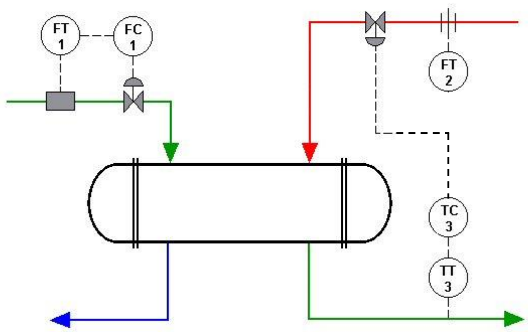
OMNI Process Solutions

How to Develop a Successful Control Strategy?

What is a control strategy?

Even process control professionals have difficulty offering a precise definition of the term 'control strategy'. This is because it's such a broad subject – ranging from the inner working of the PID algorithm to product quality objectives. However, some general descriptors of the 'control strategy' would surely include the following statements.

- It defines the variables that are controlled and the variables that are manipulated in the process system. In the example below the Reactor Feed temperature TC3 is the controlled variable and the steam flow control valve is the manipulated variable.



- It determines the variability pathways and 'how much' variability is moved from the controlled variables to the manipulated variables. A successful strategy moves variability ***from*** key process variables ***towards*** less critical processes. In the example TC3 moves variability from the reactor feed temperature into the steam header.
- It reflects the process variability objectives for the key processes. Resources need to be focused on ensuring low variability in the key process loops.
- It defines to a large degree the operator's role in managing the process. This includes the control modes available to the operator, bumpless transfer approach, automatic mode switching, and startup or shutdown automation.

What are the attributes of a successful control strategy?

A successful control strategy has the following attributes.

- It is tailored to the process objectives and is focused on delivering low variability in the key process variables.
- It responds effectively to important disturbances.
- It delivers consistent control performance over the entire operating range (i.e. the control loop dynamics are relatively linear)
- It is understandable to the operators and is relatively easy to operate. The control loops operate in design mode the vast majority of time.
- It delivers smooth (bumpless) transition between operating modes.
- It accounts for unexpected events such as sensor or valve failure.
- It provides decision making information to the operator.

How to develop a successful control strategy?

Developing a successful control strategy requires a strong understanding of the process objectives, the operating modes, process and control fundamentals and instrumentation. Accordingly, the development team should be multidisciplinary. A process control specialist is usually best equipped to lead the effort but there needs to be plenty of input from the process engineering, instrumentation and operations groups.

There are some key concepts that the development team needs to use in defining the best strategy.

- The control strategy needs to be matched to the known process disturbances. The important disturbances should be identified and characterized *at the beginning* of the control strategy design process.
- The control strategy needs to be developed analytically (i.e. math is involved) in order to ensure that the controller will work well over the entire operating range.
- The PID feedback control loop has limitations. It is only effective in responding to *relatively slow* external disturbances. External disturbances faster than 20 times the process deadtime or time constant are not going to be attenuated significantly by the feedback controller. The slower the dynamics the less capable the feedback controller.
- Advanced regulatory strategies such as cascade, ratio and feedforward have the potential to substantially improve control response to external disturbances. Implementing these more advanced strategies increases capital and maintenance costs and operator training requirements.
- Process non-linearities will significantly compromise feedback control performance, usually by requiring more conservative controller tuning. The control strategy should minimize non-linearities, particularly for key loops.
- Non-linearities should be pushed as far down the control strategy as possible. A fast slave loop can deal with a non linear process gain much more effectively (i.e. less impact on the master process) than a slow master loop. Control valve tracking non-linearities (backlash, stiction) will not only compromise loop performance but will also increase process variability via controller induced limit cycles

How can Omni Process Solutions help?

Omni Process Solutions has extensive experience in developing best practice control strategies for our clients in the pulp and paper industry.

Our control strategy development services include the following.

- Process and Control strategy review
- Data collection and analysis to identify the primary disturbances
- Development of conceptual control strategy
- Translation of strategy into detailed control logic diagrams for DCS /PLC configuration
- Developing customized process simulation to evaluate and test control strategy performance
- Factory acceptance checkout of control system logic
- Start-up assistance including logic testing, operator training and loop tuning

Developing a Successful Control Strategy – A Case Study

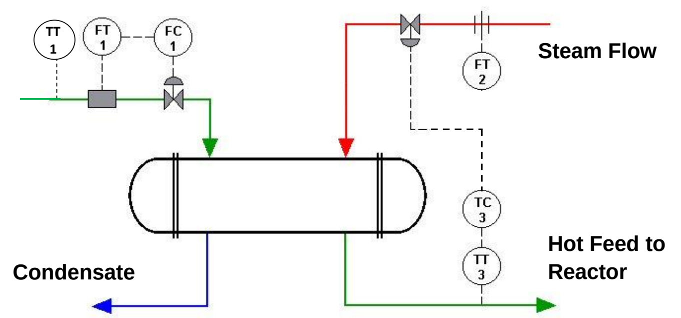
Let's consider the pathway to a successful control strategy using the following case study.

Current Status

Good control of the Reactor Feed temperature is critical because of its impact on product quality. Plant management has decreed that the TC3 variability should be less than 2% of mean.

The current control strategy is straightforward and inexpensive. The reactor feed temperature controller TC3 adjusts the steam flow to the heat exchanger by directly adjusting the steam flow control valve.

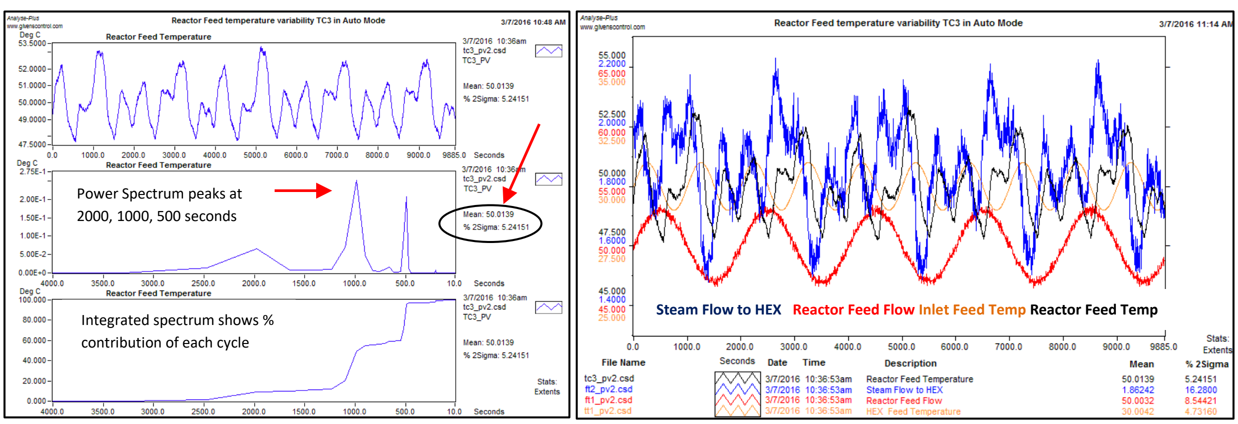
$$SteamFlow \propto C_v P_{IN} \sqrt{(P_{IN} - P_{OUT})}$$



TC3 adjusts the steam control valve directly. Increasing the steam flow rate to the Heat Exchanger increases the heat transfer rate to the Reactor Feed stock. The temperature sensor is mounted in the reactor feed pipeline downstream of the Heat Exchanger.

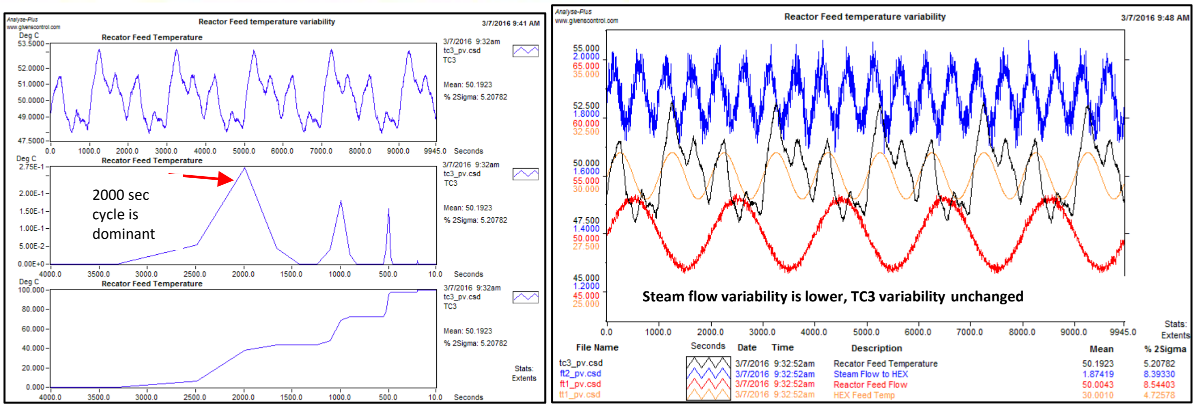
$$FeedTemperature \propto SteamFlowFT2 / FeedflowFT1$$

Currently the TC3 variability in Auto mode is too high – over 5 % of mean. The majority of the variability is a result of 3 disturbance cycles. The reactor feed FT1 cycles at a period of 2000 seconds, the steam flow FT2 at 500 seconds and the Inlet Temperature TT1 at 1000 seconds.



TC3 variability in Auto mode

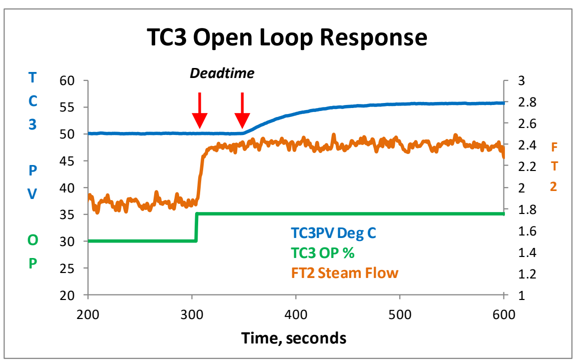
We place the TC3 controller into manual mode to understand the impact of the control action. We are disappointed when we discover that the variability in manual mode is 5.2% of mean – *the same as Auto mode*. The power spectrum analysis indicates that the 2000 second cycle is more dominant in manual mode, the 500 second cycle less dominant. The TC3 control action is increasing steam flow (FT1) variability without reducing temperature variability.



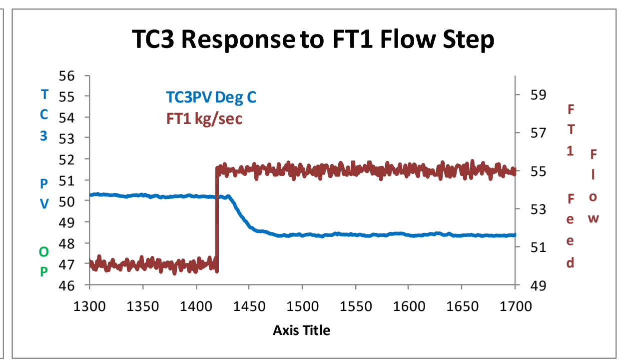
TC3 variability in manual mode

<u>Investigating TC3 control performance</u>

Before making changes to the control strategy, we conduct open loop bump tests to determine if the TC3 feedback control performance can be improved. The results indicate that the TC3 process dynamics are relatively slow and include 40 seconds of deadtime.

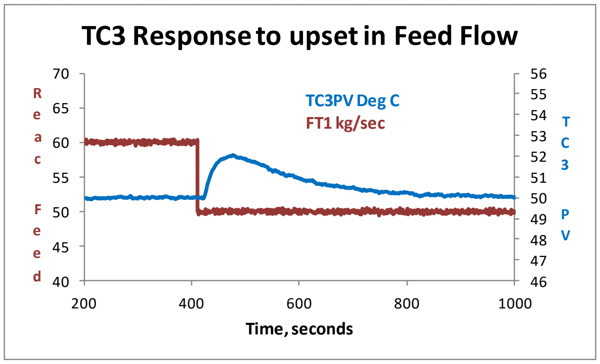


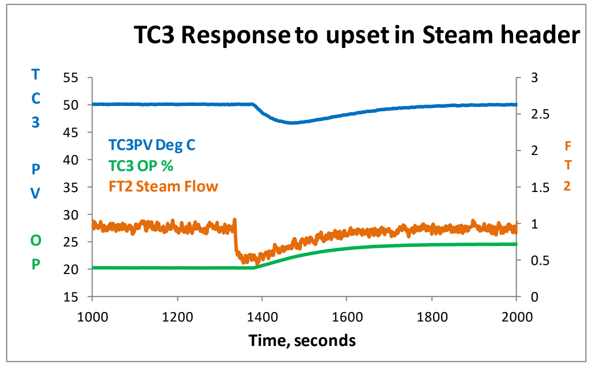
TC3 open loop bump test



TC3 open loop response to a Reactor Feed step

Based on these dynamics we choose a Lambda value of 120 seconds and calculate the tuning constants. To our chagrin, we find that the current tuning is not significantly different from our proposed tuning. We test the new tuning by stepping the reactor feed rate and observing that it takes TC3 approximately 7 minutes to recover fully. We remember the formula for the controller cutoff period and realize that even with the new tuning, TC3 is too slow to respond effectively to the 500 and 1000 second disturbances. In fact it will likely amplify the 500 second disturbance. The limitations of the TC3 feedback controller are starting to sink in!

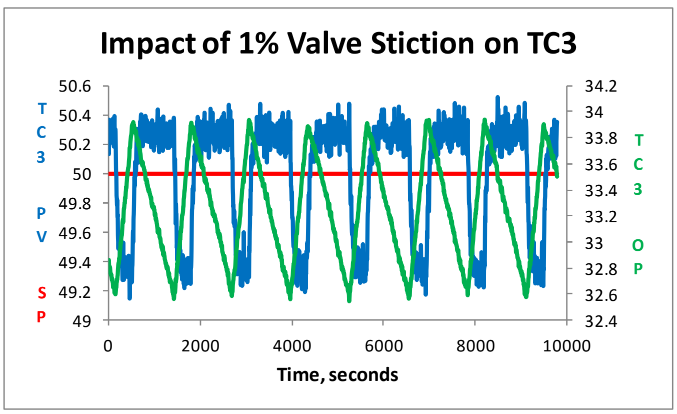




TC3 closed loop response to FT1 step

TC3 closed loop response to a steam flow step disturbance

Moreover, we realize that the TC3 process dynamics will be highly non-linear. The process gain and the deadtime will decrease as the reactor feed rate increases. If we try to speed up the tuning significantly we risk destabilizing the controller at low reactor flow conditions. The open loop bump tests have also revealed 1% stiction in the temperature control valve. This stiction will contribute a slow limit cycle (period of approximately 1000 seconds) in TC3.



Modifying the control strategy to reduce TC3 variability

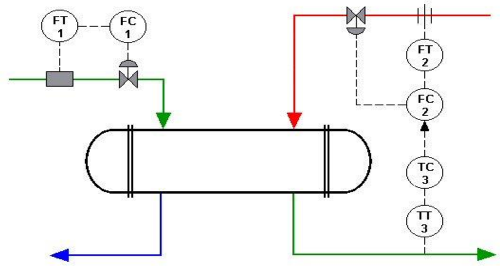
After conducting a process control survey we conclude that we won't be able to eliminate the disturbances for the for-seeable future. It's time to consider control strategy options that may help us in achieving our TC3 variability target of 2% of mean.

Control Option 1 – Implementing a Temperature to Steam Flow Cascade Strategy

The 500 second steam header (FT2) cycle appears to be responsible for approximately 30% of the overall TC3 variance. And our analysis has shown that the TC3 controller will *amplify* 500 second disturbances.

A cascade strategy where the TC3 controller adjusts the steam flow controller (FC2) ***setpoint*** rather than the control valve – might be in order. The FC2 controller has fast dynamics (and no deadtime). A reasonable lambda value for this loop would be 5 seconds – fast enough to respond to a 500 second disturbance cycle - effectively shielding TC3 from the disturbance.

The FC2 controller would also be responsible for dealing with the 1% control valve stiction. The fast FC2 controller will drive through the stiction very quickly – generating a fast steam flow cycle that should have little impact on Reactor feed temperature. Furthermore, the cascade strategy will linearize the TC3 process gain to some extent since a 1% step in the TC3 output will always produce a consistent steam flow change.



Cascade Strategy

TC3 adjusts the steam flow FC2 setpoint.

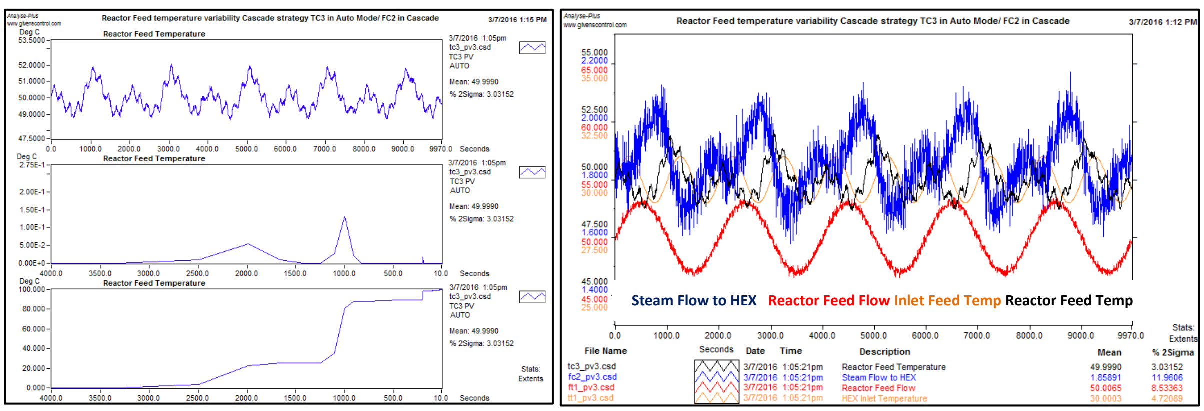
The FC2 response to steam header disturbances is fast, shielding TC3.

The fast FC2 tuning reduces vulnerability to valve backlash and stiction.

Shows a Temperature to Steam Flow cascade strategy

We implement the cascade strategy and find that the TC3 variability has been reduced from 5.2% to 3% of mean. The 500 second cycle has virtually disappeared and the 2000 and 1000 second cycles are substantially smaller. Management is very pleased with the reduction in product quality losses.

There were some costs in implementing the cascade strategy. We purchased a vortex flow sensor and hired a consultant to develop the DCS configuration. We spent time tuning the TC3 and FC2 controllers - which needed to be properly coordinated. Most importantly, the operators were trained to understand (and use) the new strategy.

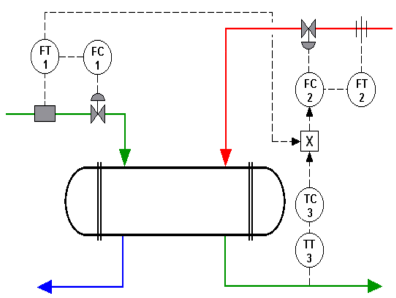


TC3 variability with the cascade strategy implemented. The variability has decreased from 5.2% to 3% of mean.

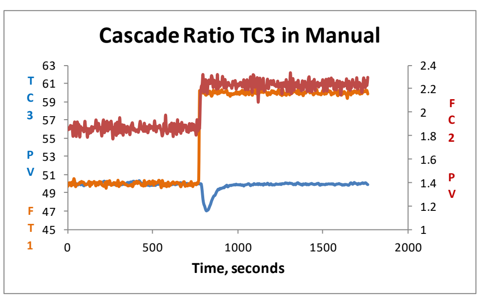
Control Option 2 – Implementing a Cascade Ratio Strategy

We are still above our TC3 variability target of 2% of mean. Approximately 80% of the remaining variance is a result of the 1000 and 2000 second cycles in TC3. It's important to remember that while the FC2 steam flow controller is a shield against steam header upsets, the slow TC3 controller is still responsible for all other disturbances. Even after retuning, the TC3 controller is only capable of attenuating 75% of the 2000 second cycle – and almost none of the 1000 second cycle.

We energy balance the heat exchanger and realize that keeping the steam to reactor feed ratio constant will keep TC3 relatively constant when the Reactor Feed flow is changing. Accordingly, we design a cascade ratio strategy where the TC3 controller adjusts the steam to feedrate *ratio* (i.e. kg steam/kg feedstock) target rather than the steam flowrate target. The ratio target from TC3 is multiplied by the reactor feed flowrate (FT1) to calculate the steam flowrate (FC2) setpoint. A reactor flowrate change will result in an immediate change to the steam flow setpoint. The FC2 controller will quickly bring the steam flowrate to the new target, maintaining the steam to reactor feed ratio constant and minimizing the impact on TC3.



Cascade Ratio Strategy
TC3 adjusts the Steam Flow to Reactor Feed Flow Ratio. The ratio target is multiplied by the Reactor Feed flow FT1 to calculate the Steam Flow FC2 setpoint.
The ratio strategy compensates immediately for Feed flow variation.

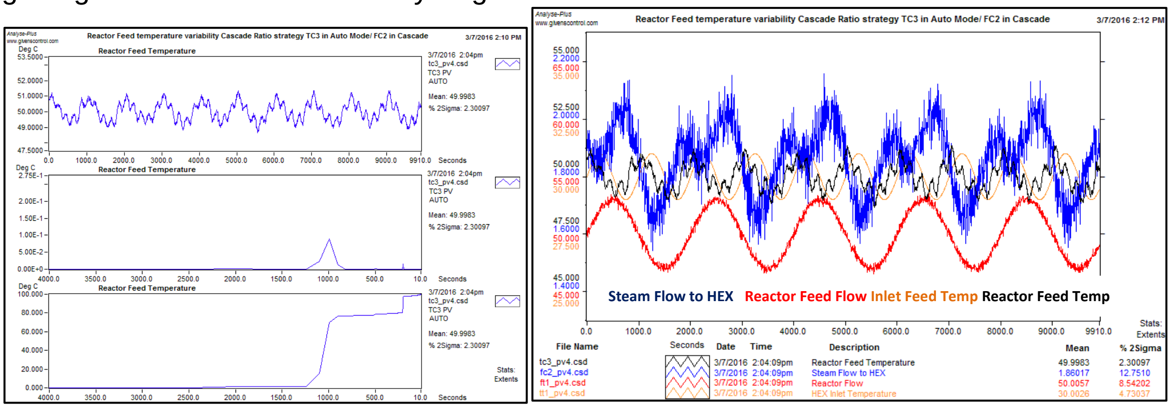


Ratio strategy results in immediate steam flow response to Reactor flow change

We get an added bonus. The cascade ratio strategy linearizes the TC3 process gain with respect to reactor flow. TC3 is now adjusting the ratio target rather than the steam flowrate. If the reactor flow feedrate is relatively high, a 1% TC3 output step will result in a relatively high steam flow setpoint step. Conversely if the reactor flow feedrate is relatively low, a 1% TC3 output step will result in a relatively low steam flow setpoint step. In either scenario the steady state temperature change to the 1% output step will be relatively constant. The more linear TC3 process gain will permit faster TC3 controller tuning.

We implement the cascade ratio strategy and find that the TC3 variability has decreased from 3% to 2.3% of mean. The 2000 second cycle has been virtually eliminated. The dominant TC3 cycle is at a period of 1000 seconds – accounting for 75% of the remaining variance.

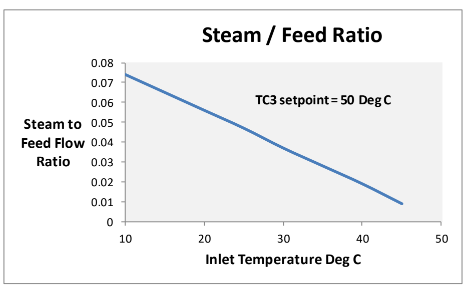
There were further costs in implementing the cascade ratio strategy. An accurate reactor feed flow sensor was installed and further operator training was conducted. But we are getting close to the 2% variability target.

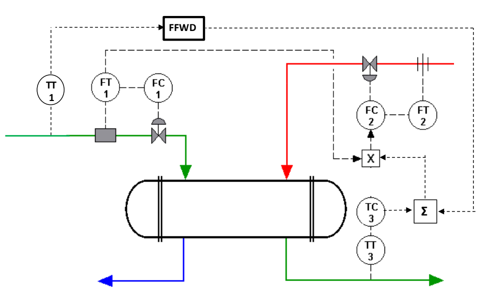


TC3 variability with the cascade ratio strategy implemented. The variability has decreased from 3.0% to 2.3% of mean.

<u>Control Option 3 – Implementing a Cascade Ratio with Feedforward Strategy</u>

The Inlet Feed Temperature to the Heat Exchanger TT1 is the source of the almost 2 Deg C 1000 second cycle in TC3. Unfortunately, the TC3 feedback controller is almost completely ineffective in attenuating this disturbance. We need another approach. The energy balance showed that the *steam to reactor feed ratio* versus *inlet temperature* relationship was linear. We can set up a feedforward controller to automatically adjust the steam to reactor feed ratio when the inlet feed temperature changed. A decrease in TT1 would result in an immediate increase in the Steam to Reactor Feed ratio. An increase in TT1 would result in an immediate decrease in the Steam to Reactor Feed ratio.





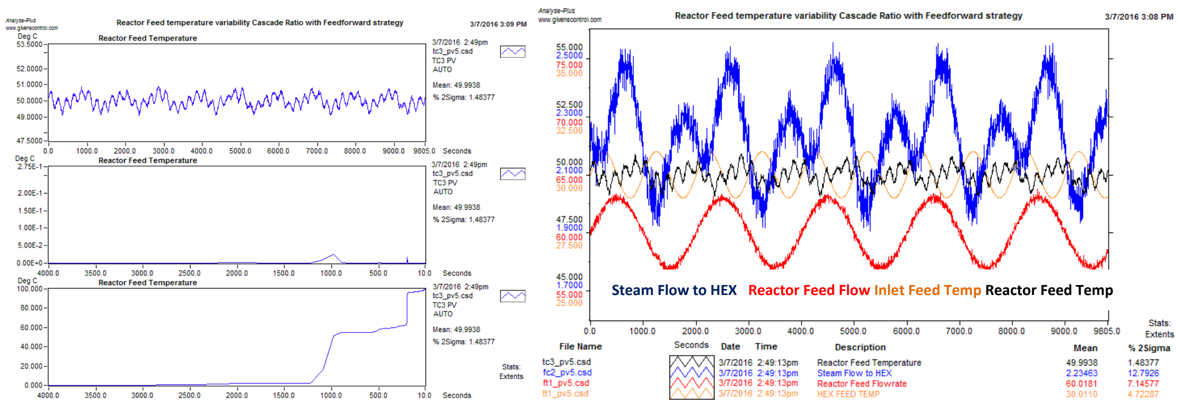
Cascade Ratio Strategy

TC3 adjusts the Steam Flow to Reactor Feed Flow Ratio. The ratio target is multiplied by the Reactor Feed flow FT1 to calculate the Steam Flow FC2 setpoint.

The ratio strategy compensates immediately for Feed flow variation.

We implement the Feedforward strategy. The amplitude of the 1000 second cycle has been reduced by 75% and the variability has now dropped from 2.3 to 1.4% of mean.

While this strategy is more expensive, it is focused on delivering low variability in the key process variable (TC3), responds effectively to the major disturbances, and delivers consistent control performance over the entire operating range. We have met our target!



TC3 variability with the feedforward strategy added. The variability has decreased from 2.3% to 1.4% of mean.