Development of a cold engine setup for experimentation with exhaust silencers.

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Introduction

Experiments with new concepts of exhaust systems are difficult to perform without a representative sound source. Nowadays, the preliminairy experiments are carried out on loudspeaker and fan setups. However, the acoustical circumstances of these setups differs considerably with the circumstances of an operational engine. At the other hand, engine experiments require prototype silencers which must be constructed using heat and corrosion resistant material and special instrumentation is needed. Therefore, the cold engine setup has been developed, which generates realistic engine noise and the associated gas flow using compressed air. With this device, experiments with new concepts of exhaust systems can be carried out without taking precautions against the hot corrosive gases of an operational engine exhaust. The prototype silencers can be constructed economically and measurements can be carried out using standard sensors. The acoustical impedance and the source spectrum of the cold engine test rig are similar to a regular combustion engine. As a result, the experiments carried out on the cold engine test rig can be reliably extrapolated to operational engine conditions.

Principle

Figure 1 presents the indicator diagram of an internal combustion engine. The cycle starts at IVO, where the engine takes fresh gas. Then, the gas is compressed and ignited. After combustion, the gas expands while performing mechanical work. When the exhaust valve opens at EVO, the remaining pressure blows down in the exhaust. The rest of the gas is scavenged by the piston and

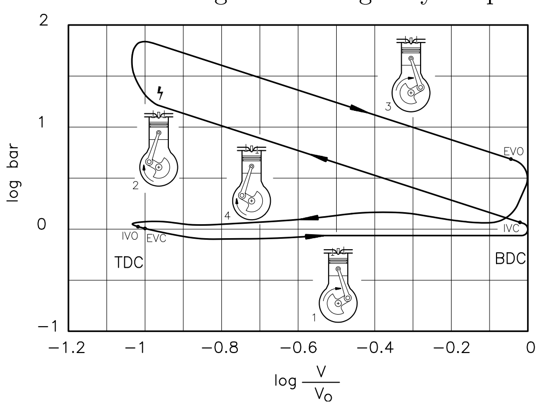

Figure 1: Indicator diagram of an internal combustion engine.

the cycle repeats. The blowdown phase is responsable for the exhaust noise. The piston displacement during the blowdown phase is rather small, such that the exhaust noise can be considered as a discharge of a constant volume. The test rig, presented schematically in figure 2, is based on discharging constant volumes. It consists of a

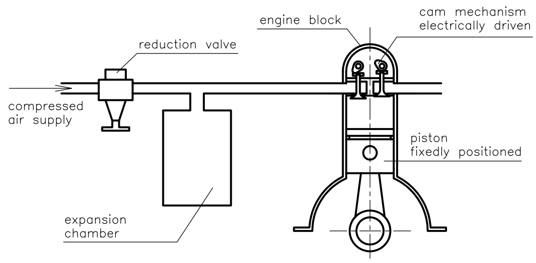

Figure 2: Scheme of the cold engine setup.

regular engine block which pistons are fixed at the bottom dead points. The intake manifold is connected via an expansion vessel and a pressure reduction valve to a normal pressurized air supply network. The pressure supplied at the intake manifold corresponds to the pressure at the point EVO in the indicator diagram in figure 1. The cam mechanism of the engine block is driven by an electric motor, which rotational speed is controlled by a frequency converter. During the inlet stroke, the cylinder is charged to the intake manifold pressure level. When the outlet valve opens, the cylinder discharges and the pressure pulse propagates through the exhaust. The discharge takes a few milliseconds. These pressure pulses exhibit similar behaviour as these of an operational combustion engine. Figure 3 presents the cold engine setup which is build using a Volkswagen 1600 cm^3 engine.

Figure 3: The cold engine setup.

Characteristics

The source characteristics are its acoustic impedance and its source strength. The acoustic impedance at the ex-

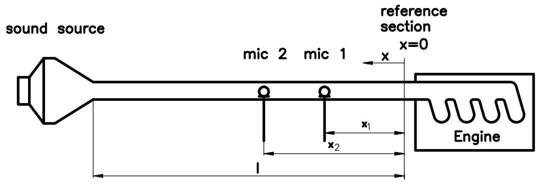

Figure 4: Measurement of the exhaust acoustical impedance.

haust has been measured using the ISO-10534-2 two mi-

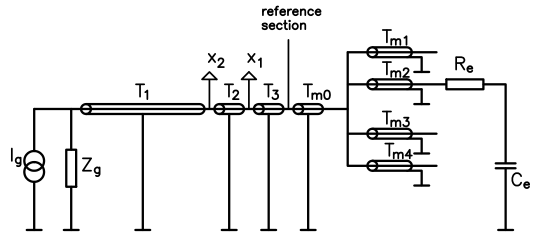

Figure 5: Electrical circuit for an engine in frequency domain.

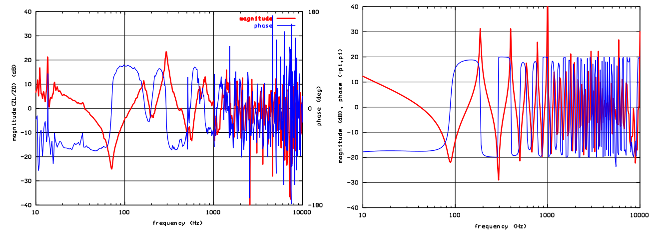

Figure 6: Measured (*left*) and simulated (*right*) exhaust impedance (0 dB= characteristic duct impedance).

crophone transfer function method, as presented in figure 4. The exhaust noise is avoided by closing the air supply of the setup. The camshaft is run by the electric motor, such that the movement of the valve train is included in the measurement. The acoustic impedance is also simulated using the equivalent electric circuit presented in figure 5. The capacitor C_e represents the cylinder volume, the resistor R_e the exhaust valve resistance and the transmission lines T_{m1}, T_{m2}, T_{m3}, T_{m4} and T_{m0} the exhaust manifold, whereupon the duct T_1, T_3 and T_3 is connected. Figure 6 presents the measured (left) and simulated exhaust acoustic impedance in magnitude (thick red) and phase (thin blue). These are similar. The low frequency part depends on the volume of the cylinder and the manifold, until the Helmholtz resonance between the cylinder volume and the acoustic mass in the manifold occurs around 80 Hz. This resonance is damped by the exhaust valve resistance. The following resonances are all internal manifold resonances. The acoustic impedance is rotational speed independent.

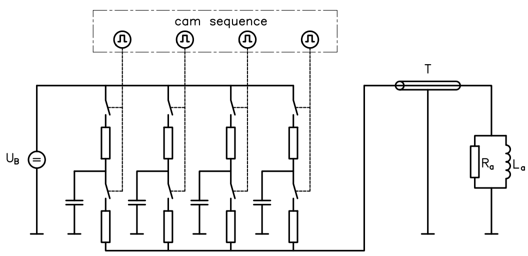

Figure 7: Circuit for cold engine setup in time domain.

The electrical analog circuit to simulate the cold engine in time domain is presented in figure 7. The four capacitors represent the cylinders, the upper four switch-resistor combinations the intake valves and the lower four switch-resistor combinations the exhaust valves, actuated in the same sequence as the camshaft actuates the valves. The connected transmission line T represent the exhaust duct closed by the open air radiator R_a and L_a. The capacitors are charged by the source U_B. The pressure during time in one cylinder and the exhaust manifold are displayed in figure 8. The cylinder charges during the intake cycle until 200 kPa at 0.2 s and discharges into the exhaust at 0.5 s. The pressure pulses (thin blue) are travelling in the exhaust duct and accesses the cylinder during the opening time of the exhaust valve. At figure 8 right, the proces is simulated using the electrical circuit presented in figure 7. From the time data of the manifold pressure, the power spectra are determined and presented in figure 9. Both measured and simulated power spectra exhibit a typical −20dB/decade line, which corresponds to pulse discharges over a volume. The simulations using the electrical circuit agrees well with the measured results.

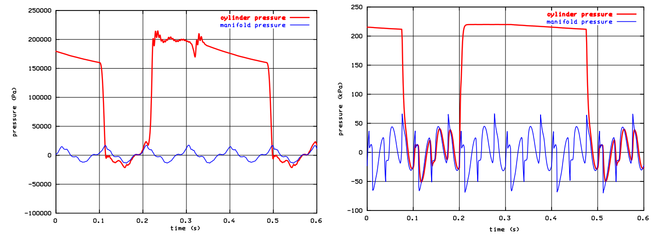

Figure 8: Measured (*left*) ans simulated (*right*) pressure in cylinder and exhaust manifold.

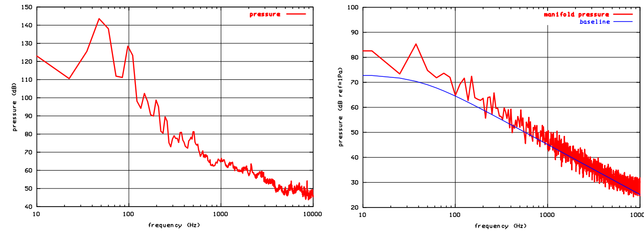

Figure 9: Measured (*left*) and simulated (*right*) exhaust power spectrum.

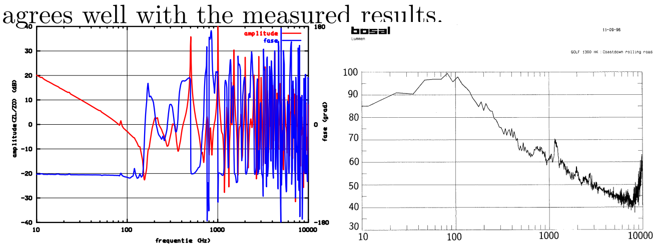

Figure 10: Exhaust impedance (*left*) and exhaust power spectrum (*right*) of an operational engine.

Figure 10 presents the acoustical impedance and the source spectrum measured on an operational engine [1]. The engine exhibits the same characteristics as the cold engine setup.

Conclusion

A cold engine test rig has been developed, which generates realistic exhaust noise using compressed air. It allows economical development of new concepts of exhaust systems and new types of experiments, such as flow measurements using transparant mufflers, can be carried out. The acoustical impedance and the source spectrum of the cold engine simulator are found to be similar to a regular internal combustion engine. As a result, the experiments carried out on the cold engine simulator can be reliably extrapolated to operational engine conditions.

References

[1] Boonen R., Sas P., "Determination of the acoustical impedance of an internal combustion engine exhaust", proc. of the ISMA2002 Conference, (2002), Leuven, Belgium, pp. 1939-1946, (available at *www.isma-isaac.be/publications*)