Optical Technologies for Diagnostics and Control of Combustion Processes Dynamics

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ABSTRACT

During the past decade and especially in these very last years the abatement of pollutants emission has been representing a relevant topic of research: special emphasis has been given to lean premixed combustion and some novel combustion regimes, such as MILD combustion, which have the intrinsic potential to lessen pollution. Besides these environmentally important issues, more specific issues concerning combustion stability are becoming more and more central due to the interest in burning CCS derived synthetic gases.

This paper reports ENEA's experience in developing a new diagnostic optical technique called ODC (Optical Diagnostics of Combustion), patented by ENEA. The flame radiant energy is sampled by means of a photo-diode and analyzed in terms of its power spectral density, phase and correlations to characterize the operating mode of a burner. The photo-diode UDT455HS used in ODC system, whose characteristics are a spectral response of 200-1100 nm (UV-IR range) and a sampling frequency up to 5 MHz. Flame radiative emission signal is analyzed by using an integrated module implemented in LABVIEW platform. Experience on several burners, either premixed or not, and fed with different fuels, showed that the signal associated to flame radiative emission carries a large amount of information, related to chemistry, its interaction with turbulence, acoustics. This strategy is not intrusive because it needs just an optical access, quite common in new combustion chambers. A sapphire fiber probe allows the direct access to combustion chamber. The structural features of photo-diodes make their application feasible in both land-based and aerospace power plants. Furthermore, the analysis can be performed in real time, making also feasible their integration in a control loop.

Accurate statistics can be achieved by the ODC system and due to its high sampling frequency it is easy to implement efficient and fast diagnostic algorithms for real-time control. By performing analysis in the frequency domain, ODC is useful for diagnostics of both fluid-dynamics and thermo-acoustic instabilities. In particular, it is possible to detect characteristic frequencies of a burner, know the mean axial velocity component, and identify the onset of thermo-acoustic instabilities.

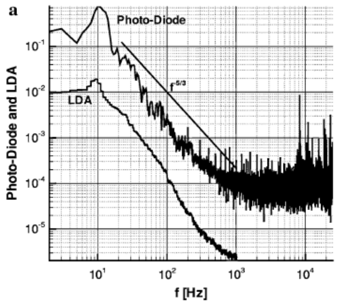
In this work, data coming from previous experimental works are exploited. In particular:

a) Burner A is a **2 kW premixed CH4/Air axisymmetric bluff-body burner** located in ENEA Research Center in Rome (Italy).
b) Burner B is a **250kW Premixed Liquid Oil/Air Burner** (with a rapid swirler premixer) located in Savona Combustion Laboratory (DIMSET/SCL, Italy).
c) Burner C is the **5MW Isotherm Pwr Flameless oxy-combustion plant**, that operates in

MILD regime, with temperatures (of the gases inside the reactor) in the range of 1500 – 1800°C, nominal pressure of 4 bar. This mild burner is located inside ANSALDO Ricerche center in Gioia del Colle (Italy) and the owner is ITEA Spa.

Figure 1a reports a comparison between the radiative emission spectrum coming from burner A and a velocity spectrum obtained by means of Laser Doppler Anemometry (LDA) at the center of the region seen by the photo-diode. What is quite striking is that both the spectra exhibit a clear range of $f^{-5/3}$ scaling, typical of turbulent inertial range, and that the same main frequency (10 Hz) is measured by both techniques. Information at very high frequencies are gained, and this can show chemical and acoustic effects in combustion.

Experience on burner B showed that the onset of thermo-acoustic instabilities ("humming") appears as a fast increase of radiative emission amplitude (see Fig.1b and 1c). During the transition to the unstable regime many new frequencies appear, then the system selects only certain frequencies, the phase difference is ~120° and tends to 180°. The auto-correlation of radiative emission signal becomes nonzero and larger than pressure auto-correlation; its spectrum goes far from the reference stable spectrum, particularly in the macroscale and dissipative – chemical ranges. When the system is experiencing fully developed humming (see Fig.1c), it pulsates at one frequency, and the radiative emission signal is fully auto-correlated. Precursor events of instability are detected some seconds before its fully developed state, thus suggesting the ODC as a controller to avoid humming state.



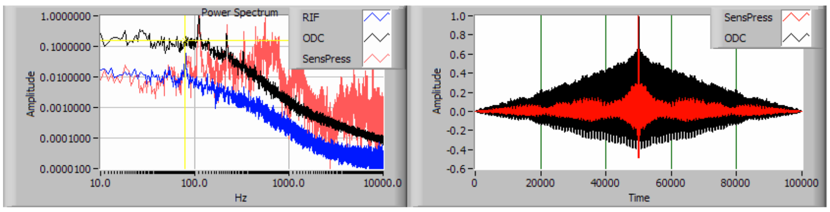


Figure 1a: axial velocity fluctuation spectrum obtained by means of LDA (burner A).
Figure 1b,c: characterization of the unstable mode (thermo-acoustic instability) of burner B.

In the oxy-combustion process experiencing a MILD regime (burner C), some pulses of radiative emission were detected (Fig. 2). These pulses were supposed to be related to the evolution of local combustion processes, and in particular, the rising phase to the start of oxidation and the decreasing one to heat transfer mainly. Data revealed that the rising and decreasing times can be assumed as good indicators of the reactive process and they can be used to quickly detect precursor phenomena of the state of the process.

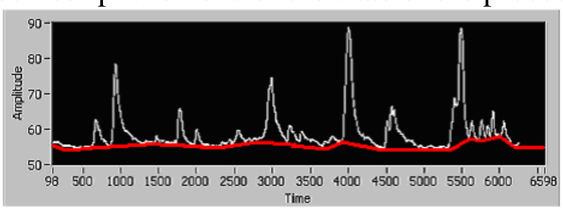


Figure 2: radiative emission signal sampled by ODC in the inlet region of a combustion chamber in MILD regime. It is the sum of the background level (red line) and the flame pulse (white line).

Keywords: ODC, humming, thermo-acoustic instability, MILD, frequency analysis, flame radiative emission.

Proposed Topic: Diagnostics