A thermoacoustic rig to test materials for challenging environments

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Abstract. The setup of a thermoacoustic rig capable of performing modal analysis at high temperatures is described. Using an array of quartz lamps, temperatures of up to 900 °C were achieved. Furthermore, specimens have been exposed to a temperature gradient with the same quartz lamps. A shaker mechanically excited test specimens to up to 4000 Hz while modal shapes were acquired through pulsed laser digital image correlation. The setup allows materials to be tested for demanding environments such as hypersonic flight or fusion reactors. The modal shape of a geometrically-reinforced rectangular specimen during high temperature loading is provided as an example.

Introduction

The design and implementation of a thermoacoustic rig capable of performing vibration experiments at temperatures above 1000K is described. This rig has been used previously in work reported in multiple publications (eg., 1-3); however, the setup itself has not been described in detail to date and has recently been upgraded to achieve higher temperatures, from about 600 to 900 °C and frequencies, from 1000 to 4000 Hz. The rig allows experiments replicating extreme environments to be conducted. Specifically, the modal frequencies and shapes of specimens at high temperatures can be observed. As a result, materials for applications where components are exposed to demanding environments can be tested. Examples of this include the aeroacoustic loads experienced during hypersonic flight, or the thermal and vibration loads experienced by plasma-facing components of a fusion reactor.

Methods

Thermomechanical experiments were performed with a shaker for mechanical excitation and quartz lamps for heating. The main components of the setup have been summarized in Fig 1. Temperature was controlled by 22 individually programable halogen quartz lamps (QIR 240 1000 V2D, Ushio, Steinhöring, Germany). The quartz lamps have a power rating of 1 kW each which, when set to maximum power, lead to temperatures of up to 900 °C on the specimen surface. The heat lamps can also be set to varying power outputs to produce a desired temperature or spatially-varying distribution of temperature. Temperature across the specimen was measured using an infrared camera (TIM 400, MICRO-EPSILON UK, Birkenhead, UK) which was located 210 cm from the specimen, leading to a spatial resolution of 0.8 mm/cm.

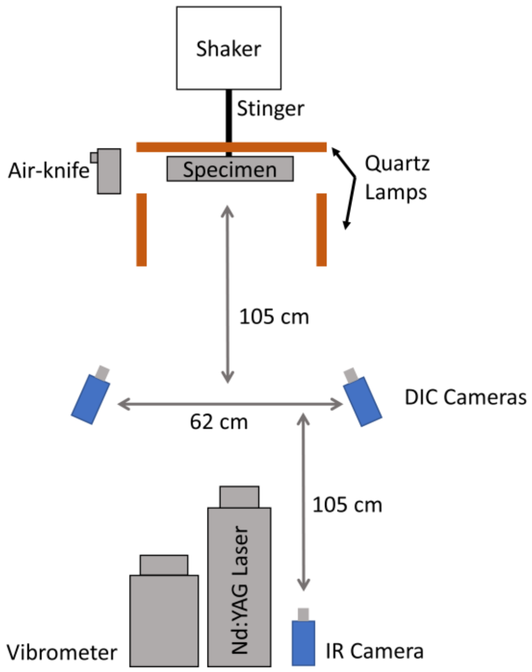

Figure 1: Diagram showing the basic setup of the thermoacoustic rig

A shaker (V100, DataPhysics, San Jose, CA, USA), which is capable of reaching frequencies of up to 4000Hz, was utilized in vibration experiments. The specimen was bolted on to the shaker through a steel stinger. The resonance frequencies of the specimen were found through a frequency response function (FRF). The input signal to produce the FRF was found from an accelerometer attached to the shaker and the output signal was provided by a laser doppler vibrometer (OFV-503, Polytec GmbH, Waldbronn, Germany). Specimens were harmonically loaded at their resonance frequencies through a function generator. The modal shapes could then be determined via pulsed laser digital image correlation (PL-DIC). The PL-DIC system used a pulsed Nd:YAG laser (Nano L-200, Litron, Rugby, UK) to trigger the acquisition of an image from a pair of stereoscopic DIC cameras (2 MP Stingray F-201b, Allied Vision Technologies GmbH, Stradtroda, Germany). The laser produced a 4 ns pulse of green light at a wavelength of 532 nm. A narrowband optical filter corresponding to the laser wavelength was placed in front of the cameras, stopping them from being blinded by the radiation emitted during heating. Additionally, the effects of any heat haze were mitigated through an air-knife, which blew a stream of air across the specimen. A total of 100 images were recorded in each experiment, which corresponded to two and a half wave cycles. Modal shapes were found from the maximum deflection of the plate.

Results

The setup has been successfully used for multiple thermoacoustic experiments in the past (e.g., 1-3). As an example, the temperature distribution and modal shape of a geometrically-reinforced Hastelloy X plate are shown in Fig. 2. The plate, with dimensions of 250 x 150 mm, was mechanically loaded at a frequency of 664 Hz while the heat lamps were set to half their maximum power. Figure 2a shows that a relatively uniform temperature distribution was achieved across the plate with a nominal temperature of 550 °C. Fig. 2b shows the modal shape at a nominal temperature of 550 °C at 664 Hz as measured by PL-DIC. Despite the high temperatures involved, the DIC image was not significantly affected by heat haze at the test conditions.

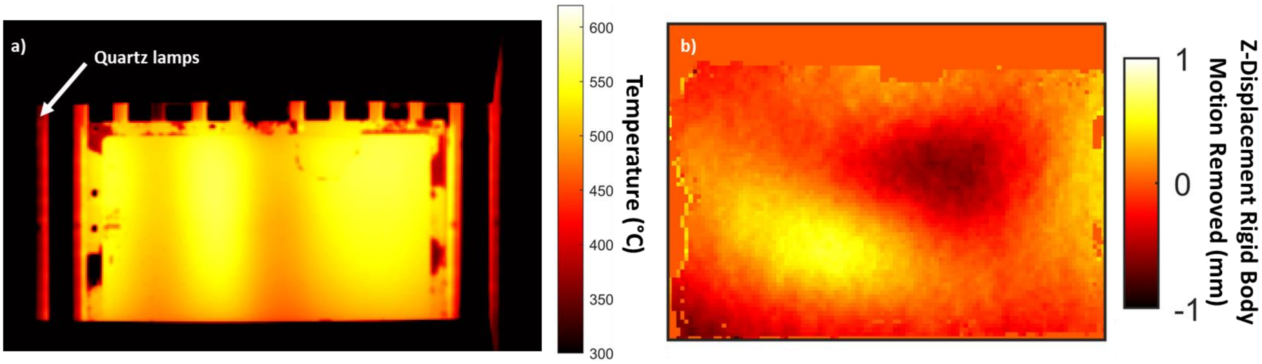

Figure 2: a) Temperature distribution across a geometrically reinforced plate b) the modal shape of the plate at 664 Hz when quartz lamps were set to 50% of maximum power.

Conclusion

The setup of a thermoacoustic rig to test materials in extreme environments was described. Temperatures of up to 900 °C were achieved by using quartz lamps, while a shaker was used for mechanical excitation up to 4000 Hz. Additionally, the setup allowed a temperature distribution to be applied across the specimen and to evaluate its effect on modal behaviour. Results demonstrated that high temperature modal analysis is feasible using this experimental rig. As a result, a means to test materials in demanding environments has been demonstrated.

References

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