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Thesis Title: Alternative fuels and combustion modes to lower pollutant emissions from conventional internal combustion engines

PhD cycle: 29th **Tutor(s)**: E. Spessa, D. Misul

Abstract

The present thesis covers the utilization of alternative fuels and combustion modes in production internal combustion engines to face the problem of pollution and energy diversification in the automotive sector. In particular, the first part deals with alternative fuels in conventional combustion mode in spark-ignition engines, whereas the second part concerns conventional diesel fuel with non-conventional PCCI combustion mode in compression-ignition engines.

More into details, the first part pertains to the usage of alternative fuels with conventional combustion in spark-ignition internal combustion engines, such as bio-gas and hydrogen-enriched compressed natural gas and, in particular, with the need to identify which kind of fuel blend is present in the vehicle tank, since engine performance and emission strongly depends on the fuel mixture composition being fed to the engine.

The production of HCNG from biomass results in a wide range of possible gas mixtures, having a strong impact on engine performance and emissions. The research work conducted in the first part of this thesis focused on finding an algorithm capable of identifying which mixture is actually injected into the engine starting from data readily available from the engine control unit. The scenario in which the vehicle is fueled at the gas station with an unknown mixture composition has been replicated on test bench by using different fuels. Data acquired were used to build and validate the recognition method. Given a possible set of mixtures, the algorithm computes the relevant thermo-physical properties and using data from the engine control unit, like air-mass flow at the intake, estimates an injection duration. A subset of the sample blends that represents the possible variety of mixtures that could be present in the vehicle tank has been chosen. The mixture that shows the minimum error in terms of injection duration, from a comparison of the estimated injection duration with the one actuated by the engine control unit, is then identified as the actual one. The algorithm showed a very good prediction capability with the test fuel blends, with a maximum uncertainty of 5% on hydrogen content on HCNG blends. The recognition algorithm converges after less than 10 different engine working conditions, expressed in terms of speed and load. The candidate set has been extended to a full factorial set of 2 million blends, to validate the ability of the recognition method to correctly match the real fuel.

The second part is devoted to the study of a premixed-charge compression ignition (PCCI) combustion mode in a 3.0L Euro VI heavy-duty diesel production engine, focusing on statistical

techniques exploited to optimize pollutant emissions and performance. Furthermore, a preliminary study of pressure-based combustion control technique has been conducted to evaluate if it has all the necessary features to be implemented during PCCI operations.

This kind of non-conventional combustion has been achieved by anticipating the start of injection and recirculating high amounts of exhaust gas in the intake manifold. The result is a highly premixed and diluted charge, which lowers significantly the in-cylinder temperature during the combustion, thus avoiding the formation of soot and of nitrogen oxides in the charge. As a first step, preliminary tests have been run on different engine working points, in order to identify which control variables are the most influential and in which range they can be varied to achieve the PCCI conditions. As a second step, an experimental campaign has been conducted, following a Design of Experiment (DoE) approach. Based on these results, quadratic regression models have been fitted. The models have been then validated on experimental points, providing a good prediction capability. As a last step, single-objective and multi-objective optimizations have been performed, in order to find a proper combination of the input factors that satisfied the desired values for the outputs. Optimal points have been experimentally replicated and compared to the standard engine calibration. A strong reduction (up to 94%) of NO_x and Soot has been observed, while penalties in CO and HC (up to 10 times compared to the standard calibration), bsfc (up to 13%), and CN have been noticed. The increment in CO and HC can be addressed by using a proper after-treatment system, while bsfc and CN represent the major drawbacks of this kind of combustion. Aiming to further optimize and control the combustion process, preliminary tests implementing a pressure-based approach to control the phasing of the combustion have been run in PCCI mode, showing high potentialities, especially as far as cyclic and cylinder-to-cylinder variation are concerned.