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PNEUMATIC CONTROL VALVE STICTION DETECTION AND QUANTIFICATION

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ABSTRACT*: Pneumatic control valves are playing major role in the closed loop process control system. It is found in literature there are 20-30% (chodhury et al 2005) of process industries having limit cycle oscillations due to control valve nonlinearity which is the only mechanical device in closed loop process control system and deteriorate the end products. In the control valve stiction is the major nonlinearity problem than the other nonlinearities like backlash, hysteresis and saturation. This stiction nonlinearity causes the wastage of utility in the process industry. Recently there are so many methods to understand, define, model and detect stiction. Here for identification of stiction the Adaptive Neuro Fuzzy Inference Methodology have been used. For a vertical two tank level process with kano's model of stiction is considered to obtain necessary required data to formulate objective function. Here the ANFIS method simultaneously detect and quantify stiction. The work is being carried out in the MATLAB/SIMULINK platform.*

Keywords*— ANFIS, Control valve, Dead band, Stiction, Nonlinearity*

I.INTRODUCTION

Nonlinearity plays a significant role in the closed loop performance of a process. If a process is highly nonlinear, a linear controller may not perform well. Linear control systems made of linear devices which mean they obey the superposition principle. Nonlinear control systems cover a wider class of systems that do not obey the superposition principle. The presence of nonlinearities in a process can affect its control performance adversely. nonlinearities in pneumatic control valves like stiction may cause oscillations in process variables.

The control valve is the actuator for most process control loops and, as the only moving part in the loop, its function is to implement the control action. If the control valve malfunctions, the performance of the control loop is likely to deteriorate, no matter how good the controller is. Commonly encountered control 3 valve problems include nonlinear responses to the demand signal caused by effects such as stiction, deadband or saturation. Because of these problems, the control loop may be oscillatory, which in turn may cause oscillations in many process variables causing a range of operational problems including increased valve wear.

Stiction in control valves is thought to occur due to degradation of seal, depletion of lubricant, inclusion of foreign matter, activation at metal sliding surfaces at high temperatures and tight packing around the stem. The resistance offered from the stem packing is often considered as the main cause of stiction. Another very common cause of stiction is indirectly related to regulations on volatile organic compound emissions.

The following figure will show the pictorial representation of the control valve

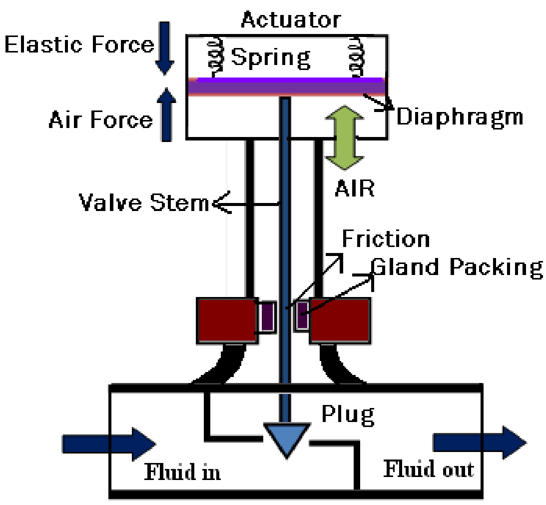

Figure: 1.1 Control Valve

A Model based segmentation method [6] described to detect stiction in control valves. It is necessary to detect and estimate the amount of stiction so as to feed correct amount of input to the process as manipulated variable. Usual conventional model also fails to map nonlinear behavior of Stiction in pneumatic control valve. In this paper, the ANFIS method is used for modeling and identification of the control valve stiction.

II.BACKGROUND

A. STICTION: "Stiction is a property of an element such that its smooth movement in response to a varying input is preceded by a static part (dead-band + stick-band) followed by a sudden abrupt jump called „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 dynamic friction during smooth movement". Figure1.1 shows the schematic general structure of a pneumatic control valve. The phase plot of the input-output behavior of a valve "suffering from stiction" is described as shown in Figure 1.2. It consists of four components: dead-band, stick-band, slip jump and the moving phase. When the valve comes to a rest or changes the direction at point A in Figure 1.2 the valve sticks as it cannot overcome the force due to static friction. After the controller output overcomes the dead-band AB plus the stick-band BC of the valve, the valve jumps to a new position D and continues to move. Due to very low or zero velocity, the valve may stick again in between points D and E while travelling in the same direction. In such a case the magnitude of the dead-band is zero and only the stickband is present.

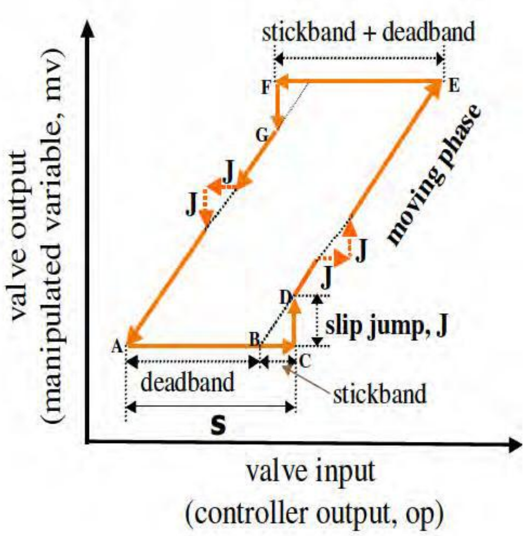

Figure: 1.2 Input (Op)-Output (Mv) Behaviour Of Sticky Valve

B. CLOSED LOOP PROCESS CONTROL SYSTEM:

The general block diagram of process control valve (in closed-loop) with stiction is illustrated in Figure 1.3. In the control loop diagram, 'r' denotes reference input, the controller gain is denoted as Gc, the control valve gain is represented as Gv and the process gain is denoted as Gp. Measurements of the process variable PV and controller output OP were used to estimate the parameters of a Hammerstein system, consisting of a non linear control valve stiction model and a linear process model. The process output is denoted as ' y_b ' and the external disturbance is denoted as ' y_d '. Finally, the process variable PV is denoted 'y' and the expression of output is described as follows,

$$y = y_b + y_d = N(u) + y_d \qquad (2.1)$$

Where, y_b is the process component in equation (2.1) in terms of control valve output ' u_v ' and process transfer function 'N'. The identification of the linear dynamics (valve&process) is decoupled from the nonlinear element (stiction). The decoupling between the nonlinear and the linear component is achieved by an iterativeprocedure.

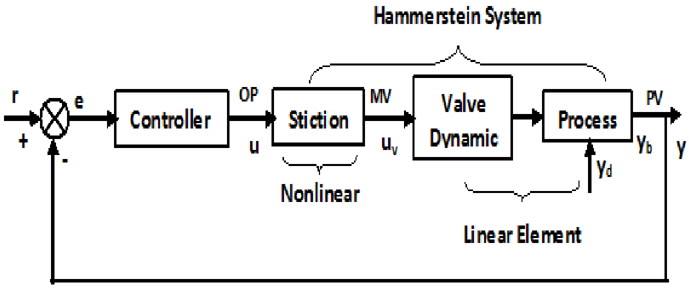

Figure:1.3 CONTROL LOOP WITH STICKY VALVE

III. DETECTION OF STICTION: A BRIEF REVIEW

Numerous research works on stiction nonlinearity in control valve are available in literature based on their modelling, identification, estimating and controlling. There have been many attempts to understand, define, model and detect stiction in control valves, but quantification of the actual amount of stiction still remains a challenge. The definition and modeling of control valve stiction have discussed and they demonstrated a method to detect and quantify the actual amount of valve stiction using routine operating data. The proposed method was completely data-driven model. No additional excitation or experimentation of the plant was required.

Separable least-squares and global search algorithms has presented a procedure for quantifying control valve stiction in control loops. Measurements of the controlled variable PV and controller output OP were used to estimate the parameters of a Hammerstein model structure, consisting of a connection of a two-parameter stiction model and a linear low-order process model. As the objective function was non-smooth, gradient-free optimization algorithms, i.e., pattern search PS methods or genetic algorithms GA were used for fixing the global minimum of the parameters of the valve stiction model, subordinated with a least-squares estimator for identifying the linear model parameters. Different approaches for selecting the model structure of the linear model part were discussed. Their results show that this optimization-based technique recovers accurate and reliable estimates of the stiction model parameters, dead-band + stick-band S and slip-jump J, from normal operating data for self-regulating and integrating processes. The robustness of the proposed approach was proven considering a range of test conditions including different process types, controller settings and measurement noise

IV. KANO'S STICTION MODEL

The two-parameter model as discussed in has been modified in attempted to relate *S* and *J* to the elastic force, air pressure and frictional force. In Kano's model, *S* corresponds to the summation of static and dynamic friction and *J* corresponds to the difference between the static and dynamic friction. Having this in mind, they offered an alternative flow chart for simulating stiction. The flowchart for stiction simulation is presented in Fig.4.1 The input and output of this valve-stiction model are the controller output *u* and the valve position *y*, respectively. Here, the controller output is transformed to the range corresponding to the valve position in advance.

In Kano's model, two states of the valve are explicitly distinguished, denoted by the variable *stp*. In the moving state *stp* has the value 0, while in the resting state *stp* is 1. In addition, the controller output at the moment the valve state changes from moving to resting is defined as u_S. The u_S is updated and the state is changed to the resting state (*stp* =1) only when the valve stops or changes its direction ($\Delta u(t) - \Delta u(t-1) \leq 0$) while its state is moving (*stp*=0). Then, the two conditions concerning the difference between $u(t)$ and u_S are checked unless the valve is in a moving state. The first condition judges whether the valve changes its direction and overcomes the maximum static friction

$$y(t) = u(t) - df_d = u(t) - \frac{d(S - J)}{2}. \qquad (4.1)$$

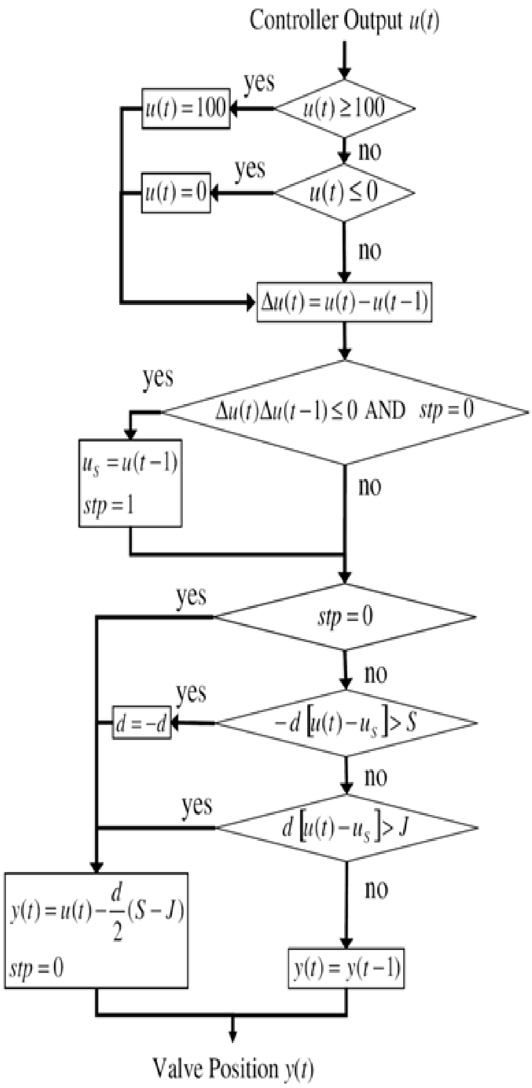

FIGURE 4.1. FLOW CHART OF KANO'S STICTION MODEL

Here, $d = \pm 1$ denotes the direction of frictional force. The second condition judges whether the valve moves in the similar direction and overcomes friction.

V. PROBLEM STATEMENT AND PROPOSED METHODOLOGY

For stiction modeling there are number of methods used to identify such as curve fitting method, cross correlation method, relay fitting method, Hilbert method, Fourier method, etc. These methods works based on the principle of either by decomposing the signal or comparing or over lapping the signal with sinusoidal or triangular reference wave forms. The objective function used here is to determine the stiction level is based on the least square error or mean error of the signal. The existing methods are having major drawbacks to determine the percentage of stiction presence in the system. Presence of Stiction is classified as week stiction, strong stiction and no stiction category. Results obtained by these methods having poor accuracy (classifying either no stiction or week stiction as strong category or strong presence of stiction is identified as week or no stiction category) / determining level or difficulties in algorithm establishment.

Many control loops in process plants perform poorly due to valve stiction which is one of the most common equipment problems. It is well known that valve stiction in control loops causes oscillations in the form of periodic finite-amplitude instabilities, known as limit cycles. This phenomenon increases variability in product quality, accelerates equipment wear, or leads to control-system instability. Several methods have been developed to detect valve stiction in the last decade. However, all these methods require either detailed process knowledge or user interaction which is not desirable for automated monitoring systems. Since, at present there is no method to quantify these performance problems.

The proposed methodology will be having the ability to overcome those discussed disadvantages and having an advantage of ability to determine the percentage of stiction level presence in the system. As we discussed above/earlier to overcome those disadvantages the proposed methodology uses adaptive neuro fuzzy (ANFIS) inference system for determine the presence as well as percentage of stiction present in the system. Adaptive neuro fuzzy inference system is a kind of neural network that is based on Takagi–Sugeno fuzzy inference system. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. The proposed ANFIS can construct an input-output mapping based on human knowledge and appropriate membership functions to generate the stipulated input-output data pairs. In the simulation, the ANFIS is employed to model nonlinear functions, and predict a chaotic time series, all yielding a remarkable result.

VI.MODELLING OF PROPOSED SYSTEM

System is designed to be having a data logging units at the places, marked in error, controller output, and valve output. Objective/cost function is defined to be ratio of above mentioned variables, expressed in equation (5.1 & 5.2) below.

$$\text{INPUT}=\left\{\begin{array}{l}\dfrac{error\ e(t)}{input\ i(t)}\\ \dfrac{controller\ variable\ co(t)}{input\ i(t)}\\ \dfrac{Manipulated\ variable\ mv(t)}{input\ i(t)}\end{array}\right\} \qquad (5.1)$$

$$\text{OUTPUT}=\{stiction\ \ (0-1)\}$$

VII. COUPLED TWO TANK SYSTEM

The control of liquid level in tanks and flow between tanks is a basic problem in the process industries. In vital industries such as petro-chemical industries, paper making industries, water treatment industries have coupled tanks processes of chemical or mixing treatment in the tanks. The level of fluid in the tanks and interacting between the tanks must be controlled. It is essential for control system engineers to understand how coupled tanks control systems work and how the level control problem is solved. The problem of level control in coupled tanks processes are system dynamics and interacting characteristic. The State Space equation of the two tank coupled system is represented as below

$$A=\begin{bmatrix}-1 & 1\\ 1 & -2\end{bmatrix} \qquad B=[1\ \ 0]$$

$$C=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} \text{ and } \qquad D=[0\ \ 0]$$

VIII. SIMULATION RESULTS AND DISCUSSION

A vertical two tank system (level process) is considered for our test case. To introduce stiction presence in the test case system Kano's stiction model is taken into consideration; similarly other models (Choudhary's Model, He's Model, etc…) can also possibly to be implemented. Proposed system is established in MATLAB/Simulink environment. Results are obtained with interval of 10% of stiction increment. The required values of input and output are estimated using equation (5.1 & 5.2). For test case fuzzy system is designed as three input (error, OP & MV) and single output (stiction). There are three membership function were selected for each variable (error, OP & MV) to process the system and the membership function areas are defined as Gaussian surfaces. Along with the obtained fuzzy system MATLAB 'anfis' function is used to create an adaptive neuro fuzzy structure required to determine the percentage of stiction level . To prove the efficiency of the proposed system, it is executed with different stiction level (from 0 to 100% with 1% increment). Using ANFIS structure the amount of stiction in percentage is obtained and compared.

The graph represented in Fig.8.1 shows clearly, there is non-oscillatory response when stiction is not introduced in control valve. From the graph it is understood that the control valve is performing in a smooth way and it is also understood that the closed loop performance of the system is acceptable one. On the other hand if a small stiction introduced in control valve, it leads continues oscillations both in process variable (PV) as well as in the controller output (OP). Hence, it is clearly understood that the control valve is not functioning in a systematic manner and valve needs identification of stiction level in it. Fig.8.2 Express the graphical representation between actual stiction level and calculated stiction level using ANFIS algorithm. Fig.8.3 indicates the error level presence in proposed methodology.

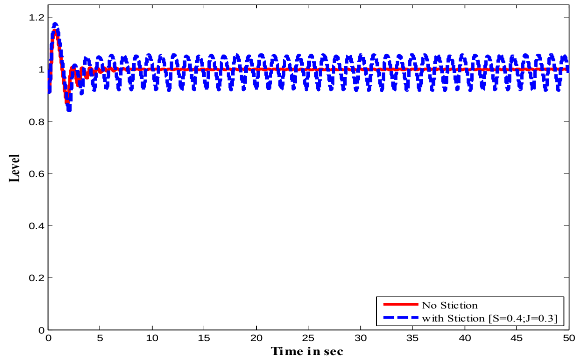

Figure 8.1. waveform obtained with and without the presence of stiction

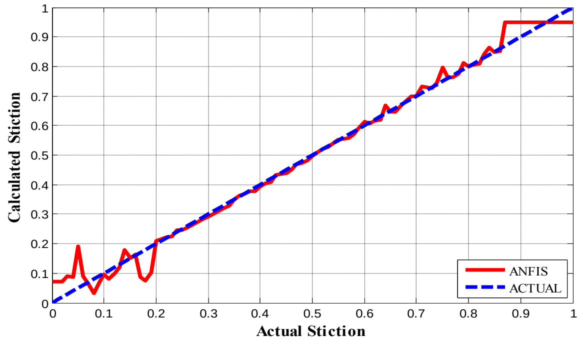

Figure 8.2. waveform obtained actual and calculated stiction level

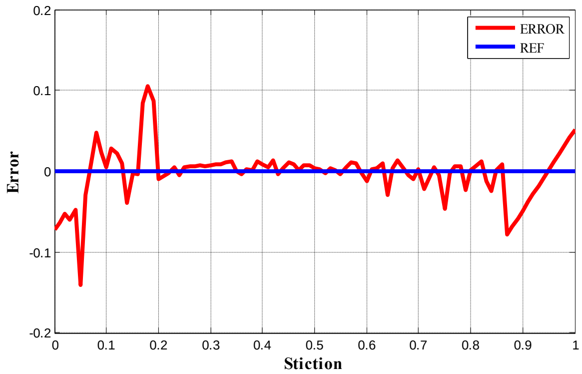

Figure 8.3. waveform obtained between stiction and the error

IX. SUMMARY AND CONCLUSION

Stiction in control valve produces oscillation thereby degrades the closed loop performance of the system. A detailed study on detection, identification and quantification of stiction in control valves is presented here. Stiction is detected and identified using different conventional methods and the same is presented using ANFIS techniques in this work, where reliable results were obtained. Two tanks system in series are used for this work to study the closed loop behavior using a flow control valve with stiction. From the obtained results it is clear that proposed methodology is superior over existing methods used for stiction detection. The ability of proposed method to detect and estimate the exact level of stiction present is also proved. From Fig.8.3 it is clear that the proposed method have a peak error of 10% and average error of 3% which is in the acceptable range compared with existing methods used to determine the stiction level in the system.

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