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Combustion Waves: Theory and Experiment: Poster session
N2-P-003002

Experimental Observation of the Instability Mode in the Combustion Wave by the Differential Chronoscopy Method

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INTRODUCTIONS

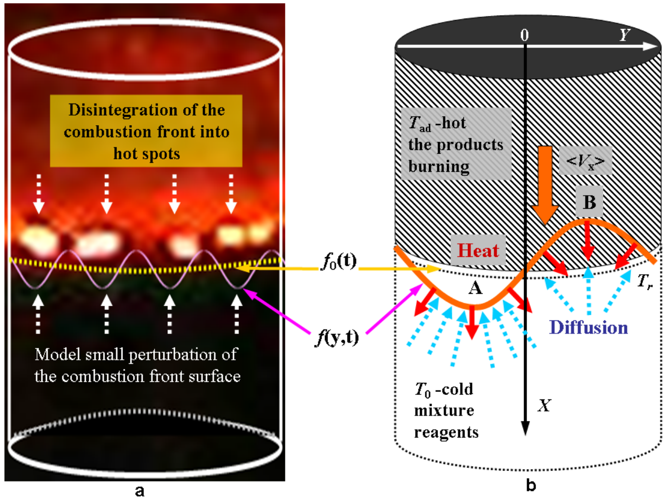


Fig. 1.
Difference between the theoretical model and experimental data on the thermal structure of the combustion wave (a); the mode of thermal instability (zone A) and diffusion instability (zone B) in the Zel'dovich – Rosenblatt model (b).

The classical regime of diffusion instability in the form of a concave line of the combustion front f(y,t) in zone B in Fig. 1 (b), on the experimental video frames it looks like a “cold zone” between local “hot spots”, which is explained by the presence of unreacted components in this “cold zone” due to a reduced diffusion flux. In general, the discrete thermal structure of the combustion wave, consisting of “hot spots” and “cold zones”, is located on the front line f0(t), which corresponds to the unperturbed propagation mode of the reaction, which in the arbitrary case is possible only with the value of the Lewis number Le=D/a close to 1. It should be noted that the observed size (~ 150-200 microns) of "hot spots" in Fig. 1 (a) exceeds the particle size (10-30 μm), therefore, the discreteness of the combustion wave is interconnected not only with the particle size, but also has a pronounced “collective” effect on the scale of local microheterogeneity. The purpose of this paper is to describe the features of the propagation of a combustion wave in the mode of spin instability, which is observed using high-speed video.

B. Zel'dovich, and A. G. Istratov, “Diffusion-thermal instability of laminar flame,” Prikl. Mekh. Tekh. Fiz., No. 4, pp. 21–26, 1962.

P. Gulyaev at al, “Instability of the Ni-Al combustion wave in the Zeldovich-Barenblatt parameters.” JPCS, V. 1353. 012036. 2019.

EXPERIMENTAL TECHNIQUE

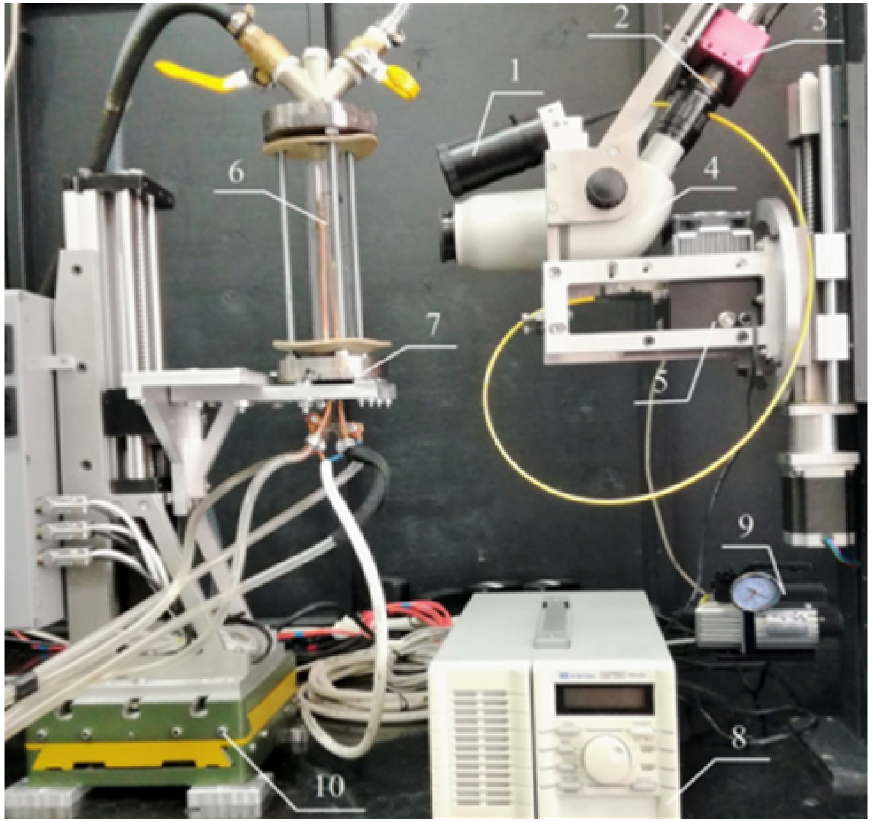
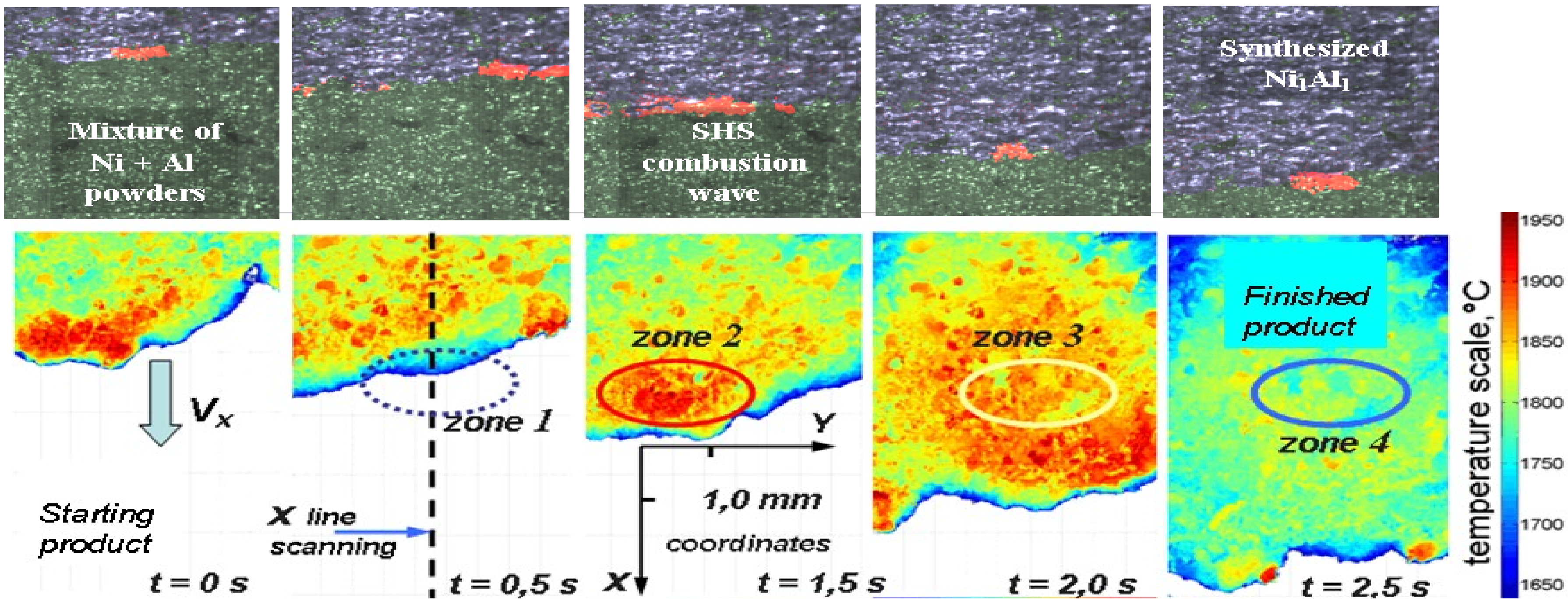


Fig.2.
Experimental setup for observing SHS combustion wave instability.

1- Optical Spectral Analysis Port (Computar MLN-10x, Computar Optics Group, USA);
2 -Interference Light Filters (SL-525-40, SL-725-40);
3 - High-Rate TV Camera;
4 –Stereomicroscope;
5-Spectrometer ASEQ LR1-T (Aseq Instruments, Canada);
6-Test sample with SHS combustion wave;
7 -Sample electric heater;
8 - Programmable Electric Heating Source PSH-2035 (Good Will Instrument Co., Taiwan);
9-Vacuum Pump (VP-215);
10- 3D sample positioning system.

AN EXPERIMENTAL PROCEDURE FOR RECORDING THE INSTABILITY OF COMBUSTION WAVES



High-speed video *(1000 fps)* of combustion wave *(resolution 5,85*10-6 m / pixel)*

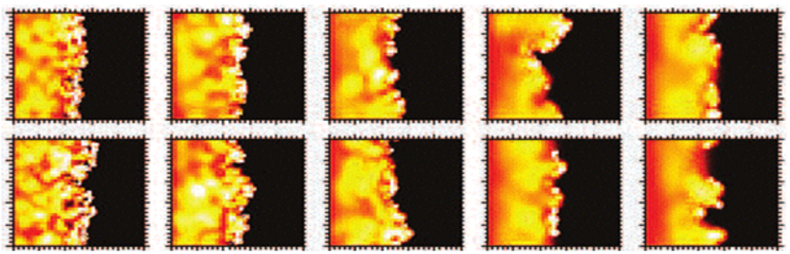


Fig. 3. Diffusion instability mode of the SHS combustion wave.

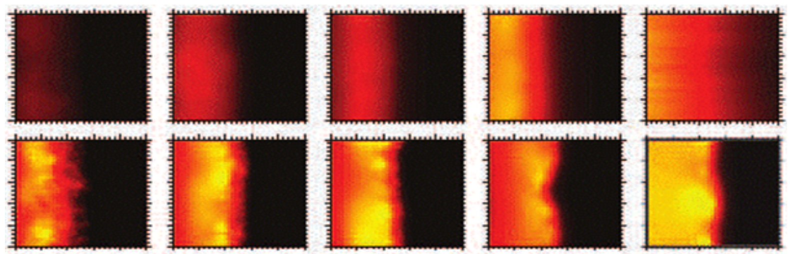


Fig. 4. Thermal instability mode of the SHS combustion wave.

SIMPLE VISUALIZATION METHOD

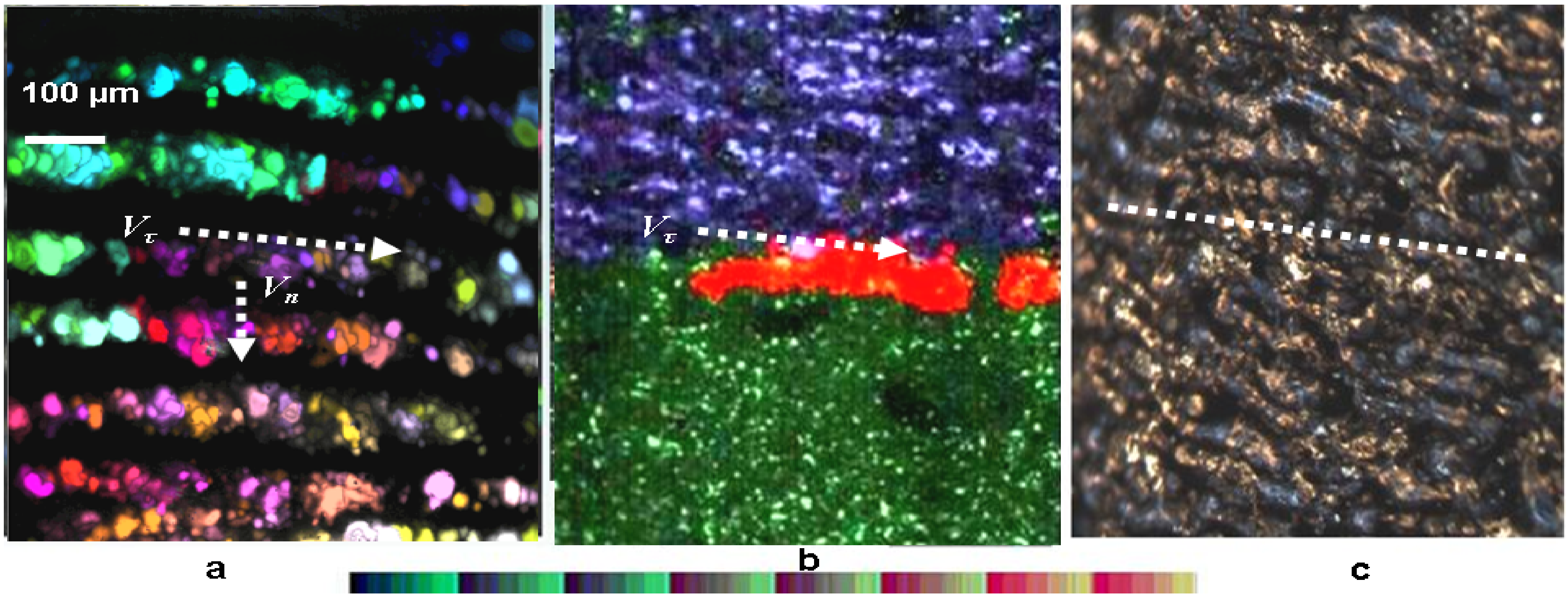
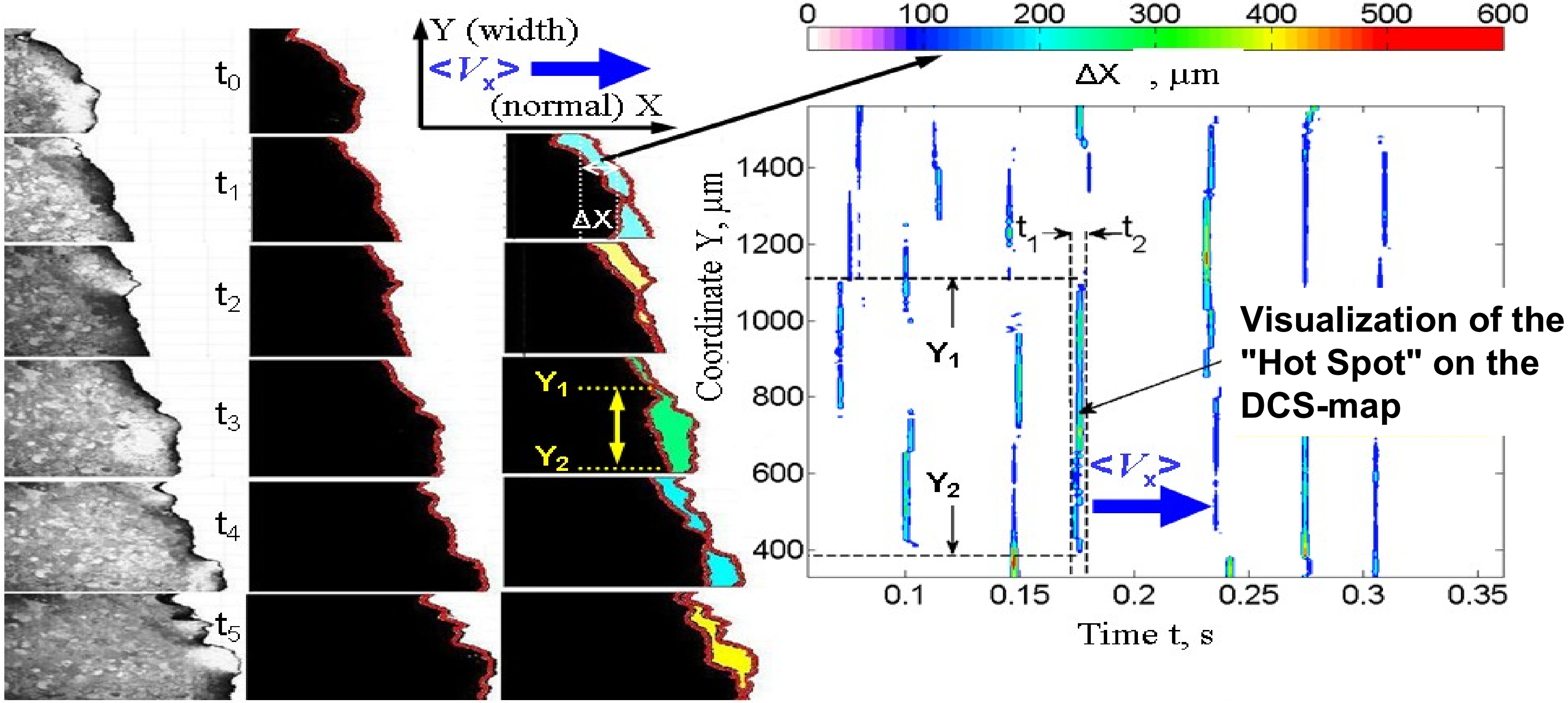
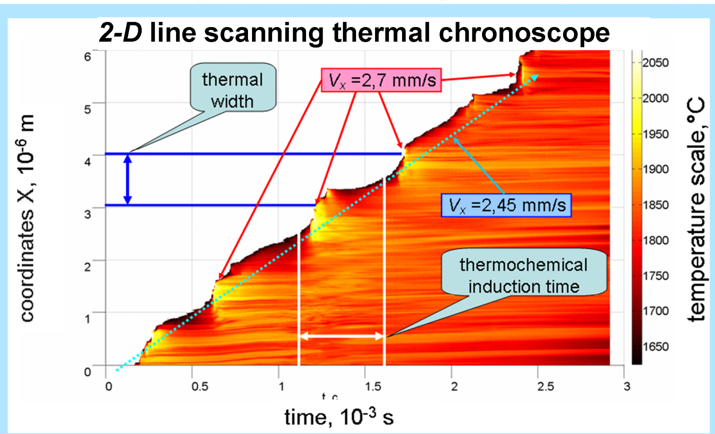


Fig. 5. Topography and sequence of occurrence of “hot spots” structures in the SHS combustion wave with a chromatic ignition time scale (a); direction of propagation of the elementary "hot spot" (b); layered surface morphology of SHS products with traces of "hot spots" (c).

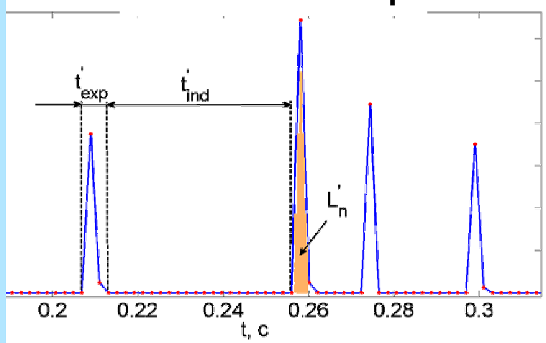
M.P. Boronenko at al, “Phase formation time evaluation in NiAl combustion systems by the thermal fields visualization method,” Scientific Visualization, vol. 7(5), pp. 102-108, 2015.

VISUALIZATION BY DIFFERENTIAL CHRONOSCOPY (DCS)

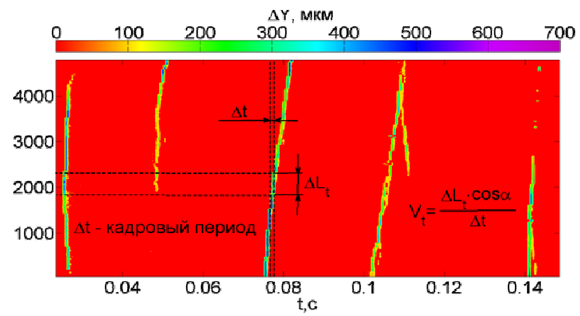




1-D line DCS-map



2-D line DCS-map



RESULTS AND DISCUSSION

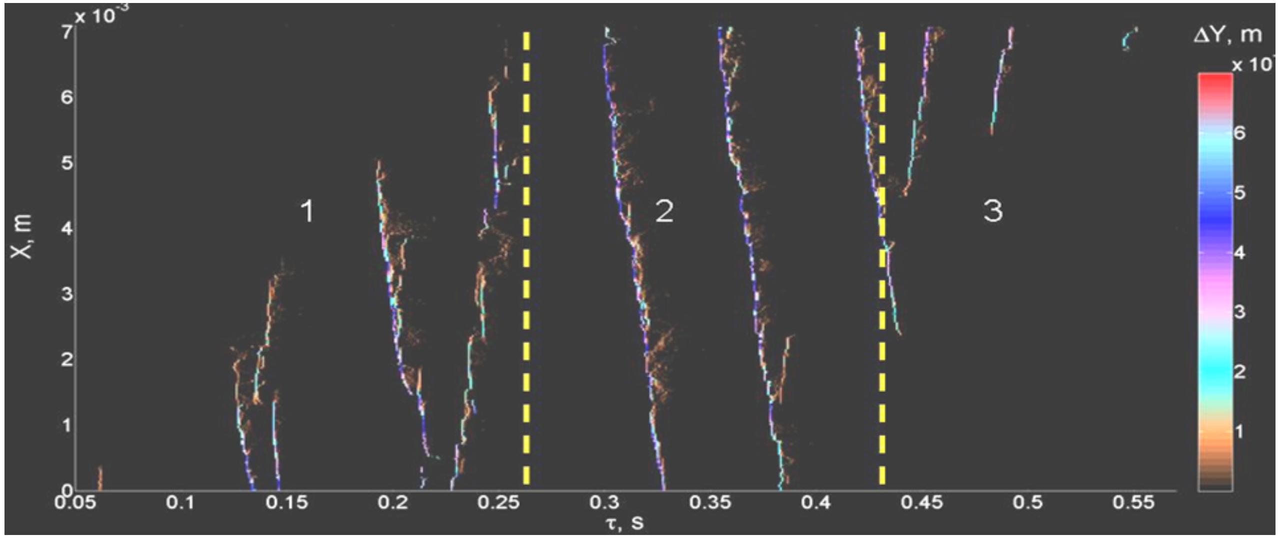
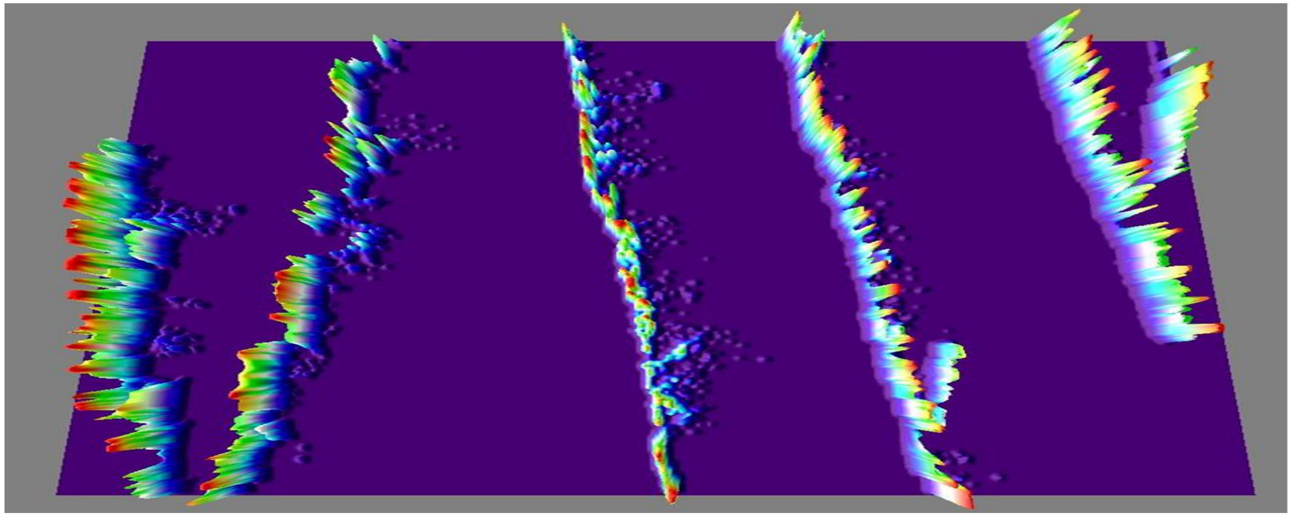
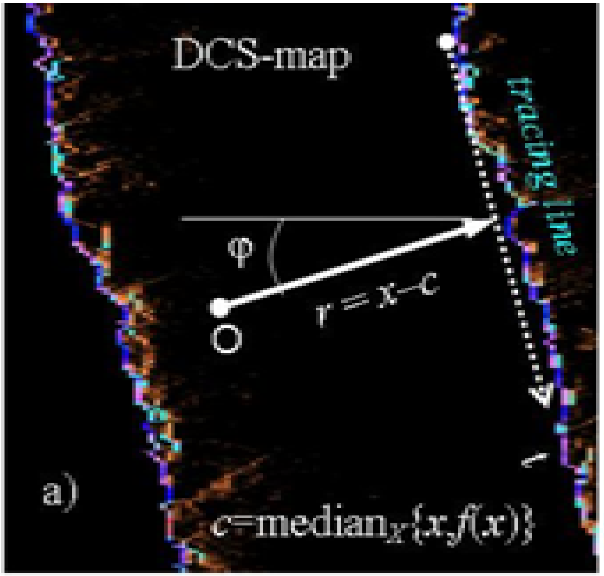
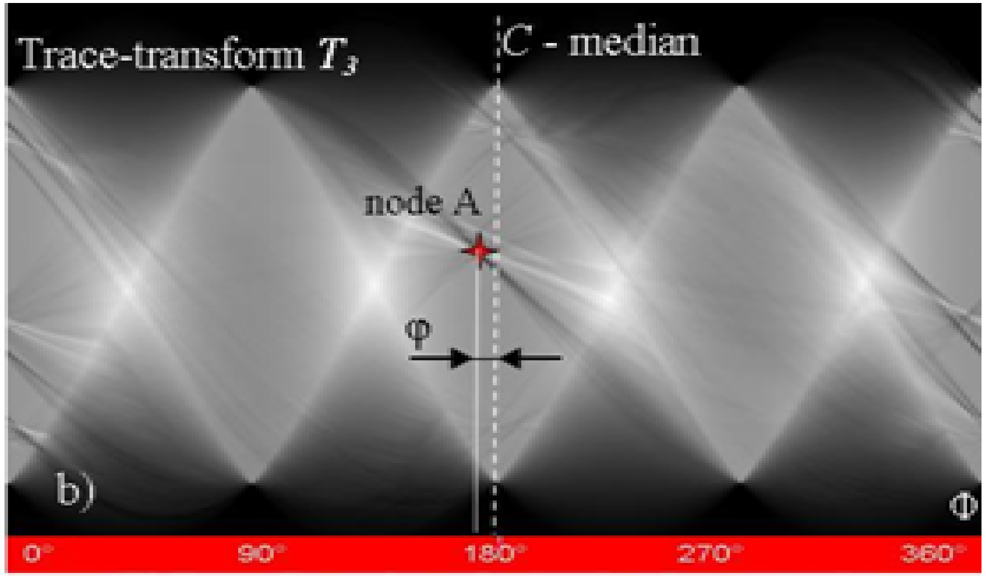


Fig. 6. A high-rate 3D chronogram (2000 fps) visualizes points of the combustion front with spin instability



THE TRACE TRANSFORM FOR THE DCS-MAP





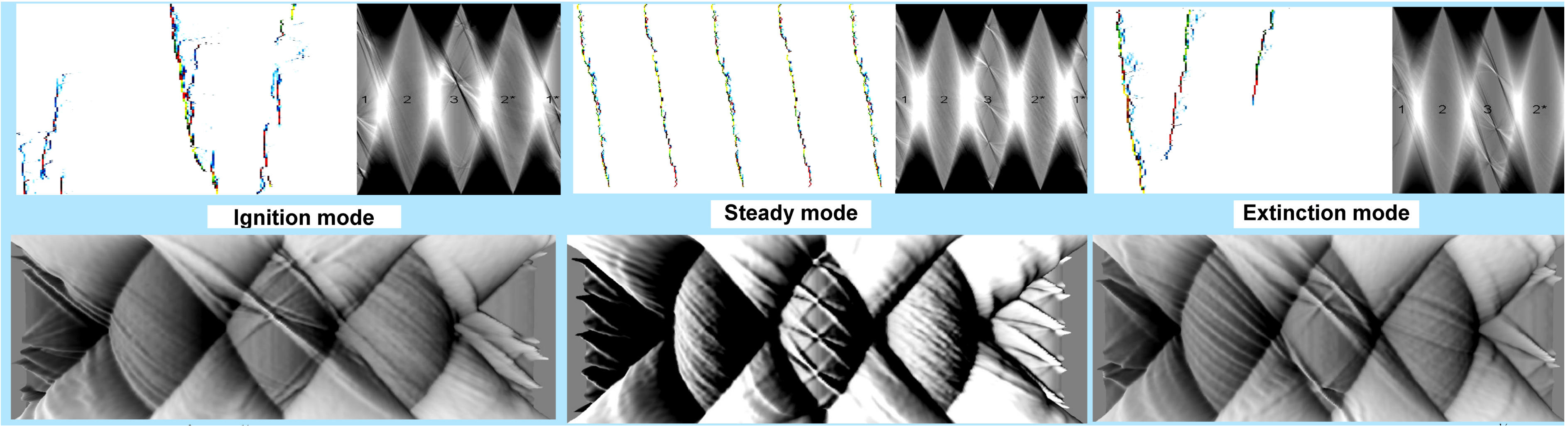
Significant differences of this work, in addition to increasing the frame rate of video recording up to 2000 fps, include the choice of the Trace transform core for processing DCS-map data in the form :

$$T_3: \quad T(f(t)) = \left| \int_{c^*}^{\infty} e^{i5\log(r)} r f(t) dt \right|,$$

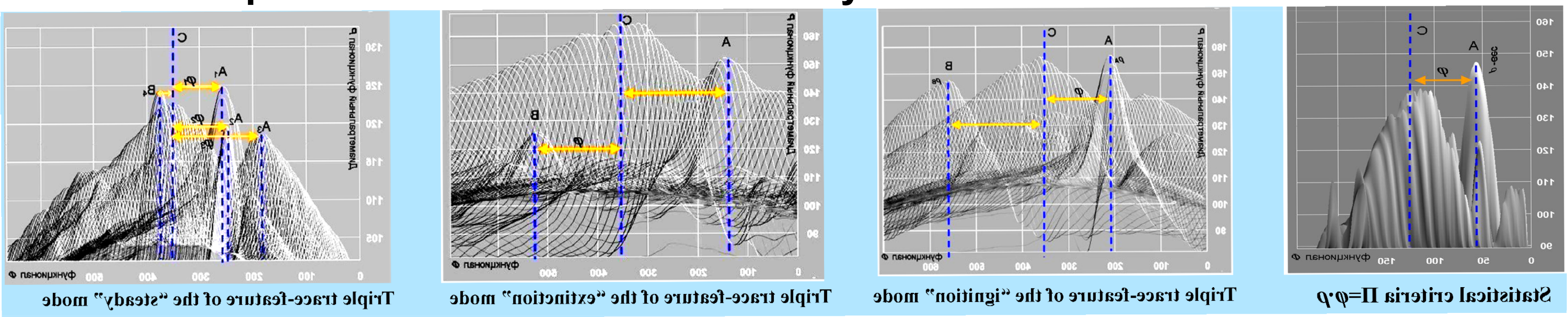
where $r = x–c$, and c=median $x\{x,f(x)\}$.

P.Gulyaev, V. Jordan, "Trace-Analysis of Images of the Differential Chronogram of the Combustion Wave for Recognition of Transitional Modes of SHS," CEUR Workshop Proceedings, vol. 1940, pp. 37–44, 2017.

TRACE TRANSFORM DIRECT IMAGE OF THE SHS COMBUSTION WAVE CHRONOGRAM (DCS-MAP)

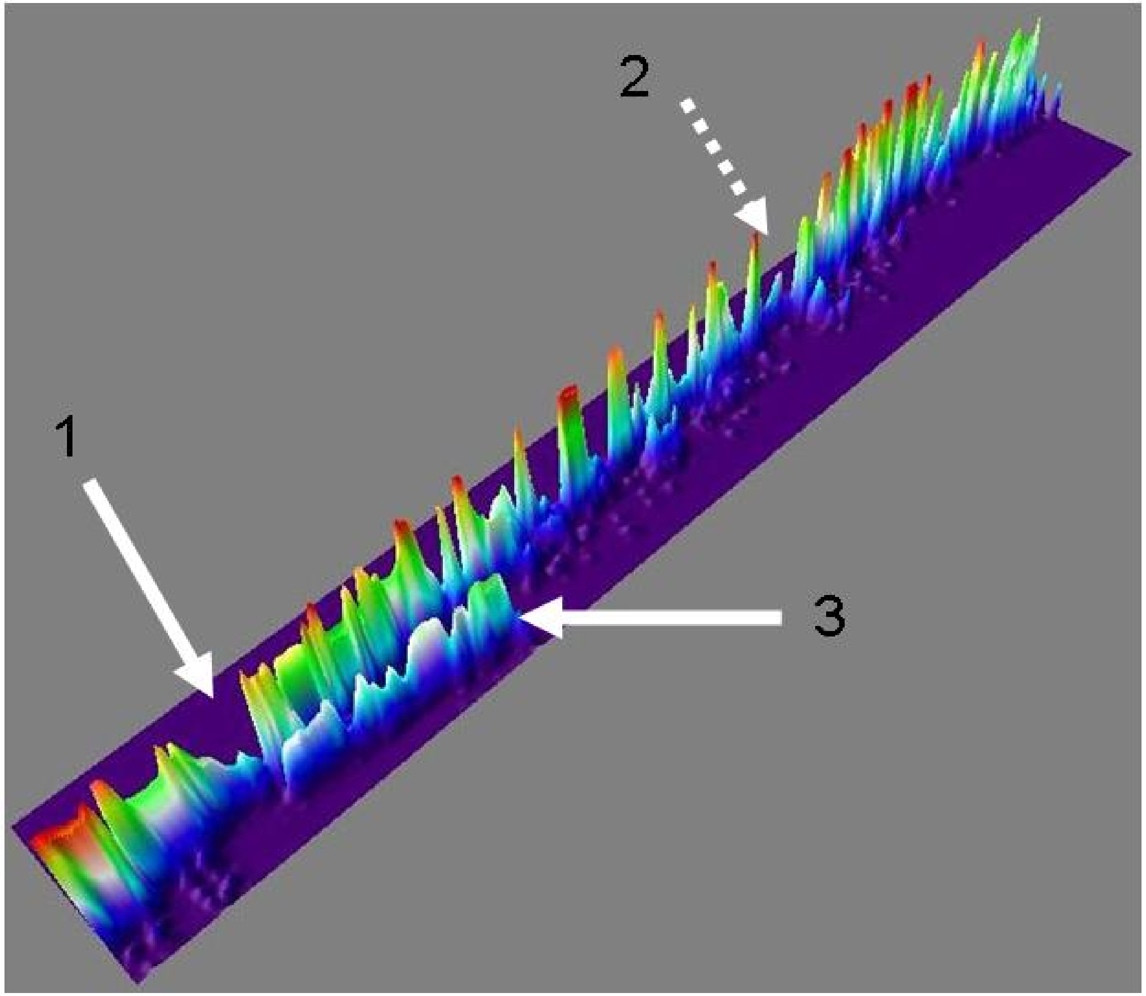


Triple trace-feature of the Instability mode in the Combustion Wave



The simplest statistical criteria, to recognize the critical combustion mode, a triple trace-features can be given in the form $\Pi=\sum(\varphi_i \cdot \rho_j)$, where ρ_j is the statistical weight of the local maximum A_i or B_i in the histogram of the corresponding diametral functional P.

SPIN INSTABILITY MODE OF COMBUSTION WAVE



DCS-map of spin instability:
1- node of “strong” instability;
2 - node "weak" instability;
3 - a branch of a part of the combustion front in the direction of the opposite spin.

CONCLUSIONS

- 1. The spin combustion mode is characterized by a high tangential velocity relative to the normal to the unperturbed combustion front: $10<(V_\tau/V_n)<100$. Under such conditions, it is necessary to calculate the weighted average value of the Lewis number over the entire line of the combustion front $f_0(t)$, taking into account the contribution of the “hot spots” and “cold zones”, so that in a wide range of speeds V_τ the average sign of absolute stability is $Le \sim 1$.
- 2. The loss of thermal stability in the spin combustion mode, when the direction of the tangential velocity V_τ is reversed, should be distinguished into a special type, called the "spin instability", since this is caused by a special hysteresis dependence of the combustion speed on temperature, which changes sharply as a result of an increase in the internal heat removal to inert additives or a decrease in heat release in a random region of a depleted non-stoichiometric mixture of reagents (defect in the powder mixture).
- 3. With a short-term occurrence of spin instability, the primary combustion wave splits into a decaying "reflected" wave with diffusion instability ($Le > 1$) and a "passing" wave, which continues the path of the primary wave, but in the mode of thermal instability ($Le < 1$) and with a delay corresponding to the time of thermochemical induction.
- 4. The application of the differential chronoscopy method allows, regardless of the masking effect of the random spatial structure of the combustion front, the moment of spin instability to be visualized along the characteristic branches from the isocline lines on the DCS-map, and the subsequent Trace analysis gives an unambiguous correspondence between the distribution of nodal points φi in the median part of Trace -image and a statistical sign of spin stability in the form: $\Pi=\Sigma(\varphi_i \times \rho_j)$, where ρ_j is the statistical weight of the corresponding “left” Ai or “right” Bi local maximum or on the distribution histogram.

Acknowledgment

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