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Synthesis of a System for Adaptive Suboptimal Control of the Natural Gas Purification Process

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ABSTRACT: A mathematical model of the process of absorption cleaning of natural gas has been developed, which makes it possible to establish a quantitative relationship between the main input and output variables and to synthesize the control laws of the process under consideration. On the basis of the developed algorithms, an adaptive system for suboptimal control of the process of natural gas absorption purification is proposed.

KEYWORDS: mathematical model, absorption process, system, adaptive control, suboptimal, algorithm, parametric, indignation.

I. INTRODUCTION

It is necessary to note the influence of the gas composition on the complexity of its preparation and processing. Hydrocarbon gases contain a significant amount of acidic components of gases, water vapor, mechanical impurities, and salts, small amounts of oil and hydrocarbon condensate.

For transportation through main gas pipelines, it is necessary to thoroughly clean the gas from solid impurities, corrosive components and moisture, since they contribute to the rapid wear of expensive equipment and cause disturbances in normal operating conditions.

In world practice, the first place in the field of removing acidic components from hydrocarbon gas is occupied by amine purification processes [1, 2].

Apparatus in which absorption processes are carried out; called absorbers. They are: cylindrical columns in which the gas to be cleaned and the absorbent come into contact. Various methods are used to increase the contact surface area [3-5]. The most important indicator of an absorber is to ensure low losses of absorbent.

The structure of the mathematical model of the absorption process will take the form [6, 7]

$$\begin{bmatrix} y(t) \\ x(t) \end{bmatrix} = F(p)(I+\Delta_i)\begin{bmatrix} L(t) \\ G(t) \end{bmatrix} + K(p)f(t), \qquad (1)$$

where I is the identity matrix, $F(\lambda)$ is the nominal transfer matrix function with a relative degree of γ, and $K(\lambda)$ is the transfer matrix function for disturbances.

We will synthesize the system for adaptive control of the purification process on the basis of a mathematical model of the absorption process (1).

We will carry out the synthesis of adaptive suboptimal algorithmic support under the following assumptions:

Unknown constant coefficients of matrix Δ_i depend on some vector of unknown parameters $\zeta \in \Xi$, where Ξ is a known bounded set.

Output signals $y(t)$ and $x(t)$ and controlled inputs $L(t)$ and $G(t)$ are available for measurement.

The aim of the control is to minimize the H_∞ - norm of the transfer function $F_1(p)$ of the tracking error $e(t) = y(t) - y_m(t)$ of the output $y(t) = [y; x]^T$ for the reference signal $y_m(t) = [y^*; x^*]^T$:

$$\|F_1(j\omega)\|_\infty < \delta,$$

δ - small positive number, ω - vibration frequency, j - imaginary unit, $y_m(t)$ - smooth bounded function.

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We rewrite system (1) by taking $y(t)=[y(t);x(t)]^T$, $u(t)=[L(t);G(t)]^T$:

$$y(t)=F(p)(I+\Delta_i)u(t)+K(p)f(t). \quad (2)$$

We transform equation (2) to the form:

$$y(t)=F(p)u(t)+\varphi(t).$$

in which function $\varphi(t)=F(p)\Delta_i u(t)+D(p)f(t)$ contains parametric and external disturbances of the system.

Let's make an equation for the error $e(t)=y(t)-y_m(t)$:

$$e(t)=F(p)u(t)+\varphi_1(t), \quad (3)$$

with function $\varphi_1(t)=\varphi(t)-y_m(t)$.

Consider the nominal plant obtained from (3) with zero parametric and external disturbances $\varphi_1(t)$:

$$e_н(t)=F(p)u_0(t),$$

and solve for it the standard problem of constructing a H_∞ -optimal controller $u_0(t)$ [8,9]:

$$u_0(t)=-C(p)e_н(t), \quad (4)$$

$C(p)$ - stabilizing regulator.

Add and subtract the expression for $u_0(t)$ from (4) in system (3) and rewrite it as:

$$e(t)=F(p)u(t)+\varphi_2(t), \quad (5)$$

Here $u(t)$ is the signal required to compensate for parametric and functional uncertainties, function $\varphi_2(t)=\varphi_1(t)+F(p)u_0(t)$.

To isolate signal 1 containing system uncertainties, we introduce an auxiliary circuit [10]

$$e_v(t)=F(p)u(t), \quad (6)$$

taking into account (5), (6), we compose the mismatch equation $\varepsilon(t)=e(t)-e_v(t)$:

$$\varepsilon(t)=\varphi_2(t).$$

Thus, to compensate for function $\varphi_2(t)$, which contains parametric and external disturbances, we define signal $u(t)$ in the form:

$$u(t)=-F^{-1}(p)\hat{\varepsilon}(t)=-\hat{\varphi}_2(t), \quad (7)$$

where $\hat{\varepsilon}(t)$, $\hat{\varphi}_2(t)$ - estimates of functions $\varphi_2(t)$ and $\varepsilon(t)$, respectively, formed by the observer:

$$u(t)=-(g^T\hat{\xi}(t)+\frac{\Delta Q_0(p)}{R_0(p)}\varepsilon(t))=-\hat{\varphi}_1(x,u,t), \quad (8)$$

To assess the accuracy of observations, consider the vector of deviations $\eta_i(t)=\Gamma^{-1}(\hat{\varepsilon}_i(t)-\theta_i(t))$. Then, taking into account the equation of its dynamics $\eta(t)=\Gamma^{-1}(\hat{\xi}(t)-\theta(t))$ and the equation of signal $u(t)$ (7), the equation of error (3) will take the form:

$$e(t)=\mu^\gamma[L;L]\cdot\begin{bmatrix}\overline{\eta}_1(t)\\ \overline{\eta}_2(t)\end{bmatrix}.$$

The mathematical model of the absorption process (1) as a result of a stepwise effect on the input of an object based on an active experimental method takes the following form [6,7]:

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$F(p)=\frac{1}{14p+1}\begin{bmatrix}0.723 & -0.791\\ 1.026 & -1.012\end{bmatrix}$ - nominal transfer function with relative degree $\gamma=1;\ \Delta_I=\begin{bmatrix}\Delta_1 & 0\\ 0 & \Delta_2\end{bmatrix};\ K(p)=\begin{bmatrix}k_1(p)\\ k_2(p)\end{bmatrix}$.

Uncertainty class Ξ we define by the inequalities: $0\le\Delta_i\le 1,\ i=1,2,\ |f(t)|\le 6$.

The desired process quality is set by a reference signal $y_m(t)=\left[y^*;x^*\right]^T$.

The task is to minimize the H_∞-norm of the tracking error transfer function $e(t)=y(t)-y_m(t)$.

The auxiliary contour equation (6) takes the form:

$$e_v(t)=\frac{1}{14p+1}\begin{bmatrix}0.723 & -0.791\\ 1.026 & -1.012\end{bmatrix}u(t).$$

Control law (7) is defined as:

$$u(t)=-(14p+1)\begin{bmatrix}-12.667 & 9.901\\ -12.843 & 9.05\end{bmatrix}\hat{\xi}(t).$$

To estimate the derivatives of the signal $\varepsilon(t)$, we use the observer (8), in which $F_0=\begin{bmatrix}0 & 0\\ 0 & 0\end{bmatrix};\ Q^T=[-2,-1],\ \mu=0.01$:

$$\begin{cases}\dot{\hat{\xi}}_1(t)=\hat{\xi}_2(t)+2\mu^{-1}(\varepsilon(t)-\hat{\varepsilon}(t)),\\ \dot{\hat{\xi}}_2(t)=\mu^{-2}(\varepsilon(t)-\hat{\varepsilon}(t)), \qquad \hat{\varepsilon}(t)=L\hat{\xi}(t),\end{cases}$$

where $\varepsilon(t)=e_v(t)-e(t)$.

To convert the signal coming from the regulator to the absorption actuator, consider a DC motor with independent excitation, the transfer function of which has the form [11-14]:

$$W(p)=\frac{1}{0.15p+1}.$$

It is assumed that the raw gas is supplied at a rate of $Q=1$ with a concentration of $z_f=0.5$. The behavior of the absorption process is considered for the following values of the reference signal $y_m(t)=\left[y^*;x^*\right]^T=[0.3;\ 0.7]^T$ and $y_m(t)=\left[y^*;x^*\right]^T=[0.98;\ 0.02]^T$.

If an external bounded disturbance $f(t)=0.5+0.2\sin 0.5t$ is applied to the input of the control plant, then using the inverse (Fig. 1.) and diagonal (Fig. 2.) controllers, we obtain the following results:

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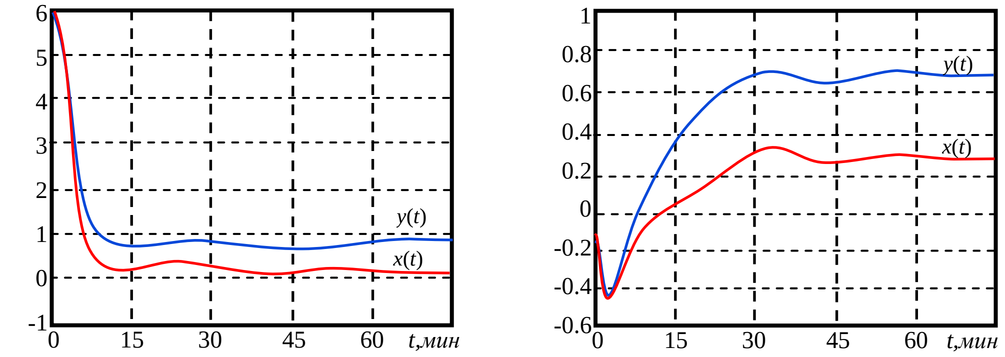

Fig. 1. Transient processes for $y_m(t)=[0.99;\ 0.01]^T$ and $y_m(t)=[0.4;\ 0.6]^T$ when using inverse controller $C_1(p)$ and applying external disturbance $f(t)$ to the input of the object

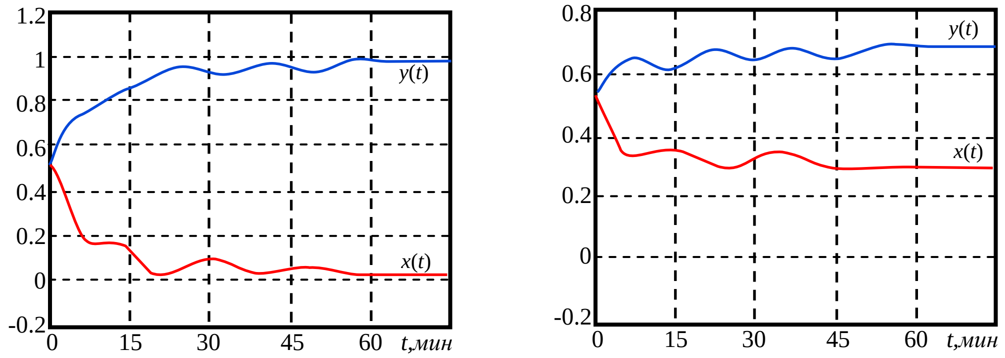

Fig. 2. Transient processes for $y_m(t)=[0.99;\ 0.01]^T$ and $y_m(t)=[0.4;\ 0.6]^T$ when using diagonal controller $C_2(p)$ and the presence of external disturbances $f(t)$.

The synthesized adaptive suboptimal control law makes it possible to achieve high quality tracking of the reference trajectory with changing system parameters and in the presence of uncontrolled external disturbances. The advantage of the proposed control system is also an improvement in the quality of transient processes.

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