Scanned-Wavelength Temperature Sensors for Combustion Instabilities

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Motivation

Fuel lean combustion is often employed to reduce pollutant emissions (CO, NOx,…) and increase gas turbine lifetime via reduced temperature. However, lean combustion is susceptible to thermoacoustic instabilities and lean blowout (LBO). Thermoacoustic instabilities are due to the coupling of heat release to acoustic oscillations, and lead to reduced combustion efficiency and increased pollutant emissions. LBO can lead to significant safety hazards and risk-based costs. Thus, practical use of lean combustion requires real-time control to suppress acoustic instabilities and avoid LBO.

Overview

An important part of any control strategy is a robust sensor to monitor a meaningful control variable. Gas temperature is an important parameter of combustion, and thus has potential for use as a control variable in physics-based control strategies. A fast, real-time temperature sensor has been developed for combustion gases using a single tunable, fiber-coupled, DFB diode laser (see reference). A specific H2O line pair near 1.4 micron is targeted for non-intrusive measurements of gas temperature using a scanned-wavelength technique with wavelength modulation and 2f detection. Gas temperature is inferred from the ratio of the second harmonic signals of the two selected H2O transitions. Real-time thermometry at 2 kHz has been successfully demonstrated in gas- and liquid- fuelled swirl flames.

This T-sensor is applied to combustion control demonstrations. Figure 1 shows the experimental setup to suppress the natural combustion instability from confinement of the swirl-stabilized flame in a duct. The sensor output signal is time-delayed and amplified to drive the speakers to modulate the intake air pressure. The FFT power spectra of the sensor output signal when control off and on clearly illustrates the suppression of the thermoacoustic instability at 390 Hz by the phase-delay feedback control (see Figure 2).

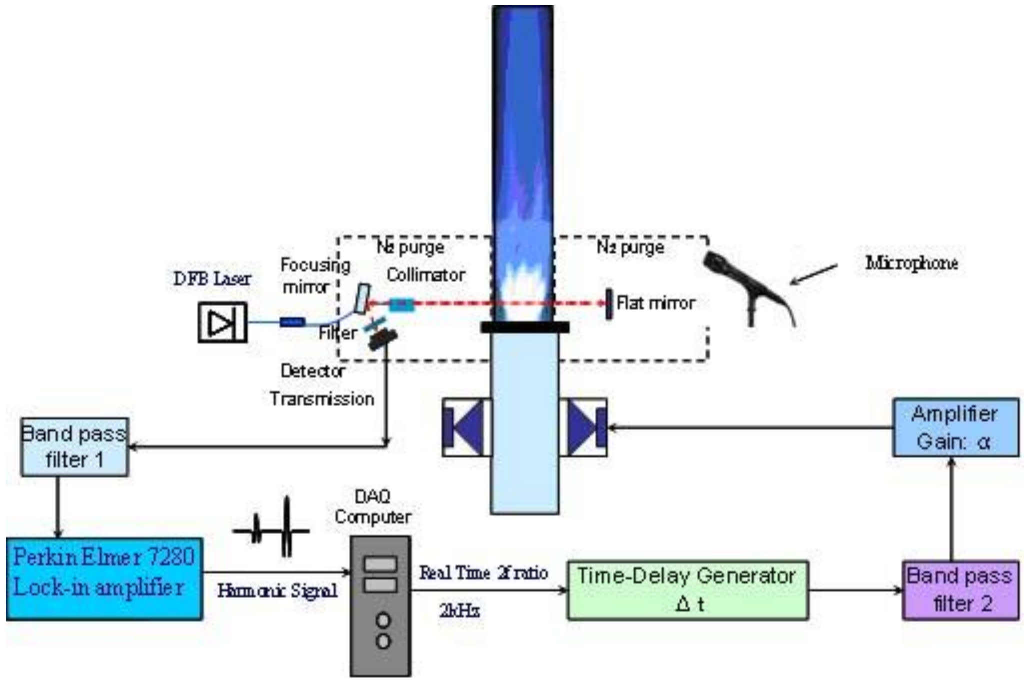

Figure 1: Experiment setup for suppressing thermoacoustic instability using real-time T-sensor.

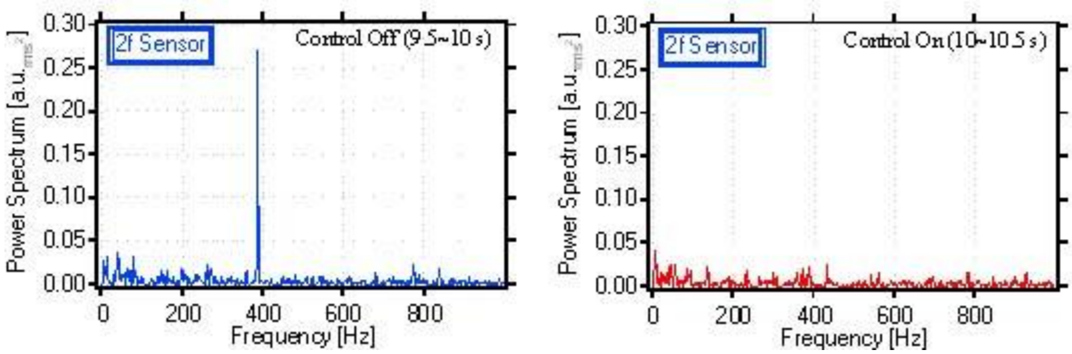

Figure 2: FFT power spectra with and without control.

The fast T-sensor has also been used to avoid LBO. Near LBO, the flame has more low-frequency T fluctuations as illustrated in Fig. 3 where the fraction of the power measured by the T-sensor in 0-50 Hz frequency range increases near LBO. Active control strategy to prevent LBO based on this observation is being studied in the swirl-stabilized combustor.

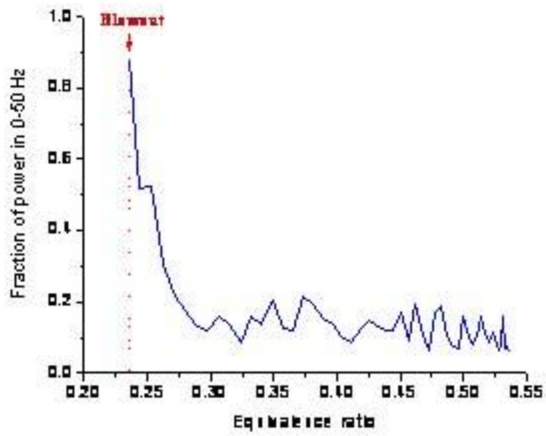

Figure 3: Fraction of FFT power in 0-50 Hz of the T-sensor output signal as a function of equivalence ratio.

References

1. Xin Zhou, Xiang Liu, Jay B Jeffries and R K Hanson "Development of a sensor for temperature and water concentration in combustion gases using a single tunable diode laser", Meas. Sci. Technol. 14(2003) 1459-1468.
2. X. Zhou, J.B. Jeffries, and R.K. Hanson, "Development of a fast temperature sensor for combustion gases using a single tunable diode laser", Appl. Phys. B 81, 711-722 (2005).