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TWO-DEGREE-OF-FREEDOM CONTROL OF A SEMI-BATCH REACTOR PROCESS

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Abstract: *This contribution deals with controlling of semi-batch reactor used for chromium sludge regeneration process. A comparison of three process control approaches is presented. Usual PID controller without online identification (OI) and adaptive PID controller were adapted to semi-batch rector process in our previous studies. The new one - two-degree-of-freedom (2DOF) controller is developed for the same reactor control in this study*

Key words: *2DOF, temperature control, online identification, semi-batch reactor, polynomial method*

1. INTRODUCTION

Leather industry is perceived as a producer of pollutants in form of chrome-tanned solid waste. This waste is assuming to have great importance as a potential threat to human health, because it contains trivalent chromium (Cr III), which can oxidise to its hexavalent form (Cr VI) under various conditions. One of the numerous possible solutions of the chrome-tanned waste problem is its enzymatic dechromation.

A process of chromium waste recycling can takes place in batch or semi-batch reactors. This process releases huge amount of heat and thus the temperature control is necessary. The temperature profile during recycling operation usually follows three stages (Bouhenchir et al., 2010): (i) heating of the reaction mixture up to the desired reaction temperature, (ii) maintenance of the system at this temperature and (iii) cooling stage in order to minimize the formation of by-products. Any controller used to control the reactor must be able to take into account these different stages.

In the literature some papers have been published which discuss the control of a batch or semi-batch reactor. A global linearization control strategy was applied, with online state and parameter estimation for a polymerization reactor (Beyer et al 2008). However, the authors concluded that the implementation of the proposed method is still difficult due to the missing support of required mathematical functions. A two-degrees-of-freedom (2-DOF) decoupling control scheme was found as a satisfactory for multiple-input multiple-output processes with time delays (Liu, 2007).

This paper presents results of experiments obtained by simulations and control of the semi-batch process using PID controller without online identification, adaptive PID controller and pole placement 2 degree-of-freedom (2DOF) controller with compensator for second order processes. The paper is organised as follows. In section 2, the semi-batch reactor and 2DOF controller are described; section 3 presents simulation results and section 4 concludes the current work and suggests new areas for investigation.

2. METHODS SECTION

A controlled process is strongly exothermic. The change of the chromium sludge input flow rate serves as a manipulated variable. Detailed description of a batch process including mathematical model is given in previous work (Macků, 2003).

2.1 Pole placement 2 degree-of-freedom controller with compensator for second order processes

In this work, 2DOF controller was applied to calculate the optimal temperature trajectory to reach desired properties in minimum time.

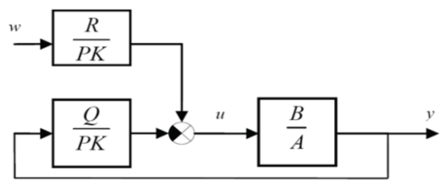

Fig. 1. 2DOF control loop

Feedback controller:

$$G_R = \frac{Q(z^{-1})}{P(z^{-1})K(z^{-1})} = \frac{q_0 + q_1 z^{-1} + q_2 z^{-2}}{(1+p_1 z^{-1})(1-z^{-1})} \tag{1}$$

Feedforward controller for a step reference signal:

$$G_F = \frac{R(z^{-1})}{P(z^{-1})K(z^{-1})} = \frac{r_0}{(1+p_1 z^{-1})(1-z^{-1})} \tag{2}$$

Characteristic polynomial of closed loop:

$$A(z^{-1})P(z^{-1})K(z^{-1}) + B(z^{-1})Q(z^{-1}) = D(z^{-1}) \tag{3}$$

2.2 Online identification method

Proportional-integral-derivate (PID) controllers have been the most commonly used feedback controllers in the past years. The popularity and widespread use of PID controllers attributed to their simplicity and robustness but it cannot effectively control some complicated or fast running systems since the response of a plant depends on only the gain P, I and D. Most of the PID tuning rules developed in the past years use the conventional methods. For example, the Ziegler-Nichols approach often leads to a rather oscillatory response to set-point changes because of system non-linearities and various uncertainties such as modelling error and external disturbances. These methods provide simple tuning formulae to determine the PID controller parameters. However, since only a small amount of information on the dynamic behaviour of the process is used, in many situations they do not provide good enough tuning or produce a satisfactory closed-loop response.

This was the reason to improve classical PID controller with parameters tuned according to Ziegler-Nichols from previous study (Novosad, 2007). Controller was equipped by recursive least squares identification based on ARX model which can be used for the discrete on-line identification of processes described by the following transfer function:

$$G(z)=\frac{B(z^{-1})}{A(z^{-1})}=\frac{b_1z^{-1}+b_2z^{-2}+...+b_mz^{-m}}{1+a_1z^{-1}+a_2z^{-2}+...+a_nz^{-n}}z^{-d} \qquad (4)$$

The estimated output of the process in the step is computed on the basis of the previous process inputs and outputs according to the equation:

$$\hat{y}_k=-\hat{a}_1y_{k-1}-...-\hat{a}_ny_{k-n} \\ +\hat{b}_1u_{k-d-1}+...+\hat{b}_mu_{k-d-m} \qquad (5)$$

where $\hat{a}_1,...\hat{a}_n,\hat{b}_1,...,\hat{b}_m$ are the current estimations of the process parameters. This equation can be also written in vector form, which is more suitable for further work:

$$\hat{y}_k=\Theta_{k-1}^T\cdot\Phi_k \\ \Phi_{k-1}=\left[\hat{a}_1,...\hat{a}_n,\hat{b}_1,...\hat{b}_m\right]^T \qquad (6) \\ \Phi_k=\left[-y_{k-1},...-y_{k-n},u_{k-d-1},...u_{k-d-m}\right]^T$$

The vector Θ_{k-1} contains the process parameter estimations computed in the previous step and the vector Φ_k includes output and input values for computation of current output y_k. This on-line identification is also used for 2DOF controller.

3. RESULTS SECTION

Identification of suitable models which accurately describe a batch reactor process is essential to successful optimization and control. In this study, on a semi-batch reactor by means of a simulation, 2DOF controller was tested and the effect of changes of the various parameters for a quality of the regulation process was monitored.

Figure 2 shows comparison of different methods of controlling semi-batch process. It can be seen that behaviour of adaptive PID controller and 2DOF controller are almost similar, both without oscillating and overshoots. In case of 2DOF, setpoint is reached faster for about 250 s. On the other hand, the performances in case of PID controller without OI is slightly worse with overshoot at the beginning of the process and followed by undershoot.

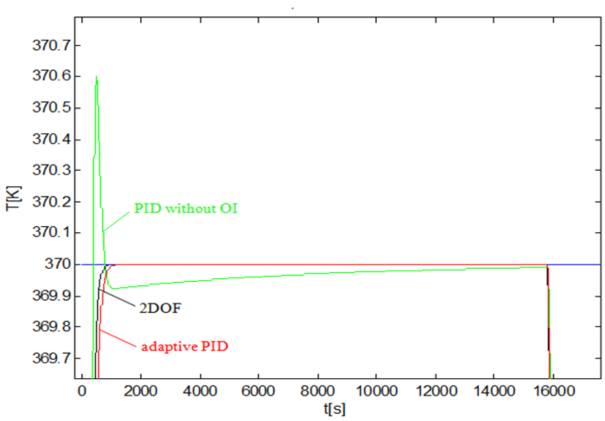

Fig. 2. Comparison of the temperature profiles – detailed view

Some differences in feeding can be also showed (Fig. 3). Maximum feeding (3 $kg.s^{-1}$) is reached in cases of controllers with online identification (adaptive PID and 2DOF). 2DOF controller provides the highest rates of the feeding at the beginning of the process and then feeding fall until the zero - feeding is stopped for about 150 s.

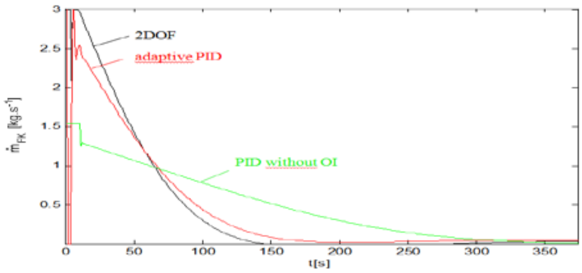

Fig. 3. Comparison of the feeding profiles at the beginning of the process

4. DISCUSSION SECTION

In this study, the 2DOF controller for the temperature control in a semi-batch reactor was demonstrated by simulation means. The implemented control strategy was also compared with two control strategies using PID controllers applied on the same process in the previous works (Novosad, 2007; Novosad & Macků, 2010). Based on presented results it can be concluded that proposed 2DOF controller can effectively overcomes problems with oscillating around the desired value in comparison with PID controller without online identification. The quality of the regulation process in cases of controllers with implemented online identification (adaptive PID and 2DOF) shows satisfactory results.

5. ACKNOWLEDGMENTS

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