

3 Steps to Better Steam Temperature Control

Proven Strategies to Minimize Thermal Stress and Tube Leaks



Commercial power generators are having to significantly change how they operate their coal and gas units because of the impact of intermittent renewables and cheaper natural gas. In many cases, plants were not designed to cycle load as they are required to do in today's market.

Increased cycling places additional mechanical stresses on boilers and heat recovery steam generators (HRSGs), particularly influenced by underperforming superheat and reheat loops. The suboptimal performance of these important loops can increase the frequency of tube leaks.

This white paper describes the steps necessary to better handle the rigors of plant cycling, including:

1. Validating your critical steam temperature measurements
2. Ensuring optimal steam attemperation
3. Improving your control methodologies

STEP 1

Ensure Your Temperature Measurement is Correct

Validate Your Key Performance Indication

Load following and other cycling units require more precise temperature control because of frequent temperature set point changes, but this calls for a more rigorous measurement approach. Power plants commonly deploy direct wire redundant thermocouples which isn't a problem during steady state conditions since you can correlate temperature against pressure.

Measurement accuracy is more difficult when units are cycling, however. And on top of this, there is electromagnetic interference (EMI) present in all plants that can adversely impact thermocouples. Power Magazine wrote that a 10mV noise spike (common in plants) can equate to a 50°F spike, which could lead to negative situations such as a boiler shutdown. Perhaps the most compelling reason, though, is that EPRI has estimated running a 500MW unit at 1 to 2°F-higher reheat temperature can represent a 2MW gain in efficiency.

On-Scale and Off-Scale Failure Modes

Two common failure modes exist. The mode most easily detected is where the sensor simply stops working and the operator receives an alarm. This is referred to as an off-scale failure and is usually the best understood. The more difficult and hazardous mode is called an on-scale failure. In this case, the temperature reading looks correct, but the sensing element is damaged and is providing an incorrect

temperature. Direct-wiring thermocouples provides little indication of an on-scale failure caused by a drifting thermocouple due to wire thinning, sensor degradation, or corrosion (Figure 1).

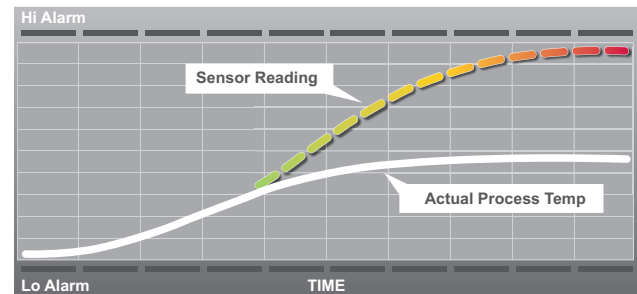


Figure 1: On-scale sensor failure.

Advanced Transmitters and Thermocouple Diagnostics

With this new operating reality, plants should reevaluate their approach to this important measurement. How can you confidently control steam temperature while your plant is consistently changing if you aren't 100 percent sure about the validity of the reading?

A best practice for accomplishing this is to use a temperature transmitter in lieu of direct-wire inputs. Some advanced transmitters are much less sensitive to EMI and include special diagnostics that can tell you when your thermocouples are degrading. This type of transmitter runs diagnostics that continually monitor the resistance of a thermocouple loop. When a user-defined limit is reached, an alert is triggered (Figure 2).

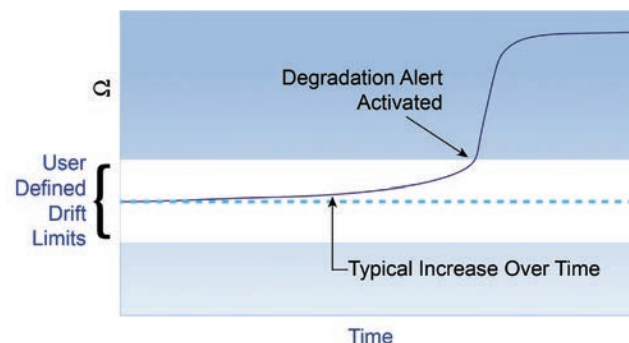


Figure 2: Transmitter sensor diagnostics.

This allows you to confidently operate very close to a desired temperature while always knowing whether your temperature measurements are compromised. Being that tube leaks from thermal stress are a

leading cause of forced outages, advanced temperature sensing can be a cost-effective way to safely maximize megawatt production. Plus, a transmitter that helps provide temperature certainty establishes a great baseline infrastructure for more advanced controlling techniques.

STEP 2

Ensure Your Attemperators are Working Properly

Thermal Stress of Pressure Components

Many units are required to startup and shutdown more frequently, which places additional thermal stress on HRSG pressure components. Operating like this also places stress on your steam attemperators as they are in service much more. Now add in more low load operation and the performance of your sprays are suddenly an important variable. Any combination of control valve trim and nozzle problems will adversely affect the performance of your unit by introducing unwanted thermal transients.

Attemperation loops are mechanically challenging and require proper sizing of both the control valve and a spray nozzle. Unfortunately, many units were not originally designed for today's cycling duties, and as such, some attemperation loops do not function properly through the entire load range.

The spray associated with superheat and reheat is engineered so that it covers much of a pipe without contacting the surface. This provides the correct amount of cooling with no adverse thermal effects. A malfunctioning nozzle does not atomize properly and will over- or under-spray the steam. Over-spray causes localized quenching on the piping surface or water fallout that can lead to carryover to the turbine. Under-spray results in hot and cold spots within the loop and inaccurate temperature readings. This in turn can jeopardize the system by controlling to an incorrect set point (Figure 3).



Figure 3: Attemperator overspray, proper spray, and underspray.

Unwanted spray patterns are the result of common issues associated with deteriorated spray nozzles, including plugged ends, broken tips, and blown (missing) tips (Figure 4).



Plugged Nozzle



Plugged Nozzle



Blown Nozzle Tip



Broken Nozzle

Figure 4: Examples of spray nozzle problems.

You Mean We're Supposed to Inspect and Change Them?

A best practice is to inspect your attemperators and change spray nozzles on a regular basis. For example, our recommendation from experience is that:

1. Insertion style desuperheaters should be inspected annually
2. Nozzles should be changed every 18 to 30 months
3. All insulation should be removed so that both the welds and the piping can be evaluated
4. Ensure a strainer is installed upstream of the spray valve
5. Bore scopes should be used for internal piping and liner reviews

Control Valve Performance is Critical

A properly functioning control valve creates a consistent and measurable change in flow in response to a step change in its position. One that is ideally ranged should have a linear "installed" flow characteristic throughout its range of travel since most control algorithms are mathematically linear. The selection of the valve internals or trim characteristic is mostly dependent on the pressure drop dynamics across the valve, which depend on the type of feed pump and spray nozzle design. For a plant that was not designed to cycle frequently, the assumption that the valve is properly ranged may be incorrect and a complete replacement may be required. Response over a wider range of operation is critical (Figure 5).

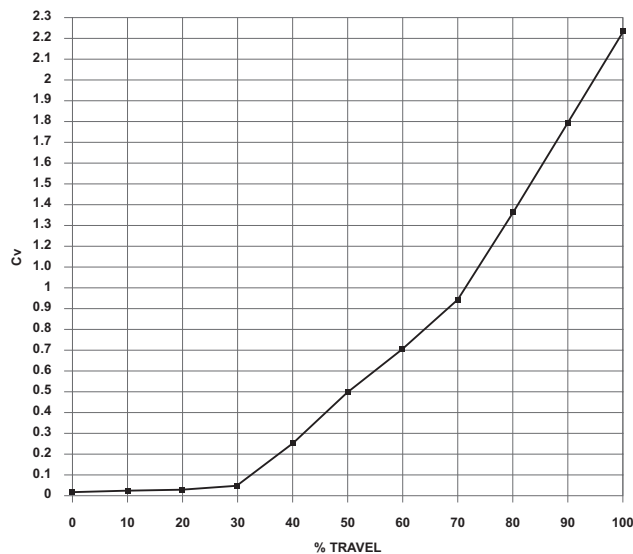


Figure 5: Example of proper valve response.

In this discussion, let's assume that the valve sizing is correct. Superheat and reheat control valves must accurately regulate the amount of water provided to the spray nozzles, but are subject to high ranges and cavitation. If this is not considered, the valve may experience high friction, which will prevent smooth operation through the range. It may also experience seat wear from the pressure differential when shut off (Figure 6).

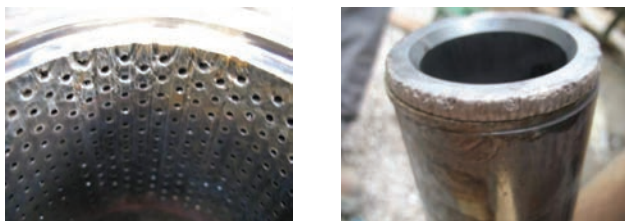


Figure 6: Examples of valve trim damage.

Some recommendations for attemperator control valves include:

1. Check the design of the control valve and attemperator spray valve against real-world operating conditions
2. Follow guidelines for minimum straight run pipe length
3. Install a severe service metal seated spray water block valve upstream that can achieve tight shut-off for extended periods of time. This will help prevent seat wear on the control valve
4. Consider changing to anti-cavitation valve trim

STEP 3

Improve Your Methods for Control

Operate Closer to Your Limits with Reduced Variability

It's often said in the automation business that a plant can only manage what is measured and it can only optimize what is controlled. Now that the foundation is in place for properly measuring steam temperature and controlling superheat and reheat sprays, it's time to look at how to optimize the entire loop to better handle the rigors of cycling.

Depending on the operation of an individual plant, there are likely different operating profiles. Some common steam temperature control goals are:

Goal	Reduce overshoot during load ramps
Method	Boiler fuel/air, gas turbine and duct burner load disturbance models
Benefits	Heat rate improvement (10°F is roughly 0.5 MWhr)

Goal	Reduce quenching (over-spray) during startups
Method	Improved control using startup HRSG model (high air flow and low fuel)
Benefits	Reduced header blending time and metal fatigue

Goal	Reduce control error standard deviation
Method	Model-based control
Benefits	Reduced piping fatigue and improved actuator life from a reduction in overall valve cycles Ability to run closer to design temperatures Reduced heat rate

Traditional Versus Advanced Control Strategies

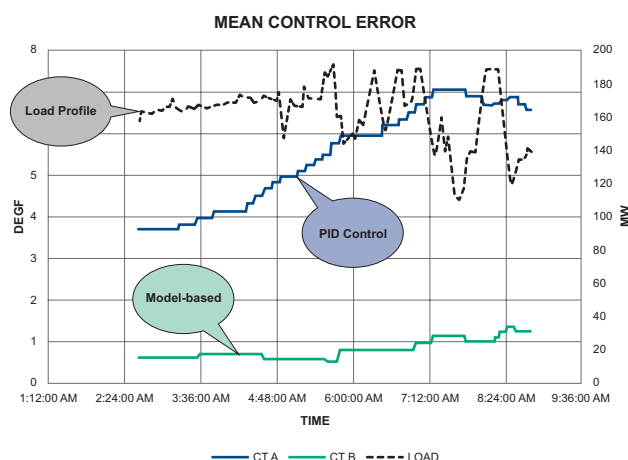
The more things change, the more they remain the same. That mantra is true in the power industry, as control system design often remains unchanged even though many plants are now being frequently cycled. Case in point is steam temperature control, where the algorithms are sometimes asked to do more than they are ideally suited for.

Traditional proportional, integral, and derivative (PID) control strategies for long lag-time processes will have limitations on the ability to ensure stable performance. PID control for steam temperature can get very complex as structures such as cascade, feed-forward, and adaptive gain and integral functions

are used to control the multiple variables. This method does not specifically control a steam temperature process model, but rather reacts to a host of individual inputs that are constantly changing. Consequently, this reactionary mode does not learn, nor does it anticipate what is going to happen based on current inputs or concepts that are critical to achieving tight control with ever-changing conditions.

A better approach is to deploy an advanced control strategy, such as model predictive control (MPC), which dynamically models the steam temperature process and, unlike PID control, can anticipate future events based on current operating conditions. MPC develops a multivariable steam process model that accurately reflects the numerous interrelationships of all the various associated process inputs, such as fuel, combustion turbine load, ambient temperature, heat exchanger fouling, and valve performance.

Here's a practical example of how this works. When a plant receives an automatic demand to increase load, there are many changes in the process that start taking place. The MPC model "knows" what is happening and how everything reacts together, so it can anticipate the actions needed to get there as quickly as possible without exceeding any plant designs. The prediction horizon in MPC allows a rapid and correct anticipation of the necessary control response to set the temperature at the design point without overshooting it, which could damage the HRSG. In the chart below we compare a well-tuned PID control to the MPC response on a load increase.



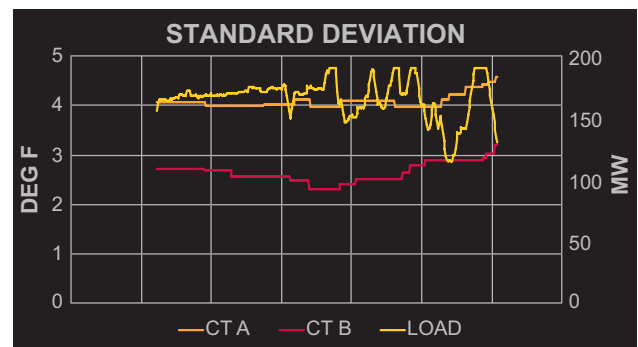
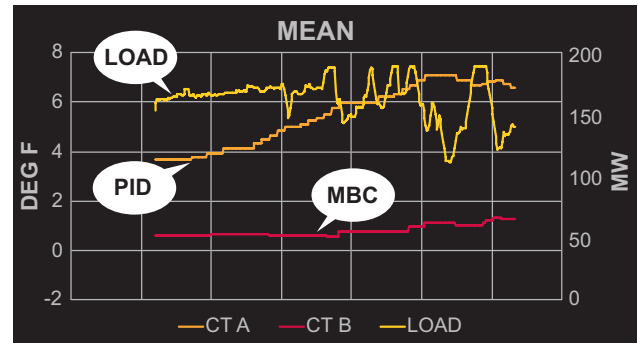
Control Error (DEGF)	CT A	CT B ⁴
Mean	< 7.0	< 1.33

BUSINESS RESULTS

The best way to demonstrate an integrated steam temperature approach is to show actual installations and their associated control benefits. Below are specific examples where this method has shown benefits for improving plant performance.

Example 1

2x1 Combined Cycle Plant

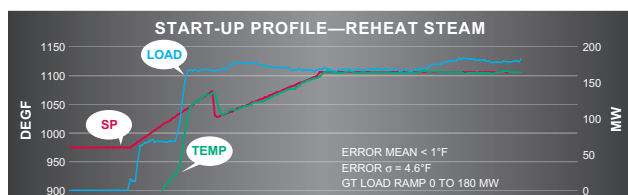


Control Error (DEGF)	CT A (PID)	CT B (MPC)
Mean	< 7.0	< 1.33
Standard Deviation	< 5.1	< 3.1
Maximal	14.6	7.7
Minimal	-21.0	-12.4

- Dual spray system with poorly performing control valves—large leakage
- Operating steam temperature increased by 8°F resulting in immediate heat rate benefit

Example 2

3x1 Combined Cycle Plant



Error (DEGF)	HP Steam	Reheat Steam
Mean	< 1.0	< 0.5
STD DEV σ	< 1.2	< 1.0
Maximal	3.5	5.0
Minimal	-5.0	-6.0

CONCLUSION

With today's more complex operating demands, asset owners need to pay closer attention to how steam temperature is controlled. From enhanced measurement techniques, to improved attemperation, to model-based control, many plants are taking the path to better control and fewer tube leaks. These operators can ramp faster and meet the demands of cycling while confidently avoiding temperature excursions.