VARIABILITY IS NOT REMOVED: IT IS MOVED!

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INTRODUCTION

An oft-unrecognized by-product of good process control is the introduction of variability elsewhere in the process. We overlook this by-product because we typically view the goal of a control loop in simple terms; that is, we wish to maintain the process variable (PV) at set point (SP), in spite of load changes, set point changes, and disturbances. To dutifully achieve this goal, the controller continually manipulates another variable (usually flow) by moving a valve or some other final control element. This action returns the PV to SP. From a simple viewpoint, this is good process control.

By moving the final control element, a change has been created in both the PV and the manipulated variable. Thus the controller removes the deviation in PV from SP for the loop by causing variability elsewhere. In a temperature loop manipulating steam flow, this may not be a concern; we have moved the variability to the steam header. In a level loop manipulating outlet flow from a tank, though, we may be moving the variability in inlet flow to the downstream process. This paper will show that consideration must be given to where variability is moved when designing control strategy and when tuning loops. We will also show how to correctly assess variability for different processes, and how to tune loops to move variability where it may be least costly to you.

CAN YOU ACTUALLY REDUCE OR ELIMINATE VARIABILITY?

In some instances, you can reduce or eliminate process variability instead of simply moving it elsewhere in your plant. This will be the case where equipment is performing poorly (e.g. sticky valves), or you have an incorrect control strategy, inappropriate PID controller tuning values, incorrect PV filtering, or poor process design. If you have insufficient PV filtering, this will result in the controller responding to noise in the measurement. This ‘noisy’ feedback may introduce variation to the process. If you filter excessively, you will add delay time to the loop, resulting in instability and/or slow response to deviations from SP. Sticky valves will cause cycling. Poor tuning may also cause
cycling. Figure 1, below shows a level loop that cycles due to a small integral time (Kp=1.0, Ti=0.5 min/repeat). The cycling resulted in added variability to both the level and the downstream process, since the tank outlet flow is the manipulated variable. Figure 2 shows the same loop with more appropriate tuning, eliminating the cycle and providing a smoother flow to the downstream process.

FIG. 1 – A LEVEL LOOP WITH TUNING THAT CAUSES CYCLING

FIG. 2 – THE SAME LEVEL LOOP WITH APPROPRIATE TUNING.
HOW DO YOU MEASURE VARIABILITY?

LOOPS WITH CONSTANT SET POINTS

Some measures of variability quantify the deviation in the PV from the average of the PV. If the average PV is equal to the SP, as is the case for a constant SP, then this is often a good measure of variability. Examples of such measures are the variance, standard deviation, and the variability. Variance indicates the dispersion of the data, and is defined as the sum of the squares of the deviation from the mean. The larger the spread of the data, the larger the variance will be. This is easily seen in a histogram. Standard deviation is the square root of the variance. A way of standardizing the standard deviation between two or more variables is to divide by the mean. Percent variability is an example of this and is calculated as two standard deviations divided by the mean, times 100%.

Figure 3 shows the statistics for the level loop data previously shown in Figures 1 and 2, with original tuning (left, Kp=1.0, Ti=0.5 min/repeat) and more appropriate tuning (right, Kp=11.0, Ti=2.0 min/repeat). In both cases, the mean is at or near set point (50%). The standard deviation, variance, and variability are reduced with more appropriate tuning.

FIG. 3 - STATISTICS FOR THE LEVEL LOOP SHOWN IN FIGS. 1 AND 2, BEFORE (LEFT) AND AFTER TUNING.
LOOPS WITH LARGE MEANS

For a PV with a large mean, the variability may be misleading, since the calculation involves dividing by the mean. Figure 4 shows such a case with a temperature loop that is operated above 700 °F. In such cases, it is useful to look at the range of control, in this case in excess of 8 °F.

![Table of loop statistics]

**FIG. 4 - STATISTICS FOR A LOOP WITH A LARGE MEAN.**

LOOPS WITH CHANGING SET POINTS

Measures of variability that are dependent on the mean may be inappropriate for loops with frequently changing set points, as in the case of inner loops in a cascade strategy. This is because the mean, like the SP, is not stationary. IAE may be a better measure in this case. IAE is the Integrated Absolute Error between process variable and set point. It is the area on the time graph between the set point and the process variable. Smaller IAEs are better since it means you were running closer to set point for that time.

LOOPS THAT EFFECT DOWNSTREAM PROCESSES

For some loops, movement in the controller output (CO) has a strong effect not only on the loop’s PV, but also on another part of the process. Rapid CO movement in response to a disturbance may even have a detrimental effect elsewhere in the process. In this case, it would be more important to keep the CO from moving rapidly, with the understanding that the PV may deviate often from SP. A measure
of CO movement would be a good way to assess the effect the loop has elsewhere. Valve travel and reversals per unit time are two such measures.

HOW TO MANAGE VARIABILITY IF YOU CANNOT ELIMINATE IT

If variability is resulting from disturbances you cannot eliminate and are not originating from within your process (e.g. poor tuning, bad equipment, etc.), then you must decide where it is least costly to move this variability. Figure 5 shows an overview of a multi-loop process, with a discussion of where variability should be moved. In this process, maintaining temperature at SP is most important. The level is a surge tank. Sources of disturbances to temperature include inlet product flow rate and temperature, and other steam users sharing the steam header. Tuning the TC aggressively will move variability from disturbances to the steam header. Tuning LC aggressively would move variability from tank inlet disturbances to the flow of product to the heat exchanger. This would have an adverse effect on temperature control, so it may be better to tune the LC less aggressively and allow the tank level to fluctuate some with inlet flow disturbances.

Figure 6 shows what would happen if we tuned the level in Figure 5 aggressively. Tuning the level loop aggressively (Kp=4.0, Ti=0.75 min/repeat), keeps the PV close to SP, but moves the CO quite a bit. PV Variability = 8.5%. CO Travel = 6,240%/hour. In this case, any inlet flow variability to the tank would be passed downstream, causing increased variability in the temperature control.

Figure 7 shows tuning after it was decided to allow the level in Figure 5 to deviate from SP vs. tight control, in order to minimize the effect on the downstream process (temperature). Tuning the level loop in Figure 5 less aggressively (Kp=1.6, Ti=0.6 min/repeat) results in greater level variability, but moves the CO much less. PV Variability = 13.1%. CO Travel = 860%/hour. In this case, much of the inlet flow variability to the tank would be felt as variability in level, resulting in less variability in the temperature control.
FIG. 6 - TUNING THE LEVEL LOOP IN FIGURE 5 AGGRESSIVELY

FIG. 7 - TUNING THE LEVEL LOOP IN FIGURE 5 LESS AGGRESSIVELY

CONCLUSION

We have shown (1) that control loops may require different measures of variability, and (2) that we need to be aware that our efforts to keep a PV at its SP will move variability elsewhere in the process.
In some cases, deviation from the mean is a good measure of variability. In others, deviation from the set point (which may be moving) is a better choice. In yet others, how well the PV tracks the set point is less a concern than in how the rest of the process is effected by the movement in the controller output. In the last case, tuning the loop less aggressively will still allow the loop to handle disturbances, but without moving 100% of the variability in the disturbance to the rest of the process.

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