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Gas turbine fuel nozzle refurbishment

Follow these guidelines to improve reliability and reduce emissions

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One principal cause of damage to gas turbine hot-section components is imbalanced fuel distribution due to dirty or defective fuel nozzles. Having more fuel flowing to one nozzle and less to another will also cause more NO_x and CO emissions because hot and cold spots are simultaneously existing in the combustion section. Those same hot spots reduce creep life of the combustion liners, transition pieces, and turbine nozzles and blades. Luckily, these problems can be minimized by careful refurbishment and calibration of the fuel nozzles.

Fuel nozzle malfunctions. Gas turbines typically have multiple fuel nozzles through which fuel is injected into the combustion zone (Fig. 1). Ideally, fuel flowrate through each nozzle should be uniform and mixing of fuel with air should be equally effective for each nozzle. If liquid fuel is being injected, atomization of the fuel droplets should also be identical for each nozzle.

However, flow maldistributions can often occur among the different fuel nozzles in a turbine. Causes of nonuniform flows can include:

- Manufacturing defects (e.g., machining burrs or nicks)
- Improper assembly (e.g., leaking gaskets, mismatched parts)
- Changes in nozzle flow area due to erosion or coke and ash deposits
- Cracks in the nozzle due to fatigue
- Faulty operation of check valves in fuel lines.

If maldistributions occur, the result will be uneven firing temperatures around the combustion section circumference. Since most gas turbines do not have thermocouples at the exit of the combustors, these uneven firing temperatures are typically detected by thermocouples mounted further downstream. Single-shaft gas turbines usually have an array of thermocouples installed around the circumference of the turbine outlet, while multiple-shaft turbines typically have a thermocouple array around the power turbine inlet.

Almost all gas turbine control systems monitor "exhaust temperature spread" (i.e., maximum – minimum) and issue an alarm when this reaches an OEM-specified value. The challenge for the turbine operations and maintenance staff is then to figure out the source of the high-temperature spread.

Some swirl is in the flow as it passes through the turbine. Consequently, one cannot assume that an abnormally high or low temperature at the 4 o'clock position in the exhaust was caused by the fuel nozzle located at the 4 o'clock position in the combustion section. It may come from the fuel nozzle at the 2 o'clock or 6 o'clock position, or even further away.

Gas turbine performance monitoring software has now developed to the point that it can calculate the amount of swirl in the flow and rotate the position of the exhaust thermocouples to indicate the location of the fuel nozzle that produced the flow passing by each thermocouple.[1] An example of the graphical output from this type of analysis is shown in Fig. 2.

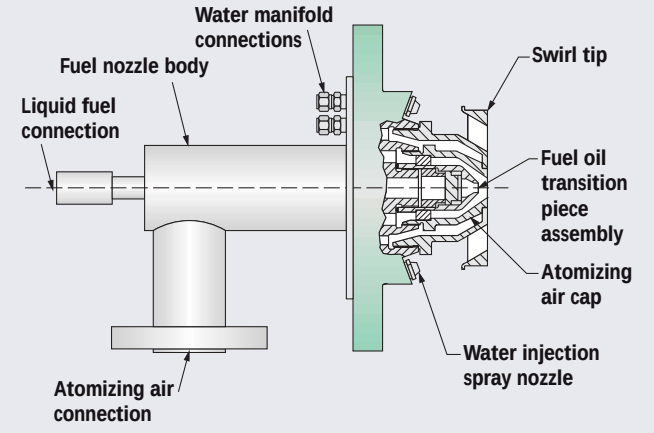


FIG. 1. A typical gas turbine will have 6 to 16 of these fuel nozzles.

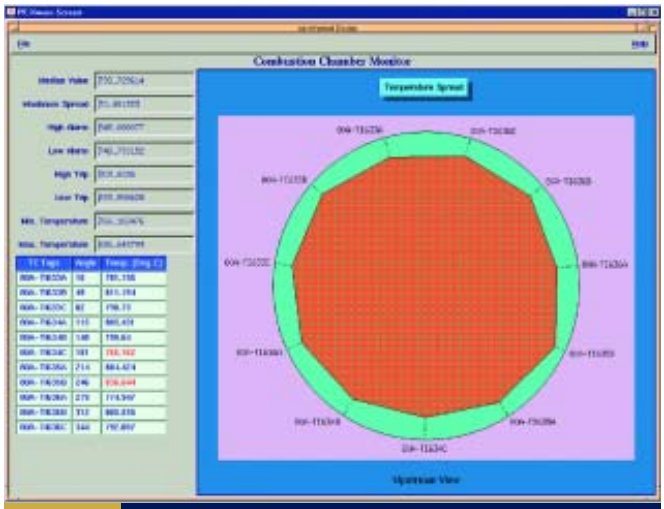


FIG. 2. Example of a combustion monitor graphical output.

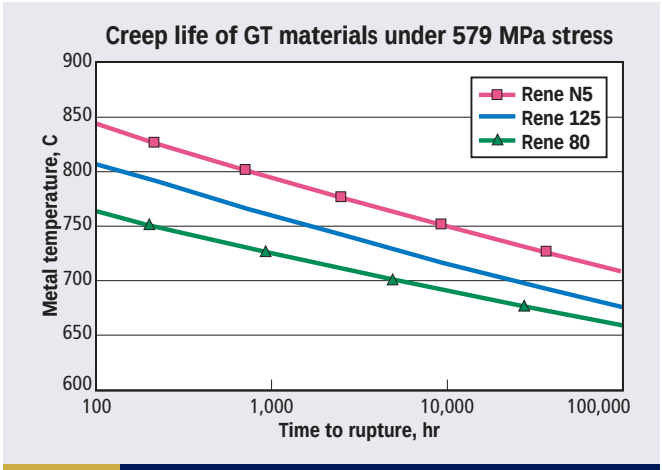


FIG. 3. **Creep life of metal components is extremely sensitive to metal temperature.**

Temperature spreads at the gas turbine exhaust would correspond to even greater temperature spreads at the combustor section outlet. If one models the turbine section as an isentropic expansion of perfect gas, from basic thermodynamic principals it can be shown that temperature at the turbine section inlet, T_t, is related to the exhaust temperature, T_x, by the following formula:

$$T_t = T_x\left(\frac{P_t}{P_x}\right)^{k-1/k} \quad (1)$$

where k is the ratio of specific heats, P_t/P_x is the pressure ratio across the turbine, and the temperatures are taken as absolute values. Basic algebra then dictates that the difference between maximum and minimum temperatures at the turbine inlet, ΔT_{t-max}, is related to the exhaust temperature spread, ΔT_{x-max}, by:

$$\Delta T_{t-max} = \Delta T_{t-max}\left(\frac{P_t}{P_x}\right)^{k-1/k} \quad (2)$$

Using typical values of 12 for pressure ratio and 1.3 for k in Eq. 2 shows that, when the exhaust temperature spread is 50°C, maximum and minimum temperatures at the turbine inlet will be 89°C.

Impact of maldistributions. Nonuniform combustion will cause higher emissions of either NO_x (due to hot spots in the combustion zone) or CO and unburned hydrocarbons (due to cold spots and poor mixing or atomization).

If too much fuel is injected through one or more fuel nozzles, the combustion gases exiting from that region will be hotter than the average. This will reduce life of the hot section parts that are exposed to the hotter flow.

Creep life of metal components in the hot section of a gas turbine is extremely sensitive to metal temperature. Fig. 3 shows the relationship between metal temperature and creep life of several materials typically used in gas turbine hot sections. Note that a temperature increase of only 50°C will reduce the materials' life by an order of magnitude.

The consequences of hot-section component failures caused by overheating can be quite costly. In extreme cases, combustion liner failures can allow hot flames to impinge on the turbine pressure casing, which can lead to catastrophic engine failure. Even before casing failures occur, broken pieces of the liner can pass into the expander section and cause extensive blade damage.[2]



FIG. 4. **A disassembled fuel nozzle before (left) and after (right) refurbishment.**

Fuel maldistribution correction. Due to rapid degradation of hot-section parts life that can take place, corrective action should always be taken whenever high exhaust temperature spreads are encountered. While there can be other causes of the high spreads (see below), the most logical place to start is the fuel nozzles.

When a set of fuel nozzles is removed for testing and refurbishment, it should be put through a multistep process called for in OEM maintenance protocols. During the process, each nozzle is disassembled, cleaned and inspected. Any worn-out parts are repaired or replaced, and the nozzles are rebuilt, flow tested and calibrated to ensure uniform flow. Typical "before" and "after" photos of refurbished fuel nozzles are shown in Fig. 4. A key step in the process is the inspection, which can help in the problem diagnosis. For example, many combustion problems can be diagnosed by examining the wear patterns on the nozzles.

The flow tests are conducted with an apparatus that supplies the liquid or gas fuel, and atomizing air and NO_x suppression water if applicable, to the nozzle at the OEM-specified conditions. Based on the flow versus pressure results of each nozzle, adjustments are made in the flow path geometry to ensure uniform flow at similar conditions. Typically, a set of nozzles can be tuned to provide no more than 3% deviation in flow among the nozzles.

Since temperature increase across a gas turbine combustor can be on the order of 800°C (1,440°F), a 3% difference in fuel flow should result in a firing temperature spread on the order of 24°C (43°F). This is within typical OEM guidelines; however, based on the earlier discussion of the impact of metal temperature on creep life, even smaller spreads could yield a significant improvement in parts life.

In addition to the flow tests, the nozzle spray patterns should be checked for irregularities, and the nozzle body should be pressure tested to check for leaks and to verify proper gasket seating. Also, the check valves in the fuel lines leading to the nozzles should be cleaned, inspected and pressure tested to ensure leak-free operation.

Case study. A West Coast refinery was experiencing excessive temperature spreads in the exhaust of its gas turbines. It sent their fuel nozzles to a lab for testing and refurbishment. Upon receipt, each nozzle was flow tested to confirm whether the nozzles were providing uniform flow. As shown in Fig. 5, the flow discharge coefficients, *Cd*, of the nozzles—an indication of the flow delivered for a given supply pressure—deviated by almost 6%. After cleaning and refurbishing the flow passages, the deviation in *Cd*

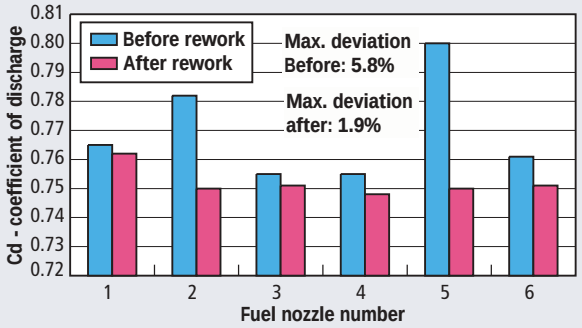


FIG. 5. **After cleaning and refurbishment of the flow passages, the deviation in *Cd* was less than 2%.**

was less than 2%. Once the reworked fuel nozzles were reinstalled in the gas turbine, the temperature spread was reduced to 22°C (40°F) versus an average of 72°C (130°F) before refurbishment. The cause and effect were obviously identified.

Other causes of high exhaust temperature spreads. Two other sources of high-temperature spreads can be the combustion liner and the first-stage turbine nozzles. The metal liner of the combustion zone is carefully designed to allow a specific amount of air into the flame zone and then an additional amount in the dilution zone. Air flow to each zone is determined by the size and number of holes in the liner. As the liners wear, cracks can occur and eventually produce new paths for the air flow, which will distort the combustion process.

A third potential source of nonuniform fuel/air ratios is nonuniform flow areas downstream of the combustion zone. During normal operation, flow through the turbine section first-stage nozzles is choked. To ensure uniform flow through each combustor upstream of the first-stage nozzles, the cross-section flow area at the nozzle "throat" should be identical. However, nonuniformities can occur due to manufacturing defects, nozzle erosion or fouling nozzles. HP

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[2] Dundas, R. E., D. A. Sullivan and F. Abegg, "Performance Monitoring of Gas Turbines for Failure Prevention," ASME Technical Paper 92-GT-267, June 1992.



Jeffrey N. Phillips is vice president of Fern Engineering, Inc. He holds a BA in mathematics from Austin College, a BS in mechanical engineering from Washington University, and MS and PhD degrees in mechanical engineering from Stanford University. Dr. Phillips' industrial experience has focused on analyzing gas turbine and combined cycle power plant performance. He has particular interest in use of nonconventional fuels in gas turbines. Prior to joining Fern, he worked for the Royal Dutch/Shell Group on developing a coal gasification process.



Paul Simas is the manager of fuel nozzle refurbishment for Fern Engineering, Inc. He has over 20 years of experience in fuel nozzle testing, refurbishment and design. Recent projects have included the fuel nozzle design for landfill gas and development of a device that converts a GE dual-fuel nozzle to gas-only use and eliminates need for purge air while also allowing the nozzle to be easily restored to dual-fuel operation.

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