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A novel intelligent controller for combating stiction in pneumatic control valves

Puneet Mishra*, Vineet Kumar, K.P.S. Rana

Division of Instrumentation and Control Engineering, Netaji Subhas Institute of Technology, New Delhi, India

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ABSTRACT

Pneumatic control valve introduces limit cycles in process variables due to stiction nonlinearity. In this paper a novel stiction combating intelligent controller (SCIC) based on fuzzy logic has been proposed. The proposed technique reduces the complexity of the overall control scheme as it does not require any additional compensator. The SCIC controller is a variable gain fuzzy Proportional Integral (PI) controller making use of Takagi-Sugeno (TS) scheme. The performance of the SCIC controller has been investigated and compared with conventional PI controller on a laboratory scale flow process. SCIC controller outperformed PI controller and provided promising performance with lesser aggressive stem movement.

1. Introduction

In chemical and other process industry such as petrochemical refineries, fertilizer plants, waste water treatment plants etc, large number of flow control loops can be observed. Flow often acts as manipulated variable for other process variables' control loops, such as, temperature, composition, level etc. Flow control loops can also be found extensively in a plant as the inner loop in cascade control and in ratio control scheme. In nutshell, flow control loops play a vital role in determining the performance and efficiency of a plant, directly or indirectly. Thus flow control is undoubtedly of great concern in a process plant. It is a well known fact that generally pneumatic control valves are used to manipulate flow in a chemical industry rather than motorized valves. The reason being motorized valves use electric current as its input, which is undesirable in case of a chemical industry dealing with hazardous fluids which may get ignited due to an electric spark. Pneumatic control valve broadly consists of two parts, diaphragm and the valve body. Diaphragm converts pressure signal from the controller into displacement signal and propagates it to plug assembly through a stem. The plug assembly, consisting of plug and plug seat, further manipulates the flow by introducing or removing obstruction in the flow line. Depending upon the flow requirement valve size is decided. In a large scale industry dealing with large amounts of fluids, pneumatic control valves may be huge. For movement of stem in such valves large force is required which is generated by the pressure signal through diaphragm. In these valves, to move stem from steady condition requires greater force as compared to alter the movement of stem when it is already in motion. Due to this fact pneumatic control valve suffers from stiction and their input output behavior become highly nonlinear. This nonlinear behavior is quite similar to backlash nonlinearity, generally found in gearing arrangements. Typical input output characteristic of an air-to-open pneumatic control valve is shown in Fig. 1. It can be clearly inferred from the characteristics that the movement of stem cannot be reversed until a specific input change, equal to "deadband (D) plus stick band (J)", denoted as stiction band (S) in Fig. 1, is not achieved. Another feature of this characteristic is "stick-slip" phenomena, also known as slip-jump behavior. This stick slip behavior occurs whenever stem becomes stationary and valve input changes in such a way so as to move stem in the same direction. Static friction is the friction offered when body is stationary and the dynamic friction is the friction offered when body is moving. Since static friction is greater than dynamic friction, larger force is required to move stem from steady position than the force required by stem in moving condition. As soon as the valve input surpasses 'S', the energy stored in actuator forces the stem to move abruptly and thereafter smoothly until valve sticks again (Choudhury et al., 2008). Various researchers and organizations have given different definition about stiction and the one given by Choudhury et al. (2005) is very lucid and can replicate the physical behaviour of stiction (Choudhury et al., 2005), "*stiction is a property of an element such that its movement in response to a varying input is preceded by a static part (deadband plus stickband) followed by a sudden abrupt jump called slip-jump. Its origin in a mechanical system is static friction which exceeds the friction during smooth movement*".

* Corresponding author. Tel.: +91 11 25099050; fax: +91 11 25099022.
E-mail addresses: puneet.mishra@ymail.com (P. Mishra), vineetkuamr27@gmail.com (V. Kumar), kpsrana1@gmail.com (K.P.S. Rana).

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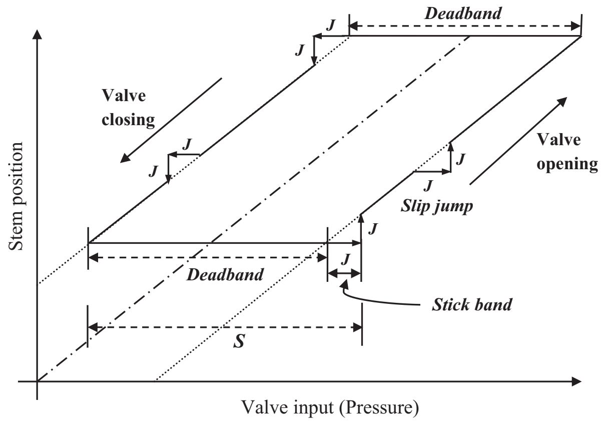

Fig. 1. Typical input output characteristic of an air-to-open pneumatic control valve with stiction.

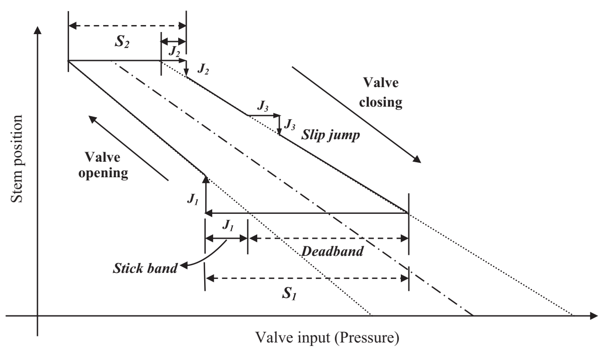

Fig. 2. Generalized input output characteristic of an air-to-close pneumatic control valve with stiction.

Generally the value of '*S*' is not same for valve traversal in both directions. There can be different values of '*S*' for the upward and downward movement of stem. For the same cause the valve characteristic shown in Fig. 1 is not general and shows a special case where '*S*' is common at every point of stem traversal. More generalized representation of the valve characteristic can be shown as in Fig. 2. As shown in the figure, the value of '*S*' can depend upon the instantaneous position of stem and varies for whole operating range. This variation of '*S*' poses a very critical problem in quantification of plant parameters and thereby modeling of the valve characteristic becomes very tedious.

Rinehart (1997) reported in his survey that nearly 80% of the control valves were not in accordance with dynamic performance standards either due to improper sizing or due to other valve nonlinearities such as stiction (Rinehart, 1997). The stiction in control valve can introduce limit cycles in a flow loop and also in the other process variables (*PV*) associated with flow variable. The oscillations in *PV* may directly affect the quality of the throughput of process, accelerate the equipment wear and thereby reduce the profitability of plant (Karra & Karim, 2009). Proper maintenance of the control valves may reduce stiction severity and performance of the associated control loops can be improved (Beckman & Jury, 1997). The maintenance work is usually performed during production stops, typically, at an interval of 6 months to 3 years. The time duration between two consecutive plant shutdown is quite long and losses incurred in this period can be very high and are undesirable (Srinivasan & Rengaswamy, 2008).

Various approaches have been presented to curb stiction related oscillation in *PV* with the help of compensating algorithms in conjunction with controller. Armstrong-Hèlouvry et al. (1994) presented a very good survey on modeling, analysis and compensation methods for friction in machines. This work surveys broad range of fields including tribology, lubrication, physics and control. Various compensation methods to overcome stiction in machines, such as stiff proportional derivative (*PD*) control, *PD* with integral control with deadband, dithering and impulsive control techniques were discussed (Armstrong-Hèlouvry et al., 1994). Dithering and impulsive control technique uses high frequency pulses, which are added to control signal to overcome stiction. The added pulses are generally filtered by low pass characteristic of pneumatic acuators making these techniques ineffective in pneumatic control valve (Srinivasan & Rengaswamy, 2008). Kayihan and Doyle (2000) presented a control scheme for stiction in pneumatic control valve to replace positioners using linear PI control (Kayihan & Doyle, 2000). They proposed a local nonlinear controller using input output linearization with internal model control, to control the position of stem in a process control valve. It was assumed in forming input output linearization control law, that exact information about the valve is available, which is not the case always. Gerry and Ruel (2001) have suggested some measures to detect stiction and reduce its effect on process variable in a control loop. For stiction detection and quantification, they have recommended increasing the controller output in small steps, until a change in *PV* is detected. As soon as a change in *PV* appears, the increment in controller output is assumed to be the measure of stiction (Gerry & Ruel, 2001). To reduce the effect of stiction they have proposed few online measures such as use of PI controller with bandgap; adjustment of the positioner parameters, if installed; replacement of integral control from PI controller with proportional control using high proportional gain etc. These methods are not feasible for a large scale plant since a plant operator cannot make changes to a huge number of pneumatic control valves installed in the plant. "Knocker method" presented by Hägglund (2002), uses short pulses with variable width and amplitude, which are determined from status of control action. These short pulses are added in control signal for stiction compensation (Hägglund, 2002). However to implement the Knocker method efficiently, one has to tune the amplitude, pulse width, and time between each pulse. Though methods are available to automate the process of application of knocker pulse and the *PV* variability was reduced to six to seven times but on the expense of increased stem movement (Srinivasan & Rengaswamy, 2005). The aggressive stem movement is not desired to avoid valve wear and tear. Srinivasan and Rengaswamy (2008) presented an efficient stiction compensation technique "two move approach" (Srinivasan & Rengaswamy, 2008). The output of the compensator at each instant was derived on the basis of instantaneous value of controller output (*OP*), derivative of controller output and the '*S*'. Thus compensation scheme was highly dependent on exact measurement of stiction measure. It was also assumed that there is no mismatch between plant and its mathematical model, which cannot be guaranteed in a real world scenario. Farenzena and Trierweiler (2010) presented a modification to the existing "two move approach" (Farenzena & Trierweiler (2010). Mohammad and Huang (2012) proposed that through proper controller tuning the amplitude and frequency of stiction related oscillation can be reduced on the basis of describing function analysis (Mohammad & Huang, 2012). Their work presented actions to be taken for different types of processes and controller combinations. But in most of the cases stiction oscillations only get reduced, not completely removed. Cuadros, Munaro, and Munareto (2012) presented an improved method for stiction handling in control valves (Cuadros et al., 2012). It was assumed while setting the compensator parameters that valve dynamics and the process dynamics are same, which is not always true. Their approach could handle disturbances but was unable to perform well in cascade loop, where setpoint to the flow loop could move rapidly (Cuadros et al., 2012).