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Frequency analysis and experimental validation for stiction phenomenon in multi-loop processes

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ABSTRACT

The existence of static friction, also known as stiction nonlinearity, in a control valve may lead the entire system to limit cycles. Despite numerous studies on modeling, detection and compensation of this phenomenon, lack of a reliable methodology to predict occurrence and properties of such oscillations, particularly in multi-loop settings, is quite sensible. This work focuses on frequency analysis of multi-loop processes oscillating due to stiction. Before using any of the existing stiction models for the analysis, a comparison between existing stiction models and actual lab data is carried out. Derivation of a mathematical representation of the condition, under which stiction-induced oscillations occur in a multi-loop system, is the main achievement of the proposed analysis. This condition enables users to predict and compare the severity of the oscillations, i.e. values of frequencies and magnitudes, in different situations. Results of the theoretical discussion are validated by both simulation and experimental studies.

1. Introduction

There exist hundreds or thousands of control loops in a typical modern chemical plant. These control loops are designed to maintain processes at proper operating conditions. Acceptable performance and reliability of such control loops ensure the high level of quality of the products. Observing oscillations in different signals of a control system is considered as a result of unsatisfactory performance. These oscillations may have different causes, e.g., aggressive controller tuning, external disturbance and existence of nonlinearity in the system [36]. Classified as nonlinearity, sensors and equipment failures usually play a major role in causing a loop to oscillate. As one of the most important parts of a control loop, which is responsible for execution of the control command, control valve is a potential source of nonlinear behavior. Reports show that diverse nonlinearities in control valves, such as hysteresis, backlash, deadband, deadzone and stiction (static friction), are root causes of 20–30% of all oscillations [10,19,25,37]. According to [24], stiction severity equivalent or more than 1% of the valve travel length can cause the system to oscillate, while this upper limit for hysteresis nonlinearity is determined as 3%. Such facts make the stiction phenomenon an interesting area of study, which faces researchers with wide range of challenges like stiction modeling, detection, quantification and compensation. A summary and comparison of numerous algorithms for detection of stiction are presented by [3]. Quantification of stiction nonlinearity using various approaches, which are considered as a simultaneous detection method, has been reported in [32,18,34,26,16,15,29,5]. Also, several authors have done research on control and compensation of stiction in faulty control systems [35,38,31,20,21]. Brief discussion of existing stiction models and related literature will be presented in Section 1.2. More detailed study of these models can be found in [22].

1.1. Definition of stiction

ANSI defines the stiction phenomenon as “*The resistance to the start of motion, usually measured as the difference between the driving values required to overcome static friction upscale and downscale*” [33]. Moreover, many other phrases have been quoted for definition of stiction in different references [12,2,13,24], among which the one by Choudhury et al. can reflect the behavior of stiction nonlinearity more completely: “*Stiction is 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. Slip jump is expressed as a percentage of the output span. Its origin in a mechanical system is static friction which exceeds the friction during smooth movement*” [27]. Fig. 1 illustrates a typical pneumatic control valve. It is also shown that stiction occurs at interface of packing and the valve stem.

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