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Valve stiction estimation using global optimisation

M. Farenzena*, J.O. Trierweiler

Group of Intensification, Modelling, Simulation, Control and Optimisation of Processes (GIMSCOP), Department of Chemical Engineering, Federal University of Rio Grande do Sul (UFRGS), Rua Luiz Englert, s/n CEP: 90040-040, Porto Alegre, RS, Brazil

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ABSTRACT

Valve stiction is the most frequent cause of loop oscillations. Thus, detecting and quantifying this valve problem is essential to ensuring plant profitability. In this work, a novel one-stage procedure to estimate stiction parameters is proposed using a two-parameter stiction model. The optimisation problem is computed using a global optimisation algorithm. These two propositions make the stiction computation more efficient and computationally faster than the currently available method. The applicability of the proposed approach is illustrated using a large number of simulated and industrial valves. Moreover, to isolate the impact of each proposition, the novel method is compared with the currently available technique, which is based on a two-stage scheme. The results show that the global optimisation algorithm is more efficient than the direct search and genetic algorithms, as previously proposed by Jelali (2008). The two-stage procedure provides a better estimate of the apparent stiction, whereas the one-stage procedure provides a better slipjump value.

1. Introduction

Today, it is common knowledge that ensuring and assessing the performance of each control loop is essential to maintain plant profitability. One factor that can increase loop variability and decrease plant profitability is plant-wide oscillations, whose cause can be external disturbances, aggressive controller tuning, or loop nonlinearities (e.g., stiction and dead-zones; Horch, 1999). The major source of oscillations in industrial control loops is valve stiction (Choudhury, Jain & Shah, 2008). The incidence of this kind of valve damage is high, occurring in close to 30% of all industrial valves, as shown in many reports (Bialkowski, 1993). Taking into account the impact of oscillations and the incidence of stiction, it is clear that methodologies to detect and to quantify this defect are required.

Evaluating loop stiction is not a new issue. The first studies were performed in the 1950s (Brown, 1958). However, in recent years, a considerable effort has been made to diagnose and solve this valve problem automatically using only normal operating data (i.e., the controller output (*OP*) and process variable (*PV*)). Those works that have dealt with stiction can be divided into four groups: modelling stiction phenomenon, detecting valve stiction, estimating stiction parameters, and compensating this valve defect. The main publications in each of these four fields are listed here: (i) modelling (Chen, Tan, & Huang, 2008; Choudhury, Thornhill, & Shah, 2005; Garcia, 2008), (ii) detection (He, Wang, Pottmann, & Qin, 2007; Horch, 1999; Rossi & Scali, 2005; Ruel, 2000; Scali & Ghelardoni, 2008; Singhal & Salsbury, 2005; Stenman, Gustafsson, & Forsman, 2003; Yamashita, 2006), (iii) quantification (Choudhury et al., 2008; Choudhury, Shah, Thornhill & Shook, 2006; Jelali, 2008), and (iv) compensation (Hagglund, 2002; Srinivasan & Rengaswamy, 2008).

In the literature, there are a significant number of methodologies to detect stiction using only process variable and controller output, without using information on the stem position. However, the efficiency of these methods for the detection of stiction in industrial loops is still awaiting confirmation (Jelali & Huang, 2010). In addition, another open issue is the estimation of stiction parameters using only routine operating data, without the stem position.

The first work that proposes two techniques to estimate the apparent stiction (Choudhury et al., 2006) was based on the ellipsoidal behaviour seen in *PV* versus *OP* plot. Choudhury et al. (2006) suggest using *c-means* clustering or fitting an ellipsis in this figure; the stiction is measured on the basis of the maximum width in the horizontal axis. Recently, two works have proposed techniques to compute stiction parameters (apparent stiction (S) and slipjump (J)). The first, proposed by Choudhury et al. (2008), is based on a grid search, where a grid with values of S and J is built, and, for each point, the model valve output is computed (MV), the linear process model is identified, and the mean square error is computed (MSE). The minimum value of the grid determines the stiction estimate. Later, Jelali (2008) introduced

* Corresponding author. Tel.: +55 51 3308 3918; fax: +55 51 3308 3277.
E-mail addresses: farenz@enq.ufrgs.br (M. Farenzena), jorge@enq.ufrgs.br (J.O. Trierweiler).

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an approach based on the least-squares and global search algorithms. The technique is divided into two stages: first, the nonlinear (stiction) model is estimated, and then the (linear) plant model is identified. Again, based on the MSE, the plant and stiction parameters are computed. The solution of the optimisation proposed in Jelali's method requires a stochastic algorithm to find the optimum because of the high number of local minima.

The main advantages of the proposed methods to compute the two stiction parameters are to predict the limit cycles caused by this valve problem and use this information for maintenance purposes or to compensate valve stiction. Choudhury's method is very fast. However, the predicted values can be affected by errors depending on grid dimension. On the other hand, if the grid is narrow, the computation time is large. Jelali's method is very dependent on the initial guess, and because of the search algorithm, the computation time is close to twenty minutes for each valve.

The scope of the contribution of this paper is to solve some of these limitations using a novel technique to estimate the stiction parameters with a single-stage optimisation procedure. Results shows that, using a deterministic global optimisation algorithm, which does not require an initial guess, stiction values can be estimated in less than six minutes with a percentage error of less of than 10% for FOPTD models and less than 13% for integrators. The validity of the proposed method was corroborated against simulation and industrial case studies.

Moreover, to distinguish the impact of each proposed contribution, a systematic comparison between the methods available in the literature and the proposed technique is presented.

The paper is organised as follows. In Section 2, the stiction phenomenon is defined, as are the methodologies that are used to estimate it. Section 3 introduces the method proposed in this work to estimate stiction parameters using a one-stage procedure and global optimisation algorithms. The applicability of the proposed technique is corroborated with application to simulation and industrial valves in Sections 4 and 5, respectively. In Section 6, a systematic comparison between the proposed one-stage method and the two-stage method is presented. The paper ends with concluding remarks.

2. Stiction: model and computation

According to Ruel (2000), stiction can be defined as: "the resistance to the start of motion, usually measured as the difference between the driving values required to overcome static friction upscale and down scale.

The word stiction is a combination of the words stick and friction, created to emphasise the difference between static and dynamic friction. For example, it is sometimes hard to move a piece of furniture. You apply increasing pressure and it suddenly gives, moving rapidly. Similarly, stiction causes the piston of an air cylinder to suddenly lurch forward at the start of a stroke or to move jerkily during its travel.
Stiction exists when the static (starting) friction exceeds the dynamic (moving) friction inside the valve. Stiction describes the valve's stem (or shaft) sticking when small changes are attempted. Friction of a moving object is less than when it is stationary. Stiction can keep the stem from moving for small control input changes, and then the stem moves when there is enough force to free it. The result of stiction is that the force required to get the stem to move is more than is required to go to the desired stem position. In presence of stiction, the movement is jumpy."

In the work of Choudhury et al. (2005), a good discussion on the definition of stiction is given in detail.

2.1. Stiction: model

A sticky valve has four components in the phase plot (stem position (*MV*) versus controller output (*OP*)), shown in Fig. 1: deadband (*DB*), stickband (*SB*), slipjump (*J*), and moving phase (*MP*).

When the valve changes its direction (*A*), the valve becomes sticky. The controller should overcome the deadband (*AB*) plus the stickband (BC), which is called the staticband or apparent stiction. Then, the valve jumps to a new position (*D*). The stiction model consists of two parameters, *S* (staticband) and *J* (slipjump). Next, the valve starts moving, until its direction changes again or until the valve comes to rest between *D* and *E*.

The deadband and stickband represent the behaviour of the valve when it is not moving, although the input of the valve keeps changing. Slipjump represents the abrupt release of potential energy stored in the actuator due to high static friction in the form of kinetic energy as the valve starts to move. The magnitude of the slipjump is crucial to determining the limit cycle amplitude and frequency.

In all methods used to estimate stiction, including the proposed method, the control loop is represented by a Hammerstein model, in which the nonlinear part is described by the two-parameter model and the linear part is the process plant and the controller, as illustrated in Fig. 2.

Here, *G* is the linear plant model, *w* is white noise, *r* is the setpoint, and *C* is the *PI* controller. The stiction model used in this work was proposed by Kano, Maruta, Kugemoto, and Shimizu (2004), where the stiction phenomenon is represented by a two-parameter model.

2.2. Stiction: computation

In the literature, only a small number of works estimate the stiction parameters. Here, four of them will be briefly described: two to compute the staticband (*S*) and two to estimate both the stiction parameters (*S* and *J*).

The first work proposes techniques to compute only one stiction parameter (i.e., the apparent stiction (*S*)). For this purpose, two methods are available: c-means clustering and ellipsis fitting (Choudhury et al., 2006). Both of them are based on the premise that the phase plot between *PV* and *OP* has an elliptical pattern.

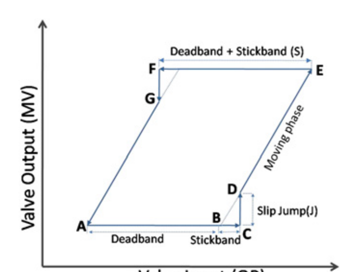

Fig. 1. Relation between controller output (*OP*) and valve position (*MV*) for a sticky valve.

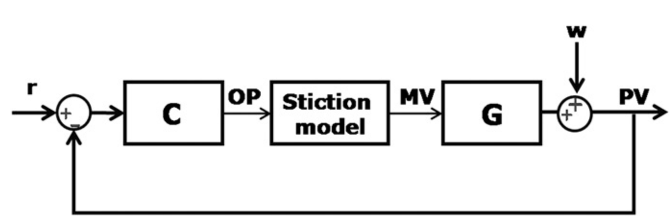

Fig. 2. Closed-loop scheme used to generate the simulation data.