# DIPARTIMENTO DI INGEGNERIA
# CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE - PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING - 34TH CYCLE

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| Title of the research activity: | Development of innovative combustion systems for the reduction of polluting emissions and energy consumption by ICEs, and of methodologies for the analysis of their behavior and their production. |
| State of the art: | The process of technological development of internal combustion engines (ICEs) is nowadays driven by two main factors consisting in the need to reduce polluting emissions harmful to human health, and the need to reduce the specific consumption of the engines and therefore to limit CO2 production.<br>This development is the consequence of the imposition of increasingly stringent regulations concerning emissions (carbon monoxide, unburnt hydrocarbons, particulates and nitrogen oxides [1]), both for engines used for transport vehicles and for stationary power plants for electricity generation or cogeneration systems.<br>The transition to a type of economy completely independent from fossil fuels is not possible immediately; therefore, a phase of gradual transition from internal combustion engines to the large-scale use of electric motors and the exploitation of renewable energy sources is necessary.<br>In the context of this transition, there is a need to pursue a research work on the various types of ICEs in order to understand even more deeply the various phenomena underlying the conversion of energy, with a view to developing subsystems aimed at maximizing the efficiency (with lower CO2 production) and the limitation of the production of pollutants in the combustion chamber in order to reduce the quantity of chemical species to be converted in the aftertreatment systems. |
| Short description and objectives of the research activity: | The research project concerns the study of physical phenomena occurring inside the engine, with particular reference to ignition systems and low temperature combustion systems, and their optimization through the use of advanced systems and concepts. This path will be divided into an initial phase of analysis of publications on the state of the art in the engine industry and in the subsequent phases of instrumentation and equipment integration for experimental research such as those present in the laboratories of the Engineering Department of the University of Perugia. Moreover, results will be produced for a comparison with the CFD numerical simulations. Finally, particular attention will also be given to the development of methodologies and tools for the analysis of systems behavior, as long as to industrial production systems.<br>The two main areas of research are:<br>- The study of the behavior of spark ignition (SI) engines operating with lean and/or strongly diluted mixtures (lean combustion [2]), such that high thermal efficiencies can be achieved. In such cases the operating limits are given by approaching unstable conditions described by factors such as the IMEP COV (Coefficient of Variation of Indicated Mean Effective Pressure). To extend these limits, innovative ignition systems such as multiple spark systems, corona-effect ignition systems (e.g. ACIS - Advanced Corona Ignition System [3-6]) or microwave [7-8] are used, in order to overcome the intrinsic problems of conventional ignition systems.<br>- The use of low temperature combustion (LTC - Low Temperature Combustion [9]). Compression ignition (CI) engines have a generally higher efficiency than spark-ignition engines, but in the standard operating regimes with lean mixture, large quantities of nitrogen oxides are formed due to the high temperatures that ensure the activation energies for the dissociation of chemical species into polluting products such as NOx. Due to the presence of areas in which there is a locally rich mixture, on the other hand, particulate matter formation occurs, therefore the compression of a homogeneous or premixed charge at reduced temperatures would allow the simultaneous reduction of both main pollutants together with the improvement of overall efficiency due to a lower heat flux transferred from the working fluid to the chamber walls. |

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| | As part of the present research project, different technologies, potentially able to allow the increase of global efficiency and the reduction of emissions, will be tested. Pursuing the two above mentioned lines, the performance of ignition prototype systems for SI engines will be analyzed. A system designed to enable innovative low temperature GCI combustion processes will also be implemented and studied. Experimental research may possibly be accompanied by evaluations in terms of numerical CFD-3D simulations [10-12].<br>The project will be able to exploit equipments and systems supplied by the Engineering Test Laboratory of the Engineering Department of Perugia.<br>As far as LTC research is concerned, the transformation of the optical access engine is planned in order to use a typical diesel common-rail system for the high pressure injection of gasoline. The injection system is managed through a system based on SW-controlled input / output cards developed as part of this research.<br>On the optical access engine, which will also be used, in another configuration, to analyze the corona and / or microwave ignition system, it is possible to perform non-intrusive observation of the internal cylinder combustion processes. This analysis is possible through the use of a high-speed camera (up to 106 fps) and a subsequent post-processing phase of the images through calculation codes developed on site. This methodology is particularly useful for the analysis of the evolution of the flame front [13,14] in its early propagation phases, in which the phenomenon is so rapid that it requires high temporal and spatial resolutions.<br>Last but not least, cyclic dispersion phenomena are expected to be investigated (thanks to high speed acquisitions extended for several cycles), which are characteristic of internal combustion engines and can limit their functioning in many operating points, through synchronized acquisitions of both images of the evolution of the deflagration front, and of the combustion parameters that can be calculated on the basis of the measurement of the internal cylinder pressure values. |
| Bibliography: | 1. Mariani, F.; Grimaldi, C.N.; Battistoni, M.; 2014, "Diesel engine NOx emissions control: An advanced method for the O2 evaluation in the intake flow", Applied Energy, 113, 576-588.<br>2. Aleiferis, P.G.; Taylor, A.M.K.P.; Ishii, K.; Urata, Y.; 2004, "The nature of early flame development in a lean-burn stratified-charge spark-ignition engine", Combustion and Flame, 136, 283-302<br>3. Alger, T.; Gingrich, J.; Roberts, C.; Mangold, B. et al.; 2013, "A High-Energy Continuous Discharge Ignition System for Dilute Engine Applications", SAE Technical Paper 2013-01-1628<br>4. Pancheshnyi, S.V.; Lacoste, D.A.; Bourdon, A.; Laux, C.O.; 2006, "Ignition of Propane-Air Mixture by a Repetitively Pulsed Nanosecond Discharge", IEEE Transactions on Plasma Science, 34, 2478-2487<br>5. Cimarello, A., Grimaldi, C.N., Mariani, F., Battistoni, M., and Dal Re, M., “Analysis of RF Corona Ignition in Lean Operating Conditions Using an Optical Access Engine,” SAE Technical Paper, 2017-24-0673<br>6. Cimarello, A., Cruccolini, V., Discepoli, G., Battistoni, M., Mariani, F., Grimaldi, C., and Dal Re, M., “Combustion Behavior of an RF Corona Ignition System with Different Control Strategies,” SAE Technical Paper, 2018-01-1132<br>7. Nishiyama, A. and Ikeda, Y., “Improvement of Lean Limit and Fuel Consumption Using Microwave Plasma Ignition Technology,” SAE Technical Papers, 2012-01-1139<br>8. Ikeda, Y., Padala, S., Makita, M., and Nishiyama, A., “Development of Innovative Microwave Plasma Ignition System with Compact Microwave Discharge Igniter,” SAE Technical Papers, 2015-24-2434<br>9. Mao, B., Chen, P., Liu, H., Zheng, Z., and Yao, M., “Gasoline compression ignition operation on a multi-cylinder heavy duty diesel engine,” Fuel 215, 339–351<br>10. Battistoni, M.; Grimaldi, C.N.; 2012, "Numerical analysis of injector flow and spray characteristics from diesel injectors using fossil and biodiesel fuels", Applied Energy, 97, 656-666<br>11. Battistoni, M.; Grimaldi, C.N.; 2010, "Analysis of Transient Cavitating Flows in Diesel Injectors Using Diesel and Biodiesel Fuels", SAE Int. J. Fuels Lubr. 3, 879-900<br>12. Battistoni, M., Grimaldi, C.N., Cruccolini, V., Discepoli, G., and Cesare, M. De, “Assessment of Port Water Injection Strategies to Control Knock in a GDI Engine through Multi-Cycle CFD Simulations,” SAE Technical Paper, |

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| | 2017-24-0034<br>13. Merola, S.; Sementa, P.; Tornatore, C.; 2011," Experiments on knocking and abnormal combustion through optical diagnostics in a boosted spark ignition port fuel injection engine", International Journal of Automotive Technology, 12, 93−101<br>14. Donadio, G.; Poggiani, C.; Rondoni, L.; Grimaldi, C.N.; De Cesare, M.; Bellato, N.; 2014, "Combustion Analysis in an Optical Access Engine", Energy Procedia, 45, 959-966 |
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