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Oscillation Compensator using a new Controller PI-Fuzzy Control for Pneumatic Stiction Valve

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Abstract: *Static Friction is a very general reason for oscillations in control valves in the process industry. Most of the oscillation problem due to the nonlinearities as the stiction problem producing the limit cycle leading the increase of variability in the process. Stiction problem emerging in pneumatic valve due to the ages leads the oscillation steady state response. In this work, a review and evaluation of an existing improved method for Stiction compensation is undertaken. The existing method reduces variation in process variable and valve stem movement. Then a new method is developed to cater for the limitations observed during review and evaluation. This method uses PI-Fuzzy applied to remove presence of oscillation during close-open valve process. The PI Fuzzy control is a nonlinear control method which eliminates the Sticky valve. The performance of the new approach is compared to that of the improved stiction compensation. The superiority in performance of the proposed PI fuzzy controller compensators is demonstrated through simulation in Simulink/MATLAB.*
Keywords: *Stiction, oscillation, control valve, PI fuzzy*

I. Introduction

Most of the oscillation problem due to the nonlinearities as the stiction problem producing the limit cycle leading the increase of variability in the process. Oscillation problems also can be generated by the presence of deadband and backlash. The corresponding input-output characteristic can be altered by the presence of nonlinearities factor in fig 1. Deadband and stick band as static part are described with S and J expresses the slip jump.

Detection of the stiction presence is investigated in control system by identifying some variable such controller output (OP) and controlled variable (PV) [1]. Furthermore the quantification for stiction is also observed [2] in order to obtain the proper schedule to perform maintenance once the stiction is detected commonly every 6 months and 3 years. The control method to compensate the presence of oscillation is developed to get a desirable output performance by removing oscillation without regular maintenances.
In recent years and this year , many methodologies in the literature are available to compensate the stiction [3-12], and also many controllers including PID controllers, PI controller

And other controllers based on the compensation valve have been developed to control various processes such as Kionget al.[13], addressed the friction modeling in servomechanisms by dual relay feedback approach., The friction model components that was targeting were Coulomb and viscous friction., A PID was used as feedback motion controller and in the compensation part, a feed forward friction compensator was tuned adaptively based on the dual relay friction components identification. Mohammad and Huang [14], presented a new framework for stiction compensation by retuning the PID controller based on trajectories plotting “root locus”. They determined the conditions in order to avoid oscillations or a limit cycle to take place in the process. It must be noted that the parameters tuning should be in the allowable parameter ranges. Which are set based on process needs and limitations. Prior knowledge of these ranges are essential for the tuning procedures. He proved the idea experimentally. Mishra et al [15], used stiction combating intelligent controller (SCIC) to curb stiction. SCIC replaces the linear PI controller in the control loop, it can be considered as variable gain PI controller based on fuzzy logic that use Takagi-Sugeno (TS) scheme. Mishra tested the performance of his proposed controller using a laboratory scale flow process. His controller outperformed the normal linear PI controller in stiction reduction with lesser aggressive stem movement. Chen Li and Choudhury group [16], proposed a mechanism to compensate the oscillation in cascade controllers, through the tuning of the outer and the inner controller. They supported there method with detailed frequency analysis, finally they validated it through simulation examples and a pilot-scale flow-level cascade control experiment.

Artificial intelligence along with conventional control in these days will appear as the most desirable approach in various industries including electronics industries, drives and power systems. In this paper we employed PI-fuzzy controller rather than other controllers because it can control the Stucky valve problem better and we can use it in the industrial applications.The system model is simulated under Matlab Simulink environment. Stiction compensation algorithms for pneumatic control valves have addressed by Hagglund T [17] and Kayihan et al. [18]. In reference [18] they developed an actuator design which be able to work separately of the overall distributed control system (DCS).This actuator propose is a nonlinear smart actuator local to the valve. The approach of Kayihan et al, needs a valve model with valve parameters (e.g., stem length, ,stem mass, etc.) and also the process model to be known a priori. Achieving such whole valve and model information for several hundred valves is a practical limitation. The approach proposed in reference [17] is a model-free method. The idea of this method is to adjoin a particular pulse called "knocker" to the controller output (OP) to compensate the valve stiction. The knocker pulse is described by an amplitude (a), a pulse width (↵), and a time among each pulse (hk). The option of parameters is critical for the compensation of stiction, specifically the pulse amplitude is really essential for the knocker technique to work [19].Alancardek et al. In reference [20] have proposed a new method for quanti cation of dead band and stiction in control loops . It being based on describing function method The purpose of the method to calculate approximately dead band and stiction and the results of this method will be reliable and useful.

Horch [21], observed few of the available oscillation detection methods and points out the require for reliable diagnosis of oscillation without human dealings. And he said all methods have particular strengths and weaknesses and it is necessary to know these when applying them to real-world data. In this paper the structure is as follows: In Section I elaborated the brief nonlinear problem presence in pneumatic valve and literature review. In section II discussed the control valve stiction. In section III stiction model of pneumatic valve is presented - its controlling strategies with different controllers. Fuzzy logic controller, stiction compensation and proposed method to obtain and reduce the oscillation behavior is introduced in section IV. At last Section V directs how the simulation is carried out and the results are expressed.

II. Control Valve Stiction

Pneumatic control valves have been used in most of the control loops as a final control element in process industries. Fig. 1 shows the diagram of a typical pneumatic valve.Stiction occurs due to the soft movement of the valve stem is stuck at the packing area by excessive static friction.The sudden slip of the stem after the controller output satisfactorily overcomes the undesirable effect of the control loop caused by the static friction .

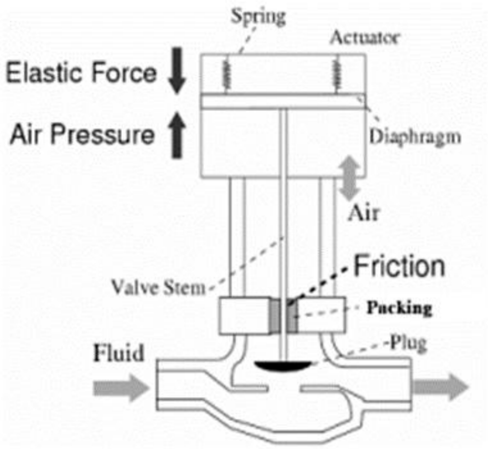

Fig. 1 Structure of pneumatic control valve [22]

III. Stiction Model Of Pneumatic Valve

Input output relation for a pneumatic valve section can be seen in fig 2. In Garcia [23], eight proposed model is developed. One of the models, Karnopp model will be used in this paper can describe the control valve dynamic as stick-slip.The parameter used in this paper also was employed in karnopp model (using S as the static part and J as slip jump). Newton law will give m, x, describes as mass of the valve, and the steam position respectively.

$$m\frac{d^2x}{dt^2} = \sum Forces = F_{pressure} - F_{spring} - F_{friction} \quad (1)$$

$$F_{Pressure} = Sa.P \quad (2)$$

$$F_{Spring} = Km.x \quad (3)$$

$$F_{Friction}(v) = \left[F_c + (F_s - F_c)e^{-\left(\frac{v}{v_s}\right)^2}\right] sgn(v) + F_v v \quad (4)$$

$$m\ddot{x} = P(t).Sa - Km.x - (Fc + F_v\dot{x}) \quad (5)$$

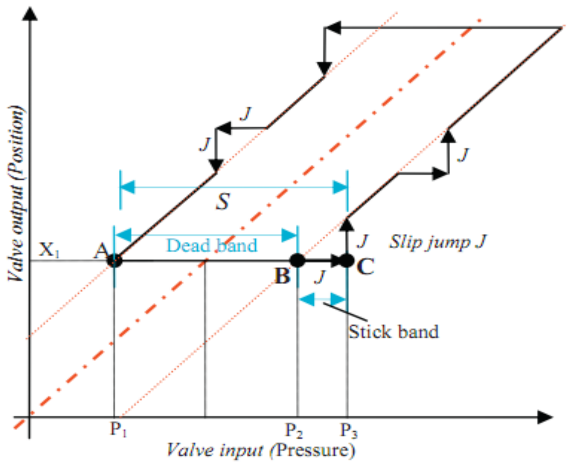

Fig. 2 Corresponding pressure and valve relation for pneumatic control valves.

When valve stem is at point A, B and C, the stem valve is getting stuck and it has the initial velocity and acceleration as zero. The Eq. (1) becomes:

$$F_{Pressure} = F_{Spring} + F_{Friction}$$

When valve in point A the corresponding equation for describing it will be:

$$P_1.Sa = K_m.X_1 - F_c \quad (6)$$

When valve stem in point B and C, the equation can be derived as Eq. (7) and (8).

$$P_2.Sa = K_m.X_1 + F_c \quad (7)$$

$$P_3.Sa = K_m.X_1 + F_s \quad (8)$$

When v has some values that more than 0. The model Karnopp valve for stem can be presented as Eq. (5). The constant values used to simulate the system are mentioned in Garcia 2008. Viscous friction coefficient (Fv) and mass (m) are 612 Ns/m and m=1.36 kg. As the big comparison between two values, the system can be approximated as first order with time constant τv=Fv/Km.

IV. Stiction Compensation And Fuzzy Controller

Stiction of valves is a real problem in the process industry and require prompt attention. It mostly entails repair schedule in order to put the valve back in working condition. Yet, this is not a feasible solution economically as it involves production outage which we generally try to avoid. Hence, a solution is sought which will circumvent this scenario. The general techniques available involve compensation for the problem rather than taking it out of service. Hence, available compensation algorithms will be examined in the following section though these methods are few in numbers.

A) Knocker or Dither technique

The most well-known compensation algorithm is the "Knocker" approach proposed by Hagglund [17]. This is the first algorithm designed specifically for valve stiction and has shortcomings. It involves predesigning a signal for the controller output in order to control the fluctuation in the output process. The signal introduced composed of successive pulses with constant amplitude, width and time. Its effects is to increase the process output by increasing the movement of the valve.This result in more wear and tear leading to additional mechanical damage to the valve. Due to this, we only use this as a stop-gap solution until a lasting solution could be found. A diagram of a control loop containing a compensator is exposed in fig.3 as follows.

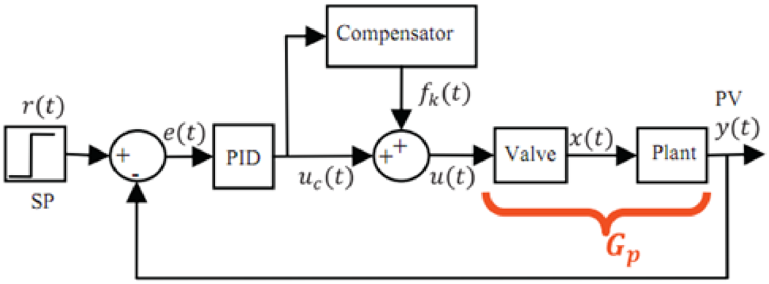

Fig 3. Block diagram of the control loop with a knocker

$$U(t) = U_c(t) + sign\left(\frac{du_c(t)}{dt}\right).fk(t) \qquad (9)$$

$$f_k(t) = |u_c(t)| + \alpha.d$$
$$f_k(t+1) = -u_c(t+1)$$

$$x(t) = \begin{cases} x(t-1) \; if \; |u(t) - x(t-1)| \leq d \\ u(t) \qquad\qquad otherwise \end{cases} \qquad (10)$$

With x(t) and x(t-1) is defined as current state and previous stated. In addition, u(t) represents as controller input variable and d is stiction band.

B) Fuzzy logic controller

The system of the Fuzzy Logic Controller shown in fig.4 which consists of the three departments. They are fuzzification, defuzzification and the rule base.Fuzzification, the first section of the FLC, converts the real inputs of the system to fuzzy values. After that these fuzzy values are sent to the part of the rule-base and processed with fuzzy rules, and then these resulting fuzzy values are sent to the defuzzification section.

$$\mu_{MU(x)} = \max(\min(\frac{x - x_1}{xT - x_1}, \frac{x_2 - x_1}{x_2 - xT}, 0) \qquad (11)$$

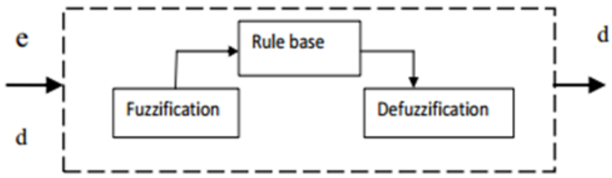

Fig 4. Basic configuration of a FLC

In this part, the fuzzy results are changed to exact values using the method of the centre area.The error and the error variation of the input data of the FLC's input variables are exposed in Fig. 5 and 6. Membership functions were used as a triangle. These functions are called high, average and low for pressure as input of valve(error of FLC's) and for the stiction valve nostiction,halfstiction and fullstiction as a Variation of error and the data vary between 0 and 10.

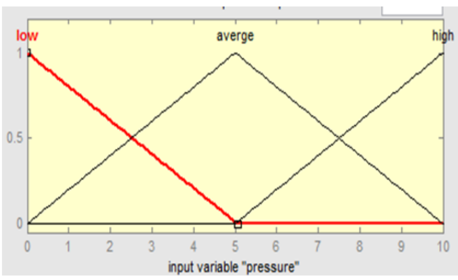

Fig 5. Error membership functions

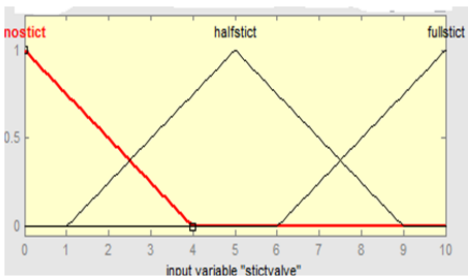

Fig 6. Variation of error membership functions

In Table 1, the rules of the FLC are specified. There are 9 rules in total due to the 3-ruled input variables.

Table 1. Fuzzy rule base

Pressure Stiction Valve	high	avarege	low
Nostiction	Open	Small open	Small open
halfstiction	Open	Small open	Small open
fullstiction	Small open	Small open	Close

The membership triangle function as seen in the Fig. 7, is defined as follows , the output space of the Fuzzy Logic Controller is shown In Fig. 7. These data also vary between 0 and 10.

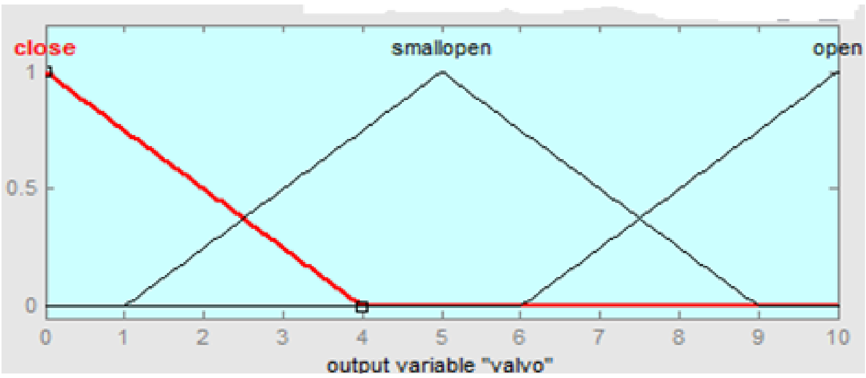

Fig 7. Output space (valve position)

V. Simulation And Results

The performance of the newly designed controller is evaluated in this section through simulation. The controllers are applied to a valve model and the process of the system. Unit step is used as a reference input for the system model to eliminate the sticky valve problems because the PI Fuzzy control is nonlinear control. The model of the valve system is shown in Fig 8. The block diagram of the proposed is shown in Fig. 8 which contains two main blocks, the controlled model valve and the FPIC.

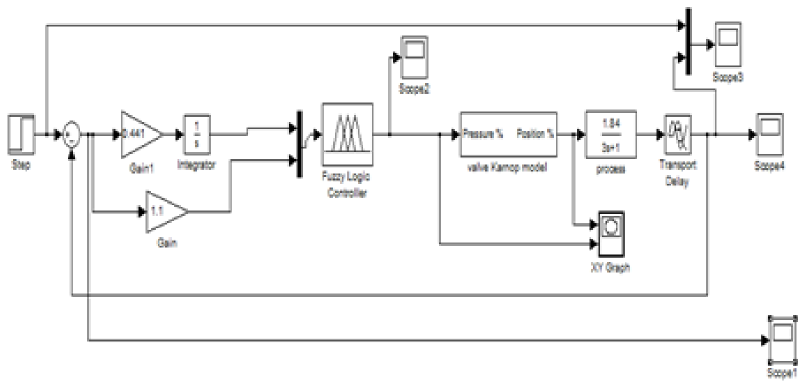

Fig 8. Block diagram of proposed PI fuzzy

Time of the simulation is 50 Sec, after running the model proposed in the MATLB/Simulink we got the results as shown in figures 9-11 as follows:

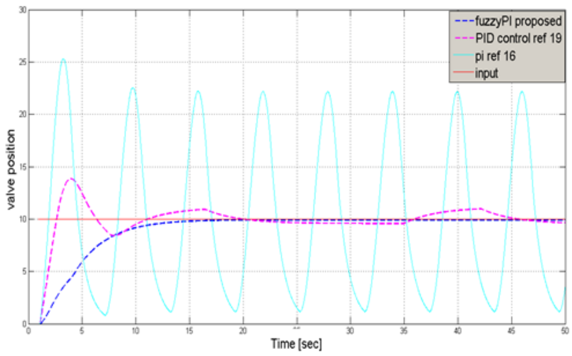

Fig.9. Input and output for the model valve with PIFC and PID controller in reference [23] and also PI with different process as in reference [20].

Fig. 9, The input and output of the proposed fuzzy controller are shown. It is seen that compared to the case of sticky compensation techniques in references [20] and [23], the output becomes stable quickly and settles down without further fluctuation. This implies better performance and also good controller because the fuzzy control is a nonlinear control.On the other hand the response of the PID controller in ref 23 is seen that the stiction problem is very much present in the simulation output. The input and output for the model valve using improved method compensation clearly shows this. As we see the PID controller in reference 23 has a better response than the controller PI in reference 20 which has a great oscillation and higher overshood but in both of them the system is marginally stable.

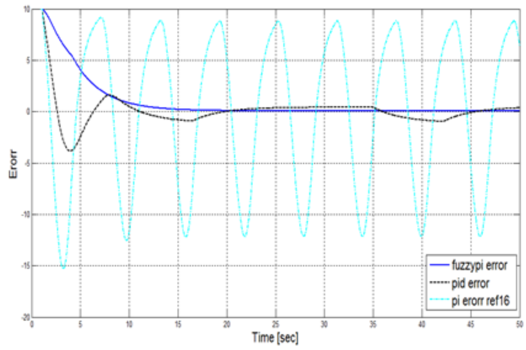

Fig. 10 Error signal system PIFC and signal of the improved control method [23] and also an error signal in [20].

In fig 10, the error signal system when we use the PIFC and the error signal of the improved control method in references 20 and 23 is shown. It is seen that the error signal of the PIFC is very small, around 0.0001mm. This performance is very good as it means the error can be tolerated but the error signal of the improved control method [23] shows the error signal which oscillates around zero. This is not very good for the valve and we aim to further reduce the error and in reference [20] the error signal has a bad oscillation around zero.Fig. 11 shows the control signals for three controllers applying to the valve system as follows.

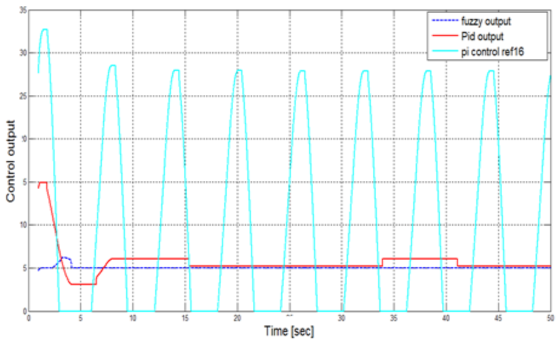

Fig. 11 control signals of the PI- fuzzy controller with the control signal of the improved control method in referances [20] and [23].

The figure above shows the control signal of the PI- fuzzy controller with the control signal of the improved control method which shows the control signal of the improved control method. This is what the controller uses to control the valve and it can be seen that it fluctuates.Figure 12 shows the Rule surface of Fuzzy Logic Controller as follows:

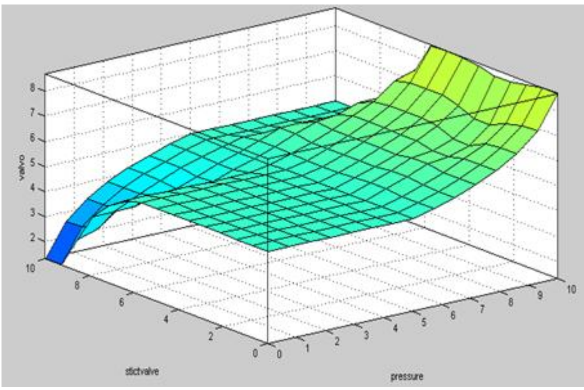

Fig. 12 Rule surface of Fuzzy Logic Controller

VI. Conclusion

Many models are used these days to control various non-linear processes. In this work, Fuzzy controller based PI controller have proved to be an asset in this respect. They have a versatile nature and can be easily tuned which gives room for maneuver during controller design. Improved method for Stiction compensation in references [20] and [23] is evaluated and also is developed by using a new PI-Fuzzy controller. The performance of the new approaches is compared with improved stiction compensation. The proposed method produced better performance as demonstrated using simulation.

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