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Defining of the Power of a Control Loop Actuator

B.T. Budai*

Ural Federal University named after the first President of Russia B.N.Yeltsin, 19 Mira street, Ekaterinburg, 620002, Russia

Abstract

The input harmonical signal is usually used to define the power consumed by actuators of control loops of regulative systems. It's shown that if there are no limits imposed on the type of input disturbance, the power consumption may increase up to two times.

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Keywords: control loops; regulative systems; input signal; signal of error; power of actuators; astatism

1. Introduction

In mechanical engineering it appeas a need to design control loops (CL) for regulative systems of high precision [1–5]. A typical structure of a CL is represented on the fig.1a, where $K_c(p,n)$, $\Delta K_c(p,n)$ – transmission factors of the CL and control error (CI), respectively, as functions of the Laplas transformation parameter p and astatism of n-th order, $K_s(p)-$ transmission factor of the sensor error, $K_k(p)-$ transmission factor of the corrector filter (KF), $K_a(p)-$ transmission factor of the CL actuator.

The extremely unfavorable input disturbances $x_m(t)$ can't be reproduced in time at output of CL with actuators of small transmission factors $K_a(p)$, so large dynamic errors of reproduction of input disturbances exist in this case.

On the contrary, too powerful actuators lid not only to the propotional growth in mass but as well to nonlinere effects, such as clearances and insensitive zones $\Delta x_м(t) \approx x_м(t) - \hat{x}_м(t)$ [5-8].

* Corresponding author. +7-909-702-0590; fax: 8-343-375-93-50.
E-mail address: buda080316@rambler.ru

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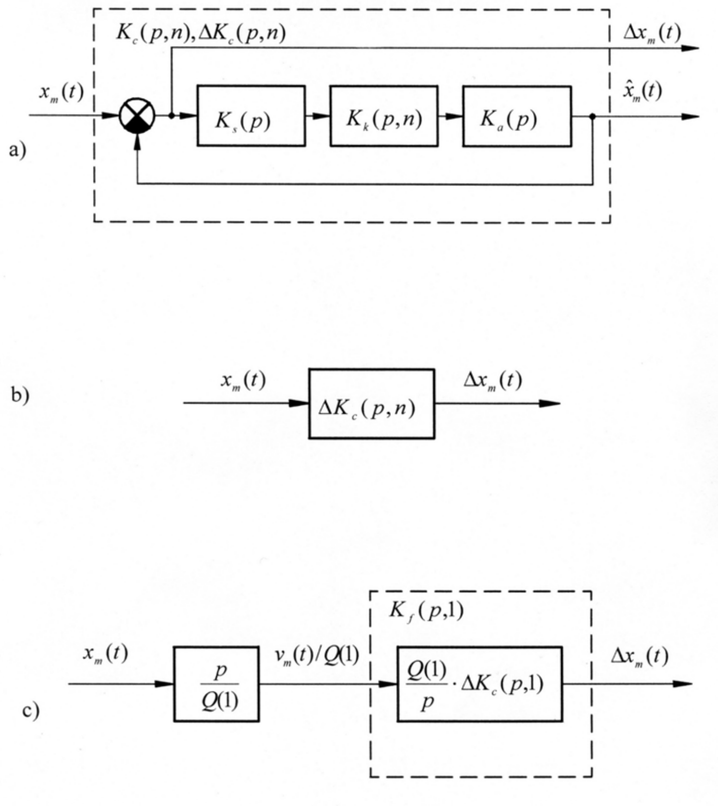

Fig. 1. Equivalent transformation block diagram KU.

Thus, there is a problem which concerns the estimation of the highist possible unfaverable disturbances, that determine the power of CL actuators. It's considered that fluctuation errors are determined by the band of system and don't exceed the dynamic error, and errors due to clearances and friction don't exceed the fluctuation error [5].

2. Etimation of the extremely unfavorable disturbances of the loops

It's known that maximum power for actuator rotation is proportional to square of the maximum input signal of the CL actuater, that may be reprisented as

$$U_{a.m}(t) \approx \Delta x_m(t) \cdot K_s(p) \cdot K_c(p,n) \cdot K_a(p), \quad (1)$$

where

$$\Delta x_m(t) \approx x_m(t) \cdot \Delta K_c(p,n).$$

In accodence with (1), lat's find the maximum value of the error corresponding to the maximum value of the signal requaered to turn the CL actuater.

In control loops (CL) of regulative systems, for example, in servo optical mechanics systems, it needs to evaluate the maximum amplitude ΔA_m of the control error $\Delta x_m(t)$ caused by extremely unfavorable input disturbance $x_m(t)$ [1–5]

$$\Delta K_c(p,n) = 1 - K_c(p,n), \tag{2}$$

The error (1) with regard for the formula (2) may be equated to

$$\Delta x_m(t) = \frac{x_{m.t}^{(n)}(t)}{Q(n)} \cdot K_f(p,n), \tag{3}$$

where $Q(n)$ is the Q factor of the n-th order,

$$K_f(p,n) = \frac{\Delta K_c(p,n)}{p^n}. \tag{4}$$

Transformations (1), (2), (4) may be considered as transformation of frequency spectrum of n-th order derivative of the input disturbance $x_м(t)$ [3]. For instance, for CL with astantism of the first order equations (1) and (3), (4) may be expressed in terms of structural schemes for amplitude-fase-frequency factors $K_f(p,1)$ (3), $\Delta K_c(p,1)$ (4) given on the fig.2b, 2c, where $v_m(t) = x_{mt}^{'}(t)$.

The type of frequency-response characteristic (FRC) of transmission factor (TF) $K_f(w,n) = |K_f(p,n)|$, $p = j \cdot w$ for frequencies much less and much more than the cutoff frequency w_1 of CL, is defined by a ratio

$$K_f(w,n) = \begin{cases} 1, w << w_1, \\ 0, w >> w_1. \end{cases} \tag{5}$$

At frequencies $w \approx w_1$, the type of FRC TF (frequency-response characteristic of transmission factor) $K_f(w,n)$ is specified by stability factor of CL: at small stability factors – increase of FRC $K_c(w,n)$ и $K_f(w,n)$ at frequencies $w \approx w_1$ (fig.1*a*, pos.1 and pos.2).

Usually input disturbances are limited by the first derivatives [9-19]. Thus type of the extreme disturbance limited by the first n or (n+1) derivatives, at which the amplitude of the error ΔA_m is maximum, but doesn't exceed maximum permissible value, is of grate interest. The disturbance is traditionally represented in the harmonic form [2]:

$$x_m(t) = A_m \cdot \sin(w \cdot t), \tag{6}$$

where A_m – amplitude of the extreme harmonic disturbance. The values of amplitude A_m at frequency w of harmonic signal (6) are such that restrict disturbance $x_m(t)$ by the first n derivatives with maximum values. Hence A_m – is the function of frequency, $A_m = A_m(w)$.

For example, for CL with astatism of first order we have [2]

$$A_m(w) = \begin{cases} \dfrac{v_m}{w}, w \le w_0, \\ \dfrac{a_m}{w^2}, w \ge w_0, \end{cases} \tag{7}$$

where $w_0 = a_m / v_m$, v_m, a_m – are the maximum values of derivatives of disturbance $x_m(t)$ (6) with respect to velocity and acceleration.

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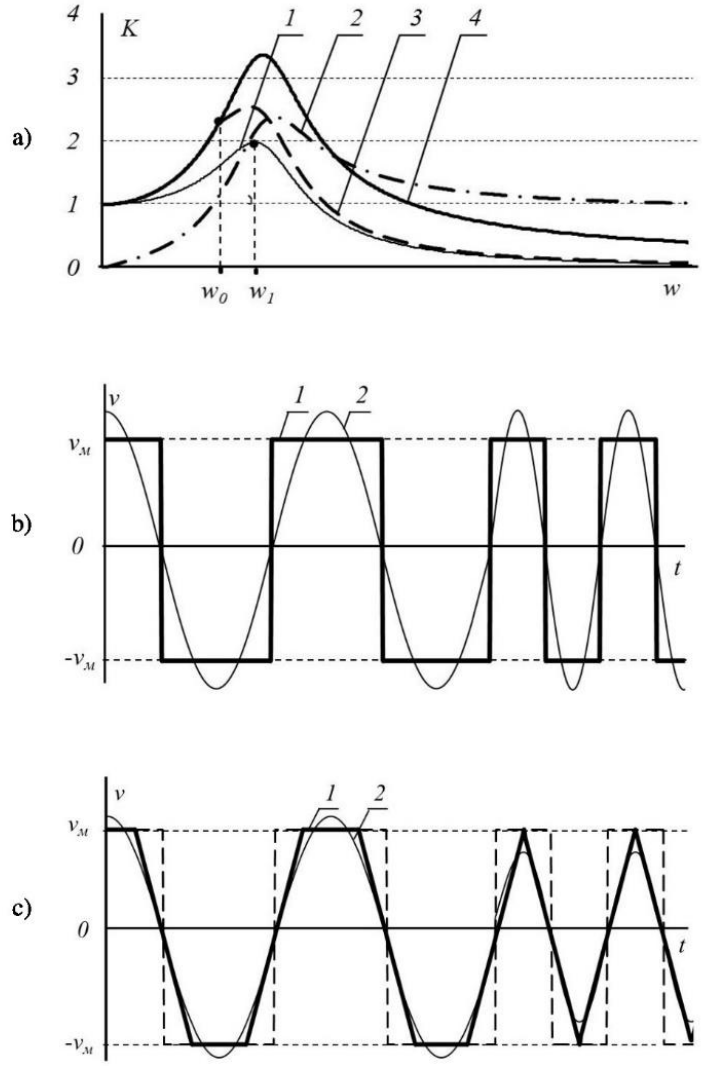

Fig. 2. An evaluation of the maximum error of control.

The traditional approach to the assessment of extreme disturbance does not answer two important questions: how extreme is the harmonic disturbance compared to more complicated type of disturbances that have derivatives with gaps, and how the resistance reserves of CL affect the amplitude of error $\Delta x_m(t)$ at these disturbances.

To answer these questions, we consider first CL with astatism of first order and large reserve of sustainability. Wherein the FRC TF (5) may be taken as rectangular. It can be shown that when the disturbance is restricted only by speed, at the outlet of the filter (4) the amplitude

$$\Delta A_m = \frac{4}{\pi} \cdot \frac{v_m}{Q(1)} \tag{8}$$

of error $\Delta x_m(t)$ is maximum, if the derivative of input disturbance - meander with the amplitude v_m (fig.2b, pos.1)

$$\Delta x_{m.t}^{'}(t) = v_m \cdot sign(\sin(w \cdot t)), \tag{9}$$

and with frequency

$$w = \left(\tfrac{1}{3} \cdot w_1, ..., w_1 \right) \tag{10}$$

In this case, the amplitude (8) – is the amplitude of first harmonics of meander (9) (fig.2b, pos.2). Decrease of frequency of the input signal compared with (10) leads to penetration of higher harmonics in the pass band of the filter (5), and therefore there will be a reduction in the amplitude of errors from level (8) to the level (7). However, due to the shallow recession of the FRC of real TF $K_f(w,n)$ at frequencies which are outside the passband $w > w_1$, even if conditions (10) are satisfied it does not result in complete suppression of highist harmonics. Therefore, the best suppression of harmonics in real CL with considerable stability is at frequencies $w \approx w_1$. Growth of FRC $K_f(w,n)$ at frequency w_1 and small reserves of CL stability (fig.2*a,* pos. 2) only enhance the reasons because of which the amplitude of the error becomes maximum at $w \approx w_1$.

Similar results may be obtained for CL with astatism of higher order [15–19].

3. Conclusion

Thus, actually regardless of stability reserve for CL with astatism of n-th order, the periodic disturbance with cutoff frequency of CL is extremely unfavorable if gaps of n-th derivative exist. Such disturbance may lead to growth of amplitudes error, compared to harmonic disturbance of the same frequency, maximum in $4/\pi$ times. It will increase the maximum power consumed by CL actuator in $(4/\pi)^2 \approx 2$ times. Similar results may be obtained for CL with astatism of higher order

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