INTRODUCTION

The Diesel Engine Design – DED - Ph.D. program is a crossover academic path that point out to achieve the basic steps to define an integrate engine design methodology that is able to melt both the structural and performance aspects to obtain an innovative diesel engine that support hybridization for vehicle application.

The DED program is defined among the Doctoral School of Politecnico di Torino – PoliTo and the General Motors Powertrain Europe – GMPT-E – Advanced Engineering. Tutor from GMPT-E is Lorenzo Magro, Base Engine Technology Manager and Base Engine Architecture of Diesel Advance Engineering Department while tutor from PoliTo is Cristiana Delprete, professor of "Powertrain Components Design" and Supervisor of the "Design of Powertrain and Engine Components" research group of Mechanical and Aerospace Engineering Department of Politecnico di Torino.

The background to go through the program activities are a deep knowledge about structural engine design and a wide and exhaustive overview on both engine performance simulation and hybrid systems for vehicle application. To complete both my academic background and the DED background, I have attended several courses in Turin and around Europe.

Until now, there are not a bright way to design a new engine because the engine targets are not strongly linked with the marketplace or in other words with vehicle performance. With the DED program, it wants to bond the engine design with the customer requirements linked to it. To achieve this aim, it is necessary understand and define exactly the border of engine design to go towards the marketplace.

A car for 2020 may be a hybrid vehicle with a high attention to the fuel consumption and the CO_2 emissions, which has an attractive cost for the engine market – first of all China and India – with a high level of reliability. This means that this engine could be use as the main engine or as an internal combustion engine for a hybrid powertrain; it will have a strong attention at engine weight and consequently the material that it will use. And in the end, the technology used in the engine that will be a trade off among cost and engine performance in terms of torque, power, break specific fuel consumption, weight, emissions and components dimension.

The innovation introduced through the Ph.D. program to engine design is the development process starting from the evaluation of operational and geometrical characteristics of the engine to satisfy fuel consumption, pollutant emissions and performance requirements for a lead application and cost vehicle. Usually, a new engine is the evolution of an existing engine or just respect manufacturing requirements. In this thesis, in partnership with General Motors, the development process of new engine concept has been defined from green field to the first proto engine.

In according with Project Management – Body of Knowledge handbook, the development process of new engine concept could summarize in four stage: collection of draft ideas to obtain budget; dominant concept selection and development; dominant concept analysis and refinements; concept verification and handover to engineering process. Moreover, there are three cross – steps processes: budgeting, human resources allocation, and risk evaluation. The development process of new engine concept starts sharing the business strategic targets. Next, draft vehicle data as mass, drag and roadload coefficients, cost down characteristics, top speed and acceleration are included in the development process. This data come directly from the market and the new engine concept has to be able to satisfy customer requirements. In fact, the engine parameters to guarantee vehicle performance, consumption, pollutant emissions and engine cost, dimensions and mass are defined. Then the project manager makes the proposals of vehicles could equip with the new engine concept and ask to business board to certify the new technologies that are produced through the research activities. At this point, there is an important activity to highlight the new engine concept respects the project requirements and achieve the project targets. Next, the process is enlarged to the suppliers and in particular, that ones can be able to manufacture the new technologies find out during the research activities. Then the risk evaluation is completed and the risk management starts to analyze all possible scenarios as what happen if the project is not realized or what happen if it does not fit the project specifications, for instance. Meanwhile, the analysis and validation activity are carried out to be reliable and confident as much as possible about the structural and thermo-dynamic performance of new engine concept. The last two main activities are the intellectual property protection of research findings through copyright requests, and the documenting of new best practices find out during the development process.

The goals of the present thesis is the definition of a development process for new engine concept through which it could realize an internal combustion engine able to reduce CO_2 pollutant emission of 10%, engine mass of 15%, and cost of 20% in comparison to GMPT-E engine reference for this class of engine. Furthermore, the optimization of engine concept through some functional parameters that enhance both performance and design characteristic of new engine concept. For new engine concept, a new layout of valvetrain system has been applied and then it needs to characterize cinematically and dynamically. Finally, friction analysis of cam roller lubricated contact has been done.

The starting point of new engine concept development process are the customer needs, in terms of performance and vehicle dimensions, tried to find them out through market analysis, focused on hybrid vehicles, seen the importance of this technology on the automotive market development. Next, I investigate the worldwide market of hybrid vehicle to know what kind of vehicle support hybridization and in which way; then I classify the hybrid market by vehicle segment to understand equalities and differences among different segments. At this point, I move the focus from the vehicle to the powertrain system of a specific segment. So the next step is to investigate the powertrain systems of different vehicle into the same segment in terms of: ICE torque and power, electric motor torque and power, type of electric motor, number of cylinders, displacement.

Then, I analyze the new or different feature to support hybridization of internal combustion engine as hybrid system architecture, electric motors used in hybrid system, static electric converters and batteries technologies. In the end, I sum up the design methodology evolution of hybrid propulsion system from separated approach to merged one. Then I analyzed the optimal operation line of an internal combustion engine and energy flows in full hybrid system in follow modes: IC engine start, pure electric, regenerative breaking, booster, electric transmission, pure thermal, battery charge or auxiliary power and power split. And finally, I study the most used hybrid propulsion system in the sedan segment as Honda Integrated Motor Assist, Toyota Hybrid Synergy Drive, General Motors Hybrid and Two Mode Systems and Nissan Hybrid System. In the end I analyze the main engine components as cylinder block, liners, cylinder head, oil pan, piston, connecting rod and crankshaft in terms of functions, materials, manufacturing process, cost and technology.

After the customer chooses the dimensions and the shape of the vehicle, it is possible to simulate the vehicle performance and then verify if the engine performance satisfies the customer. This verification is possible through a synthetic mathematical model of vehicle dynamic I realize and I investigate the possibility to use commercial software as GT-Drive to implement the IC engine characteristic to verify if it achieves customer requirements of vehicle performance.

At this point, I define the deployment process from the customer requirements to the engine target setting. In particular, I have started with the engine concept generation and development process in according with Ulrich and Eppinger. Then I present the way to identify the dominant engine concept and the modification management process. Finally, I present the deployment process in detailed and the performance tree to link the voice of customers with technical specification of the engine as the target brake torque curve.

Next step, I develop the engine core through an archetype that contains all the references to be the starting point for engine design, and in particular for cylinder head and engine block. Primarily, the archetype takes account of manufacturing constraints as head block fasteners distance and inter-bore distance: in this way is possible identify bigger engine bore and through a research activity carried on by GMPT-E R&D on bore stroke ratio, the optimum stroke has been identified. Moreover, the archetype takes into account the principal structural constraints as inter-valves distance, injector and glow plug location, wall thick between ports and injector and, at the end, the distance among valve and cylinder liner. I estimate the valves dimension through the breath engine capacity index as the ratio between port reference area without valve stem and bore area. The reason of this index is the extreme difficulty to evaluate the volumetric efficiency in an embryonic phase of design; this parameter could guarantee the maximum engine filling. Through benchmarking activities I carry on, I work on index bore charts to identify an ambitious but real value of the index to implement into the archetype.

I realize a 1-D fluid-dynamic model of complete engine, integrating the data extract from archetype, to evaluate the engine concept capacity to generate performance. This model has been used to investigate several functional parameters as exhaust breath engine capacity to optimize the archetype, turbocharger screening activity to choose the best machine in terms of dimensions - technology - performance, cam profile effects on engine performance, peak firing pressure on engine performance and design.

Once the archetype of engine core concept has been defined and performance evaluated, it is possible to start with whole engine design. One of the innovative features of the concept is the new valvetrain system layout and then I have defined a methodology to analyze it. Valvetrain system is one of the key system for engine performance that involves several aspects as kinematic, dynamic and lubrication. The analyzed valvetrain system is from an existing engine but I have applied the developed methodology on a new engine concept valvetrain layout. The valvetrain system has been characterized by me both cinematically and dynamically through a multi-body model.

A deep literature review on cam – roller contact in valvetrain system subjected to elasto-hydrodynamic lubrication regime has been done by me. Two multi-body model of valvetrain have been realized by me. The first one in quasi-static mode has the aim to build up a tool to evaluate the kinematic characteristics of cam profile. Indeed, the second one has the targets of fully kinematic and dynamic characterization and extracting the kinematic and dynamic input data of lubricated elasto-hydrodynamic roller-cam contact. Then I have developed an elasto-hydrodynamic model of roller-cam contact to evaluate the oil film thickness through Grubin equation proposed by Rahnejat and Gohar, the viscous and boundary friction force and, in the end, the power loss. Both activities on valvetrain has been carried out at Loughborough Univeristy in the third year of Ph.D. program, within the Group of Dynamic of Wolfson School of Mechanical and Manufacturing Engineering under the supervision of Professor Homer Rahnejat.