Gas Dynamics of Exhaust Valves

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Due to tougher legislations on exhaust emissions from combustion-engine vehicles, the development of more efficient engines with lower emissions is necessary. Exhaust gases are hot and at high pressure and are thus rich in energy and to maximize the energy recovery, the engine system needs optimisation. In current one-dimensional engine simulations complex flows (such as the flow past the exhaust valves) are represented by a straight pipe-flow with a corresponding discharge coefficient, usually obtained experimentally under assumption of quasi-steadiness and independence of pressure ratio. Here these assumptions are investigated in a dynamic flow setup at different pressure ratios, with both static and dynamic valves (corresponding to engine speeds in the range 800-1350 rpm). Furthermore, experiments investigating the shock system in the exhaust port have been performed.

Experimental setups:
The upper photo shows the setup for the dynamic valve experiments designed for evaluation of the discharge coefficient ($C_D$). The valve is operated using a linear motor, which allows for a controllable valve lift profile. The exhaust port is connected to a straight outlet pipe exhausting to atmosphere. By measuring the initial temperature and the pressure in the cylinder as function of time, the dynamic mass flow can be obtained using the isentropic relationship and the gas law, giving $C_D$ as function of time, i.e. as a function of valve lift.

$$C_D = \frac{n_{actual}}{n_{ideal}}$$

The lower photo shows the setup used for visualising shock waves in the exhaust port. It is a 30 degree slice of the above described geometry. It has two windows which allow for optical access to the valve seat region as well as the exhaust port. The gas dynamics in the port have been captured using high speed Schlieren imaging (6000 fps), under both steady and dynamic conditions.

Results:
In the left figure $C_D$ for different equivalent engine speeds is plotted as a function of valve lift over port diameter ($l/d$). The value of $C_D$ shows a large dependency on engine speed, where a faster opening speed leads to a higher value of $C_D$. Note that $C_D$ obtained with a static valve can be seen to generally overestimate the value of $C_D$. The right figure shows Schlieren images of the exhaust port with a Dynamic valve (top), static valve at a “low” pressure ratio (middle) and static valve at a similar pressure ratio as in the dynamic valve case (bottom). The flow is from the right to the left in the photos.

Summary and Conclusion:
A large dependence on both valve opening speed and pressure ratio is found. Measurements using a static valve overestimates the value of $C_D$ and shows a different shock pattern in the exhaust port, compared to a dynamic valve. This indicates that any study of the exhaust valve flow (quantitative or qualitative) should be performed under dynamic conditions at relevant pressure ratios.

Reference

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