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PIV and LDA measurements of the swirling flow in a low-speed two-stroke diesel engine

K. M. Ingvorsen[a], K. E. Meyer[a], J. H. Walther[a,b] and S. Mayer[c]

Low-Speed two-stroke (LSTS) marine diesel engines are used to power oil tankers and container ships. To replace the old combustion gas in the cylinder with a fresh air charge for the next engine cycle, the uniflow-scavenging method is used. At the end of the power stroke, the piston uncovers a series of angled scavenge ports located circumferentially around the bottom of the liner. Fresh air is blown into the cylinder through the ports thereby creating a swirling flow that forces the combustion gas out through the exhaust valve in the cylinder cover. Detailed knowledge of the turbulent swirling in-cylinder flow is needed in order to reduce the emissions levels and optimize the overall engine performance.

Recently, Ingvorsen et al.[1] developed an experimental scale model of an engine cylinder and characterized the turbulent swirling flow under steady-flow conditions using stereoscopic particle image velocimetry (PIV) and laser Doppler anemometry (LDA). The present work extends this work, by considering a dynamic case, where the scavenge ports are opened and closed by the moving piston. The purpose of the work is to obtain an increased understanding of the dynamic behavior of the complex swirling flow, including the coherent structures such as the vortex breakdown. Furthermore, the experimental results serve as a database for validation of computational fluid dynamics (CFD) models.

The model has a transparent cylinder with a diameter of D = 190 mm and a movable piston driven by a programmable linear motor. The swirl is generated using 30 equally spaced ports, and cases with port angles of 0°, 10°, 20°, and 30° are investigated. The swirling flow is characterized using phase-locked PIV and LDA for a Reynolds number of Re = 50,000. The results include radial profiles of phase-averaged mean and rms-velocity, proper orthogonal decomposition analysis (POD), probability density functions of the instantaneous velocity, and visualizations of the mixing process between the combustion gas and the scavenge air.

Among other things, it is shown that for the 20° case, a central recirculation zone is formed shortly after the piston has passed the bottom position (see Figure 1), indicating that a vortex breakdown has occurred. The POD analysis indicates that a double helical structure exist near the breakdown region. Time resolved LDA measurements of the axial velocity component indicates that large unsteady flow structures exist in the cylinder after the piston has closed the ports. The rate of swirl decay is investigated by computing the angular momentum from the radial velocity profiles. It is found that the decay rate can be accurately predicted using simple friction formulas based on the flow over a flat plate.

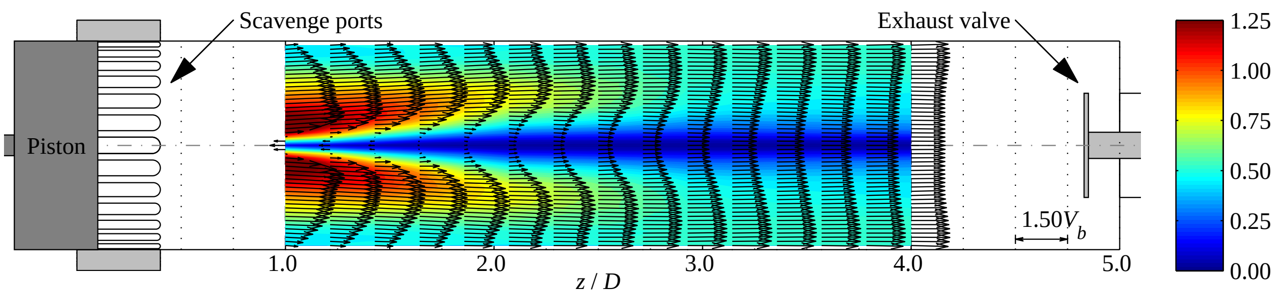

Figure 1: Visualization of the measured phase-averaged velocity field shortly after the piston has passed bottom dead center. The radial and axial velocity is shown by vectors and the tangential/swirl velocity (V_θ / V_b) is shown by the color contours. Note the reverse flow near the centerline at z / D = 1.0 indicating that a vortex breakdown is formed.

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[1] Ingvorsen et al, Exp. Fluids. **54**, 1494 (2013)