage supplied to the system has constant value $U=C$. Voltage at the motor changes according to the current I change by the following rule.

Middle contact neutral position: voltage is zero, current changes slightly $-b < I < b$ (Fig. 1.14). At some current value $I=b$ relay turns on, thus applying voltage $U=C$ to one drive winding. At negative value of I the same occurs, but the other winding is fed with constant voltage, thus providing negative blades rotation. The interval $-b < I < b$ is called relay dead band.

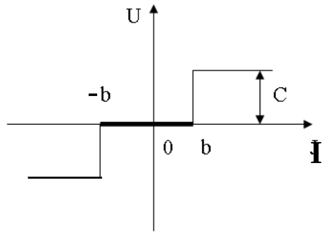

Fig. 1.14. The dependence of voltage on current

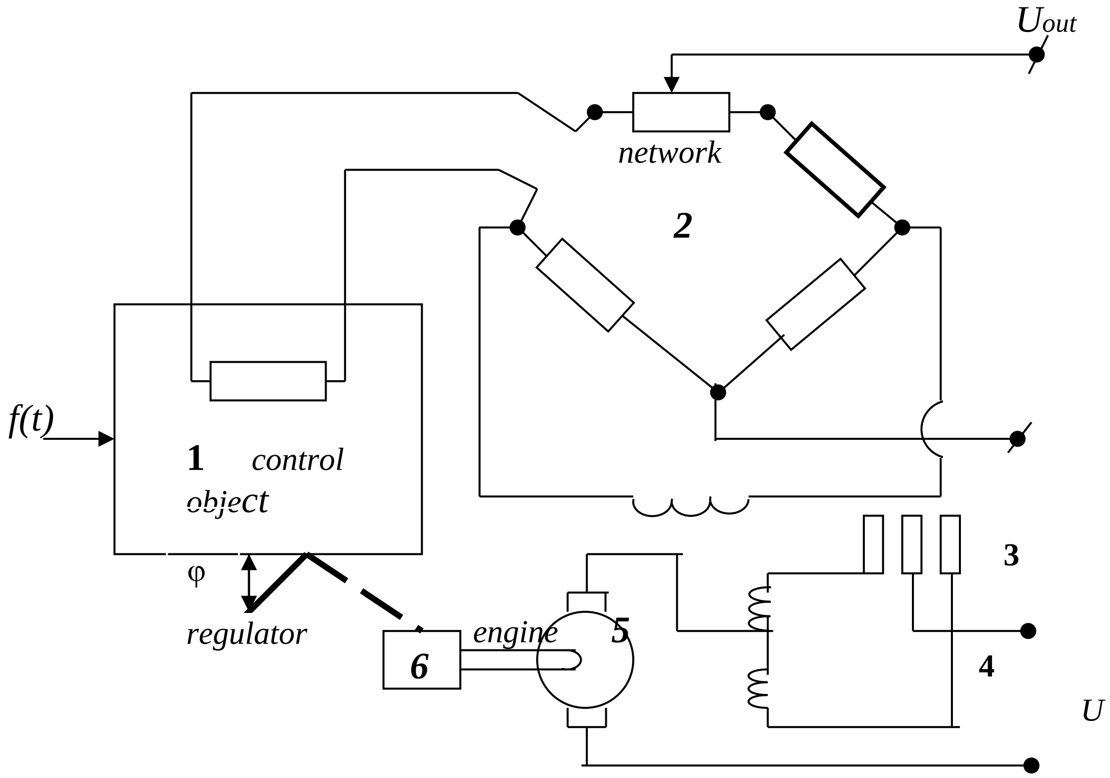

Fig. 1.15. An example of relay system

Having considered continuous, relay and discrete systems we can move on to the discussion of the second criterion of our classification: linearity and nonlinearity.

Dynamic behavior of *a Linear System* can be defined in terms of linear algebraic, differential or difference equations. Linear systems follow the principle of superposition, stated as follows: system output due to several inputs equals to the sum of corresponding system outputs due to each of these inputs. Superposition principle applies only to linear systems.

A Nonlinear System is a system with at least one link violating linearity of its steady-state characteristic or having any other nonlinearity in equations describing it (square root, multiplication of variables etc.).