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Review and comparison of techniques of analysis of valve stiction: From modeling to smart diagnosis

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ABSTRACT

The importance of evaluating valve conditions and detecting the onset of possible malfunctions is recognized as a key issue in control performance monitoring, as they may affect heavily the loop operation and have a direct influence on product quality and then plant economy. In particular valve stiction, a phenomenon which shows itself with similar effects to other causes (as incorrect tuning, external disturbance), but requires specific interventions to eliminate it. This paper aims to be a review of the state of the art about valve stiction, by covering fundamental and applicative issues, classical and innovative approaches.

Being a comprehensive review paper, the approach of presentation of the examined material necessarily follows the categorization of previous survey papers (which are carefully acknowledged). Techniques illustrated in each category are compared pointing out analogies and differences, showing more appealing features and possible points of weakness. In most cases, comparative application on industrial data is performed, and some guidelines for the choice of best methodologies are provided. These aspects have to be considered as added values of the work.

The paper starts with an illustration of basic aspects of the phenomenon of valve stiction, with description of its origin and physical mechanisms, and details about the effects on control variables. Then, different models of valve stiction are examined, and traditional detection techniques and smart diagnosis approaches, based on additional measurements, are presented. Then, the paper illustrates identification and quantification methods, compensation techniques, and software packages proposed for control loop performance assessment.

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1. Introduction

Valve malfunctions, hysteresis, backlash, dead-band, and mainly stiction, have been known since early times to be important causes of performance degradation in industrial control loops (Ruel, 2000). Such problems have been studied within the Process Control community as topics of Performance Monitoring/Assessment of control systems of industrial plants (Jelali, 2006), since they affect plant routine operations and impose periodical shutdowns to remove them. Therefore, they can influence the overall product quality and plant economy.

Oscillations in process variables induced by stiction, can be confused with other causes of malfunction, as incorrect controller tuning, presence of external disturbances, multi loop interactions, and other valve internal problems. In addition, such type of nonlinear oscillations cannot be completely eliminated by controller detuning or by the action of digital valve positioners.

Therefore, the problem of valve stiction must be diagnosed as early as possible, and appropriate actions to take should be suggested to plant operators. This explains the large effort on the subject, carried out by academic research in the last twenty years, facing different aspects of the phenomenon. As fall out, the techniques originated by research work have been adopted in most commercial software packages, initially proposed mostly for retuning purposes.

Several works of review about valve stiction have appeared, even though mostly devoted to specific issues: on stiction detection techniques (Horch, 2006; Choudhury et al., 2008a; Jelali and Scali, 2010; Daneshwar and Noh, 2012), on stiction models (Garcia, 2008), and on stiction compensation methods (Daneshwar and Noh, 2012; Silva and Garcia, 2014). Global reviews, not including smart diagnosis, have been recently proposed by Arumugam and Panda (2011), Brásio et al. (2014b).

Following this short recall about the impact of stiction in control valves, this paper aims to be a comprehensive survey of the most significant works concerning this complex phenomenon, starting from modeling and ending with enhancements in diagnosis and quantification made possible by smart instrumentation. Being mainly a review paper, it necessarily follows the structure of the more recent review paper on the subject (Brásio et al., 2014b), but with a careful updating on publications of last three years, new insights in the comparison and in the application of techniques, and a specific focus on perspectives open by smart diagnosis. The survey consists of pointing out analogies and differences among several recent techniques and showing their more appealing features and possible weak points. Results from the comparison of different approaches are synthesized in tables by reporting significant indices of merit and by providing some guidelines for the choice of best methodologies.

The remainder of the paper is organized as follows. Section 2 presents an illustration of basic aspects of the phenomenon and related oscillations in the control loop, while Section 3 presents different models to describe and reproduce its effects. Section 4 is devoted to the illustration of stiction detection techniques, to recognize its presence since the early stage, while Section 5 covers smart diagnosis, with the possibilities created by the availability of additional measurements and smart instrumentation. Section 6 illustrates stiction quantification methods which allow one to estimate the amount of stiction and its evolution in time. Section 7 deals with compensation techniques to face on-line the detrimental effects of valve stiction. The paper ends with Section 8, where features of different commercial and academic software packages are synthesized. Finally, in Section 9 conclusions are drawn.

2. Phenomenon description

The term *stiction* – contracted form of static friction – was coined in the process industry to stress the difference between static and dynamic friction (Ruel, 2000). Although friction is a long-time-studied topic in tribology, the phenomenon of stiction in industrial control valves has been defined formally only quite recently. Choudhury et al. (2005) have proposed a comprehensive characterization of the physical principle, thus differentiating it from similar valve malfunctions, as backlash, hysteresis, and dead-band.

Stiction is defined as 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', which is expressed as a percentage of the output span. Its origin in a mechanical system is static friction which exceeds the dynamic friction during smooth movement"* (Choudhury et al., 2005).

The difference between the final and initial position values necessary to outdo static friction is considered as the amount of this nonlinear phenomenon. For example, 5% of stiction implies that once the valve gets blocked, it will restart to move and then to vary its actual position only after a cumulative change in control signal exceeding 5% (Choudhury et al., 2005).

In Fig. 1, the five main variables of a "standard" control loop are indicated. Set Point (SP), Process Variable (PV), and Controller Output (OP) are usually recorded, while the actual valve position (VP), is not available in general. Only smart sensors (e.g., encoders) allow one to measure valve position, whereas,