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A Valve Stiction and Time Delay Control Method Based on Fuzzy Smith Internal Model Principle

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In the process of chemical production, the phenomenon of control valve's stiction is very common. This phenomenon causes control loop oscillation and has a negative effect on the quality and cost of the product. Time delay exists widely in industrial process, which leads to the variation of the dynamic response of the system. In this paper, taking the stiction model proposed by Kano as an example, then puts forward a method of smith internal model control based on fuzzy theory. This paper try to solve the stiction problem by controller designed. This control method can realize the parameter self-tuning and overcome the stiction. Simulation results show that the method proposed can effectively overcome the loop oscillation and improve the performance of the system.

1. Introduction

Valve is one of the most important terminal units in today's industry. It has been widely used in the chemical industry and other fields. In the development of control valve, its performance is closely related to the whole production process. Good performance of the control valve can improve production efficiency and reduce energy consumption and save raw materials and improve safety. However, if there are some faults in the valve such as stiction, it will seriously affect the performance of the entire control process. Therefore, the modelling and compensation control of stiction problem are particularly important. Time delay is one of the most important characteristics of the system quality in the industrial process. The system can be improved by improving the control method of the valve positioner. Therefore, this paper designs a control method which can overcome the stiction characteristic of control valve and industrial time lag, which is helpful to optimize the industrial process and improve the production efficiency.

The modelling of stiction can be divided into mechanism modelling and data-driven modelling. From the classical physics and Newton's law, the mechanism model needs a large number of parameters, such as stem mass, spring coefficient and etc. These parameters are difficult to be accurately identified and have many uncertainties. Data-driven modelling has been widely used in recent years due to its less parameters and less computation. Stenman et al. (2003) presents a single parameter model firstly, but the output of the valve is a ladder, which does not conform to the actual situation. Choudhury (2004) puts forward a two-parameter model, which makes the model of the regulating valve closer to the reality. Kano et al. (2004) proposed an improved two parameter model, that the S and J parameters and the valve friction. These models mentioned previously are widely used. Aiming at the problem of stiction in control valve, Kayihan et al. (2000) designed the nonlinear controller that is used to compensate for the valve stiction, but the effect was not ideal and it required a lot of valve a priori knowledge. Hagglund et al. (2002) proposed the Knocker method, it added an additional compensation signal in the loop controller output signal. The compensation signal consisted of a constant amplitude, width and time interval of the pulse sequence. But the method took the valve's frequent actions as the cost. Srinivasan et al. (2008) pointed out that the parameter setting of the Knocker compensation signal in the original Hagglund method was rough, and the compensation effect was not optimal. He put forward the detailed parameter setting method. The first step was measuring valve friction nonlinear strength, then adjusted the parameters of the compensator according to the nonlinear strength. It

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can decrease fluctuation range of the loop output. However, this approach would also lead to intense movement of the valve rod then speed up the wear and tear of the valve. Srinivasan used a two-step method, using the outputs of the position loop valve as the basis for the design of compensation signal, but need steady knowledge of loop oscillation, and not allowed to change the object set value. Junlin Han et al. (2010) proposed an improved PI control method and PI fuzzy control method, which effectively overcame the system loop oscillation, but did not take into account the effects of time delay on the system. At present, few scholars solved the stiction problem from the point of view of controller design.
In this regard, this paper proposes a control method based on fuzzy principle, it combines internal model and fuzzy principle to self-tuning parameters, and overcome the stiction problem. Then designs smith controller which solves the problem of time delay and effectively improves the system performances when model mismatch. This paper uses the model by Kano to represent the stiction characteristic of the control valve. Finally, by simulation the method can effectively overcome the oscillation caused by the stiction characteristic and improve the stability and rapidity of the system. It can provide a method to overcome the stiction problem by designing a controller.

2. Valve model

Flow control valve is an important device in the industrial process, which mainly consists of actuator and valve body. According to the implementation of the energy used, valves are divided into pneumatic, electric and hydraulic. In this paper, we mainly discuss the pneumatic actuator control valve. The transfer function of the valve's dynamic process is usually described by Eq(1):

$$G_v(s) = \frac{K_v}{T_v s + 1} e^{-s\tau_v} \tag{1}$$

When the control valve is used for a period of time, there will appear stiction phenomenon as Figure 1.As shown, the output of normal control valve should be the linear l. Because of stiction characteristics the output will not be linear with the input. When the stem begins to move, it acts as two steps. Firstly, the stem are sticking. Secondly, the stem jumps suddenly. This phenomenon affects the control valve adjustment performance. When the control valve is studied, a model is usually required to describe the stiction properties. Kano et al. (2004) give the block diagram of the valve static friction model. The model clearly describes the stiction problem and can be applied to deterministic and random events. It is widely used in the research of control valve.

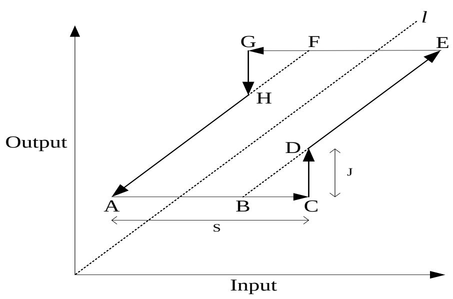

Figure 1: Control valve input and output

In summary, this is a valve based on Hammerstein model. This model has linear part and nonlinear part, the linear part is as a first-order model and time delay and nonlinear part is the stiction model proposed by Kano.

3. Principle and design of controller

3.1 Fuzzy principle

Fuzzy control is a kind of science and technology from the field of fuzzy mathematics, computer science, artificial intelligence, knowledge engineering and other disciplines. It is different from the traditional control, it need not know the mathematical model of the control object, and its core is the intelligent fuzzy controller. It changes the physical quantity of the actual measurement into the fuzzy subset of the linguistic variable universe. Fuzzy reasoning is called a database, and its output subset is determined by the state of the system. Clarity is the process of transforming the fuzzy control quantity obtained by fuzzy inference into the output control quantity.

3.2 Control system

The internal model control system and the smith predictor are combined to improve the performance of the system. The system structure diagram is shown in Figure 2.

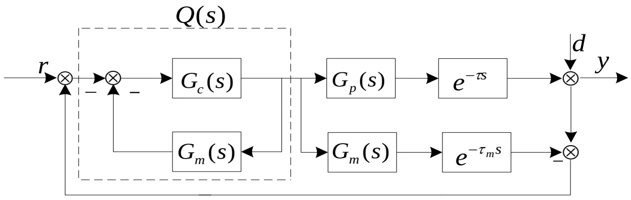

Figure 2: Structure of IMC-Smith

Using fuzzy principle combined with internal model controller achieves the self-tuning parameters, which improves the accuracy of the system and eliminates of oscillation caused by stiction. Establish control system as shown in Figure 3.

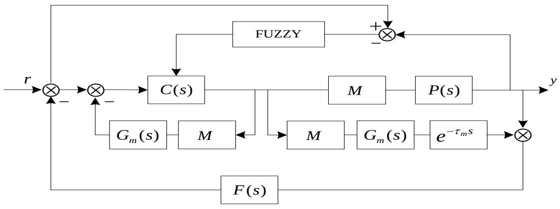

Figure 3: Structure of control system

The C(s) is the equivalent of the feedback controller, P(s) is the mathematical model of the controlled object of the extra time delay, and M is control valve stiction model. The C(s) is modified by fuzzy controller to realize parameter λ. The correction formula is Eq(2)

$$\lambda = \lambda_0 + \Delta\lambda \quad (2)$$

The membership function is shown in Figure 4.

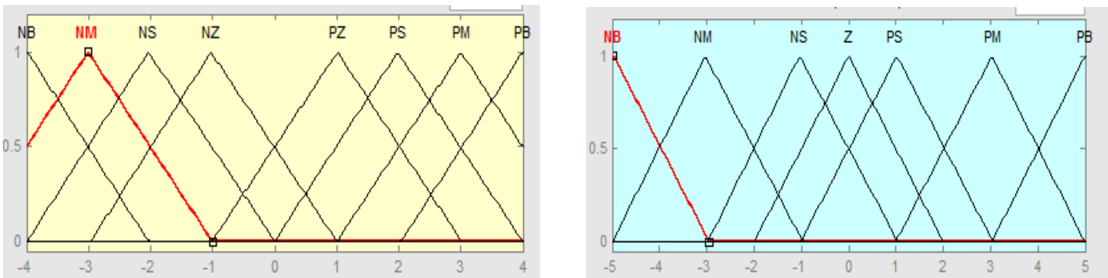

Figure4 Membership function of E and Δλ

Table 1: Rules of fuzzy control

E and EC	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	ZO
NM	PB	PB	PM	PS	PS	ZO	ZO
NS	PB	PM	PM	PS	ZO	ZO	NS
NZ	PB	PM	PS	ZO	ZO	NS	NM
PZ	PM	PS	ZO	ZO	NS	NS	PB
PS	PS	ZO	ZO	NS	NS	NM	NB
PB	ZO	NS	NS	NB	NB	NB	NB
PM	ZO	ZO	NS	NS	NM	NB	NB

4. Simulation

4.1 Model

Firstly, the model of the valve is established. Taking the HA1D type pneumatic control valve as an example. The valve characteristic can be expressed as a common first order inertial delay object in industry. Regulating valve characteristic transfer function as shown in Eq(3).

$$G(s) = \frac{1.1}{2.33s+1}e^{-10s} \tag{3}$$

In MATLAB, according to the stiction model flow chart by Kano, we achieve the establishment of control valve model by S documents. The sine signal is used as the input signal to test its sine response, such as Figure 5. The horizontal coordinate is the time and the amplitude of the sine signal is the sine signal. We can obtain the OP-MV characteristics of the valve too. The horizontal axis is values of the input signal for the controller and the vertical axis is the output signal of the valve after the value of the model.

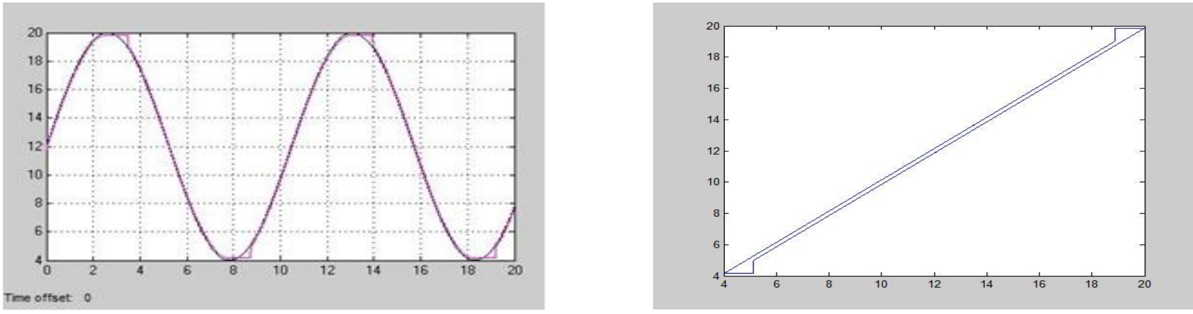

Figure 5: Sinusoidal response and OP-MV

From the graph, it can be known that the model we used is more close to the actual characteristics of the control valve, and it is practical.

4.2 Control system

The PI controller is shown in Eq(4). K_c is 1.32 and T_i is 1.22s.

$$C(s) = K_C\left(1+\frac{1}{T_i s}\right) \tag{4}$$

Taking into account the actual control system model is difficult to match with the mathematical model, so we need a simulation test when it mismatches the model in the fuzzy Smith internal system. In this control system, a step signal with a size of 10 is entered, and the simulation time is 500 s. First, when the model is matched, the parameters of the controller are adjusted according to the output of the system, until the control effect is the best. Observed response curves, as shown in Figure 6 "no-M"(no-mismatch). Then the following three kinds of situations are simulated.

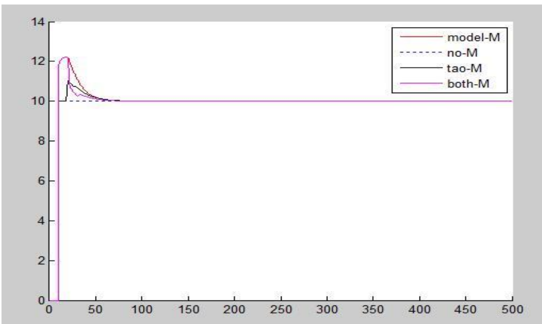

Figure 6: Step response

(1) When the time delay is matched, the first order function model does not match: take K=0.9,T=2.25, observe the response curve, as shown in Figure 6, "model-M";

(2) When the first-order function model is matched, the time delay does not match: the time delay term coefficient $\tau = 12$, the response curve is observed, as shown in Figure 6, "tao-M".

(3) When they are all mismatched, the parameters are put as mentioned above, the response curve is observed, as shown in Figure 6, "both-M".

It can be shown from Figure 6 that when the model is not matched with time delay, the system will have a certain overshoot, but soon it will be stable. It can be known that the method can guarantee the stability of the system under the condition of model mismatched. In the fuzzy internal model smith system, considering the model and time delay mismatched. The parameters are as mentioned above, assuming the valve don't appear stiction at the beginning, then do not add stiction model. Adding a size of 10 step signal as the test signal, according to the output of the controller parameters and fuzzy rules, adjust the system's parameters until the output is stable. Then the stiction of the system was simulated with the stiction model added, in which the parameter S was 8 and J was 4. Then observe the system output, and compare with PID control method. It is shown as Figure 7.

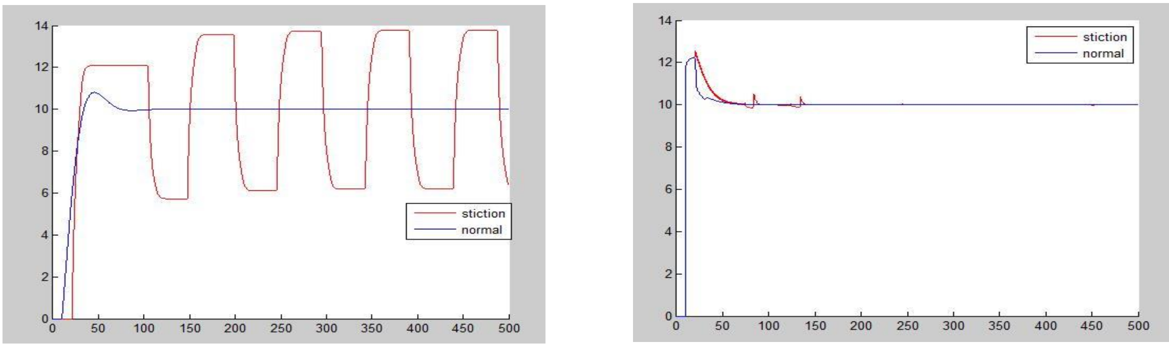

Figure 7: Step response of PID and FSIMC

4.3 Analysis

Figure 7 shows that when the system appears stiction problem, in the traditional PI control method, system appears oscillation obviously. In the FSIMC control method, system begins to appear small amplitude oscillations, but then the system goes into a stable state with no obvious oscillation. The FSIMC method is more rapid and it has better dynamic performance with no obvious oscillation, the system is more stable. For the control valve, valve stem has no longer frequent action, it can improve the service life of the valve control. Although the method produces a little overshoot, it is allowed for improvement in the degree of rapidity and stability.

In the chemical process, the smart valve positioner will controll the flow of liquid by the opening of the valve, so that the process achieves the production requirements in a timely manner. The rapid response of the system is conducive to the adjustment of the liquid flow which can help the system to meet the requirements of industrial production. If the valve can not take timely response, not only will cause industrial production process behind the industrial requirements of the target, and even there are security risks.

At the same time, the stability of control system output also accounts for a large proportion in the production process. If the output of the system is not stable enough, it will lead to low production efficiency and be not conducive to precise control of the production process, then increase the cost virtually and reduce the economic benefits. Security problems may arise if the output is substantially unstable. The rapidity and stability should be taken into account. According to the above analysis, the smith internal model control method based on the fuzzy principle has good performances on the dynamic response and steady state, which can satisfy the requirement of rapidity and stability. And it is an effective control method.

4. Conclusions

In this paper, the fuzzy principle and the internal model smith predictor are combined to form a fuzzy Smith internal model control method. The method is used to solve the stiction problem. The simulation results show that the fuzzy Smith internal model control method has better dynamic and static performance. For the chemical process, the method can give consideration to both rapidity and stability, which provides a way to overcome the stiction characteristics by designing a controller of the valve in the chemical process.

References

Chen, S.L., Tan K.K., Huang S., 2008, Two-Layer Binary Tree Data-Driven Model for Valve Stiction, Ind. Chem. Res., 47(8), 2842-2848.

Choudhury M., Thornhill N. F., Shah S.L., 2004, A Data-Driven Model for Valve Stiction, Control Engineering Practice, 13(5), 641-658.

Edgar C.R., Postlethwaite B.E., 2000, MIMO Fuzzy Internal Model Control, Automatica, 36(6), 867-877.

Gaicia C.E., Morari M., 1982, A Unifying Review and Some New Results, Ind. Eng. Chem. Proc. Dev, 21(2), 308-323.

Hagglund T., 2002, A Friction Compensator for Pneumatic Control Valves, Journal of Process Control, 12, 897-904.

Han J, Wang S., Xie L., Zhou M., 2010, Research on Control Method to Overcome the Stiction Characteristic of Valve, Computers and Applied Chemistry, 27(1), 68-72.

He Q.P., Wang J., 2007, A Curve Fitting Method for Detecting Valve Suction in Oscillating Control Loops, Ind. Eng. Chem. Res., 46(13), 4549-4560.

Kano M., Maruta H., Kugemoto H., Shimizu K., 2004. Practical Model and Detection Algorithm for Valve Stiction, 7th IFAC Symposium on Dynamics and Control of Process Systems, Cambridge, USA, 37(9), 859-864, doi:10.1016/S1474-6670(17)31917-1.

Kayihan., F., Doyle J., 2000, Friction Compensation for a Process Control Valve, Control Engineering Practice, 8, 799-812.

Srinivasan R., Rengaswamy R., 2005, Suction Compensation in Process Control Loops: A Framework for Integrating Suction Measure and Compensation, Ind. Eng. Chem. Res., 44, 9164-9174.

Stenman A., Gustafsson F., Forsman K., 2003, A Segmentation-based Method for Detection of Stiction in Control Valves, International Journal of Adaptive Control and Signal Processing, 17(7-9), 625-634.