PARALLEL SIMULATION FOR THE OPTIMUM REGULATION OF AIR DISTRIBUTION

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Abstract

This paper considers the parallel simulation of mine ventilation system, which is complex topological network object. The mathematical model of this network object is shortly described. The analysis of the qualitative characteristics of the network object control system of the air distribution was carried out with the use of massive-parallel model, which was realised in Parallaxis language. Simulation has confirmed, that the law of control by the senior derivative, accepted in regulators, has properties of natural adaptation and independence of functioning of regulators under the conditions of fast changes of network parameters and provides accuracy acceptable in practice.

The mine ventilation system, which distributes air among consumers with the purpose of decreasing to a safe level the concentration of harmful industrial gases in the atmosphere, is complex topological network object.

To establish a safe concentration of harmful gases, when their emission has boundary frequency of the order of $0.05\ s^{-1}$, the optimum regulation of air distribution should provide a law of establishment of the required flow rates both in character, and in duration of transition. For technological reasons it is rather important, that the transition has non-periodic character, even in the presence of harmonic containing finite number of fluctuations.

The transport movement in an uncontrolled network causes essential high-frequency fluctuations of resistance of the network branches and according to the flow rate with boundary circular frequency ω=0.2-0.3 s^{-1}. Effective indemnification of these fast changes is the major dynamic problem of a system, regulating the air distribution in a network object.

At the preliminary stage of the development of a network object control system we carry out the synthesis of a control system, which is optimum in quality for a separate branch of the network. Qualitative characteristics of a network object control system as a whole are analysed with the application of a parallel mathematical model.

In general, aerodynamic processes in a separate branch of a network object are described by non-linear telegraphic equations:

$$-\frac{\partial H}{\partial x}=\frac{\rho_b}{F_b}\frac{\partial G}{\partial t}+RG^2; \qquad (1)$$

$$-\frac{\partial G}{\partial x}=\frac{F_b}{\rho_b a^2}\frac{\partial H}{\partial t}. \qquad (2)$$

Here H is a pressure along the axis of a branch; G - air flow rate; ρ_b - air density; a - speed of a sound in the air; F_b - section of a branch; R - specific resistance of a branch; x - distance of the given point from the beginning of a branch.

The equations (1) and (2) describe dynamics of a branch in an unlimited range of frequencies up to $\omega = \infty$. In the limited interval under consideration of the working frequencies of the order $0.5\ s^{-1}$ more simple models of dynamics of a branch as a controlled object can be used for the control system synthesis. Linear system of telegraphic equations is considered for the synthesis of an approximate model of aerodynamic processes in a network branch:

$$-\frac{\partial P}{\partial x}=\frac{\rho_b}{F_b}\frac{\partial Q}{\partial t}+rQ; \tag{3}$$

$$-\frac{\partial Q}{\partial x}=\frac{F_b}{\rho_b a^2}\frac{\partial P}{\partial t}, \tag{4}$$

where $r = 2RG_H$ - differential specific resistance of a branch in the vicinity of a stationary nominal mode $G = G_H$;

$Q(x,t) = [G(x,t) - G_H]$ - deviation of the air flow rate from nominal mode;

$P(x,t) = [H(x,t) - H_H(x)]$ - deviation of pressure from nominal pressure $H_H(x)$ in stationary mode;

$H_H(x) = [H_K^H + RG_H^2(l_b-x)]$ - pressure distribution along a branch at nominal flow rate;

l_b - length of a branch.

According to (3) and (4) the resistance of a branch in the final section (at the end of a branch) is defined by the expression

$$W(s) = P_K(s) / Q(s) = -\bar{\rho} th(\gamma\tau/2), \tag{5}$$

where $\tau = 2\,l_b/a$; $\gamma^2 = s(s+\delta)$; $\delta = \dfrac{rF_b}{\rho_b}$; $\bar{\rho} = \dfrac{\rho\gamma}{s}$; $\rho = \dfrac{\rho_b a}{F_b}$.

Approximating (1) and (2) by the method of straight lines and expanding function (5) in a Taylor series for branches of real networks in the essential range of frequencies in the presence of square-law resistance the following models of a branch as an object under control can be obtained:

$$K_i(p)G' + R_sG^2 = \Delta H_0. \tag{6}$$

Here $R_s = (R_b + R_c)$ is a total resistance of a controlled branch; $R_b = Rl_b$ is a resistance of a branch; R_c is a controlled resistance of a pressure-differential device; ΔH_0 is a general depression of an autocontrolled branch; $K_i(p) = K_1(p), K_2(p), K_3(p)$ are factors of inertia for models of aerodynamics in a branch of the third, second and first orders, respectively;

$$K_3(p) = (a_3p^2 + a_2p + a_1);\quad a_3 = \frac{\tau^2}{24}M_b;\quad M_b = \frac{\rho_b \ell_b}{F_b};\quad a_2 = \frac{\tau^2}{12}rl_b + b_2 r_g^{\,H};$$

$$a_1 = \frac{\tau^2 r\ell_b}{24T_b} + M_b;\quad b_1 = \frac{\tau^2}{8T_b};\quad b_2 = \frac{\tau^2}{8};\quad T_b = \frac{M_b}{rl_b};\quad r_g^{\,H} = R_g^{\,H}G_H;$$

$R_g^{\,H}$ - nominal resistance of a pressure-differential device;

$$K_2(p) = (e_2p + e_1);\quad e_2 = \frac{\tau^2}{4}r_g^{\,H};\quad e_1 = \frac{\tau^2}{4T_b}r_g^{\,H} + M_b;$$

$$K_1(p) = M_b;$$

It is shown, that the equations of the third, second and first orders describe adequately the dynamics of branches with the length of 2000, 600 and 300 meters respectively in the range under consideration of essential control frequencies of the order of $0.5\ s^{-1}$ of. The adequacy of the models is justified by the high degree of convergence of the frequency characteristics of simplified models and of the corresponding gear function (5). In the time interval a chained line of elements with four poles was used as a reference model for the accuracy evaluation of approximate models. Control processes optimum in quality in autocontrolled branches were designed with the help of equation (5)

$$A_0^i(p)G = G^0(t), \tag{7}$$

where $G^0(t)$ is a given debit of air in a branch under control; G is a current flow rate of a branch;

$A_0^i(p) = A_0^3(p), A_0^2(p), A_0^1(p)$ are the optimum operator of the characteristic equation of transitions in branches of the third, second and first orders, respectively;

$A_0^3(p) = (a_3^0p^3+a_2^0p^2+a_1^0p+1)$;
$A_0^2(p) = (e_2^0p^2+e_1^0p+1)$;
$A_0^1(p) = T_b^0+1$;
$a_3^0, a_2^0, a_1^0, e_2^0, e_1^0, T_b^0$ are optimum constant factors of the characteristic equation for branches of appropriate length.

For the maintenance of natural adaptation regulation in a system is performed according to the law

$$u = K\,(G_T^{(n)} - G^{(n)}), \tag{8}$$

where $G_T^{(n)} = A_0^{(n)}G$ is the desirable value of the senior derivative of equation (7) in an autocontrolled branch; $G^{(n)}$ is the current value of the senior derivative, K is a parameter of a regulator set-up.

The resistance of a pressure-differential device of a branch is defined, in general, by a non-linear function

$$R_p(u) = f_d\,(u), \tag{9}$$

where $f_d(u)$ is an aerodynamic characteristic of the pressure-differential device. The formation of values of current phase co-ordinates of a branch and of the senior derivative is carried out by a real differentiating filter:

$$N_f^1(p)G_f = G(t), \tag{10}$$

with $N_f^i = N_f^3, N_f^2, N_f^1$ is a characteristic equation of the filter of the third, second and first orders, respectively.

The order of the filter inertia (10) is assumed to be less than minimum time constant of the equation of a branch (6). According to this

$$G^{(i)} = G_f^{(i)}, \tag{11}$$

where $G^{(i)}$ is the evaluation by derivative of an air flow rate.

The system of equations (6) - (11) defines the required amplification factor of a regulator and the border of the control system stability area in a separate network branch as a function of parameters of the filter and regulator. Aerodynamics of controlled network object is described as a whole by the planimetric equation

$$S_xK_x(p)G'_x + S_yK_y(p)G'_y + SR_sZ = SH. \tag{12}$$

Here $K_x(p)$, $K_y(p)$ are matrixes of inertia factors, corresponding to branches of a tree and antitree of a network; H is a vector of depression of draft sources; R_s is a matrix of total aerodynamic resistance of all branches of a network; S_x, S_y, S are matrixes of planimetric factors of a network; Z is a vector of square-law flow rates of a network. The flows of the tree and antitree of a network object are connected by the equation of a continuity

$$G_x = -\,WG_y, \tag{13}$$

where $W = A_x^{-1}A_y$ are matrixes of factors corresponding to the tree and antitree of a network. Taking into account (13) we shall present an equation (12) in the form of

$$W_yG_y = SH - SR_sZ, \tag{14}$$

with $W_y = S_yK_y(p) - S_xK_x(p)W$.

The analysis of the qualitative characteristics of the network object control system of the air distribution was carried out with the use of massive-parallel model of the network object. In the parallel model each vector element of the equation systems (7) - (11), (14) is assigned to a processor in the processor grid of MasPar system. The software of the massive-parallel model is realised in Parallaxis language.

During simulation the following issues are considered:

- transitions of establishment of a natural flow distribution in non-controllable network;
- improvement of the required flow distribution in various points of the areas of stability and non-periodicity of control processes;
- qualitative characteristics of static and dynamic errors when improving optimum trajectories in various modes of the system operation;
- invariance of system to the change of fast non-stationary parameters of a network object;
- border of the areas of stability and non-periodicity of the control processes depending on the amplification factor a regulator and on the parameters of set-up of differentiating filters of local control systems.

Simulation has confirmed, that the law of control by the senior derivative, accepted in regulators, has properties of natural adaptation and independence of functioning of regulators under the conditions of fast changes of network parameters and provides accuracy acceptable in practice. The researches confirm, that the border of stability area of a network and periodicity of the control processes practically coincide with theoretical calculations in the vicinity of typical nominal mode of the network operation.

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