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CONTROL VALVE STICKBAND COMPENSATOR

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Abstract: Control valve stiction is a common problem experienced by process control loops and is one of the main causes of loop cycling during a control session. This paper proposes a simple effective stickband compensator which was applied to a plant for reducing stickband and limit cycle amplitude within a unity feedback system. The technique is based on a 'stickband-jacket' applied across the input and the output of the actual control valve. The feedback error signal is used to vary the width of the stickband and limit cycle frequency. The compensator adds a single increment to the controller's degree-of-freedom and can be easily added to any existing control loop.

Keywords: Control valve, stiction, stickband, limit cycle, compensator

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1. INTRODUCTION

Nonlinearities in process control valves have a major effect on the performance of a process control loop. Deadband, stiction, positioner overshoot are regular sources of nonlinearities in process control valves. The most severe and common nonlinearities in process control valves are static friction (stiction) and hysteresis (Hagglund, 2002). There have been many different views on the definition of stiction. From (Choudhury, 2005), "Stiction is a property of an element such that its smooth movement in response to a varying input is preceded by a sudden abrupt jump called the slip-jump. Slip-jump is expressed as a percentage of the output span. Its origin in a mechanical system is static friction which exceeds the friction during smooth movement." The phase plot describing the input- output behaviour of a valve experiencing stiction is shown in Fig. 1 (Choudhury, 2005a), (Entech, 1998). With regard to Fig. 1, we have four regions: dead band, stickband, slip jump and the moving phase (A-G and E-D). The valve will stick when it comes to rest or changes direction at point A. The valve jumps to position D once the controller output overcomes the deadband (AB and the stickband (BC), and there after continues to move past position D. Due to very low or zero velocity, the valve may stick again in between points D and E whilst travelling in the same direction. Stiction results in limit cycling and compromises the closed-loop stability of the process.

2. GENERAL OVERVIEW OF STICTION MODELLING

The two methods used to model stiction are the data driven model and the physical model. Several examples of stiction exist in the literature (Karnopp, 1985; Rossi and Scali, 2005), such as a physical model similar to the Karnopp model which is based on a force balance system implemented in Simulink. Physical models of stiction require parameters such as the valve frictional force, static friction, and valve stem mass, spring constant and actuator air pressure. These parameters are difficult to obtain as they rely on the empirical experience of the practitioner. Data dependent models quantify stiction as a percentage of valve travel or span of the input signal (Choudhury, 2005a).The data driven model utilises two parameters from plant data, namely the valve dead band, plus the stick band with its associated slip-jump.

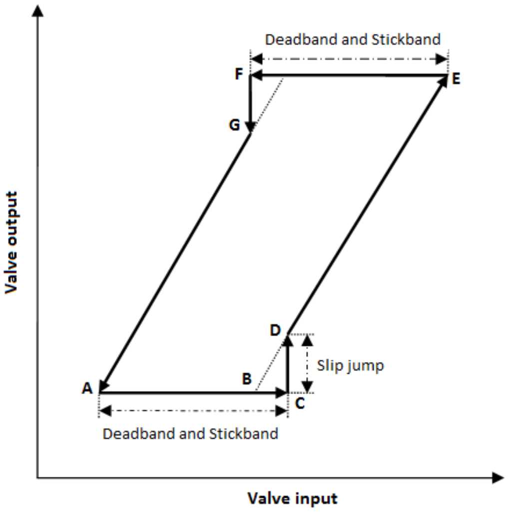

Fig.1. Input- output behaviour of a sticky valve (Choudhury, 2005a)

Choudhury (2005b) applied Newton's second law to model static friction to derive a data driven approximate model of stiction (1).

$$M\ddot{x}(t) = \sum\left(F_a(t), F_r(t), F_f(t), F_p(t), F_j(t)\right) \qquad (1)$$

With regards to (1), M is the mass of the moving body and x is the relative stem position; F_a denotes the force applied by the pneumatic actuator and Fr = -kx represents the spring force where k is the spring constant. F_f, F_p and F_j are the forces due to frictional force, pressure and an additional force required to shift the valve into its seat, respectively (Choudhury, 2005a). F_f can be expressed by (2):

$$F_f = \begin{cases} -F_c sgn(\dot{x}) - \dot{x}F_v \quad if\ x \neq 0 \\ -(F_a + F_r)\ if\,\dot{x} = 0\ and |F_a + F_r| \leq F_s \\ -F_s sgn(F_a + F_r)\ \ if\,\dot{x} = 0\ and |F_a + F_r| > F_s \end{cases} \qquad (2)$$

F_c is coulomb friction, F_v indicates the viscous friction and F_s denotes the maximum static friction that must be overcome for valve movement (Choudhury, 2005a).

2.1. Plant overview

The plant used in the study is given in Fig.2. The signalling conditions are shown in Table 1. An electro-pneumatic valve positioner is used to position a pneumatic butterfly valve via a pneumatic actuator. The cam is part of the positioner that influences the stroke of the actuator as shown in Fig.3. An obstruction was placed on the cam in order to alter the valve characteristic for simulating valve stiction.

2.2. Review of Methods to confirm stiction

A direct test to detect stiction is possible by comparing PV to the controller's output signal (CO) for determining the valve's slip characteristics curve (Gerry and Ruel, 2001; Singal and Salsbury, 2005; Rossi and Scali, 2005). CO is a saw tooth wave and the PV is square for a sticky valve as shown in Fig. 4. The method of comparing PV to CO is a practical method used by control practitioners to detect stiction. Horch (2001) proposed a method based on a cross correlation between CO and PV. From the correlation plot in Fig. 5, the flat region of nonlinearity indicates the valve's stickband. Rengaswamy *et al.* (2001) applied an artificial neural network to detect stiction by associating square and triangular waves to the presence of stiction. Fig. 5 and Fig. 6 shows the impact of varying degrees of stiction which confirms the results of (Rengaswamy, 2001), (Choudhury, 2008) and (Romano, 2008).

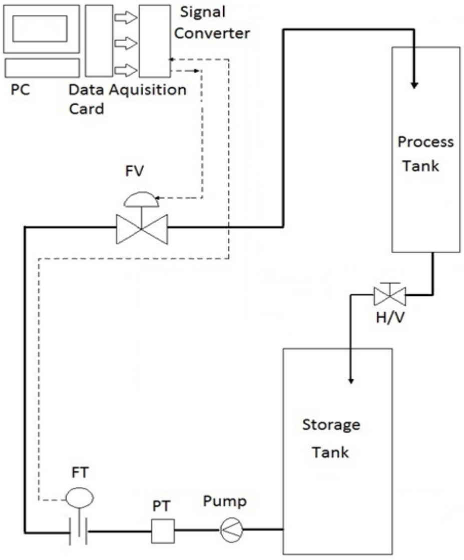

Fig.2. Plant

Table 1. Loop signals

CO	V	mA
0	0	4
2.5	2.5	8
5	5	12
7.5	7.5	16
10	10	20

Fig.3. Cam with modification

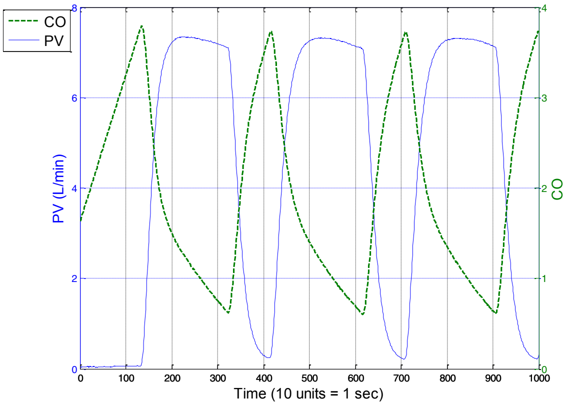

Fig. 4. Closed loop response with stiction present

From Fig. 5 and Fig. 6 we observe the following:

- Cycling amplitude increases with stiction size due to an increased CO.
- Dead zone size increases with stiction.
- Limit cycle frequency reduces with stiction increases.

3. STICTION COMPENSATION

3.1. Stiction compensation methods

Hagglund's knocker (2002) utilises knocker pulses as a additive to CO for overcoming stiction. Kayihan and Doyle (2000) proposed a stiction compensator based on the control valve's operating parameters. The drawback of both methods is the increased stem movement that leads to an increased rate of valve deterioration (De Souza *et. al*, 2012). Many other stiction compensation methods are widely available in the literature.

3.2. Proposed Stickband compensation method

The stickband compensator device proposed in this paper is based on Glattfelder's and Schauffelberger's (1986) technique where an 'anti-windup jacket' is placed around the model of the saturation nonlinearity in order to minimise the effect of the nonlinearity on the loop's behaviour during a control session. Glattfelder and Schauffelberger's (1986) technique reduces the impact of integral windup which occurs when the integral controller calls for a control action that the valve is not capable of producing, usually during plant start-up and load changes. This results in limit cycling and overshoots in process variable. We have applied this technique to reduce the width of the stickband in control loops experiencing stiction nonlinearity.

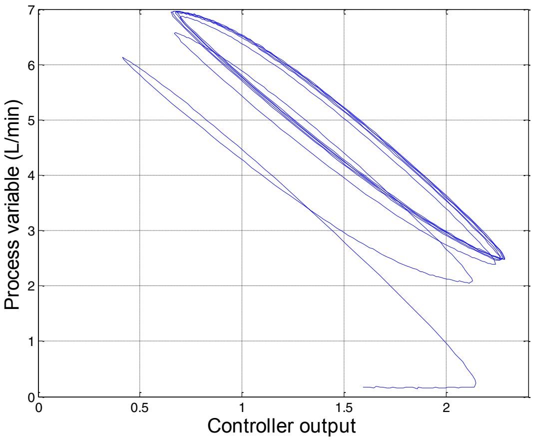

Fig. 5. Correlation plot for weak stiction

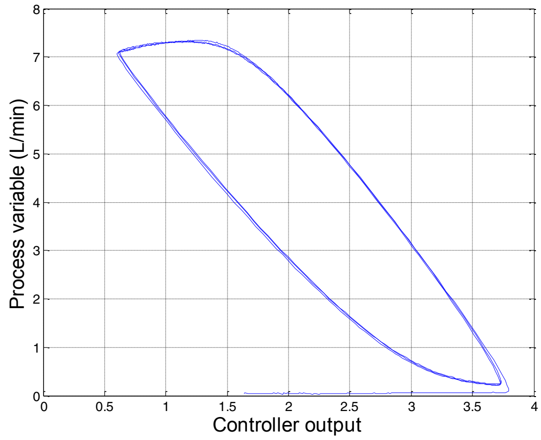

Fig. 6. Correlation plot for strong stiction

The schematic of the 'stickband compensator' is given in Fig. 7, where the feedback from the so-called 'stickband-jacket' is used to create an additional feedback signal for the integral controller. With regards to Fig. 7, the output of the controller (u_c) is compared to the input signal to the process (u'_c) to yield the stiction error (e'). The compensator gain Ks is used to vary the width of the stickband within its upper and lower bands.

3.1 Control loop with the stickband compensator

The compensator is included in the topology of a Type 1 PI/ PID controller and the governing algorithms are defined as follows:

$$U_{PI}(t) = K_p e(t) + \int_{t0}^{tf}[K_i e(t) - K_s(u_c - u'_c)]dt = K_p e(t) + \int_{t0}^{tf}[K_i e(t) - K_s e'(t)]dt \tag{3}$$

$$U_{PID}(t) = K_p e(t) + \int_{t0}^{tf}[K_i e(t) - K_s e'(t)]dt + K_d e(t)dt \tag{4}$$

Equations 3 and 4 are based on the ideal PID algorithm. With regards to equation 3, u_c is the controller output, u'_c denotes the output from the valve and e(t) represents the instantaneous error signal; K_p, K_i and K_d represent the gains of the proportional, integral and derivative controller, respectively; K_S denotes the gain of the stick-band compensator. Utilising Ks in the feedback loop shifts the control from 1-degree of freedom (DOF) to 2-DOF. The loop response converges faster for increases in Ks, with increased oscillations; the opposite applies when K_S is reduced. The impact of K_S on loop behaviour is described by (5).

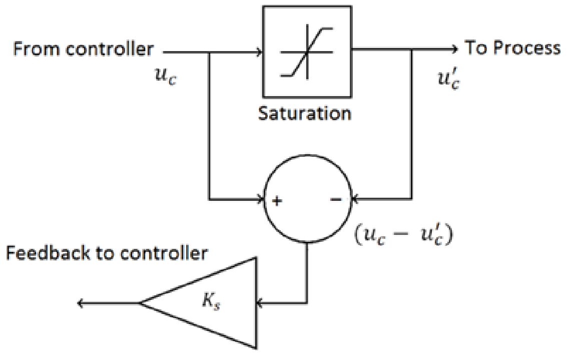

Fig. 7. Stickband compensator

$$K_s = \begin{cases} > 1 & \text{high oscillation frequency with reduced stickband} \\ < 1 & \text{increased stickband with low oscillating frequency} \\ 1 & \text{optimal setting} \\ 0 & \text{zero compensation} \end{cases} \quad (5)$$

4. DISCUSSION OF RESULTS

The response of the plant where the stickband compensator was applied is shown in Fig. 8. With regards to Fig. 8, the stick-band is substantially reduced when the compensator is applied. The amplitude of the oscillations is reduced but is accompanied by an increase in limit cycle frequency. D-action substantially reduces the oscillation amplitude, whilst P-only control eliminates the oscillation and stickband, but yields poor servo tracking.

By limiting the amplitude of the oscillation, the net impact of the compensator is to maintain loop operation within the *(-1+j0)* region of the Nyquist plot, hence ensuring stable gain and phase margins

5. ANALYSIS AND CONCLUSION

The closed-loop correlation plots for PI and PID control is shown in Fig. 9 to Fig. 13.

1. The compensator reduces the width of the stick-band and limit cycle amplitude (cf. Fig.9 *vs* Fig.10 and Fig. 11). Reduced amplitude is brought about by a decrease in the valve's kinetic and potential energies.
2. The reduction in the PV and CO is due to the compensator's internal feedback limiting the integral action at saturation (cf. Fig.10 and Fig. 12).
3. With regards to Fig. 13: For only P-only control and with no compensation present we observe that the response does not have any limit cycling. This also holds true for the response without the compensator. The cost though is poor servo tracking
4. The compensator reduces product wastage and saves energy.

The stiction compensator reduced stickband width without totally eliminating the source of the valve stiction. P-only control with the stiction compensator displays promising results, but achieving the setpoint remains a challenge. The research is currently in progress and potential solutions are being investigated. To eliminate the stiction, the valve will have to be removed from production during scheduled maintenance and the stiction contributors such as the packing and valve lining within the valve assembly must be attended to.

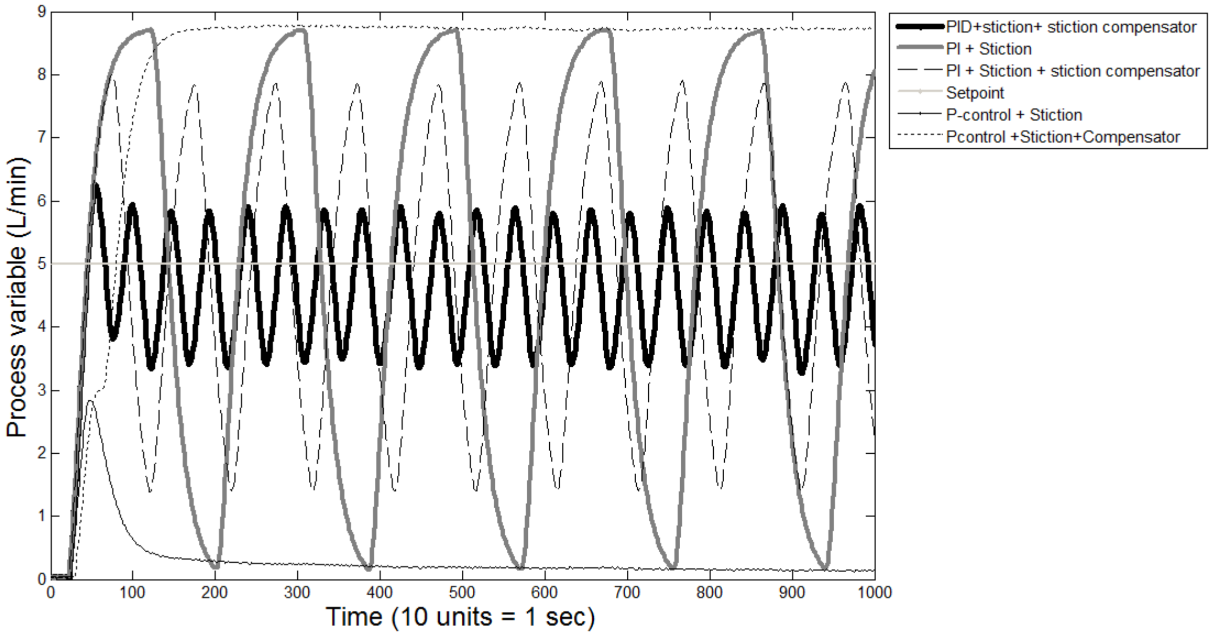

Fig. 8. Plant response with stickband compensator

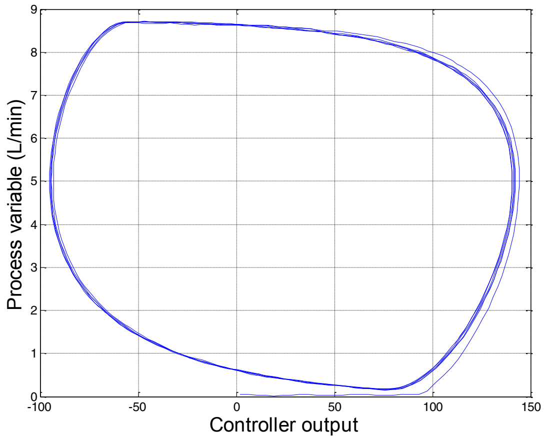

Fig. 9. Correlation with PI control without stickband compensator.

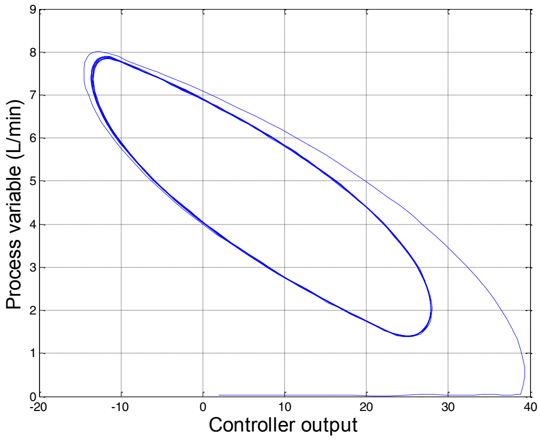

Fig. 10. Correlation with PI control with stickband compensator.

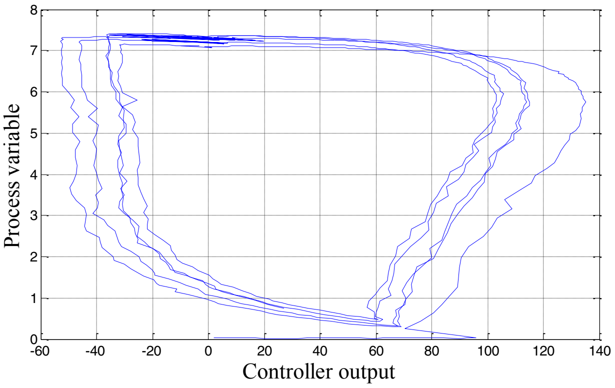

Fig. 11. Correlation with PID control and no stickband compensator.

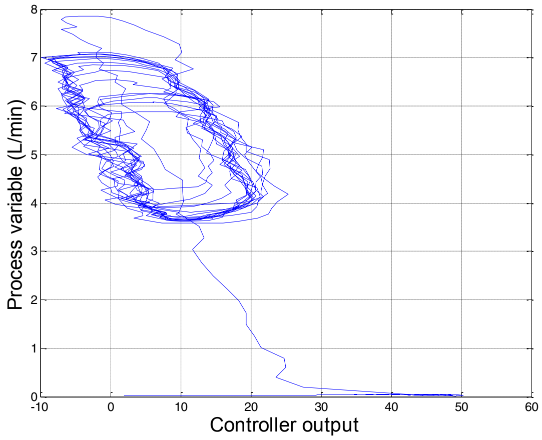

Fig. 12. Correlation with PID control and stickband compensator.

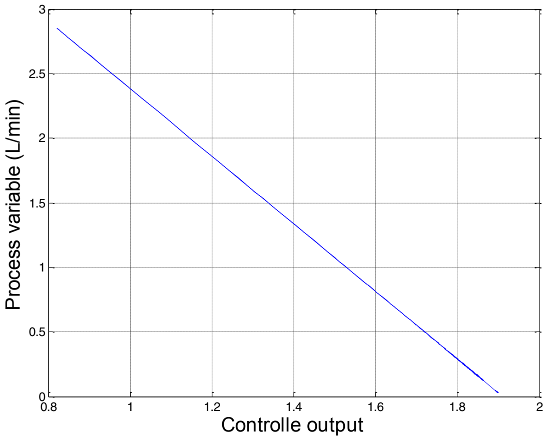

Fig. 13. Correlation for P-control and stiction compensator.

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