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Stability of spinning detonation waves

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ABSTRACT

The present paper reports the results of a study of the stability of spinning detonation near the detonation limits. The detonation velocity as well as the structure are observed for long distances of propagation. Stable mixtures (with regular transverse wave pattern) and unstable mixtures (with irregular transverse wave pattern) are investigated. It is found that the local velocity fluctuates as the spinning detonation propagates and the fluctuations increase when past the first onset of spinning detonation towards the limits (failure). For stable mixtures of $C_2H_2 + 2.5O_2$ with high argon dilution, the fluctuations are less than for unstable mixtures of $C_2H_2 + 5N_2O$ and $CH_4 + 2O_2$. Limits are indicated by abrupt failure of the detonation after some distance of propagation. Long smoked foils (~3 m) indicate that the spinning structure is not constant, but varies periodically as the detonation propagates. Past the first onset of spinning detonation, the fluctuation in the spin structure occurs more frequently and failure is evidenced by the disappearance of transverse waves trajectory on the smoked foil. For stable mixtures, the spinning detonation structure is more stable with a constant pitch and a well defined straight trajectory of the "spin head". However for unstable mixtures, the spinning detonation is more unstable with varying spin pitch and a "wavy" trajectory of the "spin head". Also extraneous modes appear periodically superimposed on the spin mode. Subjecting the detonation to a finite perturbation narrows the range in which spinning detonation can be observed. In general the detonation suffers a disruption both in the structure and velocity but recovers after some distance downstream of the obstacle. However for the very unstable mixture of $CH_4 + 2O_2$, it is found that past the limits, abrupt reinitiation occurs downstream of the obstacle similar to the phenomenon of the onset of detonation as in DDT.

1. Introduction

Spin detonations occur near (or at) the detonation limits [1–5]. It represents the lowest steady propagation mode of the detonation wave because past spinning detonations towards the limits, the detonation is generally highly unstable with large fluctuations in both the propagation velocity as well as the structure (e.g. pulsating and galloping detonations [6]). Thus it was suggested by Dove and Wagner [7] that the appearance of spinning detonations can be used to define the limits. However, the observation of a spinning detonation does not correspond to a unique composition (or initial pressure). There is a range of conditions in which spinning detonations persist after its first appearance. This was first noted by Gordon et al. [8] who studied near limit detonations in H_2–O_2 mixtures in a 20 mm diameter tube. In a later study of ethylene–air detonations near the lean limit, Donato [9] also reported that spinning detonations occur over a range of mixture composition. He carried out experiments using tube diameters of 28 mm, 48 mm and 145 mm. Wolanski et al. [10] observed spinning detonations in CH_4–air detonations in a 63.5 mm square tube over the entire range of composition of 8–14.5% CH_4. Thus it is clear that spinning detonations do not correspond to a unique condition for a criterion for detonation limits.

In the study of Donato [9] and Moen et al. [11] they claimed that past its first appearance, spinning detonations are unstable and would fail when subjected to a finite perturbation. Donato [9] also suggested that past its first appearance, spinning detonations are essentially unstable combustion phenomenon resonating at the fundamental acoustic mode of the tube. Hence they do not correspond to the same mechanism for the propagation of self-sustained detonations. This explains why when the resonant coupling with the acoustic vibration is temporarily disrupted, the spinning detonation fails and cannot resume its original structure. In support of his argument, Donato showed that at the first onset, the spin pitch when equaled to the cell length give a transverse wave spacing that agree with values from other independent

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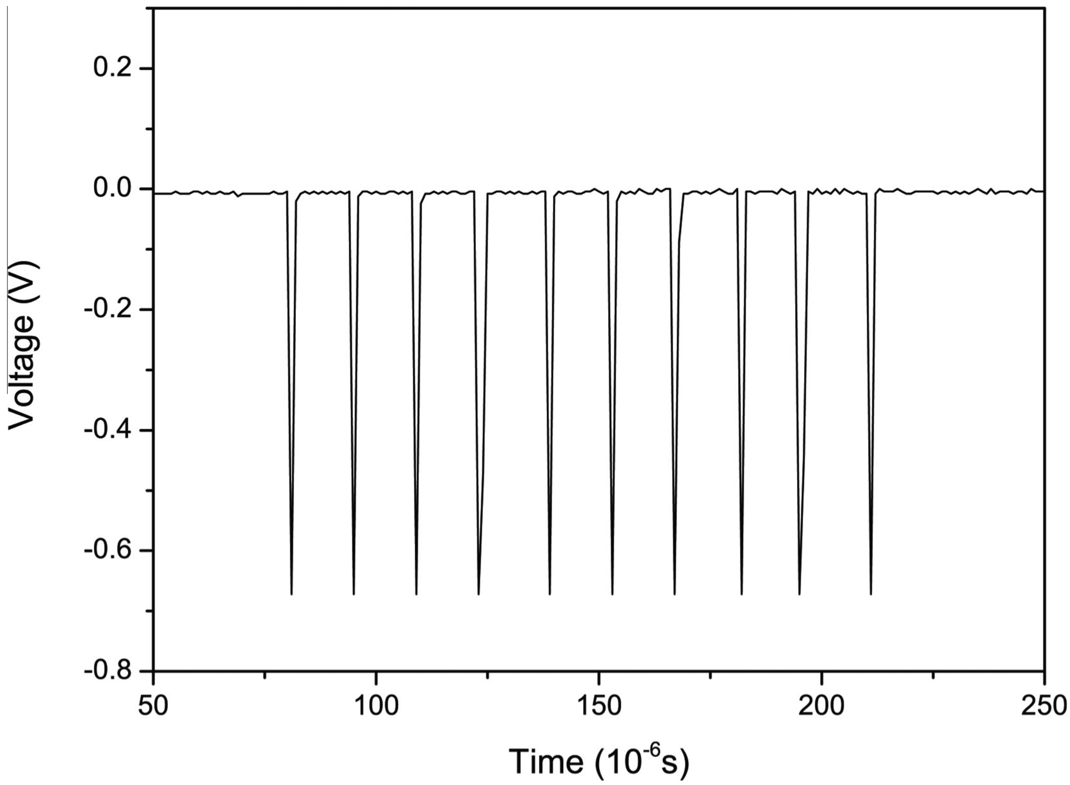

Fig. 1. Sample signals from the optical fibers.

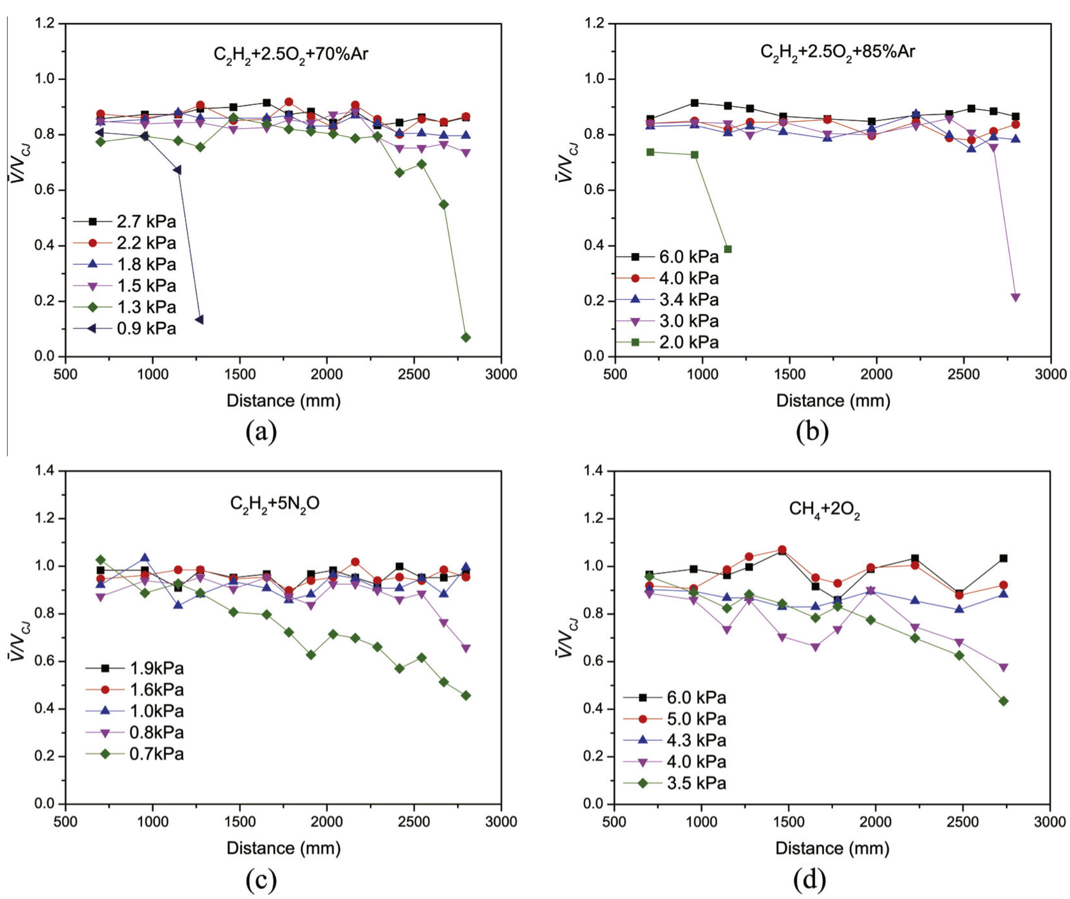

Fig. 2. The variations of the local detonation velocity of four mixtures.