GT-SUITE USERS CONFERENCE
FRANKFURT, OCTOBER 4TH 2004

EGR Transient Simulation of a Turbocharged Diesel Engine using GT-Power

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PRESENTATION OVERVIEW

- **INTRODUCTION**

- **GT-POWER MODEL DESCRIPTION**

- **TRANSIENT OF THE EGR PERCENTAGE AT CONSTANT ENGINE SPEED AND LOAD**

- **TRANSIENT OF EGR AND LOAD AT CONSTANT ENGINE SPEED**

- **REMARKS AND CONCLUSIONS**
INTRODUCTION

The growing of the high speed DI diesel technology during the last 5 years had allowed the modern diesel engines to reach levels of performance and refinement just unthinkable in the middle of the last decade.

In parallel with this continuous evolution of performance, the diesel engine manufacturers have to face a very important problem: the legislators impose a drastic reduction in pollutant emissions for the next years. This pushes the diesel community to invest more and more efforts in this direction.

The use of a modern 1D code like GT-Power could be helpful, allowing a better understanding of fluid dynamics phenomena at part load points and during transient phases. In this sense, it could give support to engine testing and control development.
INTRODUCTION

IN THE SHORT/MID TERM A GOOD SOLUTION SEEMS TO BE THE COMBINATION OF:

• DPF TO CONTROL PM;
• HIGH PERCENTAGE OF COOLED EGR TO REDUCE NOx.

- CO (CATALYST TECHNOLOGIES)
- HC
- NOx
- PM

- NEDC test driving cycle and regulated pollutants -

TRUE ISSUE FOR THE NEXT YEARS

MANY EFFORTS ARE DEVOTED IN TWO DIRECTIONS:

“Engine-emission” reduction

Optimization of:
- Injection system
- swirl
- ....

After-treatment systems

Advanced combustion processes

- EGR
- NOx
- PM

- DPF
- SCR
- NOx trap
- ....

NEED FOR A BETTER AND BETTER UNDERSTANDING OF THE EGR EFFECTS ON THE ENGINE PERFORMANCE

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# INTRODUCTION

A COMPLETE EMISSION-ORIENTED ANALYSIS OF THE ENGINE WITH GT-POWER CAN FOLLOW 3 STEPS:

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<td>Turbomatching</td>
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<td>EGR-cooler sizing</td>
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THE RESULTS OF THE PRESENT ANALYSIS REFER TO A 4 CYLINDER 1.9 LITER DIESEL ENGINE, EQUIPPED WITH A VGT TURBOCHARGER AND A COOLED EGR SYSTEM.

THE AIM IS TO UNDERSTAND THE FLUID DYNAMICS PHENOMENA INVOLVED IN A TRANSIENT OF EGR AND LOAD, LIKE IN A SUDDEN ACCELERATION FROM A LOW LOAD AND SPEED CONDITION.
INTRODUCTION

How to select the A/F values for the ECU map?

Quick rise in torque (low A/F) COMPROMISE Limited smoke emission (high A/F)

Steady-state tests are usually not enough. It is necessary to make long and expensive transient tests on the dynamic bench/vehicle.

How could GT-Power help?

In order to better understand the fluid-dynamics phenomena, 2 steps have been considered:

- EGR transient at constant BMEP;
- EGR and load transient.

SUDDEN ACCELERATION FROM A PART LOAD POINT

Sketch of the ECU control logic during a sudden acceleration

ECU

A/F = f(RPM, \( \dot{m}_a \))

EGR-valve opening

open loop

fueling

time

t₀

A/F = f(RPM, \( \dot{m}_a \))

EGR-valve opening

open loop

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t₀
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- TRANSIENT OF THE EGR PERCENTAGE AT CONSTANT ENGINE SPEED AND LOAD

- TRANSIENT OF EGR AND LOAD AT CONSTANT ENGINE SPEED

- REMARKS AND CONCLUSIONS
INTAKE SYSTEM:
- AIR FILTER
- COMPRESSOR
- CHARGE AIR COOLER
- MANIFOLD

EXHAUST SYSTEM:
- MANIFOLD
- VGT TURBINE
- EXHAUST NOZZLE

EGR-COOLER

CONTROL SYSTEM ON:
- TURBOCHARGER
- FUELLING

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Location of the air flow meter

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AIR
EGR
EXHAUST GAS

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GT-POWER MODEL DESCRIPTION

AIR
EGR
EXHAUST GAS
GT-POWER MODEL DESCRIPTION

EGR-COOLER MODEL

Effectiveness (from supplier)

\[ \varepsilon \]

\[ m_{\text{coolant}}(\text{erpm}) \]

\[ m_{\text{GAS}} \]

MAP

SENSORS OF:

- \( T_{\text{gas\_IN}} \)
- \( \text{gas mass flow rate} \)
- \( \text{erpm} \)

\[ \text{FROM } \varepsilon \text{ and } T_{\text{gas\_IN}} \rightarrow T_{\text{gas\_OUT}} \text{ WHICH IS IMPOSED AT THE OUTLET OF THE EGR-COOLER} \]
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Steady-state target: control on fuelling to keep the BMEP constant
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INITIAL STEADY-STATE CONDITION: ALMOST 35% EGR

1500 ERPM – 2 BAR BMEP

TRANSIENT OF THE EGR PERCENTAGE

Transverse orifice diameter profile

Initial steady-state condition
INTRODUCTION

INITIAL STEADY-STATE CONDITION: ALMOST 35% EGR

1500 ERPM – 2 BAR BMEP

Transition at \( t = 4 \text{s} \)

FINAL STEADY-STATE CONDITION: 0% EGR

TRANSIENT OF THE EGR PERCENTAGE

Initial steady-state condition

Ideal step closure of the EGR-valve

Final steady-state condition

Air Cleaner

EGR-valve opening [%]

EGR-valve closing

Transient orifice diameter profile

Time [sec]
TRANSIENT OF THE EGR PERCENTAGE

TURBOCHARGER PARAMETERS ANALYSIS

INITIAL STEADY-STATE CONDITION: ALMOST 35% EGR

1500 ERPM – 2 BAR BMEP

Transition at t = 4s

FINAL STEADY-STATE CONDITION: 0% EGR

The in-turbine-massflow increases.

As a consequence, TC speed increases too.

Therefore, there is a slight rise in boost pressure

Constant turbine rack position
DESCRIPTION OF AIR AND EGR TRANSIENTS

INITIAL STEADY-STATE CONDITION: ALMOST 35% EGR

FINAL STEADY-STATE CONDITION: 0% EGR

1500 ERPM – 2 BAR BMEP

Transition at \( t = 4s \)

TRANSIENT OF THE EGR PERCENTAGE

In spite of the step-closure of the EGR valve, the in-cylinder EGR fraction doesn’t go to 0% immediately.

"Engine" airflow:
- takes time to reach its steady-state value;
- is late compared to "air flow meter signal".

"Air flow meter" signal is the massflow from the "air flow meter" pipe: the short delay introduced by the real component is not considered here.
In fact, when the EGR-valve closes...

...the mass flow rate at the air inlet rises suddenly to compensate the lack of EGR.
The air flow-meter, near to the air inlet, shows this quick rise.

...the manifold contains almost 65% air + 35% EGR on average (initial steady-state condition).

During the following intake phases, the EGR flow rate which comes from the manifold into the cylinders is replaced by the air: the EGR% decreases down to 0% and the air% increases. Therefore, the “engine” airflow rises but it is late compared to the “air flow meter” signal.

The duration of this transient is highly influenced by:

- volume of the manifold: volume \( \rightarrow \) time \( \uparrow \) (greater volume to empty out);
- volumetric efficiency: vol\( \text{ef} \) \( \downarrow \) time \( \uparrow \) (less volume trapped at each cycle);
- engine speed: RPM \( \downarrow \) time \( \uparrow \) (increase in the engine cycle duration).

For instance: effect of the intake manifold volume on the EGR transient duration
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1) The simulation reaches steady-state condition (1500x2 with 35% EGR)

A steady-state target object controls the fuel flow in order to keep the BMEP constant (2bar)

1500 RPM 2 bar BMEP

BMEP sensor
1) The simulation reaches steady-state condition (1500x2 with 35% EGR)

2) Step-closure of the EGR-valve and transition to a new fuelling control

A switch object regulates the transition to a different fuelling control system.

The EGR-valve closing step-function is the same of the previous case.
1) The simulation reaches steady-state condition (1500x2 with 35% EGR)

2) Step-closure of the EGR-valve and transition to a new fuelling control

3) Rise in fuelling and consequently in BMEP.

An Air/Fuel Ratio = 19* is imposed: the fuel flow is calculated according to the signal of the airflow sensor (from previous cycle).

*minimum A/F compatible with smoke limits (from steady state tests)

\[
\text{fuel [mg / stroke]} = \frac{\text{airflow}}{\text{rpm}} \cdot \frac{2}{\text{ncyl}}
\]
Comparison between EGR transient and EGR+BMEP transient

The EGR fraction trend is the same in both cases (volume of the int. manifold, volef and rpm are the same)
TURBOCHARGER PARAMETERS ANALYSIS

Turbine power greater than compressor one

Turbocharger acceleration

Increase in boost pressure

Boost pressure transient

Constant turbine rack position
After 4 s, an A/F = 19 is imposed (according to the airflow of the previous cycle).

Actually, the ECU receives the information about the airflow from the air flow meter.

To simulate this condition, the “engine airflow” sensor could be replaced with an “air flow meter” sensor *.

* Sensor of mass flow rate from “air flow meter” pipe
In fact, as already known, the “engine” airflow is late compared to the “AFM” signal during the whole transient. As a consequence, a fuelling control based on the AFM signal could lead to an engine A/F ratio less than the target value:

For this reason, the A/F values set in the ECU according to steady-state tests need to be corrected through transient tests to avoid an excessive smoke emission during transient phases.

With the “AFM” fuelling control, the A/F ratio is less than the target value during the whole transient.
On the other side, this plot allows to evaluate the correlation between “AFM” and “engine” airflows at each instant.

Repeating this analysis for all the representative transients, it is possible to build some transfer functions TF to introduce into the ECU.

This allows to correct the steady-state A/F ratios, thus reducing the number of required experimental transient tests or hardware modifications.

For this reason, the A/F values set in the ECU according to steady-state tests need to be corrected through transient tests to avoid an excessive smoke emission during transient phases.
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REMARKS AND CONCLUSIONS

THE USE OF GT-POWER CODE ALLOWS TO UNDERSTAND THE FLUID-DYNAMICS AND TURBOCHARGER PHENOMENA INVOLVED IN A TRANSIENT.

IN PARTICULAR, THE PRESENT ANALYSIS SHOWS THAT:

• DURING A SUDDEN ACCELERATION FROM A PART LOAD POINT AN EGR TRANSIENT AND A BOOST PRESSURE TRANSIENT PHASES COULD BE RECOGNIZED. THE CODE ALLOWS TO IDENTIFY THE RELEVANT PARAMETERS (E.G. THE VOLUME OF THE INTAKE MANIFOLD…)

• DURING TRANSIENT PHASES THE OUTPUT OF THE AIR FLOW METER COULD BE NOT REPRESENTATIVE OF THE TOTAL IN-CYLINDER TRAPPED AIRFLOW. THIS COULD RISE PROBLEMS (E.G. NOT CONTROLLED SMOKE EMISSION) WHEN FUELLING IS CALCULATED IN OPEN LOOP BY THE ECU ACCORDING TO THAT SIGNAL;

• BY THE USE OF GT-POWER IT IS POSSIBLE TO IDENTIFY THE CORRELATION BETWEEN THE SIGNAL OF THE AIR FLOW METER AND THE TOTAL IN-CYLINDER TRAPPED AIRFLOW DURING TRANSIENT PHASES. THIS COULD ALLOW AN EASIER CONTROL OF THE ENGINE A/F RATIO REDUCING THE NEED OF EXPENSIVE TRANSIENT TESTS.