VALVE HYSTERESIS AND STICTION SYNTHESIS AND DATA BASED ANALYSIS

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Abstract: This work presents a methodology that allows to detect and quantify two of the most common problems that limit control valves performance in process industry: stiction and hysteresis. As the final element in any control system, a problem in a valve will cause low loop efficiency, even when a sophisticated control algorithm is present. Algorithms to create synthetic data with pure stiction and/or hysteresis was developed, and based on the synthesis methodology, equivalent analysis tools were constructed, allowing quantify valve problems. *Copyright © 2002 IFAC*

Keywords: hysteresis, valve nonlinearity measurement, control loop performance assessment.

1. INTRODUCTION

Control process performance is known to be the way to ensure product quality and low cost of the production in chemical plants. Otherwise, raw materials, operating conditions and even process itself change with the time, in such way that control systems need to be periodically reviewed. In a chemical plant with hundreds or thousands of control loops, an approach based on reviewing loop-by-loop is infeasible, and to make it possible, automatic tools are being developed and used in the industry.

Oscillation is one of the main causes of poor performance of control loops, being caused by ill tunned controllers or, more frequently, by problems in the final loop elements, the valves. The most common industrial problems involving control valves are correlated with hysteresis, stiction and dead-band. This terms often cause some confusion, at one time that the effects are almost the same: oscillation. Otherwise, the problems have different origins, as explained in Choudhury (2005), and the confusion can conduce to a wrong understanding on the real trouble.

This work will discuss main issues related to stiction and hysteresis, introducing a methodology that allows creating artificial data with pure hysteresis or stiction. The methodology can be used in reverse way, measuring the intensity of hysteresis or stiction in real process data.

The paper is organized as follows: section 2 shows industrial motivation to this work, section 3 define the terms stiction and hysteresis, working to reduce the misunderstanding in field. In section 4, the developed methods to create and analyse data with hysteresis and stiction are presented and briefly discussed, being the conclusions and future orientation to the work presented in section 5.

2. MOTIVATION

Oscillatory feedback control loops are a common occurrence due to controller tuning, control valve stiction and hysteresis, poor process and control system design, and oscillatory disturbances (Bialkowski, 1992; Ender 1993; Miao and Seborg, 1999). Bialkowski (1992) reported that about 30% of oscillatory loops are related to control valve problems.

Figure 1 shows real data from a problematic valve in a refinery that clearly suffers from hysteresis and stiction. This valve will cause oscillation in the control loop, and this oscillation will be transferred to the process quality properties, even when the process uses advanced and sophisticated control systems.

The development here presented main objectives are to distinguish and to quantify different valves responses based in data sets.

Data based indexes to measure valve nonlinearities can be easily implemented in commercial control loop performance assessment tools, given online or snapshot information about problems that are related with the physical final element in a control loop. This approach saves time in controller parameters tuning and loop step test, that causes disturbs in the process operation.

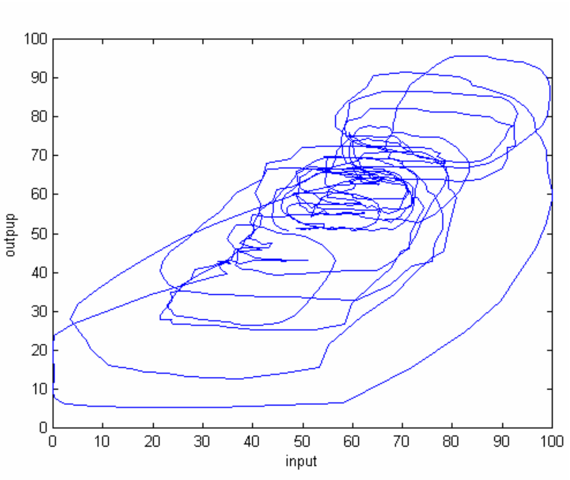


Fig. 1. Real process data suffering hysteresis and stiction problems.

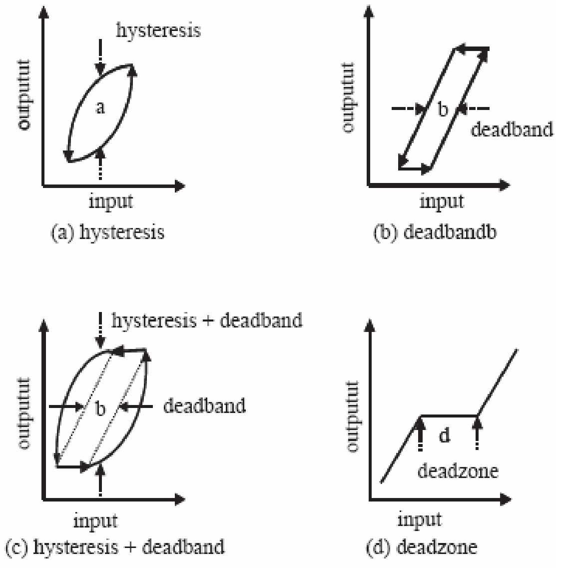
3. DEFINITIONS

Control literature and organizations have defined the terms hysteresis, dead-band, and other correlated ones in different ways, creating some confusion. Following the work presented by (Choudhury, *et al*., 2005), that show a review on the subject, here will be assumed the concepts presented briefly in figure 2, that present valves input (or OP – Output from controller) and output (or PV – Process Variable) values for valves with the problems discussed in this paper.

Figure 2(a) shows results from a system with pure hysteresis, that can be defined like a “property of the element evidenced by the dependence of the value of the output, for a given excursion of the input, upon the history of prior excursions and the direction of the current traverse” (ISA, 1979). In other words, hysteresis can be understood as a dynamical dependency that a property of the system, in the case of interest the valve position, have to the direction in which the driving force is being applied.

Figure 2(b) shows dead-band, defined formally as ‘‘the range through which an input signal may be varied, upon reversal of direction, without initiating an observable change in output signal’’ (ISA, 1979). It is important to note that dead-band, or stiction, will occur only when the valve driving force changes direction.

Figure 2(c) show the composition of hysteresis and stiction, and figure 2(d) shows a valve with deadzone, that is “a predetermined range of input through which the output remains unchanged, irrespective of the direction of change of the input signal” (ISA, 1979), and will not be discussed in this work.



(a) hysteresis

(b) deadbandb

(c) hysteresis + deadband

(d) deadzone

Fig. 2. Hysteresis, deadband or stiction, and deadzone graphical definitions.

Other terms discussed in (Choudry, et. al., 2005), as slip jump, and stickband, that are present in any valves, but cannot be detected in a data based methodology, will not be discussed here.

4. HYSTERESIS AND STICTION ALGORITHMS

There were developed algorithms to generate data with pure hysteresis and pure stiction, where the term “pure” is being used to represent noise and process dynamics free, and algorithms to measure the amount of these properties in process data sets.

In this first moment of development, algorithms are being tested together, creating artificial data with pure hysteresis and stiction and so analysing it. Here will be briefly presented the algorithms bases and some comparison between the expected and reached hysteresis and stiction indexes.

To the synthesis algorithms, there are defined sets of inputs, that represent the valve driving force, or, in a control loop, represents the controller output, and an index that indicate the amount of hysteresis or stiction to be included in the system. The results are valve positions (PV or outputs).

In the analysis algorithms, there are informed the inputs and outputs (process or generated data), and one index meaning the amount of hysteresis or stiction is calculated. This index is desired to be the same that is informed in the synthesis algorithm.

It is important to point out the use of Matlab as basis in the development and the STPR-Tools (Statistical Pattern Recognition) in linear projections, clustering and distribution measurements.

4.1 Hysteresis data synthesis

The systematic to understand hysteresis passes by a recognition in the pattern in which the results are presented. In this work, it will be used two kinds of hysteresis patterns: one based on first order systems dynamic responses and other based on sine-cosine functions. These patterns are presented in figures 3 and 4, respectivally.

When constructing a first order dynamic kind signal, each input point OP is evaluated, taking into account inicial point, direction and final point in a valve travel, using the function below

$$PV = K \times \left(1 - e^{-\frac{OP}{tau/hist}} \right) \qquad (1)$$

where K is the “gain”, or difference between the first point in a turn and the final point, *tau* represent the dynamic, and *hist* is the index that extend or reduce the hysteresis.

By definition, if *hist* is a value larger then 0.6, the sin cosine based function is automatically chosen, and the function used is

$$PV = K \times hist \times \sin\left(\pi \times \frac{OP}{tau} + \frac{OP}{tau} \right) \qquad (2)$$

Both input data set, that represents controller outputs, or OP, and hysteresis index are normalized. Data set is adjusted to a 0-100% range, in such way that, independent of the original data set, algorithm uses full scale. Hysteresis index is scaled in a 0-1 range, being interval divided into two base functions.

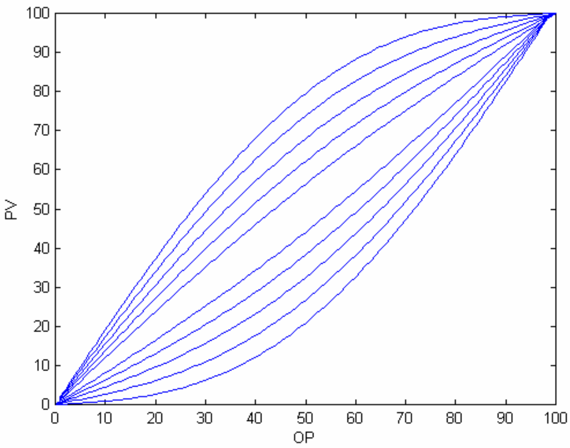


Fig. 3. Artificial data with hysteresis created with first order dynamic systems function (equation 1).

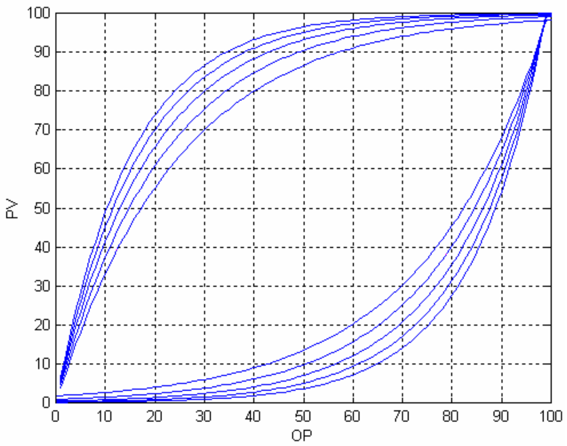


Fig. 4. Artificial data with hysteresis, created with sine and cosine functions.

The requirement of two different functions is caused by problems in one and another when used to represent data in distinct regions. When using equation with *hist* greater than 0.5, in a full range valve turn, the equation gives a gap. Otherwise, using equation 2 with *hist* lower than 0.6, it can be produced data with PV out of range 0-100%.

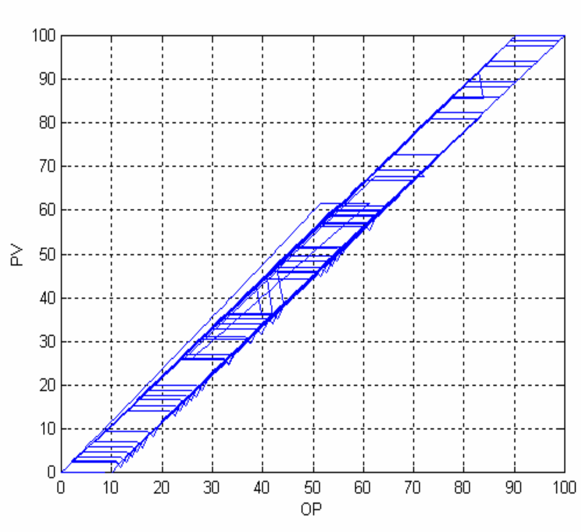


Fig. 5. Artificial data with fixed stiction index and random OP set.

4.2 *Stiction data synthesis*

To recognize stiction, its is not necessary do develop patterns, once the problems are not dynamics, but statics. Figure 5 shows results for systems with stiction.

The data set is normalized as in the hysteresis data synthesis algorithm, to the 0-100% range. The stiction index is informed in units of OP variation to move PV.

4.3 *Hysteresis data analysis*

To quantify hysteresis in process data, it is necessary to measure the “opening” in one I/O graph. To do this, the first step is recognizing direction in controller signal (OP), up or down. This step is easily done scanning data.

After data separation, the groups are arranged in clusters, that will be inherently isolated if hysteresis is present. To measure the separation between clusters, it is used a linear projection of original data in one axis. To determine the projection axis, it is possible to use PLS (partial least squares) or LDA (linear discriminant analysis) methods (Franc and Hlavac, 2004), but the simple diagonal axis brings better results in data clustering.

Distribution of projected data in the axis is determined using maximum likelihood estimation of a Gaussian mixture model (Lauritzen and Wermuth, 1989).

Figure 6 shows the diagonal axis (straight line), the directions in OP, up or down, and the normal distribution of the points.

Systems with more hysteresis will produce moved away peaks, so the hysteresis index is obtained directly from the distance between peaks.

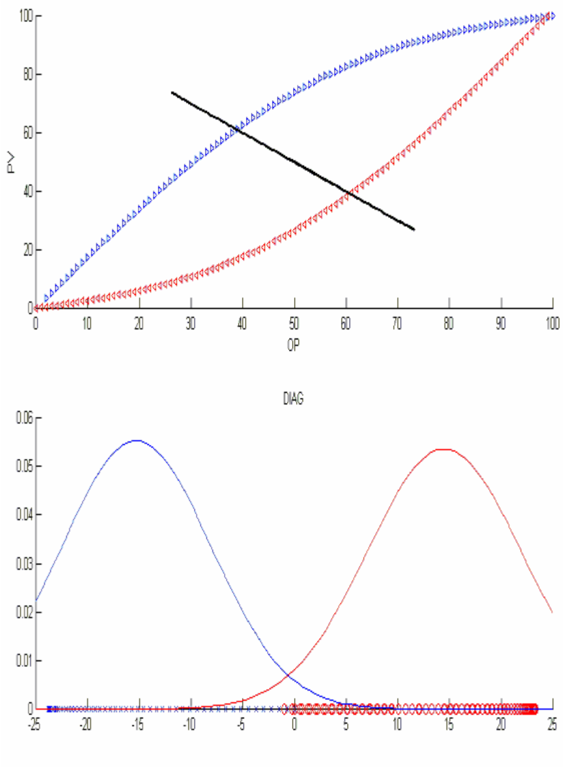


Fig. 6. Hysteresis measurement system.

Figure 7 illustrates two different curves, generated with more or less hysteresis, allowing comparison.

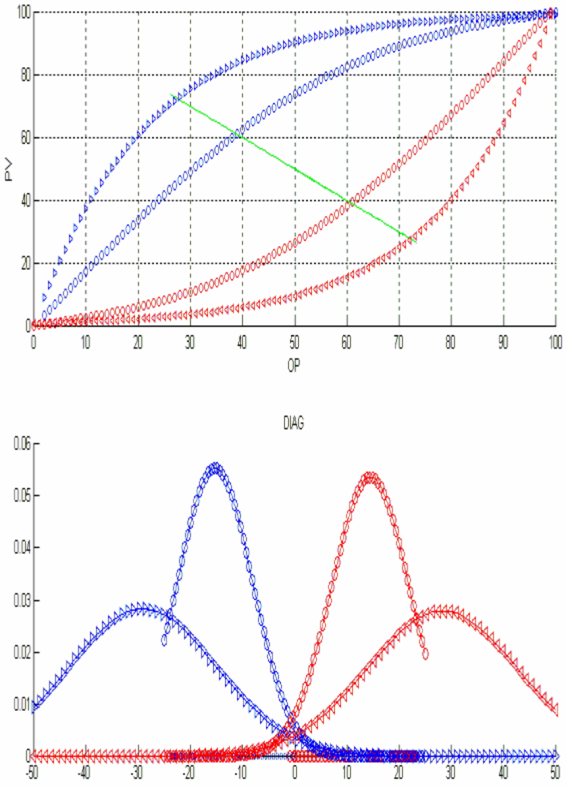


Fig. 7. Two different curves, showing distance betwwen peaks in function of the hysteresis ammount.

4.4 Stiction data analysis

To quantify stiction, process data is scanned, so direction changes in data set can be easily detected. Algorithm understands that until three in sequence PV points do not leave a determined moving band (1% by default), the valve is in stiction.

The amount of stiction is the mean OP variation to take off PV from this band.

4.5 Algorithms calibration

Proposed algorithms validation were made generating data sets with different hysteresis and stiction degrees. Analysing data set and comparing found indexes with that ones used in synthesis , it is possible to .

Hysteresis algorithm was tested creating and analysing data with indexes from 0 to 0.5, to test data created with equation 1, and from 0.6 to 1, to test data created with equation 2. The gap between bands is a deliberated scheme to separate the base equations.

Figure 8 shows the indexes used in generation, in horizontal axis, and result from the analysis algorithm, in the vertical. The straight line shows that that the algorithm catches hysteresis from original data.

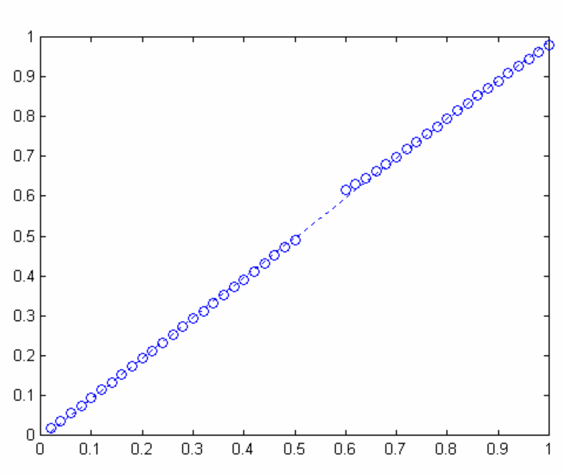


Fig. 8. Hysteresis algorithm test results.

In the same way, stiction algorithm was tested creating data with known stiction degree, and so this data is analysed. Results with original and calculated stiction are presented in figure 9. Again, the resultant straight line shows good correlation between synthesis and analysis algorithms.

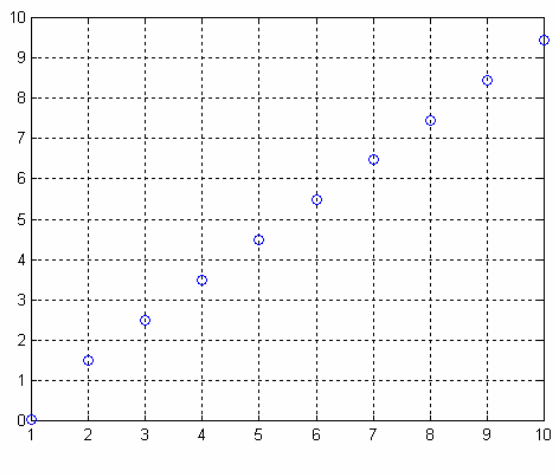


Fig. 9. Stiction algorithm test results.

5 CONCLUSIONS AND NEXT STEPS

The developed system give good results, allowing generation and analysis of data with pure hysteresis and stiction. The calibration of algorithms functions gives reproducibility in data analysis.

From now, it is necessary to develop routines that can work with both valve hysteresis and stiction satisfactorily, differentiating these factors. Dead band needs also to be detected and measurable.

Methodology needs also be tested in industrial process problems, beyond the created data sets, to be validated. Here, also filtering techniques will be explorated.

Finally, it is desired to use process variables directly, instead of valve inputs and outputs. Valve I/O signal is not ever available, but the use of process variables is not direct, once process dynamics need to be taken into account.

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