DIPARTIMENTO DI INGEGNERIA
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE - PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING - 36TH CYCLE

Title of the research activity:	Development of innovative combustion systems for internal combustion engines, aimed at reducing pollutant emissions and energy consumption.
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 pollutant emissions harmful to human health, and the need to reduce the specific consumption of the engines and therefore to limit CO_2 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 internal combustion engines (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 CO_2 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, in particular non-equilibrium plasma ignition and low temperature combustion, 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. CFD-3D numerical simulations of the combustion generated by these concepts will be performed as well, and a tuning of the models will be carried out thanks to a comparison with experimental data. 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. 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, corona-effect ignition systems (e.g. ACIS - Advanced Corona Ignition System [3-6], and BDI – Barrier Discharge Igniter [7]) or microwave [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 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. 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. The physical comprehension of the phenomena will be helped by the use of CFD-3D simulations [10-12]. The project will be able to exploit equipment and systems supplied by the Engineering Test Laboratory of the Engineering Department of Perugia. 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. 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 1 Mfps) 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 [13,14,15] in its early propagation phases, in which the phenomenon is so rapid that it requires high temporal and spatial resolutions. Last but not least, cyclic dispersion phenomena are expected to be investigated (thanks to high speed acquisitions extended for several cycles) [16], 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. The analysis of innovative ignition systems will be performed not only with an experimental approach, but also with numerical simulations [17]: models will be set up for the implementation of the particular types of igniters, that are often characterized by different shapes, materials, and operational behavior. The ignition system itself will be studied as well in terms of mechanical (both static and dynamic) characterization; the electromagnetic behaviour will also be analyzed and optimized. The different approaches and analyses can be considered separately or in conjunction in the proposed projects.
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