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# Effects of exhaust gas recycle in a downsized gasoline engine

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## HIGHLIGHTS

- ▶ EGR reduces both knock intensity and exhaust gas temperature with respect to pure air–gasoline fueling.
- ▶ Both air–fuel ratio and spark advance can be improved by adopting new boost pressure levels.
- ▶ Optimizing the main control parameters the power output can be recovered.
- ▶ Experimental analyses show that the new control strategy allows increasing fuel economy at the same power output.

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## ABSTRACT

Lately, the exhaust gas recycle usage, widely diffused in Diesel engines, has been adopted in SI engines as well. It is a cheap technique which allows a sound control of NO formation meanwhile it can improve engine thermodynamics.

In this paper, the influence of EGR on the operation of a turbocharged spark ignition engine has been evaluated by using both experimental and numerical techniques. In particular, since knock occurrence is a crucial point in the optimization of a turbocharged SI engine, the improvement in knock resistance, at high load operation, has been assessed. First, a method for knock detection and quantification has been illustrated. Then, the influence of EGR on engine performance, octane requirement and exhaust gas temperature was measured at two different rotational speed values and WOT operation.

Since EGR has produced a drop in engine performance (between 10% and 13%) and an increase in knock resistance, a new set of main control variables has been determined in order to restore the original torque level while achieving a significant decrease in specific fuel consumption (between 6% and 11%).

At the end, numerical analyses of engine combustion, aimed to explain the results of experimental investigations, have been carried out and a summary is reported in the paper.


## 1. Introduction

Downsizing of spark ignition engines is a design trend which is going to be more and more diffused into the world car market. At a given torque value, small swept volume engines permit, in general, to limit some typical engine losses (for instance: pumping and friction losses). Turbocharging or supercharging restores the power levels while fuel economy at part load is improved. Thus, downsized turbocharged engines could represent an effective way in reducing $CO_2$ emissions [1].

In the past, when the turbocharging of spark-ignition engines was aimed just to increase the engine specific power, this kind of engines achieved poor efficiency levels due to the strong pressure ratio reductions performed in order to prevent knock risks. Furthermore, at high load operation, the spark time was delayed and the air fuel mixture was enriched. Nowadays, since the primary goal of downsizing is improving the engine efficiency at partial operation, every measure, worsening the engine thermodynamics, would represent just a contradiction [2].

EGR was originally used in Diesel engines as a means for the reduction of thermal $NO_x$ due to the reduction of burnt gases temperature produced by the fresh charge dilution with a percentage of exhaust gas reintroduced at engine intake [3,8].

Nowadays, EGR is adopted also in spark ignition engines. The main reason of this choice is that EGR could control the $NO_x$ formation rate while improves the engine efficiency at partial load [4]. Often, EGR is realized by re-aspirating the burnt gases within the combustion chamber exploiting variable valve timing systems (internal EGR) [5], as an alternative, an apposite circuit, from the exhaust port to the intake, can be build up (external EGR).

Also at high loads, EGR could produce several kinds of benefits. Lowering the burnt gas temperature by means of charge dilution could contemporarily reduce knock risks and exhaust temperature

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either at the catalyst inlet or at the turbine inlet [6,7]. The results reported hereafter indicate that a drop of about 35 °C in exhaust temperature is obtainable with a 0.1 value of the EGR rate.

Naturally, EGR produces also a deterioration in engine performance since the volumetric efficiency decreases, therefore the value of torque delivered is reduced. In addition, large amounts of recycled gases could significantly slow down the flame development, thus instable combustion could occur producing large cyclic variations, a deterioration in car drivability and an increase in pollutant levels [8,9]. The results reported in the present paper have shown an increase of 40% in the duration of flame development and the doubling of the coefficient of variation in IMEP.

In previous works, authors investigated the potential of exhaust gas recirculation in spark ignition engines. In [10], external cooled EGR was adopted in a naturally aspirated SI engine fueled with stoichiometric mixtures. At WOT operation the engine performance, with the use of EGR or in absence of recycle, were compared. The effects of charge dilution were the decrease of the flame speed, the augmentation of the end gas auto-ignition time and the reduction of the exhaust gas temperature. At high load and low speed operation, these two circumstances lead to higher efficiency levels by a proper spark advance optimization.

In [11], numerical tools were utilized to investigate the effect of the exhaust gas recycle on performance and knock resistance of a turbocharged spark-ignition engine at high or WOT operation. Results show that EGR could improve the knock resistance. Since exhaust gases reach lower temperature levels, a mixture enrichment is no more necessary in order to cool them. In this way, damages to the exhaust turbine or the noble metals of catalytic converters can be avoided. The boost pressure can be increased in order to compensate the decrease in volumetric efficiency. In conclusion, EGR could be an advantageous technique for the improvement of specific fuel consumption in downsized engines at full load operation.

In this paper, the effects of external EGR in a turbocharged spark ignition engine at high load operation have been measured. A short route EGR system has been considered. The main engine control parameters have been calibrated in order to deliver a given torque output with the minimum specific fuel consumption. Once more, the obtained results show that EGR could be a sound method for the improvement of spark ignition engine fuel saving.

## 2. Experimental setup

The engine under study has been widely described in [11]. Briefly, it features four cylinders (total piston displacement 1368 $cm^3$) and four valves per cylinder. The geometrical compression ratio is equal to 9.8. A waste-gate IHI turbocharger group (model RHF3) is coupled to the engine close to the exhaust manifold. Fuel is introduced prior to inlet valves by means of Bosch EV14ST injectors.

The engine performs a very high specific power (110 kW at 5500 rpm). As usual in turbocharged SI engine, at high loads, the spark time is delayed due to the knock risk. Furthermore, particularly rich mixtures are adopted in order to limit the exhaust gas temperature at turbine inlet. As a consequence, the engine shows poor efficiency levels at full load operation.

In order to estimate the EGR potential, analyses have been carried out by testing a short route EGR circuit where the exhaust gas is taken upstream of the exhaust turbine and is recycled to the intake, downstream of the compressor before the intercooler inlet, thus EGR is partially cooled (Figs. 1 and 2).

Experimental tests have been performed at the steady-state test bench of the Energy Systems Laboratory at the University of Cassino and Southern Latium.

The experimental equipment has been widely described in [10]. Briefly, the engine was coupled to a Borghi and Saveri Fe260 dynamometer, while an AVL Puma 5.3 controlled the tests providing also to the data acquisition.

In order to measure the in cylinder pressure development avoiding fluctuations and dumping effects, an AVL GM14D quartz transducer (sensitivity 19 pC/bar) was fitted flush with the combustion chamber of the first cylinder. Crank angle based measure-

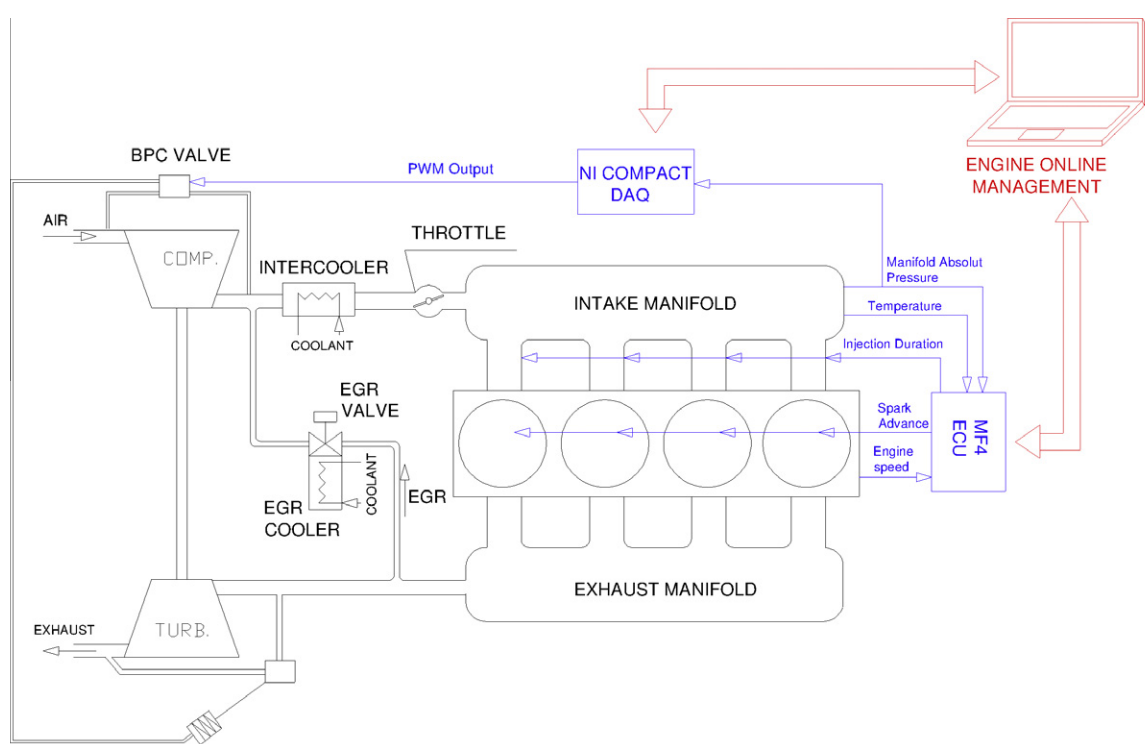


**Fig. 1.** Engine layout with exhaust gas recycle (EGR configuration).