

Modern Advanced Process Control Implementation and PID Tuning Optimization inside the DCS or PLC

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ABSTRACT

Application of closed-loop advanced control in industry has rapidly increased since the 1990s. The terms “DCS”, “PLC”, “PID”, “APC”, “Computer Control”, “Process Optimization”, “MPC”, “Model-Based Control” etc. are ubiquitous in process control literature. A prerequisite for APC/MPC success is a well-designed primary PID control platform with optimized tuning. Increasing application of advanced control schemes places higher demands on the skills and experience level of process control engineers and technicians. This paper describes some powerful practical process control software tools aimed at helping control engineers and technicians to design and implement control schemes inside the DCS for improving plant control. These tools and the methodology can help plants to maximize production rates, minimize utilities and increase the plant’s profits.

KEYWORDS

Process control applications, APC, advanced process control, system identification, PID tuning simulation and optimization.

1. Process Control Application Hierarchy

All modern chemical plants are equipped with DCS (distributed control system) or PLC (programmable logic controllers). Various forms of closed-loop control schemes are implemented inside a DCS or a PLC. Fig. 1 shows common industrial process control software applications split into three major categories. At the lowest level, are the *Primary Control* loops – mostly PID controllers for controlling flows, pressures, levels, temperatures and other variables in the plant. To handle slow process dynamics, multivariable interactions, long dead times and complex control loops, pure PIDs alone cannot effectively provide the best control quality and *Advanced Process Control (APC)* applications are necessary. Furthermore, in order to incorporate market, economic conditions, process and equipment constraints and nonlinearities, a third application level – *Online Optimization* can further provide monetary benefits.

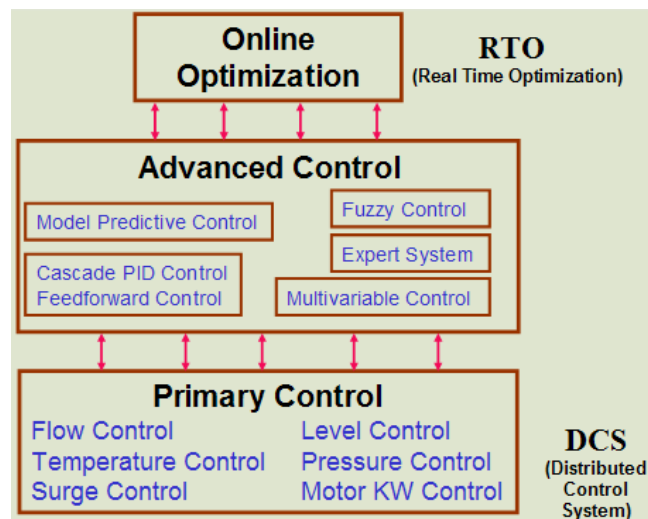


Fig.1. Process Control Application Hierarchy

Primary control and DCS-based Advanced Control, if correctly implemented can significantly increase the plant's profit margins. Optimized primary and advanced control stabilizes process operation and pushes the operation closer to process, equipment and economic constraints. This increases production rates, minimizes operating costs and improves product quality.

2. Challenges facing Modern Control Rooms

The increasing use of primary and advanced control poses the following challenges in the control rooms:

1. New control engineers and DCS/PLC technicians come into the plant on regular basis. They need to be trained on practical process control.
2. Many primary and DCS-based advanced control concepts cannot be taught easily at schools and colleges. Learning practical process control skills quickly is not easy.
3. Changes in process or operating conditions, nonlinearities, external unmeasured disturbances can impact closed-loop control quality resulting in inefficient operation including lost production and could even cause equipment shutdowns and safety/reliability incidents.
4. Constant software and hardware upgrades add to the maintenance challenges in the control room.

3. Attractive Opportunities to Increase Profits using DCS Advanced Control

Using modern DCS and PLCs, various powerful, robust money-making control schemes can be implemented. This paper describes several powerful techniques for designing and implementing DCS/PLC-resident advanced control schemes. These include:

1. Process Dynamics Identification
2. Primary and Advanced Control PID Tuning Optimization
3. Online Adaptive Control
4. Model-Based Control for Product Quality
5. Production Rate Maximization
6. Engineer, Technician and Operator Practical Process Control Training

4. Process Control Tools for Control Rooms

Any modern DCS or PLC is capable of archiving real-time process data that can be exported in Excel files for data analysis. Many DCS and PLC systems also have OPC servers and OPC client software that allows trending and archiving of real-time process data. Process data analysis can help to identify system dynamics, which in turn can be used for optimizing base-level primary PID controllers and also for designing APC systems. In this paper, we describe some powerful tools and methods designed especially for use by control engineers and technicians in the plant control room environment. These tools are simple and can be used effectively by both engineers and technicians. Various illustrative examples on the application of these tools in the chemical plant control rooms are described below.

5. Process Dynamics Identification

Chemical processes range process dynamics from as fast as milliseconds on compressor surge control and motor control to as low as many hours in tall super-fractionators distillation columns. In modern control rooms, there are plenty of data sets available containing the controller OP (output), PV (process variable) and SP (set point). Data may contain OP step changes with the controller in manual mode, or may contain SP changes in auto mode. There are many opportunities in the plant where the operator may have made changes to the SP or OP. All these data sets are abundantly available from the plants data historians that continuously archive the data.

With modern process dynamics identification software tools like Pitops, the identification takes just a few minutes. See Fig. 2 showing pressure control (PC) data.

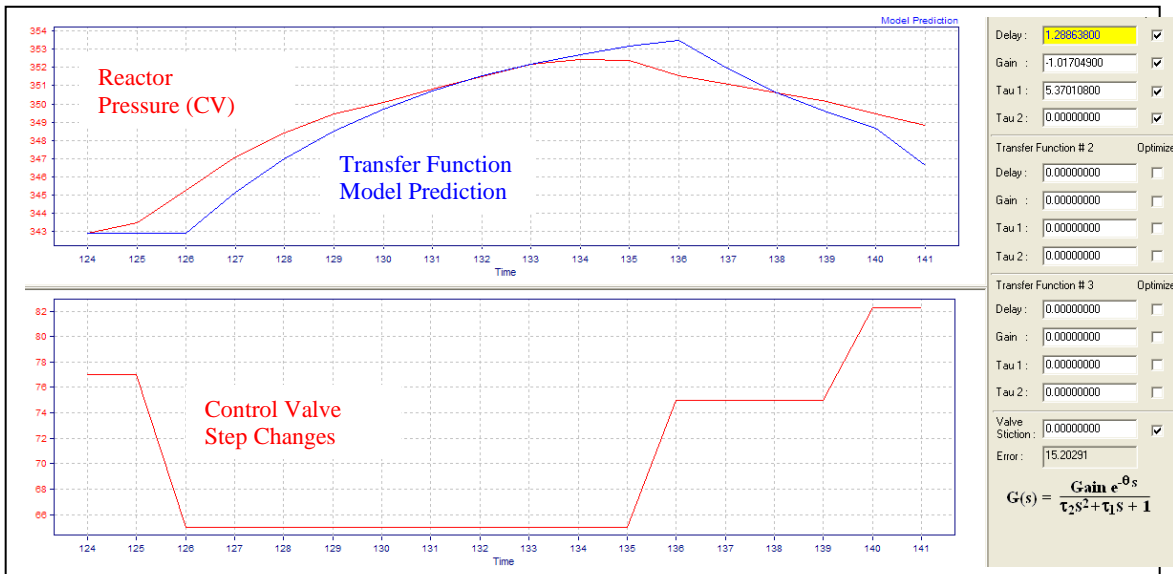


Fig.2. Pressure Control Transfer Function Dynamics Identification

The PC's output (valve position) was moved a few times (bottom window) which causes the pressure PV to respond (red trend in top window). The Pitops identification tool identifies the transfer function parameters as shown on the right side of the fig.: Time Delay = 1.3 minutes, Process Gain = -1.01 psi / %valve position and Time Constant = 5.4 minutes. The blue trend in the top window shows the transfer function model prediction. The transfer function parameters are very useful. They can be used to optimally tune the PC, or to implement adaptive control, or to implement an optimal feedforward controller depending on the loop characteristics and process needs.

Fig. 3 shows data on a tank level controller (LC). The LC's output (valve position) was moved a few times (bottom window) which causes the level PV to respond (red trend in top window). The Pitops software tool identifies the zero order (ramp or integrating type) transfer function parameters as shown on the right side of Figure 3: Time Delay = 9.0 minutes, Process Gain = -0.091% level / %valve position / minute. Note that this is a zero order transfer function (has ramp rate and dead time only but no time constants).

Notice the simplicity of the approach – the software reads in the PV and OP data and then determines the transfer function parameters all in the time domain which is easy to understand and use by everyone. Pitops software tool does not use the Z (discrete domain) which is harder to understand and apply.

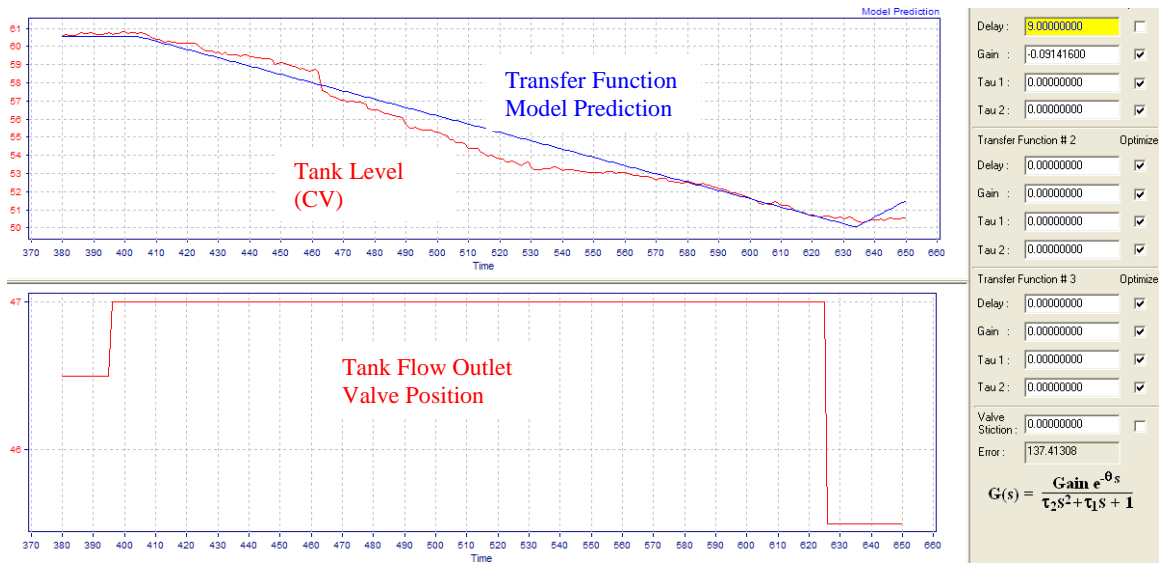


Fig.3. Level Control Transfer Function Dynamics Identification

Fig. 4 shows more step test data on the same level control example. With more step tests on this control loop, some nonlinearity is visible; this can be because of valve stiction, flow meter problems or unmeasured disturbances that could mask the effect of the control valve step tests. The Pitops software identification algorithm determines control valve stiction also based on the OP and PV data.

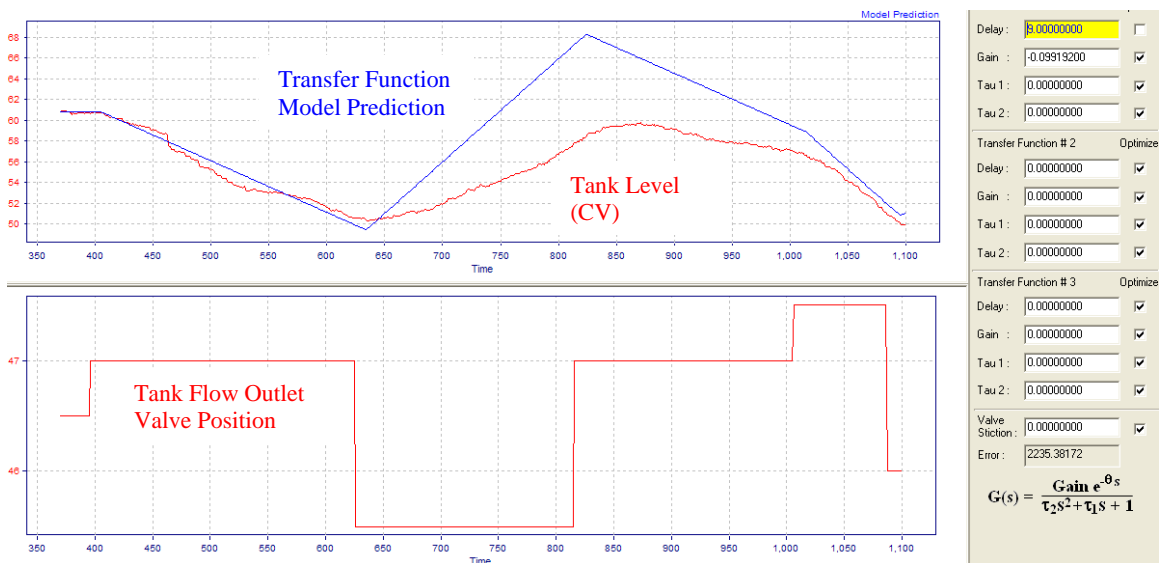


Fig.4. Level Control Transfer Function Dynamics Identification – Multiple Step

The above example used open-loop data (with controller in manual mode). Fig. 5 shows transfer function parameter identification using closed-loop data (with controller in auto mode). This example is a temperature controller manipulating a steam flow controller in a batch process. The TC output is often zero (no steam flow), but gets used as needed by the batch control sequence. Optimal tuning of the TC was hard because the TC is not always in control during the day shift. Using closed-loop control data on temperature and steam flow setpoint, the transfer function was identified by the new software tool. The transfer function delay time = 1 minute, process gain = 1.234 °C / (kg/h) and Time Constant = 23.7 minutes. Notice the simplicity of this closed-loop identification, all in the time domain.

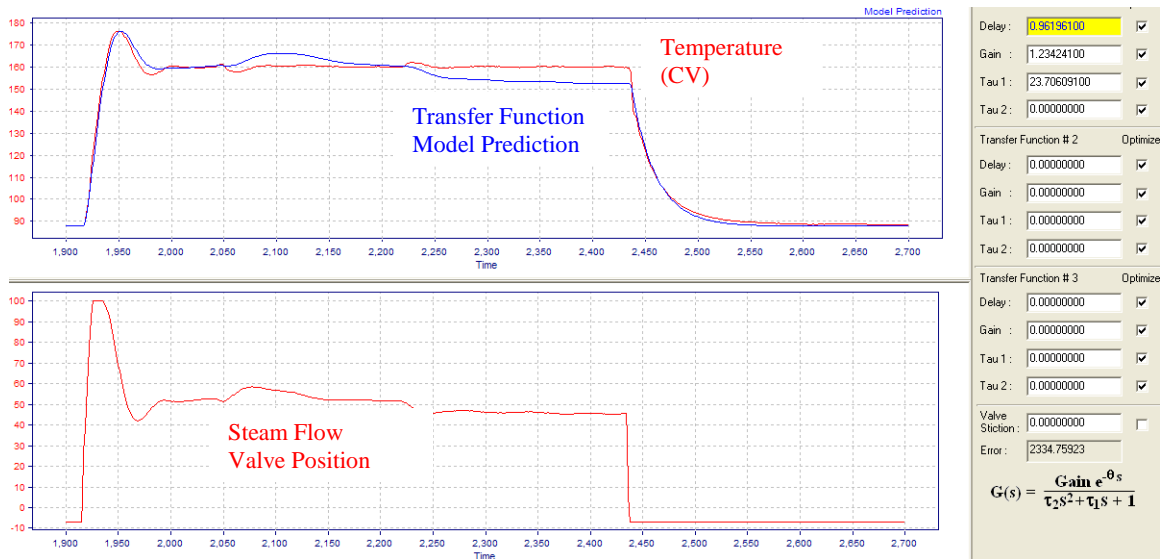


Fig.5. Temperature Control Transfer Function Dynamics Identification – Closed Loop Mode

Fig. 6 shows a Multivariable Model-Predictive Controller in closed-loop mode simultaneously manipulating three MVs (Distillation Column Feed, Side Product Flow and Reflux Flow). The product impurity is impacted by all three MVs (red trend in the

top trend). The software identifies all three second order transfer functions with dead time simultaneously using the closed-loop data.

This identification can be used to improve the step response coefficient models or transfer function models used in any of the commercially used multivariable model-predictive controllers to improve the controller performance.

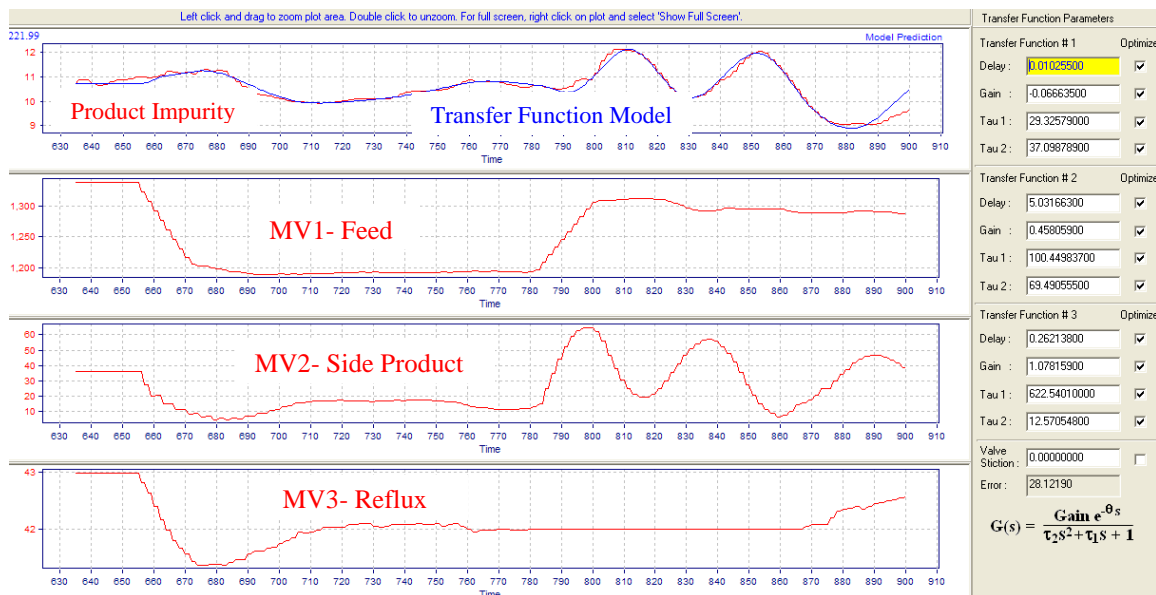


Fig.6. Multivariable Distillation Transfer Function Dynamics Identification – Closed Loop Mode

6. PID Tuning Optimization

Knowing the process transfer function helps to optimally tune base-level and cascade/advanced control type PIDs. Fig. 7 shows an industrial pressure control example. The bottom window shows the PC's output. The top window shows the SP (blue trend) and PV (red trend).

The PC's objective is to not only provide crisp SP control but also to respond aggressively when hit by a disturbance. Disturbances can come and go anytime and it is important for the PC to respond quickly by closing or opening the valve immediately. The key is that such aggressive control action needed during disturbance rejection should not result in sustained oscillations at steady state.

The tuning optimization software generates such tuning parameters that give crisp, non-oscillatory SP control while responding quickly during fast and large disturbances. Use of the tuning software on this example resulted in increasing the controller proportional gain from 2 to 11 in one step and the integral from 8 to 3 minutes.

Without modern optimization software tools, control engineers confronted with tuning such a PC would not have the confidence to increase the controller gain that drastically from 2 to 11 in one step. They would have crept up the gain from 2 to 2.5 and 3 etc. over a much longer time period. And since the disturbance does not come all the time, it is hard to manually tune the loop for optimal control without the help of modern software tools.

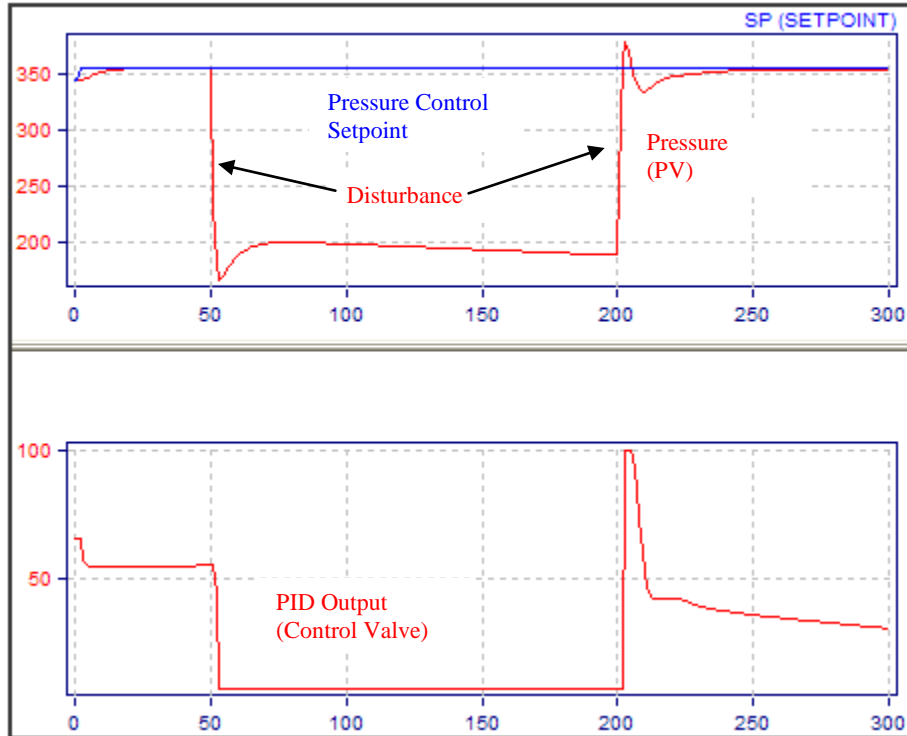


Fig.7. PID Tuning Optimization in presence of SP change and typical disturbance

Fig. 8 shows how the software optimizes PID tuning in the presence of signal noise. It mimics the real process by simulating the same level and frequency of white signal noise seen in the real process. In just a few minutes, the optimizer converts the real process signal characteristics into a custom simulation comprising typical set point changes, signal noise and disturbances followed by PID tuning optimization.

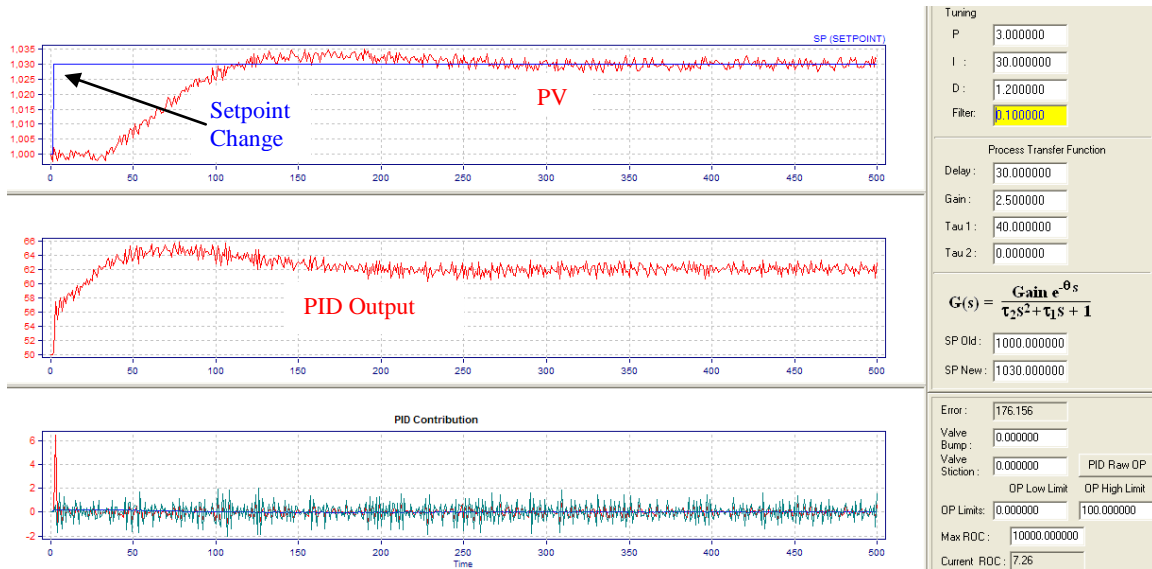


Fig.8. PID Tuning Optimization in presence of SP change and typical disturbance

7. PID Cascade Control

Cascade controllers are common in all chemical processes. Cascade controllers can be fast as in PC to FC chains or slow as in AC to TC or TC to TC cascades controlling product stream quality measured by online analysis or temperature inferential controllers. The optimization software simulates both slave and cascade process dynamics and then optimizes cascade PID tuning. Fig. 9 shows an example showing a master AC (online analysis control) to a slave TC (distillation tray temperature control).

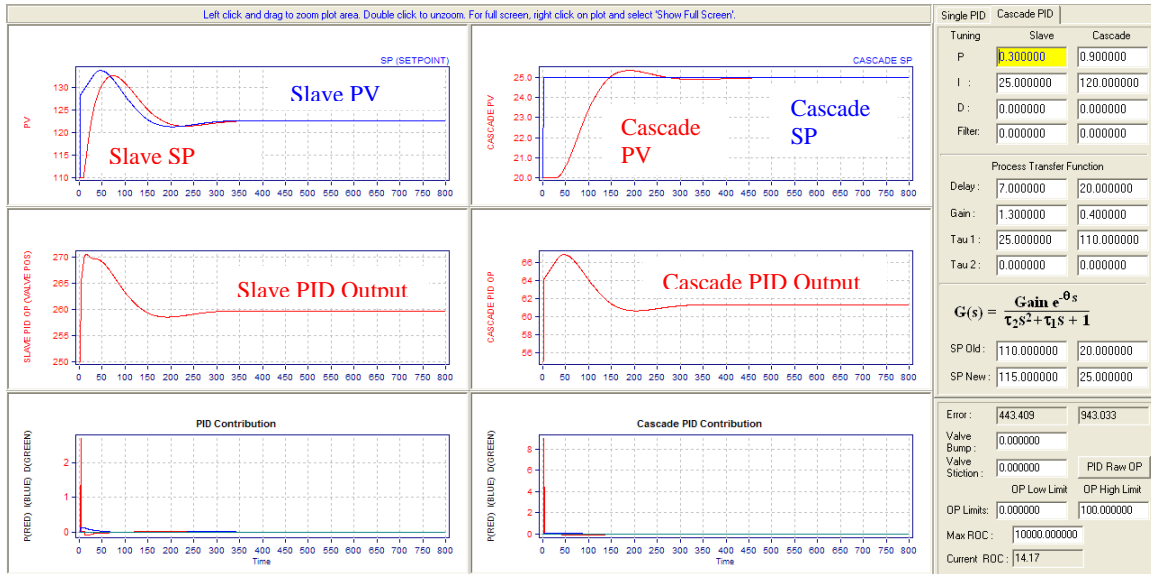


Fig.9. PID Tuning Optimization in presence of SP change and typical disturbance

8. Production Rate Maximizers

One of the most powerful schemes to maximize plant profits is by implementing production rate maximizer schemes in the DCS or even PLC, as illustrated in Fig. 10. As many as ten or more constraints can be implemented as part of the constraint pusher schemes. The optimization software identifies the process dynamics for all the constraints and then precisely optimizes all the tuning parameters.

9. Custom Control Simulations

It is important for the control engineer or technician to easily identify dynamics and try different simulation options easily to perform “what-if” scenarios on a PC simulation provided by the optimization software. Too often, without proper software tools, most engineers and technicians try the old fashioned “trial-and-error” approach which is too

slow and ineffective. Fig. 11 shows how a sinusoidal disturbance can be quickly added to a simulation to check the impact of tuning changes and controller output response.

10. Feedforward Control

In all chemical processes, control quality can be significantly improved on various important control schemes using feedforward control. Unfortunately, almost all feedforward tuning parameters are estimated today in the control room by trial-and-error or “best-guessed” estimates.

The software tool provides powerful functionality to mathematically identify the feedforward parameters - lead, lag, gain and dead time. Understanding how feedforwards work allows building creative new applications all inside in the DCS or PLC for numerous other innovative purposes.

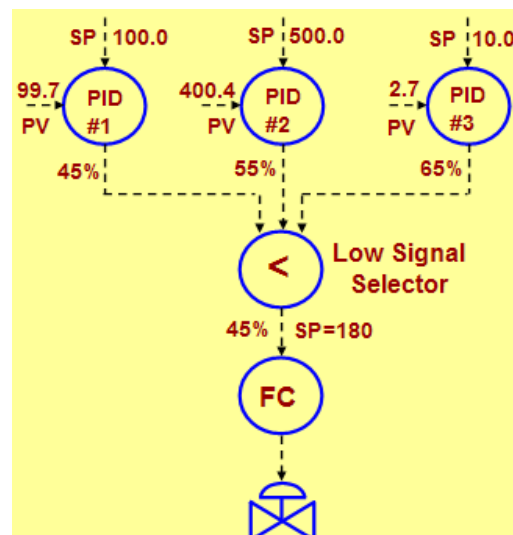


Fig.10. Production Rate Maximizer Controllers inside DCS or PLC

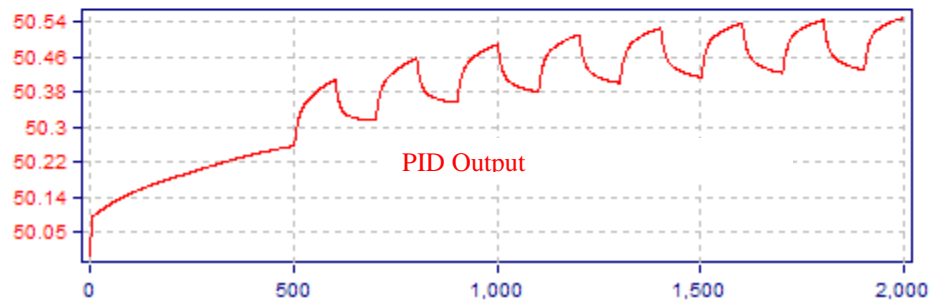
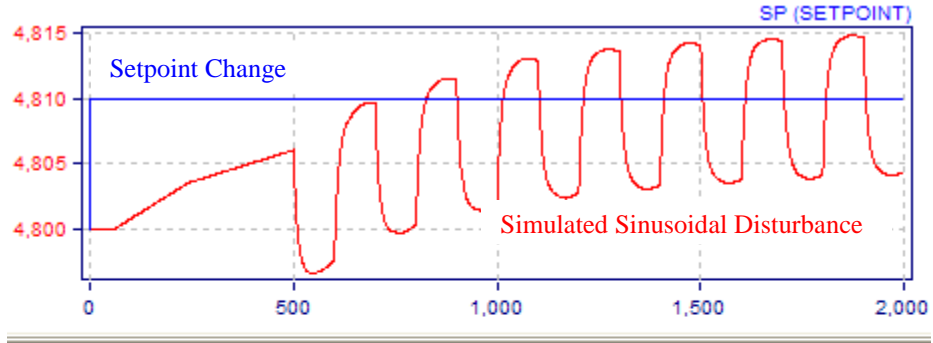


Fig.11. Adding a Sinusoidal Disturbance to a Setpoint Change

Fig. 12 shows a pulse signal input to a feedforward transfer function with the lead constant less than the lag constant.

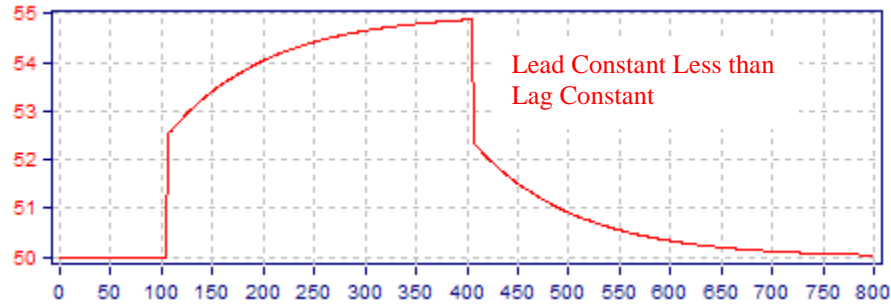


Fig.12. Higher Lag Constant in a Feedforward Scheme

Fig. 13 shows a pulse signal input to a feedforward transfer function with the lead constant higher than the lag constant. Notice the differences in the response in the two cases.

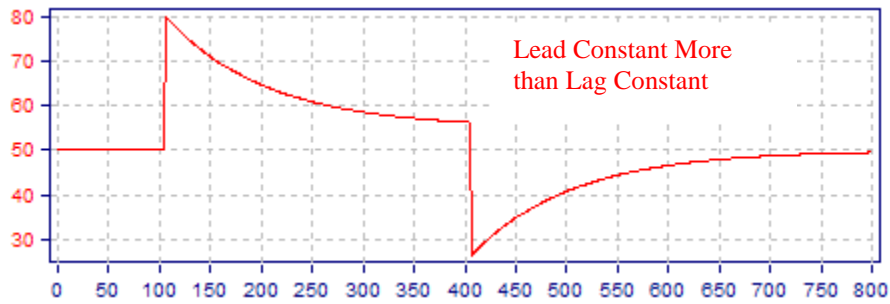


Fig.13. Higher Lead Constant in a Feedforward Scheme

All these simulations can calculations can be easily performed with the software tool. By mastering the quantitative details of how feedforwards work, an engineer or technician can easily build powerful feedforward control schemes inside the DCS or PLC with numerous benefits. Fig. 14 shows a sample calculation overview of a feedforward control scheme.

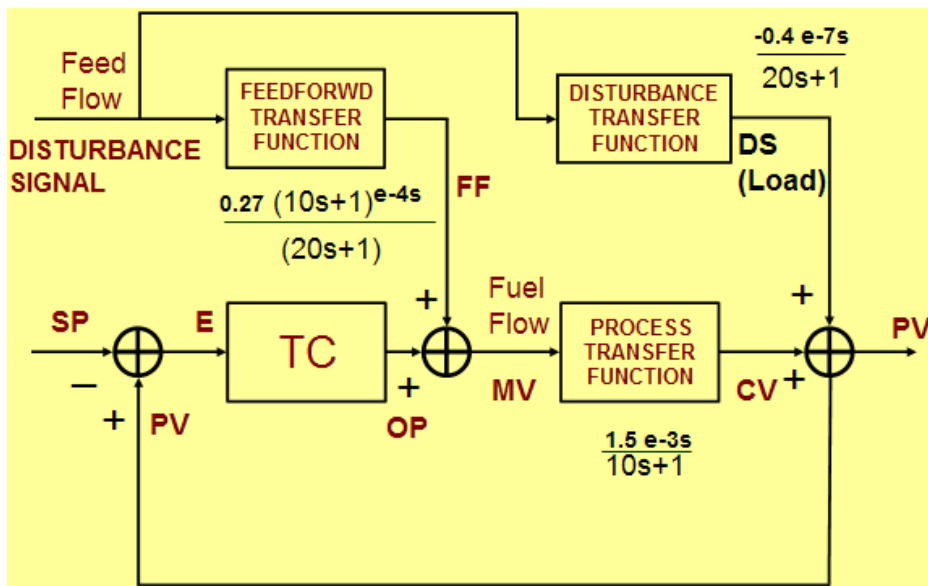


Fig.14. Feed forward Parameter Calculations

11. Model-Based Controllers

Another big opportunity is the implementation of model-based controllers in the DCS or PLC. Any model based on rigorous, empirical, semi-empirical or regressed models can be implemented in the DCS using once through or iterative calculations. Such models can be used to implement closed-loop controllers in the DCS or PLC. Furthermore, measurement feedback such as from online gas chromatographs or laboratory analysis can be incorporated into the predictive models. The modern software tools help to design model-based controllers with predictive, corrective and feedback closed-loop control action. An overview of the implementation is shown in Fig. 15.

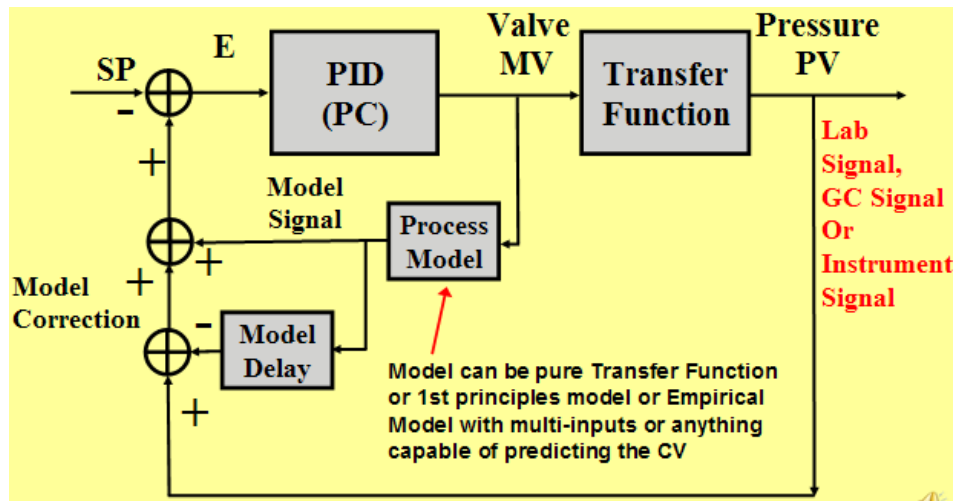


Fig.15. Implementing Model-Based Control inside DCS or PLC

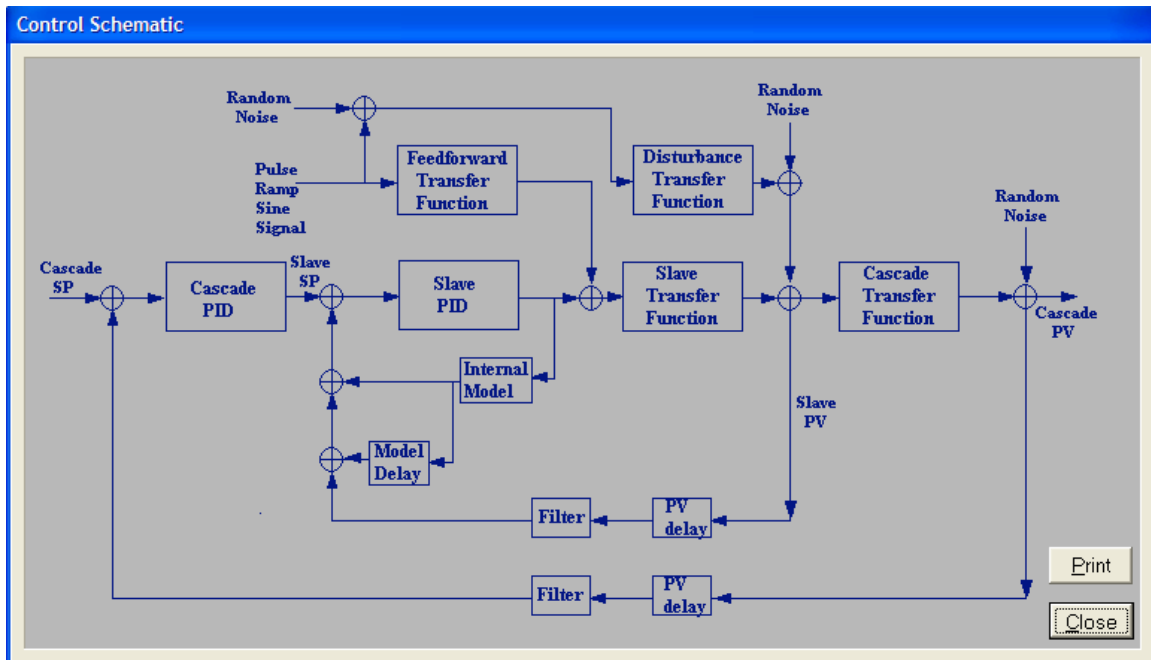


Fig.16. Process Control Simulation Functions

12. Summary

Since the 80s, an increasingly large number of DCS and PLC systems are controlling chemical processes. For many years, the basic hardware and software skills were being learnt and mastered to ensure control system reliability and safety. Now, the control community is past that stage and is ready to push the functions and capabilities of the DCS and PLC systems like never before. Numerous powerful process control applications can be implemented in the DCS or PLC with increased recurring average annual profits ranging from \$50K to \$3 million, depending on the size and type of the plant. However, to realize these benefits, chemical plant managements need to properly train their control engineers and technicians and provide modern process control software tools to aid their implementation and design.

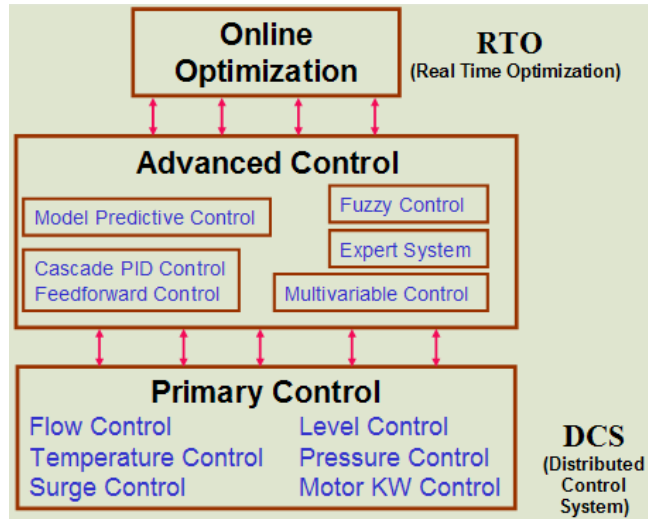


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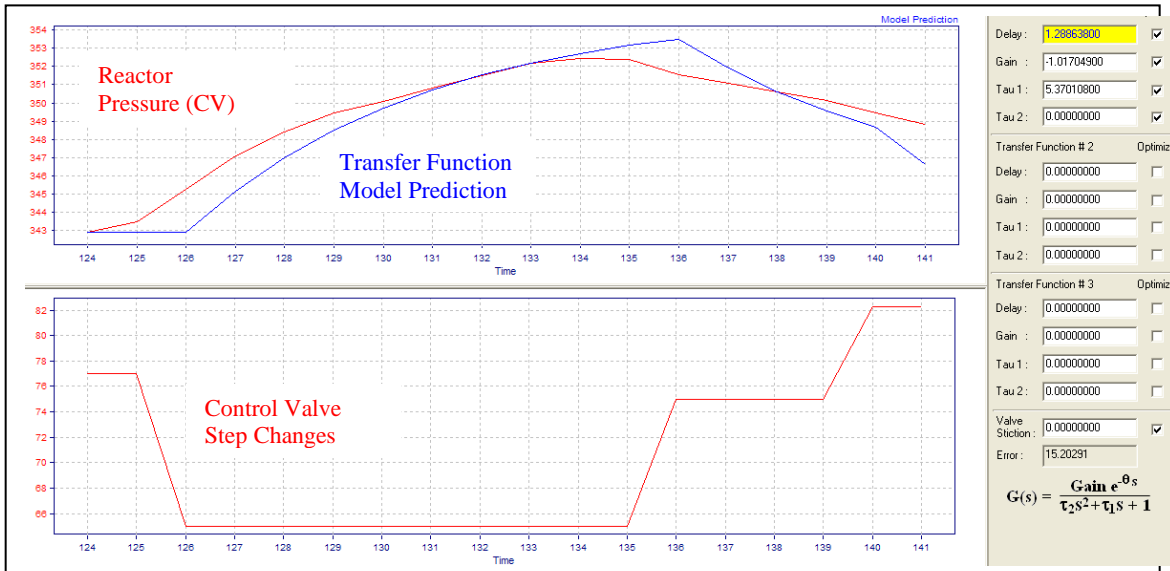


Fig.2. Pressure Control Transfer Function Dynamics Identification

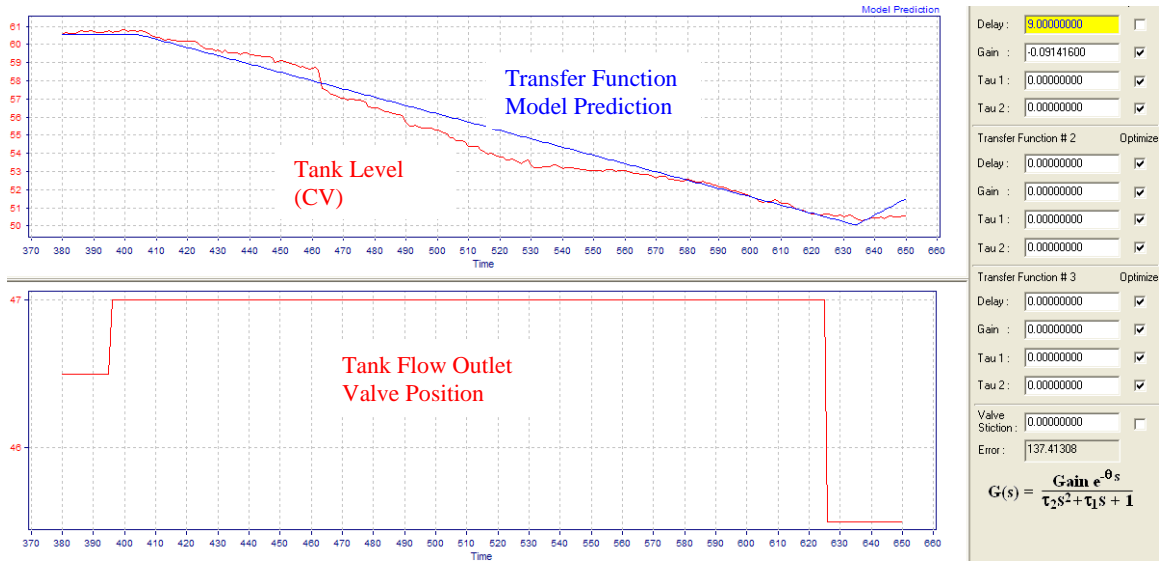


Fig.3. Level Control Transfer Function Dynamics Identification

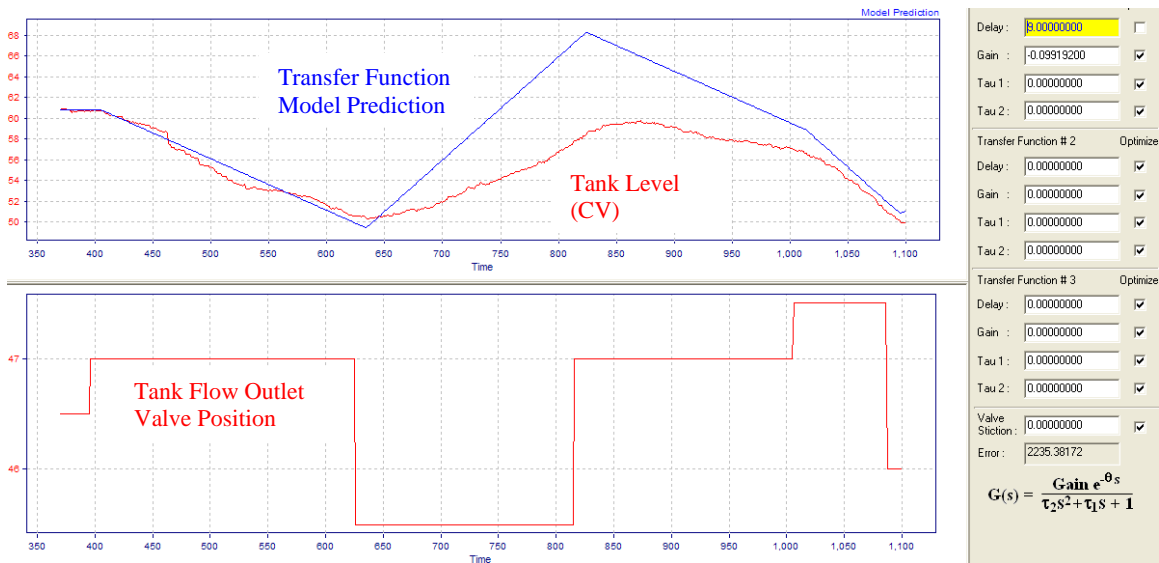


Fig.4. Level Control Transfer Function Dynamics Identification – Multiple Step

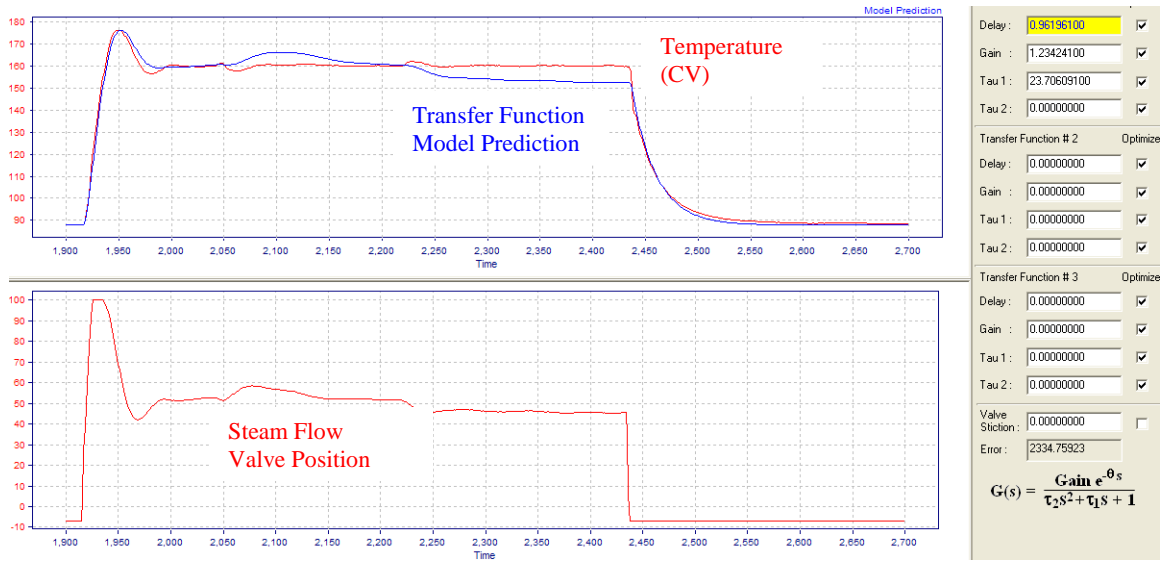


Fig.5. Temperature Control Transfer Function Dynamics Identification – Closed Loop Mode

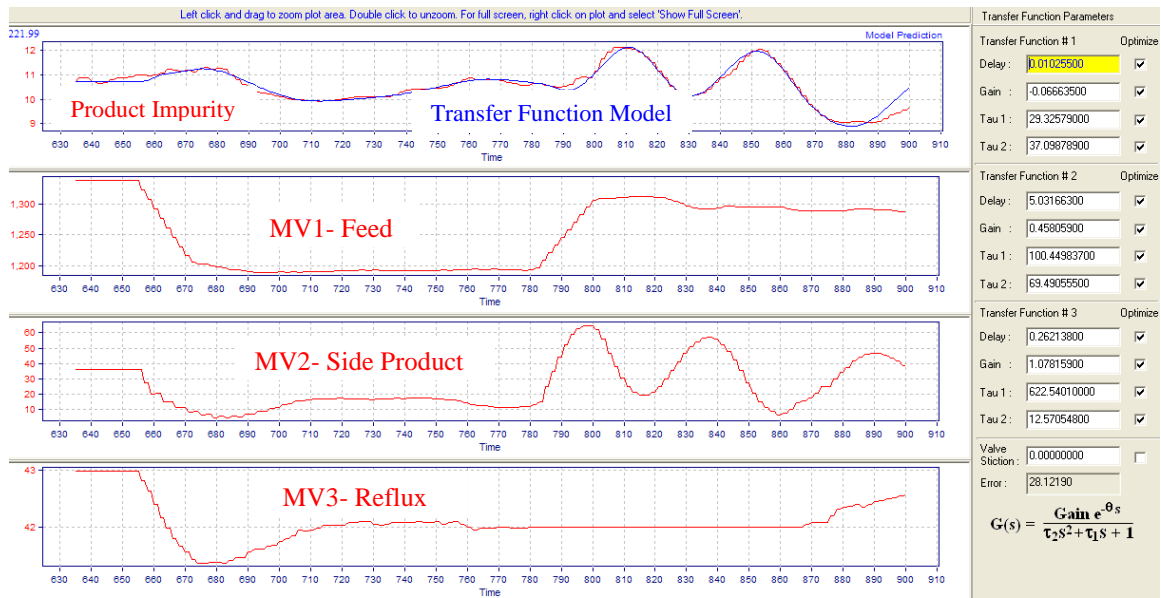


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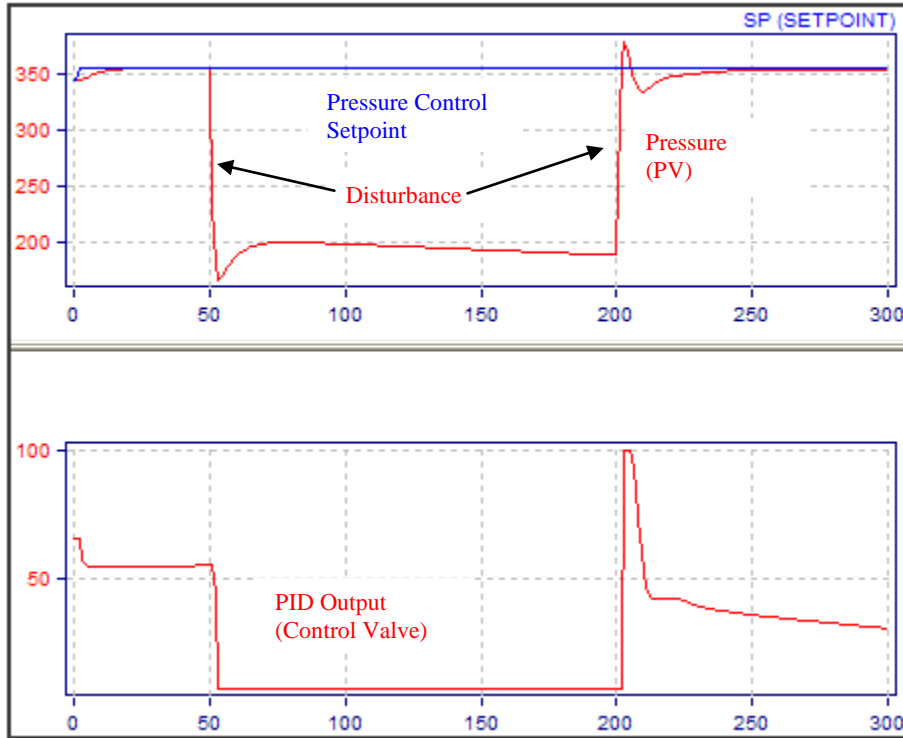


Fig.7. PID Tuning Optimization in presence of SP change and typical disturbance

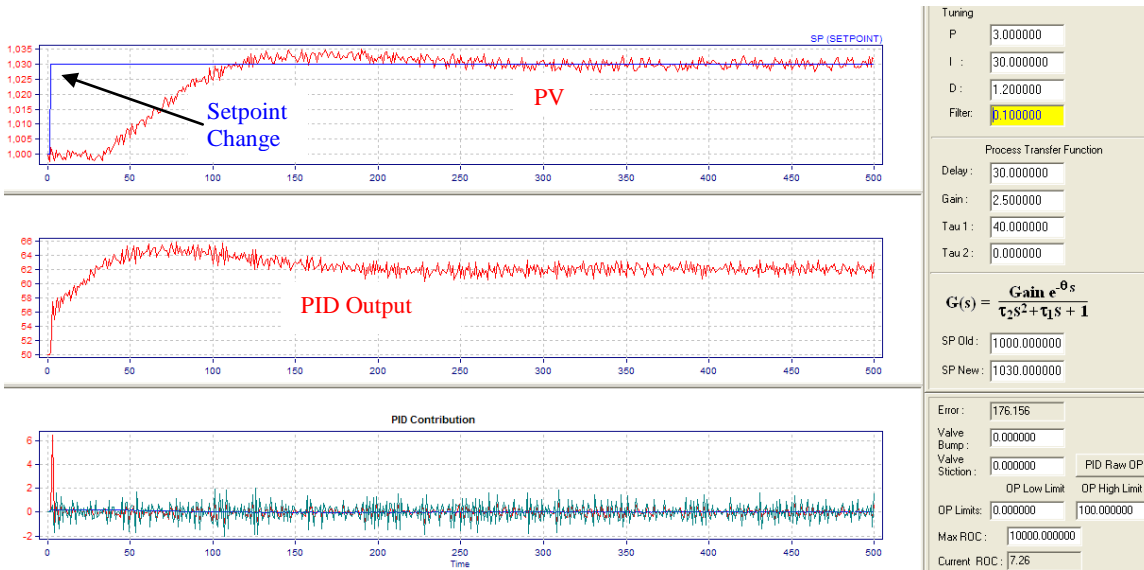


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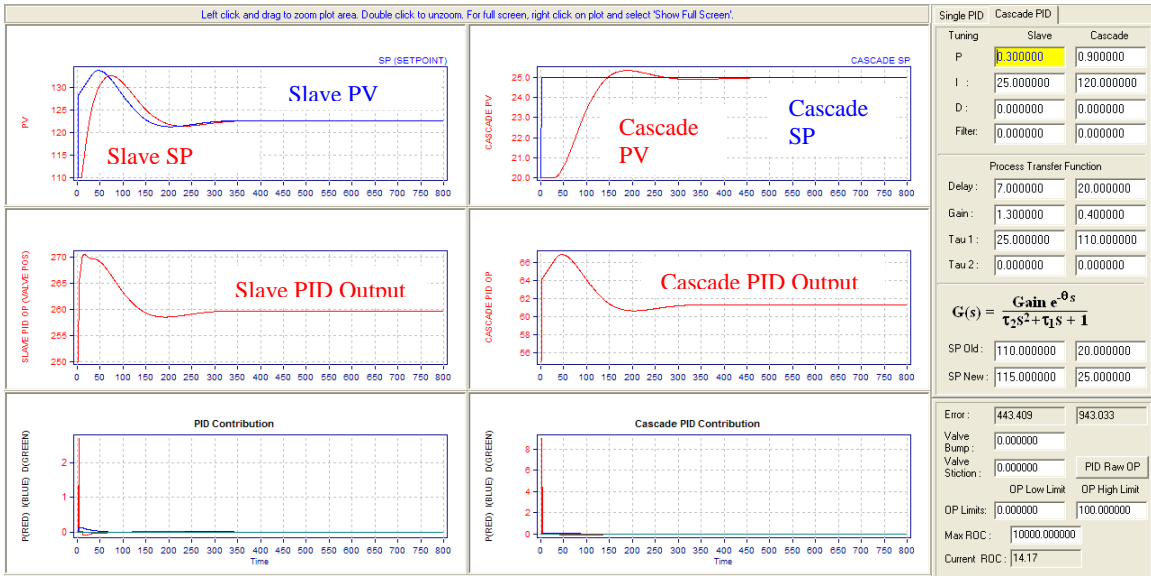


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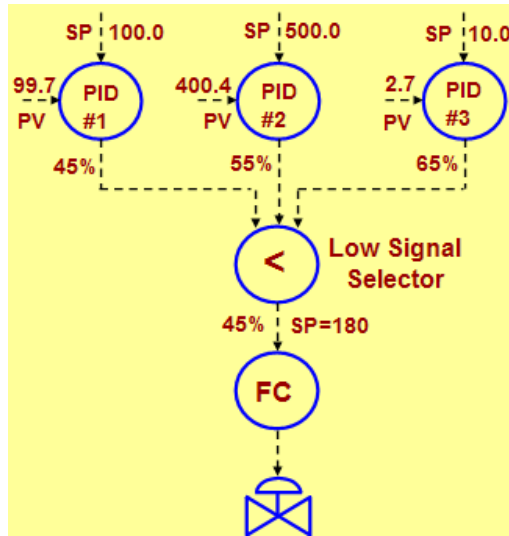


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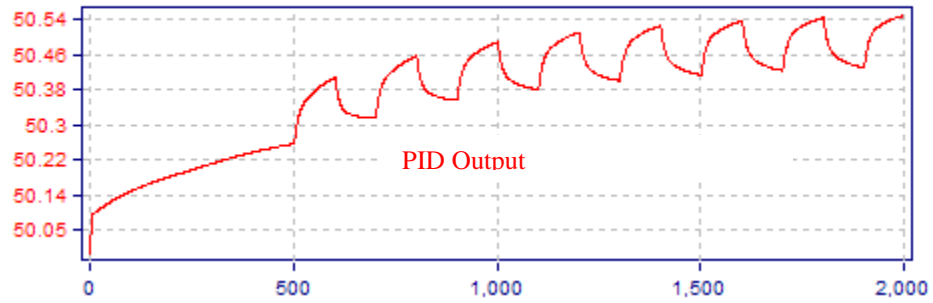
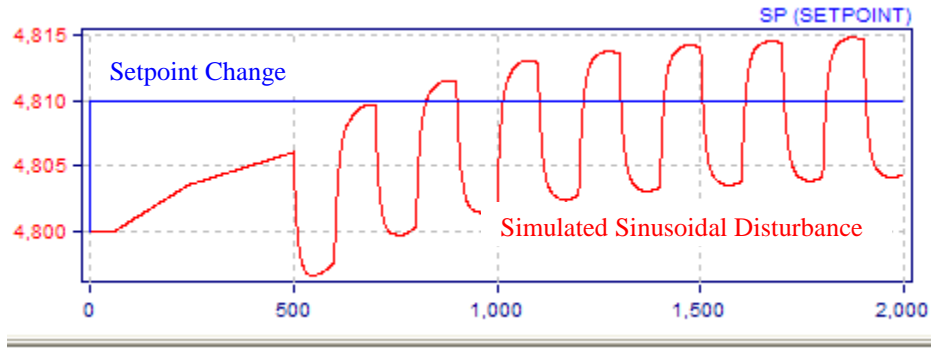


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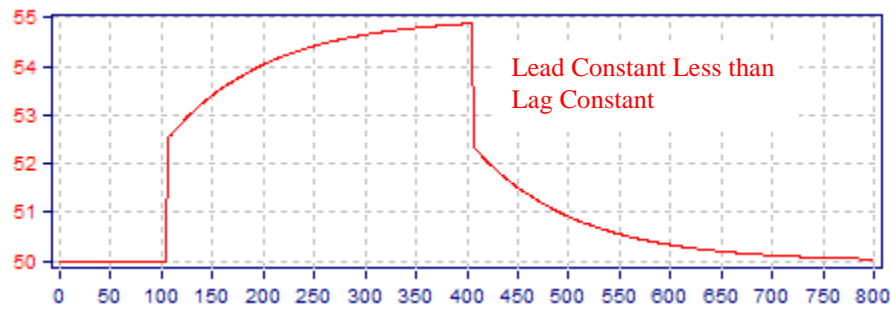


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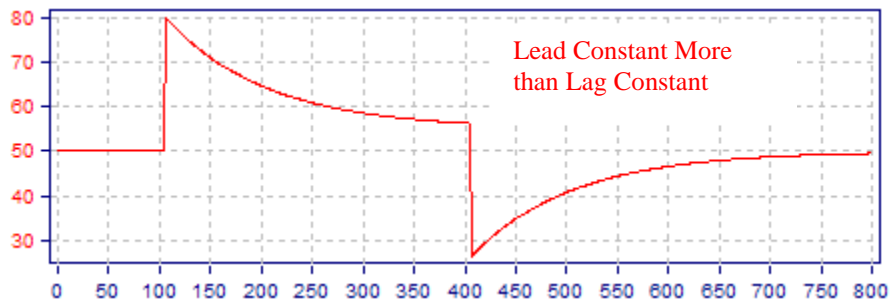


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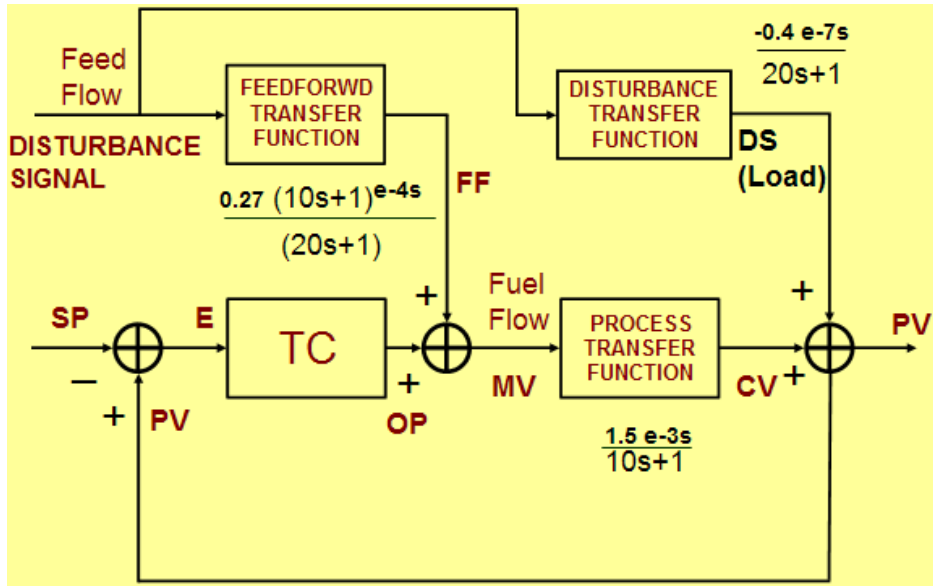


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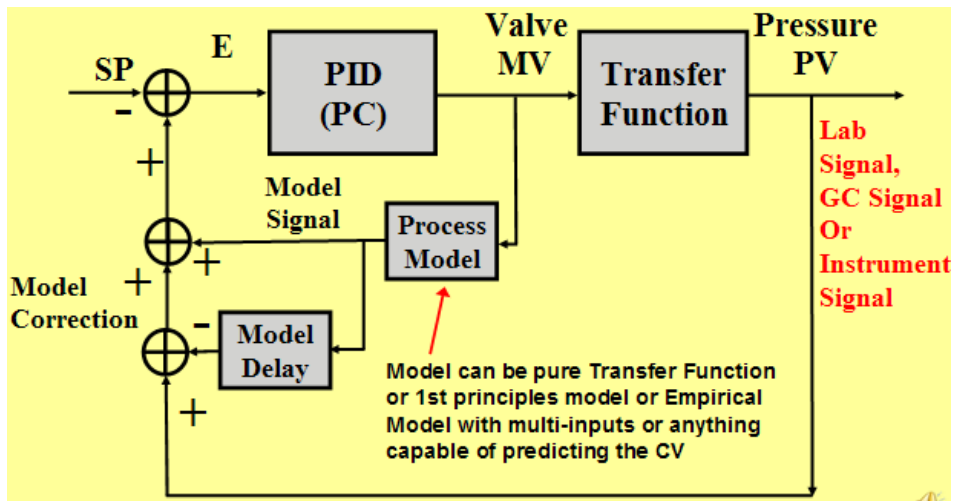


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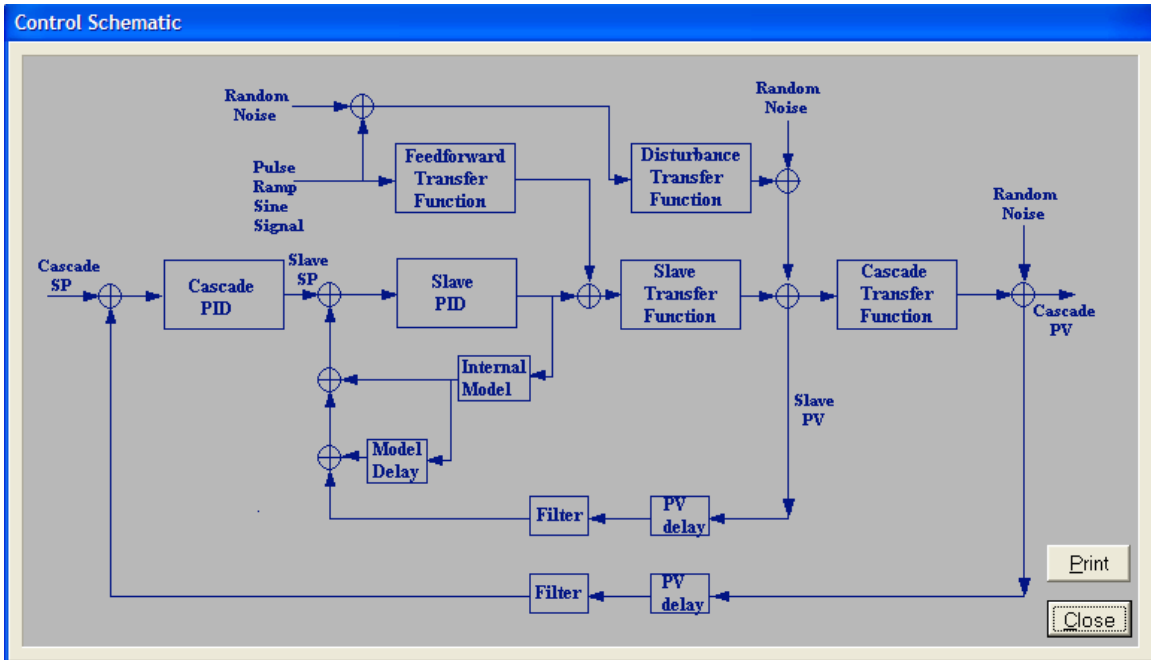


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