Highly reliable low NOx combustion systems for gas turbines

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Introduction

Environmental regulations require lower NO_x emissions from gas turbines, which can be achieved by lean combustion. The disadvantage of this solution is that thermoacoustic instabilities can arise in the combustion chamber (figure 1), which decrease the efficiency and reliability of the system and may lead to structural damage. The project is a cooperation between groups of Applied Mechanics and Polymer Engineering, Thermal Engineering and other EU partners.

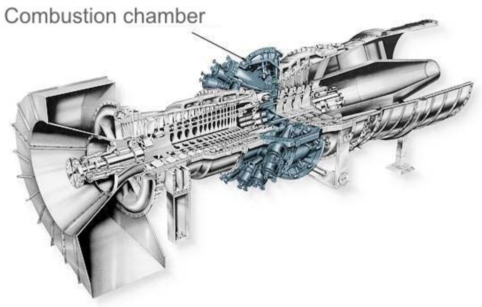

Figure 1 : Combustion chamber in Siemens gas turbine

Objective

The objective of the research project is to study both the thermoacoustic system and its interaction with the structure that surrounds it. The problem will be approached with both measurements on a specially designed test rig and numerical studies of the test rig. The setup will be designed such that conclusions can be drawn on the real size gas turbine. When the structural vibrations can be calculated the life expectance of the structure can be estimated.

Test rig

The test rig has a thermal power of 500 kW. Pressure, temperatures and vibrations of the liner will be measured. Optical access to the combustion chamber is provided by quartz glass windows, through which the flame front can be observed using laser induced chemo-fluorescence.

Modeling

The measurements are supported with numerical calculations using a combination of Computational Fluid Dynamics using CFX and Finite Elements Methods using Ansys. The flame can be an acoustic source as well as an amplifier of sound. This can be implemented in the generally applicable acoustic wave equation as source term.

$$\frac{\partial}{\partial t}\left[\frac{1}{c^2}\frac{\partial p}{\partial t}\right] - \nabla^2 p = \frac{\partial}{\partial t}\left[\frac{\gamma - 1}{c^2} q\right]$$

In which t is time, p is pressure fluctuation, c is speed of sound, γ is the ratio of specific heats and q is the heat release. The heat release can be influenced by the acoustic field itself. The feedback loop can lead to instability which is accompanied by very high pressure levels.

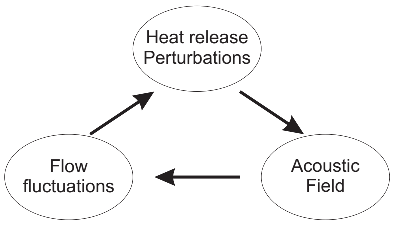

Figure 2 : Thermoacoustic feedback

The acoustic field is coupled with the structure via the pressures p, which results in a coupled set of system equations. For the FEM method this gives the following asymmetric set of equations of motion

$$\begin{bmatrix} \mathbf{M} & \mathbf{0} \\ \mathbf{M}^{\mathbf{fs}} & \mathbf{M}^{\mathbf{p}} \end{bmatrix} \begin{Bmatrix} \ddot{\mathbf{u}} \\ \ddot{\mathbf{p}} \end{Bmatrix} + \begin{bmatrix} \mathbf{K} & \mathbf{K}^{\mathbf{fs}} \\ \mathbf{0} & \mathbf{K}^{\mathbf{p}} \end{bmatrix} \begin{Bmatrix} \mathbf{u} \\ \mathbf{p} \end{Bmatrix} = \begin{Bmatrix} \mathbf{f} \\ \mathbf{q} \end{Bmatrix}$$

in which $\mathbf{M}$ and $\mathbf{K}$ represent the mass respectively stiffness matrix, $\mathbf{f}$ the force vector containing the loads applied to the structure and $\mathbf{q}$ the acoustic forcing term, superscripts $\mathbf{fs}$ denote the parts due to the fluid structure interface.

References

1. Klein, S.A. (2000) On the acoustics of turbulent non-premixed flames, PhD thesis, University of Twente, Enschede.