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Reduction of fuel consumption and pollutant emissions from vehicles

Implementation of low-temperature diesel combustion and development of an advanced central tire inflation system

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Abstract

The high level of greenhouse gases as well as the presence of anthropogenic toxic gases in the atmosphere are responsible for climate change and diseases, and the transportation sector is recognized as one of the root causes of these issues. For this reason, the need for reduction of pollutant emissions and fuel consumption from vehicles has leaded the technological innovation in the automotive field, at least in the last sixty years. These topics can be addressed both through engine (or power unit) technologies and vehicle technologies, the first related to the process that leads to the production of mechanical power on-board, the latter referring to the vehicle power demand, i.e. how the mechanical power available from the engine is managed to overcome resistances. This dissertation presents a research work developed to address both these topics, and to assess the combined effect of two technologies, one related to combustion engines and the other related to the reduction of vehicle power demand. Specifically, the PhD activity here presented has developed two main projects in parallel: on the engine side, the aim of the research activity was the implementation of a non-conventional diesel combustion strategy, namely a premixed-charge compression ignition (PCCI) combustion mode, as a way to abate the production of soot and nitrogen oxides in the cylinder; on the vehicle side, the project work has been devoted to the development of an automatic system for smart management of tire pressure on board and to assess the effects of tire pressure on vehicle energy demand and fuel consumption. Finally, the combined effect of the two technologies has been assessed through simulations on a light-duty commercial vehicle.

More in detail, the potentialities of the abovementioned PCCI combustion has been experimentally assessed first on a production diesel engine for light-duty commercial vehicles, and later applied to a prototype version of the same engine, developed on-purpose to extend the range of application of the PCCI combustion mode. By means of a single early injection strategy and a high EGR rate, and keeping the overall air-fuel mixture in a narrow lean range close to the stoichiometric condition (i.e., $\lambda =$ 1.1-1.35), it was possible to implement on the prototype engine the PCCI combustion mode up to 8.5 bar bmep and 3000 rpm. In this area, that is almost half of the speed-load map of the engine, it was possible to reduce by more than 85% the engine-out emissions of nitrogen oxides (NOx) and by more than 90% the soot engine-out emissions. Nevertheless, this also produced an increase of fuel consumption by 3-11% and a high increase in the emissions of unburned hydrocarbons (HC) and carbon monoxide (CO), which have been partially treated through a diesel oxidation catalyst. Mayor issues are highlighted at low engine load, where the catalyst does not reach the light off temperature due to the low temperature of the exhaust gases.

In order to improve the control over the combustion process, aiming at the enhancement of the application of PCCI combustion mode, combustion phasing controls have also been tested and models for the accurate control of EGR flow rate have been developed. These topics have been implemented and tested on the original production engine only, both under conventional diesel combustion and under PCCI combustion. The results of these activities, and their potential benefits on PCCI combustion, will also be discussed in this thesis.

For what concerns the reduction of vehicle power demand through the automatic management of tire pressure, the project was first developed on a passenger car, which included the design and test of a dedicated system to be installed on board, and the assessment of the potential effects of tire pressure management on driving cycles and on an annual mission. For passenger cars, the potentiality of this technology has been assessed as a reduction of 1-1.4% in fuel consumption on an annual basis, and up to 2.8% if the reference case is a common misuse condition. Then, the study has been extended and replicated on a light-duty and a heavy-duty commercial vehicle. For this purpose, a software tool was specifically developed to assess the effect of tire pressure on vehicle energy demand and fuel consumption, being this software designed to include the tire pressure as a variable parameter to be set for each simulation, and possibly also variable along a simulation. The fuel economy improvement obtainable on an annual basis through this kind of technology was estimated in 1.7-1.9% on a heavy-duty truck and of 1.7-2.1% on a light-duty commercial vehicle, if the reference case for comparison is a common misuse condition. Also for commercial vehicles, a dedicated system layout and its integration on board have been discussed and a preliminary design is reported in this dissertation.

Finally, the combined effect of the two technologies on a light-duty commercial vehicle has been simulated on some reference driving cycles and on annual missions. PCCI combustion has proved to reduce NOx emissions by up to 20-73%, and soot by 32-78%, in highway and urban driving respectively. A significant increase in engine-out HC and CO emissions is remarked, although the tailpipe emissions with warm engine are estimated below Euro VI limits. The increase in fuel consumption due to PCCI combustion is estimated as 1.6-2.4% on an annual basis, and can be largely mitigated by the introduction of an automatic tire pressure management system. Considering also side benefits, i.e. the reduction of tire wear and urea consumption, the combined effect of the two technologies would lead to a reduction of the total cost of ownership of the vehicle, which would make these technologies of interest for the market of commercial vehicles.