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An improved valve stiction simulation model based on ISA standard tests

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ABSTRACT

The Choudhury valve model is a widely adopted data-driven model to study the behaviour of valve stiction. A recent study (Garcia, 2008) revealed that valve stiction simulation based on Choudhury's simulation model (Choudhury, Thornhill, & Shah, 2005) fails to pass eight out of fifteen Industry Standard Architecture (ISA) standard tests (ISA, 2000, 2006) for real control valves. In this study, the ISA testing results are further elaborated for this model. It is found that three minor deficiencies lead to the discrepancies between the Choudhury Model outputs and the expected ones when (i) the valve input signal changes the direction of travel, (ii) the initial stem position does not stay on the working curves l_1 and l_2, and (iii) the valve input signal changes in a ramp–pause–ramp manner. To address the above deficiencies, an improved version of the Choudhury Model, termed as XCH Model, is proposed. Assessments along with the ISA standards presented by Garcia (2008) demonstrate the proposed XCH Model passes all the ISA standard tests and thus provides a more realistic simulation of a real industrial valve being able to exhibit stiction behaviour.

1. Introduction

Oscillations in control loops usually lead to inferior quality products, larger rejection rates, increased energy consumption and harder abrasion of equipment, etc., which may decrease plant profit. The causes of oscillations include poor controller tuning, control valve stiction, poor process design or oscillatory disturbances, etc. (Horch, 2006; Miao TaS, 1999; Othman, Dumont, & Davies, 1996). Control valves are the most common final control elements in control loops in the process industry and recent work (Bialkowski, 1993; Choudhury, Thornhill, & Shah, 2005; Qi & Huang, 2011) indicates that nearly 30% of the oscillatory loops are caused by valve nonlinearity related problems including stiction, hysteresis, deadband or deadzone. Moreover, it is well known that valve stiction usually results in stable limit cycles (Cuadros, Munaro, & Munareto, 2012; Alexander Horch, 1999; Romano & Garcia, 2011).

Pneumatic control valves are the most commonly used valves in process industry due to their high performance. Seal degradation, unnecessary tightening, expended metal at high working temperature, lubricant depletion are deemed to be the main reasons of pneumatic valve stiction (Hagglund, 1995, 2002). In order to be able to detect, quantify and compensate valve stiction, a prerequisite is to develop valve models to analyses and simulate stiction behaviour. In the last decade, first-principal physical models as well as data-driven models have been proposed (Garcia, 2008; Mohieddine Jelali, 2010). Physical models rely on the description of the motion of stem with Newton's second law (Choudhury et al., 2005; Garcia, 2008) and contain a number of hard-to-estimate physical parameters including spring coefficient, mass of the moving parts and various friction coefficient. This makes the simulation of an actual valve with physical models a time-consuming and difficult task. In contrast, data-driven models have only a few parameters to identify and are thus easy to define and simple to understand (Jelali, 2008; Kwan, Ren, & Huang, 2008; Srinivasan, Rengaswamy, Narasimhan, & Miller, 2005). Data-driven models have been proposed by Choudhury et al. (2005), He, Wang, Pottmann, and Qin (2007) and Stenman, Gustafsson, and Forsman (2003). Among these models, the Choudhury Model is widely used for stiction simulation purposes.

In order to contrast the performance of different valve stiction models, Garcia (2008) recently conducted comprehensive tests on eight valve models with different input signals and valve friction coefficients. The tests were designed according to the recommendations by Industry Standard Architecture (ISA) standards for real control valves. A total number of five testing input signals were generated in Garcia (2008) and for each valve model, three typical stiction levels varying from small to mean and high ones were studied. The simulation results highlighted that, for data-driven models, only the Kano Model passed all tests. The outputs of the Choudhury Model did not comply with the expected values in

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eight out of fifteen standard tests (Garcia, 2008). It should be noted that although the testing input signals recommended by ISA standards may rarely occur in reality and the Choudhury Model hence works well in many practical closed-loop cases, it is still interesting and worth the effort to investigate the reasons that cause the malfunctions of the Choudhury Model. This will deepen the understanding the phenomena of real valves and improve the further development of new data-driven valve stiction models.

This article presents a thorough investigation of the ISA testing results and proposes improvements of the Choudhury Model. It is found that there are three issues in this model that cause the discrepancies between the model outputs and the expected ones: (i) when the controller output or valve input changes its direction, (ii) when the initial stem position does not stay on the working curves l_1 or l_2 (see Fig. 2), and (ii) when the controller output changes in a ramp–pause–ramp manner.

The second contribution of this work is the development of an improved version of the Choudhury Model based on the logic corrections for the above three cases. The new model introduces new logic to simulate the slipping behaviour. Assessments along with the procedures presented by Garcia (2008) demonstrate that the proposed model passes all the ISA tests and thus provide more realistic simulation of real industrial pneumatic valve.

The rest of this article is organized as follows. The Choudhury Model and the ISA testing results are summarized next. Section 3 presents the analysis the deficiencies of the Choudhury model and the improved data-driven valve stiction model, the XCH Model, is presented in Section 4. Finally, Section 5 provides a summary of this article.

2. The Choudhury model and ISA standard valve tests

This section briefly summarizes the flowchart of the Choudhury Model first in Section 2.1, followed by the valve tests design according to the recommendations in ISA standards 75.25.01-2000 (ISA, 2000) and 75.26.01-2006 (ISA, 2006). The discrepancies between the model outputs and the expected ones are presented in Section 2.3.

2.1. Summary of the Choudhury model

The simplicity of the Choudhury Model bases on the fact that it only has two parameters S and J (Choudhury, Shah, & Thornhill, 2004; Choudhury et al., 2005; Mhhieddine Jelali & Huang, 2009). The flowchart and expected input–output behaviour for the model are shown in Figs. 1 and 2, respectively. The corresponding variables and parameters are listed in Table 1.

As illustrated in Fig. 2, four typical behaviours of a sticky valve including deadband, stickband, slip jump and the moving phase are described in Rossi and Scali (2005). Suppose the valve starts to move from point A, the MV will stay unchanged if the OP

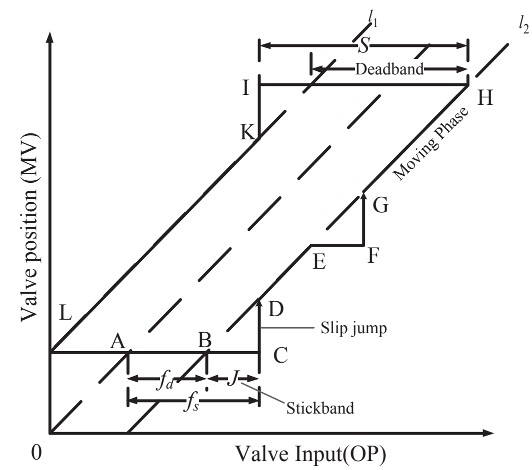

Fig. 2. The schematic diagram for sticky valve (Mhhieddine Jelali & Huang, 2009).

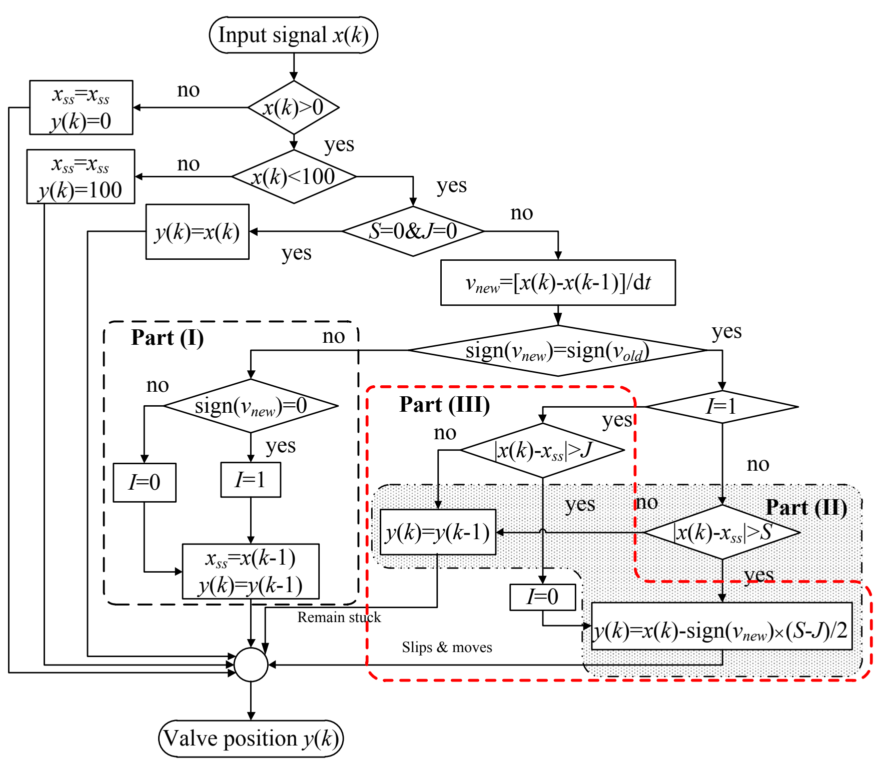

Fig. 1. Flowchart of the Choudhury model.