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CONTROL OF CHEMICAL REACTOR FOR CONSECUTIVE REACTION II

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The second part of our paper deals with a simulation of the chemical reactor control using a self-tuning regulator. The behaviour of the control loop in the case of the disturbance in the set-point and in the manipulated variable has been investigated. Furthermore, the adaptibility of the self-tuning regulator with the parameters changes has been checked.

Introduction

This paper follows the communication[1] and presents results on the control of the chemical reactor (CSTR) for a consecutive reaction by the self-tuning regulator.

We consider the reactor as the serial connection of the nonlinear element

$$y_u = S_1 + S_2(u - p_o)^2 \tag{1}$$

and the linear element, described by difference equation (sampling interval T = 8 time units)

$$y(k) - 0.5846\,y(k-1) + 0.0608\,y(k-2) = 0.1320\,y_u(k-1) + 0.3441\,y_u(k-2) \tag{2}$$

The steady-state behaviour for different temperatures of the reaction mixture t_1 =

30 °C, t_2 = 20 °C and t_3 = 10 °C correspond to the curves (b), (a) and (c) in Fig. 1. The steady-state characteristic curve (a) is described by the equation

$$y_u = 0.375[1-(u-1)^2] \tag{3}$$

The parameters S_1 and S_2 were determined in such a way to trace the curves (b), (a) and (c) of real reactor characteristic (see Ref.[1]).

The reactor modelled by the equations (1) and (2) is described in our control algorithm (in the region of the operating point P_1) by the difference equation with differences of $u(k)$ and $y(k)$

$$\Delta y(k) + a\Delta y(k-1) = b_1\Delta u(k-1) + b_2\Delta u(k-2) + b_3\Delta u(k-3) \tag{4}$$

The on-line estimates of the parameters $\hat{a}$, $\hat{b}_i$ $(i = 1, 2, 3)$ are used for the calculation of the regulator coefficients

$$u(k) \doteq \delta^{-1}\left\{r_1\Delta u(k-1) + r_2\Delta u(k-2) + S_1[y(k) - w] + S_2[y(k-1) - w]\right\} \tag{5}$$

The quality of the control can be influenced by the penalty coefficient h, which is a component of the quadratic criterion.

The simulation of the operating point setting, the on-line identification and the control loop closing was described in the first part of our paper[1].

Furthermore, the results of the simulation calculations will be presented

1) for the plant regime change (e.g. for the change of the operating point position P_1 on the static characteristic curve (a));
2) for the flow disturbance (e.g. for the disturbance acting in the manipulated variable).

In the next part, the adaptation properties of the control algorithm will be checked:

1) for the temperature change of the reaction mixture,
2) for the property change of the input raw-material.

In conclusion the properties of the self-tunig regulator working in the region of the static characteristic curve with negative gain will be checked.

Change of the Operating Point Position

It is desirable to test the dynamic behaviour of the closed loop for the step change of the set-point. Step changes of the required value from w = 0.325 (the reactor in the operating point P_1 on the static characteristic curve (a) - Fig. 1) to

1. w = 0.37 (see response (1) in Fig. 2),
2. w = 0.385 (see response (2) in Fig. 2),
3. w = 0.225 (see response (3) in Fig. 2).

were made in the 15th control step.

The difference between responses (1) and (2) can be explained by the fact that the required value change $\Delta w_3 = -0.1$ is larger than $\Delta w_1 = 0.04$. The next

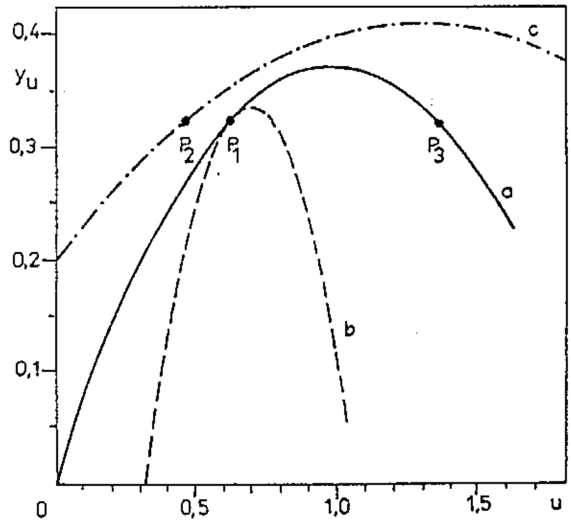

Fig. 1 Static characteristics of the CSTR model

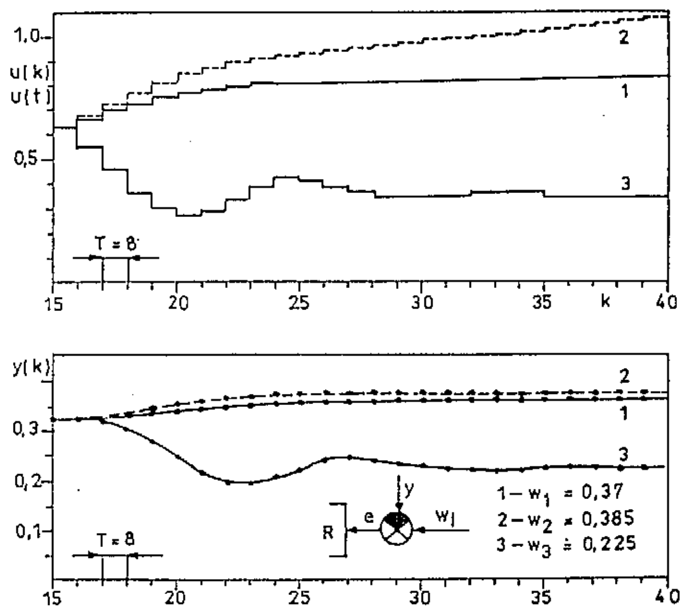

Fig. 2 Response to a step change of the required value

reason is that the reactor gain in the area of the steady-state characteristic curve is larger in front of the operating point P_1 in comparison with the reactor gain in the area behind the point P_1. In the second case (2), when the required value of the controlled variable is greater than the maximum, the manipulated variable is permanently increasing while the controlled variable is constant. This fact could be used for the operating point of the CSTR adjustement.

Influence of Disturbances in the Manipulated Variable

It is desired to test the dynamic behaviour of the closed loop for the step change Z_u of the manipulated variable changing the reactor input in the 15th control step.

Consider the following two cases
1. $Z_{u1} = +0.2$,
2. $Z_{u2} = -0.2$.

The manipulated and controlled variable - see Fig. 3. The monotonous elimination of the disturbance in the first case is again connected with the operating point motion in the area of the smaller gain in comparison with the second case.

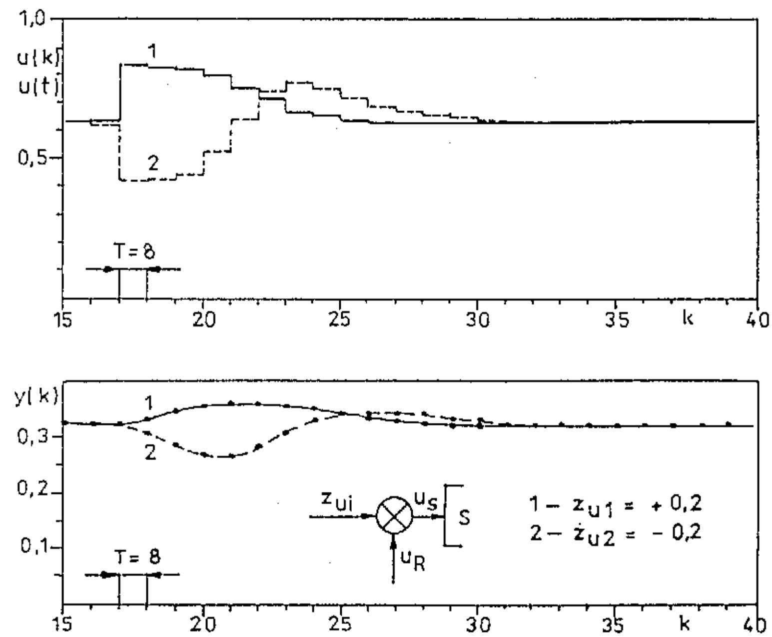

Fig. 3 Response to a step change of the manipulated variable

Adaptive Properties of the Control Algorithm for the Change of Parameters

The change of the CSTR parameters can be produced first of all by the change in the temperature of the reaction mixture or by the change in properties of the feed to the reactor. It can be expected that the changes of parameters have the character of a monotonous course which can be simulated by an exponential function.

Adaptive Properties of the Control Algorithm for the Changes in Reaction Mixture Temperature

Let consider the set-point control for $w = 0.325$
1) for change of parameters corresponding to the transfer from the steady - state characteristic curve (a) to (b) - see Fig. 1;
2) for change of parameters corresponding to the transfer from the steady-state characteristic curve (a) to (c) - see Fig. 1

The parameters S_1, S_2, p_0 in Eq. (1) are changed from the 15[th] control step following the equations

$$S_1(k) = S_{10} + z_{m1}(k)$$

$$S_2(k) = S_{20} + z_{m2}(k) \qquad (6a,b,c)$$

$$p_0(k) = p_{00} + z_{m3}(k)$$

where S_{10}, S_{20}, p_{00} are the initial values of parameters corresponding to the characteristic curve (a) - see Fig. 1 and

$$z_{m1}(k) = -a z_{m1}(k-1) + b\Delta S_{10}$$

$$z_{m2}(k) = -a z_{m2}(k-1) + b\Delta S_{20} \qquad (7a,b,c)$$

$$z_{m3}(k) = -a z_{m3}(k-1) + b\Delta p_{00}$$

The simulation of the parameters changes is ensured. by Eqs (6) and (7). In Eqs (7a,b,c) it is

1) $\Delta S_{10} = -0.04$; $\Delta S_{20} = -1.965$; $\Delta p_{00} = 0.3$
   the changes of parameters for which the steady-state characteristic curve (a) is converted to (b) and
2) $\Delta S_{10} = 0.04$; $\Delta S_{20} = 0.25$; $\Delta p_{00} = -0.3$
   are the changes of parameters for which the steady-state characteristic curve (a) is converted to (c).

The presented changes of parameters roughly correspond to temperature changes of ∓10 °C. It results from the function analysis of the real reactor (its steady-state characteristic). It is possible to set up the speed of the changes by means of coefficients a, b in Eqs (7a,b,c). The manipulated and controlled variable for two cases shown above and for a = - 0,9 ; b = 0,1 are given in Fig. 4.

It is evident that the results are very favourable (negligible changes of the manipulated and controlled variables). In the case of the transfer from (a) to (b) the tapering curve contributes to the increasing of the manipulated variable while the left shifting curve to the decreasing one. The dynamic behaviour is then influenced by the parameters change ΔS_{10} only. The same situation is seen in the case of conversion from (a) to (b).

The quality of the control is almost independent on the speed of the change. Even with the increasing speed e.g. for a $a \to 0$, $b \to 1$ the changes of u and y approach zero. This means that the results are better than in Fig. 4 for $a = -0.9$; $b = 0.1$. The reason is in that e.g. a step-change of the parameters corresponding to the step-conversion from (a) to (b) leaves the u-coordinate of the operating point P_1 almost without the any change.

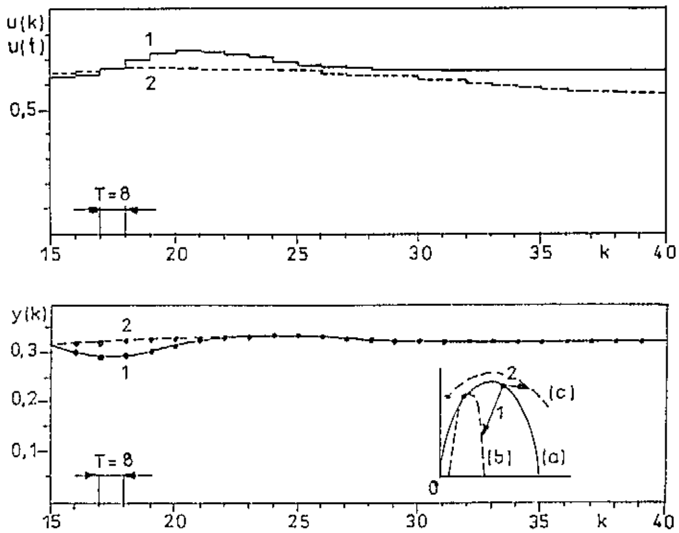

Fig. 4 Response to a change of the reaction mixture temperature

Adaptive Properties of the Control Algorithm for the Change of the Feed

In this case it is assumed that the changes of all three parameters (tapering, lowering and shifting) are not so close to the characteristics in Fig. 1. Owing to this fact the results need not be so favourable as in the previous chapter.

Figure 5 presents the manipulated and controlled variable for $\Delta S_{10} = 0$; $\Delta p_{00} = 0$; $\Delta S_{20} = -1.965$ e.g. for the tapering of the steady-state curve only. The coefficients $a = -0.9$ and $b = 0.1$. The controlled variable reaches negative values; its limitation produces a bad control results. Better results in manipulated and controlled variables can be reached in the case of the shifting or lowering of the steady-state characteristic curve only. The quality of the control strongly depends on the speed of the change. E.g. for $a = -0.6$; $b = 0.4$ the controlled variable reaches the limit values of ∓ 0.36 and the manipulated variable +1.27; - 0.44. For step-change (e.g. $a = 0$; $b = 1$) the control loop is not stable.

Properties of the Control Algorithm in the Area of the Steady-state Characteristic Curve with Negative Gain

The properties of the control algorithm were investigated for the same gain as given above with the following difference: the CSTR operates (Fig. 6) with input signal $u = 1.365$. In the course of first 10 steps, on-line identification is performed.

Then the control loop is closed and in the 17th step is introduced a disturbance in the manipulated variable $Z_u = 0.2$. Before the 17th control step the reactor behaviour corresponds to the system with positive gain (see the positive signs of the estimates $\hat{b}_j$).

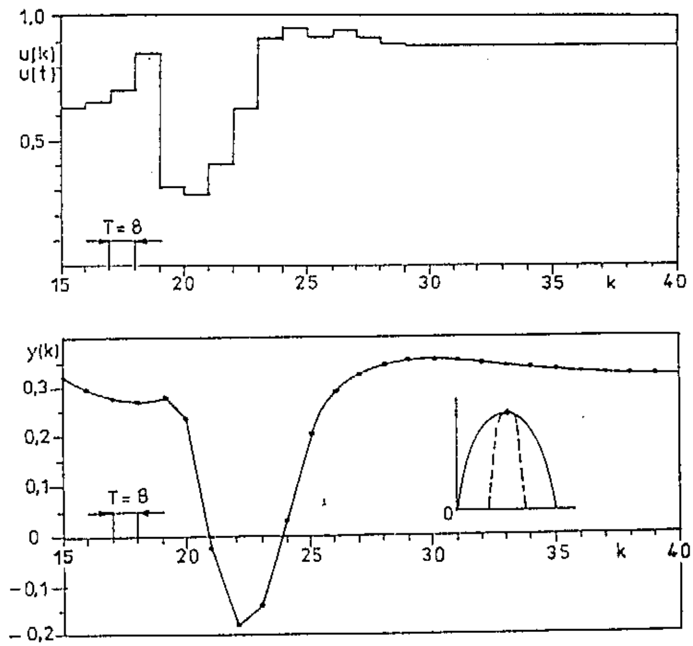

Fig. 5 Response to a change of the feed

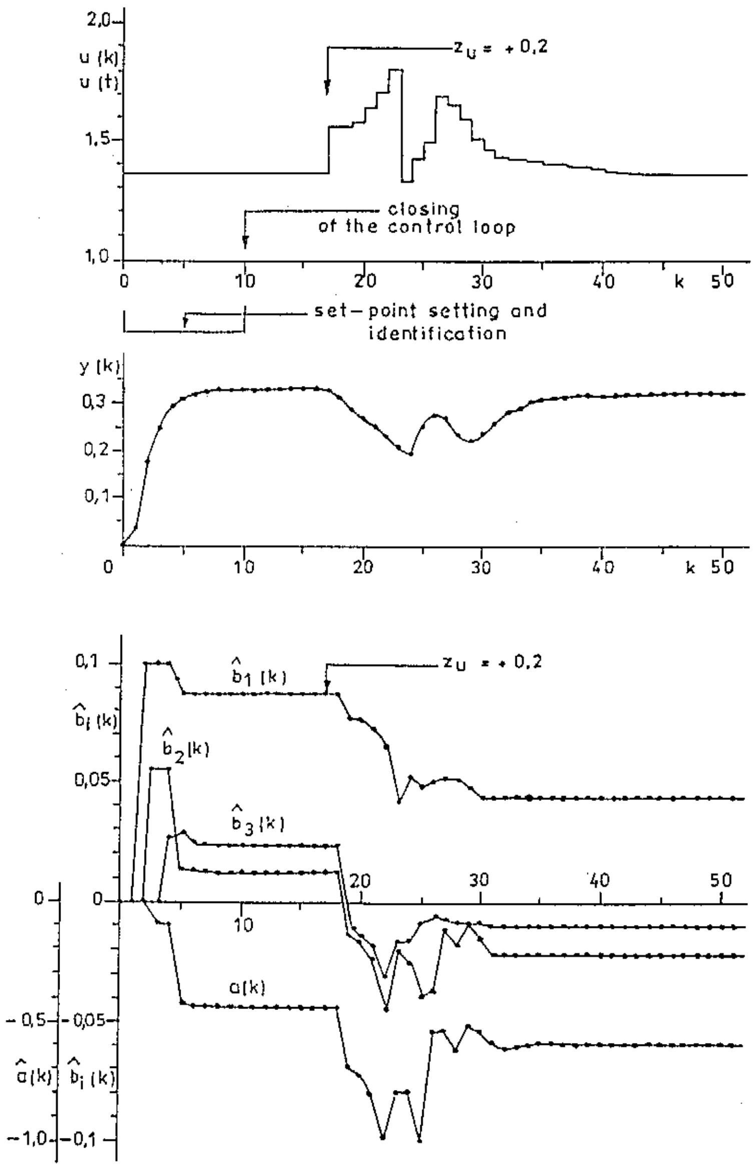

Fig. 6 Response and parameters courses in the area with negative gain

Beginning from the 17th control step the reactor goes to the region of the negative gain (see the signs of $\hat{b}_2(k)$, $\hat{b}_3(k)$). The time functios u and y are strongly oscillating; it is the result of the conversion from the positive gain area to the negative one. On the basis of these results, the CSTR would operate in positive gain area only.

Conclusion

This paper presents results of the suboptimal concentration control of the CSTR with self-tuning regulator. Regarding the parabolic character of the steady-state characteristics it is possible to operate essentially either in the positive or in the negative gain area. To reach reasonable control results, it is suitable to operate in the positive gain area only.

The tuning of the operating - point and the on-line identification are realized without problems. The closing of the control loop is strokeless, the set-point control is realized with zero - controlled variable deviation.

For the step-change of the required concentration value, the manipulated and controlled variable change monotonously or with damped oscillations. It depends on the size and sign change.

The disturbances influencing the manipulated variable are eliminated in approximately 12 control steps.

Adaptive properties of the control algorithm are very good, namely if the change of the steady-state characteristic curve is produced by a temperature change. In this case the character of the control is almost independent on the speed of the parameters change.

In conclusion, it can be said that the simulation results of the CSTR are favourable. It is therefore possible to expect a success in area of the control application.

References

1. Drábek O., Krejčí S.: This Journal.