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# Time Based Stiction Compensation

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**Abstract:** Sticking valves tend to cause cycles in control systems used in industry, degrading product quality and yield. Many attempts have been made to alleviate the impact of stiction. Mechanical knockers are used with success to knock loose the sticking components. Most other stiction compensation methods attempt to find ways to move the control output by an amount greater than the stiction band, while still getting the valve position as close as possible to the desired position. This paper shows how, instead of overcoming stiction and getting the valve position to the control output, the valve can be moved such that over time, the valve is on average at the correct position, while still moving the valve in increments that are larger than the stiction band.

*Keywords:* manufacturing plant controls, stiction compensation, process control

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## 1. INTRODUCTION

This paper describes an advanced regulatory control (ARC) method (Gous et al., 2023; Skogestad, 2003) for dealing with valve stiction in process control applications. Valve stiction remains a problem in industry, and as a result has received significant attention in the literature (Daiguji and Yamashita, 2022; De Souza L. Cuadros et al., 2012; Di Capaci et al., 2016; Hägglund, 2002; Mohammad and Huang, 2012; Silva and Garcia, 2014; Skogestad, 2023; Srinivasan and Rengaswamy, 2005).

Stiction, short for static friction (Huba et al., 2011), refers to when an object withstands a force that is applied due to static friction that must be overcome to set the object in motion from a stationary position. It is the resistance to the start of movement between two surfaces that are in contact with each other. In process control it usually applies to a valve stem that will not start moving when the control system changes the position of the manipulated variable (MV) $u$. Because of the valve stiction, the controller output to the valve $u$, will not always be the same as the actual valve position ($u'$). The control system will keep moving $u$ in the same direction until the change in $u$ is large enough to overcome the static friction and the valve moves to a new position. This is usually due to either a rough valve stem or the packing that prevents process material from escaping past the valve stem.

An electronic signal $u$ is normally sent to a valve positioner where the electronic signal is translated to a pressure signal that pushes a diaphragm in the desired direction. Once enough pressure is built up, the static friction will be overcome and the valve stem will move. The amount that $u$ must change before the valve stem will move is referred to as the stiction band. To determine the stiction band, the control loop is taken out of automatic mode into manual mode. The engineer will start making cumulative, but small moves in $u$, in the opposite direction to which the valve had been moving. Once the cumulative change in $u$ is larger than the stiction band the valve will move to a new position and the direction in which the level was moving will change. The stiction band is defined as:

$$SB = |u_i - u_f| \tag{1}$$

where $u_i$ is the value of $u$ at the beginning of the test and $u_f$ is the value of $u$ when the process response is seen in the controlled variable (CV) $y$.

When the valve moves, it will typically have moved too far because the integral action of the controller would have kept adjusting $u$ while the valve position did not change. This will cause a reversal of $y$ which will lead to a cycle.

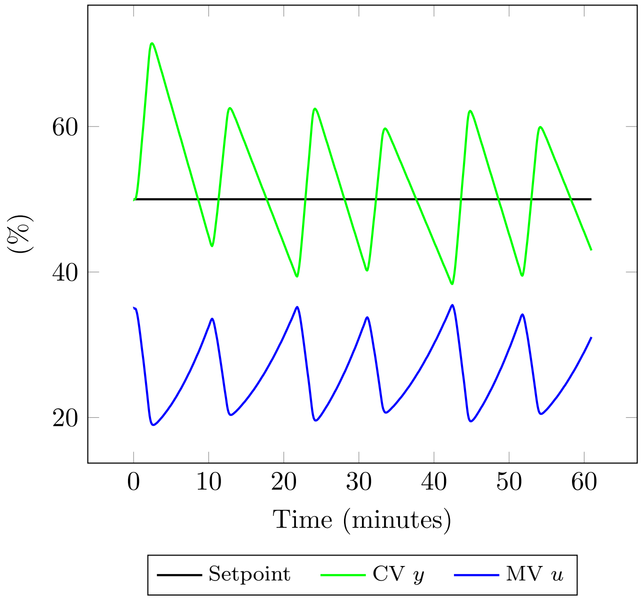

Fig. 1. Typical stiction pattern.

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Often this leads to cycles with sharp reversals in $y$ as shown in Figure 1, which can be taken as an indication of stiction, although this is not always the case. Stiction decreases control performance in level control because levels integrate while the valve is stuck.

Stiction should not be confused with backlash (Desoer and Shahruz, 1986), or hysteresis. Backlash is a form of deadband that results from a temporary discontinuity between the input and the output of a device when the input of the device changes direction. Hysteresis is the maximum difference in output value for any single input value during a calibration cycle, excluding errors due to deadband.

Backlash occurs when the control system changes the direction of $u$ and no effect on $y$ is seen initially. Further changes in the same direction does not cause the same effect. A good example of backlash was found on a boiler plant where a sprocket and chain opened and closed dampers that supply air to the furnace of the boilers (Rambalee et al., 2010). The chain was not stretched tightly around the sprockets and every time the control system changed the direction of $u$, a significant amount of slack had to be overcome before the sprocket on the damper side would start moving. The problem was solved by shortening the chains.

The obvious solution to stiction is to replace or repair the faulty final control element. This is often not an option that is available if the plant has to be shut down in order to repair or replace the valve. Therefore, several attempts have been made at modifying or extending control algorithms by adding a compensation method in order to decrease the impact of stiction (Daiguji and Yamashita, 2022; De Souza L. Cuadros et al., 2012; Di Capaci et al., 2016; Hägglund, 2002; Mohammad and Huang, 2012; Silva and Garcia, 2014; Srinivasan and Rengaswamy, 2005).

Control engineers attempt to solve the effects of valve stiction in two opposite ways. The first is to tune the proportional-integral (PI) controller extremely aggressively which will start a cycle. The advantage of this method is that the process may filter out the rapid changes and that, on average, $y$ should be at the desired position. The disadvantage is that it adds strain to an already failing system, which could hasten its demise, causing a plant shutdown. The second method is to substantially decrease the control action. The premise behind this method is that when stiction is overcome, the valve position will jump to a new value, and hopefully this new value will be close to where $u$ should be. This method was proven ineffective by Silva and Garcia (2014).

Another way to decrease the effects of stiction is to use a valve positioner. This is a controller that measures the valve position, compares it to $u$ and takes control action when there is a difference. This does not solve the issue of stiction as the stiction remains. The valve positioner can, however, take much faster control action as the valve response to changes in $u$ should be much faster than say the response of a level in a feed drum. This also adds more strain to an already broken system.

The knocker method (Hägglund, 2002) of stiction compensation involves periodically applying a brief, controlled force or vibration to the valve actuator to “knock” the valve stem, helping it overcome stiction without changing the control signal. This method can be implemented as mechanical knockers that physically tap or vibrate the valve or actuator assembly at regular intervals. Although it works well, this method can obviously not be seen as an advanced regulatory solution. Another method is applying short, high-amplitude pulse signals to the actuator to create a similar effect as mechanical knocking. These pulses are designed to be strong enough to overcome stiction but brief enough to prevent significant valve movement and consequent process disturbance. As these pulses are induced from the control system, they may be considered as advanced regulatory control systems.

The practise of detuning a controller suffering from stiction was expanded by De Souza L. Cuadros et al. (2012). The basic principle involves monitoring the control signal sent to the valve actuator and identifying when this signal is within a certain threshold or deadband range where movements are likely to be ineffective or counterproductive due to stiction. When small signal changes are detected that do not exceed this predefined threshold, the control system temporarily freezes $u$ in its current position, preventing it from making minor adjustments that would not overcome the stiction. The valve is only moved when the control signal change is significant enough to ensure that the actuator’s force will be sufficient to overcome the static friction and will effect a desired change in $y$.

Other approaches (Di Capaci et al., 2016; Mohammad and Huang, 2012; Srinivasan and Rengaswamy, 2005) use a two-step method, where the valve is first moved in one direction, in a step change that is larger than the stiction band, and then a step in the opposite direction, also greater than the stiction band, that will bring the valve opening to its desired value. This method of compensation will severely increase stress on the valve as well as introduce short but large disturbances to the process.

The contribution of this article is the introduction of a time based control approach to compensate for valve stiction. The article introduces the approach and evaluates the results of the approach as applied to an industrial problem.

## 2. COMPENSATING FOR STICTION BY VARYING VALVE POSITION OVER TIME

### *2.1 Time based stiction compensation*

The aim of time based stiction compensation is to keep the valve at the desired position $u$ (expressed as a percentage) on average for a period time instead of getting the valve to the exact desired position at each time instance.

A control interval is defined as:

$$t_{CI} = t_1 + t_2. \tag{2}$$

The valve is set at a high value $u_{Hi}$ for a period of time $t_1$ and to a low value $u_{Lo}$ for a period of time $t_2$. The desired value of $u$ over $t_{CI}$ is the average:

$$\bar{u} = \frac{t_1 u_{Hi} + t_2 u_{Lo}}{t_{CI}}. \tag{3}$$

This approach is illustrated graphically in Figure 2, showing how to overcome $SB \leq 10$ % to step $u$ from 46.7% to

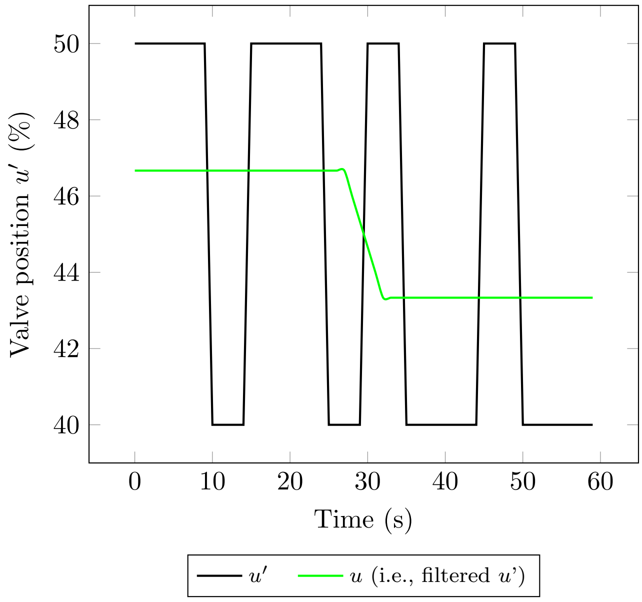

Fig. 2. Time based valve position compensation

43.3%. The valve is set to $u_{Hi} = 50$ % for $t_1 = 10$ s and $u_{Lo} = 40$ % for $t_2 = 5$ s to maintain the valve on average at $\bar{u} = 46.7$ % over the period $t_{CI} = 15$ s. At $t = 30$ s, the valve is set to $u_{Hi} = 50$ % for $t_1 = 5$ s and $u_{Lo} = 40$ % for $t_2 = 10$ s to maintain the valve on average at $\bar{u} = 43.3$ %. The green line in Figure 2 is the result of a central averaging filter with a span of 15 s.

Consider the following example. A control system attempts to control the level of a drum where a PI level controller writes directly to a valve on the outlet from the drum. The desired value of $u$ is at 45%, the valve is currently at 40% and $SB = 20$ %. If the value of $u$ is written to the valve, nothing will happen because the 5% that the valve is required to move is less than $SB$. Instead the valve can be moved to $u_{Hi} = 60$ %, which will overcome the stiction. If the valve is kept at $u_{Hi} = 60$ % for $t_A = 0.25t_{CI}$, and at $u_{Lo} = 40$ % for $t_B = 0.75t_{CI}$, the average value for $t_{CI}$ will be $\bar{u} = 45$ %.

For a reasonably long $t_{CI}$, the average valve position $\bar{u} = 45$ % should keep the average of the level at setpoint $y_{SP}$. However, if $t_{CI}$ is long, the level will may move further away from $y_{SP}$ during the interval $t_{CI}$ than what operators are comfortable with. Should a shorter $t_{CI}$ be chosen, the stiction compensation will move the valve too frequently and increase stress on an already broken system. Operators will also not be comfortable with a valve that moves too frequently. It is recommended that $t_{CI}$ be chosen such that operators are comfortable with the difference between the highest and lowest values of the level during each interval $t_{CI}$.

In the case of a short $t_{CI}$, if the $t_{CI}$ approaches the execution interval of the distributed control system (DCS), granularity is introduced. For instance, if the PI controller as well as the stiction compensation executes at 1 s, and a $t_{CI}$ of 5 s is chosen, the minimum time that can be spent at $\bar{u}$ will be one fifth of $t_{CI}$, and the resolution of $u'$ becomes an issue.

### *2.2 Implementation on DCS*

The deployment of the time based compensation algorithm on a DCS is shown in Figure 3. The algorithm in Figure 3 uses two timers. The first timer, Timer A, starts the compensation interval by counting down $t_{CI}$ chosen by the engineer. When the timer starts, the desired value of $u$ is read from the PI controller. This value of $u$ will be used for the entirety of the current cycle, and will only be updated at the next compensation interval. This is done by the block called 'Push', which pushes the desired value of $u$ to numeric block 'OP_In' when Timer A has counted down.

Calculation block A determines the necessary high and low $u'$ values based on the desired $u$:

$$u_{Hi} = SB\left(\left\lfloor \frac{u+SB}{SB} \right\rfloor\right) \tag{4}$$

$$u_{Lo} = u_{Hi} - SB. \tag{5}$$

Calculation block B determines the time to keep $u'$ at $u_{Hi}$:

$$t_1 = \left\lfloor \frac{u_{Hi-u}}{SB} t_{CI} \right\rfloor. \tag{6}$$

The value $t_1$ is sent to Timer B. While Timer B is counting down, calculation block B will pass $u_{Hi}$ to calculation block C. When timer B stops, calculation block B passes $u_{Lo}$ to calculation block C. Calculation block C passes the value it receives to the valve. When Timer A has completed, it resets itself and Timer B to start a new control interval.

CycleOn is used as a switch to enable or disable the stiction compensation. If it is set to 1, calculation block C will pass its most recently received value (either $u_{Lo}$ or $u_{Hi}$) to the valve, otherwise it will send the unaltered value of $u$ from the PI controller to the valve.

### *2.3 Time based stiction compensation with move suppression*

De Souza L. Cuadros et al. (2012) show that effect of stiction can be reduced by only implementing changes in $u$ when absolutely necessary. Time based stiction compensation, which moves the control valve up and down with a magnitude greater than $SB$ every cycle, can be combined with ramp horizon control (RHC) (Gous et al., 2021, 2023) to only apply control moves when necessary.

For RHC, the current rate of change of $y$ is extended over a ramp horizon $T_{RH}$, such that:

$$y_{k+T_{RH}} = y_k + T_{RH}\left(\frac{dy}{dt}\right)_k \tag{7}$$

where $y_{k+T_{RH}}$ is the predicted value at $T_{RH}$ and $y_k$ is the current value. If the predicted value does not violate a high or low limit, no control moves are made. Otherwise, a move is implemented. The size of the move in $u$ that prevents the limit from being violated within $T_{RH}$ is given by:

$$\Delta u = \Delta y/(KT_{RH}) \tag{8}$$

where $K$ is the process slope gain and $\Delta y$ is the difference between the active limit and the current value of $y$. The gain $K$ is the rate of change in $y$ when $u$ is moved by one engineering unit:

$$K = \Delta y/(\Delta u \Delta t) \tag{9}$$

where $\Delta y$ is the change in $y$ over time period $\Delta t$.

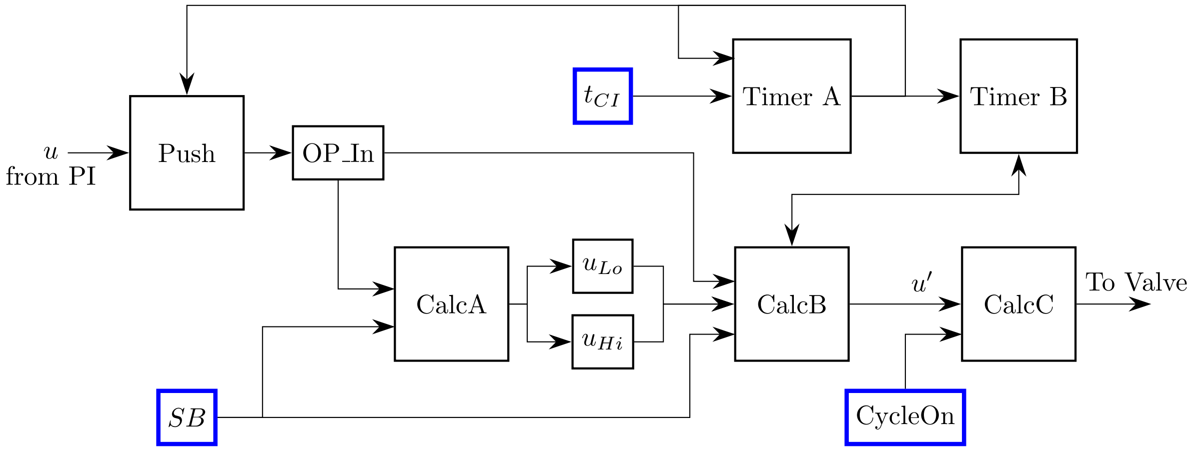

Fig. 3. Implementation of time based stiction compensation on a DCS. The blocks highlighted in blue are inputs required from the control engineer.

Figure 5 indicates the DCS implementation of RHC to augment Figure 3 to achieve time based stiction compensation with move suppression. The blocks highlighted in blue are inputs required from the control engineer.

To suppress moves, the value of $y$ is filtered to minimise the impact of noise using a standard filter block (Filt in Figure 5) . This value is passed through a deadtime block (DT) of 1 minute and calculation block ROC then calculates the current rate of change of $y$ ($\delta y$). Block SSVal calculates the extrapolated value of $y$ at time $T_{RH}$ as $y + \delta y \times T_{RH}$. If this calculation determines that $y$ will be outside the allowed $Gap$ at time $T_{RH}$, then the output of SSVal will instruct calculation block C in Figure 3 to implement the value of $u'$, otherwise, $u'$ is not changed.

## 3. RESULTS OF STICTION COMPENSATION SIMULATION

### *3.1 Simulation results of time based stiction compensation*

The simulation was used to compare the results of varying the time instead of the position of $u$. Several simulations compared the results of different stiction bands and how they impact controller performance. The results were compared to a system without stiction. Simulations were done to compare the results of combining move suppression with time based stiction compensation.

The feed drum shown in Figure 4 was simulated in Honeywell's Experion DCS. The DCS was used to simulate the control action required, as well as the time based stiction compensation algorithm. The DCS was linked via open platform communications (OPC) to a bespoke process simulator that simulated a sticking valve. The simulation compared the effect of different stiction bands on the valve.

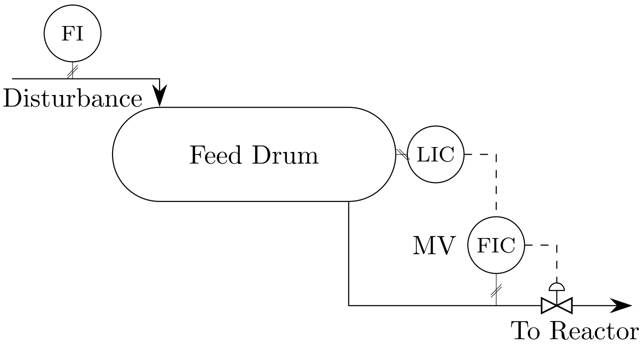

Fig. 4. Feed drum process flow diagram.

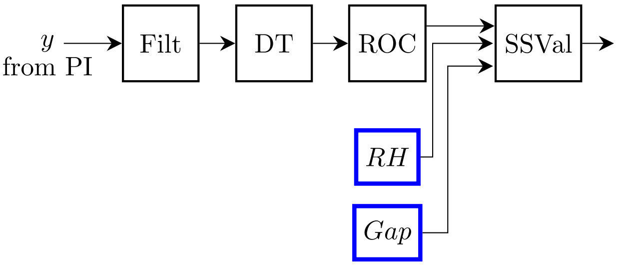

Fig. 5. Implementation of move suppression on a DCS.

Figure 6 shows how the simulated CV $y$ and MV $u$ reacts to a step disturbance to the flow into the drum. The same magnitude step disturbance of 10 $\mathrm{m}^3/\mathrm{h}$ is used for all simulations. The CV $y$ in the figure shows typical responses of the level to changes in the MV $u$. Stiction bands of 0%, 5% and 10% are used. The simulated values for $y$ are very similar to what is seen in industry when a valve sticks. Because the valve jumps from a low to a high position and back, typically a sawtooth pattern will emerge.

In industry the turning points of $y$ will normally be smoother due to process and signal filtering. Typical cycles in industry will not cycle symmetrically around $y^{SP}$, but there may be a large offset to either side depending on initial conditions. Because the simulation started with a large disturbance that the PI reacted to, initially the average value for the cycles seem to be close to $y^{SP}$ in the simulations.

The different trends in Figure 6 shows that the PI controller can cope with smaller stiction bands, but the larger the stiction band, the more excessive the valve travel becomes. Therefore the error between $y$ and $y^{SP}$ becomes larger, and $y$ moves closer to alarm and trip limits while increased movement of $u$ may exacerbate existing valve damage.

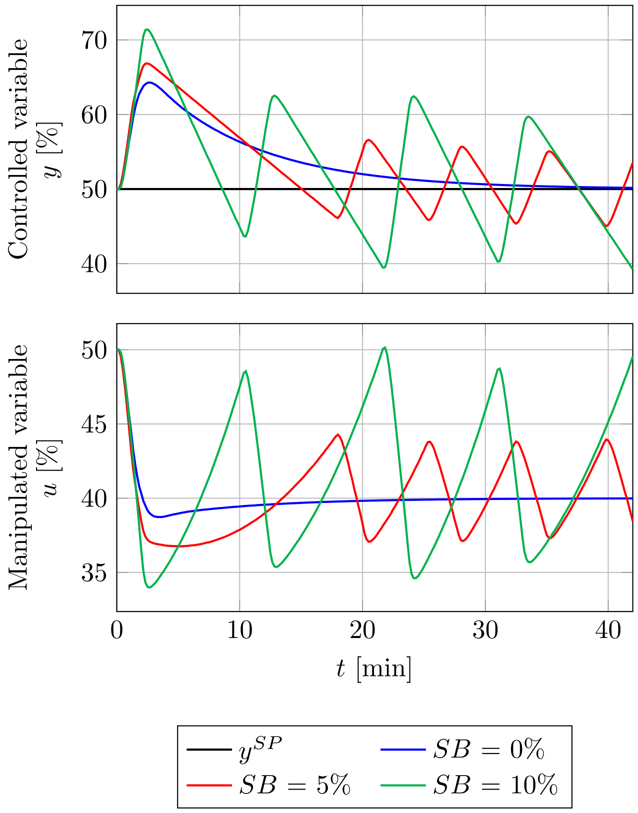

Fig. 6. Impact of different stiction bands.

Figure 7 shows how the time based stiction compensation is able to closely approximate the original control response when no stiction is present. Though $y$ and $u$ both cycle, the step disturbance is rejected in a way that is quite close to the system without stiction and $y$ is brought back to $y^{SP}$ in the same amount of time as the original system.

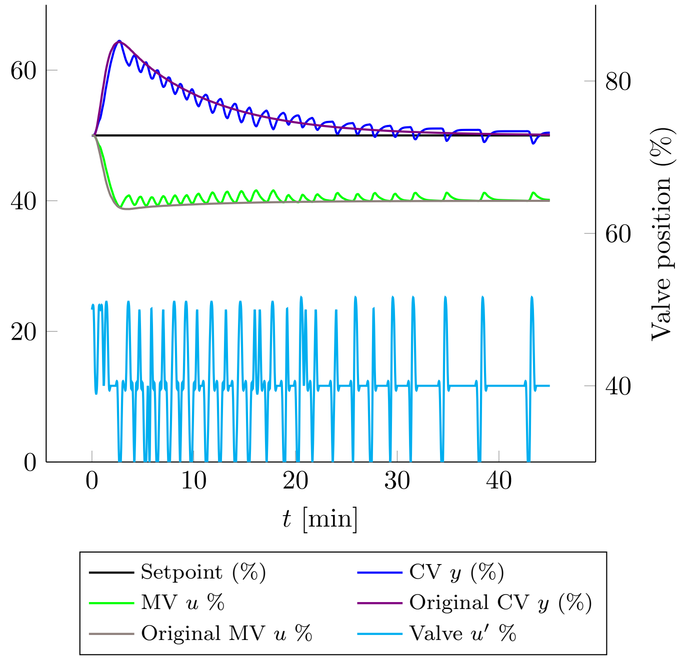

Fig. 7. Impact of time based stiction compensation.

### *3.2 Simulation results of time based stiction compensation with move suppression*

When simulating time based stiction with move suppression it shows how this can minimise valve travel at the expense of increased error. As shown in Figure 8, time based compensation with move suppression will bring $y$ back to $y^{SP}$ after a single disturbance, but not as well as when using only time base stiction compensation. The advantage is that less control moves are required to control the process. Therefore this method was implemented on a process plant, the results can be seen in Section 4.

## 4. TIME BASED STICTION COMPENSATION APPLIED IN INDUSTRY

The method of time-based stiction compensation with move suppression was implemented on a tank in industry that had stiction in excess of 7% in a make-up water valve.

Figure 9 shows the results of time based stiction compensation with move suppression. A gap of 4% on both sides of the $y^{SP}$ of 35% was used with a maximum rate of change of 4% per minute and a minimum rate of change of 0.5% per minute. Unfortunately, the data historian on the plant stored the output of the compensation algorithm and not the controller output, which is an issue when comparing the result with the previous graphs. It also brings the comparison of the standard deviation in Table 1 into question. However, the decrease in valve movement was substantial.

A comparison of the level without and with stiction compensation is shown in Table 1. This shows that the time-based compensation with move suppression kept $y$ close to $y^{SP}$ while decreasing valve position variability.

To compare the reduction in valve travel the standard deviation of $u$ and the total variance of $u$ (TV) (Skogestad,

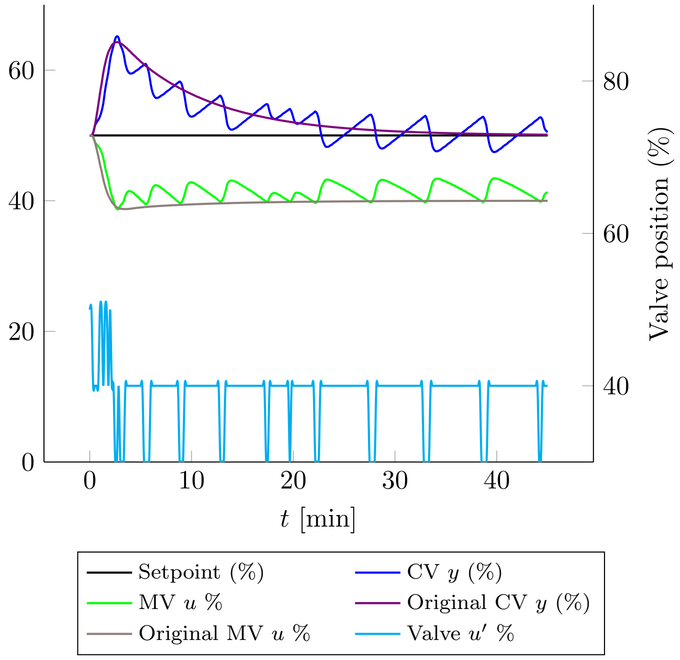

Fig. 8. Impact of move suppression.

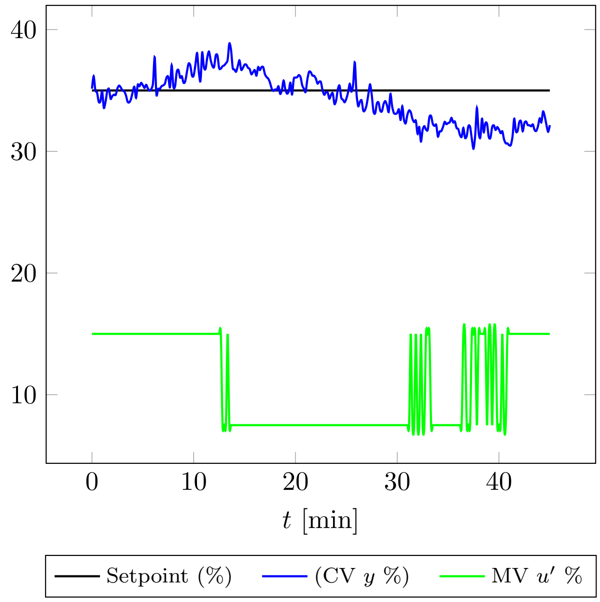

Fig. 9. Results of time-based stiction compensation on an industrial plant.

Table 1. Comparison of plant results.

| | Max $y$ | Min $y$ | $\sigma_u$ | TV/$N$ |
|---|---|---|---|---|
| Initial tuning | 46.3 | 34.8 | 13.7 | 4.2 |
| Time-based stiction compensation | 42.2 | 26.2 | 4.4 | 0.65 |

2003) will be used. If the total variance of a dataset is divided by the number of datapoints, the result can be compared to another dataset with more or less entries, therefore TV/$N$ is used.

$$\sigma_u = \sqrt{\frac{1}{N-1}\Sigma_{k=2}^{N}\left[(u_k - u_{k-1}) - \mu\right]^2}, \tag{10}$$

$$\mathrm{TV} = \Sigma_{k=1}^{N}|u_{k+1} - u_k| \tag{11}$$

For (10) and (11), $N$ is the number of datapoints in the dataset and $\mu$ is the mean of $u$ over the dataset.

## 5. CONCLUSION

Using simulations it was shown that using time based stiction compensation by keeping the average valve position during a cycle at the output of the controller, can lead to improved controller performance. When adding the ability of the algorithm to suppress making changes in $u$ when $y$ is not at risk of going too far from $y^{SP}$ in a set period, the method of time based stiction compensation with move suppression will let $y$ move over a larger range, but it is still able to control $y$ successfully. This was demonstrated in simulation and by an implementation on a drum level in industry.

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