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NUMERICAL INVESTIGATION OF ONE- AND TWO-WAY FLUID-STRUCTURE INTERACTION IN COMBUSTION SYSTEMS

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Summary. This paper presents numerical results of the fluid-structure investigation in a generic gas turbine combustion chamber. Results are obtained with the use of CFX-10 and ANSYS-10 commercial codes. The influence of the pressure changes inside the combustion chamber on the vibration pattern of the liner walls and vice versa is investigated.

1 INTRODUCTION

The combustion instabilities which occur in many types of gas combustion have significant meaning for their life time. The flame together with its intrinsic instabilities results in fluctuations in the acoustic field inside the typical combustion chamber [1,2]. The fluctuations are imposed the liner structure, which starts to vibrate [3]. The vibration can lead to fatigue damage of the liner and induce also extra fluctuations in the acoustic pressure. The acoustic wave propagates to the flame source and can even amplify fluctuations in the released heat, thus in the acoustic field. Stronger fluctuating pressure results in stronger fluctuations in the wall structure. This way the complete feedback loop is made, which causes much faster fatigue damage of the liner and whole combustion system.

This work presents the numerical predictions of the pressure changes inside the combustion chamber as a result of fluctuations in the fuel to air equivalence ratio. Reacting flow calculations inside the combustion chamber are done with the use of an URANS approach and CFX-10 commercial code. Further, the pressure from the near wall region is transferred to the structural analysis (FEM) in the Ansys-10 package, where the wall displacements are computed [4]. In order to see the effect of the wall vibration, the information about mesh displacement is sent by Ansys to the CFX code which calculates, based on this information, the pressure changes inside the combustion chamber. Exchange information between fluid and structural codes is possible with the use of the MFX code. The bucket search method is used as a mapping algorithm. This method partitions the interface into small cells for more efficient interface data mapping [5]. Loads are transferred with the use of the global conservative interpolation method. In this paper loops from CFX to Ansys (one-way interaction) and back from Ansys to CFX (two–way interaction) are investigated separately. This way it is possible to observe the impact of the wall vibration on the pressure pattern inside the chamber as well as influence of the new pressure on the wall vibration. Results are compared with the modal analysis done for the liner structure with the combustion chamber and the cooling passage cavities. This way the hazardous eigenmodes are predicted.

2 NUMERICAL MODELS

2.1 CFD Model for transient one- and two-way interaction analysis

Numerical calculations of the reacting flow inside the combustion chamber are done for the quarter part of the initial geometry. This allows reducing significantly the number of elements and therefore the overall computational time. The standard k-ε model available in the CFX code is used for the turbulence modelling, the Eddy Dissipation and the Finite Chemistry Rate scheme for the combustion. To obtain pressure fluctuations inside the combustion chamber the equivalence ratio is pulsated with frequency 100 Hz and amplitude equal to 5%. Numerical conditions are adequate to the experimental conditions depicted in table 1. Inlet velocity profile is taken form the previous calculation of the whole setup together with the plenum. The average static pressure is imposed on the outlet. Periodic boundary conditions are prescribed to side walls while the adiabatic no-slip to the cover walls. Total number of 632 000 unstructural elements, which are mostly placed in the combustion zone, is used.

Power	Abs. pressure	Air factor	Total mass flow	Air preheating temp.
150 kW	1.5 bar	1.8	90.64 g/s	573 K

Table 1. Operating conditions

2.2 FEM Model for transient one- and two-way interaction analysis

The walls of the liner of the combustion setup available at the University of Twente are consisted with two parts connected together by modular sections. This section assures small thermal stresses during work at high temperature. In the middle of the wall, the flexible section with thickness much smaller that surrounding structure is placed to amplified structure vibrations. On account of the minor influence of the thermal stresses on the liner behaviour, the model of the wall is reduced to one plate with flexible section but without modular connection and holes for pressure transducers and thermocouples. Uniform temperature equal to 760^{o}C and material properties of SS310 adequate to this temperature are used for analysis. The side parts of the wall are treated as the clamped-clamped. Total number of 19 000 equally distributed SOLID92 tetrahedral elements is used for dynamic calculations. Mechanical loads are transferred from the CFX code to Ansys via interface which is created on the one side of the liner structure. In order to send information lossless, both numerical models must be coincidence in space. Information about displacements and forces are shared every time step equal to 0.5ms. Total calculation time is set up to 0.25s.

2.3 FEM Modal analysis

Model of the liner with the combustion chamber and the cooling passage cavities is investigated in the modal analysis. The wall and the air cavities have temperature adequate to operating conditions presented in tab. 1. Only the flexible section of the liner is investigated. The other stiff parts have no significant influence on the eigenfrequencies. Model is consisted with the shell elements SHELL63 and the acoustics elements FLUID30. Elements with the ability to recognize the structure from one side and the fluid from another (FLUID30) are placed between the fluid and the structure. To prevent the direct connection pressure degrees of freedom from combustion chamber and air passage at the interface, structure is divided on two equal parts. These parts are connected each other in this way that any deformations in one structure cases the same deformation in the other. The walls are clamped on the both ends.

3 RESULTS

Numerical calculations showed the influence of the wall vibration on the pressure in the combustion chamber (fig. 1).

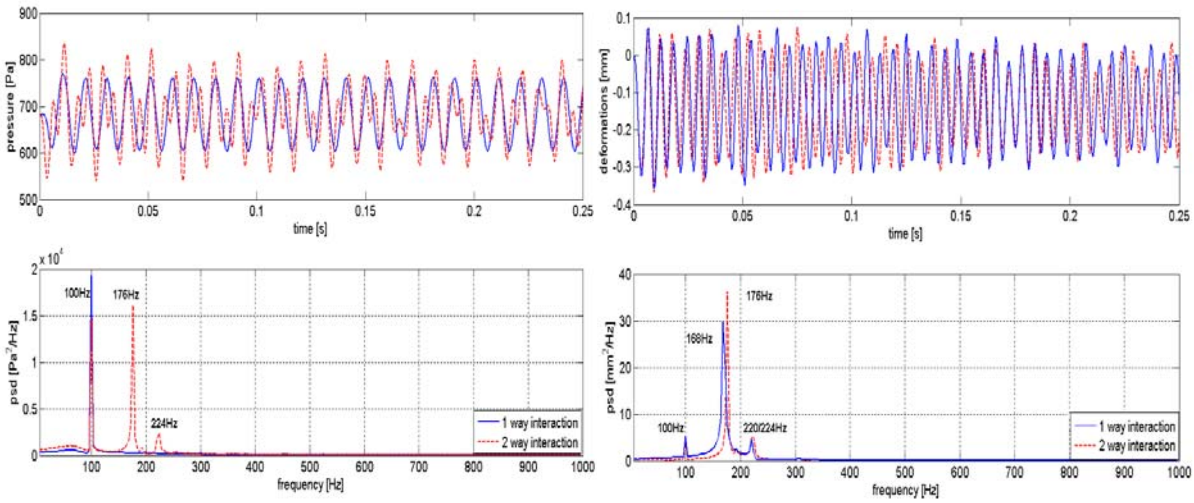

Fig.1. Pressure (left) and deformation (right) pattern during one- and two-way analysis

During one-way analysis, the forces are transferred only from CFX to Ansys, therefore no feedback from the wall vibration to the pressure field inside the chamber is observed. The changes in the pressure field inside the combustion chamber are caused by the forcing pulsation of the mass fraction ratio of the fuel to air ratio in the inlet flow. Only one peak at frequency 100 Hz in Fourier spectrum can be observed. However, when two-way interaction is performed, two extra peaks at frequency of 176 Hz and 224 Hz are observed. The Fourier spectrum of deformations in the two-way analysis shows peaks exactly at the same position as the spectrum of pressure. Those peaks must come from the vibrating structure, thus the vibrating liner induce additional changes in the pressure field. It is also noticeable, that these changes do not affect significantly the amplitude of vibration. Small shift in the vibration

frequency of the structural system is observed compared to the one-way interaction.
Modal analysis shows that the frequency of the wall vibration is highly dependent on the mode shape. Synchronized modes are responsible mostly for changes in the induction of the pressure pattern (fig. 2). This type of modes is characterized by significant change in volume which results in the pressure changes.

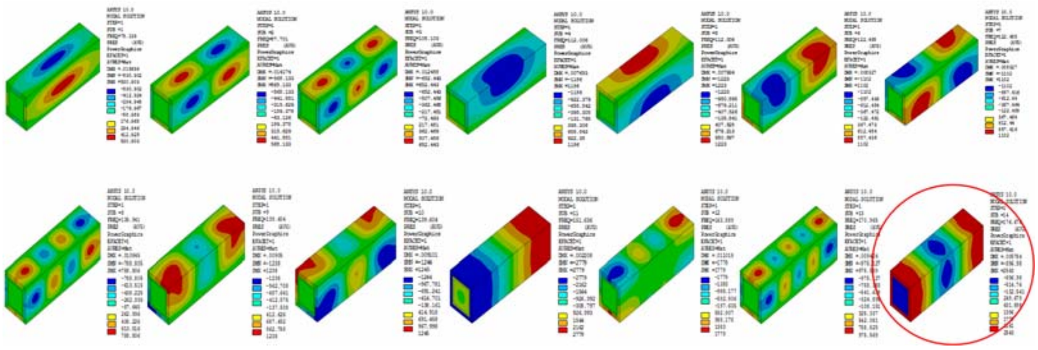

Fig. 2. Results of modal analysis, mode in red circle is the synchronise mode at frequency 176 Hz

4 CONCLUSIONS

Presented results show the differences between one- and two-way interaction. It is shown that one-way interaction can be a useful approximation in the prediction of amplitude and vibration pattern of the structure. Two-way interaction should be used on the other hand for the analysis of the pressure field inside the combustion chamber. At the beginning of transient calculations, during both analyses, a high peak caused by the initial imposition of high pressure on the wall face could be observed. This peak could induce some additional vibrations in the liner at the start of the simulation. Practically this can be considered an unimportant artefact. Nevertheless, the main behaviour of the fluid-structure system is assumed to be correct. Similar peaks can be observed as well during combustion processes, when some instability occurs.

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