Methodology for engine simulation in support of engine control testing and development

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Summary

- Magneti Marelli Powertrain
- Engine simulation model methodology
- Development of a 1-D simulation model
- Results of the model
- Some application examples
- Conclusions
Magneti Marelli Powertrain is Magneti Marelli business line dedicated to engines and transmissions components production for cars, motorbikes and light vehicles.

**GASOLINE ENGINE CONTROL**
- ECUs
- Injectors
- Throttle bodies
- Intake manifolds
- Fuel rails
- Multifuel systems
- GDI pumps

**DIESEL ENGINE CONTROL**
- ECUs
- Low pressure parts
- Mechatronic throttle bodies
- Intake manifold with variable swirl control

**TRANSMISSION**
- Freechoice AMT
- ECUs
- Hydraulic power units
- DCT
Aim: engine modeling for testing engine components and control strategies

Magneti Marelli is not an engine maker

The complete description of the engine components could be not available:

- reverse engineering;
- experimental tests and simplified modeling.

The model should be fast both in its assembly and in its execution: 1-D or 0-D simulation (local 3-D only for particular purposes)
Engine model applications

GT-Power most attractive features for Magneti Marelli

- Predictive analysis of fluid dynamic engine conditions (intake and exhaust system, EGR, turbocharger, etc.)
- In cylinder thermodynamic conditions (temperature, pressure) starting from experimental data
- Integration with other GT-SUITE modules for other components simulation (injection system, cooling system, etc.)
- 3-D codes integration: in-cylinder conditions at IVC
- In cylinder thermodynamic conditions (temperature, pressure) prediction *
- Emission prediction varying calibration parameters*

*only predictive combustion models
Setting of the characteristic time scale and to evaluate CPU time and experimental data needed for the simulation.

Creation of a 1-D simulation model

GT-Power diesel engine model for Magneti Marelli: 1-D multi-purpose 4 cylinder HSDI diesel engine model for all the main components simulation

Main components external to cylinder block:

- Intercooler
- EGR system
- Turbocharger with VGT
- Exhaust gas aftertreatment components (DOC, DPF)
Creation of a 1-D simulation model

GT-Power modeling tools: the 3D drawing of many components (eventually by means of reverse engineering) can be used and discretized.
Creation of a 1-D simulation model

GT-Power “Black box” simplified modeling, intercooler and EGR-Cooler, optimizer

<table>
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<tr>
<th>SPEED</th>
<th>1261</th>
<th>1268</th>
<th>2010</th>
<th>2016</th>
<th>3006</th>
<th>3017</th>
<th>4006</th>
<th>4013</th>
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<td>1664</td>
<td>1209</td>
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<tr>
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<td>0.21%</td>
<td>0.23%</td>
<td>0.23%</td>
<td>0.00%</td>
<td>-0.17%</td>
<td>-0.40%</td>
</tr>
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</table>
Creation of a 1-D simulation model

Turbocharger modeling

Compressor and turbine maps
VGT correlation in operating steady-state points
1-D engine model: combustion

Calibration of combustion model by means of single cylinder “fast” model

- Based on cylinder boundary condition (EGR included)
- Parameters interchangeable with complete engine model

0-D combustion DI-Jet model (Morel Wahiduzzaman, 1996)

- Complex spray parameters setting
- Only two parameters variation ($\text{SMD}_{\text{mult}}, \text{L}_{\text{mult,breakup}}$)

Fuel injection obtained by external models (integration with predictive injection model in GT-Suite running)

Fast model: few minutes for cycle simulation for single cylinder
Development of a 1-D simulation model

0-D combustion model: DI-Jet

After the tuning by means of a single-cylinder model, the model agrees with experimental results in a wide range of engine functioning conditions.

BMEP 6 bar, Speed 2750 rpm, EGR 25%, 3 injections
Development of a 1-D simulation model

0-D combustion model: DI-Jet

After the tuning by means of a single-cylinder model, the model agrees with experimental results in a wide range of engine functioning conditions.

BMEP 4 bar, Speed 2000 rpm, EGR 28%, 3 injections
Development of a 1-D simulation model

0-D combustion model: DI-Jet

After the tuning by means of a single-cylinder model, the model agrees with experimental results in a wide range of engine functioning conditions.

BMEP 13 bar, Speed 2000 rpm, EGR 7%, 3 injections
Development of a 1-D simulation model

0-D combustion model: DI-Jet

After the tuning by means of a single-cylinder model, the model agrees with experimental results in a wide range of engine functioning conditions.

BMEP 16 bar, Speed 4000 rpm, no EGR, 1 injection
Engine model

GT-Power complete diesel engine model

Calibration through 12 selected operation points in very different conditions in terms of speed, injection, EGR, etc.

- PID control for turbocharger
- Imposed EGR valve position
## Development of a 1-D simulation model

### Model results in different operation points

<table>
<thead>
<tr>
<th>Point number</th>
<th>SPEED [rpm]</th>
<th>BMEP [bar]</th>
<th>EGR [%]</th>
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![Air flow-rate graph](image1)

![IMEP graph](image2)
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**EGR**

![EGR graph](image)

**NOx**

![NOx graph](image)
Application of a 1-D simulation model

GT-Power model application: HP (high pressure) vs LP (low pressure) EGR

**HP EGR**

**LP EGR**
Application of the model for in cylinder 3-D simulation

GT-Power and 3-D codes: KIVA 3-V, StarCD, OpenFOAM

**Boundary conditions for 3D combustion simulation**

Valve closed:
- Temperature IVC
- Pressure IVC

Valve moving:
- Pressure profile
- Temperature profile

GT-Power 1D simulation
- non-predictive comb. model

GT-Power 1D simulation
- predictive comb. model

EGR from experimental data (excel file)

EGR prediction by 1-D engine model

HR model

Dijet model
Conclusions

GT-Power engine model created is useful for testing engine components

The methodology makes use of reverse engineering and simplified black box models

Diesel combustion predictive model can be effectively used for a complete engine simulation

Other GT-SUITE activities running:

- Detailed hydraulic system simulation and control
- Coupled systems simulation
- 0-D “fast” models (Virtual DOE, Neural Networks)
Thanks for your attention