Reducing Gas Turbine NOx and CO Emissions Through Improved Combustor Design

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Abstract

The combustor section of simple- and combined-cycle gas turbines can be thought of as the heart of the system. Proper combustor design and operation are critical for establishing maximum unit performance. Combustor design also has a significant impact on air pollutant formation, particularly with regard to nitrogen oxide (NOx) and carbon monoxide (CO) production. This paper outlines a new field test and validated combustor design that minimizes formation of these two pollutions without any loss of efficiency.

Discharge limits for NOx and CO are becoming increasingly stringent. One of the most logical control solutions is to reduce emissions at the source. This can be a double-edged sword, as higher combustion temperatures improve turbine efficiency and reduce CO, but increase NOx. The opposite effect occurs at lower combustion temperatures. The low-emission combustor outlined in this paper reduces a 7EA gas-turbine NOx emissions to less than 6 part-per-million (ppm) and CO to less than 2 ppm, while at the same time maximizing turbine efficiency. The combustor has been designed to be a drop in replacement for existing combustion turbines, most notably the General Electric Frame 7EA. This offers excellent potential for simple emissions reductions in many operating units. Similar combustors will soon be available for use on GE Frame 6B and Frame 9E units.

Important features of the combustion system include primary and secondary fuel feed for flexibility during load change and off-peak operation, precision fuel nozzles to enhance combustion efficiency and minimize flashback, improved combustor flow dynamics, and a unique airflow design that lowers peak flame temperature and enhances cooling/durability of combustor components.

A number of alternative methods exist to control combustion turbine air emissions. These include water injection into the turbine and post-combustion control through such techniques as selective catalytic reduction (SCR). However, the former technique is not capable of reducing NOx to the single-digit (ppm) limits currently in place or expected at many sites, while SCR adds complexity and expense to any project. The advanced technology illustrated in the paper offers a system that addresses air emission and performance issues in one device.
Introduction

Natural gas-fired simple- and combined-cycle power plants have become the preferred choice for new power generation. Factors that influence this popularity include life cycle costs, ease and speed of plant construction, and simplicity of design. Another factor, environmentally-related, is that combustion turbines produce only half the carbon dioxide of a corresponding coal-fired plant.

Nonetheless, air pollution control issues are still important, most particularly with regard to emissions of NOx and CO. NOx formation in natural gas-fired combustion turbines is a function of temperature and residence time. The process is known as thermal NOx production, in which high temperatures cause a decomposition of atmospheric nitrogen (N2) into single atoms that then react with oxygen to form nitrogen oxide species. The reaction is minor below about a flame temperature of 2800°F, but NOx production increases rapidly as the temperature increases beyond this point. Average temperatures in a combustion turbine are typically lower than this threshold temperature, but certain regions may be hotter, and it is in these locations that excess NOx will form.

Carbon monoxide is generated by incomplete combustion. Factors that influence CO formation include improper fuel-air ratios and inadequate fuel-air mixing. In addition to generating CO, these factors lower combustion temperatures and reduce the efficiency of the machine.

The Low Emission Combustor (LEC) developed by PSM addresses these two issues.

Low Emission Combustor

Figure 1 outlines the LEC. Principal components include the primary and secondary fuel nozzles and combustion zones, the flow venturi, the flow sleeve, the dilution stage, and the transition piece. In combination, these devices maximize combustion efficiency and minimize pollutant formation. Simple- and combined-cycle turbines are often operated in a peaking or cyclic mode. The changing load conditions require flexibility in fuel-air mixing and combustion. The following steps outline how the two fuel nozzles operate alone or in combination as a unit comes on line and ramps up to full power.

Primary Mode – All fuel enters through the primary fuel nozzles and the flame is located in the primary zone (Figure 2a). This combustion process is for initial startup and low load operation.

Lean-Lean Mode – As load increases to intermediate levels, the fuel feed is split between the primary fuel nozzles
and secondary fuel nozzle and the flame is located in both the primary and secondary zones (Figure 2b).

**Transfer Mode** – This is a transition mode between lean-lean and premix mode, and all fuel flows through the secondary nozzle and combustion takes place exclusively in the secondary flame zone. This process is usually of very short duration (Figure 2c).

**Premix Mode** – This is the mode of combustion for mid- to high-load operation. Once again fuel feed is split between the primary and secondary fuel nozzles, but the flame resides completely within the secondary zone of the combustor (Figure 2d). Fuel and air feed to the primary zone provides good mixing that enhances the combustion process.

The venturi plays a key role in the combustion process. The forward cone of the venturi provides a confined space for the diffusion flame (the fuel and air is not premixed and burns at maximum flame temperature) during the primary and lean-lean mode of operation. The forward cone also enhances fuel-air mixing during the premix mode for the fluids entering the secondary zone. The venturi throat and downstream cone create a sudden expansion and strong recirculation region. The strong recirculation is essential for combustion stability and the venturi throat serves to prevent flash back at premix mode.

In all operating modes, one or both of the venturi cones are exposed to high temperatures. A technique for keeping the venturi from overheating is convective cooling, in which a portion of the inlet air is diverted through an annular space along the cold side wall of the venturi. In existing designs, the air flows in the same direction as the combustion gas and enters the combustor downstream of the venturi. In the LEC system, the air flows in the opposite direction of the combustion gas, with convection being aided by trip strips in the annular space that induce turbulence for improved heat transfer performance. Field test data has shown that this arrangement keeps venturi metal temperatures well below maximum temperature limits, which increase component life. More importantly, the cooling air enters the primary combustion chamber. This lowers flame temperature during the premix mode of operation, which correspondingly lowers NOx production. Also, in conventional designs the introduction of cooling air at the downstream end of the venturi may induce some flame quenching with a subsequent increase in CO. The counter-flow design avoids this issue.
In the LEC combustion system, an advanced cooling technique is incorporated known as “effusion cooling”. The effusion holes are precisely controlled in size, angle, pattern and locations. This cooling scheme keeps the metal temperature well below maximum allowable material temperatures and therefore extends component life.

Combustion airflows enter the dilution zone through dilution holes in the dilution stage. The dilution holes are a part of the air staging scheme in the LEC system to provide stable operation in all loads. By diverting a portion of the compressor discharge air to a location downstream of the combustion zone, the fuel-air ratio is kept appropriate in the combustion zone to prevent lean-blow out.

**Fuel Nozzle Details**

Fuel nozzle design has an important effect upon combustion efficiency, stability and emissions. Conventional primary fuel nozzles contain metering plates (orifices) that reside upstream of the fuel injection ports (Figure 3). The PSM primary nozzles achieve excellent operability at all loads without the need for the meter plates. This also reduces the manufacturing costs. In addition, conventional secondary fuel nozzles typically have two fuel circuits, one for the diffusion pilot gas and one for premixed gas (Figure 4). The bulk of the fuel flows to the premixed region, while the center fuel feed produces a “diffusion” flame that helps stabilize combustion. Unfortunately, the diffusion flame increases NOx production. The PSM secondary fuel nozzle does not require a diffusion flame pilot and maintains good combustion stability via a premixed pilot. This also helps to lower NOx emissions.

**Retrofit to Existing Machines**

A key feature of the LEC is that it is designed to be a “drop-in” replacement for existing combustors, particularly those of the General Electric Frame 7EA turbines. In other words, the LEC system is completely interchangeable. Thus, after removal of the existing combustor, the LEC may be simply bolted into place followed by hookup of fuel and air connections. Combustors will soon be available that can be retrofitted to GE Frame 6B and Frame 9E units as well.

**Results and Conclusion**

The LEC combustion system was installed on a TransAlta (Canada) GE Frame 7EA turbine during 2001. Emission levels were measured by an independent company at 5.5 ppm NOx and 1.5 ppm CO. The unit has since operated for over 5,500 hours. These low emissions levels provide an excellent option for the use of PSM LEC system on both new and existing machines. Clearly it is an alternative to techniques that require significant modifications and chemical expense (SCR) or methods (water injection) that are only partially successful in reducing emissions.
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Figure 1. Low emission combustion system
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Figure 2. Operation modes
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Figure 2. Operation modes
Figure 3. Conventional primary fuel nozzle

Figure 4. Secondary fuel nozzle. (a) Conventional secondary fuel nozzle (b) LEC design