ULTRA-FAST X-RAY IMAGING OF HIGH-PRESSURE HIGH-SPEED DIESEL SPRAYS

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INTRODUCTION

To make the combustion of diesel engines more efficient and cleaner, fully understanding of the breakup and atomization mechanism of high-speed diesel jets is a key. Due to the multiple scattering by a large amount of droplets in the near-nozzle region, experiments with conventional laser optical techniques lead to no detailed understanding of the true structure and breakup of high-speed jets (1, 2). X-ray phase-contrast imaging, with contrast from boundaries and interfaces of materials with different refraction index or abrupt thickness variations (3), has been demonstrated to visualize the transient phenomenon dynamics (4). By using X-ray phase-contrast imaging with brilliant X-ray in APS, we provide a quantitative study of the instability and breakup of a high-speed jet.

EXPERIMENTAL

As shown in Figure 1, we used an X-ray beam generated from the APS electron storage ring with a hybrid-singlet fill pattern, in which a single electron pulse (150 ps long) is separated from a train of electrons (472 ns long) by a 1.59 μs gap on both sides. The X-ray beams pass through a millisecond shutter, a microsecond shutter, and the spray. The transmitted 150 ps X-ray pulse is visualized with a fast scintillator crystal and captured with a fast gated CCD camera in beamline 32-ID.
A diesel injector and a single-orifice hydroground nozzle with 180 μm diameter was used to inject diesel fuel into stagnant 0.1 MPa nitrogen gas. The injection duration is set to 1 μs. The shutters, CCD camera, and injection system were synchronized to the X-ray pulses from the APS storage ring. The exposure time is 1 μs. The field of view of the imaging system was 680×855 μm^2 and resolved in 1024×1280 pixels.

RESULTS

As shown in Figure 2 for injection pressure 40 MPa, surprisingly, the fuel jet remained as a liquid column rather than broken into droplets near the injection nozzle. The images were taken at quasi-steady state during 1 ms spray event. With the ultrahigh temporal and spatial resolution, the entire breakup process can be visualized: First, the instability waves (wavelength A) grow on the surface of the diesel jet to a distance Z from the nozzle exit; the wave further causes breakup into ligaments. In the one hundred-year history of diesel engines, it is the first time that diesel jet breakup was clearly captured. The surface wave structure is a function of injection pressure which determines the velocity of the fuel jet. The average wavelength and breakup distance can be correlated with the injection pressure (Figure 3), as well as the liquid fuel properties, such as viscosity, surface tension and density. These results will undoubtedly facilitate better understanding the breakup of high-speed liquid jets and testing of hydrodynamic simulation of the process.

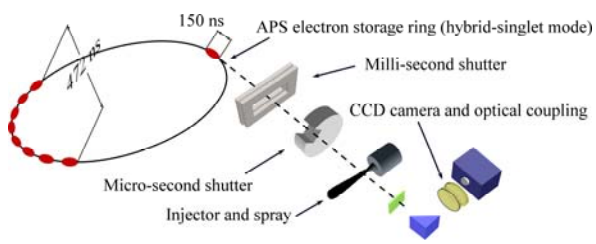

Figure 1 Schematic diagram of the experimental setup.

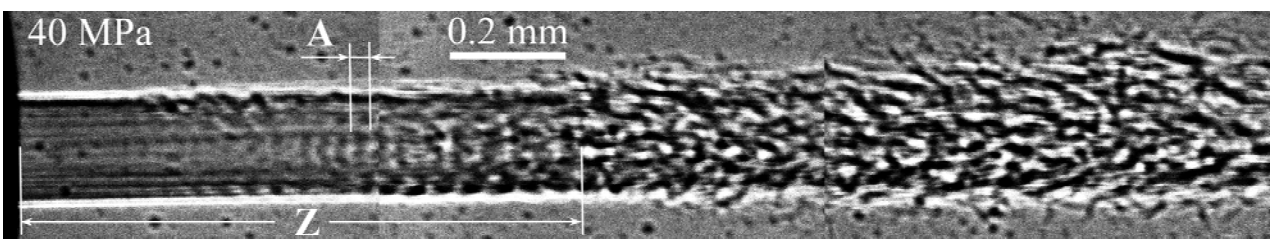

Figure 2 Illustration of wave of high-speed jet.

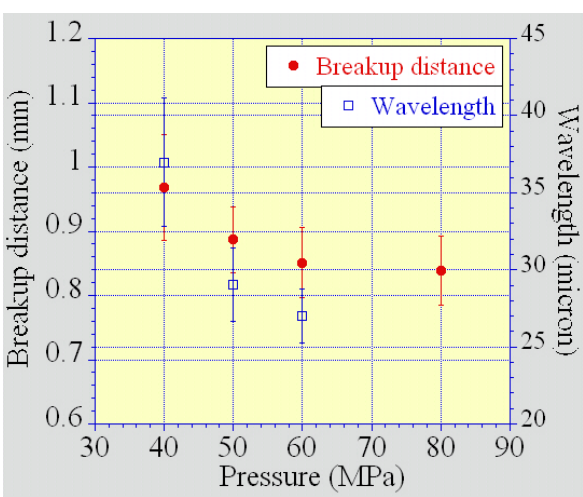

Figure 3 Influence of injection pressure to breakup distance and average wavelength of high-speed jet.

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