# S&V OBSERVER

## Combustor Acoustic Simulation Improves Reliability of Siemens Power Generation Systems

To further increase power generation performance, the development of modern gas turbines focuses on realizing higher turbine inlet temperature and lower nitrogen-derivative emissions. Due to high-power densities, the advanced combustion systems of gas turbines, unfortunately, are prone to produce complex thermo-acoustic instabilities and combustion-driven vibrations. These oscillations reduce the operational range and potentially generate reliability problems and possibly engine failure. Detailed acoustic simulations already performed during the combustor design phase are becoming increasingly important to design gas turbines with reduced instabilities and extend their operational envelope. By using LMS SYSNOISE, Siemens engineers gain early insights into the acoustic performance of their design and simulate more operating conditions than feasible through physical prototype testing.

**Reducing the Cost per Kilowatt.** Increasingly fierce competition driven by deregulation and privatization is dictating ever-lower power generation costs. Cost cuts can be realized by establishing an economic plant operation centering on low investment and life cycle costs. Maximum operating economy relies on optimum compression and combustion, pushing forward into new thermodynamic regions and higher combustion temperatures. One of the main challenges resides in reconciling competitive engine characteristics with strict environmental targets, including low carbon and nitrogen derivative emissions. In addition, customers also appreciate easily-serviceable designs and long intervals between major overhauls.

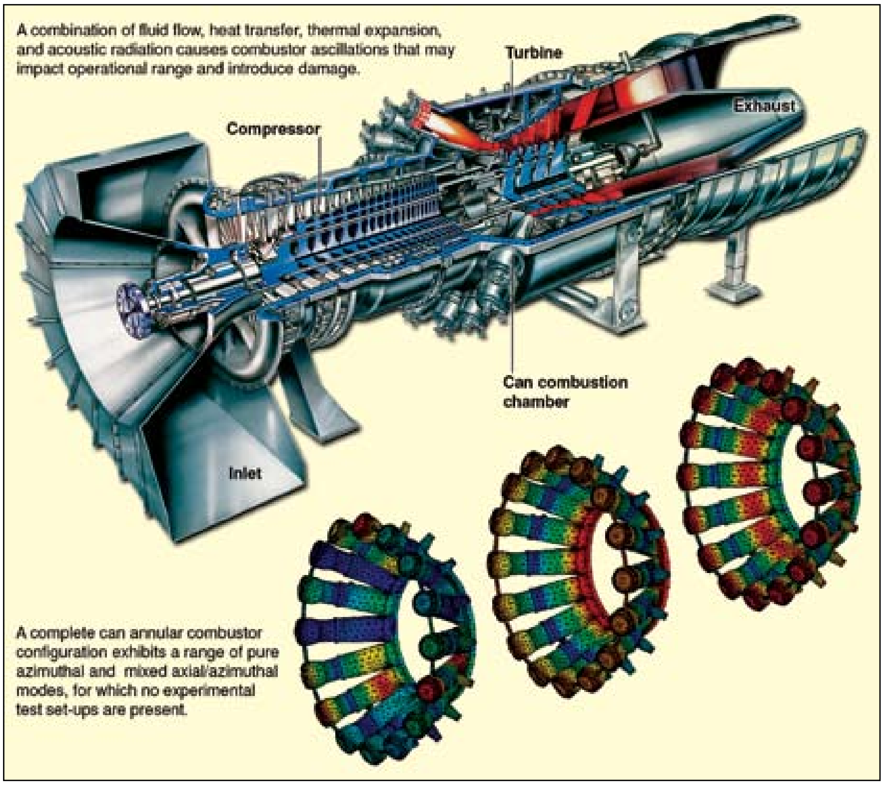
A phenomenon that potentially influences the reliability of power generation systems is the presence of thermo-acoustic oscillations in the combustion chamber. An annular can combustion system, for example, typically includes 16 or more separate can-shaped combustion chambers, distributed on a circle perpendicular to the symmetrical axis of the engine. In each of these cans, a burner continuously injects a mixture of fuel gas and compressed air to power the turbine and generate the requested electrical power. Combustor oscillations are determined by a feedback cycle that combines the effects of fluid flow, heat transfer, thermal expansion and acoustic oscillations, a cocktail potentially causing severe engine malfunctions. Several test rigs and prototypes are constructed to test and evaluate a comprehensive number of characteristic conditions. The disadvantage of prototype testing is that it requires major resources and does not allow flexible investigations of all conditions. Therefore, the capability to predict thermo-acoustic instabilities is vitally important to increase the performance and to extend the reliability of gas turbine power plants.

**A Specific Approach to Combustor Optimization.** To develop specific measures that prevent thermo-acoustic instability, Siemens engineers analyze the complicated relationship and interaction between acoustic performance and thermal heat release. Since eigenfrequencies and acoustic mode shapes are strongly coupled to the stability analysis, the Finite-Element (FE) mode analysis and subsequent stability analysis are the main tasks in the thermo-acoustic prediction and evaluation process. Siemens Power Generation selected LMS SYSNOISE as the key application for acoustic modeling and simulation, because of its widespread use and extensive acoustic simulation capabilities.

In the combustion optimization process followed at Siemens, engineers take the output of Computational Fluid Dynamics (CFD) simulations, including steady-state flow velocity, temperature and fluid properties, as input for acoustic simulations. Various scaled acoustic models are used: an FE model of a single-can combustor configuration; an extended FE model that also includes the incoming flow path upstream from the burner, turbine vanes and exhaust passage; and a complete multi-can annular combustor setup. An important part of the

acoustic FE modeling is the definition of specific boundary conditions, that are determined mathematically or experimentally. Siemens engineers validate the results from acoustic simulation using appropriate tests performed on specifically designed single-can test rigs.

**New Advances in Combustor Acoustic FE Modeling.** The implications of defining boundaries of the FE analysis of a single-can configuration are investigated using LMS SYSNOISE. The FE model includes the whole combustion chamber starting at the head end plate and ending at the exit of the transition piece upstream from the turbine inlet. The crucial regions through the burner as well as through the termination at the exit of the combustion chamber are characterized by absorbent boundary conditions. The acoustic boundary condition at the exit of the burner, i.e. at the inlet into the combustion chamber, is represented by a specific impedance, which is quantified experimentally using an atmospheric test rig without combustion. At the exit of the combustion chamber, the guide vanes of the turbine – or a Vane Simulation Section (VSS) in case of test rigs – define the acoustic boundary condition. Sophisti-



A combination of fluid flow, heat transfer, thermal expansion, and acoustic radiation causes combustor oscillations that may impact operational range and introduce damage.

A complete can annular combustor configuration exhibits a range of pure azimuthal and mixed axial/azimuthal modes, for which no experimental test set-ups are present.

cated mathematical approaches are used to describe the flow field downstream from these obstacles. Compared to the fluid flow behind the vanes, cylinders generate more vortices, which affect the reflection of the exit boundary condition. The FE model obtained is suitable for analyzing the effects of different impedances, for example, from different types of burners and varying Mach-numbers (steady-state flow velocities). The acoustic simulations show that the burner type has a significant impact, while the flow velocity in the combustion chamber affects the mode shapes of the acoustic pressure only marginally.

When extending the FE model of a combustor test rig with a VSS – which replaces the vanes of the turbine stages – and a downstream exhaust discharge tube, it became clear that the Mach-number cannot be neglected. The presence of narrow passages causes the geometry's acoustic properties to be influenced by the speed of the flow. Siemens engineers determined the reflection coefficient of the VSS on the basis of the acoustic pressure distribution, obtained by FE simulations performed in LMS SYSNOISE. The extended FE model is particularly suited to determine the impedance of the boundary upstream of the VSS and its dependency on the Mach-number through this section. The results showed a strong dependency on the Mach-number through the VSS.

**Acoustic Modes of a Can Annular Combustor Setup.** To study can-can interactions, an FE analysis of a complete multi-can annular combustor configuration was performed. The annular manifold upstream from the turbine inlet interconnects combustion chambers with adjacent units. The absorbent acoustic boundary conditions used to describe the burner and chamber exit areas were defined in the same way as for a single-can model. Simulations in LMS SYSNOISE show that, besides the axial modes along each single can combustion chamber, the complete can annular combustor configuration triggers a range of additional acoustic modes. They include pure azimuthal and mixed axial/azimuthal modes. Since there are no test rigs available for measuring the complete can annular combustor configuration, these modes are only predictable by performing acoustic simulations in LMS SYSNOISE.

The main reason why Siemens performs these acoustic evaluations is to make sure all potentially hindering or obstructing eigenfrequencies and acoustic velocities are known early on in the design and development process. This enables Siemens engineers to implement specific countermeasures to interfere disturbing eigenfrequencies, for example by developing and installing particular burner outlet extensions and acoustic resonators. The length of the extensions mounted on burner outlets defines the frequency that can excite the feedback cycle and, hence, affect the risk of combustion instabilities. The installation of these extension units is a quite affordable solution that is particularly useful to suppress oscillations in the intermediate range of frequencies, typically from 50 to 500 Hz. The sensitivity of these extensions makes this type of countermeasure somewhat harder to tune. The use of acoustic resonators, which are part of a standard engine design, is another way to influence acoustic eigen frequencies. This approach is applied very efficiently to control acoustic signals with shorter wavelengths, i.e. high frequencies from 1 to 3 kHz. A practical way to avoid recurrent FE meshing is to estimate the geometry analytically and then the design using LMS SYSNOISE.

Although optimization of fluid flow, combustion and heat transfer remain primary objectives in gas turbine development, more attention is paid to the interrelations between acoustic performance and operation reliability and efficiency. The combination of virtual prototype simulations with LMS SYSNOISE and adequate experimental testing allows Siemens to efficiently simulate the impact of specific design modifications and operating conditions on the acoustic performance of gas turbines. The predicted acoustic eigenfrequencies and mode shapes of single combustion chambers and annular-can combustion systems are essential in optimizing combustor designs and increasing the competitive position of Siemens power generation systems.

---

For more information on SYSNOISE and other LMS products, please visit www.lmsintl.com.