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

Title of the research activity:	Development and implementation of CFD-3D methodologies for the analysis of innovative combustion systems for the reduction of polluting emissions and energy consumption by ICEs.
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. 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. 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. In the context of this transition, there is a need to pursue a research work on the various types of ICE 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 that is proposed concerns the study of physical phenomena that take place inside the engine, with particular reference to ignition systems and low temperature combustion systems, and their optimization through the use of innovative systems and advanced concepts. This path will be divided into an initial phase of analysis of publications on the state of the art in the field of numerical simulation CFD codes. The two main areas of research are: - 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 or 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. - 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 formation occurs, therefore the use of a compression by compression of a homogeneous or premixed charge at reduced temperatures would allow the simultaneous reduction of both the main pollutants together with the improvement of overall efficiency due to a lower flow of heat transferred from the working fluid to the walls of the chamber. As part of the present research project, it will therefore proceed to test different technologies potentially able to allow the increase of global efficiency and the reduction of emissions. Pursuing the two above mentioned strands, the performance of ignition prototype systems for SI engines (controlled ignition) will be analyzed, as well as a system designed to enable innovative low temperature

	GCI combustion processes to be implemented. We also propose to develop fluid dynamic simulation models (CFD-3D [10-12]). They will run on high performance computing platforms (HPCs) as large-clusters for massive computation, so as to exploit the predictive potential of sophisticated models that are generally overly expensive for standard computational platforms, often affected by arbitrariness due to compromises and simplifications traditionally present in applied engineering. The activity will be carried out to deepen the study of three-dimensional, non-stationary, multi-phase and chemically reactive flows, such as those typical of direct injection of fuel in the chamber, as well as mixtures diluted with flue gases. At the same time, the possibility of modeling the electromagnetic emission of innovative igniters [13] in a direct or indirect way through the use of their energy emission will be analyzed. For running such simulations, it is necessary to have a large number of processors connected in parallel to obtain useful results in a reasonable amount of time. In addition to the computational resources available at the University which will be used for the development of the models and for pre- and post-processing phases, further resources will be provided by Cineca (Bologna) and Argonne (Chicago).
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. 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 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 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 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 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 7. Nishiyama, A. and Ikeda, Y., "Improvement of Lean Limit and Fuel Consumption Using Microwave Plasma Ignition Technology," SAE Technical Papers, 2012-01-1139 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 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 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 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 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, 2017-24-0034 13. Scarcelli, R., Zhang, A., Wallner, T., Breden, D. et al., "Multi-dimensional Modeling of Non-equilibrium Plasma for Automotive Applications," SAE Technical Paper, 2018-01-0198
Scientific coordinator (s)	C. N. Grimaldi, M. Battistoni, F. Mariani
Contact (s)	Carlo.grimaldi@unipg.it, michele.battistoni@unipg.it, francesco.mariani@unipg.it