NUMERICAL SIMULATION TO IMPROVE ENGINE CONTROL DURING TIP-IN MANOEUVRES
Presentation overview

• Introduction
• Experimental set-up
• The engine model
• The vehicle and driveline model
• Model validation
• Evaluation of control strategies
• Conclusions
• Future work
**Introduction**

Vehicle driveability has nowadays undoubtedly become a key success factor for passenger cars, thus setting a further target for the designers besides pollutant emissions, fuel consumption and vehicle performance.

However, while the determination of fuel consumption and exhaust emissions follows well established standards, objective and reproducible criteria for the evaluation of a vehicle’s driveability are more difficult to be defined: a rating system based on the subjective assessments of experienced test drivers recorded during a sequence of relevant manoeuvres is usually employed.

One of the most common among these manoeuvres is the so called “tip-in”, that is a sudden opening of the throttle operated from conditions of low speed and low load.
**Introduction**

**Tip-in manoeuvres**

**Sudden opening of the throttle**

![Graph showing sudden opening of the throttle](image)

**Vehicle jerkings and acceleration fluctuations**

![Graph showing vehicle jerkings and acceleration fluctuations](image)

The abrupt change of the torque delivered by the engine excites the torsional natural frequencies of the driveline, causing vehicle jerking and acceleration fluctuations, which are the main responsible for the driver’s and passengers’ perception and assessment of performance and comfort.
Introduction

Tip-in manoeuvres: The role of numerical simulation

The vehicle’s behavior during tip-in is obviously determined by the powertrain design, but the engine management system may play a decisive role, especially with modern “torque based” systems, which are able to decouple the engine response from the driver’s demand by means, for example, of a “drive by wire” (DBW) throttle, that electronically filters the throttle valve opening command during fast acceleration transients, smoothing the vehicle response to sharp driver’s requests.

However, since designing and tuning the engine control system 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 strategies can be tested and tuned “on a desk” seems to be very promising.
Introduction

Tip-in manoeuvres:
The role of numerical simulation

The aim of this work is therefore to evaluate the potential of numerical simulation in the analysis of the dynamic transient response of a vehicle during tip-in manoeuvres, so as to reduce the experimental tests required to optimize the control strategies of the engine management system.
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# Experimental set-up

**VEHICLE: FIAT PUNTO**

## MAIN ENGINE FEATURES

<table>
<thead>
<tr>
<th>Type</th>
<th>S.I. 4 cylinders in line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore/Stroke</td>
<td>70.8 / 78.86 mm</td>
</tr>
<tr>
<td>Displacement</td>
<td>1242 cm³</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>10.6 : 1</td>
</tr>
<tr>
<td>Combustion Chamber</td>
<td>Pent-roof</td>
</tr>
<tr>
<td>Maximum Power</td>
<td>52 kW @ 5000 rpm</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>107 Nm @ 4000 rpm</td>
</tr>
<tr>
<td>Fuel Metering System</td>
<td>Multi-point electronic injection</td>
</tr>
<tr>
<td>Distribution</td>
<td>DOHC, 4 valves/cylinder</td>
</tr>
</tbody>
</table>
**Experimental set-up**

**DATA ACQUISITION SYSTEM**

- **Data analysis**
  - Amplifier
  - f-V Converter
  - A/F Analyzer
  - Power supply

- **Digital acquisition**

**Acquired signals**

1. Wheels angular speed
2. Engine angular speed
3. Air-Fuel ratio
4. Throttle opening
5. Vehicle longitudinal acceleration
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The engine model

Main features of the engine model

intake plenum + primary intake runners

air inlet

air filter + Helmotz resonator

connecting pipe + throttle

exhaust manifold

Close coupled catalyst
Validation of the engine model: full load conditions

Global quantities

The engine model

Brake torque [Nm]

Brake power [kW]

n [rpm]
The engine model

Validation of the engine model: full load conditions
Instantaneous quantities

W.O.T n = 4000 r.p.m.
The engine model

Validation of the engine model: part load conditions

1500 rpm

inlet manifold pressure [mbar]

bmep [bar]

EXP
SIM
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The vehicle and driveline model

Schematic diagram of the driveline

- Front-wheel drive
- 5 speed gear box
- Asymmetric axle shafts
The vehicle and driveline model

9 DOF Torsional Model
(Matlab-Simulink)

Equivalent inertia:
1. Engine
2. Clutch + Gear-box + Differential
3. 5. Hub + rim
4. 6. Tyres
9. 9’. Vehicle

Engine torque

Load torque

Load torque
Simulation Scheme

GT-Power Engine model

MATLAB - SIMULINK Driveline and Vehicle Model

Engine speed

Engine torque

Throttle opening

A / F

Simulation Scheme
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**Model validation**

Validation of the complete engine-vehicle model

**Example:** 2\textsuperscript{nd} gear - Initial engine speed: 1500 rpm

*Time history of the throttle opening*
Model validation

Example: 2\textsuperscript{nd} gear transmission ratio

Engine angular speed: simulation vs experimental results
**Model validation**

**Example: 2\textsuperscript{nd} gear transmission ratio**

Vehicle longitudinal acceleration: simulation vs experimental results
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Use of the model for the evaluation of control strategies

After the assessment of the accuracy and of the reliability of the complete engine-vehicle model, the numerical simulation has been used as a prediction tool to analyze the impact of different control strategies on vehicle driveability during tip-in. The two following strategies were evaluated:

- drive by wire control
- spark advance control
Evaluation of control strategies

“Drive by wire” (DBW) throttle control

Time history of the throttle opening

- Direct control
- DBW

load [%] vs. time [s]
Evaluation of control strategies

“Drive by wire” (DBW) throttle control

Engine angular speed: comparison between DBW and direct control in 2\textsuperscript{nd} gear
Evaluation of control strategies

“Drive by wire” (DBW) throttle control

Vehicle acceleration: comparison between DBW and direct control in 2\textsuperscript{nd} gear
Evaluation of control strategies

“Drive by wire” (DBW) throttle control

Jerk and vehicle acceleration during tip-in: comparison between DBW and direct control in 2\textsuperscript{nd} gear
Evaluation of control strategies

Spark advance controller

![Graph showing evaluation of control strategies with and without spark advance controller]
Evaluation of control strategies

Spark advance controller

Engine angular speed:
comparison between simulation with and without spark advance controller
Evaluation of control strategies

Spark advance controller

Vehicle acceleration: comparison between simulation with and without spark advance controller
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A one-dimensional fluid-dynamic engine model was employed in conjunction with a Matlab-Simulink vehicle and driveline model to analyze the dynamic transient response of a gasoline passenger car during tip-in manoeuvres.

A detailed validation process of the complete engine-vehicle model, based on several sets of experimental data, was performed.

The numerical simulation was shown to be reliable and helpful for the study of proper control strategies of the engine management system aiming to enhance the vehicle driveability.
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Further investigations will be devoted to the improvement of the simulation of the vehicle acceleration, by means of more detailed models for the driveline and the vehicle.

On the engine side the analysis will be extended to the evaluation of more detailed ECU models, in order to better represent the behavior of torque based systems.

Moreover, the use of more detailed combustion models to obtain essential information such as knock likelihood caused by spark timing increases will also be evaluated.
FUTURE WORK

Example of a more detailed ECU model of a torque based system.
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A/F during tip-in