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Optimize surge vessel control

Proportional only algorithm complements multivariable predictive control

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Surge vessel level control can be key to stable process operation during significant load disturbances. A variety of level control techniques with the objective of using available surge capacity to smooth the load disturbance are reviewed. One simple and novel approach has been used in a number of advanced process control (APC) projects to complement the higher-level applications.

When designing an APC solution for a process unit, improving process stability is a fundamental objective. Often significant process variability is driven by load disturbances outside of the process unit, and there is a real need to attenuate these within the scope of the APC solution. Intelligent use of surge vessel capacity can often provide significant benefits to process stability and economic return of the APC project.

To assess the various techniques, a study was completed using an offline DCS simulation to illustrate relative performance. The simulation consisted of four identical surge drums, each with a different level control approach. Each of the drum simulations was perturbed with an identical load pattern, and the response data collected for analysis. Statistics focused on load disturbance attenuation were developed to allow each approach to be assessed.

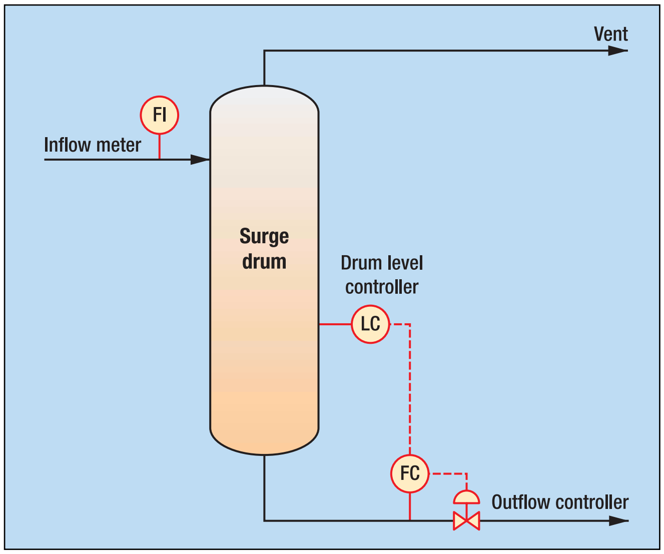

Fig. 1. A surge drum simulation was constructed to compare different approaches.

For surge drums that do not require a target level to be maintained, results illustrate some significant stability advantages in use of the proportional only technique. Although this approach is not new,[1,2,3] industry practice is not to deviate from the comfort of a specified level target. Some of the advantages and disadvantages of this approach are further discussed with particular focus on how it can complement multivariable predictive control (MPC) applications.

Why deviate from PI control? When improving dynamic performance of a process unit, one regularly overlooked area of opportunity is use of available surge capacity to attenuate load disturbances. To put it bluntly: You have paid for the vessel construction and the product held in inventory, why not use it to the advantage of the process? In addition, process economics are generally driven by throughput, on-specification product yield and energy consumption, and there are no prizes for having surge drum levels held tightly to setpoints.

Most surge drum level control problems are addressed with a proportional and integral (PI) algorithm with tuning for slow "averaging" control. Most of the time this will yield satisfactory results. However, for a set of particularly difficult applications where charge flow was suffering cyclic swings of ±50% of normal load, an alternative approach was suggested as a better way to minimize impact on the downstream process. To validate this idea and quantify the benefits, a performance study of all practical solutions was required.

Study objectives and level control alternatives. Study objectives were to quantify alternative approaches in performance measurements that reflected downstream process stability (i.e. management of the manipulated flow specifically). Since there was no specific need to maintain tight setpoint control, the viable alternatives to PI control included:

- A proportional only control algorithm—this standard DCS algorithm was enhanced to assist with initializing the bias term.
- A nonlinear level control algorithm—this algorithm uses drum geometry and a flow imbalance calculation based on successive level samples to predict future level trends. Modest moves are applied to achieve a target level within the constraint limits, while more aggressive moves are applied outside of constraint limits to quickly return level to the accepted range.
- An MPC package that uses a model of the level response to the manipulated flow in conjunction with a prediction error update to predict future level trends. Modest moves are applied to achieve the optimizer target when *prediction* is within control limits, whereas more aggressive moves are applied when prediction is outside of constraint limits to maintain level within the accepted range. The inflow meter is used as a disturbance variable with a feedforward model to drum level.

Continued

Table 1. Surge drum simulation components

Component	Execution frequency, s	Range	Comments
Inflow meter	5	0–100 m^3/h	Written directly to by load pattern generator
Outflow controller	2	0–100 m^3/h	Input is lagged translation of output (0.03 min.), to provide some realistic dynamics PI tuning: *K* = 0.5 and *I* = 0.1 min.
Drum level meter	5	0–100%	Level calculation based on flow imbalance and drum geometry Radius = 1.4 m, level transmitter span = 3.0 m

Table 2. Four different level control algorithms

Algorithm	Execution frequency, s	Tuning
PI controller	5	*K* = 1.4 and *I* = 40 min. 50% level setpoint
Proportional only controller	10	*K* = 1.25
Nonlinear controller	30	Constraint limits: 20% and 80% 50% level target Horizon times: “outside constraints” of 60 min. “within constraints” of 90 min.
Multivariable predictive controller	30	Constraint limits: 20% and 80% 50% level optimizer target Horizon times: control of 40 min. optimizer of 133 min.

Table 3. Move statistics for level controllers

	PI	P-only	Nonlinear	MPC
Average	0.37	0.31	0.38	0.35
Maximum	5.38	4.44	23.66	12.73
Sum of Squares	2299	1548	4907	3593
RMS	0.73	0.60	1.07	0.92
Zero moves, %	5.92	22.28	2.69	2.74

To ensure an equal basis of comparison, tuning was selected based on equivalent use of available level range. Outflow controller management was the key performance indicator for each level control technique.

Simulation design. To compare the different approaches, a surge drum simulation (Fig. 1) was constructed using the components shown in Table 1.

This drum simulation design was duplicated four times and four different level control components were added (Table 2).

The four solution techniques were simultaneously subjected to an identical load disturbance pattern. Fig. 2 illustrates the load disturbance pattern that took approximately 1.5 days to complete (real-time simulation speed). Both square and sinusoidal wave perturbations of ±20% and ±80% of normal load were used to stress test the simulations and measure overall performance under a variety of conditions.

While the perturbation sequence was executing, performance data were collected at 30-sec intervals.

Results. Figs. 3 and 4 show resulting level and outflow responses to the last five hours of inlet flow perturbations.

Results shown in Tables 3 and 4 are focused on load disturbance attenuation. The first metric shown is the average move size. Moves were calculated as the absolute value of the difference between current and previous outflow values (i.e., the 30-sec snapshot values). Average and maximum move sizes for the whole perturbation sequence are shown in Table 3. Also shown in the table are the sum of the squares and the root mean square (RMS) values of the move sizes.

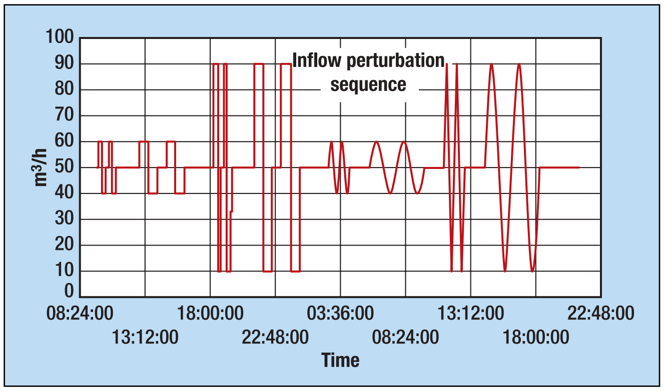

Fig. 2. The load disturbance pattern took approximately 1.5 days to complete.

The numbers of zero value moves were also calculated as a percentage of the total sample set. A zero move was taken as a change of less than 0.001% of the outflow range.

It can be seen from Table 3 that the proportional only level controller not only made the smallest moves, but also the least number of moves to attenuate the perturbations. This minimum movement approach will result in fewer disturbances to the downstream processes.

Some other interesting observations were made regarding the two model-based controllers (i.e., the nonlinear level controller and the MPC application). These controllers made much larger and nearly continuous moves to counter the inflow disturbances. This result is most likely to be a reflection more on the nature of the cyclic perturbation signal than the general performance of the algorithm. That is, a less sophisticated approach to the control problem is more likely to let a cyclic load disturbance wash through the drum with minimal impact on the manipulated variable.

The key disturbance attenuation measurements, standard deviations of the flow signals, are shown in Table 4. A reduction in standard deviation can be interpreted as an attenuation of the perturbation, i.e., partially absorbing the disturbance by utilizing the surge capacity as opposed to transmitting it to the downstream process.

Clearly, the proportional only level controller significantly reduces disturbance transmission, while the traditional PI controller does relatively little in terms of disturbance absorption. Interestingly, the nonlinear approach appears to amplify the net variability—a somewhat expected result, since the load pattern results in multiple violations of the constraint limits where there is effectively a gain discontinuity. Accordingly, this approach is better suited to surge drums that regularly experience smaller load disturbances (e.g., ±20% of normal load).

Although these results indicate some stability advantages with the proportional only approach, they illustrate performance observed with a unique load pattern and a single set of tunings for each algorithm. Although different tunings may lead to improved performance, it is unlikely that rankings of each approach, with respect to the chosen metrics, will change if equivalent use of surge capacity is maintained.

Proportional only level control—pros and cons. One aspect of the proportional only approach, which is not emphasized by the study results, is that the level where the controller stabilizes is purely a function of load—no operator setpoint is specified.

Table 4. Standard deviations of the flows

	Inflow	Outflow PI	Outflow P-only	Outflow nonlinear	Outflow MPC
Standard deviation	17.51	17.04	14.10	18.54	16.46
% reduction		2.7	19.4	–5.9	6.0

For the study simulation, average and final loads are equal to the median load and, hence, the steady-state level is 50%. For most continuous processes, average load is near the high end of the load distribution and, therefore, level will also tend to stabilize at the higher end of the accepted range. Although this may initially bring some discomfort to the process operator, this behavior is fundamental to the objective of using the surge capacity. Naturally, exact level behavior is a function of controller tuning and will be a balance between minimizing gain (maximizing use of surge capacity) and controlling within an acceptable range.

The MPC configuration used in the study is typical for MPC packages with the facility of midrange optimizer targets. One may argue that disposing of the optimizer target leaves a truly "minimum movement" MPC application, since no criterion specifies a preferred point within the control range. This is where the proportional only algorithm distinguishes itself to the benefit of the process—level is directly related to load and, thus, is always best positioned to absorb the next likely load disturbance (i.e., low level at low load and vice versa). Customizing the MPC application to specify the optimizer target as a function of load is possible and would provide performance very similar to the proportional only algorithm. This approach may, however, be considered as "using a sledge-hammer to crack a walnut" if the purpose of the MPC were solely the surge drum level control.

Before adopting any new approach, the control engineer must become aware of what constitutes an appropriate application and what potential pitfalls may be awaiting. The proportional only technique is most appropriate for a specific class of level control problems where:

1. Maintaining a specific setpoint is not required and level is allowed to stabilize anywhere within a reasonably wide range of operation.

2. The manipulated variable has adequate rangeability to reject load disturbances without saturating. That is even though level may be sitting relatively high in the accepted level range, there is always enough outflow capacity to ensure that a surge in inflow does not put the level "over the top." If manipulated variable saturation is regular, it may be necessary to maintain an approach with a midrange target to ensure adequate accumulation time is available before level extremes are reached.

3. The level dynamic to the manipulated variable is reasonably quick. Substantial measurement delay or lag can result in a phase lag that induces a cycle with a proportional only approach (this is also true for PI control).

When considering whether to convert a PI controller to proportional only, one should review the load history carefully to establish whether criterion # 2 is met. If so, this load distribution data will also provide the basis of the tuning exercise—proportional only controller gain and bias are simply calculated such that minimum and maximum accepted level constraints map directly to minimum and maximum load, respectively.

Although our case study deals with a vertical drum, this approach is equally applicable to a horizontal drum. Generally, the level measurement range is well within the maximum span of a horizontal drum, and vessel curvature effects are minimal. For those cases where level span is large relative to drum diameter, the proportional only algorithm effectively provides some degree of gain inflation as level approaches the extreme limits (i.e., a non-linear gain relative to the volume of inventory which can be advantageous for protecting level limits).

As with other algorithms, major shifts in process operations will warrant a tuning review. A change in average load, however, will result in a shift in average level in addition to the shift in manipulated variable position (whereas one would only expect the latter effect with a setpoint-based control algorithm).

Thus, with proportional only control, outflow and steady-state level are locked together, and a step in inflow results in a first-order response of outflow with unity gain. For the right application, there are multiple advantages of using a proportional only level algorithm:

- Minimum gain can be achieved since level is always positioned best to absorb the next load disturbance. For example, if level and load are high, level is best positioned to absorb a drop in load. Minimizing controller gain provides minimum manipulated variable movement.
- Manipulated variable overshoot is eliminated since there is no requirement to achieve a target level. The only objective is to balance level—when this is achieved, the manipulated variable stops moving.
- In cases where the measurement device is mechanical, reliability can sometimes be improved by exercising the measurement (for example, sticky or icy services). Since level is directly related to load, it moves with load variations (as opposed to setpoint control which maintains the same steady-state level regardless of load).
- Arbitrary setpoint changes that result in downstream disturbances are eliminated. Since level operating point is a function of load and tuning, individual preferences for operating points are forced into the melting pot during the tuning exercise and removed from day-to-day operation.
- The tuning exercise is reduced to a relatively trivial procedure based on a load history study. Manual trial-and-error methods of tuning slow level controllers can be very time-consuming and computer packages often require data from open-loop tests.

Furthermore, where the application considered is within the scope of an MPC solution (in particular, where the surge drum is located in the process between an independent and dependent variable), further advantages can improve project return:[4]

- Although gain is minimized, dynamics are quick with no outflow overshoot. This provides high-quality MPC models that are short (for good dependent variable control) and more repeatable.
- MPC model development is often based on process perturbation (step testing) using step sizes much greater than used by the online controller. Measured responses through a slow PI level controller often show overshoot that may not be present when the MPC controller is online. With a proportional only approach, step test models are identical to the behavior with MPC online.
- MPC models are generally fixed form (i.e., fixed deadtime and lag constants) developed at normal operating conditions. Surge drums can induce error in models dependent on transport time, when there are significant load changes—for example, transport of compositional effects through the surge drum. Depending on drum geometry, proportional only control can provide some useful dynamic compensation to aid fixed-form models—that is, lower load results in lower level and the drum lag constant is more consistent.
- Leaving a proportional only level controller in the regulatory control layer allows surge capacity to be intelligently used

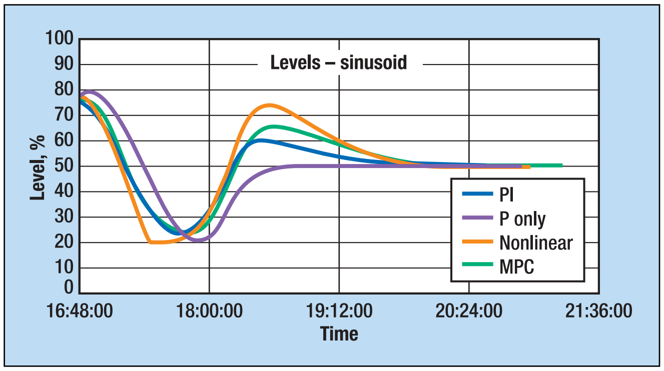

Fig. 3. Drum level responses.

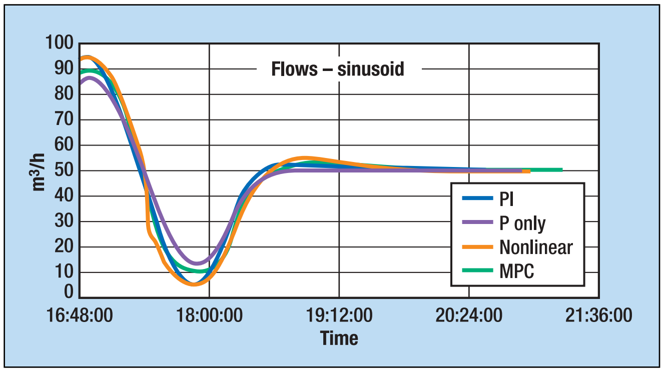

Fig. 4. Outflow responses.

without including it in the MPC design. This can greatly simplify the MPC application structure and shorten time required to develop and commission MPC.

Proportional only level control is a useful inclusion for the control engineer's toolbox and can often bring significant stability benefits for appropriate applications. This technique can also complement the use of MPC and result in a hybrid APC solution that is more robust, simpler in design and improves the return on the project investment. ■

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