Controller settings search area determination in the condition of reduced sensitivity to control object parameters drift

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Abstract. A definition method for the area of controller admissible parameters set-up in an aircraft, machine-building and other industries is offered in this article. Admissible adjustments areas of controller parameters are defined, at which closed control systems have smaller sensitivity to possible deviations of object parameters regulation during their operation. The examples of method applied to automatic control systems of vacuum in the furnace and drum-type boiler flow rate controller are considered.

1. Introduction
The methodology of robust controller’s creation was used for the synthesis of automatic control system (ACS) of various assignments wide distribution [1].

Giving ACS robust properties provides its reduced sensitivity to uncontrolled variations in the parameters of the control object (CO) [2]. Such “rudeness” of ACS preserves its serviceability at operation. The problem of ACS robustness is particularly relevant in the aerospace industry and in the field of energy production, as the operating conditions of the CO are strict for long period of operation. The decommissioning of the CO for its identification is usually impossible. Economic consequences of ACS gradual or sudden refusal are very significant, and, in case of failure, disasters are possible.

A significant addition to the known methods of ACS robust properties increase [3], increasing their efficiency can serve preliminary controller parameters set-up area definition considering reduced sensitivity to changes in the parameters of the CO, to further in this area to find the optimal for the selected criterion robust settings of the controller [4].

2. Problem statement
In figure 1, as example, one of the possible ways for defining the area of ACS vacuum reduced sensitivity in the furnace and the boiler’s flow rate ACS is considered [5].

To maintain a stable combustion process in the boiler furnace, it is necessary, often with the help of smoke exhausters, to remove the resulting combustion products from it. An indirect indicator of the balance between fuel and air supply to the furnace and combustion products removal is the inadmissible excess of vacuum $S$ level in the combustion chamber. The increase in the degree of vacuum in the combustion chamber leads to the increase in air suction in the furnace and flues. This reduces the efficiency of the boiler, increases electricity expense to drive the exhauster. Insufficient vacuum cannot be allowed in the furnace, as it also reduces the efficiency of the boiler. Typically, the
vacuum at the top of the furnace is maintained by regulating the performance of the smoke exhausters [6].

ACS vacuum and supply boiler; $W_{p}^{(2)}(p)$ – transfer function for the disturbance of steam consumption in the boiler ACS; $W_{x}^{(2)}(p)$ – transfer function to control the flow of feed water in the boiler ACS; $x_{i}$ – set value $x_{i} = f_{i}$; vacuum $S$ in the boiler furnace and $x_{i} = f_{i}$; preset water level $H$ in the boiler drum; $Y$ – control value, $Y = S$ in ACS vacuum and $Y = H$ in ACS supply boiler; $V$ – interference, $V = G_{a}$ – air flow in ACS vacuum and $V = G_{s}$ – steam consumption in ACS supply boiler.

Combined ACS circuit closed by the deviation of the vacuum $S(t)$ from the specified value. Proportional-integral controller (PI - controller) $W_{p}^{(1)}(p) = \frac{k_{p}^{(1)}(T_{u}p+1)}{T_{u}p}$ affects the mechanisms of smoke exhausters, changing the rate of combustion products removal [7]. Here $k_{p}^{(1)}$, $T_{u}$ – gain and time constant of the transfer function. The main perturbation of the ACS vacuum is the change in air flow $G_{s}$ due to changes in boiler performance to maintain the ratio of fuel and air. In order to compensate for this disturbance, a correction element $W_{x}^{(1)}(p) = \frac{Tp^{(1)}}{K_{r}^{(1)}(Tp^{(1)}+1)}$, is introduced into the ACS vacuum circuit, to which a signal $G_{a}$ is received proportional to the air flow.

ACS supply boiler has a similar structure. This system maintains balance between the amount of water in the boiler drum and the steam supplied to rotate the turbine by changing the feed water flow [4]. For the ACS of the boiler power supply the main disturbance is the steam consumption $G_{s}$ for the turbine rotation. The peculiarity of the system is the astatic object of regulation along the control channel. In this case, the most effective one is proportional regulator $W_{p}^{(2)}(p) = k_{p}^{(2)}[7]$

Calculated parameters $(a_{1}^{i}, b_{m}^{i}, T_{\beta}^{i}, \tau_{p}, i = 1,2,3,4, j = 11,12,21,22, m = 1, n = 11,12,21,22, \alpha = 11,12,21,22, \beta = 2, \gamma = 2)$

control objects $W_{1}^{(1)}(p) = k_{p}^{(1)} \frac{b_{1}^{(1)}p+1}{a_{1}^{(1)}p^3 + a_{2}^{(1)}p^2 + a_{1}^{(1)}p + 1}$

$W_{2}^{(1)}(p) = k_{p}^{(2)} \frac{b_{2}^{(2)}p+1}{a_{3}^{(2)}p^3 + a_{4}^{(2)}p^2 + a_{1}^{(2)}p + 1}$

$W_{1}^{(2)}(p) = \frac{1}{T_{1}^{(12)}p} - k_{p}^{(12)} \frac{b_{2}^{(12)}p+1}{a_{3}^{(12)}p^3 + a_{4}^{(12)}p^2 + a_{1}^{(12)}p + 1}$

$W_{2}^{(2)}(p) = \frac{a_{2}^{(2)}}{p+1} + \frac{1}{T_{2}^{(22)}p} \times e^{\gamma p}$ in both ACS can be determined by known methods of parametric identification, which allows to determine the calculated optimal settings of the controllers [8,9]: $K_{p}^{(1)} = K_{p_{0}}^{(1)}, T_{p}^{(1)} = T_{p_{0}}^{(1)}, K_{p}^{(2)} = K_{p_{0}}^{(2)}$.

With these settings, the calculated quality indicators of the vacuum ACS and the supply ACS (see figures 2, 3) can be considered quite satisfactory - the degree of attenuation: $\psi^{(1)} = 19.23 \%$, $\psi^{(2)} = 11 \%$, time transition process - $t_{p}^{(1)} = 95$ seconds, $t_{p}^{(2)} = 150$ seconds.
However, the deviation of the parameters of the control object during its operation, for example by 30%, while maintaining the design settings of the controller and the correction element leads to an unacceptable deterioration in quality indicators - the degree of attenuation: \( \psi(1) = 32\% \), \( \psi(2) = 6.25\% \), time transition process - \( t_p(1) = 160 \) seconds, \( t_p(2) = 185 \) seconds.

![Figure 2. Transition process of vacuum ACS, \( K_{vo}(1) = 31.8 \), \( T_uo(1) = 12.25 \).](image)

![Figure 3. Transition process supply ACS, \( K_{vo}(2) = 0.81 \).](image)

3. The area of reduced sensitivity

To determine the area of reduced sensitivity of ACS [10] to object parameters variations one should determine the resonance frequency \( \omega_p^{(1,2)} \) amplitude-frequency characteristic (AFC) ACS \( W^{(1,2)}(j\omega) \), where \( W^{(1,2)}(j\omega) = \frac{W_1^{(1,2)}(j\omega)}{1 + W_p^{(1,2)}(j\omega)\cdot W_2^{(1,2)}(j\omega)} \) - AFC ACS along the channel of disturbance \( V(t) \), (see figures 4, 5).

![Figure 4. AFC of vacuum ACS in the channel disturbance.](image)

![Figure 5. AFC of supply boiler ACS in the channel disturbance.](image)

For the obtained resonant frequency \( \omega_p^{(1,2)} \) consider the sensitivity functions

\[
\frac{dW^{(1)}(j\omega_p)}{dK_p^{(1)}} = f_1(K_p^{(1)}), \quad \frac{dW^{(1)}(j\omega_p)}{dT_u} = f_2(T_u) \quad \text{and} \quad \frac{dW^{(2)}(j\omega_p)}{dK_p^{(2)}} = f_3(K_p^{(2)}).
\]

Obviously, the region of minimum values \( f_1(K_p) \) and \( f_2(T_u) \) is preferential when choosing controller parameters to reduce the sensitivity of the ACS to changes in object parameters in order to preserve the quality of regulation.

In figures 6, 7, 8 graphics \( f_1(K_p^{(1)}), f_2(T_u) \) and \( f_3(K_p^{(2)}) \) see that for the calculated resonant frequency \( \omega_p^{(1,2)} \) minimum sensitivity area is bounded below (1).
If now by known methods [3] to search for optimal parameters of regulators in the field of reduced sensitivity (1) get new options: \( K_p^{(1)} = K_{p_{\text{new}}^{(1)}} = 33, T_u^{(1)} = T_{u_{\text{new}}^{(1)}} = 8, K_p^{(2)} = K_{p_{\text{new}}^{(2)}} = 0.6. \)

4. Conclusion
Figures 9 - 14 present the comparative results of modeling the transient response of the ACS with initial and new settings with variations of parameters on \( \pm 30\% \).

\[ K_p^{(1)} \geq 22, T_u^{(1)} \geq 3, K_p^{(2)} \geq 0.5 \]  \hspace{1cm} (1)
– to +30% at $K_{po}^{(1)}$ and $T_{uo}^{(1)}$; 3 – to -30% at $K_{pnew}^{(1)}$ and $T_{unew}^{(1)}$, 4 – to +30% at $K_{pnew}^{(1)}$ and $T_{unew}^{(1)}$.

Thus, from the figures 9-14 it is clear that both the sensitivity of the system to variations in the parameters of control objects and the deterioration in the quality of the systems due to these variations have decreased significantly, which indicates the effectiveness of the proposed method.

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