O&M modifications can boost cycling capability of existing HRSGs

The combined-cycle/cogen community increasingly recognizes the improvements needed if HRSGs are to be subjected to rigorous cycling. Of course, improvements made during the design stage offer the greatest benefits in extending cyclic life. But existing plants also can benefit from feasible changes in operations and maintenance practices

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The vast majority of heat-recovery steam generators (HRSGs) installed in North America were designed for baseload service. However, they now are being pressed into rigorous cycling duty, in response to electricity surpluses, the expiration of QF contracts, and other market factors. For the most part, these units are not designed with the flexibility needed to withstand the stress levels caused by repeated thermal cycling—stress levels that are further aggravated by the higher steam temperatures and pressures of today's larger, more efficient HRSGs.

The result, as the combined-cycle/cogeneration community increasingly is recognizing, is a high frequency of premature failures in HRSG components, typically because of fatigue or a combination of corrosion and fatigue.

Design improvements to improve durability have received much-needed press over the past few years, suggesting that the next generation of HRSGs will benefit from such new features as:

- Elimination of tube bends between headers (Fig 1).

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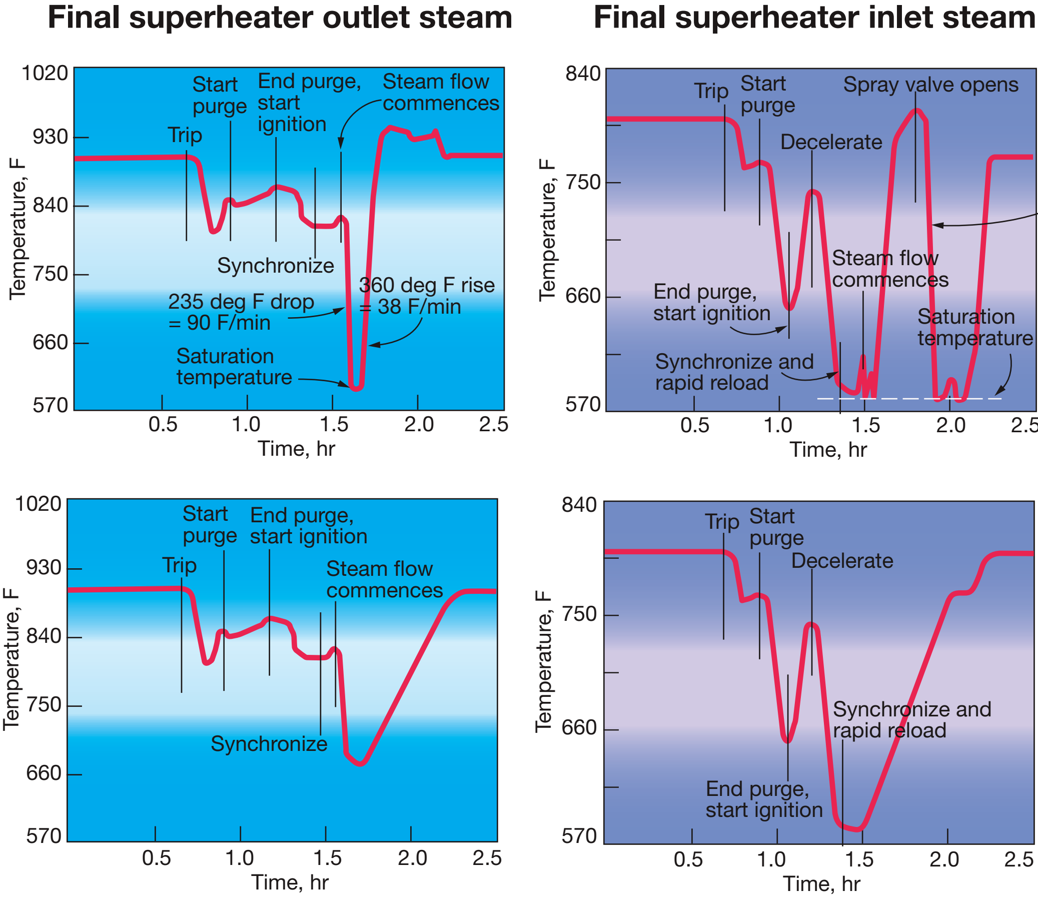
1. The newest HRSGs incorporate design improvements—such as elimination of tube bends between headers and superheaters made of P91/T91 material—to boost HRSG durability and reliability. But existing plants also can achieve improvements through O&M modifications

- Full-penetration welds at superheater and reheater tube-to-header connections.
- Ample high-pressure (HP) turbine bypass capability to provide additional flow to the reheater during startup, limiting thermal transients and keeping it cool.
- Economizer modules that can be fully vented during startup to lessen the consequences of economizer steaming.
- Forced recirculation of economizers during startup, and "blending" of cold feedwater to prevent economizer quenching.
- Superheaters made of modified 9Cr-1Mo alloy, and equipped with additional outlet nozzles, to reduce header thickness and creep-fatigue damage accumulation.
- More fully equipped steam plants that include such features as (1) an auxiliary boiler, to provide steam to the steam-turbine seals prior to startup and sparge steam to keep the HRSG warm; (2) stack dampers, to extend the time a shut down HRSG can be kept in "hot standby," the layup condition that yields the fastest return-to-service with the least thermal stress and potential for corrosion; and (3) generously sloped piping—including



2. Operators of existing plants can reduce temperature excursions—hence fatigue damage—by draining condensate and reducing gas-turbine ramp rate. Top two graphs represent no condensate drainage, and ramp rate of 5% MCR/min. Bottom two graphs represent adequate condensate drainage, and ramp rate of 2% MCR/min

header interconnections and drains—to insure all condensate and unvaporized desuperheating spray stays out of hot tubes and headers.

Drain mods

But what can owners and operators of existing plants do to boost the reliability and durability of their HRSGs already in the field? Fortunately, a lot.

Let's start with reducing low-cycle fatigue, which demands the greatest attention because it is the most difficult to overcome after the HRSG has been installed and because it can have a major impact on durability. Units that were designed for baseload operation have, in some instances, suffered low-cycle fatigue failures after as few as 100 startups.

To learn more about low-cycle fatigue during operating transients, Progress Energy instrumented several HRSGs with extensive arrays of thermocouples on tubes and headers. Data from a variety of operating maneuvers then were collected and used to verify design assumptions for the most critical components. Operating practices were then modified to mitigate the most damaging thermal events.

The thermocouple data revealed that the HP superheater and reheater of an HRSG intended even for modest cycling duty require special attention. Superheaters are subjected to a rapid increase in gas-turbine exhaust temperature during starts from any condition. In addition to the severe heat-up ramps, superheaters are vulnerable to quench cooling by condensate, as Progress Energy thermocouple data revealed. Condensation occurs in superheater tubes during every purge of the HRSG prior to gas-turbine ignition. This is because turbine exhaust-gas temperature falls below saturation temperature. The quantities of condensate are substantial during both hot and warm starts; a repeat purge can actually fill the front panel tubes of some superheaters.

All of this condensate must be removed at the peak rate at which it forms to prevent pooling and flooding. Accomplishing this requires a minimum of two adequately sized drains per header, located as close to the header ends as possible. These drain locations prevent condensate from being trapped downhill from the drains as the headers tilt and distort during thermal transients. Also required is an adequately sized and rated external blowdown system to handle the high-pressure/high-temperature drains. Note that superheater and reheater drains should be routed to separate blowdown vessels. With a common vessel the large difference in superheater and reheater pressures prevent the reheater from draining when drains are operated simultaneously. For maximum effectiveness, the drain system also should include instrumented drain pots that detect the condensate and automatically actuate tandem motor-operated drain valves—via a "martyr-master" distributed control system interlock. This will keep the lower superheater and reheater headers free of condensate at all times, while preventing needless release of steam and energy.

A decade of HRSG User's Group meetings makes clear that these drain features often are lacking in existing plants. Although retrofitting them can be challenging and expensive, such drain features can be added to mitigate fatigue damage.

The three Rs: Reducing ramp rates

Another way to mitigate fatigue damage is to moderate the heatup and cooldown ramp rates.

Most operators recognize that rapid startups can damage HRSG components, but shutdowns—both routine and emergency—can be even more damaging (Fig 2). The shutdown procedure is usually intended to keep superheater-outlet steam temperature as high as possible to permit fast reloading of the steam turbine after an overnight or weekend shutdown. In this procedure, gas-turbine exhaust-gas temperature and steam flow are both reduced rapidly during unloading, so that when gas-turbine firing stops, only moderate reduction in superheater-outlet steam temperature has occurred and the majority of the header remains near maximum steam temperature.

But as cooler air is delivered from the gas-turbine compressor during coast-down and HRSG purging, condensate rapidly develops in the superheater tubes, then runs down into hotter headers, causing these sections to quench to saturation temperature. This leads to substantial thermal stresses at the inner surface of the headers.

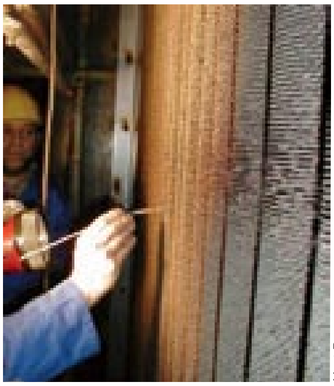
A better procedure for normal shutdown is to ramp down the superheater-outlet steam temperature during gas-turbine unloading, prior to tripping the gas turbine. Recommended ramp rate in a Progress Energy case study was 14 deg F/min to a steam temperature of about 700F. By the time condensate begins to collect in the header, the bulk temperature of the header has been reduced further to about 60 deg F above saturation temperature. This may extend the shutdown time by about 15 minutes, but it reduces fatigue damage by as much as 50%!

Even with this more conservative shutdown procedure, the substantial quantities of condensate in the superheater tubes should be drained during the gas-turbine coastdown to further minimize thermal stresses.

Rewrite startup procedure

A procedure sometimes used for hot starts deliberately lowers HP steam pressure prior to the restart. This practice is intended to reduce throttling at the steam turbine during startup, and thereby shorten the startup time. But by lowering HP steam pressure, the superheater is cooled to a lower saturation temperature, which results in a more damaging step increase—from saturation temperature up to gas-turbine exhaust temperature—during gas-turbine start up. Likewise, the HP drum is exposed to a more severe thermal cycle and greater fatigue life consumption.

To reduce thermal stresses in the superheater during hot starts, the step change should be minimized. This can be accomplished by maintaining pressure, thus saturation temperature, as high as possible in the superheater. In addition, gas-turbine exhaust temperature should be kept as low as possible until sufficient steam flow is established. Note that gas turbines equipped with inlet guide vanes tend to produce higher gas temperatures during startup than those without inlet guide vanes.



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3. Corrosion prevention is a challenge at combined-cycle and cogeneration plants because an HRSG is actually two or three boilers operating at different pressures, with steam systems often connected via cascading blowdowns

After steam flow is established, the subsequent gas-turbine ramp rate should be slow enough to maintain the temperature gradients induced by the initial step change.

Never after an emergency stop

Your startup procedures also need to include a sufficient time delay before startups are allowed after an emergency trip. Immediate restarts after an emergency stop should be expressly prohibited until superheater headers have had an opportunity to cool closer to saturation temperature. Just one immediate restart after an emergency stop can consume a large portion of the design fatigue life of a thick-walled superheater header.

What goes up, must come down

While optimizing startup and shutdown procedures it is important to understand how they work together to consume the fatigue lives of pressure parts. To accurately calculate fatigue life the boiler designer must consider complete thermal cycles—up and down—to determine the stress range experienced by the component. If only half of the cycle were considered alone—start up or shutdown—the fatigue life would be overstated by about 10 orders of magnitude.

Robbing Peter . . .

"Limiting the ramp rate sounds great, but I have to start up this plant in four hours to meet air-permit restrictions. If I don't, bad things are going to happen to me instead of the boiler."

This is the reality faced by many plant managers today, and while balancing business, regulatory, and equipment needs is a challenge, understanding "all of this design stuff" can give some relief. Since both the heat-up and cool-down portions of the thermal cycle must be considered together, it is possible to keep the fast ramp rates in one part of the cycle where time is an issue—say, during a cold start—and still reduce total fatigue life consumption by ramping slower during the other part of the cycle where time is less critical.

Another option is to develop procedures that conserve fatigue life where possible so you can "spend" it when you must. Examples of this approach include keeping the boiler pressure high for the next restart, and cooling the headers on shutdown.

Oxygen infiltration

Corrosion is another damage mechanism that can be greatly mitigated by O&M changes (Fig 3). Consider that steam drums, deaerators, and condensers typically are vented to atmosphere on shutdown, allowing oxygen—an enemy of good water chemistry—to infiltrate. This induces some corrosion while the plant is off-line, but even more corrosion as the unit subsequently is restarted and oxygenated water is fed into the plant. Proper O&M procedures can keep the oxygen out. Specific steps include:

- Maintain vacuum on the condenser. If steam is not available to the air ejectors, motor-driven vacuum pumps can be retrofit at a reasonable cost.
- Adhere to proper lay-up practices. If you expect to startup within 24 hours, it's best to put the HRSG in hot standby. All paths for energy to leave the HSRG—steam, water, hot air—should be isolated. If steam is available from another unit or an auxiliary boiler, the HRSG can be kept in hot standby for an extended period. If a quick restart is anticipated, but hot standby is no longer possible because no alternative steam source exists and the unit has cooled and depressurized, then cold wet layup is the best option.

Cold wet layup requires (1) filling and maintaining all water-side systems with an alkaline, mildly reducing solution; and (2) preventing air ingress. Ammonia is added to create the desired alkaline conditions—a pH of 10.0 or higher—while a nitrogen blanket is used to prevent air ingress. Note that if your plant has a separate deaerating tank, it needs to be blanketed with nitrogen too.

- Monitor oxygen by installing an on-line dissolved oxygen meter. This is particularly important during startup or when feedwater makeup rates are high. Many plants experience oxygen pitting in their evaporators, even though O_2 levels recorded during normal operation have remained within spec. The problem usually is the ingestion of oxygen-laden water during plant startup.

Keep your powder dry

Preventing corrosion is also important during long-term shutdowns. During these periods, dry layup is likely the best option because the proper HRSG conditions, once established, are easier to maintain, and because dry layup reduces chemical consumption. Note that if the HRSG will need to be opened and entered for maintenance during the shutdown, then dry layup is the only option (Fig 4).


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4. Proper shutdown and layup of the HRSG is needed not only to minimize corrosion during the shutdowns, but to reduce delays during the subsequent startups and ensure top performance during the operating periods

A preferred practice when going into dry layup is to "flash dry" the HRSG, taking advantage of the heat in the boiler water when the unit is first released from service. Instead of cooling the boiler then draining it, as is traditionally done to initiate dry layup, operators open all drains and vents when boiler pressure falls below about 200 psig. This allows the bulk of the boiler water to flash to steam, achieving more rapid and more thorough dry-out of HRSG internals. One user reports that units returned to service from this rapid dehumidification procedure have one-tenth the amount of iron—the tell-tale corrosion product—in their blowdown water compared to units returning from the traditional dehumidification procedure. CCJ

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