IMPROVING MISFIRE DETECTION IN AN 8-CYLINDER FERRARI ENGINE

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Presentation overview

• Introduction
• Experimental set-up
• The engine model
• Engine model validation
• Use of the simulation for the detection of possible misfire causes
• Use of the simulation for the improvement of the misfire detection
• Conclusions
• Future work
**Introduction**

The need to comply with the requirements of On-Board Diagnostic (OBDII) has greatly encouraged the research of reliable methods for misfire detection: because the diagnostic system should be implemented at minimum additional cost, several attempts have been made to obtain an estimation of the individual cylinder torque by means of inexpensive engine angular speed measurements and different techniques to identify engine misfires have been successfully accomplished.

However, some problems still remain to be solved especially for engines with an high cylinder number (typically 8 or 12 cylinders) under some operating conditions such as for instance at low load or/and at high revolution speed. Also wide cycle-to-cycle and cylinder-to-cylinder variations in the combustion process can substantially increase the engine speed fluctuations even under normal operating conditions, thus raising the background noise and hindering the misfire detection.

Because designing and tuning the engine diagnostic system to overcome these difficulties still remains a time consuming activity, several efforts have been made to explore ways that could lead to significant reductions of the development process: in particular, the use of numerical simulation to build engine models by which control and diagnostic strategies can be tested and tuned “on a desk” seems to be very promising.
However, in the usual simulation approach the pressure and inertial forces acting on the pistons and transmitted through the connecting rod to the crankshaft are often assigned as an input for the calculation of the engine angular speed.

Therefore the simulation of different engine operating conditions requires a huge amount of experimental data (i.e. pressure traces recorded at several values of engine speed and load), and the effects of large cylinder-to-cylinder and cycle-to-cycle variations can hardly be taken into account.

The aim of this work is therefore to evaluate the potential of a fully coupled engine/vehicle numerical simulation in the analysis of the dynamic transient response of an engine during a misfire event, so as to reduce the experimental tests required to design and tune diagnostic techniques for misfire detection.
## Introduction

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1: Cylinder-to-Cylinder Variations

2: Cycle-to-Cycle Variations (random combustion)

### Engine speed (without misfire)

![Graph 1](image1)

![Graph 2](image2)

### Engine speed (with misfire)

![Graph 3](image3)

![Graph 4](image4)
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**Experimental set-up**

**VEHICLE: MASERATI SPIDER**

### VEHICLE

### MAIN ENGINE FEATURES

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td>Type</td>
<td>s.i. 8 cylinders V 90°</td>
</tr>
<tr>
<td>Bore/Stroke</td>
<td>92 / 79.8 mm</td>
</tr>
<tr>
<td>Displacement</td>
<td>4244 cm³</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>11 : 1</td>
</tr>
<tr>
<td>Firing order</td>
<td>1-5-4-8-6-3-7-2</td>
</tr>
<tr>
<td>Combustion Chamber</td>
<td>Pent-roof</td>
</tr>
<tr>
<td>Maximum Power</td>
<td>287 kW @ 7000 rpm</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>451 Nm @ 4500 rpm</td>
</tr>
<tr>
<td>Fuel Metering System</td>
<td>Multi-point electronic injection</td>
</tr>
<tr>
<td>Distribution</td>
<td>DOHC, VVT, 4 valves/cylinder</td>
</tr>
</tbody>
</table>

**Image of Maserati Spider car**
Experimental set-up

Because the load inertia as well as the driveline torsional characteristics have a strong impact on the misfire detection, misfiring tests were carried out on a Maserati Spider vehicle, mounted on a chassis dynamometer.
Experimental set-up

Engine speed measurements

TOTAL SAMPLING TIME = 20s
SAMPLING FREQUENCY = 100kHz
TOTAL NUMBER OF SAMPLES = 2*10^6
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The engine model

THE ENGINE MODEL

Intake plenum

Primary intake runners

Exhaust manifolds

Close coupled catalysts

Air inlet + Air filter

Calibr. orifice

Calibr. orifice
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**Engine model validation**

**FULL LOAD CONDITION: GLOBAL QUANTITIES**

- **Airflow [kg/h]**
  - Experimental Data
  - GT-Power Data

- **BMEP [bar]**
  - Experimental Data
  - GT-Power Data

- **IMEP [bar]**
  - Experimental Data
  - GT-Power Data
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Use of the simulation for detection of possible misfire causes

CYLINDER-TO-CYLINDER ANALYSIS

After the assessment of the accuracy and reliability of the engine model, the numerical simulation could be used as an investigation tool in order to point out the conditions that can increase cylinder-to-cylinder and cycle-to-cycle variability, not only raising torque fluctuations and thus hindering the misfire detection, but also enhancing misfire event likelihood (due for example to A/F ratio imbalances between different cylinders).

Due to geometric differences in the intake and exhaust systems, individual cylinders are in fact characterized by different values of volumetric efficiency and residual gas fraction: moreover, despite the closed-loop control of the A/F ratio, because the $\lambda$ sensor is exposed to an exhaust gas mixture that originates from multiple cylinders, only the average value of A/F ratio is sensed, and individual cylinders may operate richer or leaner than the mean A/F ratio value, due to their different breathing characteristics and to the variability of the injectors.
For these reasons, not only different contributions to the engine torque are given by each individual cylinder (thus enhancing cylinder-to-cylinder fluctuations and making misfire diagnostic more difficult), but also a different cylinder-to-cylinder misfiring likelihood may be expected in some operating conditions, due to unfavorable A/F ratio and residual gas fraction values.

The validated engine model was therefore employed for the study of such a kind of imbalances, by analyzing some physical quantities which can hardly be measured during experimental tests, such as individual volumetric efficiencies and residual gas fractions.
Use of the simulation for detection of possible misfire causes

VOLUMETRIC EFFICIENCIES AT FULL LOAD

![Graph showing volumetric efficiencies at full load with engine speed on the x-axis and λv on the y-axis. The graph includes curves for Cyl 1 to Cyl 8 and an average line.]
Use of the simulation for detection of possible misfire causes

OVERLAP OF THE EXHAUST PERIODS

**FIRING ORDER:**
1 – 5 – 4 – 8 – 6 – 3 – 7 – 2

**RIGHT BANK**
- Cyl 11
- Cyl 4
- Cyl 3
- Cyl 2

**LEFT BANK**
- Cyl 5
- Cyl 6
- Cyl 8
- Cyl 7

**DAMPER**
- 8
- 7
- 6
- 5
- 4
- 3
- 2
- 1

**FLYWHEEL**
Use of the simulation for detection of possible misfire causes

RESIDUAL GAS FRACTION
AT IVC AT FULL LOAD
Use of the simulation for detection of possible misfire causes

RELATIVE AIR/FUEL RATIO
AT FULL LOAD

Engine speed [ rpm ]

λ

[ - ]
Use of the simulation for detection of possible misfire causes

COEFFICIENT OF VARIATION OF IMEP AT FULL LOAD
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Use of the simulation for the improvement of misfire detection

CRANKSHAFT SPEED ANALYSIS

The simulation can also be used to reproduce the crankshaft speed signal, in order to obtain an analysis tool by which misfire detection techniques can be tested and tuned “on a desk”, thus reducing the experimental tests which are usually required during the development process.

The investigation was focused on the two following operating conditions with two different load layouts:

- 4000 rpm and WOT (4000@WOT) engine test bench layout;
- 3000 rpm and 4 bar of BMEP (3000@4) chassis dyno layout.
In order to evaluate the effects of cyclic variation of combustion on the engine speed, a Wiebe function parameters were extracted from the experimental cylinder pressure traces (500 consecutive engine cycle for each cylinder).

After evaluating the statistical distribution of the combustion duration (BDUR parameter) and phasing (THB50 parameter), combustion variability was simulated through a random number generation.
RANDOM COMBUSTION
REPEATABLE COMBUSTION
3000 rpm and 4 bar of BMEP
3000 rpm and 4 bar of BMEP

**EXPERIMENTAL DATA**

- Engine speed (rpm) vs. Time [s]
- Amplitude vs. Frequency [Hz]

**SIMULATION DATA**

- Engine speed (rpm) vs. Time [s]
- Amplitude vs. Frequency [Hz]
Use of the simulation for the improvement of misfire detection

EXAMPLE OF MISFIRE INDEX CALCULATION

**Engine angular speed**

**Misfire index LU**

**Engine angular speed**

**Misfire index LU**

**SIMULATION RESULTS**

**EXPERIMENTAL RESULTS**
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**Conclusions**

A one-dimensional fluid-dynamic engine model of an 8 cylinders high-performance s.i. engine coupled with a vehicle and driveline model was used to simulate the effects of misfire events on the engine angular speed.

The simulated engine speed signal was then compared with experimental measurements, and after this validation process, the model could be used to analyze different techniques for misfire detection thus reducing the required experimental tests.
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Future work

The subject discussed in this paper represents the first part of a wide research program: the on-going activity is now focused on the refinement of the mechanical model of the crankshaft, as well as on the evaluation of alternative techniques for misfire detection based on the simultaneous analysis of the engine revolution speed and of the oxygen content of the exhaust gases.
**Future work**

Moreover, the effects of misfire phenomena on engine block vibrations will be analyzed, showing the potential for coupling with the engine mounting system natural frequencies.
Acknowledgments

The authors wish to thank:

Dr. Marcigliano, Dr. Morettini, Dr. Parisi and Dr. Valentini (Ferrari Auto S.p.A.) for their helpful contribution during the experimental and simulation data processing, as well as Dr. Morel, Dr. Okarmus and Dr. Wilken (Gamma Technologies) for their support and suggestions during the simulation activity.
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