International Conference on Fractional Differentiation and its Applications, Novi Sad, Serbia, July 18 - 20, 2016

ICFDA16

Multivariable fractional order PID control of the cryogenic process of mixing of two gaseous airs flows: D decomposition method

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Motivation

In the air production cryogenic liquid [1], the nowadays energy concern and operation requirement can rather exploit the advances in control systems theory to derive optimally designed closed-loop plants that can operate near their maximum capacity without the need for overestimated security margins. In recent years,considerable attention has been paid to control systems whose controllers are of a fractional order,[2], i.e. for real applications,to develop advanced methods for $PI^{\beta}D^{\alpha}$ controller design and parameter tuning. Here, we suggest and obtain a new algorithms of multivariable fractional PID control applying D-decomposition method in the producing of technical gases.

Problem formulation

First of all, it is necessary to determine the transfer function (1), (Two-Input Two-Output (TITO) control system) of the cryogenic process(CP) of mixing of two gaseous airs flows at different temperatures before entrance of expansion turbine, Fig.1.

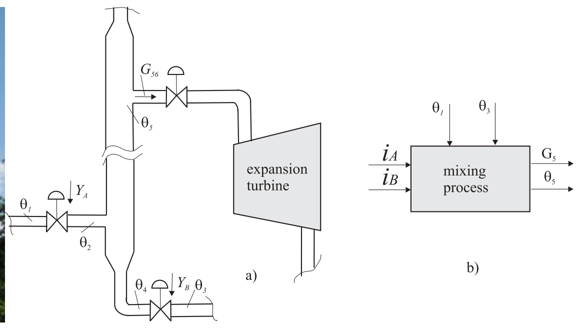


Figure 1A.Cryogenic plant for obtaining oxygen and nitrogen in the "Factory of technical gases" in Bor

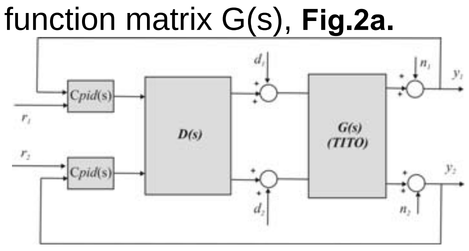
Figure 1B. a)Symbolic-functional scheme of the CP of mixing of two gaseous airs, b) Diagram of the CP.

$$\begin{pmatrix} g_5(s) \\ \theta_5(s) \end{pmatrix} = \begin{bmatrix} \dfrac{2963.04}{(s+0.2)(s+27.78)} & \dfrac{747.5}{(s+0.2)(s+8.62)} \\ \dfrac{11.27}{(s+0.2)(s+27.78)} & \dfrac{-2.26}{(s+0.2)(s+8.62)} \end{bmatrix} \begin{pmatrix} i_A(s) \\ i_B(s) \end{pmatrix} \quad (1)$$

$g_5(t)\,[m_N^3/h]$- deviation values flow from the nominal value of gas's air flow, $\theta_5(t)\,[K]$-value of temperature deviation from the nominal value of gas's air temperature; $z_1(t)=\theta_1(t), z_2(t)=\theta_3(t)\,[K]$ -value of temperature deviation from the nominal value of temperature of given exchangers, respectively; $i_A(t), i_B(t)\,[mA]$,- deviation values of the control signal from the nominal value of the control signal for the correction device at $TV946A$, $TV946B$, respectively.

The main results

Here, an effective procedure for decentralized SISO design is proposed using decoupler D(s), (2),[3] together with process transfer function matrix G(s), **Fig.2a.**



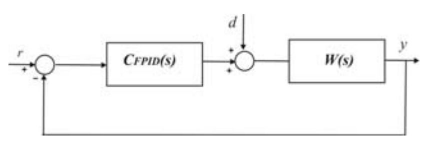


Figure 2.a) TITO system Gp(s) with the decoupler D(s) and PID controllers

Figure 2.b)Feedback control system for decoupled TITO system W(s)

where is $k_{ii}(s) = -5(s+0.2)$, $ii=1,2$ and diagonal W(s) is

$$D(s) = \mathrm{adj}(G(s)) \cdot \begin{bmatrix} k_{11}(s) & 0 \\ 0 & k_{22}(s) \end{bmatrix} = \begin{bmatrix} 1.313/(0.116s+1) & 2.029/(0.036s+1) \\ 433.587/(0.116s+1) & -533.304/(0.036s+1) \end{bmatrix}, \quad (2)$$

$$W(s) = D(s)G(s) = diag(w_{ii}), ii=1,2, \quad K = 1579.85$$
$$w_{ii}(s) = G_{objb}(s)/G_{obji}(s) = 1579.85/\left((0.116s+1)(0.036s+1)(5s+1)\right) \quad (3)$$

$$G_{obji}(j\omega) = R_{Gi}(\omega) + jI_{Gi}(\omega) = \left(1-0.7642\omega^2\right) + j\omega\left(5.15-0.021\omega^2\right) \quad (4)$$

Fractional controller is defined by, Fig.2b.

$$C_{FPID}(s) = \left(k_p + k_i/s + k_d s^{\alpha}\right)/\left(T_f s + 1\right) \quad (5)$$

Using the D-decomposition method, [4] a efficient method for determining stability regions in the parameters space can be obtained taking into account characteristic polynomial of the system

$$f(j\omega) = U(\omega,k,\alpha) + jV(\omega,k,\alpha) = 0 \quad (6)$$
$$U(\omega,k,\alpha) = -T_f\omega^2 R_{Gi}(\omega) - I_{Gi}(\omega)\omega + K\cdot k_i + Kk_d\omega^{1+\alpha}\cos\left(\pi(\alpha+1)/2\right) = 0$$
$$V(\omega,k,\alpha) = -T_f\omega^2 I_{Gi}(\omega) + R_{Gi}(\omega)\omega + \omega K\cdot k_p + k_d K\omega^{1+\alpha}\sin\left(\pi(\alpha+1)/2\right) = 0$$

Solving it for parameters $k_p = k_p(\omega,\alpha), k_i = k_i(\omega,\alpha),$ for $0<\alpha\le 1$ step 0.1 and $k_d = const$ we can obtain a general solution in the $(k_p, k_i, \alpha,)$ space.

Simulation results are presented on Figs. 3.,4.,with singular line $k_i = 0$.

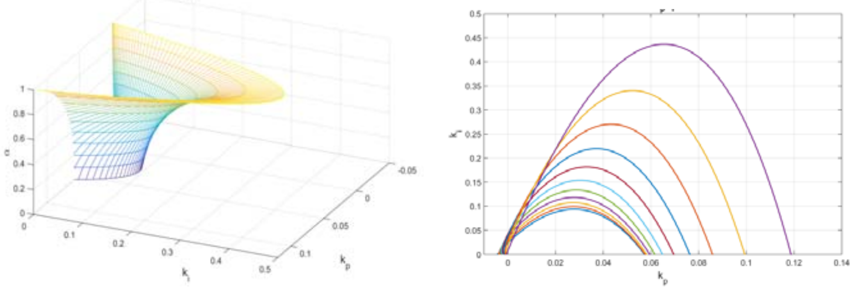


Figure 3. **a) 3D Stability regions b)2D Stability regions for** $\alpha=[0,1]$ **for** $\alpha=[0,1]$ **D-method** $\alpha = 0.7$

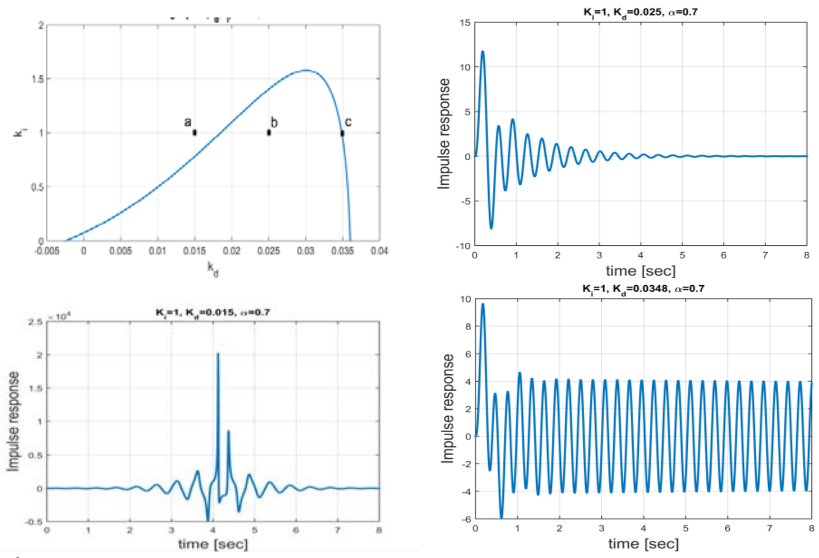


Figure 4**. a) Stability region testing b),c),d) Impulse response for points b, *c*, and *a***

When the stability regions are known the tuning of the fractional controller can be carried out.

Acknowledgment

Authors gratefully acknowledge the support of Ministry of Education, Science and Technological Development of the Republic of Serbia under the projects: TR33047(P.D.M.), TR35006(M.P.L.), TR33020 (T.B.Š).

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