STUDY ON THE COMBUSTION CONTROL FOR A COMPRESSION IGNITION ENGINE USING DIFFERENT INJECTION STRATEGIES

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Abstract. One tendency in the field of hybrid vehicles is the development of internal combustion engines specialized for driving electric generators, regarding range extender application [3]. The requirements of this application are: small fuel consumption, emissions within the imposed limits and last but not least, reliability [1], [2]. Most engine manufacturers for hybrid vehicles have oriented themselves towards spark ignition engines.

The paper analyses the limits and possibilities in which the burning process parameters and real cycle ones can be improved, for a compression ignition engine. The working regimes are set at constant load and speed, typical for the engines used for driving electrical generators.

The theoretical and experimental evaluations are realized on a single cylinder AVL 5402 engine.

The started research enhances the influence of the main parameters on the energetic performances of the engine cycle.

The results obtained will be used for the predevelopment of a diesel engine for a hybrid vehicle.

Keywords: injection; multiple injection; combustion; range extender.

1. INTRODUCTION

Stringent emission legislation and smaller fuel consumption have defined the optimization of internal combustion engines as the main task for the automotive industry in the future, since they will continue to play a major role in vehicle propulsion. Solutions today for internal combustion engine improvement include variable valve actuation (VVA), cylinder deactivation (CDA), both static and rolling, thermal management and other gas cycle related improvements by combining charging strategies with more than one turbocharger.

A particular attention must be paid upon exhaust after treatment devices, which are more complex for Diesel engines. However, modern engines using strategies for cutting down emissions and fuel consumption with start-stop systems, which are included in the hybrid category of vehicles, are in contradiction to classical exhaust gas after treatment systems, where a constantly high exhaust gas temperature is required.

Methods for achieving the exigent emission legislations in the future suppose a higher degree of electrification of the vital systems of the thermal engine, up to a complete hybridization of the propulsion system. So, the challenge is to find the right formula to efficiently combine the best of the thermal engines improvements and electric drive.

In this way, the paper wishes to propose the possibility of using a Diesel engine in a serial hybrid layout, with the focus on the advantages of this chosen configuration, which is sketched in figure 1 [3].

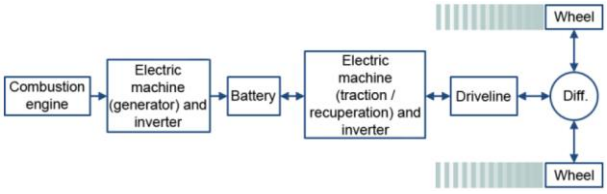

Fig. 1. The powertrain configuration of a series hybrid [3].

Since the combustion engine has no mechanical connection to the wheels, new potential design and layout options are conceivable [4].

Since the Diesel engine is used as a prime mover, only to generate electrical energy with the help of a

generator, and is not directly involved in the traction of the wheels, it may operate at a constant high thermal efficiency regime, thus improving the fuel consumption [6], [5].

The study will be carried on an experimental single cylinder AVL 5402 Diesel engine from the test cell of the Department of Automotive and Transport Engineering at Transilvania University of Brașov.

The possibilities of operation improvement of the tested engine for this application are based on modeling different injection strategies while evaluating the resulted exhaust gases.

2. APPLICATION REQUIREMENTS

The stabilized working regimes for other range extender units are different depending on the strategy chosen by the producer. The engines are usually small spark ignition and mainly run under full load, having at least two main operating points. One point may be at half of the power output at the crankshaft [4] and another at full power output when the charge level of battery is to be retained even at high speeds [4].

The proposed study follows two working regimes of speed and load for the experimental single cylinder compression ignition.

For the two working regimes, the injection parameters are modified such that the engine fulfills the initial conditions of load and speed.

The injection law can be modeled in terms of injection timing and duration of injection. The possibility to use multiple injections is also considered.

3. EXPERIMENTAL COMPRESSION IGNITION SINGLE CYLINDER TESTING

The main parameters of the compression ignition (CI) tested engine are presented in table 1.

Table 1. *Main parameters of the engine [7]*

Engine Parameters	Value
Bore	85 [mm]
Stroke	90 [mm]
Swept volume	510.7 [cm^3]
Offset from TDC	9.0 [mm]
Injector's number of orifices	5

The prepared engine used for the tests can be seen in figure 2 together with its equivalent model for simulation [7].

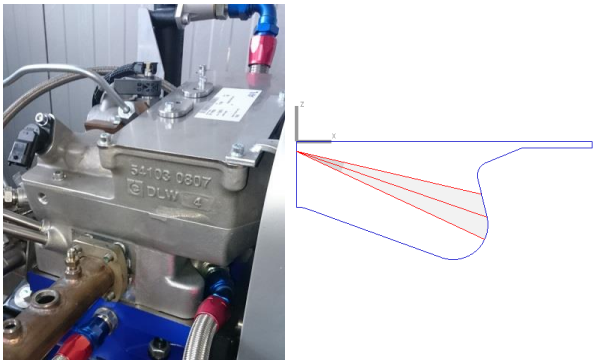

Fig. 2. The experimental engine and simulation setup.

The initial conditions for testing and testing regimes are presented in table 2.

Table 2. *Initial conditions for testing and testing regime*

Characteristics		
Atmospheric pressure at 600m alt.		0.95 [bar]
Room temperature		25 [°C]
	Test regime 1	**Test regime 2**
Dyno speed [rpm]	1500	3000
Dyno load [%]	75	75
Injection type	2 injections	2 injections
Fuel rail pressure [bar]	max. 1600	max. 1600

3.1. In-Cylinder Processes Evaluation

Data acquisition was performed with AVL hardware.

Figure 3 presents the evolution of the pressure inside the cylinder for the two testing regimes.

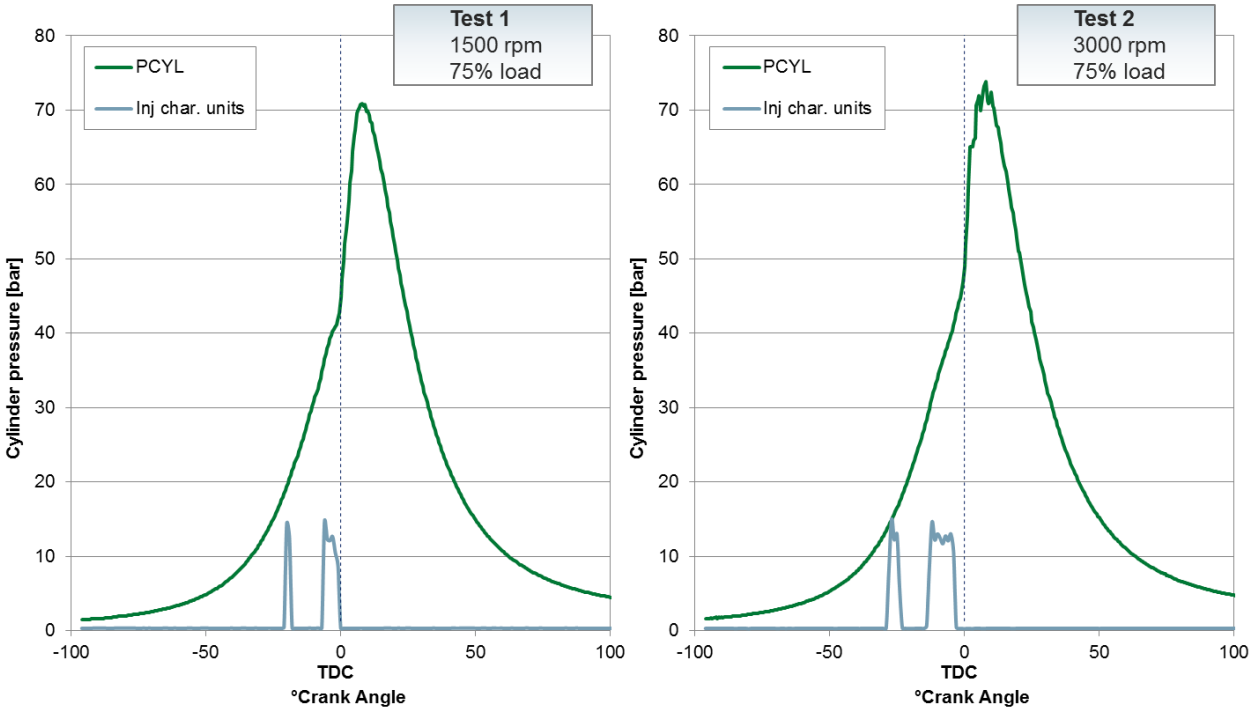

Fig.3. Cylinder pressure, injection duration and timing for the two testing regimes.

When choosing the working regimes for the experimental engine, the requirements for the electric generator application for range extender were considered. The injection modeling with two fuel injections per cycle was performed such that the resulted performances and emissions to be as good as possible. The summary of the results obtained can be observed in table 3.

Table 3. *Resulted engine performances and emissions*

Test results		
	Test regime 1 1500 rpm / 75% load	**Test regime 2** 3000 rpm / 75% load
Power output [kW]	3.7	6.05
Torque output [Nm]	23.5	19.4
Hourly consumption [kg/h]	1.092	1.849
Max. cylinder pressure [bar]	71	74
Lambda [-]	1.2	1.4
CO_2 [%]	11.9	10.1
CO [ppm]	3248	1216
NO [ppm]	789	839
NO_2 [ppm]	25	29
NO_x [ppm]	814	868

The engine runs at the synchronous speeds in both tests, but at different loads [6]. The speeds of 1500 rpm, respectively of 3000 rpm are one of the best suited speeds for driving electric generators. Using these speeds can also reduce complexity in the construction of a range extender.

The next most important result is the torque output, which should remain as constant as possible [6]. Figure 4 shows a better torque and power evolution for 75% loading of the engine.

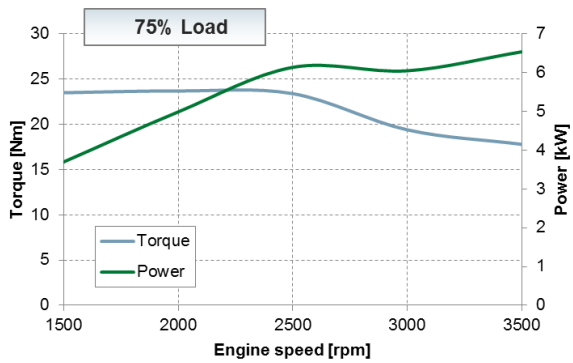

Fig. 4. Cylinder pressure, injection duration and timing for the two testing regimes.

The regime of testing at 75% load was considered instead of the 100% load due to concerns regarding safety and overloading of the engine components

The hourly consumption increases for the second regime tested, since the speed doubles and there is more fuel injected in the cylinder.

The air to fuel ratio (lambda in table) keeps close to stoichiometric and differs less from one tested regime to the other. This can be, on one hand beneficial, since the diesel after treatment is complex due to the excess of air in the exhaust gases. On the other hand, regeneration cycles may require rich fuel to air mixtures [8]. However, the range extender application considers the two working regimes at constant operation and thus, harsh accelerations, where the fuel to air mixture goes rich, are not met. Moreover, transient functioning from stop to the first regime and then to the second and back should be carried out automatically using a well-defined engine map as well as oxygen sensors on the exhaust stream, for the feedback system, and mass air flow sensor after air filter, for the open loop system, to decide on fueling amount.

4. CONCLUSIONS AND FUTURE WORK

The range extender application of an internal combustion engine in a hybrid powertrain layout, as a solution for lowering emission in road transportation, can combine the best engine combustion techniques in order to provide a constant torque output for the electric generator. Moreover, the operation points for the engine are road independent and, in exchange, the emissions can be lowered. An obvious plus of all the above is the quiet running of the engine, also a requirement for range extenders.

The two speed regimes of 1500 and 3000 rpm also correspond to electrical generators requirements of synchronous type [6]. There electrical machines are most efficient at these speeds. The load on the generator may be kept constant, while the demand of power to the wheel is assured from the batteries. In some driving regimes, the generator can supply the traction motors in a direct link and the battery to be used as a buffer to compensate for the variable loading coming from the road. This is usually the high speed driving regime, which is not the strength point of the range extender application.

The proposed study used two injections per cycle for a smooth pressure increase gradient and a better mixture formation. The application requirements do not demand for the maximum attainable cylinder pressure, but a complete burning and high combustion efficiency. The secondary injection increases moderately the pressure in the cylinder and the burning is quiet. Here, the monitored lambda parameter can offer an important information on how much the oxidation must be carried out prior after treatment.

The 75% of the load seems to be suitable for this application as a high load applied by the generator, offering a good torque output and consumption and emissions.

Future work was started on mixture formation analysis through CFD. The investigation pursues the influence of injection modeling on engine performances and emission estimation. Also, the effect of EGR on the pressure increase gradient and on the resulted lambda parameter is to be studied.

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