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A New Methodology to Compensate Stiction in Pneumatic Control Valves

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Abstract*— *Industrial surveys reported that, almost one third of poorly performing control loops are caused by nonlinearities present in the control valves, one of which is static friction. The effect of this nonlinearity is usually observed as oscillations in process variable. Since industrial plants include numerous interacting loops, the oscillations will be propagated to the entire system. Doubtlessly, repairing the faulty valves will be the only solution to this problem, which is possible only during process shut down. But, as shutting down the process to isolate the faulty valve for maintenance purposes is not economical, this solution does not count as the primary one. So, there is a need for a method to compensate the destructive effect of the stiction phenomenon in the control valve, especially when maintenance is not available. This paper focuses on existing compensation issues, followed by a proposal of a new model-based compensation approach for the stiction nonlinearity present in control valves. Performance of this method is validated by both simulation and laboratory data.

Index Terms*— *Pneumatic control valve, stiction, Stick band, stiction compensation, knocker.

I. INTRODUCTION

A typical modern chemical plant includes hundreds or even thousands of control loops. The main objectives of such control systems are to maintain the processes closer to the operating conditions. The deviations from desired values may have different root causes. Poor controller tuning, external oscillatory disturbance and nonlinearities present in the system are some known sources of poor performance [1]. This work focuses on the latter mentioned cause, nonlinearities in the control system, specifically nonlinearity as a result of stiction in control valves and the procedure for the design of compensators. In the literature, several methodologies are available to compensate the stiction[1,2,3], some of them will be depicted and the main limitations are highlighted. Achieving a non-oscillatory output without making the valve stem to move more aggressively, is the main characteristic of this algorithm.

II. CONTROL VALVE

In most of the control loops in process industries, pneumatic control valves are used as final control elements. The diagram of a typical pneumatic valve is shown in Fig. 1. The valve aims to restrict the flow of process fluid through the pipe and the valve plug is rigidly attached to a stem that is attached to a diaphragm in an air-pressure chamber in the actuator section at the top of the valve.

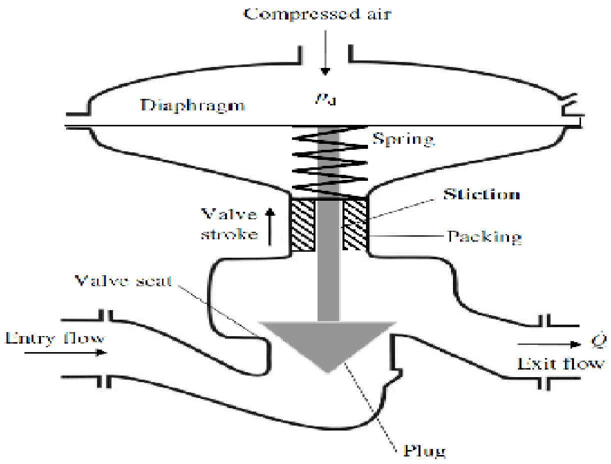

Fig.1.Typical pneumatic control valve

When compressed air is applied, the diaphragm moves down and the valve closes to restrict the flow and at the same time, the spring is compressed. Stiction in control valves is thought to occur due to seal degradation, lubricant depletion, inclusion of foreign matter, activation at metal sliding surfaces at high temperatures and/or tight packing around the stem. The resistance offered from the stem packing is often considered as the main cause of stiction.

III. INPUT–OUTPUT RELATION OF VALVES UNDER STICTION

Stiction can be best explained by the input–output behaviour of a sticky valve illustrated in Fig. 2. Without stiction, the valve would move along the dash-dotted line crossing the origin. Any amount of controller output (OP) would result in the same amount of manipulated variable (MV) change. However, for a sticky valve, static and dynamic friction components have to be taken into account [2]. The input–output behaviour then consists of four components such as deadband, stick band, slip jump and the moving phase and is characterized by the three phases:

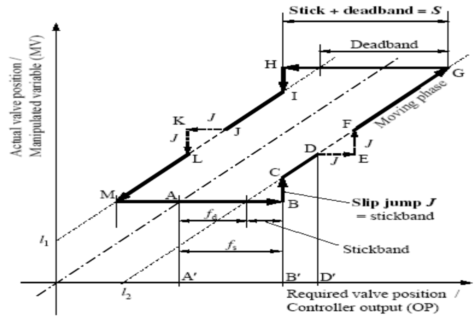

Fig.2 Input–output behaviour of a sticky valve

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- **Sticking phase:** MV is constant with the time, as the valve is stuck by the presence of the static friction force f_s. Valve deadband is due to the presence of Coulomb friction F_c, a constant friction that acts in the opposite direction to the velocity.
- **Jump phase:** MV changes abruptly, as the active force F_a unblocks the valve.
- **Moving phase:** MV varies gradually; F_a is opposed only by the dynamic friction force f_d.

IV. STICTION MODEL

Based on the sticky-valve behaviour, a valve-stiction model is proposed by He *et al.* [3] is used for simulation. He's model employs a simpler model structure compared to Choudhury's [4] or Kano's [5] model. In addition, He's model naturally handles stochastic noise and can simulate the sticky-valve behaviour similar to the ones observed in industrial cases [3] and Fig. 3 shows the flowchart of the model.

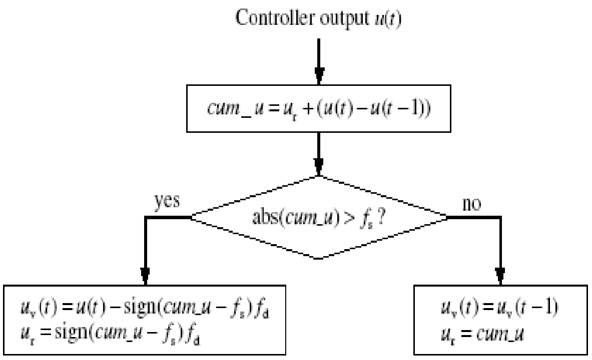

Fig. 3 Flow chart of He's two-parameter stiction model

The variable 'u_r' is the residual force acting on the valve that has not materialized a valve move. Variable '*cum_ u'* is a temporary variable that is the current net external force acting on the valve that is balanced by friction band. If the magnitude of '*cum_ u'* is large enough to overcome the static friction band f_s, the valve position $u_v(t)$ will be the controller output $u(t)$ offset by the kinetic or dynamic friction band f_d. Otherwise, the valve position will not change and *cum_ u* is the residual force on the valve to be used in the next control instant.

V. STICTION COMPENSATION

Once stiction of a valve is confirmed, scheduling the faulty valves to be repaired is the definite solution to stiction problem. But, since shutting down the process to isolate the faulty valve for maintenance purposes is not economical, this solution does not count as the primary option. A method to compensate the stiction phenomenon should be used, especially when maintenance is not available. In this section, some existing compensation algorithms will be reviewed. Unlike methods which are used for detection or quantification purposes, the methods to compensate stiction are few and limited.

A. Knocker or Dither

The most prominent method is the "knocker" approach proposed by Hagglund [6] and this method can be considered as the first compensation method specifically targeting static friction in control valves. The idea is to add a predesigned signal to the controller output in order to prevent the fluctuations in the process output. A schematic of a control loop containing a compensator is shown in fig.4

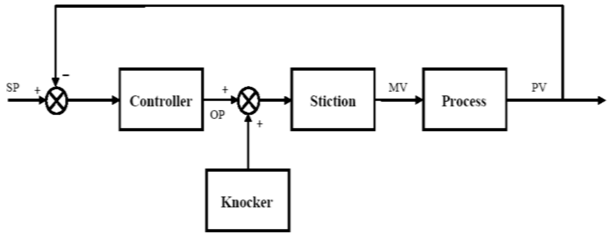

Fig 4. Block diagram of the control loop with a knocker

The additive signal consists of a sequence of pulses with constant amplitude, width, and time between each two pulses in the direction of changes in the control output signal. This compensator can successfully remove stiction-induced oscillations from the process output. This achievement is gained by making the valve stem move faster and even wider than before, because the algorithm only increases the controller output in terms of magnitude for some sampling intervals. This extra movement of the valve will increase the rate of mechanical damage, considering the significant friction force which exists between the valve stem and the sealing packing. Regardless, the mentioned method can be considered as a short-term solution to the stiction problem.

B. Constant Reinforcement

This method was presented by [7]. The main idea is similar to that of the knocker, except that the additive signal is not of pulse form. The authors suggest that the compensating signal should have a constant value. This value can be calculated using following equation, in which only the value of a_{cr} is to be chosen.

$$\alpha_k = a_{cr} sign(\Delta u) \qquad (1)$$

Similar to the previous method, this method also cannot decrease extra movements of the valve. This method is useful only for time intervals when the valve does not move in response to the controller output changes, and generally ignores extra movements.

C. Alternate Knocker Method

Ranganathan Srinivasan & Rengaswamy [8] have proposed an approach to compensate valve stiction. Here the compensator is inserted between controller and stiction model, as shown in Fig. 5.

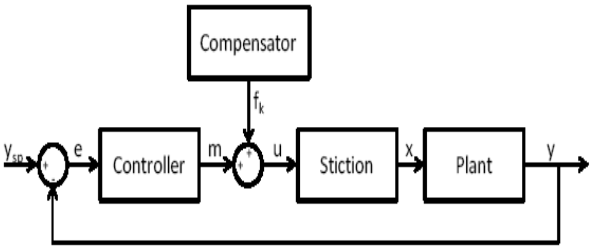

Fig.5 Control system with stiction compensator

Here 'm' is the controller output, 'f_k' is the compensator action, 'y_{sp}' is process setpoint, 'y' is process output, 'e' is the error, 'u' is the additive signal '$(m + f_k)$' that is being fed to the valve and 'x' represents the stem position. The knocker parameters for τ, h_k and a are set to 2h,5h and d/2 respectively where h is the sampling time and d is the stiction measure, the waveform of which is shown in fig.6

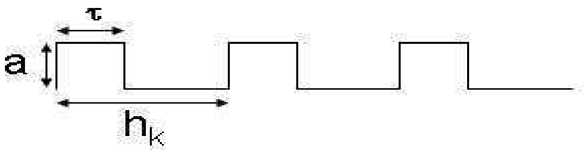

Fig.6 Knocker Pulse (a=amplitude of the pulse, τ=pulse width, h_k=time between pulses)

This method was applied for physically unrealistic single-parameter model. However, here also, the reduction of the output variability was achieved at the cost of an aggressive stem movement. Such an aggressive stem movement is not preferred as it may wear the valve quickly.

D. Two Move Compensator

This approach, which was introduced in [9], is different from the other mentioned methods. Its main focus is on maintaining the valve at its steady state position. In order to achieve this goal, at least two moves in opposite direction are required for the valve stem, because even after setting the controller output (OP) at the steady state value, there is no guarantee that the valve is located at the desired position. The signals which produce such movements should have magnitudes large enough to overcome the friction force and make the stem move, but not too large to saturate the valve. Although the idea is new and to some extent effective, there are still some limitations. For instance, it is known that the set point of the control loop may change during operation and information (correct value of OP) about the new steady states of the system with sticky valve may not be available. This method does not consider these variations, and as a result it cannot be automated to track the set point. Another disadvantage is the use of Stenman's one-parameter stiction model, which decreases the accuracy of the method.

E. Optimization Approach

Srinivasan and Rengaswamy [10] proposed another method for stiction compensation, based on an optimization procedure. The cost function should be minimized, using the compensator moves as optimization variables. The optimization procedure can lead to better results than the remaining methods, using the valve with parsimony. However, tuning the parameters is a difficult task and this procedure is computationally expensive to be applied in all sticky valves. Also, as the objective function is non-smooth, the optimizer cannot able to attain the global minimum and a possibility of getting a local minimum, so the process output cannot reach the set-point. This is because the stem position cannot move to the correct steady state value; instead it will move the stem close to it with an offset. So, the optimization method will have some real-time issues. But the proposed method is applied to real sticky valve and acceptable results were obtained.

F. The Proposed Method for Stiction Compensation

The proposed method is similar to the method proposed by Hagglund [5] and Ranganathan Srinivasan & Rengaswamy [8], but the difference is that the selection of amplitude and duration of the pulse. The waveform of the proposed method is given in fig.7. Instead of selecting the pulse of equal magnitude, here X_1 and X_2 are selected according to the stiction model and relationship is given in the following equation.

X_1=3(Stiction in % of controller span)
X_2= - (125% of X_1)
Pulse width= sampling time

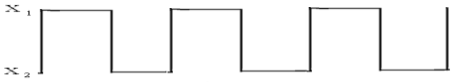

Fig.7 Waveform of the proposed method

VI. CLOSED LOOP RESPONSES

In this section, a simulated application of the proposed method will be shown.

The two-parameter model proposed by He[3] is used to simulate behavior of sticky valve.The block diagram of closed loop system with stiction is shown in fig.8. The parameters for the stiction and compensator are shown in Table 1. The process and controller used are

$$G_p(s) = \frac{1.54e^{-1.07s}}{3s+1} \tag{2}$$

$$G_c(s) = 1.1 + \frac{0.441}{s} \tag{3}$$

Table1. Parameters of stiction and compensator

Stiction parameters		**Compensator parameters**	
f_s	f_d	X_1	X_2
0.1	0.05	1.0	-1.25
0.08	0.04	0.8	-1.00
0.03	0.015	0.3	-0.375

The sampling time is selected as 0.1sec. The system is controlled in absence of stiction, and oscillates significantly in its presence. The closed loop responses of the simulated process are shown in the following figures.

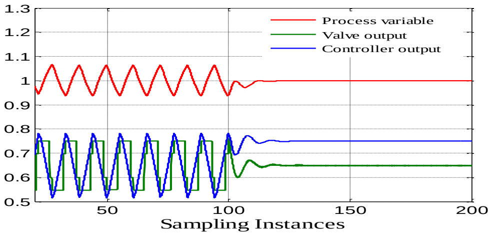

Fig.8 Closed loop response of the system with proposed compensator .(The compensating signal introduced at the 100th sampling instant with f_s=0.08, f_d=0.04; stiction=0.27% of controller span)

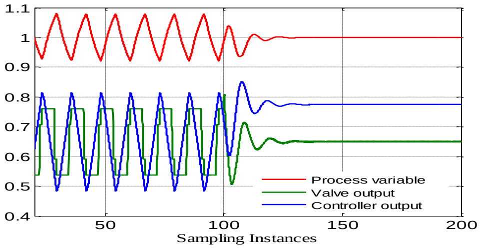

Fig.9 Closed loop response of the system with proposed compensator. (f_s=0.1,f_d=0.05; stiction=0.33% of controller span)

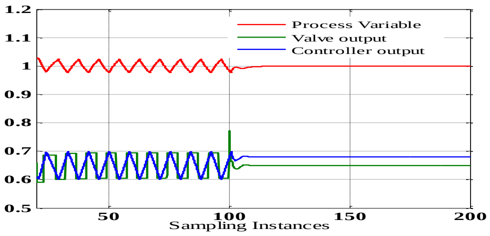

Fig.10 Closed loop response of the system with proposed compensator (f_s=0.03, f_d=0.0125 stiction=0.1% of controller span)

A model-based approach for stiction compensation is proposed. Achieving a non-oscillatory output without forcing the valve stem to move faster and wider than normal is the most important characteristic of this algorithm. Using two-parameter stiction model, which predicts the behavior of a sticky valve more precisely, this method does not need extensive prior information about the process and the controller, and can track set point changes during operation.

VII. REAL TIME IMPLEMENTATION

A. *Experimental Setup*

In order to evaluate practical efficiency of the proposed compensation method, the proposed technique is implemented on a laboratory air flow control system. The piping and instrumentation diagram of the process and its associated control system are shown in fig.11. The process variable (air flow rate) is sensed by differential pressure flow transmitter. This flow transmitter produces current output in the range of 4 to 20 mA. A current to voltage (I/V) converter is used to convert 4 to 20 mA into 1 to 5 volts. This measured voltage (Process Variable) is compared with the reference signal. The difference between the two is given as input to the controller. The controller used is a well tuned PI controller. The controller produces manipulating variable based on the difference between the set point and process variable. The manipulating variable in voltage form is converted into current by a Voltage/Current (V/I) converter. A Current/Pneumatic (I/P) converter is used to convert this current to pressure (3 to 15 psi) accepted by the control valve. The air ailure to open (AFO) pneumatic control valve restricts the path of the air flow in the process pipe line, thus controlling the air flow rate. Controller output (OP) and process variable (PV) data are used for the identification procedure. The sampling time is taken as 0.1s.

V1 to V4 - Manifold valves; FT - Flow Transmitter; MV-1 to MV-3 - Manual control valves; PS - Power Supply; M1 and M2 - Manometer connections; mA - Milliammeter; DH-De humidifier;I/P - Current to Pressure converter; AFR - Air Filter Regulator; PCV - Pneumatic Control Valve; PRG - Pressure Gauge ; G-2 - Galvanized pipe for cold air flow;

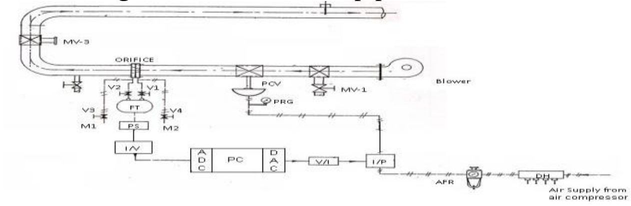

Fig. 11 Piping and Instrumentation Diagram of Laboratory Air Flow Control System

All computations reported in this study were carried out using MATLAB/Simulink and d-SPACE. All open-loop and closed-loop simulations were accomplished using Simulink. Initially it was observed that the control valve has no static friction. (less than 0.01%).

B. *Validation of the compensating Method*

First the system is operated in steady state and process parameters are found. The system is found to be a first order system and PI controller is designed. Initially as the control valve has no stiction, a tight PI controller is designed and the closed loop response is observed. Now stiction is introduced in the valve by tightening the stem packing to get 0.4% of controller span. A step change in set point of 50-60% is given. fig.12 shows the Stiction compensation for the laboratory flow loop with 0.4% stiction with stiction compensation started at t=1000sec.

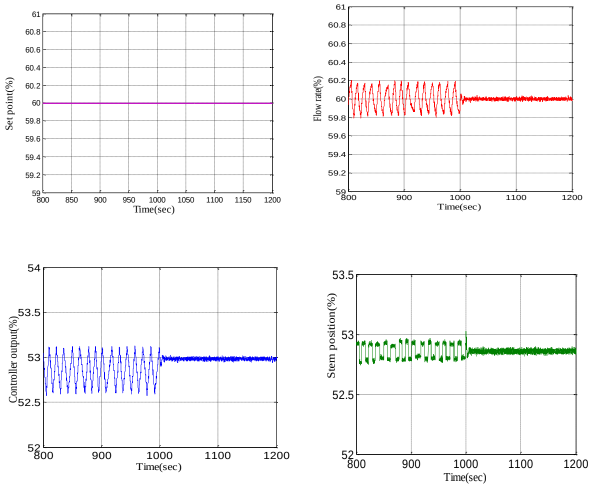

Fig.12 Stiction compensation for the laboratory flow loop with 0.4% stiction. Stiction compensation started at t=1000sec

In order to check the effectiveness of the compensator the magnitude of stiction is increased to 6% and the responses are given in fig.13. The results clearly show that the proposed approach imposes a smoother valve operation, comparing with the knocker method. But in this proposed method, the output variability is very much reduced and also the valve movement is smooth.

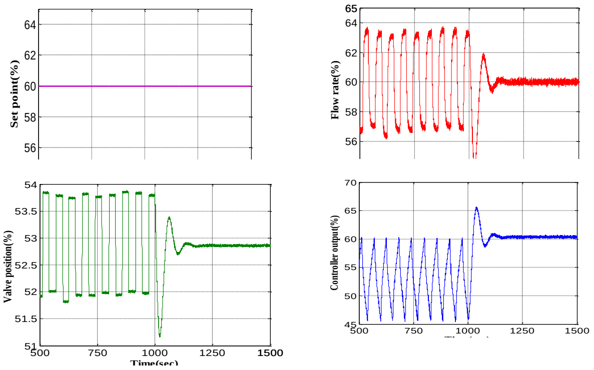

Fig.13 Stiction compensation for the laboratory flow loop with 6% stiction. Stiction compensation started at t=1000sec

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VIII. CONCLUSION

A large number of sticky valves are working in industry without maintenance; the number of stiction compensation methods is scarce. Moreover, the available methodologies try to overcome the stiction by the insertion of constant valve steps, what decrease the valve life expectancy. On the other hand, the two moves approach can increase the valve life, but it imposes a poor closed loop performance. The proposed give a better solution for both set point tracking and disturbance rejection. The proposed algorithm was also applied in a closed loop system, where reliable results were provided. Moreover, it was tested against the knocker algorithm and better results were seen.

REFERENCES

1. T. Miao and D.E. Seborg, Automatic detection of excessively oscillatory control loops, In Proceedings of the IEEE international conference on control applications, Hawaii, USA, 1999.
2. Rossi M, Scali C, A comparison of techniques for automatic detection of stiction: simulation and application to industrial data, *J Proc Control*. 2005 1:505–514.
3. He QP,Wang J, PottmannM, Qin SJ, A curve fitting method for detecting valve stiction in oscillating control loops, *Ind Eng Chem Res* 2007 46:4549–4560.
4. M.A.A.S.Choudhury, M. Jian and S.L. Shah, Definition, mdelling, detection and quantification, Journal of Process Control, 2008,Vol.18, pp.232-243.
5. M. Kano, H. Maruta, H. Kugemoto and K. Shimizu, Practical model and detection algorithm for valve stiction, IFAC Symposium on Dynamics and Control of Procces System (DYCOPS), Cambridge, USA, 2004.
6. Hagglund T, A friction compensator for pneumatic control valves, J Proc Control, 2002 Vol.12, pp.897–904.
7. Z.X. Ivan and S. Lakshminarayanan, A new unified approach to valve stiction, quantification and compensation, Industrial and Engineering chemistry research, 2009, Vol.48, pp.3474-3483.
8. Ranganathan Srinivasan and Raghunathan Rengaswamy, Techniques for Stiction Diagnosis and Compensation in Process Control Loops, Proceedings of the American Control Conference, Minneapolis, Minnesota, USA 2006.
9. Srinivasan R, Rengaswamy R, Approaches for efficient stiction compensation in process control valves. *Comput Chem Eng*, 2008 vol.32, pp.218–229.
10. Srinivasan R, Rengaswamy R, Integrating Stiction diagnosis and Stiction Compensation in Process Control Valves, 16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering, 2006.
11. Srinivasan R, Rengaswamy R, Stiction compensation in control loops: a framewok for integrating stiction measure and compensation, Industrial and Engineering Chemistry Research, 2005 , Vol.44, pp.9164–9174.