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ON THE DIVERSITIES OF MULTIVARIABLE CONTROL SYSTEMS

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Abstract: Successful system control can`t be achieved without taking into account system nature. Present paper contain overview of control strategies for various multivariable systems. Regarding the mathematical model, order of system and eventual presence of dead time have high influence on the choice of method, which can ensure appropriate design of decoupler and controller. All in order to ensure desired dynamical behaviour of system. Due to that, it is very important to recognize if controlled object is mechanical system or industrial process. Systems with two inputs and two outputs has been illustrated here. Consideration has been supported and presented by appropriate simulations from relevant investigations.
Keywords: Decoupler, Multivariable system, PID Control

1. INTRODUCTION

In a multitude of different industrial processes, the conditions for their functioning and the constraints on the feasibility of their control, it is a very broad field of research for adequate control algorithms that can ensure their given dynamic behavior. Regarding to multivariable systems, additional problem is mutual coupling between inputs and outputs. It disturbs both tuning of controller and functioning of system. Due to that, design of decoupler and controller have equal importance. There are a lot of investigations referring to decoupler synthesis [1-5]. Also, many methods for controller tuning, that were proved in single input single output systems, naturally try to find its application in the multivariable systems, with or without integrated decoupler [6-11]. Below is given an overview of the typical (commonly used) industrial processes belonging to group with the two inputs and two outputs. As it shown, various kinds and combinations of decoupler and controller can be used for control of common plants in industry.

— Analysis of the control strategy for typical industrial processes

The possibilities of different control strategies, applied to the one mechanical system and two processes, regarding achieving their desired dynamical behavior, are shown in this chapter. Both kind of objects include their main features: mechanical system - high order and process - time (transport) delay.

— Electrohydraulic servo-system for structural testing

As represent of mechanical systems, electrohydraulic servosystem for structural testing was taken here. Aim of control system is to accomplish defined load (forces) to the cantilever beam. Desired dynamical behaviour is determined by intensity and character of the forces on the piston rods. They are controlled by flow rates through the servovalves. Mathematical model of this system has been experimentally derived in [12] and shown in (1).

$$G(s)=\frac{1}{\Delta(s)}\begin{bmatrix} g_{11}(s) & g_{12}(s) \\ g_{21}(s) & g_{22}(s) \end{bmatrix}$$

$$\begin{aligned} g_{11}(s) &= 2.926\cdot10^2 s^4 + 1.9152\cdot10^4 s^3 + 1.2667\cdot10^7 s^2 + 5.5825\cdot10^7 s + 4.7959\cdot10^9 \\ g_{12}(s) &= -3.8382\cdot10^4 s^3 - 1.7068\cdot10^7 s^2 - 8.3584\cdot10^7 s - 6.4967\cdot10^9 \\ g_{21}(s) &= -4.4533\cdot10^3 s^3 - 3.2461\cdot10^6 s^2 - 1.4362\cdot10^7 s - 1.2403\cdot10^9 \\ g_{22}(s) &= 2.506\cdot10^2 s^4 + 1.6229\cdot10^4 s^3 + 6.6134\cdot10^6 s^2 + 3.0476\cdot10^6 s + 2.4813\cdot10^9 \\ \Delta(s) &= s^5 + 1.2308\cdot10^2 s^4 + 6.993\cdot10^4 s^3 + 1.5098\cdot10^6 s^2 + 3.5504\cdot10^8 s + 8.2333\cdot10^{-6} \end{aligned} \tag{1}$$

It is fifth-order system without time delay. Cancelation of mutual coupling between two control loops was carried out using inverted decoupler. It was designed based on [1]. Having in mind pretty high order of system mathematical model, mentioned kind of decoupler was utilized as static. In order to avoid unnecessary additional dynamics, transfer function of the decoupler is simple gain. Its expression is given by (2) and (3), respectively.

$$D(s)=\begin{bmatrix} 1 & d_{12}(s) \\ d_{21}(s) & 1 \end{bmatrix} \tag{2}$$

$$\begin{aligned} d_{12}(s)\Big|_{s=0} &= \frac{-g_{12}(0)}{g_{11}(0)} \\ d_{21}(s)\Big|_{s=0} &= \frac{-g_{21}(0)}{g_{22}(0)} \end{aligned} \tag{3}$$

PID controller in general case, whose equation is shown in (4) and (5), has been design using pole placement method [13].

$$K(s)=\begin{bmatrix} k_1(s) & 0 \\ 0 & k_2(s) \end{bmatrix} \tag{4}$$

$$\begin{aligned} k_1(s) &= K_{p1}+\frac{K_{i1}}{s}+K_{d1}\cdot s \\ k_2(s) &= K_{p2}+\frac{K_{i2}}{s}+K_{d2}\cdot s \end{aligned} \tag{5}$$

Beside basic system (Example 1), the same procedure was performed on the two other perturbed models with 20% increased parameters (Example 2) and 20% decreased parameters (Example 3). They are given in [13]. Therefore, three similar mathematical models were investigated in order to show effectiveness of presented approach. Reference variables has been set as follows: sine function for first output and step function for second output. Responses are given in Figure 1., where is noticeable that P controller is the least sensitive to the model perturbations, i.e. model uncertainties, because it enables the best reference tracking.

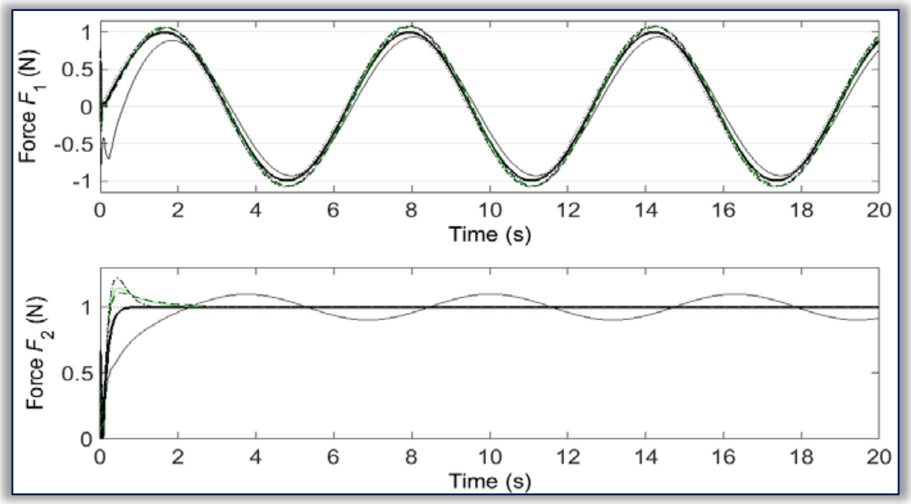

Figure 1. Forces on the cylinders (r_1 unit sine function, r_2 unit step function)
_____ Singer [12], _____ P, _____ $PI^{Ex.1}$, _._._ $PI^{Ex.2}$, _ _ _ $PI^{Ex.3}$ controllers, ... r_1,r_2 [13]

The same object (electrohydraulic servosystem) was researched in [14]. Static inverted decoupler was applied, but controller was designed in two ways. At first, using single relay feedback test for both decoupled loops, and second using Matlab toolbox (Simulink Control Design - PID Tuner) for controller tuning. Application of relay feedback test gives only P controller that enable good system performances, as it shown in Figure 2. PI and PID controllers cause system instability and due to that they weren't shown in Figure 2. Like in diagram in Figure 1 reference values are unit sine and step functions in order to make interaction between loops more obvious. Controller tuned using Matlab toolbox gives responses shown in Figure 3. P, PI and PID controllers are feasible in this case, but the best one is P controller again. It very successfully cancels mutual coupling and enable good reference tracking.

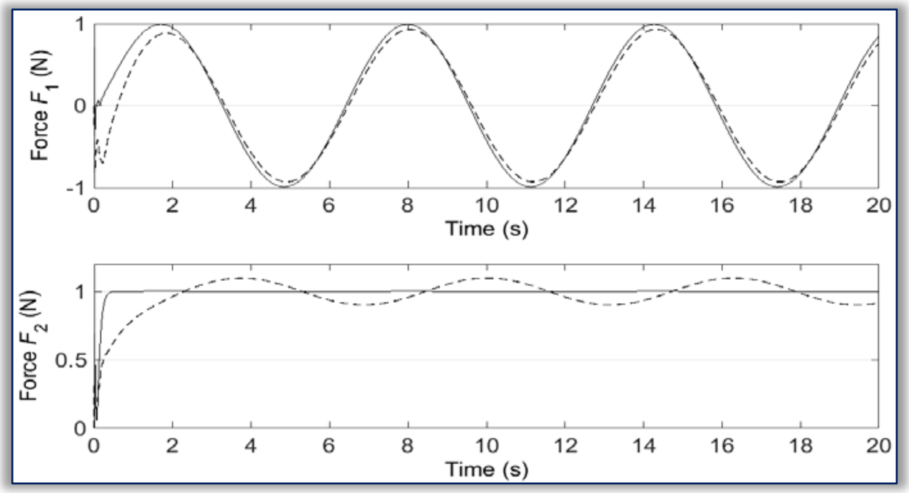

Figure 2. Forces on the cylinders (r_1 - unit sine function, r_2 - unit step function)
_ _ _ Singer [12], ____ Decoupling and P controller based on relay feedback test) [14]

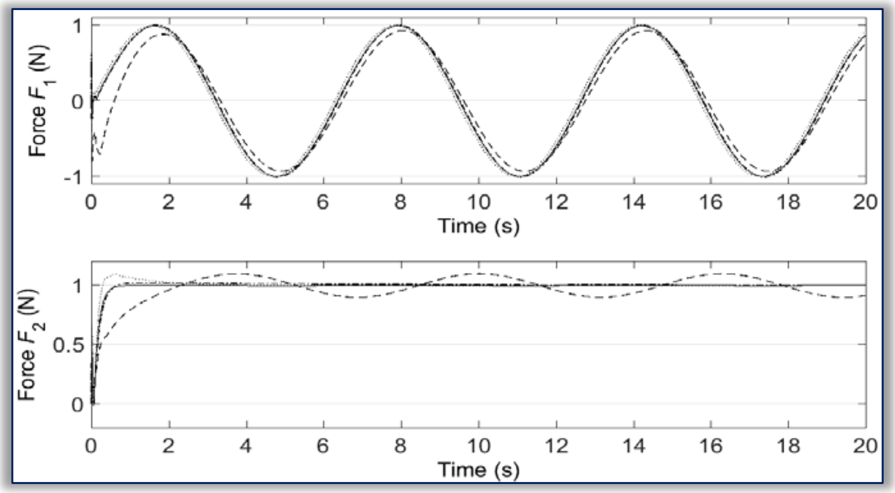

Figure 3. Forces on the cylinders: _ _ _ Singer [12], Decoupling control (____ P, ... PI, _._._ PID controllers based on Matlab toolbox) [14]

2. FLOW TANK

Level h and temperature t are controlled variables in this tank. Manipulated variables are flow rates Q_1 and Q_2 through the valves. Reference values are: h_r=1 m, and t_r=30 °C. Its transfer matrix follows (6):

$$G(s)=\begin{bmatrix} \dfrac{0,01}{63s+1} & \dfrac{0,01}{63s+1} \\ \dfrac{-0,15}{10s+1}e^{-3s} & \dfrac{0,4}{10s+1}e^{-2s} \end{bmatrix} \tag{6}$$

Two types of decoupler (direct and inverted) are compared here. They have same transfer function matrix given by (7), but difference is in direct and inverted way of conection [2].

$$D(s)=\begin{bmatrix} 1 & d_{12}(s) \\ d_{21}(s) & 1 \end{bmatrix}=\begin{bmatrix} 1 & \dfrac{-g_{12}(s)}{g_{11}(s)} \\ \dfrac{-g_{21}(s)}{g_{22}(s)} & 1 \end{bmatrix} \tag{7}$$

Simulated responses are shown in the Figure 4. In the presented example overshoot minimization was constraint in controller design. PI controllers are tuned using method in [6]. Taking into account the other indicators of process behaviour (rise time and settling time in both outputs), it is noticeable that control structure which contain direct decoupler is better.

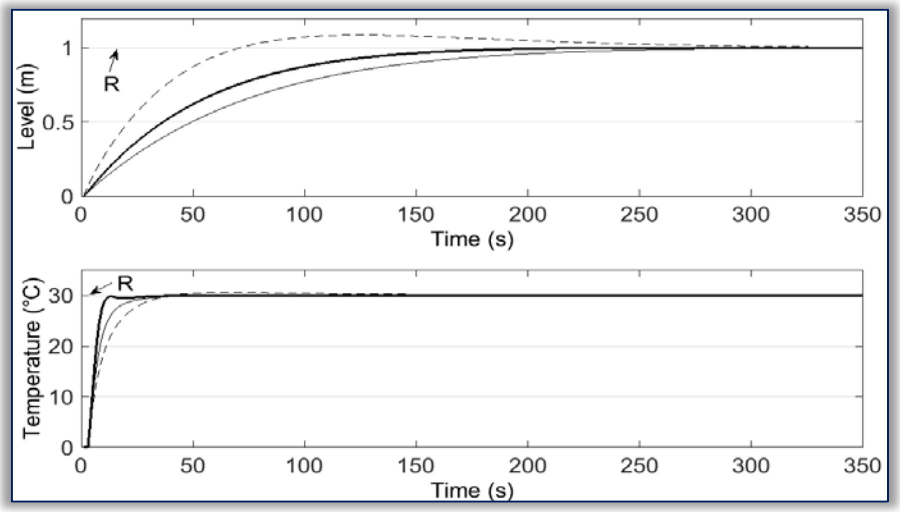

Figure 4. Comparative display of responses under two control strategies: _____with direct and _____ with inverted decoupler and _ _ _without decoupler, R - reference values [15]

3. BINARY DISTILLATION COLUMN (WATER - METHANOL)

Binary distillation column (water-methanol) is identified in [16]. Its transfer function matrix is given with (8). Controlled variables are: X_D – percentage of methanol in the distillate and X_B – percentage of methanol in the bottom products. Manipulated variables are: R – reflux flow rate and S – steam flow rate in the reboiler.

$$G(s)=\begin{bmatrix} \dfrac{12,8}{16,7s+1}e^{-s} & \dfrac{-18,9}{21s+1}e^{-3s} \\ \dfrac{6,6}{10,9s+1}e^{-7s} & \dfrac{-19,4}{14,4s+1}e^{-3s} \end{bmatrix} \tag{8}$$

Like in above mentioned examples, decoupler was designed in order to form two independent SISO (single input single output) systems. Direct decoupler was used because time delays mustn't be neglected contained in (8). D – decomposition method [7-10] was utilized for tuning PID controllers for separated loops, as it shown in (4) and (5). Criterion that contain minimizing of integral error was taking into account. Tuning procedure was carried out for two different additional constrains: first minimized overshoot and second faster responses. Simulated responses for these cases were compared with others from literature and shown in Figures 5. and 6, respectively. These diagrams prove that proposed method (Prodanovic et al. [7]) better satisfies specified conditions, without deteriorating other quality indicators of the system behavior.

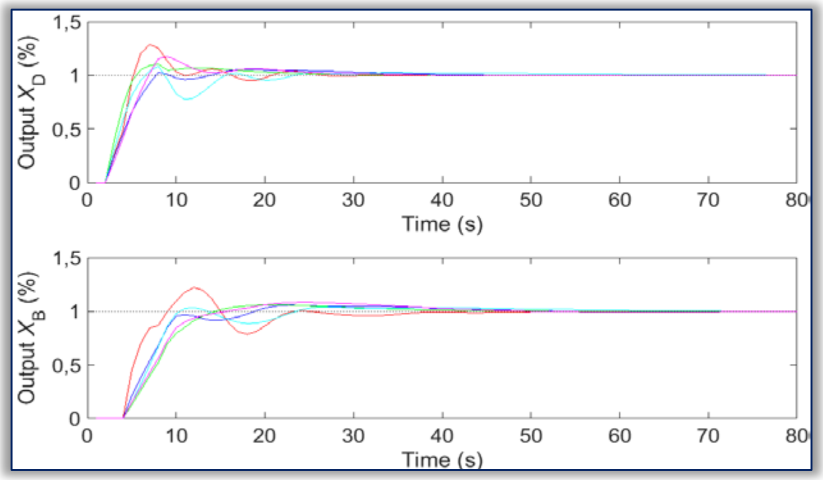

Figure 5. Wood/Berry distillation column responses (minimized overshoot)
_____ Atashpaz-Gargari et al. [11], _____ Prodanovic et al. [7], _____ Garrido et al. [3], _____ Morilla et al. [4],
_____ Wang et al. [5], ... Reference value

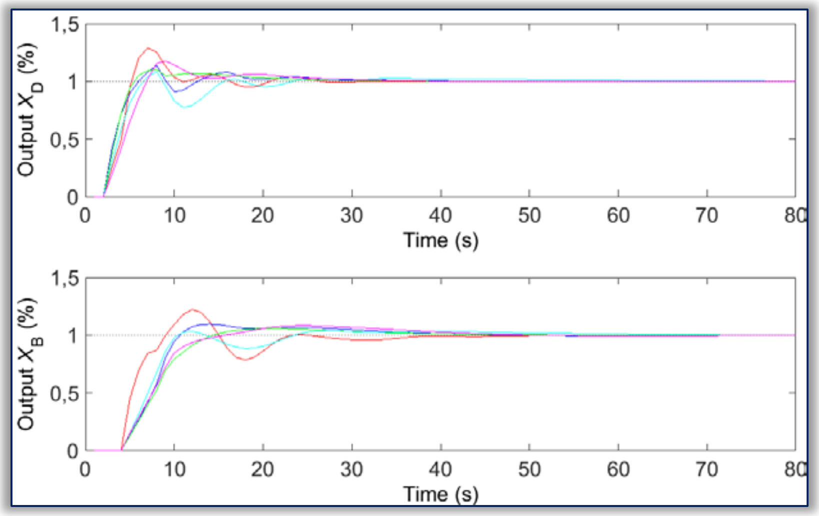

Figure 6. Wood/Berry distillation column responses (faster responses)
_____ Atashpaz-Gargari et al. [13], _____ Prodanovic et al. [7], _____ Garrido et al. [3], _____ Morilla et al. [4],
_____ Wang et al. [5], ... Reference value

4. CONCLUSIONS

There are presented various decoupler and controller design methods that can be applied to the particular objects. The complexity is much higher because of the different combinations between them. Some of them have aim to introduce as low as possible dynamic into control system, especially in mechanical systems. In the process industry, attention should be paid on the time delay. Decoupler effectiveness is indicated by level of influence of one control loop on the other. In other words, good decoupler prevent change in one response in the moment of changing of the other response. Control strategies are under following demands: increasing robustness to uncertainty, compensating mutual coupling, disturbance rejection and enabling as good as possible indicators of system behaviour. Therefore, mutual coupling cannot be solved using conventional methods that design controller for single loop. This problem is overcome with separately designed decoupler (like in present paper) or using controllers whose off-diagonal elements are not equal zero, i.e. contoller structure is changed. This overview lead to conclusion that derivation of universal rule or method is very difficult, but every object needs to be approached strictly with regard to its nature and the conditions it needs to fulfill.

Note:
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