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IMPROVEMENT OF DYNAMIC PROPERTIES OF AUTOMATIC CONTROL SYSTEMS BY MEANS OF DEADBEAT FEEDBACK.

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The use of deadbeat feedback for improvement of dynamic properties of automatic control systems is considered. In this work the following mechanism is described, for work stabilization of which, the principle of coverage is used by negative feedback. Improvement of dynamic characteristicsof the following mechanism by introduction of deadbeatfeedback is considered. The parameters of deadbeatfeedback promoting that the studied system worked with in advance set error are determined. The description and characteristics automatic control systemswith deadbeat feedback are given, the formulas defining living conditions of fluctuations are developed and operational characteristics are given.

Keywords: automatic control, feedback, the following mechanism, stability, deadbeatfeedback, dynamic characteristics.

Introduction

It is known that the feature of the following mechanisms which are usually intended for tracking mechanical movements is high precision of a signal transmission on a feedback chain. If the internal structure of unstable object of control is known, then to make object of control steady, with preservation of all of its functions demanded by technology, it is necessary to apply stabilization of object by its coverage of feedback. The lack of such technical solution consists that at an emergency situation, for example at a disruption of feedback, the object will lose stability that can lead to considerable economic and even to more serious losses. Therefore at stabilization of the object coverage by its feedback it is necessary to make sure especially of functioning reliability of this connection.

Thus in the set mode it is desirable, that the output value$X_{out.}$with very small error coincided with input value$X_{in.}$. Thereof the chain of feedback has to make a signal transmission to an entrance, for example on a comparison element as it is possible with smaller distortion [1].

Theory

Let's say that in the following mechanism instead of external rigid feedback deadbeatfeedback with transfer function is applied

$$W_{fb}(p) = \frac{k_{fb}}{1+T_{fb}\,p} \quad (1)$$

where k_{fb}-factor of transferring feedback circuit, T_{fb}-time constant.

The block diagram of similar system is given in Fig.1. Transfer function of the closed following mechanism in the presence of deadbeatfeedback has an appearance:

$$\Phi(p) = \frac{X_{out}}{X_{in}} = \frac{W_{o\,(p)}}{1+W_{o\,(p)}W_{fb\,(p)}} \quad (2)$$

where $W_o\,(p)$— transfer function of the direct channel or the opened system of regulation without feedback [2].

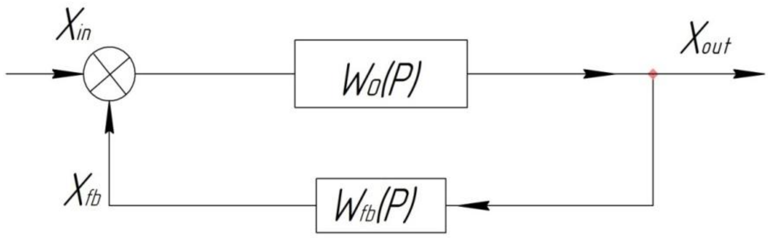

Fig.1.The block diagram of the following mechanism with deadbeatfeedback

Transfer function of the opened system with deadbeatfeedback is equal

$$W_{01}(p) = W_0(p)W_{fb}(p) \qquad (3)$$

Solution

Multiplication of a vector $W_o(j\omega)$by a vector $W_{fb}(j\omega)$will cause, as it seen from Fig.2, turn of each vector $W_{01}(j\omega)$in relation to a vector$W_o(j\omega)$on some vector corner β in the direction of an hour hand. If $k_{fb}$is chosen less than one, vectors $W_o(j\omega)$not only turn, but also decrease on the module, the curve 1 will reach new position 2 and the system will be steady. Atk_{fb}>1 vectors $W_o(j\omega)$will increase on the module, the curve 1 will reach position of the curve 3 that in itself is undesirable.

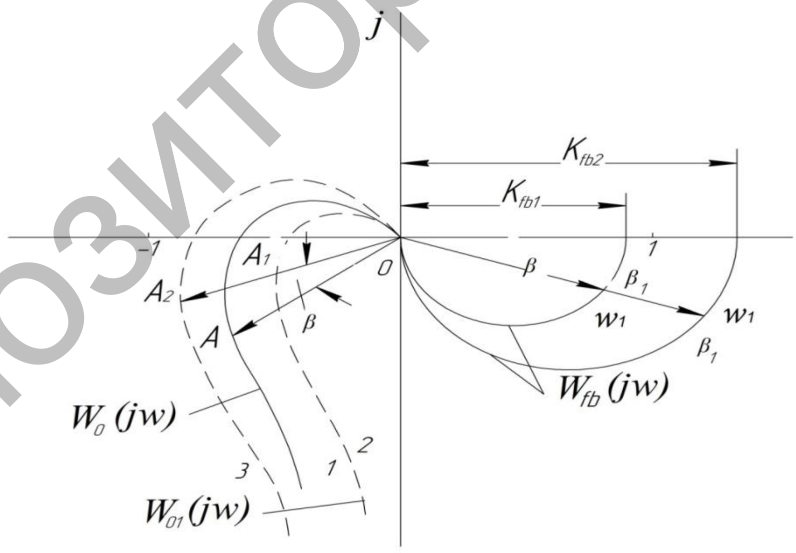

Fig.2. Hodograph curve of the following mechanism

From this it follows that for reasons of stability of the following mechanism to accept k_{fb}>1 is inexpedient. We will find out the influence of deadbeatfeedback on quality of the following mechanisms. From (2) it is easy to find expression for an error of the following mechanism:

$$X_{in} - X_{out} = e = \frac{[1+W_0(p)W_{fb}(p)-W_0(p)]}{1+W_0(p)W_{fb}(p)}X_0 \qquad (4)$$

where

$$W_o(p) = \frac{R(p)}{Q(p)} \quad (5)$$

Here Q and R are operator polynomials, and R polynomial degree for all real systems is usually lower than Q polynomial degree. For the following mechanisms with astatism of the first order

$$Q(p)=a_0p^n + a_1p^{n-1} + \cdots + a_np, \qquad R(p)=b_0p^m + b_1p^{m-1} + b_2p^{m-2} + \cdots + b_m \quad (6)$$

We will substitute in expression (4) values $W_o(p)$and$W_{fb}(p)$:

$$e = \frac{p(a_0p^{n-1}+a_1p^{n-2}+..+a_n)(1+T_{fb}p)}{p(a_0p^{n-1}+a_1p^{n-2}+..+a_n)(1+T_{fb}p)} \frac{(b_0p^m+b_1p^{m-1}+..+b_m)(k_{fb}-1-T_{fb}p)}{+k_{fb}(b_0p^m+b_1p^{m-1}+..+b_m)} X_0 \quad (7)$$

At application of usual rigid feedback

$$e = \frac{p(a_op^{n-1} + a_1p^{n-2} + \cdots + a_n) + (b_op^m + b_1p^{m-1} + \cdots + b_m)}{p(a_op^{n-1} + a_1p^{n-2} + \cdots + a_n) + (b_0p^m + b_1p^{m-1} + \cdots + b_m)}. \quad (8)$$

At$\omega_0 = px_0 = const$ from (7) we find an error of the following mechanism by speed:

$$e_{ck} = \frac{\omega_0(a_n - b_mT_{fb}) + b_m(k_{fb}-1)}{k_{fb}b_m} \quad (9)$$

In the following mechanismsat which the corner of working off is equal to the setting corner, $k_{fb}$is always equal to one:

$$e_{ck} = \frac{\omega_0(a_n - b_mT_{fb})}{b_m} \quad (10)$$

Expression (10) shows that when using deadbeatexternal feedback the error on speed will decrease, and at$T_{oc} = \frac{a_n}{b_m}$becomes zero.

We will find out the influence of deadbeatfeedback on a size of the established error at harmonious disturbance on its entrance. From (4) we will find expression for the relative system installed error at harmonious disturbance [3]:

$$\frac{e}{X_0} = \delta = \frac{[1+W_0(j\omega)W_{fb}(j\omega)-W_0(j\omega)]}{1+W_0(j\omega)W_{fb}(j\omega)} X_0 = \frac{Y_0(j\omega)+W_{fb}(j\omega)-1}{Y_0(j\omega)+W_{fb}(j\omega)} X_0 \quad (11)$$

where $Y_o(j\omega) = \frac{1}{W_o(j\omega)}$.

$$|\delta| = \frac{|DE|}{|OD|}, \quad (12)$$

so how $DE = Y_o(j\omega_i) + W_{fb}(j\omega_i) - 1, \qquad OD = Y_o(j\omega_i) + W_{fb}(j\omega_i)$.

In fig. 3 the reverse amplitude-phase characteristic of the following mechanism (curve I) and the amplitude-phase characteristic of deadbeatfeedback (curve II) are represented.

The module of the established relative error with some frequency $\omega_i$is equal to the relation of modules of vectors DE and OD (fig. 3):

At rigid external feedback $W_{fb}(j\omega) = k_{fb} = 1$ and the module of the relative established error is equal

$$|\delta| = \frac{OA}{AB} \quad (13)$$

From Fig.3 it is seen that OA vector length OA at$\omega_i \neq 0$is always more than zero. Vector length DE at some ratio of parameters of deadbeatfeedback can be made less OA and even is reduced to zero. Really, if the direction of vector OD coincides with a transversal axis, and its size is equal to one, then $|DE| = 0$and$|\delta| = 0$.

Thus, at the set size$|\delta|$ and known quantity $Y_o(j\omega)$ for a certain working frequency, using graphic construction, it is possible to pick up the parameters of deadbeatfeedback so that the relation of vectors DE and OD was equal$|\delta|$, i.e. that the studied system worked with the set error.

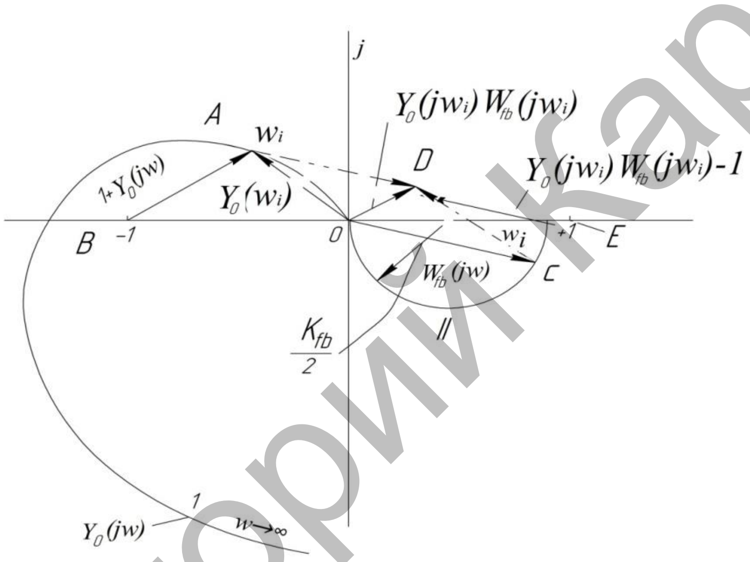

Fig.3. The amplitude-phase characteristic of the following mechanism

The phase established error at harmonious disturbance with frequencyω_i in case of rigid external feedback will be equal to a corner ABO (fig. 3)[4], and at deadbeatfeedback will be defined from expression (2):

$$\Phi(j\omega_i) = \frac{1}{Y_o(jw_i) + W_{fb}(j\omega_i)} \quad (14)$$

From Fig. 3 it is seen that $\Phi(j\omega_i) = \frac{1}{OD}$,therefore the phase error for the last case will be defined by the corner value between the vector OD and the positive direction of a transversal axis – a corner DOE (fig. 3) and by means of parameters choice of deadbeatfeedback it can be reduced or reduced to zero.

At equality to zero installed error of the system the phase error also will be equal to zero as the vector OD coincides with the positive direction of a transversal axis.

Correction of system is carried out for the purpose of providing the demanded characteristics of system, that is for the purpose of receiving the set stocks of stability and indicators of transition process. This system refers to the area of synthesis of regulation systems as at calculation of correction it is necessary to find out, what additional links have to be introduced into the system for providing set in advance characteristics [5].

We will consider practicability of introduction of deadbeat feedback in multicircuit systems of automatic control with internal rigid feedback and the disturbing influence attached to the object of regulation.

In Fig.4 the block diagram of the system containing object of regulation and the deadbeat feedback covering the regulator and replacing rigid feedback is represented.

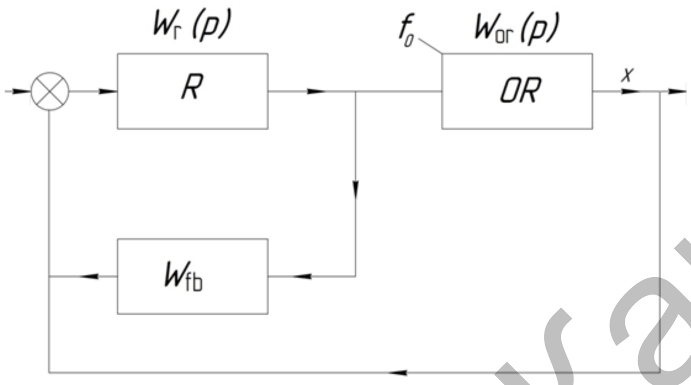

Fig.4. The block diagram object of regulation with aperiodic feedback

Let the object of regulation has transfer function of view:

$$W_{or} = \frac{k_{or}}{p\,(1+T_{or}p)} \qquad (15)$$

Let's assume that transfer function of the regulator without feedback is

$$W_{or}(p) = \frac{R(p)}{Q(p)} \qquad (16)$$

The general transfer function of the open-circuit system at the deadbeat internal feedback covering the regulator is[6]:

$$W_o(p) = \frac{W_p(p)W_{or}(p)}{1+W_p(p)W_{fb}(p)} \qquad (17)$$

or

$$W_o(p) = \frac{k_{or}(1+T_{fb}p)R(p)}{Q(p)p(1+T_{or}p)(1+T_{fb}p)+R(p)k_{fb}\,p(1+T_{or}p)} \qquad (18)$$

The object of regulation can have transfer function of other look, for example, at regulation of thermal processes

$$W_{or}(p) = \frac{k_{or}}{1+T_{or}p} \qquad (19)$$

The return transfer function of the open-circuit system has an appearance:

$$Y_o(p) = Y_{01}(p) + \frac{k_{fb}}{k_{or}}\frac{p(1+T_{or}p)}{1+T_{fb}p} \qquad (20)$$

where

$$Y_{01}(p) = \frac{1}{W_p(p)W_{or}(p)} \tag{21}$$

The part of the return amplitude-phase characteristic of the open-circuit system of regulation $Y_{01}(j\omega)$ without internal feedback (curve *I*) is given in figure 5 and change of this characteristic at introduction of internal rigid feedback (curve *III*) and deadbeat feedback (curve *II*) at $T_{fb} = T_{or.}$ is shown.

At $T_{or} > T_{fb}$ each of vectors of the characteristic *II* will turn clockwise on the corner equal to a difference of vectors arguments $\overrightarrow{1 + T_{or}J\omega} - \overrightarrow{1 + T_{fb}J\omega}$. Modules of vectors of a curve II will increase as the module of vector $\overrightarrow{1 + T_{or}J\omega}$will be more than module of vector $\overrightarrow{1 + T_{fb}J\omega}$.

At $T_{or} < T_{fb}$ vectors of characteristic *II* will turn counterclockwise and their module will decrease.

Figure 5 shows that to each vector $Y_{01}(j\omega)$ in case of application of internal rigid feedback two vectors will be added:$\frac{k_{fb}}{k_{or}}j\omega$ and $\frac{k_{fb}}{k_{or}}T_{or}\omega^2$. In case of application of internal deadbeat feedback (at $T_{or} = T_{fb}$) to each vector $Y_{01}(j\omega)$ only one vector will be added $\frac{k_{fb}}{k_{or}}j\omega$.

Therefore at internal deadbeat feedback degree of stability of system on the module less, than at internal rigid feedback. Regulation time at deadbeat feedback will be less, than at the rigid feedback as frequency in a point *E* for curve *II* is more than for curve *III* [7].

Let's find out the influence of deadbeat feedback on an error of the considered system. Transfer function of the closed-circuit system of regulation at the disturbing influence on the object of regulation (figure 4) is equal

$$\Phi(p) = \frac{\Delta x}{f_0} = \frac{W_{or}(p)}{1+W_0(p)} = \frac{W_{or}(p)Y_0(p)}{1+Y_0(p)} \tag{22}$$

where Δx- is a deviation of regulated variable from a set value.

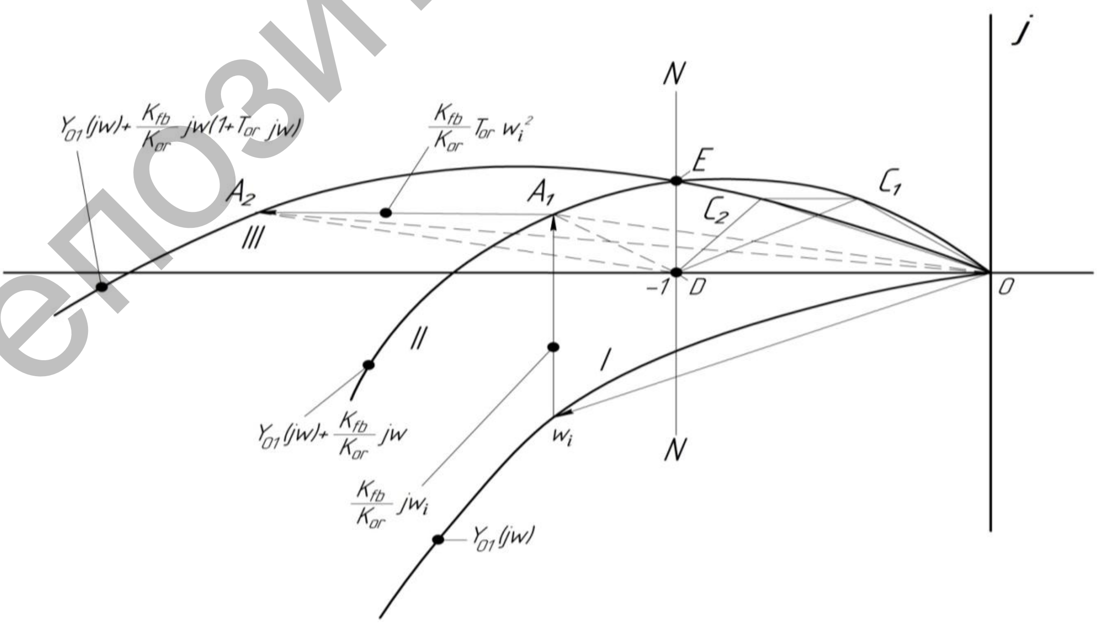

Fig.5. The amplitude-phase characteristic of the open-circuit system of regulation

The relative stable error at harmonic disturbance will be equal

$$|e| = \frac{|\Delta x|}{f_0} = \frac{|W_{or}(j\omega)||Y_0(j\omega)|}{|1+Y_0(j\omega)|} \qquad (23)$$

The vector $W_{or}(j\omega)$ for the set frequency remains constant. Therefore we will consider only influence of expression $\frac{|Y_0(j\omega)|}{|1+Y_0(j\omega)|}$ on the value $|e|$. If the object of regulation possesses rather big lag effect, obviously, working frequencies for which it is necessary to find an error, lie in the area close to the beginning of coordinates (points *C1, C2*). For points *C* and *C2* of an error will be equal: for a curve *II* $|e_1| = \frac{|OC_1|}{|DC_1|}|W_{op}(j\omega)|$, for a curve *III* $|e_2| = \frac{|OC_2|}{|DC_2|}|W_{or}(j\omega)|$, where $OC_1 = Y_0(j\omega)$, $OC_2 = Y_0{}^*(j\omega)$, $DC_1 = 1 + Y_0(j\omega)$, $DC_2 = 1 + Y_0{}^*(j\omega)$.

From figure 5 it is seen that in the area which is lying to the right of *NN* parallel imaginary axis and passing through point with coordinates (-1, $j0$), inequalities $|DC_1| > |DC_2||DC_1| < 1$и$|DC_2| < 1|OC_1| < |OC_2|$ are observed.

Therefore $\frac{|OC_1|}{|DC_1|}<\frac{|OC_2|}{|DC_2|}$, i.e. when replacing rigid internal feedback by deadbeat feedback the established error decreases. The strip of the frequencies passed by system will increase. With the increase T_{op} the vector C_1C_2 increases and the error e_2 grows.

If the forcing frequency is rather big, working frequencies of system will be removed from the beginning of coordinates (for example, points A_1A_2 in figure 5) and the established error at replacing rigid feedback by deadbeat feedback won't decrease.

Really, if to accept $OA_2 = k_1OA_1$and $DA_2 = k_2DA_1$, it is easy to receive $|e_2| = \frac{k_1}{k_2}|e_1|$. Fig. 5 shows that $k_1<k_2$, so $|e_2| < |e_1|$.

Conclusion

The conducted researches allow to draw the following conclusions:

1. Replacement of rigid internal feedback by deadbeat feedback it is expedient to produce in systems of automatic control which working frequencies are small, i.e. lie in the area close to the beginning of coordinates (to the right of straight line *NN*).

2. Replacement of rigid feedback in systems of automatic control with deadbeat feedback allows to reduce high-speed and the established amplitude and phase errors.

3. Application of deadbeat feedback can be recommended in systems of automatic control with slowly changing disturbance, for example in systems with the big period of harmonic disturbance.

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