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Numerical Simulation of Liner Vibrations in a Laboratory Combustion Chamber

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ABSTRACT: Combustion chambers are an important part of power generation systems that affect their efficiency and environmental pollutions. To reduce the pollutions, lean premixed combustion was introduced to be used instead of traditional non-premixed flames, however, this method has more tendency to become unstable. The thermal and acoustics interactions can amplify the acoustic waves and produce noise and increase the vibration level of the liner. The continuation of large amplitude vibrations can lead to failure. Therefore, the vibration modeling of the liner is very important. In this research, the vibration of a liner in a combustion chamber is investigated. The modal parameters in the cold and hot states are extracted from the finite element model. Then, model updating is utilized to modify the finite element model of the liner based on the experimental data. The flow analysis is also performed to obtain the pressure and velocity fluctuations during the analysis time. These data are used to model the flame as an acoustic source. Then, the transient analysis is evaluated to find the response of the liner due to this source. The results show the effectiveness of the updated model to predict the modal parameters and the vibration amplitude of the liner.

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1. INTRODUCTION

Combustion chambers are one of the main parts of power generation systems that affect the efficiency and environmental pollutions of these systems. To reduce the pollutions, lean premixed combustion was developed to replace the traditional non-premixed flames. However, this method has more tendency to become unstable. The interaction between the released thermal energy and the pressure waves inside the combustion chamber can cause severe fluctuations in pressure and lead to instability that increases noise and vibration levels in the combustion chamber. In this situation, failure due to fatigue is very probable that may result in financial and human losses. Therefore, over the past decades, many efforts have been made to understand the causes of these instabilities as well as to predict and prevent them from occurring. Since 2001, several successful projects have been carried out to reduce the pollution caused by the combustion process and to increase the efficiency of gas turbines. To this end, laboratory-scale combustion chambers with operating conditions close to those of gas turbines have been constructed and combustion, acoustic and vibration interactions were investigated [1-3]. The liner of one of these combustion chambers is shown in Fig. 1. In the present research, the vibration behavior of this liner in the cold and hot states is studied. First, an initial Finite Element (FE) model is constructed. Then, this model is updated to bring the numerical modal parameters closer to the experimental ones. The accuracy of the updated model is further studied by finding the transient response of the liner due to the pressure fluctuation caused by the combustion. Note that, the pressure data are obtained using the computational flow dynamics analysis. Using the obtained data, the flame is modeled as an acoustic source and the vibration response of the liner due to this acoustic source is evaluated and compared with the experimental results.

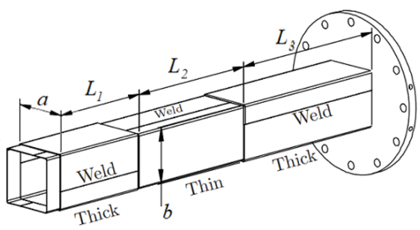

Fig. 1. The schematic diagram of the liner [2]

2. FINITE ELEMENT MODELING AND UPDATING OF THE COMBUSTION CHAMBER

The finite element model of the combustion chamber is constructed in ANSYS Mechanical APDL software. The Shell181 element is used to model the liner and the Fluid30 element is used to model the acoustic behavior of the fluid around the liner (see Fig. 2). Note that, the two-way vibration-acoustic interactions is employed. The natural frequencies

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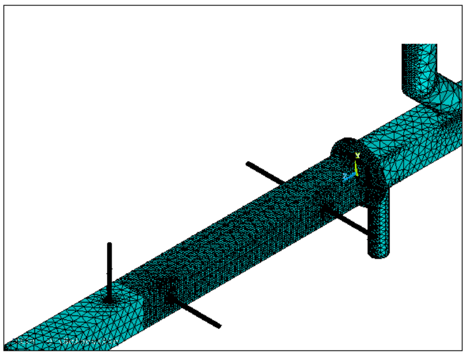

Fig. 2. The FE model of the combustion chamber

Table 1. Comparing the natural frequencies of the updated FE model with the experimental ones for the cold state

Mode No.	Natural Frequencies (Hz)		Relative Error (%)
	Updated FE Model	Experimental [2]	
1	218.66	225	2.82
2	300.11	300	0.04
3	312.42	315	0.82
4	324.91	325	0.03
5	378.61	367	3.16
6	420.21	414	0.92

Table 2. Comparing the natural frequencies of the updated FE model with the experimental ones for the hot state

Mode No.	Natural Frequencies (Hz)		Relative Error (%)
	Updated FE Model	Experimental [2]	
1	193.28	195	0.88
2	256.68	257	0.12
3	282.94	284	0.37
4	286.96	302	4.98
5	333.97	323	3.40
6	341.14	342	0.26

and the mode shapes of the liner are then determined by modal analysis using an unsymmetric solver. The initial finite element model of the liner can then be updated to minimize the difference between the natural frequencies of the FE model of the liner and the corresponding experimental values.

3. RESULTS AND DISCUSSION

The natural frequencies of the updated FE model of the liner in the cold state are tabulated in Table 1 with the maximum error equals to less than 4%.

To see how the combustion affects the modal parameters of the liner, the FE model of the liner in the hot state is also updated. Note that, the effect of the increased temperatures due to the combustion on the mechanical properties of the liner and the acoustical properties of the fluid surrounding the liner is employed with some simplification to reduce the computational costs. The obtained natural frequencies are presented in Table 2. It is seen that the optimum value for Young's modulus is 170 GPa, which is about 22% lower than the optimum value of this parameter in the cold state. If the liner temperature is approximated by averaging the maximum temperature inside the combustion chamber and temperature of the cooling air around the liner, the liner temperature is about 865 ° C. By examining the experimental graphs of Young's modulus of stainless steel 310 [4], the decrease in Young's modulus due to the above-mentioned temperature changes from the cold to the hot states is about 30%. Hence, the optimum value obtained for Young's modulus in the hot state with a 22% decrease compared to the optimal value for the cold state is in good agreement with the actual liner behavior. Moreover, there is no significant change in the optimum value of the liner density in the hot state, which is again in good agreement with the actual behavior of steel [4]. The change in optimum values of the geometrical parameters of the cross-section in the hot state is about 2 mm, but there is no significant change in the optimum values of the liner length parameters. The natural frequencies obtained from the FE model in the hot state are also compared with the corresponding experimental ones in Table 2 with the maximum error of less than 5%, which is an acceptable error.

After updating the finite element model of the liner in the hot state, using the pressure and velocity data obtained at the flow analysis using computational flow dynamics, a monopole acoustic source is defined in the vibration-acoustic model and the liner transient response due to this excitation is evaluated and compared with the experimental data. The analysis time according to the experimental data available for the comparison is 0.02 seconds and the time step is 0.0005 seconds. The velocity of a specific point on the liner together with the corresponding experimental data are plotted in Fig. 3. This diagram shows that although there are not exact point to point matchings between the numerical and experimental data, the amplitudes for the velocity of the liner are predicted well.

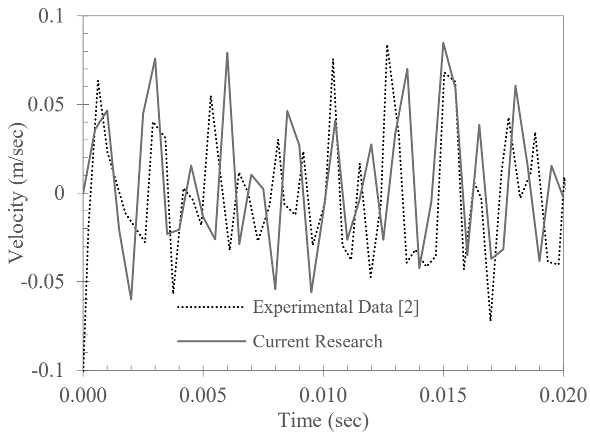

Fig. 3. Comparing the velocity-time response of a point on the liner obtained from the updated FE model with the experimental data

4. CONCLUSIONS

In this research, the vibration modeling of a laboratory-scale combustion chamber was investigated in cold and hot states. In the first step, the finite element model of the liner in the cold state was updated to minimize the difference between the numerical and experimental natural frequencies. In the hot state, due to the complexity of the combustion process and the resulting high computational costs, some simplifications were made for the flow analysis and for employing the thermal effects on the mechanical and acoustic properties of the system. The finite element model of the liner was then updated and the results were analyzed. To investigate the transient response of the liner due to the flame as an acoustic source, the linear velocity was evaluated at a specific point. Although point to point matching was not obtained, however, the amplitudes of the responses matched well with the experimental data.

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