Applied Energy 87 (2010) 2187–2193

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Experimental analysis of a spark-ignition engine using exhaust gas recycle at WOT operation

G. Fontana, E. Galloni *

Department of Industrial Engineering, University of Cassino, Via G. De Biasio 43, Cassino, Italy

ARTICLE INFO

Article history:
Received 25 June 2009
Received in revised form 17 November 2009
Accepted 17 November 2009
Available online 21 December 2009

Keywords:
Spark-ignition engine
Efficiency improvement
Exhaust gas recycle
Experimental analysis

ABSTRACT

Spark-ignition engines are still a competitive solution in a great number of applications. European manufacturers are all involved in the effort of improving fuel economy, at least at some engine operating points while meeting, of course, the pollutant emission standards.

The EGR technique, since a long time adopted in reducing the NO_x formation rate, could be an effective system for fuel economy improvement. Mainly, a de-throttle effect and decreased heat losses to the walls can be obtained in this way. Furthermore, lower exhaust gas temperatures can be reached thus avoiding damages to the noble metals of catalytic converters.

In this paper, the EGR technique has been widely investigated by carrying out an experimental analysis of a small, naturally aspirated, spark-ignition engine. In particular, at full or high load operation, attention has been paid to the combustion development and the influence of EGR rate on the values of spark advance, at knock onset limit, tolerated by the engine has been assessed. Due to lower temperature levels within the combustion chamber, the obtained results show a decreased octane requirement, thus an optimal choice of spark advance is possible. Hence a significant increase of engine efficiency has been obtained.

1. Introduction

Due to the recent agreements between European automotive producers, aimed to the decrease of CO_2 emissions, European OEM's are more and more adopting innovative techniques for the reduction of engine fuel consumption, particularly dealing with spark-ignition engines. Naturally, all the adopted measures have to meet the UE pollutant standards while engine performance and car drivability must be assured as well.

As it is well known, the crucial point of the spark-ignition engine behavior is the dramatic fall of the energy conversion efficiency at part load operation. So, many efforts have been carried out in order to decrease pumping losses and optimize the engine thermodynamic efficiency. However, knock risks impose strong limitations to the levels of both performance and efficiency of spark-ignition engines. Furthermore, at full load operation, different problems could arise since often significant mixture enrichments could be required.

In engine evolution, the Exhaust Gas Recycle (EGR) technique was firstly adopted in diesel engines in order to limit the thermal NO_x formation rate by limiting the combustion chamber temperature thanks to the dilution of the fresh charge with a certain amount of exhaust gases recycled at the engine intake. Today, EGR is commonly used also in spark-ignition engines since this technique is able to both limit the NO_x formation rate and improve engine thermodynamics at some operating points. EGR, in fact, decreases pumping losses at partial load, while improves the detonation resistance at full load operation [1–4].

Many times, EGR [5,6] is obtained by means of a re-aspiration of the exhaust gases through the exhaust valve thanks to a variable valve timing (internal EGR), rather than realizing an appropriate circuit from the exhaust to the intake port (external EGR).

Naturally, the EGR adoption modifies engine combustion characteristics: the charge dilution slows down the flame front propagation rate but increases the end gas autoignition time [7]. In modern spark-ignition engines, featuring as high as possible compression ratios, these two circumstances should be investigated since a proper spark advance optimization could lead to higher efficiency levels even at full load and low speed operation when knock risks are very high.

On the other hand, attention must be paid to such unfavorable EGR features as the decrease in volumetric efficiency, hence in torque delivered. Furthermore, an excessive amount of recycled exhaust could lead to very low combustion rates, thus instable combustion could occur, a large cycle by cycle variation, a deterioration in car drivability and an increasing pollutant formation could appear [8,9].

* Corresponding author. Tel.: +39 776 2994005; fax: +39 776 2994365.
E-mail address: galloni@unicas.it (E. Galloni).

0306-2619/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2009.11.022

Table 1
FIAT FIRE engine main characteristics.

Model	FIAT 1200 16V	Power (kW)	63@6000 rpm
Cylinder number	4	Torque (Nm)	113@4500 rpm
Number of valve per cylinder	4	Camshaft	2
Total piston displacement (cm^3)	1242	Bore × stroke (mm)	70.8 × 78.9
Compression ratio	10.2 ± 0.2	Valve timing (°)	0/32–32/0

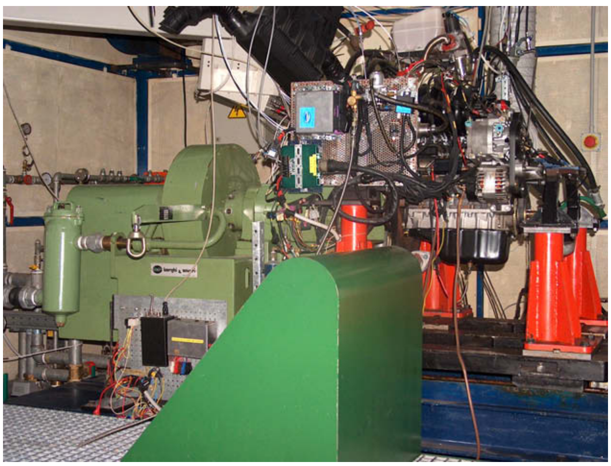

Fig. 1. Engine test bed.

In this paper, the effects of external EGR in a small spark-ignition engine, operating at full or high load and low rotational speeds, have been evaluated. Engine specific fuel consumption at a given load has been measured. In particular, unthrottled operation (with or without EGR) and partial load operation, at a given torque level, have been compared.

The obtained results illustrate that EGR could be a useful technique in improving fuel savings of spark-ignition engines at different operating points. At low loads, pumping losses could be reduced by the exhaust gas recycle while, at high loads, some engine thermodynamics could improve as well.

2. Experimental approach

The experimental tests were carried out at the test bed of the Energy Systems Laboratory of Cassino University. The engine is a FIAT FIRE 1200 16V (Table 1). This engine features four valves per cylinder, "roof" type head ceiling, whereas the pistons are carved with an axial-symmetric bowl. Both the intake design and the combustion chamber shape force, during intake and compression strokes, a strong tumble motion, which contributes to the high engine turbulence level.

The engine is coupled to an eddy current dynamometer (Fig. 1). An AVL Puma 5.3 system has been used for test control and data acquisition. The fuel consumption has been measured by a fuel balance (inaccuracy less than 0.5%), while a Horiba UEGO sensor has been used to measure the air excess ratio (inaccuracy less than 4%). A high pressure miniaturized quartz transducer (AVL GM12D) has been located in the head of the first cylinder, while a crankshaft encoder (AVL 364) provides the crank angle reference

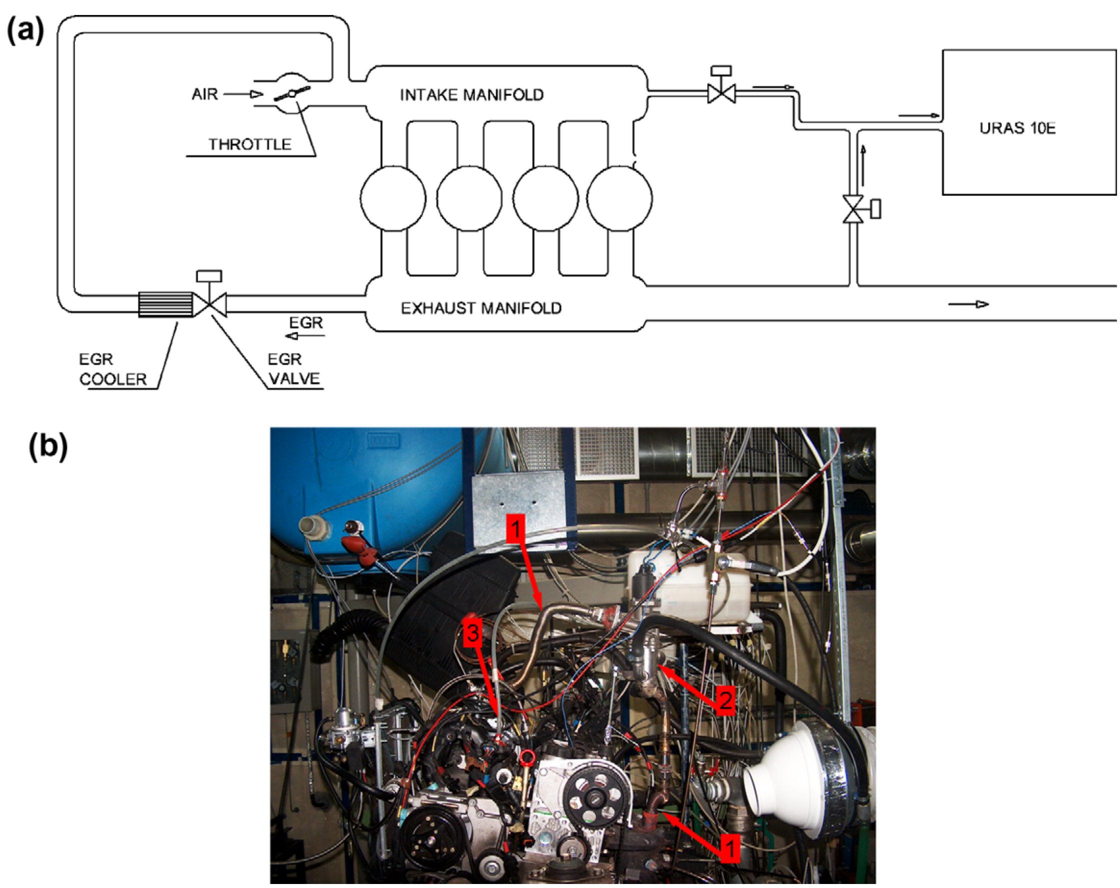

Fig. 2. (a) Exhaust gas recirculation sketch. (b) EGR test rig. 1: EGR pipe; 2: EGR control valve and heat exchanger; 3: Emission test probe for CO_2 content determination.