Real Drive Efficiency Improvement in turbocharged Engines by the use of Expansion Intake Manifold

V. Bevilacqua, G. Corvaglia, M. Böger, M. Penzel | PEG-M
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Introduction | Motivation

> EU legislation set mandatory **emission reduction targets** for new cars
  - By 2021 the fleet average to be achieved by all new cars is **95g CO₂/km**

> One of the main strategies existing for reducing CO₂ automotive emissions is the **downsizing**

> Increased downsizing level can lead to negative effects in **real driving conditions**, because, in order to protect component in the exhaust system, **enrichment** is required

> The most effective way to reduce enrichment is to reduce **Intake Air Temperature** different solutions exist:
  - Water Injection
  - Supercooling
  - AC assisted CAC
  - Expansion Intake Manifold
Introduction | Expansion intake manifold

> Invented by Dr. Theilemann and Patented by Dr. Ing. Porsche AG in 2007

> First commercial application: Porsche 911 GT2 (2008)

> System adopted on the Porsche 911 boxer 6 cylinder turbocharged engine

> The aim of the present analysis is to show the application of an expansion intake manifold to a conventional 4 cylinder engine
Introduction | Expansion intake manifold

- Two main resonance volumes produce a flow oscillation at each firing event
- The classic RAM effect of NA engines is reversed to produce the gas expansion: intake charge temperature reduction
- The lower volumetric efficiency is compensated by a higher boost pressure

- Lower knocking tendency improves Spark Advance and Reduces Enrichment Need → lower fuel consumptions at rated power
- Lower air mass flow, higher p ratio → Improved Compressor efficiency
  - Depending on Turbocharger Matching
Introduction | Engine Base model

As a reference for the analysis a conventional 2.0 liter 4-cylinder turbocharged engine developed by Porsche Engineering has been taken into account.

<table>
<thead>
<tr>
<th>Engine characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinders configuration</td>
<td>I4</td>
</tr>
<tr>
<td>Turbocharger</td>
<td>Single Stage</td>
</tr>
<tr>
<td>Max torque</td>
<td>150 Nm /l</td>
</tr>
<tr>
<td>Max Power</td>
<td>80 kW /l</td>
</tr>
</tbody>
</table>

Conventional Intake Manifold

Engine layout

20 Nm

20 g/kWh

Introduction | Engine Base model

Increase of Full Load Efficiency of a high performance turbocharged engine by the use of Expansion Intake Manifold

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Investigated Concepts | Procedure

1. **1D Model Calibration**
   - LAYOUT DEFINITION

2. **Preliminary Analysis** of 6 layout
   - Operating Point: 5500 RPM
   - Definition of the most promising layout
   - LAYOUT OPTIMIZATION

3. **Optimization Target** → BSFC improvement

4. Main geometrical parameters investigated:
   1. Intake runners
   2. Plenum Volume
   3. Distributor pipes
Investigated Concepts | Layout Selection | DOE Analysis

> **Configuration 1** shows similar trend as known for the 6 Cylinder boxer

> **Configurations 2 and 4** shows some significant potential

> **Further Presentation refers just to Configuration 1.**
Investigated Concepts | LayoutSelection

> **Configuration 1** offers the highest potential in terms of BSFC improvements

> **Configurations 2 and 4** could be used for odd cylinder number

> **Further Presentation** refers just to **Configuration 1**.

<table>
<thead>
<tr>
<th>Hardware variant</th>
<th>Distributor pipe diameter [mm]</th>
<th>Distributor pipe length [mm]</th>
<th>BSFC improvement at 5500 RPM [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>750</td>
<td>-11.41</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>840</td>
<td>-8.81</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>150</td>
<td>-3.06</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>1800</td>
<td>-4.91</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>300</td>
<td>-3.06</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
<td>200</td>
<td>-2.37</td>
</tr>
</tbody>
</table>
For **Configuration 1** further analysis were carried out to optimize the geometry.

6 different distributor **pipe lengths** have been analyzed.

- Pipe Lengths correspond to optimal configuration at different engine speed.

<table>
<thead>
<tr>
<th>Distributor Pipe Length [mm]</th>
<th>BSFC reduction WRT base model [%]</th>
<th>Engine Speed at min. BSFC [RPM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>-11.41</td>
<td>5500</td>
</tr>
<tr>
<td>820</td>
<td>-11.04</td>
<td>5200</td>
</tr>
<tr>
<td>940</td>
<td>-9.20</td>
<td>4800</td>
</tr>
<tr>
<td>1050</td>
<td>-7.11</td>
<td>4400</td>
</tr>
<tr>
<td>1170</td>
<td>-6.26</td>
<td>4000</td>
</tr>
<tr>
<td>1340</td>
<td>-9.09</td>
<td>3600</td>
</tr>
</tbody>
</table>
Investigated Concepts | Layout Optimization

- All the geometries show a BSFC increase below resonant engine speed
- This effect was further investigated

BSFC - Brake Specific Fuel Consumption

- Layout Optimization

All the geometries show a BSFC increase below resonant engine speed. This effect was further investigated.
Investigated Concepts | Layout Optimization

> The BSFC increase is due to an out of phase resonant effect
> This produces a higher intake charge temperature, thereby increasing the Knocking tendency

Switchable Expansion IM
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> In **Normal Configuration (N)**: similar behavior as the base model
> In **Resonant Configuration (R)**: lower BSFC thanks to the expansion effect
> *The out of phase resonant effect is avoided*
Increase of Full Load Efficiency of a high performance turbocharged engine by the use of Expansion Intake Manifold

Switchable IM concept was designed on the basis of an existing 4 cylinder turbo car packaging, keeping 1D requirements (1340 mm resonance length)

Both resonant (R) and normal (N) configurations were designed and numerically tested
1D-3D coupled analysis | 3D Effects Analysis

**Manifold Configuration** | **RPM range**
--- | ---
Resonant (R) | [3200 - 5500]
Normal (N) | [1500 - 3200]

- Coupled Analysis between **GT-Power** and **Converge Lite**
- The coupled simulation shows the **same pressure wave dynamics**
- Proposed concept appear feasible

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Coupled Analysis between GT-Power and Converge Lite

About **2 hours** Calculation Time for each operating point

In the **Coupled Simulation** the **3D wave effects** are clearly visible
## 1D-3D coupled analysis | CAD Design | Possible Simplifications

<table>
<thead>
<tr>
<th>Layout</th>
<th>Configurations</th>
<th>Throttle Bodies</th>
<th>On-Off Valves</th>
<th>Switch Valves</th>
<th>Notes</th>
</tr>
</thead>
</table>
| ![Diagram 1](image1) | ![Diagram 2](image2) | 2 | 2 | 0 | - Best transient behavior  
- Most expensive solution |
| ![Diagram 3](image3) | ![Diagram 4](image4) | 1 | 1 | 1 | - R configuration only at high load |
| ![Diagram 5](image5) | ![Diagram 6](image6) | 1 | 0 | 1 | - Poorer transient performance calibration  
- R configuration only at high load |
Conclusions

> TECHNOLOGY – On the basis of the 1D and 1D-3D coupled CFD calculations following consideration can be drawn about Expansion Intake Manifold applied to conventional in line engines:

**CONS**

- Relevant dimensions $\rightarrow$ manifold packaging problems
- *Not direct effect on fuel consumption reduction in homologation driving cycles*

**PRO**

- Effective technology for **BSFC reduction up to 12%** at high loads and engine speeds
- **Different** possible Layouts (also for odd cylinder number)
- **Switchable strategy** to fully exploit technology potential

> METHODOLOGY – The built-in coupling with Converge Lite:

- **Fast**: results are achieved in **acceptable calculation time**
- **Reliable**: Coupled simulation allows reliable visualization and analysis of 3D effects
Thanks for your attention!