1D Simulation and Optimization of a Formula SAE four cylinders engine

Formula SAE (Society of Automotive Engineers) is an international racecar competition which attracts engineering schools from around the world.

Formula SAE (Society of Automotive Engineers) is an international racecar competition which saw the participation of the University of Salento in the last three years (2006-2008-2009). For the races, two different cars were designed by the Salento Racing Team, a group of students dedicated to automotive design and production. Engine and powertrain simulation, prediction of experimental results and engine intake optimization are among the most important activities of the team's Engine & Drivetrain Division.

For the next car, the plan is to have it equipped with a four cylinder engine which will be optimized to comply with the general rules of the competition. One of these rules requires to place a 20 mm restriction along the main intake duct with the purpose of reducing power at highest engine speeds. The first step of the simulation work was to create a correct and simple model of the engine in order to analyze all resonance phenomena occuring in both the intake and exhaust systems.

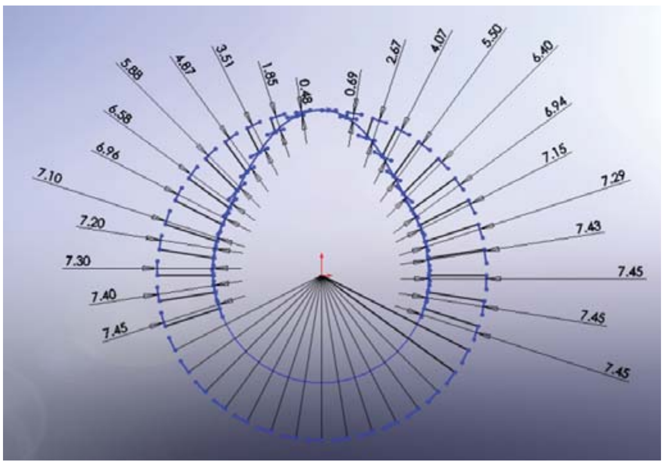

Fig. 1 - Cam profile reconstruction

The next step was to create a parametric version of this model, in order to allow a fluid and geometric optimization process of ducts and resonance plenum, with the aim to determine the main geometric values of previous systems. The planning of a future optimization is currently in progress which should define, in detail, the geometry of each component with the primary objective to achieve maximum performance in terms of engine torque and power.

1D AVL Boost model

Optimization results strongly depend on the accuracy of the 1D engine model. The 1D model has to be very accurate and simple at the same time to reduce computational cost. After a simulation of the original configuration of the engine, we chose a new exhaust system and a particular intake system layout suitable for achieving good values of torque for different engine speed. A variable intake system, with telescopic ducts, is the best choice to maximize inertial and wave effects in in-line reciprocating engines. This approach required measurements and a very good parametric CAD model of the intake and exhaust cams. A qualitative analysis of different general exhaust system layouts allowed to find a good compromise between many different solutions.

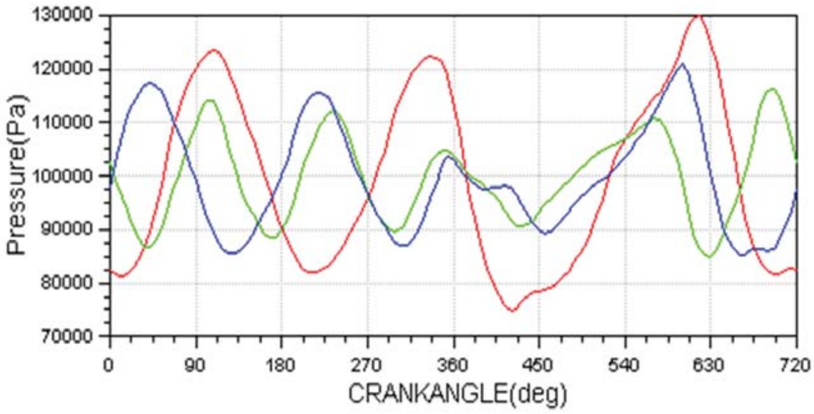

Fig. 2 - Waves behavior in the intake system for various engine speeds

During the system modeling phase, the focus was to describe perfectly the geometrical and the physical characteristics of the pipes and ducts. On the other hand, many other factors were not significant for this study; for example, the combustion phase was not modeled in detail as all results were referred to an open-valve analysis. The 1D model was created using AVL Boost© software.

Optimization strategy and objectives

The choice of input and output variables was important. We chose four general input variables and a single objective variable. A previous optimization was finalized to fix a reasonable volumetric capacity of the plenum, which is a large box of the intake system with a function to dampen the undesired effects of the restriction. The algorithm used is a traditional MOGA II genetic algorithm.

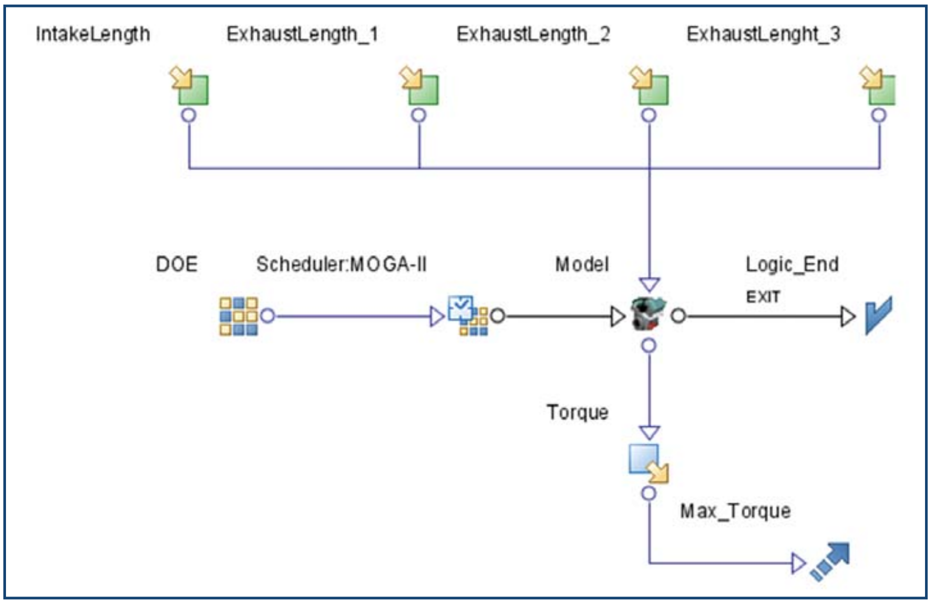

Fig. 3 - modeFRONTIER Flow Work

Torque is the output variable selected as the objective to be maximized and the length of the four pipes is the input variable. After these optimization phases, a new model was created with the new geometry of the ducts.
Each engine speed now had its optimized intake length. Therefore, a variable intake length control on the new AVL Boost model was implemented in order to predict the behavior of the engine. The optimization process also provided many different exhaust systems for different engine operating conditions. In our case, modeFRONTIER found the best compromise. The modeFRONTIER tools were very helpful during both the optimization and post processing phases.

Optimization results

The Optimization delivered an improved torque for a large range of engine speeds. In fact, the restriction on the main intake duct causes a drastic reduction of volumetric efficiency and engine torque (green line in Picture 4). The final solution was chosen in order to have a high torque at medium-low engine speeds. In fact, this is what is needed for the engine for this type of race. At medium-high engine speeds, performance worsening is acceptable because it preserves the engine structure and reduces friction losses related to fluid velocity.

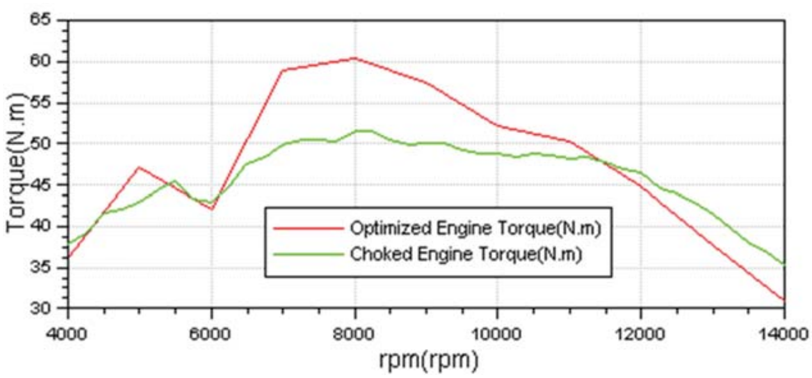

Fig. 3 – Engine performance after the optimization process

Conclusions and next steps

By using Optimization, a totally new behavior of the engine could be established, and an improved performance, compared to the choked configuration, could be achieved.

A 3D CFD simulation is now necessary to define in detail all the micro-aerodynamic geometries of every single component. Afterwards, a further 1D optimization phase will define the final layout of the exhaust system.

Matteo Tondo
Engineering Faculty of the University of Salento