Attività di ricerca dell’Università di Genova sulle prestazioni dei componenti di aspirazione e scarico di MCI automotive e sulle emissioni dei veicoli stradali in condizione di reale utilizzazione

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Intake and Exhaust Components
Research Activity
Intake and Exhaust Components Research Activity

- A dedicated test facility allows to study the behaviour of different automotive I/E components and subsystems both under steady and unsteady flow operation, with special reference to exhaust turbochargers.

- Experimental tests can be addressed to:
  - define the steady flow characteristics of I/E components in a wide operating range through suitable investigation techniques
  - investigate the behaviour of I/E components under pulsating flow conditions, highlighting the influence of the main flow parameters on components performance
  - study the transient response of I/E components and subsystems in order to optimize the relevant control strategies

- Information provided by experimental research activity are used to define empirical correlations and to improve theoretical models within engine simulation codes (GT Power environment, ...)

• “Cold” (about 400 K) and “hot” (max 1000 K) air tests on I/E components and subassemblies
• Maximum available air flow rate 0.65 kg/s at 8 bar
• Particularly suitable to test automotive turbochargers: two independent feeding lines available for the TC turbine and compressor
• Electrical air heating modular system (max power 320 kW)
• In the case of turbine investigations the turbocharger compressor acts as a dynamometer and proper experimental techniques are used to extend the definition of turbine characteristics
• Turbine and compressor performance can also be investigated under unsteady flow by using two different pulse generator systems:
  ➢ Rotating valves pulse generator
  ➢ Cylinder head pulse generator

<table>
<thead>
<tr>
<th>AF</th>
<th>Air Filter</th>
<th>LM</th>
<th>Laminar Flow Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>AH</td>
<td>Air Heater</td>
<td>PC</td>
<td>Pressure Control</td>
</tr>
<tr>
<td>AR</td>
<td>Air Reservoir</td>
<td>PG</td>
<td>Pulse Generator System</td>
</tr>
<tr>
<td>APH</td>
<td>Air Pre-Heater</td>
<td>SC</td>
<td>Screw Compressor</td>
</tr>
<tr>
<td>C</td>
<td>Compressor</td>
<td>T</td>
<td>Turbine</td>
</tr>
<tr>
<td>LC</td>
<td>Lubricating Circuit</td>
<td>TM</td>
<td>Thermal Mass Flow Meter</td>
</tr>
</tbody>
</table>
Rotating Valves Pulse Generator System

- Designed to perform parametric studies (effect of unsteady flow parameters on component performance)
- Tests on single and two-entry devices allowed
- Pulsating flow generated by diametral slot rotating valves
- Easy control of pressure pulse parameters (amplitude, mean value) at each device entry by controlling the upstream plenum pressure and by properly mixing a steady and a pulsating flow component
- Pulse frequency can be adjusted in the typical range of automotive I/E circuits (10-200 Hz)
- Unequal admission and not-phased pulsating flow conditions can be reproduced when testing two-entry devices
Cylinder Head Pulse Generator System

Application to the turbine circuit

- Designed to investigate engine intake and exhaust subsystem behaviour under unsteady flow conditions, including the effect of:
  - circuit geometry
  - valve actuation strategies

- The system is based on a motor-driven cylinder head connected to a device designed to reproduce the engine cylinder block

Application to the compressor circuit

- The cylinder head can be fitted with a fully flexible VVA system
Experimental definition of TC maps

- Measurement of turbocharger steady flow maps over an extended range to improve simulation models results
- Experimental techniques to extend turbocharger steady flow curves
- Turbine performance defined considering the effect of waste-gate valve or VGT
- Turbine efficiency decreases when the waste-gate valve is open (if isentropic power is referred to the total mass flowing through the system)
Turbine unsteady performance

- At typical pulsating flow frequencies occurring in the exhaust system of automotive engines the pulse is so rapid that mass flow does not have enough time to incrementally fill the volute volume with pressure → hysteresis loop
- Deviation of unsteady efficiency from the steady state values
- Loop area variation by changing pulse frequency and waste-gate valve opening

\[ \frac{n_t}{\sqrt{T_3}} = 6000 \text{ rpm/} \sqrt{K} \]
\[ p_{S_{3\text{mean}}} = 1.8 \text{ bar} \]
\[ \alpha_{WG} = 63 \]
2-cylinder configuration

- Significant deviation from steady state resulting in a hysteresis loop surrounding the steady state
- Surge line shifting towards lower mass flow rate levels
- Compressor stable zone enlarged under heavier unsteady flow conditions
Heat transfer effects

- At low \( n_{TC} \), compressor is strongly affected by heat transfer from turbine and oil casing → compressor outlet temperature (\( T_{T2} \)) results overestimated
- Significant impact of heat transfer on both compressor and turbine (termo-mechanical) efficiency

\[
\eta_c = \frac{T_{T2s} - T_{T1}}{T_{T2} - T_{T1}}
\]

\[
\eta_t = \eta_{TS} \cdot \eta_{mTC} = \frac{P_i}{M_{tot} \cdot \Delta h_{st}} \cdot \eta_{mTC} = \frac{P_c}{M_{tot} \cdot \Delta h_{st}}
\]

- Development of a specific model to correct TC maps for heat transfer
Modelling activities in GT-Power

Specific studies on turbocharging systems aimed at deepening and improving GT-Power interpolation and extrapolation procedure of turbocharger performance maps and engine-turbocharger matching

- Characteristic curves extension
- Improvement of variable geometry and waste-gate turbine modelling
- Extrapolation of compressor curves on the left side of the surge line
Specific studies on turbocharging systems aimed at deepening and improving GT-Power interpolation and extrapolation procedure of turbocharger performance maps and engine-turbocharger matching

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Investigation topics for efficient engine turbocharging

- Correlation between hot and cold turbine maps
- Direct measurement of turbine isentropic efficiency
- Heat transfer phenomena within the turbocharger (air-oil-water-exhaust gases)
- Evaluation of turbocharger mechanical losses
- Optimization of TC regulating device control (waste-gate, VGT) under unsteady flow conditions
- Effect of unsteady flow and transient operation on compressor and turbine performance
- Compressor surge detection and active control
- Interactions between EGR and turbocharging circuits
- Effect of aftertreatment device position on turbocharger performance
- E-boosting systems
- Subassembly characterization (TC + engine I/E circuit)
- .....
Some ICEG References on I/E Components

Assessment of road vehicles environmental impact in real-world conditions
The main investigations developed in this field are focused on:

- Definition of hot and cold exhaust emission factors for pollutants (CO, HC, \( NO_x \), \( NO_2 \), \( CO_2 \) and PM) referred to different vehicle categories (passenger cars, light and heavy duty vehicles, buses, motorcycles, mopeds, waste collection vehicles)

- Development of experimental and/or statistical methodologies for the assessment of the real circulating fleet and mileage and the definition of typical trips with the relevant driving characteristics

- Development and application of a dedicated theoretical model (PROGRESS code) to predict the environmental impact of road vehicles in urban areas

Next step:

- Vehicles modeling in GT-Suite environment to compare emissive and energy behavior on different driving cycles
Motorcycles and mopeds behavior in cold start and hot conditions (in co-operation with Istituto Motori-CNR)

- Analysis of the influence of driving cycles and real world speed patterns on hot and cold emission factors
- Effects of engine and catalyst operation on exhaust emissions in the cold transient phase

Genoa experimental speed patterns

Measured levels of speed above UDC and comparable to WMTC
RPA levels (that is, cycle dynamics) significantly higher in real conditions
Motorcycles and mopeds behavior in cold start and hot conditions (in co-operation with Istituto Motori-CNR)

CO cumulative emissions, relative air/fuel ratio and catalyst temperature during a real world driving cycle

<table>
<thead>
<tr>
<th>Driving cycle/speed</th>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
<th>Fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 47</td>
<td>68.8</td>
<td>72.9</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>IUFC (real world)</td>
<td>32.3</td>
<td>53.5</td>
<td>27.8</td>
<td>6.9</td>
</tr>
<tr>
<td>24-slow (Genoa speed)</td>
<td>39.5</td>
<td>52.3</td>
<td>26.2</td>
<td>9.3</td>
</tr>
<tr>
<td>3-slow (Genoa speed)</td>
<td>35.6</td>
<td>48.4</td>
<td>6.9</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Cold contribution as percentage of the total emission and fuel consumption on different driving cycles – Euro 2 moped
Definition of HDV daily flows through highway exits and share of vehicles entering port terminals

Classification of vehicles involved in port activities referring to type, mass range and number of axles
Acquisition and processing of instantaneous speed related to the typical trips in urban zones (highway exit – port gates) and within the port area

Average speed in port area = 4.4 km/h, idling time = 74%, travelled distance = 6.6 km

Application of PHEM to the experimental speed profiles to estimate fuel consumption and emission factors for selected HDV classes
Recent papers from ICEG on road vehicle emissions


- G. Zamboni, M. André, Evaluation of emissions and fuel consumption of Heavy-Duty Vehicles in urban areas, 21st Transport and Air Pollution Conference, Lyon, 24-26 May 2016.
Thank you for the attention!

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