Recurrence Analysis of Dynamics of Premixed and Partially Premixed Flames near Lean Blowout

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Reducing the emission of NO_X from fuel rich combustors is a major technological problem. Switching to much leaner combustors reduces the production of NO_X due to lower flame temperature. It also helps in complete combustion and engine maintenance requirements are reduced along with reduction of soot formation. Lean combustors are used in ground based engines and in aero engines among others. Gas Turbines cannot work at a high NO_X emission standard owing to strict norms from International Committee on Aviation Environment Protection. New concepts have been introduced in the gas turbine industry like LPM (lean premixed combustion), LPP (lean premixed pre-vaporized combustion), RQL (rich burn quick quench lean burn combustion) and SCR (selective catalytic reduction). Among all the techniques, lean premixed combustion appears to be most promising in aspects of cost, reliability, safety and less pollution. But, with increasing lean premixed combustion by reducing equivalence ratio, probability of blowout (static instability) increases.

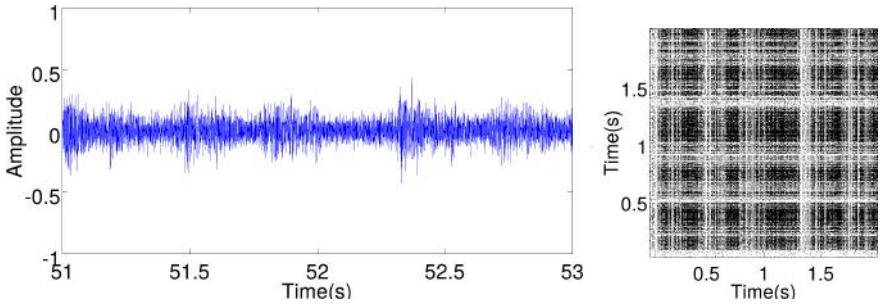

Figure 1: Time Series and the corresponding Recurrence Plot for a window of 2 seconds at $\frac{\phi}{\phi_{LBO}} = 1$

Recurrence is an intrinsic property of any deterministic dynamical system and can be used for its qualitative characterization. In existing literature [1], [2], [3] and [4] recurrence plots show interesting dynamical features in combustion systems. A similar analysis has been conducted in this work for the flame approaching lean blowout (LBO). Sound emitted by the combustor has been recorded using a microphone. The resultant audio signal has been divided into windows of 2 seconds each and recurrence quantification analysis has

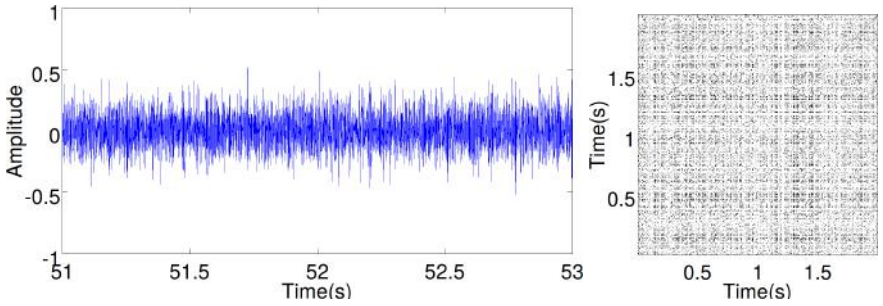

Figure 2: Time Series and the corresponding Recurrence Plot for a window of 2 seconds at $\frac{\phi}{\phi_{LBO}} = 1.09$

been done for each window. In the calculation, embedding dimension has been kept in the range of 5-6, while the delay time is in between 0.00833-0.001042. Recurrence threshold has been kept at 20% of the distance between maximum and minimum state vectors.

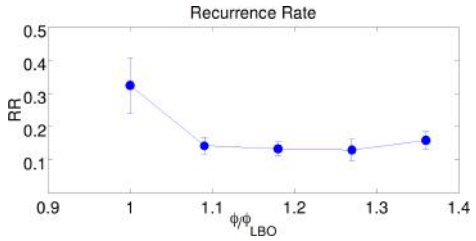

Figure 3: Variation of Recurrence Rate with $\frac{\phi}{\phi_{LBO}}$

The recurrence plot along with the time series data in Figure 1, suggest an intermittent behaviour, while in Figure 2 the recurrence plot indicates a possible chaotic dynamics. Thus, a distinct change in recurrence plot is noticed just before LBO when $\frac{\phi}{\phi_{LBO}}$ is changed from 1 to 1.09.
A quantitative analysis of line structures present in recurrence plot can help to locate some key features of the dynamical system. Some measures of recurrence quantification [5] used in this study are Recurrence Rate (RR), Determinism (DET), Average diagonal line length (L), Laminarity (LAM), Entropy (E) and Trapping Time (TT). Sharp change in recurrence rate is noticed in Figure 3, just before LBO. At $\frac{\phi}{\phi_{LBO}} = 1$, clustering of recurrence points in box like patterns results in a much higher recurrence rate. Large fluctuation is also noticed at $\frac{\phi}{\phi_{LBO}} = 1$.

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