Ask The Expert:
Gas Turbine Combustion Systems

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1. Can you tell us a little about yourself?

Mitch Cohen. I am a Senior Combustion Engineer at TTS, where I've worked since 1999. I'm responsible for generating technical solutions for customers regarding combustion, emissions, and gas turbine performance. Before TTS, I worked at GE for nine years as a combustion research engineer at GE R&D and as a combustion design engineer at GE Power Generation, working on developing 7FA Dry-Low NOx combustion systems, the DLN-2 and DLN-2.6.

2. What are the common types of combustion systems on an industrial gas turbine?

Two main combustor designs are used on industrial gas turbines: diffusion combustors and Dry-Low NOx or DLN combustors. Diffusion combustors are the older design found on legacy gas turbines manufactured before the early 1990s, while DLN combustors are employed on turbines from the early 90s onward. Diffusion combustors have a simple design in which fuel is injected directly from a single fuel manifold into the air with little or no mixing. This results in a combustion process with high stability and a very high flame temperature, leading to high NOx emissions. Diffusion combustors often employ water injection to lower their NOx emissions. In contrast, DLN combustors employ multiple fuel injection manifolds and complex combustor geometries to premix fuel and air into a homogeneous, lean mixture that results in ~1000°F lower peak flame temperatures and an order of magnitude lower NOx, but with the tradeoff of reduced flame stability and overall operability.

Another way combustion systems are categorized is gas-only vs. dual-fuel (gas and liquid fuel). In the US, most gas turbines operate with natural gas as the primary fuel and liquid fuel, if present, as a backup (commonly No. 2 distillate). Dual-fuel designs are most common in cold climates where the natural gas for power generation can be curtailed in winter because home heating use is given priority. Dual-fuel turbines are significantly more complex, both mechanically and control system-wise, than gas-only ones. Dual-fuel configurations often negatively impact the operational reliability of the gas turbine, even when it is running on gas fuel. This reliability impact occurs because dual fuel units require many complex auxiliary systems that are not present on gas-only units: liquid fuel forwarding and high-pressure supply system, atomizing air system, liquid fuel purge system, gas fuel purge system, water injection system, and water injection purge system.

3. As a GE expert, what are the major differences between an E Class and an F-class Dry Low Nox system?

The differences between E- and F-class DLN systems are driven by the primary difference between E- and F-class gas turbines: F-class turbines have a firing temperature of 350-400ºF higher than E-class turbines, 2400-2450 vs. 2020-2055ºF. DLN combustors on turbine models are typically designed to achieve 9 pm NOx emissions. On the 7EA DLN-1 combustion system, about 70-75% of the combustor air is used for premixing with the fuel to achieve the lean fuel/air mixture required for achieving 9 pm at E-class firing temperatures. On the 7FA DLN-2.6, greater than 90% of the combustor air is necessary for premixing with the fuel. Consequently, the 7FA DLN-2.6 has much less air available to cool the combustor components, requiring much more efficient and complex cooling geometries and higher-temperature materials.

A second significant difference between DLN-1 and DLN-2.6 combustion systems is the number of fuel manifolds each system operates within the full premixed operating mode. Multiple manifolds are used to inject fuel into different locations within the combustors to create localized fuel/air ratio variations that aid in maximizing combustor stability and minimizing dynamic pressure oscillations. DLN-1 combustors inject fuel through two fuel manifolds to optimize NOx and CO emissions over the range of premixed operation. DLN-2.6 combustors inject fuel through three or four-manifolds (determined during commissioning, based on dynamics) to optimize NOx and dynamics over the range of premixed operation. The greater number of fuel manifolds is a factor that makes the operation and tuning more complicated on 7FA DLN-2.6s than on 7EA DLN-1s.

4. What is meant by “tuning” a DLN system?

Tuning a DLN system involves making unit-specific control system adjustments to optimize the multiple performance parameters of the combustion system: NOx and CO emissions, dynamic pressures, stability (lean blowout margin), and load turndown. The control system adjustments generally entail determining the optimal proportions of fuel flowing through the multiple manifolds of the DLN systems and raising or lowering the two temperature control curves that specify the turbine exhaust temperature at base load and part load, respectively.

5. Why do DLN combustion systems traditionally require tuning?

The optimal performance of DLN systems requires precise control of the fuel/air ratio within the combustor. Controlling the fuel/air ratio, in turn, requires control of both the fuel flow and the airflow. In both the manufacture and repair of gas turbine combustion system components, technology exists to precisely control the hole geometry and effective flow area of fuel nozzles to achieve very uniform fuel flow to all combustion cans within a machine.

However, achieving uniform airflow to each combustion chamber is much more difficult. The major combustor components – liners, caps, and transition pieces – are all manufactured with geometric tolerances that, when stacked up in a complete combustor assembly, result from greater can-to-can airflow variability than is achievable in the fuel system. Further, between machines, there is also variability in the precise split between the compressor air used for combustion and for turbine cooling. These factors drive airflow variation within combustors and are primarily responsible for the requirement for DLN tuning after maintenance outages.

However, once a unit has undergone post-outage tuning, variations in can-to-can fuel flow can develop throughout a maintenance interval due both to partial plugging of fuel nozzles by fuel contaminants and to increased fuel flow resulting from leakage as fuel nozzle seals degrade. The variations in can-to-can fuel nozzle flow that develop over time can drive emissions or dynamic excursions that require tuning.

6. Can you tell us at least one common problem you encounter while tuning both an E-class and an F-class combustion system?

There are hundreds of 20-plus-year-old 7EA and 7FA turbines currently operating that were installed during the power boom of the early 2000s. My observation from working on units of this vintage is that many increasingly have difficulty in achieving the combustor emissions targets they were designed for and were able to accomplish in the past. Such units often have 1) combustion hardware that has been through multiple repair cycles and is near or even past its OEM-recommended useful life and 2) compressor and turbine sections with increased blade clearances and casing leaks. The inability to meet emissions compliance levels is particularly exacerbated in cold weather operations. Every winter, TTS receives numerous calls for "emergency troubleshooting" of DLN combustors that drift out of emissions compliance when "arctic freezes" come through.

On 7EA DLN-1s, it is common in cold weather for both NOx and CO emissions to increase toward their limits of 9 and 25 ppm, respectively, making it difficult to tune the units by trading off one species for the other. Sometimes, this problem can be addressed with non-standard tuning adjustments, such as modifying the inlet bleed heat schedule (on units with IBH), which simulates operation at warmer ambients.

On 7FA DLN-2.6s, cold weather often results in both high NOx emissions and increased dynamic pressure levels. The NOx can frequently be reduced to less than the 9 ppm limit, but not without leaving dynamic pressure levels at considerably higher values than recommended, negatively impacting hardware life.

7. Are there any upgrades or best practices an operator can do to minimize frequent tuning?

Many tuning issues that arise during the maintenance cycle are due to problems with instrumentation: improper calibration or calibration drift, as well as failed or intermittently failing transmitters.

A very common problem is the improper calibration of barometric pressure transducers. Barometric pressure is measured using an absolute pressure (psia) transmitter. While most power plants have calibrators for gauge pressure (psig) transmitters, many plants do not possess absolute pressure calibrators. A mistake I have observed at many power plants is a barometric pressure transmitter that site personnel have "calibrated" using an internet reading from a local weather or airport website. This method does not work because weather barometric pressure readings are always corrected to sea level and, therefore, regardless of elevation, will always read approximately 30″ Hg with small variations due to normal occurrences or high- and low-pressure weather systems. However, barometric pressure drops 1″ Hg or 3.5% for every 1000 ft. elevation. While the pressure error may seem relatively small, for each 500-foot increment of elevation, a 7EA turbine will overfire at base load by 10ºF in firing temperature if the sea level barometric pressure value is input into the control system instead of the actual barometric pressure. For example, a 7EA in Oklahoma City, OK, elevation 1300 feet, will overfire by 26ºF if the sea level value of 29.9″ Hg is incorrectly used instead of the actual value of 28.5″ Hg. Not only will this over-firing push NOx out of compliance, but it will also increase the maintenance factor on the hot gas path parts.

Other common instrumentation problems are failed inlet and exhaust pressure drop transmitters. These transmitters are not redundant; their failure can adversely impact the DLN system's operation.

Even with triple-redundant sensors such as compressor discharge pressure (CPD), gas interval pressure (P2), or compressor discharge temperature (CTD), a single intermittently spurious reading can lead to momentary combustor instabilities that, in turn, can result in the DLN system dropping out of premixed mode operation or, in extreme cases, experiencing an LBO (lean blow out) trip.