Transactions of the Korean Nuclear Society Spring Meeting
Pyeongchang, Korea, May 27-28, 2010

Compensation of Control Valves Nonlinearities in Flow Control Systems

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1. Introduction

Control valve has an important function in a nuclear power plant to regulate the inlet steam of turbine. Unfortunately, however, the control valve has inherent nonlinearities characteristics such as the static friction (stiction), backlash, and deadband [1-4]. The presence of nonlinearities in a control valve limits the control loop performance and also causes a stability problem in the system. Moreover, this condition renders the design of control system more complex and hard to be handled. Based on this phenomenon, it is desirable to improve the control systems to compensate for these inherent nonlinear characteristics of the control valve. In this paper, a procedure is presented to compensate for the stiction phenomenon of control valve for a pneumatic control valve type. A computational simulation is also presented to check on the proposed method.

2. Methods and Results

In this part, a valve and its stiction model are discussed. Since the pneumatic type is widely used in many process industries due to its low cost and simplicity, this part deals with this type of control valve.

2.1 Control Valve

The structure of a pneumatic control valve is shown in Fig. 1 [3]. In this valve, the valve is opened by an air force and closed by an elastic force. The fluid flow rate is determined by the plug position. This plug is connected to a valve steam. The stem is moved against a frictional force (static or kinetic) caused by packing. This packing is a sealing device to prevent leakage of the fluid. Moreover, the valve (stem) position cannot be changed until the input of the valve overcomes the static friction.

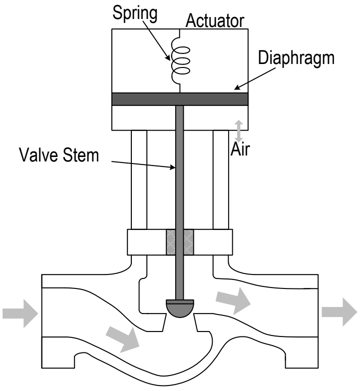


Fig. 1. A pneumatic control valve.

2.2 Stiction Characteristic

A simple relationship between the valve input (controller output) and the valve output (valve position) is shown in Fig. 2 [2]. The dashed line denotes the equilibrium states. In these states, total forces on the diaphragm are balance. The input and output of valve change in an ideal situation along this line without any friction.

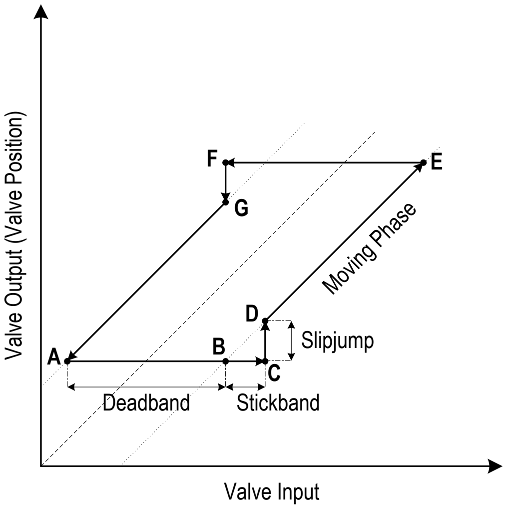


Fig. 2. Relationship between valve input and output.

2.3 Nonlinearity Analysis

The open loop behavior of the control valve model in the presence of stiction is shown in Fig. 3. The valve control is driven by a sinusoidal variation in absence of the controller. Since the input signal angular frequency and period are 1 rad/s and 2π , respectively, the output is

$$y(t)=\begin{cases} k\left(A\sin t+\alpha\right) & ,-\pi\le t\le -\frac{\pi}{2} \\ k\left(-A+\alpha\right) & ,-\frac{\pi}{2}\le t\le -\phi \\ k\left(A\sin t-\alpha\right) & ,-\phi\le t\le \frac{\pi}{2} \\ k\left(A-\alpha\right) & ,\frac{\pi}{2}\le t\le \pi-\phi \\ k\left(A\sin t+\alpha\right) & ,\pi-\phi\le t\le \pi \end{cases} \tag{1}$$

where $\alpha=\frac{(S-J)}{2}$, S is the deadband plus stickband, J is the slip-jump, $\varphi=\sin^{-1}\frac{(A-S)}{A}$, and k is the moving phase slope of input-output characteristic.

By using the Fourier analysis, the output signal can be represented as

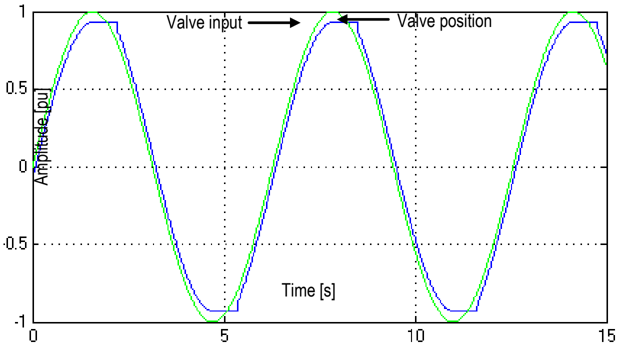


Fig. 3. Open loop behavior.

$$y(t)=\frac{a_0}{2}+\sum_{n=1}^{\infty}\left[a_n\cos nt+b_n\sin nt\right] \tag{2}$$

where

$$a_0=0$$

$$a_n=\frac{kA}{\pi}\left[\frac{1}{n+1}\cos(n+1)\phi-\frac{1}{n-1}\sin(n-1)\phi\right]+$$

$$\frac{2k}{\pi n}(A-2\alpha)\sin n\phi+\frac{2kA}{\pi n(n+1)(n-1)}\sin\left(n\frac{\pi}{2}\right)$$

$$b_n=\frac{kA}{\pi}\left[\frac{1}{n-1}\sin(n-1)\phi-\frac{1}{n+1}\sin(n+1)\phi\right]+$$

$$\frac{2k}{\pi n}(A-2\alpha)\cos n\phi,\ n=1,3,5,\cdots$$

2.4 Stiction Compensation

By assuming that the stiction effect on the system performance can be modeled as a system disturbance, the system block diagram and its stiction compensation can be simplified as in Fig. 4. If we can capture the disturbance and use it as the inverse signal of the disturbance, the disturbance effect can be eliminated.

Fig. 5(a) shows a simulation result of valve without stiction phenomenon. When the stiction is present, a nonlinearity characteristic will appear as shown in Fig. 5(b). Due to the presence of stiction, there is an oscillation in the steady state condition. This condition can degrade the system performance. In Fig. 5(b), the stiction compensator is turned on at t = 100 s and the oscillation can be reduced well (about 75 %).

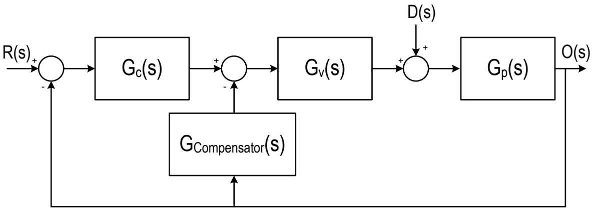
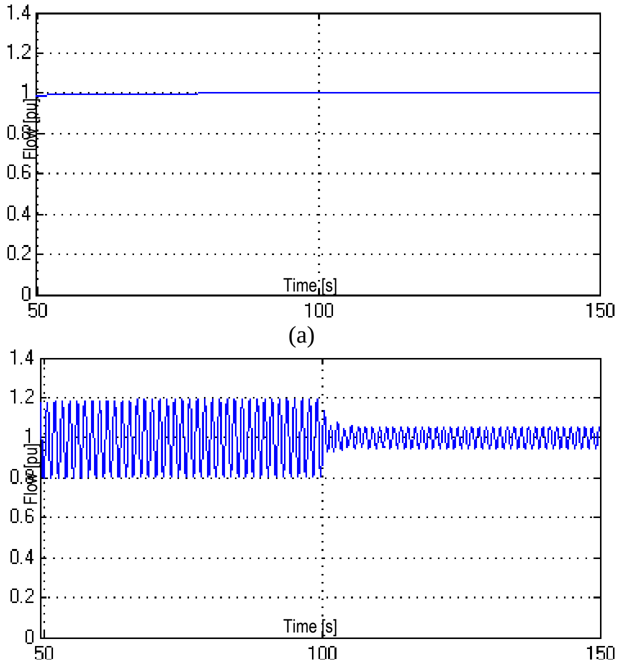


Fig. 4. Compensation block diagram.



(a)

(b)

Fig. 5. Simulation results (a) without and (b) with stiction.

3. Conclusions

A procedure has been presented in this paper to compensate for such inherent nonlinear characteristic of the control valve as stiction characteristic. The proposed method involves inserting a stiction compensator in the feedback signal. The insertion of this compensator can reduce the system oscillation due to the valve stiction.

Acknowledgments

This works was performed under the auspices of the Brain Korea 21 Energy and Resources Engineering Program funded by the Korean Ministry of Education, Science & Technology.

REFERENCES

[1] C. Garcia, Comparison of Friction Models Applied to A Control Valve, Control Engineering Practice, Vol. 16, pp.1231-1243, 2008.

[2] M.A.A.S. Choudhury, N.F. Thornhill, and S.L. Shah, Modeling Valve Stiction, Control Engineering Practice, Vol. 13, pp.641-658, 2005.

[3] M. Kano, H. Matuta, H. Kugemoto, and K. Shimizu, Practical Model and Stection Algorithm for Valve Stiction, Proceedings of the 7th IFAC DYCOPS, 2004, Boston, MA, USA.

[4] R. Srinivasan and R. Rengaswamy, Stiction Compensation in Process Control Loop: A Framework for Integrating Stiction Measure and Compensation, Industrial and Engineering Chemistry Research, Vol. 44, pp.9164-9174, 2005.