CONTROL OF SUB- AND SUPERSONIC COMBUSTION BY LASER-INDUCED EXCITATION OF SINGLET OXYGEN MOLECULES

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This paper deals with the analysis of the potentialities to control the ignition and detonation in sub- and supersonic flow of combustible $CH_4(H_2)$/air mixtures by laser-induced excitation of electronic and vibrational states of oxygen molecules. The considered approach is based on the enhancement of the chain mechanism of combustion due to formation of highly reactive radicals and atoms in chemical reactions with electronically and vibrationally excited O_2 molecules. One of the objects of our studies is the initiation of combustion front in the sub- and supersonic flows under exposure of the $CH_4(H_2)$/air mixture by laser photons at 762 nm and 687 nm wavelengths that results in the excitation of oxygen molecules to the singlet sigma electronic state with vibrational quantum numbers V"=0 and 1. Another object is the stabilization of a detonation wave in a supersonic flow of $CH_4(H_2)/O_2$ mixture over the surface of the wedge-shaped body upon exposure of the flow to laser radiation at 762 nm wavelength. In such geometry, the primary oblique shock wave formed behind the wedge apex initiates the ignition and full-scale combustion. The interaction of the compression wave generated in the combustion region and primary oblique shock produces the oblique detonation wave.

The analysis has shown that laser-induced excitation of O_2 molecules enables to initiate the ignition in sub- and supersonic flows of $CH_4(H_2)$/air mixtures at extremely low temperature (~400 K for H_2/air and ~700 K for CH_4/air mixtures) for small radiation energy delivered to a single oxygen molecule (0.05-0.3 eV). The simultaneous excitation of electronic and vibrational states of oxygen molecules by laser photons at 687 nm wavelength: $O_2(X^3\Sigma_g^-, V'=0)+h\nu \rightarrow O_2(b^1\Sigma_g^+, V''=1)$ is significantly (in a factor of 10-100) more efficient to enhance the combustion as compared to the excitation of O_2 molecules to the purely singlet sigma electronic state by laser photons at 762 nm: $O_2(X^3\Sigma_g^-, V'=0)+h\nu \rightarrow O_2(b^1\Sigma_g^+, V''=0)$. This is caused by the nonlinear effect of combined electronic and vibrational excitation of reacting molecules on the barrier and the rate of the endoergic chemical reactions. The kinetic mechanisms of the chain reaction accelerating for both cases are considered.

Moreover, the exposure of the H_2/air mixture by laser photons at 687 nm enables one to increase up to 30% the efficiency of the combustion as compared to the conventional thermal induced ignition. The simulation has demonstrated that exposure of the homogeneous supersonic flow of $CH_4(H_2)/O_2$(air) mixture in front of the wedge-shaped body apex even at the narrow near axis region makes it possible to initiate the stable detonation wave at a short (50-100 cm) distance from the wedge apex for low deposited laser radiation energy, 10^{-3} J/cm^3. Changing the laser radiation intensity it is possible to control the combustion under varying initial parameters of the flow. The considerable benefits of this approach as compared to the other methods based on the exposure of the reactive mixtures by laser radiation are demonstrated.