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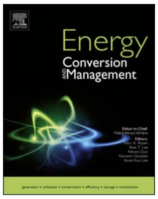

Evaluation of compression ratio and blow-by rates for spark ignition engines based on in-cylinder pressure trace analysis

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ABSTRACT

The effective compression ratio of spark ignition engines is influenced by several factors, and can feature a relatively wide range even for production power units. This is given mainly by the tolerances used for different components, but also due to the actual operating parameters that can result in different thermal regimes and therefore in dimensional variations. Given their design, optical engines are characterized by high crevice volumes and increased blow-by losses. Within this context, this work was aimed at developing a procedure for estimating the effective compression ratio and charge losses, based on the analysis of in-cylinder pressure traces. Compared to existing methods that require heat release rate modeling for ensuring good accuracy, the proposed route follows a different approach, that uses sub-models only for simulating heat transfer and blow-by losses. In this way, acceptable error levels were ensured, with minimum computational demand. The new procedure was applied on two different engine configurations, as well as operation with different fuels. Estimation of combustion efficiency was found to be an important issue for correct blow-by losses determination, while compression ratio evaluation depended mostly on the thermal regime of the piston.

1. Introduction

Internal combustion engines are well established as efficient and flexible prime-movers, with good adaptability to alternative energy sources [1]. Continuous development of this technology is undergoing, with a focus on the effects of fuel properties on combustion [2], as well as unconventional modes of operation [3,4].

Numerical simulations are being implemented on an ever wider scale in engine development, given their significant potential for reducing development times [5]. Applications range from fast calculations for real-time control [6,7], to prediction of abnormal combustion events [8–10], effects of biofuels on combustion [11,12], that can cover energy as well as exergy [13] analyses, and detailed 3D evaluations for identification of specific phenomena [14,15,16]. One productive way of improving predictive capabilities of simulation codes is to use detailed data for calibration [17], data that can be recorded in optical engines [18]. Compression ratio is one of the basic geometry parameters of engines and its correct evaluation is paramount for accurate numerical results [19], [20]. Dynamic effects such as deformation during compression and combustion can also be included in sub-models [21,22], but are less significant compared to the influence of thermal expansion. Blow-by losses are usually disregarded in production power units, given their relatively reduced influence [23], but in optical engines, they can exert an important effect [24].

Several methods have been developed for evaluating the effective compression ratio, ranging from simple procedures with reduced computational demand, to more complex ones that ensure good accuracy, but are more computationally intensive [25].

Within this context, a new technique was developed for estimating compression ratio and blow-by losses, based on in-cylinder pressure measurements. Starting from previous work that used pressure data measured during motored operation [26], a more comprehensive method was developed and implemented for determining both parameters during fired operation of spark ignition (SI) engines. Compared to existing approaches that require the simulation of heat release [25], the present procedure ensures good accuracy, without the need of modeling combustion. Its application was tested on three different engines, one derived from commercial small size applications and two with optical accessibility.

2. Material and method

2.1. Experimental setup

The in-cylinder pressure data considered was available for three different single cylinder SI engines, all coupled to a reversible electric

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Nomenclature

Definitions

A	area [m^2]
C	calibration coefficient [-]
h	specific enthalpy [J/kg]
m	mass [kg]
M	molecular mass [kg/kmol]
Nu	Nusselt number
p	pressure [Pa]
Pr	Prandtl number [-]
R	universal gas constant [J/kmol K]
Q	heat [J]
Re	Reynolds number [-]
T	temperature [K]
U	internal energy [J]
V	volume [m^3]
x	mass ratio [-]
η	efficiency [-]
γ	ratio of specific heat capacities [-]
ρ	density [kg/m^3]

Abbreviations

AFR	air-fuel ratio
CR	compression ratio
EVO	exhaust valves opening
IVC	intake valves closure
IMEP	indicated mean effective pressure
LHV	lower heating value
MFB	mass fraction burned
MBT	maximum brake torque
SA	spark advance
SI	spark ignition
TDC	top dead center
THC	total hydrocarbons
WOT	wide open throttle

Subscripts

0	ambient conditions
b	burned
bb	blow-by
comb	combustion
ht	heat transfer
r	residual
st	stoichiometric
w	wall

machine capable of ensuring motoring and braking. Two of the three power units featured practically the same geometry, with the difference that one was of commercial derivation for small size applications, while the second one featured optical accessibility through the piston crown.

Fig. 1 shows the setup common for the first two engines and illustrates the optical accessibility through the elongated piston; both units featured two different port fuel injection systems, one for liquid and one for gaseous energy sources.

Table 1 lists their main characteristics (with a for after and b for before the top dead center (TDC); all references are made to the TDC at the end of the exhaust stroke); more details can be found in [27,28,29]. For the commercial engine, crank shaft rotational speed could be varied from 2000 to 5000 rpm at wide open throttle (WOT) and stoichiometric fueling; fuel type effects were investigated for gasoline, propane and methane, with various spark timing settings close to the point of maximum brake torque (MBT). Gasoline, ethanol, methane and its blends with hydrogen were studied in the optical engine, in stoichiometric conditions, at fixed engine speed and spark timing.

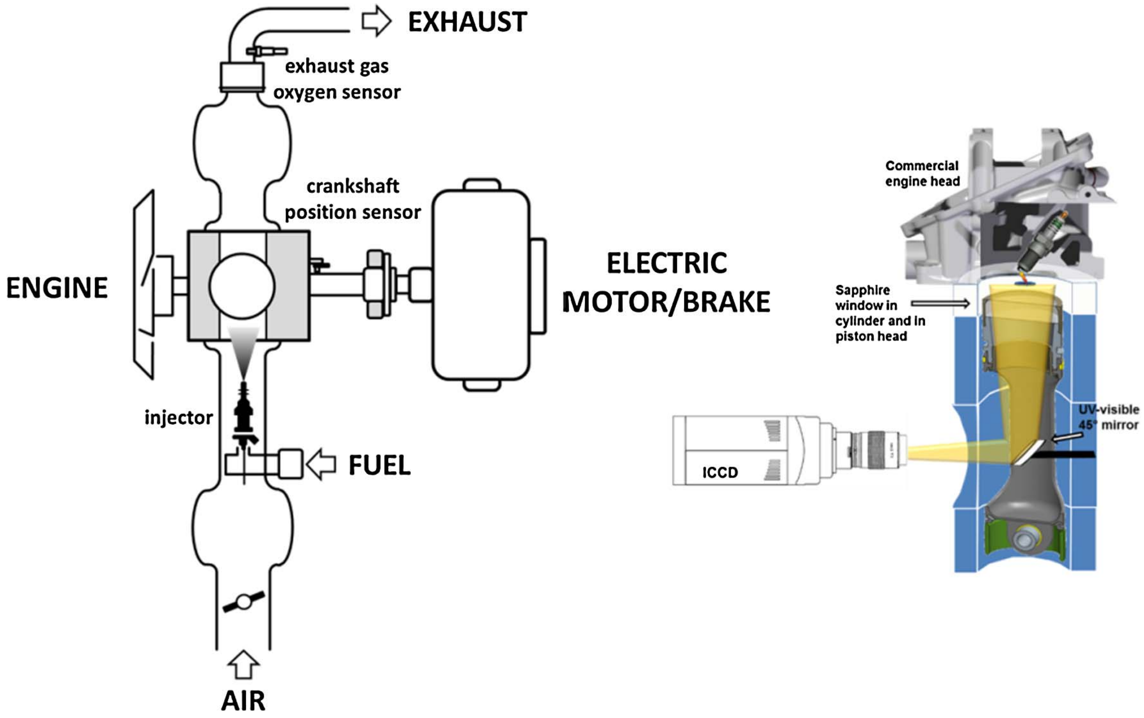

Fig. 1. Experimental setup for the small size engines (left) and illustration of the optical accessibility (right).