LOW-SPEED PRE-IGNITION
IN DI SI TURBOCHARGED ENGINES

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DOWNSIZING – WHY T-GDI?

Technology synergy with turbocharged Gasoline Direct Injection (t-GDI)

Turbocharged Engine

Ex
VCP
In
DI

Diesel

BMEP

PFI
t-GDI

Engine Speed
TURBO PERFORMANCE LEVELS

![Graph showing turbo performance levels for different engines: RA167E, t-GDI, Esprit S4S, Astra Turbo, M3 E46. The graph plots BMEP (bar) against engine speed (rpm).]
Hot spots (spark plug)
PI from bad combustion (offset), soot, diffusion burn

LSPI after misfire, bad ambient condition
Spontaneous LSPI.

Combustion deposit build up
Oil accumulation

BMEP [bar]

Engine Speed [rpm]

- t-GDI
- Esprit S4S
- Astra Turbo
- M3 E46

Turbo Performance Levels and Irregular Combustion

Rik Alewijnse, AVL Powertrain UK ltd, 12 June 2012
DEFINITION OF (LOW SPEED) PRE-IGNITION

Indication diagram of 4 cyl. t-GDI engine

- Pressure rise before spark
- Spark angle = ~2.5° before TDC CrA
- Normal combustion in cylinders 1, 3 & 4
- Superknock in cylinder 2
- Limitation of the testbed indication equipment

Engine speed - 1750 rpm
Engine load - 2133 kPa
CAUSES OF LSPI - OVERVIEW

Retarded Combustion:
- slow combustion
- ignition retard due to hot conditions
- increase of manifold pressure
- no limitation for compensation of torque loss

Ignition Malfunction:
- ignition malfunction
- ignition coil malfunction
- spark plug malfunction
- ECU malfunction
- too lean / too rich

Residual Gas:
- bad mixture
- high back pressure
- fixed hot spots
- spark plug
- exhaust pulse
- valves
- deposits in combustion chamber
- too lean / too rich

Hot Spots:
- migrant hot spots
- fixed hot spots
- spark plug
- valves
- deposits in intake port
- deposits from combustion chamber
- poor homogenization

Liquids:
- oil
- fuel
- from oil
- oil deposits
- fuel from poor spray quality
- oil from TC
- oil from valve stem seals
- oil from cylinder head gasket
- oil from piston rings
- fuel from liner wetting
- liner wetting near intake valves

Deposits:
- fuel deposits
- fuel deposits in combustion chamber
- fuel deposits
- fuel deposits in intake system
- fuel deposits in intake system
- from fuel
ROOT CAUSES OF LSPI

- Retarded Combustion
  - slow combustion
- Ignition / Injection Malfunction
  - injection malfunction / ignition malfunction
  - ignition coil malfunction
  - ignition retard due to hot conditions
- Residual Gas
- Hot Spots
- Liquids
- Deposits

Full load - Mass fraction burned

Position of Combustion Start

Results of the Visiolution measurements. In this case showing autoignition.
VISIOLUTION SYSTEM SETUP

VisioSet

VisioKnock / VisioTomo

PC

Visiolution software

angle encoder

Visiolution spark plug adapter
AVL VISIOLUTION SENSORS

VisioKnock Spark Plug Sensor

VisioTomo Head Gasket Sensor

8 Channel

40 Channel
ROOT CAUSES OF LSPI

- Retarded Combustion
  - Ignition / Injection Malfunction
  - Residual Gas
  - Hot Spots
  - Liquids
  - Deposits

Fuel spray observed on the transparent engine- vertical cross-section. In this specific case intake valve wetting (white area on the figure)

Fuel spray observed on the injector test rig

Results of the Visiolution measurements. In this case showing autoignition.

Reasons could be:
- Injector spray
- Fuel rail pressure control (cyclic deviations)

- bad mixture
- poor homogenisation
- too lean / too rich

- ignition system malfunction
- any kind of high voltage contact problem
ROOT CAUSES OF LSPI

- Retarded Combustion
- Ignition / Injection Malfunction
- Residual Gas
- Hot Spots
- Liquids
- Deposits

- High back pressure in manifold
- Exhaust pulse during valve overlap (no/negative scavenging)
ROOT CAUSES OF LSPI

- Retarded Combustion
- Ignition / Injection Malfunction
- Residual Gas
- Hot Spots
  - fixed hot spots
  - migrant hotspots
    - spark plug
    - deposits from intake port
    - valves
    - deposits in combustion chamber
  - deposits from combustion chamber
- Liquids
- Deposits

Deposits on the piston crown surface
Deposits on the combustion chamber
ROOT CAUSES OF LSPI

- **Retarded Combustion**
- **Ignition / Injection Malfunction**
- **Residual Gas**
- **Hot Spots**
- **Liquids**
- ** Deposits**

**Liquids**
- Oil from Turbo Charger
- Oil from valve stem seals
- Oil from cylinder head gasket
- Oil from piston rings
- Fuel from poor spray quality
- Fuel from wall wetting in intake ports
- Fuel from liner wetting
- Liner wetting near intake valves

**Diffusion combustion after part load**

**Results of the VVisolution measurements**

**Transparent engine**

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ROOT CAUSES OF LSPI

Results of the ViSolution measurements. In this case showing prolonged diffusion combustion.

- Retarded Combustion
- Ignition / Injection Malfunction
- Residual Gas
- Hot Spots
- Liquids
- Deposits
  - Oil deposits
  - Oil deposits in combustion chamber
  - Oil deposits in intake system
  - Fuel deposits
  - Fuel deposits in combustion chamber
  - Fuel deposits in intake system
  - Fuel deposits on piston crown due to overcooling at part load
LSPI – WORKING HYPOTHESIS

- Trigger: Internal EGR
- High Enthalpy Mixture
- Trigger: HMW HC
DESIGN ACTIONS - PREVENTATIVE

- Piston Crown
- Breather system
- Valve Stem Seals
- Map Controlled Thermostat

Source: Behr
DESIGN ACTIONS - PREVENTATIVE

Intercooler

Cam timing/Internal EGR control

Operating strategy
## POWER CYLINDER SAFETY FACTORS

<table>
<thead>
<tr>
<th>Component</th>
<th>Design target</th>
<th>Over Pressure Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Bolt</td>
<td>Gap lift</td>
<td>+++</td>
</tr>
<tr>
<td>Gasket</td>
<td>Bead fatigue</td>
<td>+++++</td>
</tr>
<tr>
<td>Liner</td>
<td>Hoop stress fatigue</td>
<td>+++</td>
</tr>
<tr>
<td>Main Bolt</td>
<td>Bearing shell retention</td>
<td>+++</td>
</tr>
<tr>
<td>Crank</td>
<td>Torsional and bending fatigue</td>
<td>++++</td>
</tr>
<tr>
<td>Rod</td>
<td>Buckling</td>
<td>+</td>
</tr>
<tr>
<td>Pin</td>
<td>Schlaefke ovalisation and bending</td>
<td>++++</td>
</tr>
<tr>
<td>Piston</td>
<td>Crown TMF 2nd Land fatigue</td>
<td>++++</td>
</tr>
<tr>
<td>Cyl Head</td>
<td>Chamber TMF</td>
<td>++++</td>
</tr>
</tbody>
</table>
DESIGN ACTIONS - ADAPTIVE

Second ring land

Con Rod

ECU detection functionality

Safety against buckling to be checked for single events up to 170bar.
CONCLUSIONS

• Turbo – Gasoline Direct Injection engines are an excellent enabler for engine downsizing to address the CO₂ reduction challenge.

• Specific performance levels in t-GDI engines are not new, but high loads below 2000 rpm mean that Low Speed Pre-Ignition needs careful consideration.

• LSPI has a range of causal factors, which are an area of active research.

• Design actions are available to reduce (but not eliminate) the occurrence of LSPI events.
  • Other design actions to accommodate the effects of occasional LSPI are also necessary.
  • Con rod design for t-GDI engines must consider compressive loading, with buckling failure as the limiting load case.
Thank You

Any Questions?