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Stiction Detection in Valve Using He's Model by Simulation of Valve Characteristic Transfer Function

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Valve stiction is one of the most prominent problems in chemical process monitoring. In each, chemical plant there are 500 – 5,000 process control loops, most of them have fluid as their main element and need valves as the primary control equipment. As those valves tend to have irregular maintenance and stick regularly. While the problem itself is not a big deal, when combined with how typical controllers in the industries work, it causes limited oscillations in the fluid flow rate as well as all related state variables of the process. Several surveys showed that valve stiction is a cause of around 20-30 % of oscillation problems, it is the main problem in process monitoring so many automatic valve stiction detection models have been developed such as Choudhury's model, Kano's model, and He's model. This paper proposes the study of valve stiction by He's model to predict by simulated valve characteristic transfer function affecting the water tank process.

1. Introduction

Valve stiction is one of the most prominent problems in chemical process monitoring (Choudhury, 2005). In each chemical plant, there are 500 – 5,000 process control loops, most of them have fluid as their main element and need a valve as the primary control equipment (Paulonis, 2003). As those valves tend to have irregular maintenance, they stick regularly. According to Raul "Stiction is a combination of the words stick and friction, created to emphasize the difference between static and dynamic friction. Stiction exists when the static (starting) friction exceeds the dynamic (moving) friction inside the valve. Stiction describes the valve's stem (or shaft) sticking when small changes are attempted." (Raul, 2000). In other words, it is an occurrence that prevents the valve from moving in a manner that a plant operator or controller wants because of forces of friction.

While the problem itself is not a big deal, when combined with how typical controllers in the industries work, it causes limited oscillations in the fluid flow rate as well as all related state variables of the process. This oscillation is a major concern in industries as about 80 % of their closed loop have the problem (Zheng et al., 2021) resulting in excessive energy and raw materials consumption as well as safety issues. Even though several surveys showed that valve stiction is a cause of around 20-30 % of the oscillation problem (He, 2007), it is not the only one. The oscillation problem can be caused by others such as external disturbances, inadequate controller tuning, or the presence of other process non-linearities. And while the solutions of oscillation problems are relatively straight-forward if the causes are known, identifying the causes can be problematic.

Since the problem is a major one in the field of process monitoring, in the last decades, many automatic valve stiction detection models such as Choudhury's model, Kano's model, and He's model (Zhang et al., 2017).

This paper proposes the study of valve stiction detection from the feedback control loop for a water tank system (Klucka, 2016) by He's model to predict by simulated valve characteristic transfer function three main types available are usually designated: Quick opening, Linear, and Equal percentage for VP (Valve Position) of He's model vs. VP (Valve Position) of valve model plots were utilized for a water tank system and looking at the process changes, it was found that there was an oscillation because the valve was stuck, causing the water in the tank to increase in height. This causes process fluctuations, causing the process variables to not approach the desired set value of 12 m, resulting in wasted energy used to control the water tank level measurement process. (Vazquez et al., 2019).

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2. Materials and Methods

2.1 Simple feedback for a valve-controlled process

The feedback level control of a close loop from Figure 1, The following variables are recorded: process variable (PV), set point (SP), valve output (MV), and controller output (CO). The error is defined as the setpoint minus the process output. It is a measure of how much the process deviates from the desired setpoint from Eq(1). The PID controller from Eq(2) by gain (K), integral (I), and derivative (D) were calculated by the auto-tune feature of the Ziegler Nichols (Kozin, 2016). The value obtained from the process of measuring the water level from the tank from Eq(3) using the Python program to calculate values.

$$e(t) = SP - PV \tag{1}$$

$$m(t)=K(e(t)+I\int e(t)dt+D(de(t)/dt)) \tag{2}$$

$$y(t) = q/A - (a(2gh)^{0.5}) /A \tag{3}$$

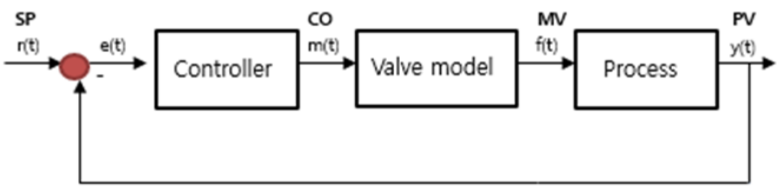

Figure 1: Diagram of the feedback control loop for a water tank system

2.2 The procedure that summarizes valve characteristics modeling system

Step 1: It will find the appropriate pipe and valve size that is suitable for the flow rate used, by finding the valve coefficient (C_v) to select the appropriate pipe and valve size from the catalog. Valve manufacturer's lock Valtek series Mark One, Flow-under, then find the flow rate from Eq(4) and find the pressure drop across the valve from Eq(5).

$$q = VA_v \tag{4}$$

$$C_v = q/N_1F_p\,(G_f/\Delta P_v)^{0.5} \tag{5}$$

Step 2: Valve model Eq(3) terms of the transfer function as shown in Figure 2, the first transfer function of the control signal function to the valve position. Valve stiction is checked as in Eq(6).

$$(dV_p/dm) = \text{valve model} \tag{6}$$

Generate the control signal at m=0 versus time at t=0 initial value and the valve position versus time as in Figure 3. Then, check the stiction by taking the control signal relative to the valve position as in. Then, He's model predicts in Figure 4 the valve characteristics model and whether there is stiction.

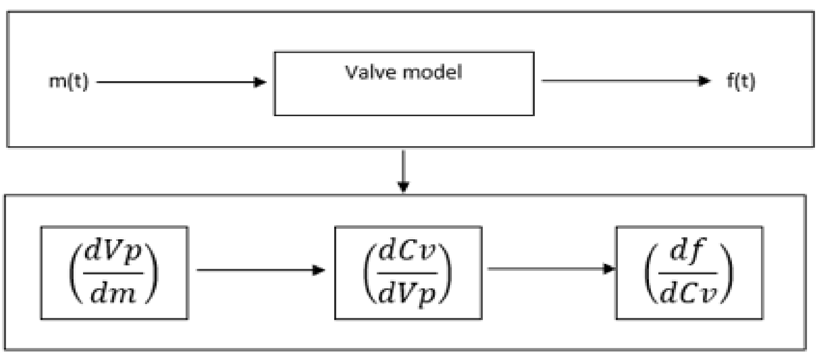

Figure 2: Valve characteristics model system used to check for valve stiction

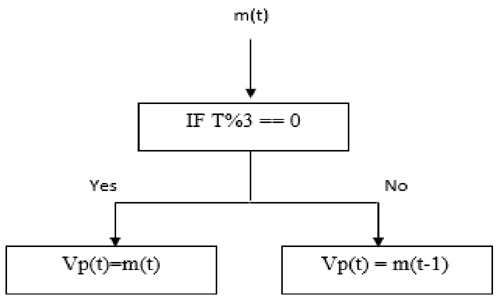

Figure 3: Schematic of Valve model

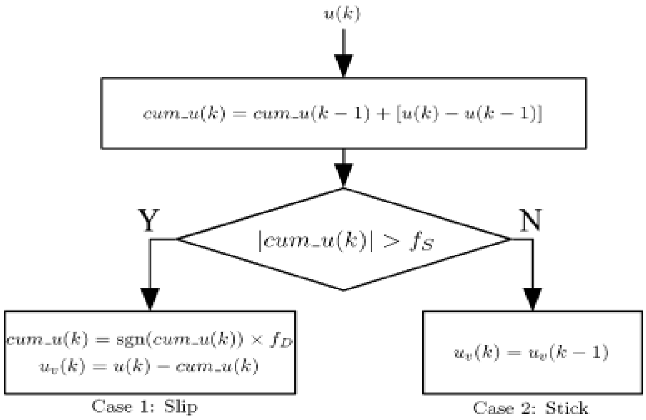

Figure *4: Schematic of He's model (Chen et al., 2008)*

Step 3: It is a function to transfer the valve position to the valve coefficient in Eq(7), the valve characteristics resulting in Eq(8), Eq(9), and Eq(10) in the function that changes due to valve stiction.

$$(dC_v/dV_p) = C_{v,max}\ (m^3/min/(kPa^{0.5}))/(fraction\ V_p) \quad (7)$$

Linear characteristic

$$V_p(x) = x \quad (8)$$

Equal percentage characteristic

$$V_p(x) = \alpha^{(x-1)} \quad (9)$$

Quick opening characteristic

$$V_p(x) = (V_p)^{0.5} \quad (10)$$

Step 4: It is to determine the output flow rate change due to valve stiction from the valve coefficient transfer function to the output water flow rate in Eq(11) from the valved before entering the water tank process.

$$(df/dC_v) = (\Delta P_v/G_f)^{0.5} \quad (11)$$

3. Results and Discussion

3.1 Parameters used for the water tank process

The valve coefficient by choosing a 0.1 m valve and tube 0.1 m will get C_v = 1.60 $m^3/min/kPa^{0.5}$ (Skousen, 2011) valve fully open then using the valve speed of 1,829 m/min and the area of valve and flow rate of 16 m^3/min is obtained from Eq(4) then the pressure drop across the valve from the Eq(5) to get ΔPv = 100 kPa.
After obtaining the various parameters used, the gas will have the desired flow rate to enter the process of measuring the water level in the tank at the desired target of 12 m and see the difference between the process variable of valve normal and valve stiction.

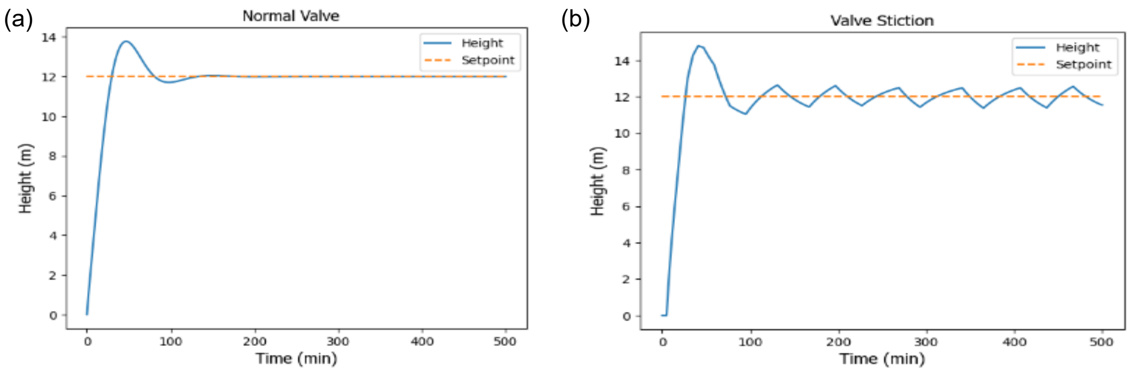

Figure 5: Illustration of (a) process variable of Valve normal, and (b) process variable of valve stiction

The comparison between a normal valve and valve stiction affects the process as shown in Figure 5a and 5b.

3.2 Check the stiction of the valve model compared to He's model

The adhesion step time of the valve model at 6 min and with a static friction distance of 1.2 is compared with that of He's model with static friction of 0.9 and dynamic friction of 0 as shown in Figure 6a and 6b. He's model was able to closely predict the valve model expecting that the mean square error method (Quadros, 2022) will be used to measure the efficiency of the model (Yame, 2005).

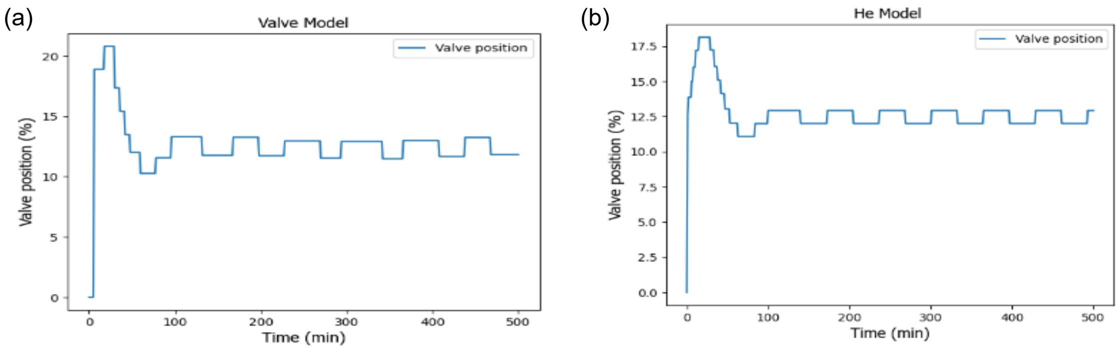

Figure 6: Illustration of (a) valve model of valve stiction, and (b) He's model of valve stiction

3.3 Check valve characteristics

There are 3 types of valves: linear, equal percentage, and fast opening. With quick opening, the valve position is less than equal percentage and linear as shown in Figure 7 (Dutta, 2023).

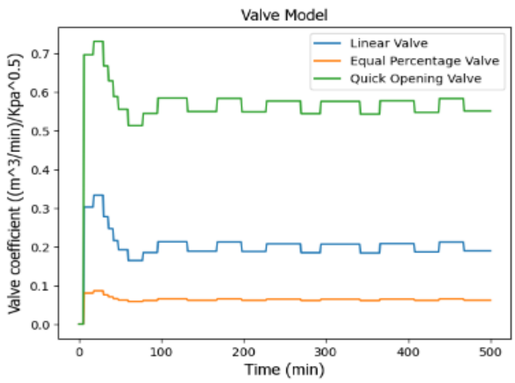

Figure 7: Illustration of linear, the equal percentage and quick opening of the normal valve

3.4 Flow characteristic

There are 3 types of flow characteristics: linear with the valve normal and valve stiction in Figure 8a and 8b, equal percentage with the valve normal and valve stiction in Figure 9a and 9b, and quick opening with the valve normal and valve stiction in Figure 10a and 10b, which valve sticking characteristics causing the signal to freeze periodically and cause the process variables to not converge to the set point.

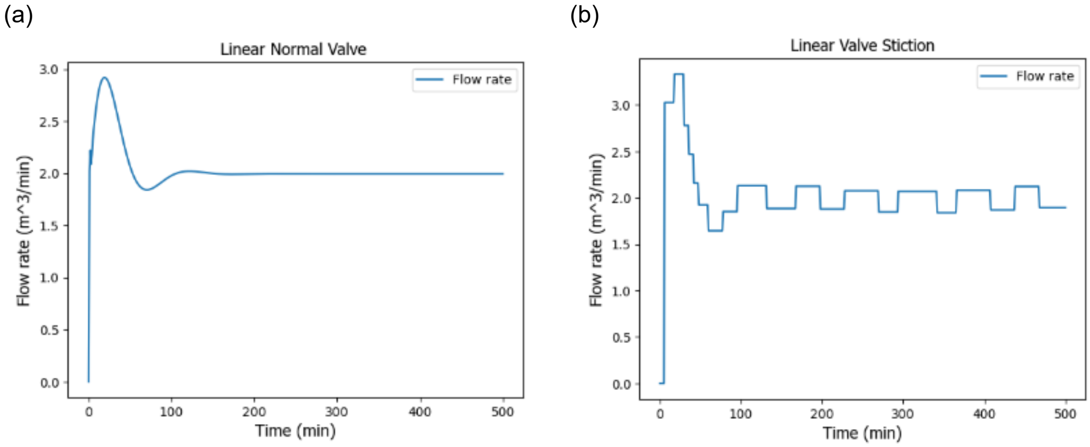

Figure 8: Illustration of (a) flow linear of valve normal, and (b) flow linear of valve stiction

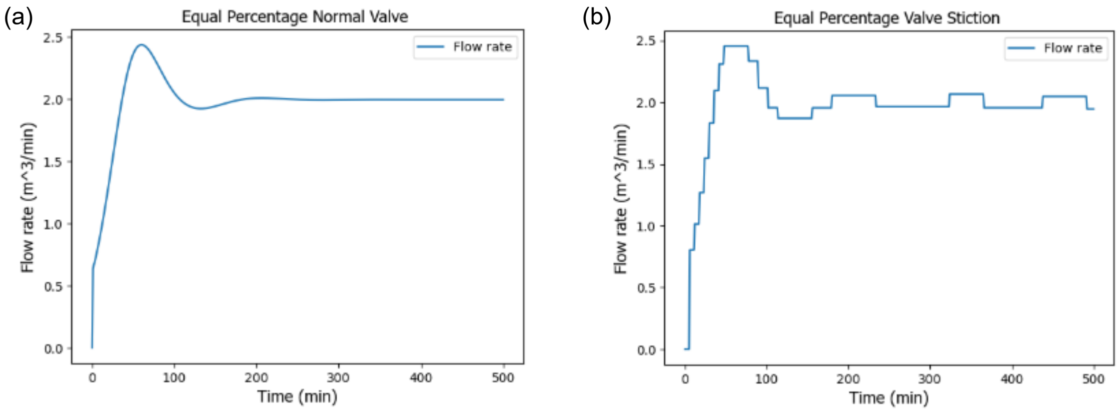

Figure 9: Illustration of (a) flow equal percentage of valve normal, and (b) flow equal percentage of valve stiction

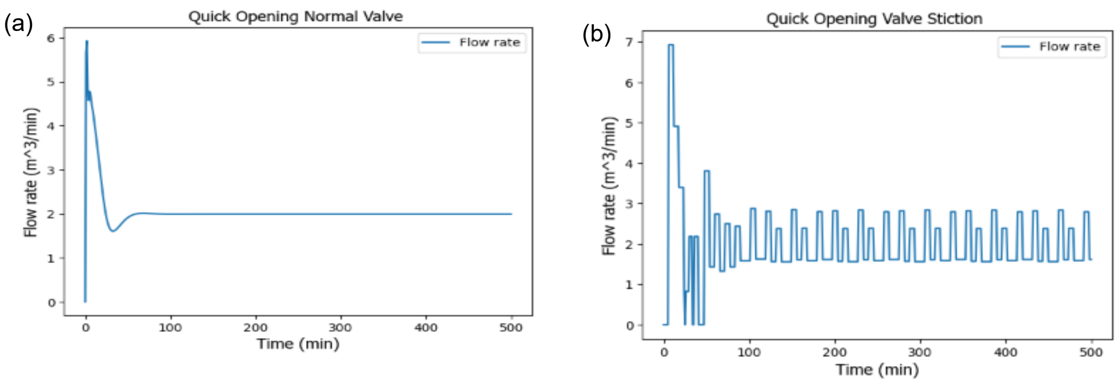

Figure 10: Illustration of (a) flow quick opening of valve normal, and (b) flow quick opening of valve stiction

4. Conclusions

Valve stiction detection from the feedback control loop for a water tank system using He's model to predict by simulated valve characteristic transfer function three main types available are usually designated: quick opening, linear, and equal percentage. In conclusion, He's model can be predictive is closest to the valve model and the stiction of the valve position due to static friction causes the process variable not to approach the desired setpoint, which is 12 m.

Nomenclature

V – outlet valve speed, m/min
A_v – valve outlet area by brand valve manufacturer Valtek, m^2
q – flow rate, m^3/min
N_1 – equation multiplier depends on the choice of units of variables
F_P – piping Geometry Factor
G_f – specific Gravity A liquid at a fixed temperature (water at 15.556 °C has a G_f of 1)
ΔP_v – pressure drop across the valve, kPa
C_v – valve coefficient, m^3/min/($kPa^{0.5}$)
A – tank cross-sectional area, m^2
h – level of the water tank level, m
g – acceleration due to gravity, kg.m/s^2

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