Lecture 15. **The principles of control in ACS**

Knowing static and dynamic properties of the control system, we may create a mathematical model of the system and find such algorithm of control, which would provide the specified algorithm of functioning at mentioned impacts. But a mathematical model is approximately shows the properties of the original, that's why algorithm of control should be bound not only with the properties of the system, but also with actual functioning of the system.

At present time we use three fundamental principles: principle of an open-loop control, control on deviation (or backward path), control on disturbance (or compensation principle).

Principle of open-loop control is in the following: the algorithm of control is selected only on the basis of specified algorithm of functioning and is not controlled by other factors – disturbances or output factors. Besides, there are few of general rules for building the open-loop systems, which anyhow depend on the particular properties of exact devices. That's why in this book this method will not be presented in details, but the combined control on disturbance and deviation will be presented more detailed.

15.1 Mismatch (deviation) control

Principle of mismatch (deviation) control or principle of control on negative feedback was compared by *N. Viner* with a stick for a blind man.

Suppose the system of following type:

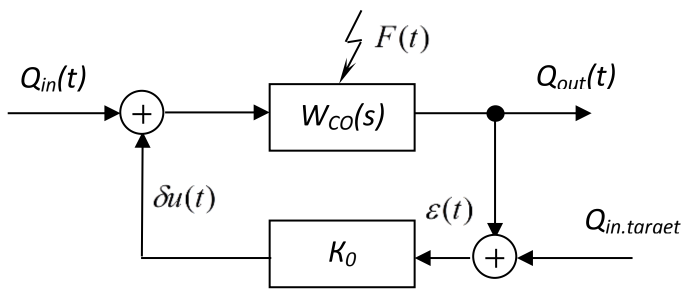

Fig. 5.13. Closed-loop system

Here $\varepsilon(t) = Q_{in.target} - Q_{out}(t)$; $\delta u(t) = K_0 \varepsilon(t)$.

This principle of control supposes that the point of disturbance application is unknown, i.e. no matter where it has been applied, perhaps, except of external disturbance there is any disturbance from nature of control object (CO) itself. Essence of the method is in the following.

At each instant of time we should gauge the controlled (output) coordinate and compare it with the task (desired value):

$$\varepsilon(t) = Q_{in.target.} - Q_{out}(t).$$

Mismatch $\varepsilon(t)$ is used to form control influences $\delta u(t)$:

$$\delta u(t) = K_0 \varepsilon(t).$$

Regulator which develops the control influence $\delta u(t)$, creates the negative feedback towards the output of the object. This path is called as *main feedback* (except it, there are some other *local feedbacks*).

Using this principle of control and knowing nothing about disturbance, we are able to control the object rather accurate.

Let's view the principle of control on mismatch or on negative feedback more thoroughly.

Now we'll write a transfer function of closed-loop system (Fig. 5.13)

$$W_{closed}(s) = \left. \frac{K_0 W_{CO}(s)}{1 + K_0 W_{CO}(s)} \right|_{K_0 W_{CO}(s) \to \infty} \to 1.$$

For a controlled system with specified transfer function of control object $W_{CO}(s)$ we need to strive for the transfer function of a closed-loop system tending to one, i.e. $W_{closed}(s) \to 1$.

The aim can be achieved, if the product of amplification coefficients of all links of the system will be tending to infinity

$$K = \prod_{i=1}^{n} k_i \to \infty.$$

The more is $\prod_{i=1}^{n} k_i$, the more qualitative the system is, as in this case the accuracy and speeding are increased, but we should always remember about its stability. OC may become unstable at common amplification coefficient K equal to critical. Hence, there is compromise *between quality of control* $\varepsilon(t) \equiv 0$ *and the system stability* $K < K_{limit}$ (or $K_{critical}$).

So, the harder requirements to quality of control are, the more difficult to realize such principle of control (golden rule of mechanics).

Qualitative reason of instability at great K: negative feedback becomes positive (because of signal inversion), as in this case we may observe phase shift more than on π (180^o).

Let's go further: can we change amplification coefficient in forward part of the system or in feedback?

Suppose that K of amplification of forward part of the system is changed to an order (as CO is amplifier): is it possible to stable such CO?

It is possible, if it will be enveloped with negative feedback linkage (Fig 5.14).

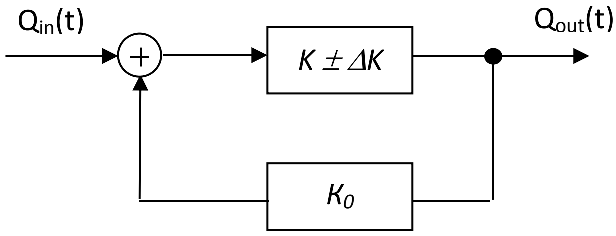

Fig. 5.14. Closed-loop system without external disturbances

Here $Q_{target} \equiv 0$; $W_{CLOSED}(s) = \dfrac{Q_{out}(s)}{Q_{in}(s)} = \dfrac{K \pm \Delta K}{1 + K_0(K \pm \Delta K)}\Bigg|_{(K \pm \Delta K) >> 1} = \dfrac{1}{K_0}$; $Q_{out}(s) = \dfrac{1}{K_0} Q_{in}(s)$.

Hence, the conclusion is: the controlled coordinate $Q_{out}(t)$ does not depend on the change of transfer constant in forward part of the system.

Generally reaching the set aim is always possible, but it limits the stability, as we should always remember that common amplification coefficient of the system K must be strictly less than K_{limit}., i.e. $K < K_{limit}$ (or $K_{critical}$).

Advantages and disadvantages of principle of mismatch control

Advantages: this principle operates at conditions of complete uncertainty of control object on disturbances.

Disadvantages:

a) to control by this principle, there always must be mismatch; we always have a static error $\varepsilon(t) \neq 0$; if there's no an error $\varepsilon(t) = 0$, then controlling disturbance $\delta u(t) = 0$, i.e. at $\varepsilon(t) \neq 0$ and $\delta u(t) \neq 0$, and at $\varepsilon(t) = 0$ and $\delta u(t) = 0$;

b) bad compromise with stability.

15.2 Principle of control on disturbance or compensation principle

Suppose the system of following type:

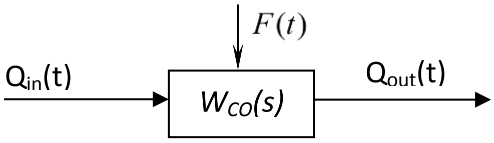

Fig. 5.15a. Open system with external disturbance

In this system:

1) application point $F(t)$ of disturbance, properties of disturbance are known;

2) two control inputs.

Consequently, the system can be presented as follows:

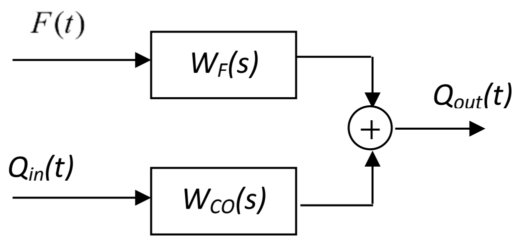

Fig. 5.15b. Open system with two outputs

We view a linear system, consequently for it the superposition principle is carried out. Let us write the superposition principle for this system (Fig. 5.15b):

$$Q_{out}(s) = W_{oc}(s)Q_{in}(s) + W_F(s)F(s).$$

Sure we want the controlled coordinate $Q_{out}(t)$ not to depend on disturbance, i.e.

$$\begin{matrix} W_F(s) \to 0 \\ W_{co}(s) \to 1 \end{matrix} \quad or \quad \begin{matrix} \dfrac{Q_{out}(s)}{F(s)} \to 0 \\ \dfrac{Q_{out}(s)}{Q_{in}(s)} \to 1 \end{matrix}.$$

In order to achieve this it is necessary to include a compensating link in the system.

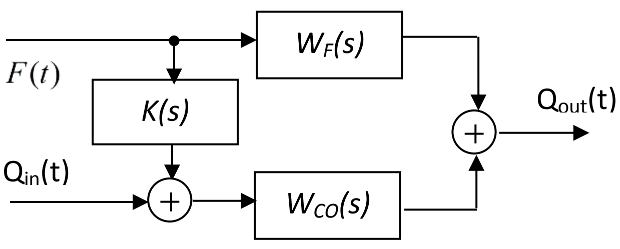

Fig. 5.16. Chart of external disturbance compensation

Then the superposition principle for the system (fig. 5.9) will be written in the following way:

$$Q_{out}(s) = W_{CO}(s)Q_{in}(s) + W_F(s)F(s) + K(s)W_{CO}(s)F(s).$$

Here the situation:

$$K(s)W_{CO}(s) = -W_F(s).$$

Hence, we will find that a transfer function of compensating link is equal to the following:

$$K(s) = -\frac{W_F(s)}{W_{CO}(s)} \quad . \tag{5.7}$$

Consequently, $Q_{out}(s) = W_{OC}(s) Q_{in.target.}(s)$.

So, we have reached the aim by including the link with transfer function, equal to (5.7): controlled value $Q_{out}(t)$ doesn't depend on any $F(t)$ of disturbance.

Let us compare the advantages of this principle of control with principle of mismatch control.

When controlling by mismatch it is possible to control with specified accuracy, including negative FbL with coefficient K_0 (Fig. 5.13).

Also, value K_0 depends on application point $F(t)$ of disturbance: if disturbance $F(t)$ is at input, then when reducing K_0 we may compensate $F(t)$; if disturbance $F(t)$ is at output, then relaxation $F(t)$ at any K_0 is impossible. That is exactly why all disturbances bring to input of the system.

When controlling by disturbance we may compensate any disturbance, having selected $K(s)$ by the data (5.7). Sometimes the principle of disturbance control is called *control on an open-loop*.

Knowing the disturbance $F(t)$, we should foresee process of control, selecting a system response, to neutralize $F(t)$ (hence, the availability of second input).

Advantages and disadvantages of the principle of disturbance control

While implementing the compensation principle there are found the following disadvantages:

a) It is required an "accurate" knowledge on place of application of perturbation action $F(t)$ and $W_F(s)$; compensation of disturbance is possible with accuracy of this knowledge.

b) Task of compensation is possible in case of "accurate" knowledge of OC characteristics ($W_{OC}(s)$), as

$$K(s) = -\frac{W_F(s)}{W_{CO}(s)}.$$

The main disadvantage is that the principle of control is not implemented if you don't know the properties of disturbances $(W_F(s))$.

Advantages:

a) to implement the process of control the mismatch (deviation) is not required, i.e. control is performed at $\varepsilon(t) \equiv 0$, $\delta u(t) \neq 0$;

b) good compromise with stability.

From an informational point of view during controlling on disturbance it is necessary to know much more either on disturbance or on CO (as you have to foresee direction of control), than during mismatch controlling. When controlling on negative feedback we gauge mismatch $\varepsilon(t)$ and in dependence on mismatch the control influence $\delta u(t)$ is developed.

15.3 *Principle of combined control*

Principle of combined control appears when viewing two previous principles:

1) On *mismatch (deviation)* – invariance to an application point of disturbance; principal availability of mismatch.

2) On *disturbance* – unavailability of mismatch; necessity of "accurate" knowledge of CO properties and "accurate" knowledge on application point of disturbance and of its properties $W_F(s)$.

Both of these principles do not contradict to each other, they supplement each other.

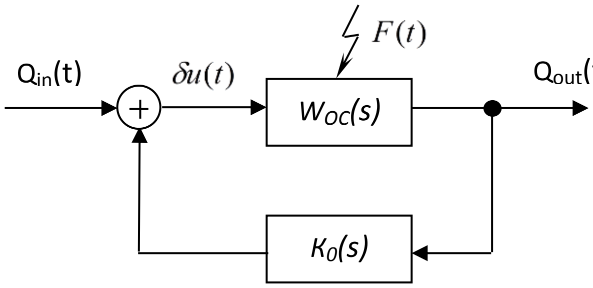

Fig. 5.17a. Principle of on negative feedback control

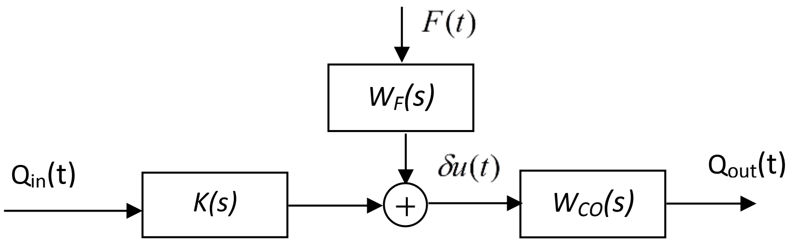

Fig. 5.17b. Principle of disturbance control

Structure of combined control:

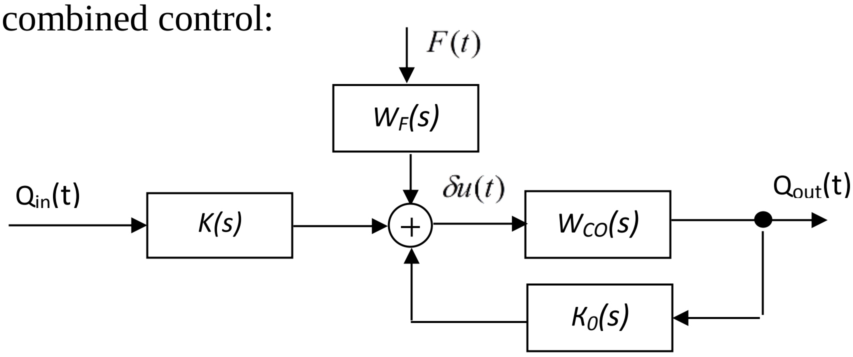

Fig. 5.17c. Principle of combined control

Structure (Fig. 5.17c) shows that selection of parameters is performed independent.