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IMPLEMENTATION OF THE CLOSED-LOOP COMBUSTION CONTROL METHODOLOGY IN DIESEL ENGINES FOR LOW-END TORQUE INCREMENT BURNING BIODIESEL

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Within the cooperative research project DAX605 between GM Powertrain Europe and Istituto Motori - CNR, the interaction among fuel quality, engine calibration and turbocharger system was investigated. This research report summarizes the main results of the activity.

It is well known that from an environmental point of view, the use of biofuels can contribute to a significant well-to-wheel reduction of greenhouse gas emissions, in particular the use of the first generation biodiesel (FAME, Fatty Acid Methl Ester) for light duty diesel engine is desirable. Therefore, it is increasingly felt by the automobile industries, the search for new technologies in order to mitigate the impact of the use of biofuels on engines developed to be primarily feeding with mineral diesel; the main purpose is to minimize the negative consequence linked to biodiesel use.

For the automotive engine, one of the main negative aspect for the end-user, derived from the use of biodiesels, is the reduction of power output, observable from lowering of the maximum torque curve. This result is due to the reduction of about 10% of the lower heating value (LHV) of a FAME compared to a traditional diesel. It follows that a torque reduction is expected, at least of a similar amount. The problem is intensified, in turbocharged engine, at low speed for the so-called low-end max torque curve. In these conditions, the exhaust gas temperature fall, which is directly related to the reduction of energy released during the combustion (burning biodiesel), brings the turbocharger to the operating limits. The automatic response of the variable geometry turbocharger (VGT) to this temperature reduction is a more pronounced closure of the variable rack. At medium and high speeds this not represents a problem, but below a specific engine speed, where normally the VGT already works with the vanes much closed and very close to the limit position, the turbocharging system is no longer able to ensure the boosting level provided by the engine calibration. The reduction of boost pressure at low speed with the use of biodiesel is responsible for further engine max torque reduction. The combined effect of the two mechanisms described, at low engine speed, can account for a torque reduction up to 25% with evident consequences for the handling. The low-end torque curve reduction mainly affects small displacement engines that usually have turbocharging systems of modest performance.

The purpose of the activity was to evaluate the capability of the closed-loop combustion control system "Clean-Teach", patented and used by GM on its latest generation of EURO5 diesel engines, to annul the torque loss burning biodiesel, particularly at low engine speeds. This technology enables individual and real-time control of IMEP (Indicated Mean Effective Pressure), cycle-by-cycle and cylinder-by-cylinder. In particular, based on in-cylinder pressure traces, the electronic control unit (ECU EDC17) using proprietary algorithms, calculates the actual value for IMEP and then compares it to the target one. As a consequence, the deviations are continuously resettled by adjusting the main injection quantity for the following combustion cycle.

The experimental activity was carried out on the four-cylinder in-line 2.0L EURO5 diesel engine A20DTH, recently released by GM Powertrain whit "CleanTech" system. For details on the engine characteristics, see "Alternative Diesel Fuels Effects on Combustion and Emissions of an Euro5 Automotive Diesel Engine" (Guido et al., SAE paper 2010-01-0472).

The mineral diesel choose as reference fuel was the commercial diesel "ESSO E-Diesel", while the biodiesel was a RME (Rapeseed Methyl-Ester).

The engine tests were done at six engine speed: 1250, 1500, 1750, 2000, 2250 and 2500; in all test points the accelerator pedal position was 100%. Two engine operation modes were considered:

- OLC, whit imep control disabled;
- CLC, whit imep control enabled.

The most significant results of the low-end torque curve activity are shown in the following.

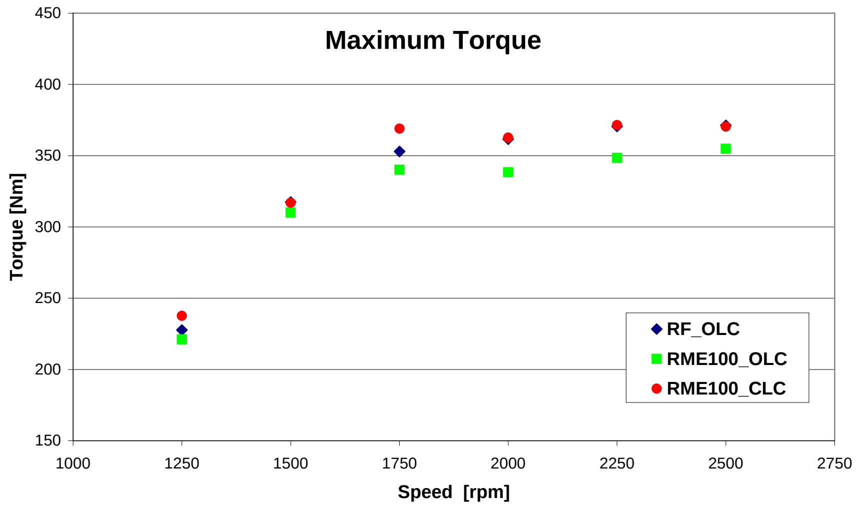

Fig. 1: Engine maximum torque curve comparison at different speed.

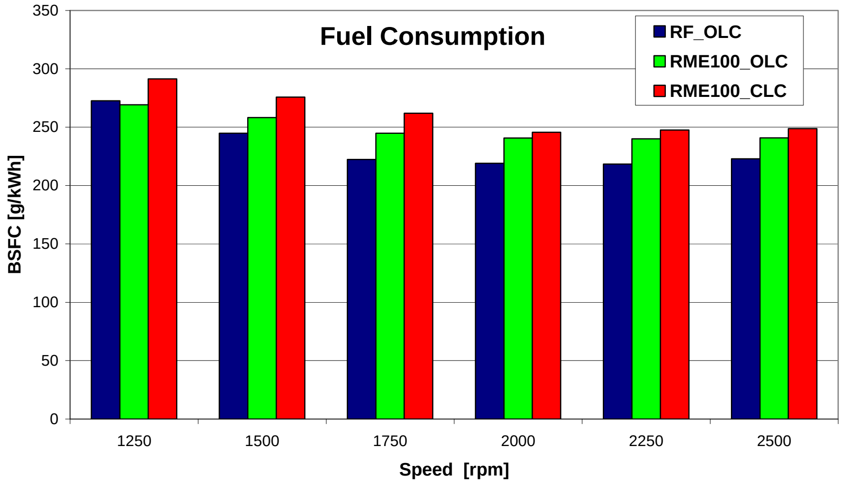

Fig. 2: Brake specific fuel consumption comparison at different speed.

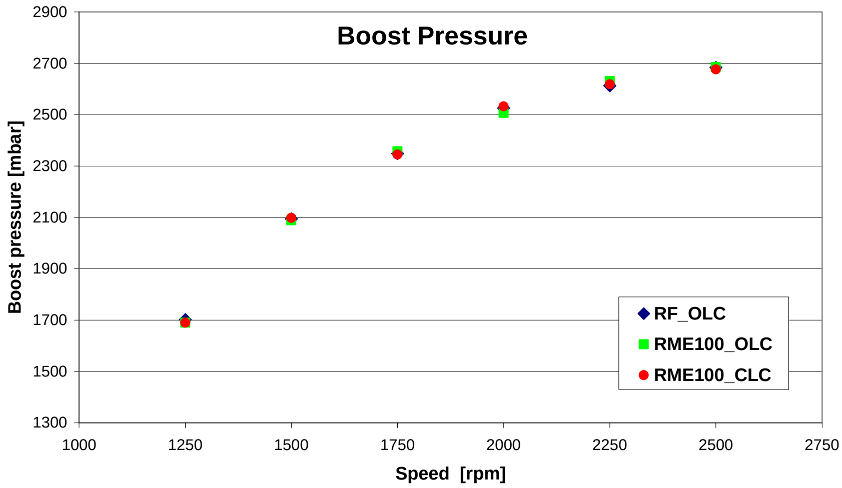

Fig. 3: Boost pressure comparison at different speed.

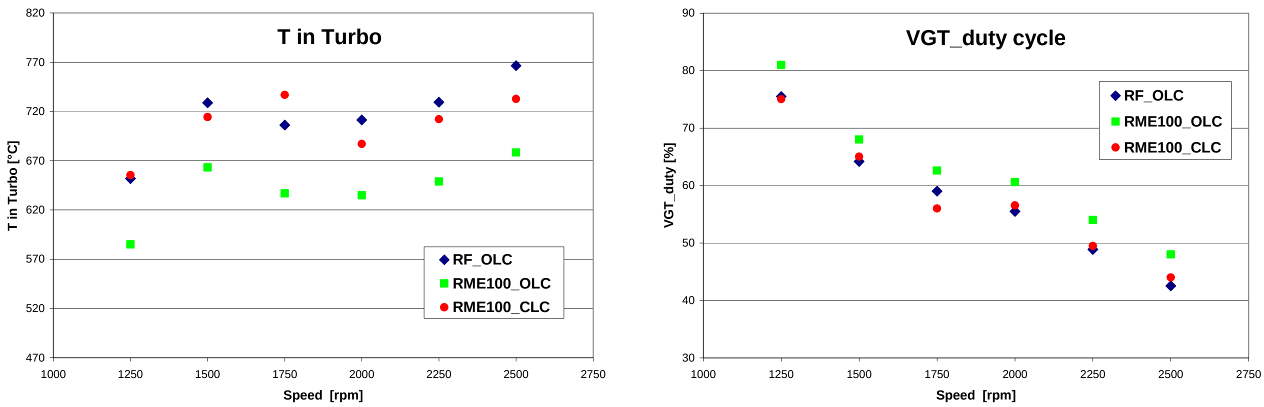

Fig. 4: VGT duty cycle percentage and exhaust gas temperature (turbocharger inlet) comparison at different speed.

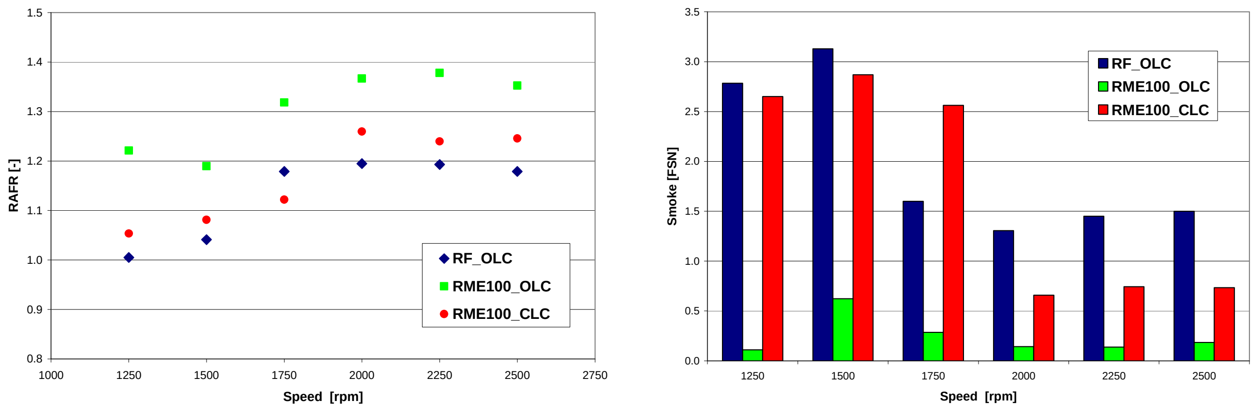

Fig. 5: Relative air to fuel ratio (RAFR) and smoke emissions comparison at different speed.

The diagrams show that in OLC operation mode there is a torque reduction burning FAME with respect to the reference fuel; at every engine speed the gap is approximately proportional to LHV penalty of biodiesel. In CLC mode the differences are reset, confirming the capability of combustion closed-loop control to compensate any influence of fuel properties on the engine maximum torque curve. Clearly, there is an increasing of the brake specific fuel consumption burning FAME at all speed in both operation mode: in OLC due to power output reduction, while in CLC due to fuel consumption increment.

The Figure 3 shows that the boost pressure for FAME is equal to reference fuel case also in OLC operation mode. This suggests that turbocharger is able to guarantee the boosting level even burning FAME, so that only the LHV penalty is responsible of maximum torque curve reduction. For the tested engine, the specific problem of low-end torque curve, linked to turbocharging system potentiality, was not found. Anyway the two diagrams in Figure 4 highlight the exhaust gas temperature reduction burning FAME in OLC mode and consequently the VGT duty cycle increasing (turbocharger vanes closing). The maintenance of the boosting level, burning FAME in OLC operating mode, is possible only for the specific good potentiality of the turbocharger that equips the tested engine.

The last two diagrams resume the internal chamber combustion condition in terms of relative air to fuel ratios and smoke emission level. For FAME is observable in OLC an increasing of RAFR and a big reduction of smoke; in CLC the RAFR values are similar to reference fuel ones and the smoke reduction, due to only FAME chemical property, is less.