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Model-Based Stiction Control of a Motorized Valve

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ABSTARCT
Motorized Valve or Motor Operated Valve (MOV) is an important item of Plant & Piping system. These valves are generally of wide size range and are used for different applications such as Pump discharge, process industries, power generation stations oil and gas, and control of wide range of fluid flow. The problems of MOV are usually Position Overshoot which could be caused as a result of aggressive tuning of the controllers, Stiction which is a combination of words stick and friction. This term is a condition that holds the valve in a particular condition and sticks it there, not allowing it to move. In this paper, existence of stiction was identified through mathematical models. Proportional controller was introduced to overcome the instability to attain steady state. Results shown, indicates that stiction causes drag, external force and delay time in output delivery. In conclusion, a model based stiction control of a motorized valve was achieved.

Keywords: **Motorized, Valve, Stiction, Overshoot, control**

I INTRODUCTION

Failure in control of flow of fluids such as gas, crude oil, steam, vapour, hot water could be very dangerous when the desired need is highly expected. Therefore the controllability of the device or devices that actualize the ease of operationality of system becomes imperative. Motorized valve is the major device used to regulate the apature for the opening and closing of flow of these fluids. Motorized Valve or Motor Operated Valve (MOV) is an important item of Plant & Piping system. These valves are generally of wide size range and are used for different applications such as Pump discharge, flow systems, process control etc. Motor Operated Valves are often called as On-Off valves as the motors serve the purpose of fully opening or fully closing valves in pipelines and other facilities. For example, cooling water lines in process pipelines where controlling of fluid is not required, motor operated valves can be used to fully allow or fully stop the fluid flow. These valves are not used for throttling purposes as they serve mainly On-Off application. Motor operated valves can be of various types e.g. Gate/,Ball,/ Butterfly etc. with actuator control. Design of Motors and valves can be different. An electric motor is mounted on the valve and geared to the valve stem so that when the motor operates, the valve will open or close. Motorized valves are proportional valves that are used when the output flow needs to be precisely controlled or continuously adjusted. A motorized valve is also a central heating system component which controls the a piping system when hot water from boiler is used to heat the radiators, or the water in a hot water cylinder for the taps. It is usually found adjacent to the hot water cylinder, e.g., in the airing cupboard. As the name implies, it is electronically operated. [1] (Sensoware, 2018)

The driving force of the motorized valve is large, and it can control the large diameter valve, such as globe valve, gate valve, etc., the utility model is especially suitable for large diameter pipelines or places where the flow of pipelines is required to be regulated. Every versatile equipment has its short comings.

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Motorized valve has the following issues and if not properly controlled the objective of the usage becomes useless. Some of the problems associated with motorized valve includes Electric conductor brokened, loose wiring terminal, supply voltage is wrong and below normal or calliberated level. Motorized control valve failures and the understanding the root causes can be a very challenging task. Four common failures associated with motorized valves apart from the ones associated with electrical faults are found at a high frequency in poorly performing control loops. These are Dead band and Stiction, Positioner overshoot, Incorrect valve sizing and Nonlinear flow characteristic.

Dead band A valve with dead band acts like there is some backlash between the controller output and the actual valve position. Every time the controller output changes direction, the dead band has to be traversed before the valve physically starts moving. Although dead band may be caused by mechanical backlash (looseness or mechanical linkages), it can also be caused by excessive friction in the valve, an undersized actuator, or a defective positioner. A control valve with dead band will cause oscillations in a level loop under PI or PID control if the controller directly drives the control valve (non-cascade). A control valve with dead band can also cause oscillations after a set point change in control loops on self-regulating processes – especially if the integral action of the controller is a little excessive.

Stiction Another very common problem found in control loops is stiction. This is short for Static Friction, and means that the valve internals are sticky. If a valve with stiction stops moving, it tends to stick in that position. Then additional force is required to overcome the stiction. The controller continues to change its output while the valve continues to stick in position. Additional pressure is mounted in the actuator. If enough pressure builds up to overcome the static friction, the valve breaks free. The valve movement quickly absorbs the excess in pressure, and often the valve overshoots its target position. [2]. (Bill Kuang, 2022) These problems always have devastating effects due to control inadequacy in control mechanism

II LITTERAUTRE REVIEW

[3] worked on a valve stiction tolerant formulation of Model Predictive Control (MPC) for industrial processes. The paper presented three different formulations of MPC to face static friction in control valves for industrial processes. A pure linear formulation, a stiction embedding structure, and a stiction inversion controller were designed. The controllers were derived for SISO systems with linear process dynamics, where valve stiction was the only nonlinearity present in the control loop. A novel smoothed stiction model was introduced to improve and fasten the dynamic optimization module of stiction embedding MPC. A stiction compensation method was revised and used as a warm-start to build a suitable trajectory for the predictive controller. The different MPC formulations were tested and compared on some simulation example. In their result, A robust behavior was verified in the presence of significant amount of white noise on the output, and even for conservative errors in the nonlinear part of plant model, that mismatched on valve dynamics parameters. [3] investigated the **c**ontrol valve basics, Sizing and selection. they investigated that a control valve is a power operated device capable of modulating flow at varying degrees between minimal flow and full capacity in response to a signal from the controlling system. They further affirmed that control valves may be broadly classified by their function as “on-off” type or “flow regulating” type. They also said that control valve is comprised of an actuator mechanism that is capable of changing the position of flow controlling element in the valve. The valve modulates flow through movement of a valve plug in relation to the port(s) located within the valve body. The valve plug is attached to a valve stem, which, in turn, is connected to the actuator. [4] worked on Design and Implementation of an Electric Actuated Valve for Precise Fluid Control. Their work focused on Fluid control as one of the essential automation application area in industry. They observed that in order to control fluids effectively and precisely, valves which are crucial components, need a controlled rotating motion which leads to implement electric motors, electronic controller and gear systems altogether. In their study, an electric motor actuated valve system was designed and prototyped. The design phases included switch mode power supply (SMPS) design, motor controller circuit design, mechanical implementation and controller design. The designed valve system was manufactured and tested using multi-disciplinary fashion. [6] Researched on an Adaptive Control Method for the Distribution Valve of a Digital Pump. they deduced that Perfect flow distribution is extremely important and essential for digital pumps. However, the fluctuation of motor speed and the change of valve dynamic characteristics cause the flow distribution flaw, which

generates the backflow of the oil in the piston chamber and the decrease in pump volumetric efficiency based on the three-dimensional and mathematical modeling of the digital pump. [7] Worked on a dead-band model and its online detection for the pilot stage of a two-stage directional flow control valve. In their paper, a detailed dead-band model describing the relationship between pilot valve spool and the flow rate of the pilot control valve was proposed. And an improved dead-band description involved with the housing clearance of the valve spool is developed to prove the dead-band uncertainty for a single valve system. Then a simple and effective method was proposed to detect the varying dead-band values in the pilot stage. This method was specially designed with a limited main spool displacement and short time interval so that it can be used for online detection without affecting the hydraulic system where the two-stage valve was involved. With the regular dead-band inverse function, comparative experimental results show that this method is effective to attenuate the large trajectory tracking error caused by the varying dead-band. This dead-band detection also can be applied to other electro-hydraulic proportional valve-controlled position control systems with unknown dead-bands.

[8] Demonstrated that the large transient power hydraulic systems, characterized by high pressure, large transient flow and high output power, have widespread industrial applications in converting powerful hydraulic energy to kinetic energy in a transient period. A conventional large flow rate directional valve was unable to be used in these applications due to the slow response. A directional control valve with fast response and high flow capacity simultaneously was presented for the large transient power hydraulic system in their paper. The valve utilizes a three-stage structure with two high-speed on/off solenoid valves as the pilot stage and two cartridge poppet valves as the secondary stage to overcome the fundamental trade off between valve response and flow capacity. A precise mathematical model of this valve considering both turbulent flow and laminar flow was developed. A test apparatus which has the ability to provide and measure transient large flow was built. The flow rate was estimated based on the pressure dynamics. The property parameters in the simulation model were optimized against measured data. According to the dynamic characteristics analysis, the valve response was split into the starting delay and opening time. The step response was rapid enough to provide a large transient flow, while the high flow capacity was not reduced due to the fast response. The main control pressure was characterized by its change time and critical open pressure and these two parameters determine the main-stage response. Some key structural factors concerned with these two parameters were discussed in detail and optimize to further reduce the response time. [9] Explained that Stiction has been reported as the most commonly occurring nonlinearity in control valves. In the literature, mechanistic and data based models were proposed to characterize stiction. In their paper, the available models were analyzed. The complexities associated with modeling stiction were highlighted. It was shown through experiments on industrial valves that in the presence of static and dynamic friction, the valve behavior is dependent on the rate of the valve input. An approach to model this rate - dependent valve behavior - which was not considered in existing data driven models was proposed.

III METHODOLOGY

A Modeling the Effect of Temperature Change Due to Process Characteristics of the Fluid Flowing through the Motorized Valve

Fig. 1: Motorized valve on a pipe for fluid control

The dynamic model of a valve system is:

$$X'(s) = \left(\frac{K_1}{\tau s+1}\right) X_1'(s) + \left(\frac{K_2}{\tau s+1}\right) W_2'(s) \quad (1)$$

Where;

W denotes flow rate

K denotes gain

ρ denotes density

V denotes volume

x_1 denotes input variable

x denotes output variable

x^1 denote deviation variable

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$\tau = \frac{V\rho}{w}$, (2)

$K_1 = \frac{\overline{W_1}}{W'}$ (3)

$K_2 = \frac{1-\bar{x}}{w}$ (4)

Note that:

$X'(s) = \mathcal{L}[x'(t)]$ (5)

$X_1'(s) = \mathcal{L}[x_1'(t)]$ (6)

The bar over a symbol denotes a nominal steady state value

The block diagram of the figure 1 below shows the detail information of equations (1-6). In the diagram, the deviation variable $X_d(s)$ denotes the change in outflow composition due to a change in inflow composition X_1'(s) (the disturbance). Similarly, X_u'(s) is a deviation variable that denotes the change in X'(s) due to a change in the manipulated variable (the flow rate, W_2'(s)). The effects of these changes are additive because X' (s) = X_d'(s) + X_u(s) as a direct consequence of the Superposition Principle for linear systems. Also, this transfer function representation is valid only for linear systems and for nonlinear systems that have been linearized, as is the case for the process model for valve actions.

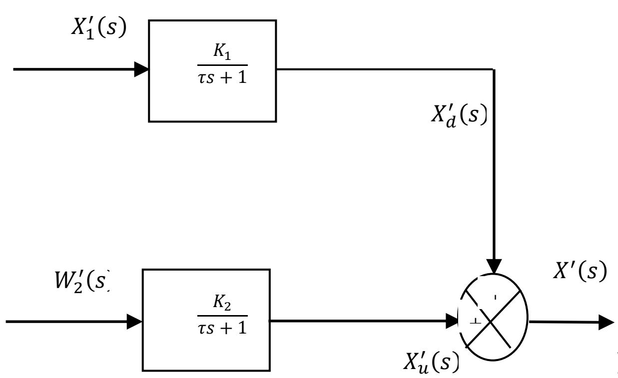

Fig.1: Block diagram of process in valve

B Stiction Models

A relay based model as given below was used to detect and quantify stiction [9]

$$x(t) = \begin{cases} x(t-1) \\ u(t) \end{cases} \quad (7)$$

If $|u(t) - x(t-1| \le d$

Equation 7 is characterized by a single parameter 'd', termed as stiction band. Here x(t) and x(t-1) are past and present stem movements, u(t) is the present controller output. The stem moves from one position to the other once it overcomes the dead band 'd'.

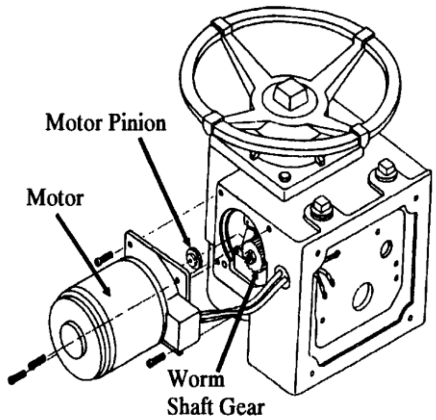

Fig. 2: Motor operated valve (MOV) [8]

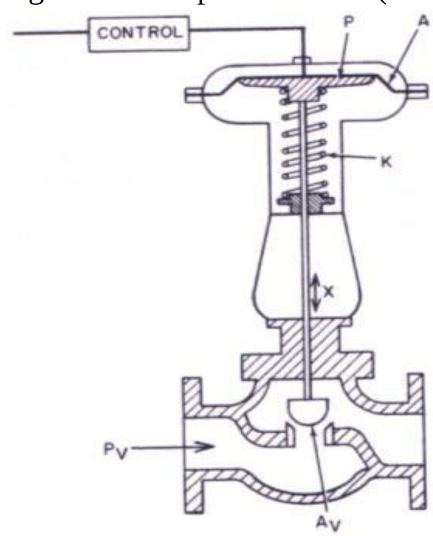

Fig 3: Mechanical view of Valve

A control valve has at least two components:

• a valve body that houses a valve seat through which the fluid flows and

• an actuator that responds to the applied signal and causes the motion of valve seat through a stem resulting in modifications to the fluid flow.

Additionally, a valve may contain a positioner that moves the stem to its desired position. Figure 3 shows a schematic of a spring and diaphragm actuator operated valve. The positioning of the stem is achieved by a balance of forces acting on the stem:

forces due to pressure on the diaphragm, the spring travel, and the fluid forces on the valve plug.
From normal friction, mass and displacement, we cam illustrate that:

At normalcy,
Let x be the threshold stem movement at a flow rate w and time t, thus at first stem displacement:
Distance = x
Flow rate = w
Time of normal displacement = t
At second displacement;
Distance = x_1
Flow rate = w_1
Time of displacement = t_1
To determine the stalment of valve stem or Stiction, we have

$x - x_1 = \Delta x$ (8)

$w - w_1 = \Delta w$ (9)

$t - t_1 = \Delta t$ (10)

If $\Delta w \leq w$ Stiction is noticed (11)

$\Delta w \geq w$ No stiction observed (12)

$\Delta x \leq x$ Stiction is observed (13)

$\Delta x \geq x$ No stiction observed (14)

$\Delta t \leq t$ No stiction observed (15)

$\Delta t \geq t$ Stiction is observed (16)

Equations 11 to equation 16 are used for simulation

IV RESUILTS

Control valve failures are quite obvious to experienced control valve technicians and Engineers and can easily be detected by loop performance assessment softwares. Others can be more difficult to detect without running specific tests. One of biggest challenges with control valves, is failure analysis during turn around onsite services. It is essential therefore to always make sure to watch out and/or test for the following valve problems. Four common failures associated with control valves, are found at a high frequency in poorly performing control loops. These are Dead band, Stiction, Positioner overshoot, Incorrect valve sizing and Nonlinear flow characteristic. Figure 4 shows valve with normal characteristics without any of the above problem and it was plotted with position set point versus the valve positioner. This is to actually ensure that there is no position overshoot which is one of the dangerous phenomenon. It could be observed that it is a linear system at that moment.

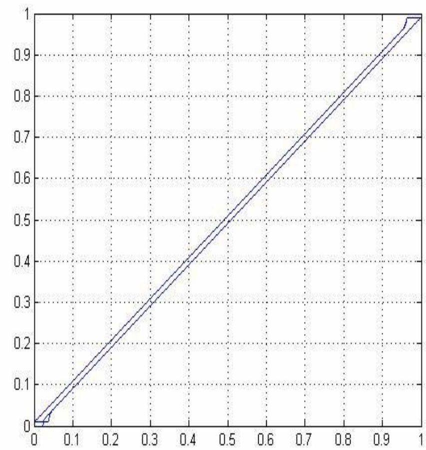

Fig.4: This is simulation result of the Valve in normal working condition and position set point versus Valve position when there is no stiction

In figure 5 below, stiction was initiated to see how the performance of the valve will be and it was discovered that there was initial time lag or what could be classified as dead zone at the beginning before the system was linearized to certain point and transient set up towards the out put end at the time of 0.7seconds and 0.85seconds. this is noticed when position set point versus valve position during Stiction. This actually shows the adverse and time wastage because of Stiction problem.

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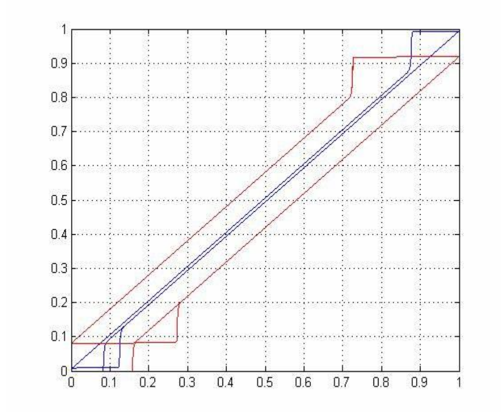

Fig.5: Simulation of position set point versus Valve position in Stiction.

In figure 6 below, it can be noticed that on simulation of the multi-step valve response under Stiction condition , the dead band or time lag is obvious, upto 5 seconds and the performance started uptill 0.5 inch of the stem movement of the valve before stability was achieved and overshoot set in up to the stem movement of .0.3543 and 0.3937 cm before the system was stable at 30 seconds.

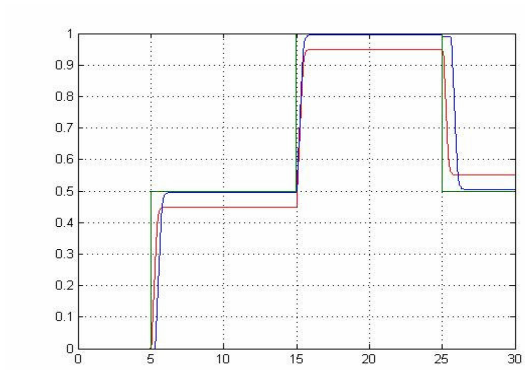

Fig. 6: Simulation of Multi-step Valve response in Stiction.

Figure 7 depicts the action of proportional controller (P) when the close loop was facing distortion of the stem response versus the output response of the valve when the overshoot and Stiction was acting on the control valve. At the initiation of the valve action to control the fluid movement, this faced the rising of the system instability close to 0.35433cm of the valve stem at approximately 21 seconds before trying to attain stability at a time of 28 to 30 seconds. At this stage, time is of enormous value and product to be delivered is at stake.

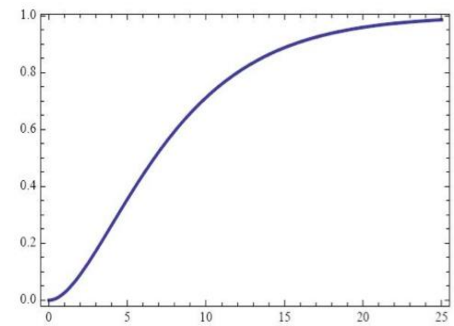

Fig.7: Controllers installed to clear stiction in the valve with rise time.

V CONCLUSION

In this paper it is shown through simulation that valves like any other mechanical system is dependent on the rate at which it is opened or closed. Comprehensive modeling of valve stiction is a complex task. Low velocity motion of a valve can lead to a staircase pattern for a ramp input. However, this is not seen when the valve is operated at a higher velocity. Process industries often experience production loss and reduced profits, and produces inferior-quality products because of stiction in control valves. Stiction is more likely to be cause of oscillations in industrial control loops. In conclusion, model-based stiction control of a motorized valves was studied, stiction was modeled and simulated. The result showed that proportional (P) controller used was able to control the system loop and brought the instability under a steady state condition.

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