A NOVEL TECHNIQUE FOR STICTION DETECTION AND COMPENSATION IN PNEUMATICALLY ACTUATED CONTROL VALVE

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Abstract- *Stiction in pneumatically actuated control valves and poor controller tunings are the two main sources of performance deprivation of control loops. The nonlinearity in control valves such as stiction is needed to be identified quantified and compensated. A new cohesive technique based online stiction detection and compensation approach is introduced here. The outcome reveals, the present method produces better performance comparing with the existing methods. Modeling, validation and performance of compensation of stiction have been analyzed and verified using Matlab/Simulink platform.*

Keywords- Compensation, Control Valve, Dead-band, Modelling, Quantification, Stiction

1. INTRODUCTION

Pneumatic actuated control valves are commonly used in all the process industries. Stiction is considered as an oscillatory behavior in the process control loop [1]. So, its detection, and compensation are important to improve process performance. A state of art review on the status of stiction is presented by Srinivasan and Panda [2]. Choudhury [9] proposed a model based stiction compensation method to calculate actual control output. There are numerous investigators like Kano [13], Chen [23], He [24] proposed model structure to simulate the behaviour of sticky-valve similar to the industrial cases. Therefore, a new technique is proposed here to detect and compensate stiction.

The block diagram of a closed loop process with valve stiction is provided in Figure 1. In Figure 1, the 'r' denoted as reference, the 'G_c', denoted as the controller gain, the 'G_v' denoted as valve gain and the 'G_p' denoted as process gain. The 'y_d' denoted as disturbance. The 'PV' denoted as process variable and the 'OP' denoted as controller output. The Hammerstein system comprising a nonlinear stiction model followed by a linear process model.

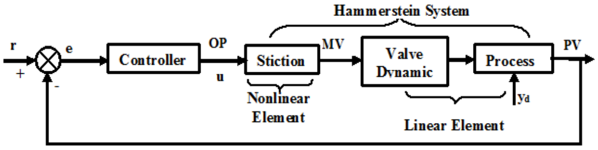


Figure 1. Block diagram of process control system

2. CONTROL VALVE STICTION

The characteristics behavior of a valve stiction is shown in Figure 2. Its behavior and operation is discussed in the article [3]. This is the typical phase plot diagram of an input-output behavior of a sticky based control valves using in almost all the chemical, petrochemical and fertilizers process industries.

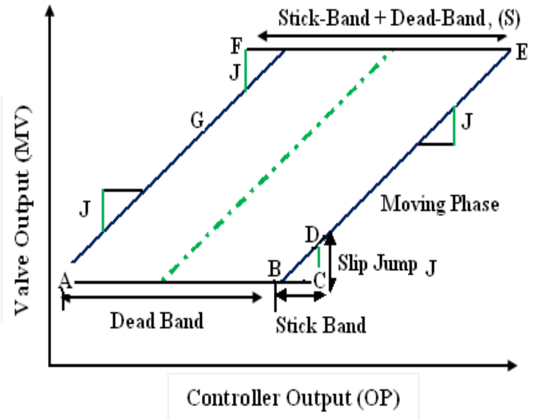


Figure 2. Input- output behavior of a sticky valve

3. STICTION COMPENSATION

Once control valve stiction is confirmed, the faulty valves have to be repaired. But, shutting down the processes for isolating the sticky valves is not an economical and also difficult for maintenance. A unified novel technique to be adopted to compensate the stiction, especially when the maintenance is not required. Some available compensation methods are reviewed here.

a). Knocker or Dither Method

The first well known technique is the “knocker” method proposed by Hägglund [14] to detect stiction. The idea is, to include a predesigned signal to prevent the oscillations in the process variable. Figure 3 shows a control loop containing a compensator.

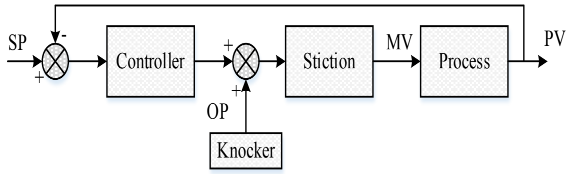


Figure 3. Control loop system with knocker

The predesigned signal having a series of pulses with a constant amplitude, width, and time. This compensator can completely remove oscillations induced by stiction from the process variable.

b). Constant Reinforcement Method

Constant reinforcement method is presented by [15]. It is also like knocker technique, except that the predesigned signal is not in the shape of pulse signal. Here, the authors proposed compensation signal with a constant value which is calculated by equation (1), in which the a_{cr} is to be chosen.

$$\alpha_k = a_{cr}\,\mathrm{sign}(\Delta u) \quad (1)$$

It is only useful for time intervals and normally ignores extra movements.

c). Alternate Knocker Method

Researchers [16] have proposed a stiction compensate method where the compensator is used in between controller and stiction model, as described in Figure 4.

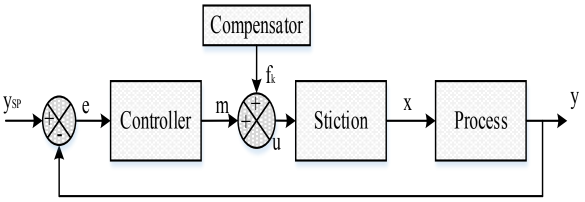


Figure 4. Closed loop system with stiction compensator

Here ‘m’ is the controller output, ‘f_k’ is the compensator action, ‘y_{sp}’ is process set point, ‘y’ is process output, ‘e’ is error, and ‘u’ predesigned signal ‘(m + fk)’ given to the control valve and ‘x’ is the position of stem. The knocker parameters for ‘τ’, ‘h_k’ and ‘a’ are set to 2h, 5h and d/2 respectively in the simulation. Where ‘h’ is the sampling time and‘d’ is the stiction measure which is shown in Figure 5

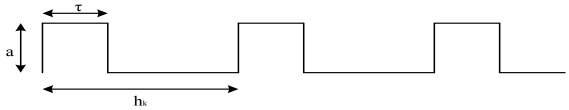


Figure 5. Knocker pulse (a=amplitude of the pulse, τ=pulse width, h_k=time between pulses)

This method was used for physically unrealistic single-parameter model. However, aggressive stem movement used to reduce the output variability. But, aggressive movement is not preferred since the stem wears quickly.

d). Proposed Method

In this proposed article, an innovative compensation method is implemented. The proposed plant having a process (two tank process for liquid level control as plant), a control valve (with Kano’s stiction model) and a Proportional plus Integral controller for closed loop control. Compensator is introduced after the valve-stiction model in the simulink block. The design requires i) Controller output ii) Valve output and iii) Plant output.

The above three parameters are considered as present and previous states which is mentioned in equation (2). They have been obtained from the real time SCADA system. For compensator purpose, Adaptive Neuro Fuzzy controller (ANFIS) is introduced between valve and plant. Controller input requirements are represented as,

$$D_p = \begin{cases} PV(t), & PV(t-1) \\ OP(t), & OP(t-1) \\ MV(t), & MV(t-1) \end{cases} \quad (2)$$

D_p is the required input of the ANFIS compensator.

Here the ANFIS compensator is used to estimate the actual position of the valve and to attain the required valve position during sticky oscillation conditions. The following considerations are taken for compensator,

a) An oscillation occurs due to stiction alone.
b) A valve stiction is modeled and is implemented with the help of Kano’s stiction model.
c) Compensator can track plant references

The State space model of the two tank liquid level process for the proposed system given as,

$$A=\begin{bmatrix}-1 & 1\\ 1 & -2\end{bmatrix};B=\begin{bmatrix}1 & 0\end{bmatrix};C=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix};D=\begin{bmatrix}0 & 0\end{bmatrix} \qquad (3)$$

With initial condition = [1; 1]

4. ANFIS SYSTEM

The ANFIS (Adaptive Nero-Fuzzy Inference System) is discussed in the article [18]. The fuzzy inference system has been considered as a model maps. The neuro-adaptive learning technique gives procedure for fuzzy modeling for learning information of a data set. The membership function computes the fuzzy inference system for tracking the given input/output data.

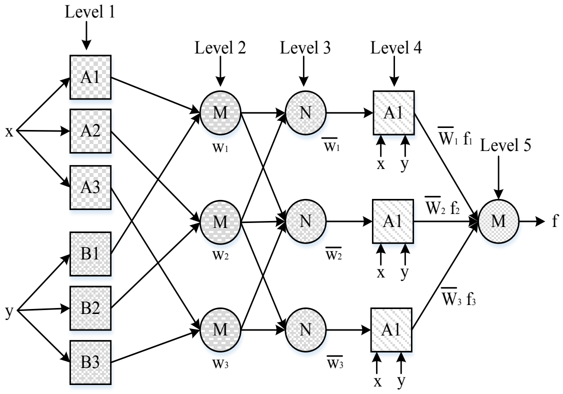


Figure 6. ANFIS Architecture

a. *ANFIS Testing and Training*

Input/output data are taken for change in stiction (from the control valve) with a sampling interval of 0.01 and for jump with a sampling interval of 0.01. A three layer input and single output fuzzy system is considered for this work. A total of 10 epochs is considered, hybrid neural model is considered for training. Figure 7 shows the ANFIS structure for the proposed compensator after training. Figure 8 shows the results of ANFIS for training data. The training responses of ANFIS controller shown in Figure 9.

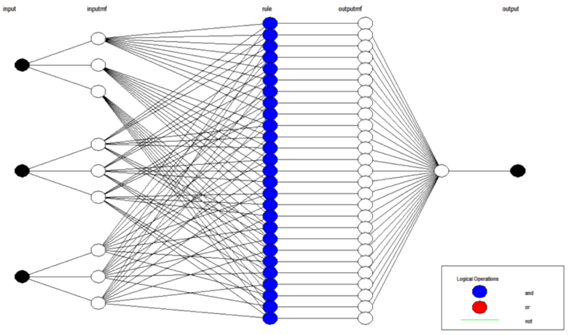


Figure 7. ANFIS Architecture after training

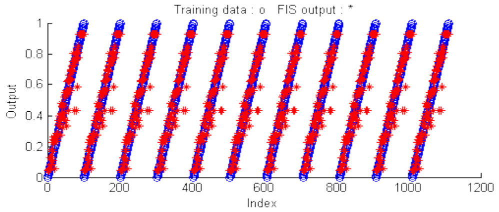
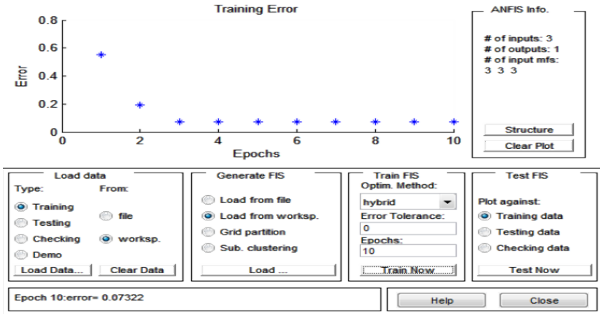


Figure 8. Simulated training and testing data (blue-actual, red-predicted by ANFIS)



# of inputs: 3
# of outputs: 1
# of input mfs:
3 3 3

Type: ● Training

From: ● worksp.

● Load from worksp.

Optim. Method: hybrid

Error Tolerance: 0

Epochs: 10

Plot against: ● Training data

Epoch 10:error= 0.07322

Figure 9. Training responses ANFIS controller

Table 1 ANFIS Information

ANFIS Information			
Total Number of nodes	78	Total parameters	135
Total Number of linear parameter	108	Total training data	1111
Nonlinear parameters	27	Number of FUZZY rules	27

5. RESULTS AND DISCUSSION

The Simulation work is supported out in matlab/simulink platform. Test data set for training is obtained with sampling time of 0.01sec. Figure 10 the outcomes of simulated response of a plant output with and without compensator.

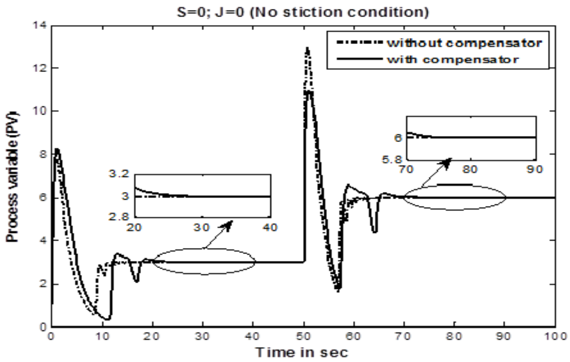


Figure 10. Simulated response of plant output with and without compensator for no stiction condition

From the Figure 10 it can be seen that the proposed compensator tracks the set point and didn’t distrub much of the plant output at no stiction condition. Characteristics of these curves are estimated as performance measure with help of ISE, IAE values of the plant output response.

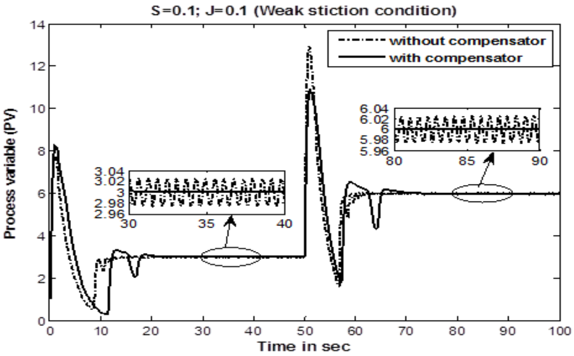


Figure 11. Simulated response with and without compensator for weak stiction (S=0.1, J=0.1),

Figure 11 presents the plant responses under weak stiction conditon, for with and without compensator. It shows the oscillation caused due to weak stiction, and the stiction is observed as 4% of oscillation occurred due to 10% of stickyness and shows oscillations after settling due to stickness after change in input introduced to Kano’s model structure for proposed plant/process model represented by equation (3).

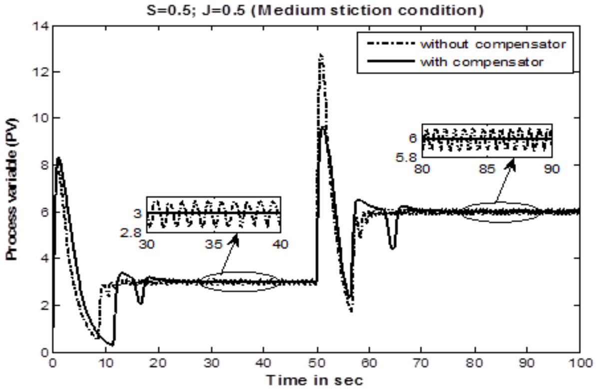


Figure 12. Simulated response with and without compensator for medium stiction (S=0.5, J=0.5),

Figure 12 presents the plant responses under medium stiction conditon, for with and without compensator. It shows the oscillation caused due to medium stiction. From the Figure, it is observed that 10% of oscillation occurred due to 50% of stickyness. It shows the oscillations after settling due to stickness after change in input introduced by the Kano’s model for proposed plant/process model represented in equation (3).

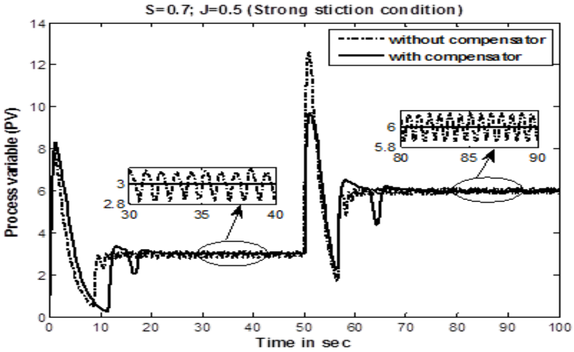


Figure 13. Simulated response with and without compensator for strong stiction condition (S=0.7,J=0.5).

Figure 13 presents the plant responses under strong stiction conditon, for with and without compensator. The Figure shows the oscillation caused due to strong stiction. From the Figure, it is observed that 20% of oscillation occurred due to 70% of stickyness and it shows the oscillations after settling due to stickness after change in input introduced by the Kano’s model for proposed process model represented by equation (3).

6. CONCLUSION

The Stiction is a major cause of oscillations in loop control giving rise to inferior performance.

Available compensation techniques are not giving satisfactory response rather it may disturb the process of the loop with a control valve without stiction. In order to elude the drawback, a proper unified model based compensator is necessary. A novel online detection and compensation method of stiction is introduced by ANFIS controller as compensator. From the results the ability of ANFIS as a compensator to remove oscillations caused by stiction in the valve has been explained. Using this new methodology, OP, MV and PV are collected to determine and quantify to compensate the system's oscillation. Hence, the proposed ANFIS compensator can be used in control loops of industrial processes.

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