Temperature control of the batch polypropylene Reactor by ADRC

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Abstract: A new control method called Active-Disturbance Rejection Controller (ADRC) is proposed for temperature control of a batch polypropylene reactor in this paper. This controller is mainly composed of three parts, i.e. “extended state observer” (ESO), input reference signal tracking-differentiator (TD) and a non-linear state error feedback (NLSEF) control law. The simulation results have shown that ADRC can obtain quite good performances with the process uncertain. As the control algorithm in DCS ADRC is developed and tested for a batch polypropylene reactor in a local Petro-Chemical plant. The experiment results have indicated that the controller can give much better dynamic responses than the other control algorithms conducted several years ago.

Key words: Polypropylene reactor, Temperature control, ADRC (Active-Disturbance Rejection Control)

1. INTRODUCTION

Batch polymerisation reactors are still extensively used to produce useful products, due to their production flexibility and similarity in principle to the laboratory reactors. To increase product quality and insure the reproducibility, it is necessary to improve the automation level of such processes. The dynamic characteristics of batch polymerisation reactors would considerably change with the progress of reaction because the reactors have strong non-linearity and the uncertainties caused by process raw materials, catalysts and so on. Therefore the control of the polypropylene rectors are very difficult in practice. In this case, it is important to design the Advanced Process Control system (APC) for the reactor control. The APC must be robust to the process non-linearity and uncertainty.

Several applications of adaptive controllers to the control of polymerisation process are reported (Embiricu.M,*et al*,1996). However, they need some assumptions for noise, disturbance and manipulated variables in order to estimate process model parameters. Recently a number of model predictive controllers which can treat constraints on manipulated variables and provide more economical operation have been reported. (Zoltan Nagy and Serban Agachi, 1997). But they can not consider the uncertainty of process parameters and the dynamics change caused by non-linearity.

In this paper, a new type of robust non-linear control strategy i.e. Active Disturbance Rejection Controller (ADRC) (Han 1998) is proposed to control the temperature of a batch polypropylene reactor.

The whole paper is organized as follows. The control problem is described in Section 2, section 3 is related to the design of the non-linear controller ADRC, including a simulation example. In section 4 the conducted experiments and results in the batch polypropylene reactor of Guangdong Petro-Chemical plant are presented..

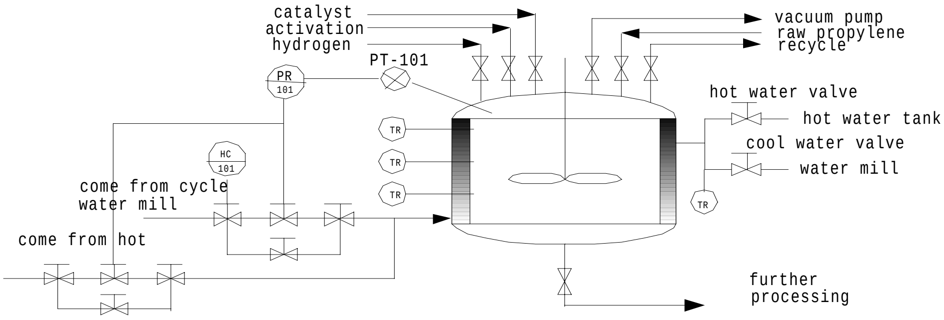

Fig.1. The sketch diagram of the batch polypropylene reactor

2. FORMULATION OF CONTROL PROBLEM

2.1 Process Description

The Fig.1 shows the sketch diagram of a batch polypropylene reactor that is under control. The batch stirred tank reactor is used to produce polypropylene. The operation of the whole process generally consists of the following steps:
As the initial step, the propylene, surfactants, initiators and monomer mixture are charged to the reactor. After this initial stage, the reaction mixture is heated to the desired temperature of polymerisation. At the third stage the polymerisation is going on, which generally will take about 3~4 hours. The last step is to cool down the reaction mixture to the temperature required for further processing,, then unload the all materials from the reactor.

2.2 Control Scheme

Since the whole process need heating and cooling respectively depending on what stage the process is in the split control scheme is applied.
When the controller output is between 0 and 50%, the controller is in cooling mode, the controller output is used to control the cooling water Sc valve. While the controller output is in the range of 50 and 100%, the controller is in heating mode, the controller is used to control the heating water valve Sh,.
When the heating water valve is open, the heating water is flowed directly into the jacket, the temperature of reaction mixture is then heated to nearly 40℃,at this point the reaction transits from endothermic to exothermic, correspondingly Sh is close and Sc is open, the temperature of the reactor is controlled to track the profile required by products quality via adjusting the flow of cooling water.

2.3.The process characteristics and control requirements

The polymerisation of propylene presents the following characteristics:

- ✧ The index of the product include: average molecular weight, molecular weight distribution (NWD), particle diameter, particle size distribution and porosity. A proper temperature would keep these index within the good range.
- ✧ The process is of batch type and the physical-chemical properties of the mixture are changing during the batch, thus the temperature control is fairly difficult.
- ✧ The disturbances often occur during the batch cycle. The process is of high nonlinear as far as the dynamic behaviour is concerned.

The control requirement imposed by the process engineer is that the maximum deviation of the temperature is within ±0.5℃ around the set point in order to ensure the good quality of the product. Therefore the previous feature of the process require advanced control method.

3. ACTIVE DISTURBANCE REJECTION CONTROLLER (ADRC)

3.1 The structure of ADRC

ADRC is developed by Professor Han in 1998. (Han 1998) In the following the scheme and control algorithm of ADRC is depicted.
In order to control a class of uncertain system:

$$y^{(n)} = f(y, \dot{y}, \cdots, y^{(n-1)}, t) + w(t) + u(t) \qquad (1)$$

where $f(y, \dot{y}, \cdots, y^{(n-1)}, t)$ represents uncertain function, $w(t)$ is an unknown disturbance , $u(t)$ is the control variable and y is the measurable state variable. The structure of non-linear active disturbance rejection controller is shown in Fig.2.

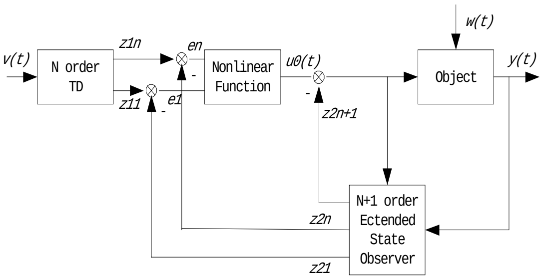

Fig.2 .The structure of ADRC

ADRC is composed of three parts: Tracking--Differentiator (TD), Extended State Observer (ESO) and Non-linear State Error Feedback (NLSEF) control law.
TD is a dynamic system where the response of the system can be designed for tracking the continuous and differential signal of the given input reference signal. Extended State Observer is used to estimate the state variables of the process and the estimation of the total disturbances. If the parameters and functions of the ADRC are properly chosen the controller is able to drive the state trajectory to the desired reference signal.

3.2 ADRC algorithm implementation

For a process of second order, the discrete algorithm of ADRC is as follows:

Tracking-Differentiator (TD)

The discrete form of TD (Han Jingqing and Yuan Lulin, 1999; Han Jingqing and Wang Wei, 1994) is

$$\begin{cases} x_1(k+1) = x_1(k) + Tx_2(k) \\ x_2(k+1) = x_2(k) \\ \qquad + Tfst(x_1(k), x_2(k), v(k), r, h) \end{cases} \qquad (2)$$

where T is sampling period, $v(k)$ is the input signal at time k, r determines the tracking rate, while h influences the filter effect when input signal is pollute by noise. The function of fst is defined as follows:

$$\delta = rh\,,\ \ \delta_0 = \delta h\,,\ \ y = x_1 - u + hx_2\,,$$

$$a_0 = \sqrt{\delta^2 + 8r\,|\,y\,|} \qquad (3)$$

$$a = \begin{cases} x_2 + y/h, |\,y\,| \le \delta_0 \\ x_2 + 0.5(a_0 - \delta)sign(y), |\,y\,| > \delta_0 \end{cases} \qquad (4)$$

$$fst = \begin{cases} -ra/\delta, |\,a\,| \le \delta \\ -rsign(a), |\,a\,| > \delta \end{cases} \qquad (5)$$

If we properly select the parameter r, TD can obtain the continuous and differential signal of the input by tracking the input reference signal $v(t)$.

Extended State Observer (ESO)

Defining non-linear function as

$$fal(x, a, \delta) = \begin{cases} |\,x\,|^a \ sign(x), |\,x\,| \ge \delta \\ x/\delta^{1-a}, |\,x\,| < \delta \end{cases} \qquad (6)$$

then the equation of ESO is

$$\begin{cases} e = z_1(k) - y(k) \\ z_1(k+1) = z_1(k) \\ \qquad + T[z_2(k) - \beta_{01} fal(e(k), a_1, \delta)] \\ z_2(k+1) = z_2(k) + \\ T[z_3(k) - \beta_{02} fal(e(k), a_2, \delta) + bu(k)] \\ z_3(k+1) = z_3(k) \\ -T\beta_{03} fal(e(k), a_2, \delta) \end{cases} \qquad (7)$$

Appropriately select the parameters of ESO: $\{a_0, a_1, a_2, \delta, \beta_{01}, \beta_{02}, \beta_{03}, b\}$, z_1 and z_2 can track the system state variables y and $\dot{y}$, while z_3 can estimate $f(y, \dot{y}, w(t))$. (Han J, 1995)

Non-linear State Error Feedback (NLSEF) control law

The final control law consists of the following equations:

$$\begin{cases} e_1 = v_1(k) - z_1(k) \\ e_2 = v_2(k) - z_2(k) \\ u_0 = \beta_1 fal(e_1, \alpha_1, \delta_1) \\ \qquad + \beta_2 fal(e_2, \alpha_2, \delta_1) \\ u(k) = u_0 - z_3(k)/b \end{cases} \qquad (8)$$

where e_1, e_2 is error and derivative of error between the outputs of TD and system output, b are modulation coefficient of the function $fal(e, \alpha, \delta)$. As a matter of fact, $f(y, \dot{y}, t) + w(t)$ is considered to be the extended state variable of uncertain system. If z_3 successfully converges to $f(y, \dot{y}, t) + w(t)$, it is possible to realize the state feedback and model, external disturbance compensation. If the parameters and function of the ADRC are suitably chosen, the system tracking,, regulation and stability can be guaranteed and the control variable $u(t)$ is able to drive the state trajectory to the desired reference signal.

3.3 Simulation example

Assumed a time variable system is as follows:

$$\begin{cases} \dot{x}_1(t) = x_2(t) \\ \dot{x}_2(t) = sign(\sin t) + u(t) \end{cases} \qquad (9)$$

The reference signal is a square wave the amplitude of which is 5 and the frequency is 0.1 Hz. To control the output of the system for tracking the reference signal, ADRC is applied to the system as shown in Fig.2, The parameters of ADRC are tuned as follows:

$$\{r, h, T, a_0, a_1, a_2, \delta, \beta_{01}, \beta_{02}, \beta_{03}, \beta_1, \beta_2, \alpha_1, \alpha_2, d, b\}$$
$$= \{10, 0.01, 0.01, 0.0.5, 0.25, 100, 65, 80, 80, 300, 0.75, 1.25, 0.1, 1\}$$

The control performance was studied by simulation and the results are presented in Fig 3.a). From the figure, it can be observed that the algorithm can give good results for the non-linear time variable process.

If the process is changed as follows:

$$\begin{cases} \dot{x}_1(t) = x_2(t) \\ \dot{x}_2(t) = 15sat(\cos t) + u(t) \end{cases} \qquad (10)$$

Keep the parameters and control scheme unchanged , Fig.3.b) illustrates the simulation result. Compare Fig.3.a) with Fig.3.b), it can be seen that the process response is almost the same, thus proving that ADRC is robust for the process change.

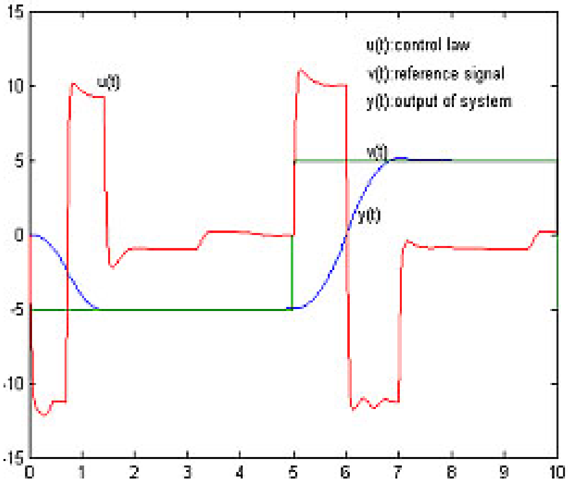

Fig. 3.a) Simulation results for system (9)

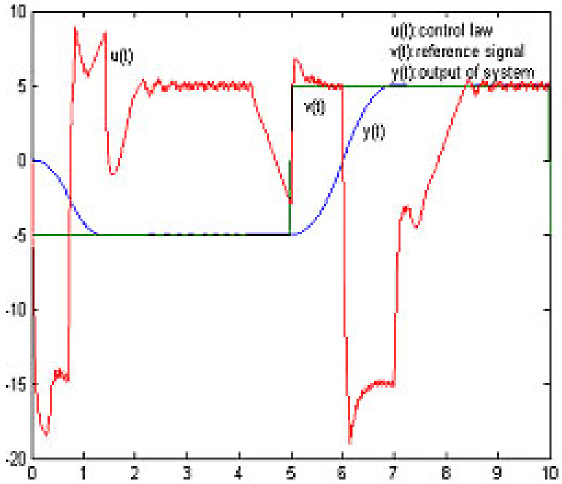

Fig. 3.b) Simulation results for system (10)

4. EXPERIMENTAL RESULTS

To verify the performance of the control based on ADRC, the tested reactor is controlled by a DCS system. ADRC control algorithm is programmed and inserted to the configuration software of DCS for the temperature control of the batch reactor. To ensure operating safety of the plant, an AUTO/MAN switch is programmed in the DCS configuration and monitoring software, When the switch is in AUTO, the plant is controlled by ADRC, while switch is to set to MAN, the plant is controlled by PID (Actually the reactor is controlled by the operators in heating stage).

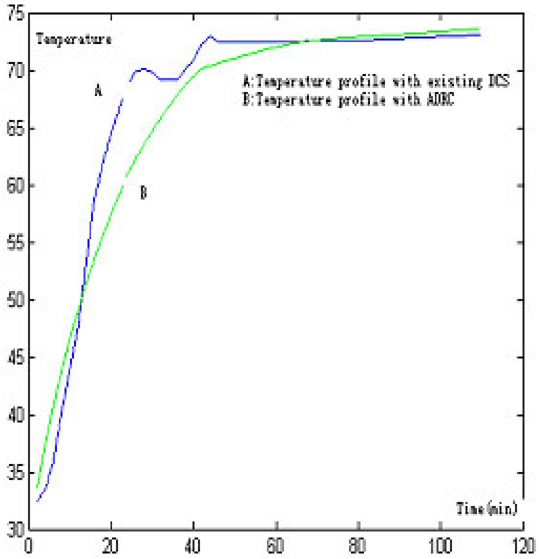

Fig.4 Responses of the temperature control in the batch reactor

In Fig. 4, the curve A shows a typical actual temperature response by PID in the rising stage of temperature. (Actually the process is manipulated by skill operators because conventional PID controller can not control the process well). Here it is shown that the temperature response is somewhat oscillated and has a little overshoot. One of the experimental result with ADRC as control algorithm is shown as Curve B. Comparing the two curves A and B it is easy to find the control performance by ADRC is obviously improved . The commissioning of the control test was lasted for nearly three month. ADRC performed fairly well in this period. Now the operating engineers and operators have completely accepted the control strategy.

5. CONCLUSION

In this paper a new robust non-linear controller ADRC is implemented for the temperature control of a batch polypropylene reactor. The Extended state observers are used to implement the state estimation and realize state feedback for the external disturbance compensation. The non-linear control law is to drive the state trajectory to the desired reference signal. ADRC has been programmed and tested in a chemical plant for controlling the reactor temperature. Both the simulation and experimental results have shown that the performance of ADRC is satisfactory. Comparing it with other control algorithms, the outstanding feature of ADRC is that it is robust to process variation and non-linearity. Besides that, it doesn't require the accurate process model. That will provide a new and hopeful choice for controlling the difficult processes in industries.

REFERENCES

Embiricu M, et al (1996), A Survey of advanced Control of Polymerization Reactors, *polym. Eng.Sci*. **vol. 36**,pp433-438

Han Jingqing and Yuan Lulin (1999), The Discrete Form of Tracking-Differentiator, *J. Sys. Sci & Math. Scis*, **vol.19**, pp268-273, (in Chinese)

Han Jingqing and Wang Wei (1994), Nonlinear Tracking-Differentiator, *J. Sys. Sci & Math. Scis*, **vol.14**, pp.177-183, (in Chinese)

Han J (1998). Active Disturbance Rejection Controller and It's Application, *Control and Decision*, **vol.13**, pp19-23, (in Chinese)

Han J (1995). The Extended State Observer of a Class of Uncertain Systems, *Control and Decision*, **vol.10**: pp85-88 (in Chinese)

Zoltan Nagy and Serban Agachi (1997), Model Predictive Control of a PVC batch reactor, *Computer & chem. Eng.*,**vol.21**,No.6,pp571-591