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SYNTHESIS ALGORITHM OF THE MOVING PLANT CONTROL SIGNALS OBSERVER

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Abstract*—*Proposed procedure of optimal observer's structure and parameters design for estimation of control surfaces deflection values which based on Wiener–Kolmogorov prediction theory.

Index Terms—Observer; stochastic processes; Wiener–Kolmogorov prediction theory.

I. INTRODUCTION

The problem of moving plants performance estimation deals with necessity of obtaining numerical values of control surfaces deflections basing on the input control signals taken from actuators. As an example of the mentioned above problem, it is possible to consider onboard data decoding taken from the airplane flight recorders. These flight records are obtained during airplane flight missions or aviation events.

A control law which is used to control the motion of dynamic plant can be represented in the following form

$$u = K_{act} u_0 + \xi , \qquad (1)$$

where u_0 is a control signal that fed to the actuator input; u represents deflections of control surfaces; K_{act} is a transfer functions that describes models of actuators dynamics; ξ characterizes noises that accompany control signal.

The control signal is measured by measuring system. The results of measuring can be represented by the following equation:

$$y = K u_0 + \eta , \qquad (2)$$

where y is the output signal obtained from measuring system; K is a transfer functions that describes dynamics of measuring system; η is a vector of additive noises that accompany measuring process.

The result of measurement can be estimated by applying optimal filtering system.

The optimal filtering is performed in the following way

$$\hat{u} = Gy, \qquad (3)$$

where G is a transfer functions of optimal observer system; $\hat{u}$ is a result of control signal estimation.

The structural block-scheme of this system is given in Fig. 1.

The error of the system, ε is used to characterize the efficiency of the estimation results. Thus, the error of estimation can be represented in the following way:

$$\varepsilon = \hat{u} - u . \qquad (4)$$

In terms of the error, given by (4), our performance index is represented as a mean-squared error of the following form [1]

$$e = \frac{1}{2\pi} \int_{-\infty}^{\infty} S_{\varepsilon\varepsilon}(j\omega) d\omega , \qquad (5)$$

where $S_{\varepsilon\varepsilon}(\omega)$ is a spectral density of the errors.

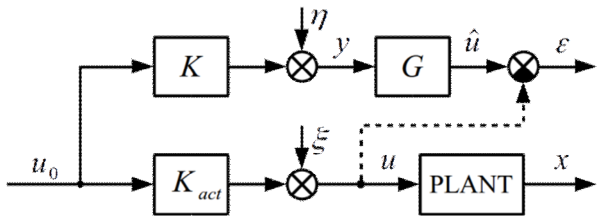

Fig. 1. Block-scheme of measuring system applied for estimating control signal

II. SOLUTION OF THE PROBLEM

The design problem involves defining structure and parameters of the function G on the basis of linear causal functions of complex variable that brings minimum to our performance index (5).

The first design step includes construction the spectral densitie for the errors of the system. Fourier Transform for the error of estimation after some transformation and simplify of expression is given below

$$\varepsilon = (GK - K_{act}) u_0 + G\eta - \xi. \qquad (6)$$

Hermitian conjugation to (6) has the following form

$$\varepsilon_* = u_{0*}(K_* G_* - K_{act*}) + \eta_* G_* - \xi_* , \qquad (7)$$

where symbol "*" is used to designate procedure of Hermitian conjugation.

According to Wiener-Khinchin theorem, it is possible to define spectral density for the errors of estimation

$$S_{\varepsilon\varepsilon} = |GK - K_{act}|^2 S_{u_0u_0} + (GK - K_{act})S_{\eta u_0}G_* + GS_{u_0\eta}(K_*G_* - K_{act*}) - (GK - K_{act})S_{\xi u_0} - S_{u_0\xi}(K_*G_* - K_{act*}) - S_{\eta\xi}G_* - GS_{\xi\eta} + S_{\xi\xi}, \quad (8)$$

and evaluate the spectral density of the signal derived on the output of measuring system

$$S_{\hat{u}\hat{u}} = |K|^2 S_{u_0u_0} + KS_{\eta u_0} + S_{u_0\eta}K_* + S_{\eta\eta}. \quad (9)$$

Taking into account (1) – (4) and (6) – (9), performance index given by (5) will take the following form

$$e = \frac{1}{2\pi j}\int_{-j\infty}^{j\infty} [|GK - K_{act}|^2 S_{u_0u_0} + (GK - K_{act})S_{\eta u_0}G_* + GS_{u_0\eta}(K_*G_* - K_{act*}) - (GK - K_{act})S_{\xi u_0} - S_{u_0\xi}(K_*G_* - K_{act*}) - S_{\eta\xi}G_* - GS_{\xi\eta} + S_{\xi\xi}]ds, \quad (10)$$

To obtain the optimal structure and parameters of the measuring system, given by G, it is possible to apply minimization approach after Kolmogorov. According to the proposed approach, it is necessary to derive the first partial derivative of the performance index (10) and determine conditions that holds zero to this derivative [2]

$$\delta e = 0. \quad (11)$$

Let us apply the following designations,

$$DD_* = S_{\hat{u}\hat{u}}. \quad (12)$$

The function which is necessary to vary has the following form

$$G_0 = GD, \quad (13)$$

where D is result of factorization of ratios (12).

As described in [2], introducing designation,

$$T = T_0 + T_+ + T_- = [K_{act}(S_{u_0u_0}K_* + S_{\eta u_0}) + S_{u_0\xi}K_* + S_{\eta\xi}]D_*^{-1} \quad (14)$$

the condition of holding performance index (11) to zero, taking into account accepted constraints, is possible to write down as

$$G_0 = T_0 + T_+ \quad (15)$$

The procedure of defining optimal structure and parameters of observer, with use (13), can be represented in the following form:

$$G = (T_0 + T_+)D^{-1}. \quad (16)$$

If you compare the resulting algorithm with algorithm of synthesis Wiener–Kolmogorov filter in [2], that these algorithms differ function T (14). Thus, if we assume that the perturbation ξ actuator is non-correlated with disturbances η of measuring system and control signals u_0, algorithm of synthesis of optimal filter-observer is reduced to an optimal algorithm synthesis of filter Wiener–Kolmogorov.

II. Observation of Control Signal in a Closed-Loop Stabilization System

Let us consider functioning of closed-loop stabilization system, where it is necessary to carry out observation of the control signal.

Let the motion of the plant is described by a set of differential equations in a Laplace form

$$Px = Mu + \psi, \quad (17)$$

where P and M are polynomial of complex variable s; x is a output signals (response of plant); u is a control input signals; ψ is a external disturbances with known model of dynamics.

The system is enclosed with a feedback control to unsure its stabilization. The feedback control applied to the system is given below

$$u_0 = Wx, \quad (18)$$

where W is a feedback controller with known transfer function.

By substituting control law given by (18) into (1), we obtain the following relation

$$u = K_{act}Wx + \xi. \quad (19)$$

The equations for plant output signal x, feedback control, u_0, and actuator control law are given below

$$x = (P - MK_{act}W)^{-1}\psi + (P - MK_{act}W)^{-1}M\xi, \quad (20)$$

$$u_0 = W(P - MK_{act}W)^{-1}\psi + W(P - MK_{act}W)^{-1}M\xi, \quad (21)$$

$$u = K_{act}W(P - MK_{act}W)^{-1}\psi + P(P - MK_{act}W)^{-1}\xi. \quad (22)$$

The structure of closed-loop system according to the proposed approach is given in Fig. 2.

According to the structure of closed-loop system, it is possible to derive the following equations

$$F_{u_0}^{\psi} = W(P - MK_{act}W)^{-1}, \quad (23)$$

$$F_{u_0}^{\xi} = W(P - MK_{act}W)^{-1}M, \quad (24)$$

$$F_u^{\psi} = K_{act}W(P - MK_{act}W)^{-1}, \quad (25)$$

$$F_u^{\xi} = P(P - MK_{act}W)^{-1}. \quad (26)$$

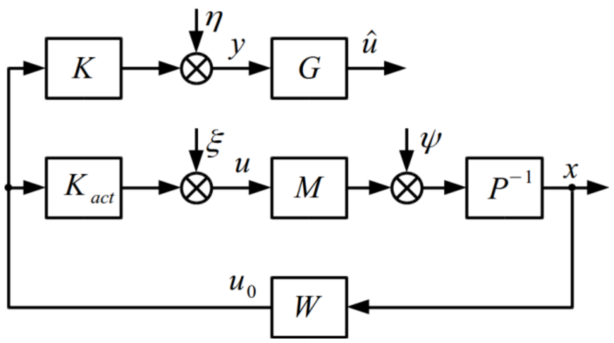

Fig. 2. Block-scheme for control signal observation in a closed-loop system

The relations for control signal u and actuator control, u_0 are given below

$$u_0 = F_{u_0}^{\psi}\psi + F_{u_0}^{\xi}\xi, \tag{27}$$

$$u = F_{u}^{\psi}\psi + F_{u}^{\xi}\xi. \tag{28}$$

By applying Wiener–Khinchin theorem, we are able to write down the equations for spectral and cross-spectral densities for the signals, given by (27) and (28), respectively.

$$S_{u_0u_0} = \left|F_{u_0}^{\psi}\right|^2 S_{\psi\psi} + F_{u_0}^{\psi} S_{\xi\psi} F_{u_0*}^{\xi} + F_{u_0}^{\xi} S_{\psi\xi} F_{u_0*}^{\psi} + \left|F_{u_0}^{\xi}\right|^2 S_{\xi\xi}, \tag{29}$$

$$S_{u_0\xi} = F_{u_0}^{\psi} S_{\xi\psi} + F_{u_0}^{\xi} S_{\xi\xi}. \tag{30}$$

This expression shows that a control signal u_0 in a closed-loop system is correlated with the perturbation signals ξ and ψ.

III. Conclusions

As follows from the expressions (29) and (30) in closed-loop system, even if the signal value of actuator disturbances ξ is not associated with the values of actuator control signal u_0, the cross spectral density of these signals not equal zero.

I.e. when presence the feedback loop control structure in system of stabilization the proposed modified synthesis algorithm of optimal observer of motion plant control signals, which based on optimal Wiener–Kolmogorov prediction theory has advantages over the observer without considering of the feedback.

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Ю. М. Безкорований, О. В. Ермолаєва. Алгоритм синтезу спостерігача сигналів керування рухомого об'єкту

Запропоновано процедуру синтезу структури та параметрів оптимального фільтра-спостерігача для оцінювання сигналів відхилення органів керування рухомого об'єкту на основі теорії фільтрації Вінера–Колмогорова.
Ключові слова: фільтр-спостерігач; стохастичні процеси; фільтр Вінера–Колмогорова.

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Ю. Н. Безкорованый, О. В. Ермолаева. Алгоритм синтеза наблюдателя сигналов управления подвижного объекта

Предложена процедура синтеза структуры и параметров оптимального фильтра-наблюдателя для оценки сигналов отклонения органов управления на основе теории фильтрации Винера–Колмогорова.
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