RESEARCHES ON COMBUSTION QUALITY FOR A GDI EXPERIMENTAL ENGINE

Stelian ȚÂRULESCU, Radu ȚÂRULESCU, Adrian ȘOICA*

*"Transilvania" University of Braşov, Romania (s.tarulescu@unitbv.ro, radu.tarulescu@unitbv.ro, a.soica@unitbv.ro)

DOI: 10.19062/2247-3173.2016.18.1.52

Abstract: *The present paper presents researches on combustion quality for a gasoline direct injection engine. The tests ware made on an AVL single cylinder test bed for gasoline and diesel engines. In this case, it was used a AVL 475 cc GDI Single Cylinder Research Engine Type 5405.The quality of the combustion for this engine was analyzed and compared with the theoretical principles. During the test was noticed that the main engines parameters are variable for 100 engine cycles. The variation occurs in function of the air temperature, air/fuel mixture formation, cooling system variation, combustion start moment and several engine design parameters. In order to increase the combustion quality, some measures can be applied: using an injection strategy with two or three phases; varying the advance angle of the spark related to TDC; varying the quantity of fuel injected per engine cycle; optimization of combustion chambers.*

Keywords: *combustion, quality, engine, direct injection.*

1. INTRODUCTION

The vehicles equipped with internal combustion engines are the main air pollution souse from transportation system. Also, internal combustion engine emissions contributed to the global warming and other environmental impacts. World-wide, various emission legislation have been put in action in a concerted effort of motivating vehicle manufacturers to produce relatively cleaner and more fuel efficient engines [1]. The new Euro 6 regulations regarding CO_2 emissions and regulated emissions including NO_x, CO, HC, and particulate matter (PM) are demanding advanced internal combustion engines with greatly improved combustion processes. Gasoline Direct Injection (GDI) is an increasingly popular type of fuel injection system employed in modern four-stroke gasoline engines. The major advantages of a GDI engine are lower emission levels, increased fuel efficiency and higher engine power output. The cooling effect of the injected fuel and the more evenly dispersed combustion mixtures allow for improved ignition timing settings which are an equally important system requirement [4].

In Fig. 1 are presented the constructive differences between Multi Point Injection (MPI) and Gasoline Direct Injection (GDI) [3]. The main improvement for GDI represents the fuel/air mixture formation. The petrol/gasoline is highly pressurized and injected by high voltage driven injectors via a common rail fuel line directly into the combustion chamber of each cylinder as opposed to conventional single or multi-point fuel injection that happens in the intake manifold tract or cylinder port. In some applications gasoline direct injection enables stratified fuel charge combustion for improved fuel efficiency and reduced emission levels at low load. The major advantages of a GDI engine are lower emission levels, increased fuel efficiency and higher engine power output [1].

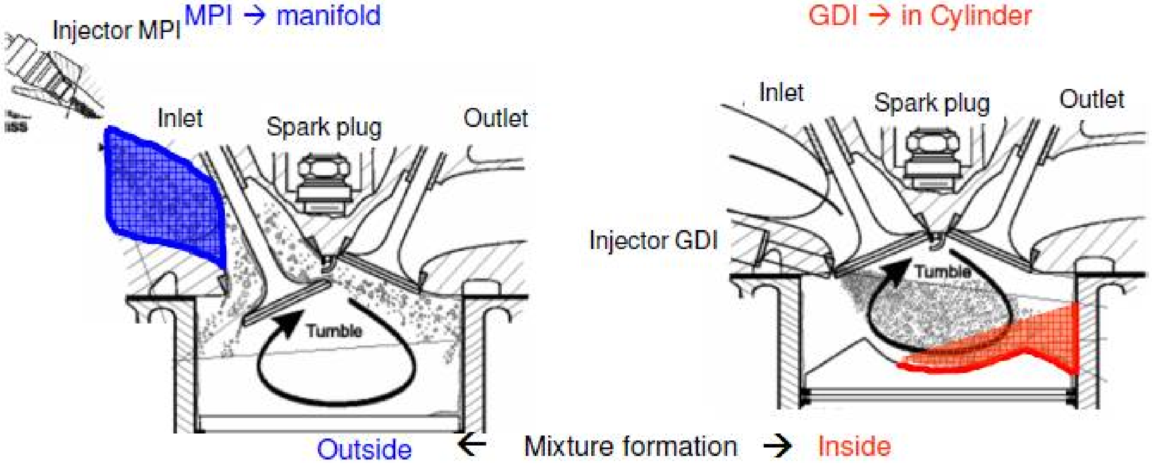

FIG. 1. The difference between Multi Point Injection (MPI) and Gasoline Direct Injection (GDI) [3]

In order to obtain data and optimize solutions for GDI engines, a research program was developed at Transilvania University of Braşov, ICDT - Research & Development Institute. The research stand is an AVL single cylinder test bed for gasoline and diesel engines. For the present paper, the tests was made on a AVL 475 cc GDI Single Cylinder Research Engine 5405. The single cylinder can be setup in several configurations (with multipoint injection, with direct injection, with turbocharger). The mixture formation and combustion processes of the fuel can be monitored through the test bed component software, AVL FIRE Commander 7.06c - IAV [2]. In Figure 2 is presented the Single cylinder test bed cell that was used for the researches.

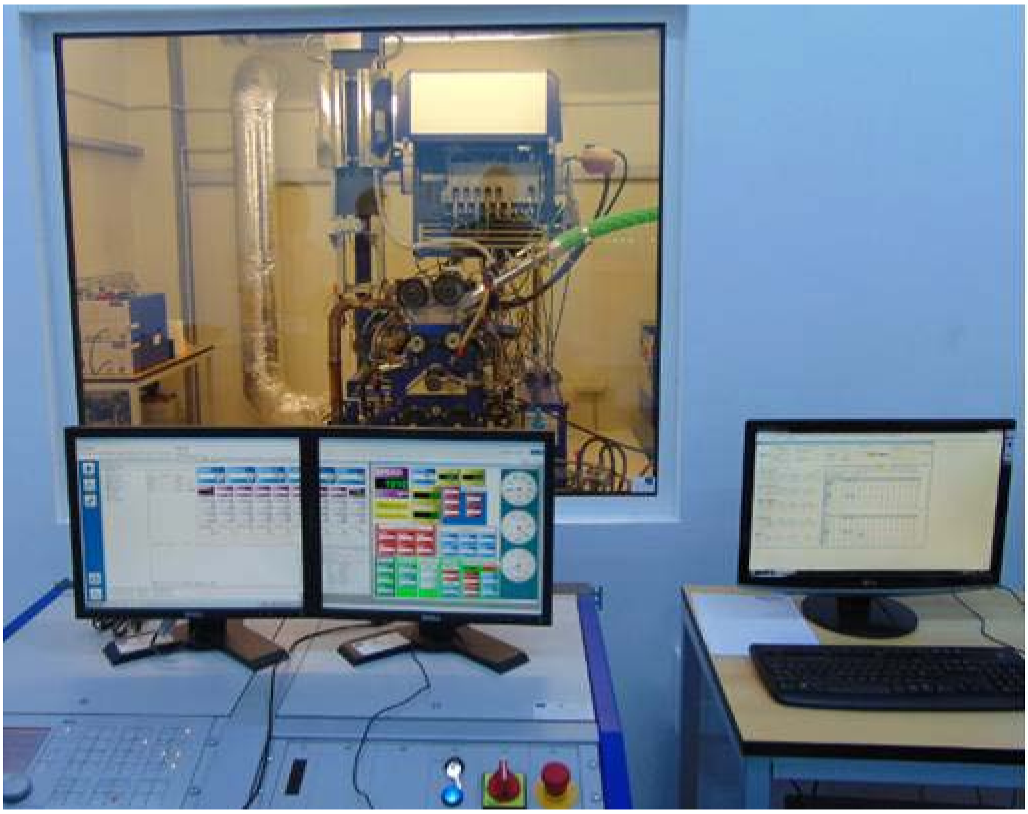

FIG. 2. The tested engine and necessary autoimmunization and software

2. COMBUSTION QUALITY EVALUATION FOR SPARK IGNITION ENGINES

The combustion of spark ignition engines can be divided into three frames: ignition and flame development; flame propagation; flame termination. Flame development is generally considered the consumption of the first 5% - 10% of the combustible mixture. During the flame development period, ignition occurs and the combustion process starts, but very little pressure rise is noticeable and little or no useful work is produced (Fig. 3). Just about all useful work produced in an engine cycle is the result of the flame propagation period of then combustion process. This is the period when the bulk of the fuel and air mass is burned (80-90%). During this time, pressure in the cylinder is greatly increased, and this provides the force to produce work in the expansion stroke. The final 5% - 10% of the mixture which burns is classified as flame termination. During this time, pressure quickly decreases and combustion stops [5].

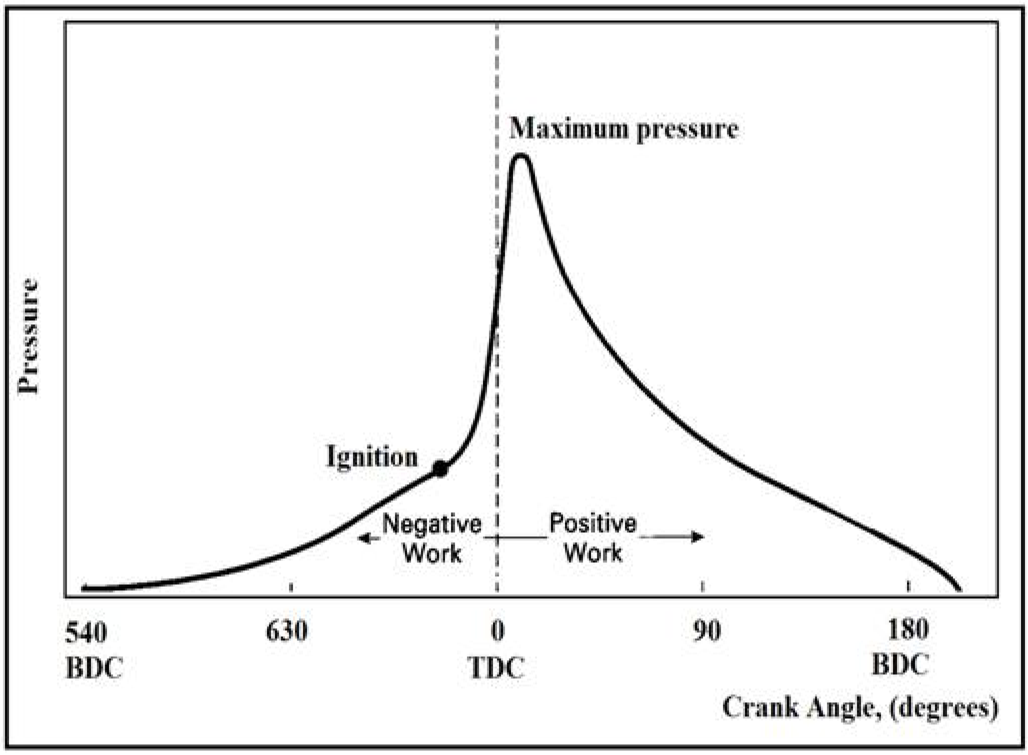

FIG. 3. Theoretical cylinder pressure curve for spark ignition (SI) engines

Theoretically, combustion would be exactly the same for every engine cycle, and there would be no cycle-to-cycle variation. This does not happen due to several variations that occur in the intake system and within the cylinder. Even if no variations occurred before combustion, the turbulence within the cylinder would cause statistical variations to occur during combustion. Temperature differences in the runners cause variations in the evaporation rates, and this causes variations in the air-fuel ratio. More fuel vapor in a hotter runner will displace more air and give a richer mixture and lower volumetric efficiency. Also, the evaporative cooling causes temperature differences and density differences. Passage of air around the throttle plate breaks into two flows, causing vortices and other variations that will then affect all downstream flow [6].

Local variations and incomplete mixing, near the spark plug, cause the initial discharge across the electrodes to vary from the average, which then initiates combustion differently cycle-to-cycle. Once there is a difference in the start of combustion, the entire following combustion process will be changed. Figure 4 shows how pressure varies as a function of time for 10 consecutive cycles in a single cylinder spark ignition engine. The ensuing combustion process for these cycles will be quite different [7].

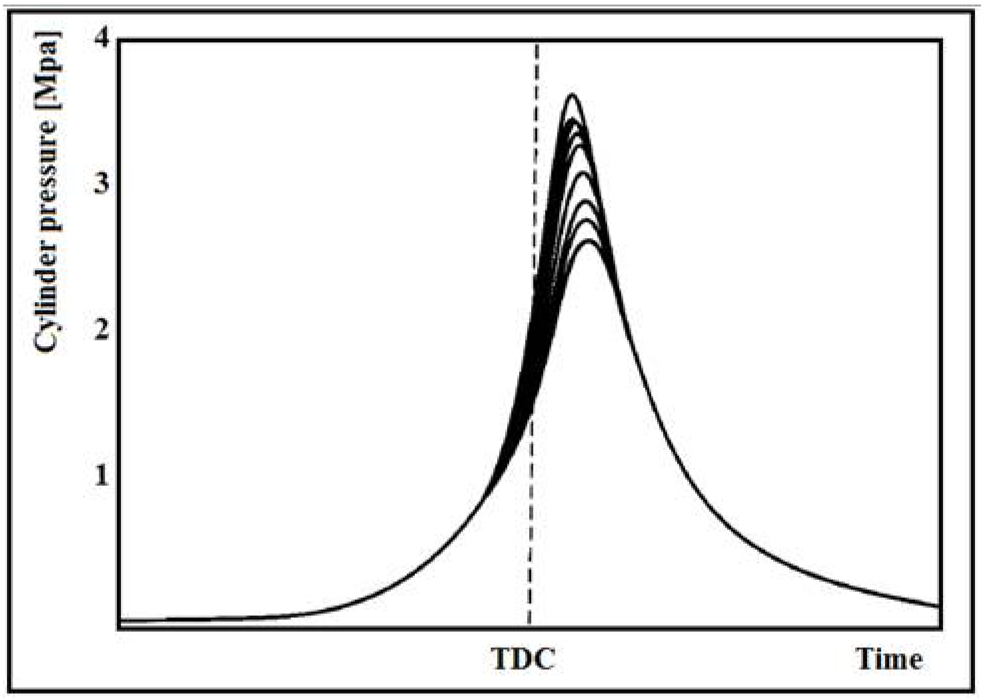

FIG. 4. Real cylinder pressure curve for spark ignition (SI) engines

3. USED EQUIPMENTS

The researches presented in the present paper ware made on a Single Cylinder Research Engine 5405 with following specifications:

- Bore: 82 mm; Stroke: 90 mm; Displacement: 475 cm^3;
- Max. speed: 6000 rpm;
- Rated power: 20 kW natural aspirated;
- Rotation inertia approx. 0,4 kgm^2;
- Combustion concept: Homogeneous, λ=1;
- Compression ratio: 11.5:1.

The test bed have some other components and systems: AVL Engine Control Unit (AVL ETU 427); Coolant and conditioning Unit 577; AVL Fuel mass flow meter - Type Flex Fuel; AVL Fuel temperature control; Intake Air Consumption Measurement Device; Particle Evaluation - Micro Soot Sensor Continuous Measurement of Soot Concentration; AVL PUMA Open Test bed Automation [8].

The used software for intake and combustion process optimization is AVL FI2RE Commander 7.06c – IAV. AVL FIRE was developed to solve the most demanding flow problems in respect to geometric complexity and chemical and physical modeling. FIRE offers a comprehensive computational fluid dynamics solution: a powerful set of modules, features and capabilities, pre-and post-processing integrated in a common environment and workflows and methods effectively supporting the use of the software to solve any problem accurately [2].

The software used for engine parameters monitoring is AVL Indicom software. During cycle based data acquisition the value of cycle time must vary all the time.

3. RESEARCH METHODOLOGY

The engine was tested in controlled laboratory conditions. The used fuel was Petrom 95 gasoline. The atmospheric temperature was constant maintained at 18 ºC.

The test was made for a load corresponding with 613 mbar manifold pressure and for 1520 rpm engine speed. The intake parameters are controlled by set the number of injections (first, second or third direct injection and one indirect injection). In this case it was used only one direct injection. The fuel mixture was adjusted by varying the amount of fuel injected per cycle (injection period - μs). The ignition time was set in crank angle degrees before top dead center. The engine combustion quality was tested for 100 engine cycles.

The parameters changes were made to obtain an optimal single cylinder pressure curve and more optimal combustion (no detonations). In the Figure 5 are presented the intake, ignition and combustion features for 475 cc GDI Single Cylinder Research Engine.

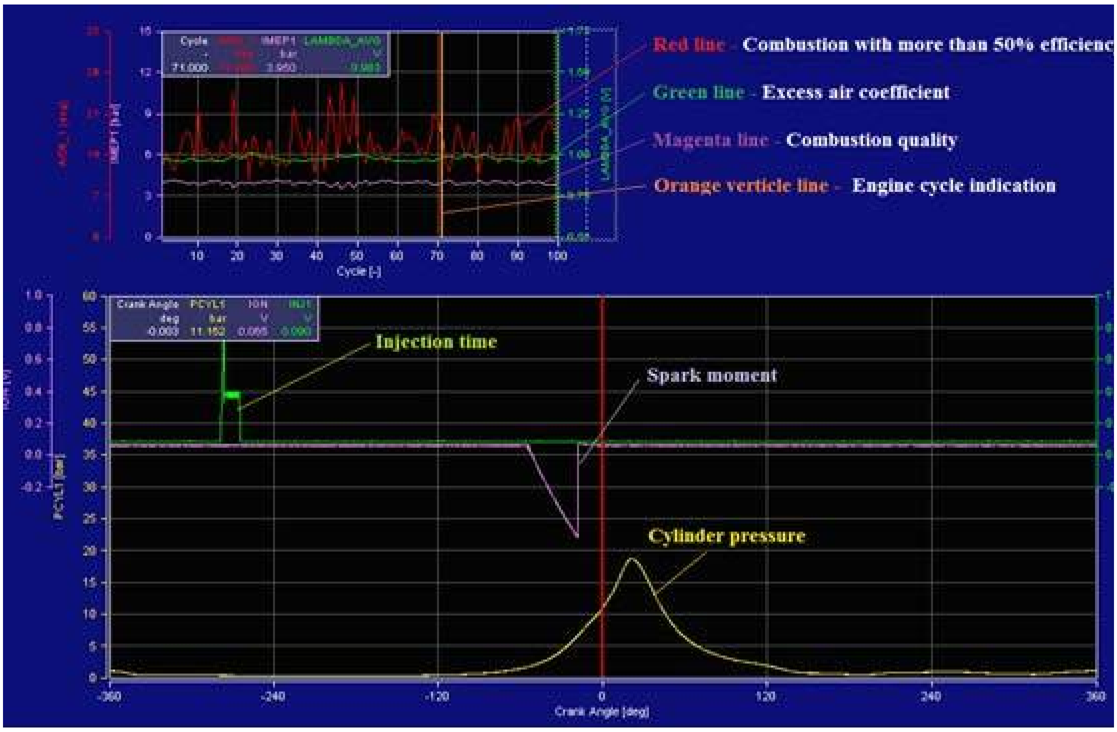

FIG. 5. Experimental cylinder pressure curve and combustion parameters for tested GDI engine

Engine combustion quality can be analyzed using a set of data from the 100 engine cycles recorded. In the top right window (Fig. 5), the combustion quality is represented by the following curves:

- A red line that represents combustion with more than 50% efficiency. The combustion is more efficient when the curve has a high amplitude.

- A green line that represents the excess air coefficient variation. The excess air coefficient (lambda) for this engine is approximately 1. If the line is almost strait the variation is low and the engine runs properly.

- A magenta line that represents the combustion quality. If this line is almost strait the combustion quality is constantly good and the engine runs properly.

- An orange cursor that indicates the actual engine cycle. This position is related to the main interface window that presents the cylinder pressure.

In the main window are presented the parameters for engine test intake, ignition and combustion. The three curves represent:

- A green curve that represents the fuel intake duration. This curve is situated at a relative distance from top dead center (TDC). In this case the advance is - 280 Crank angle degrees.

- A magenta curve that represents the ignition moment (spark propagation). This curve is also situated at a relative distance from top dead center (TDC). In this case the advance is - 50 Crank angle degrees.

- A yellow curve that represents the cylinder pressure curve for the analyzed engine, for one cycle.

For the 100 engine cycles we can observe the cylinder pressure variation. These are related to the fluctuant engine running. In figure 6 and 7 are presented two example engine cycles: cycle no. 46 and cycle no. 80.

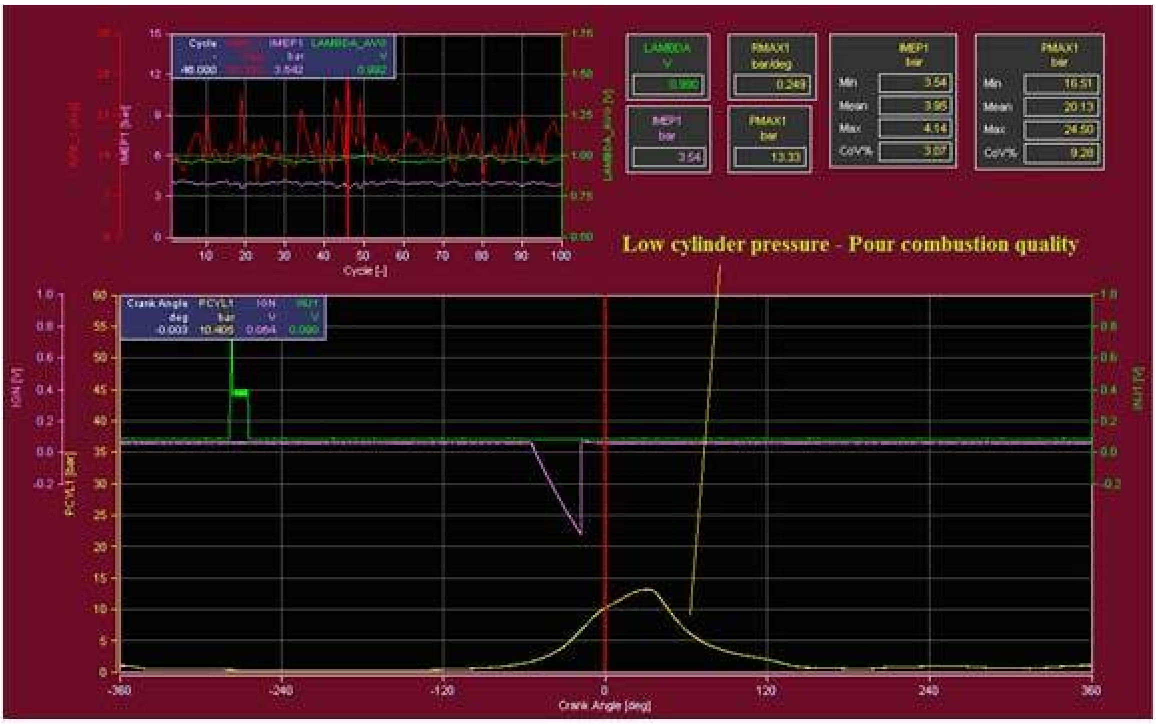

FIG. 6. An abnormal combustion engine cycle (Example: Cycle no. 46)

In Figure 6 is exemplified a motor cycle with a pour quality of combustion. It can be seen a reduced amplitude of the curve of the engine cylinder pressure. For this situation excess air coefficient is 0.990, indicated mean effective pressure is 3.54 bars and the maximum cylinder pressure is 13.33 bars.

In Figure 7 is shown an engine cycle which has a higher combustion quality. The curve of the cylinder pressure has a normal evolution, corresponding to a normal maximum cylinder pressure. For this situation excess air coefficient is 0.983, indicated mean effective pressure is 4.10 bars and the maximum cylinder pressure is 24.50 bars.

For this two examples it can be noticed the variation of the excess air coefficient (air/fuel mixture) and the indicated mean effective pressure that influence the quality of the combustion and the value for the maximum cylinder pressure.

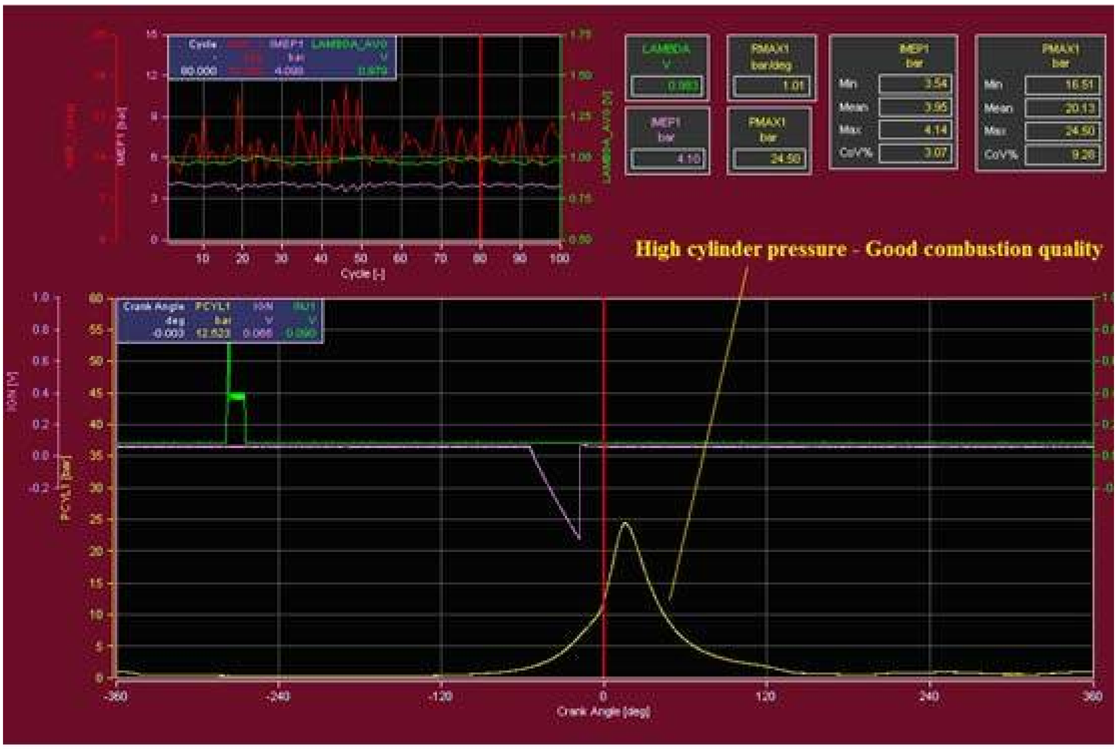

FIG. 7. An optimal combustion engine cycle (Example: Cycle no. 80)

CONCLUSIONS

In the research tests made on the experimental engine, a large set of data were collected for the analysis of combustion quality and efficiency. The combustion quality can be expressed by a set of graphical parameters, among which the most important is the engine cylinder pressure. For functional conditions (for a load corresponding with 613 mbar manifold pressure and for 1520 rpm engine speed) there were recorded 100 engine cycles. It was observed a variation of cylinder pressure curve in function of the excess air coefficient and indicated mean effective pressure.

In order to optimize engine operation and for a high quality of combustion we can take the following measures:

- using an injection strategy with two or three phases;
- varying the advance angle of the spark related to TDC;
- varying the quantity of fuel injected per engine cycle.
- optimization of combustion chambers.

All these strategies can be tested using the software component AVL FI2RE Commander 7.06c – IAV. In Figure 8 is shown the interface for AVL FI2RE Commander software [8].

Another set of measures can be related to modelling the combustion chambers. There has always been extensive debate over the optimum SI engine combustion chamber design. There are a large number of options for cylinder head and piston crown shape, spark plug location, size and number of valves, and intake port design. The major combustion chamber design objectives which relate to engine performance and emissions are: a fast combustion process, with low cycle-by-cycle variability, over the full engine operating range; a high volumetric efficiency at wide-open throttle; minimum heat loss to the combustion chamber walls; a low fuel octane requirement [9].

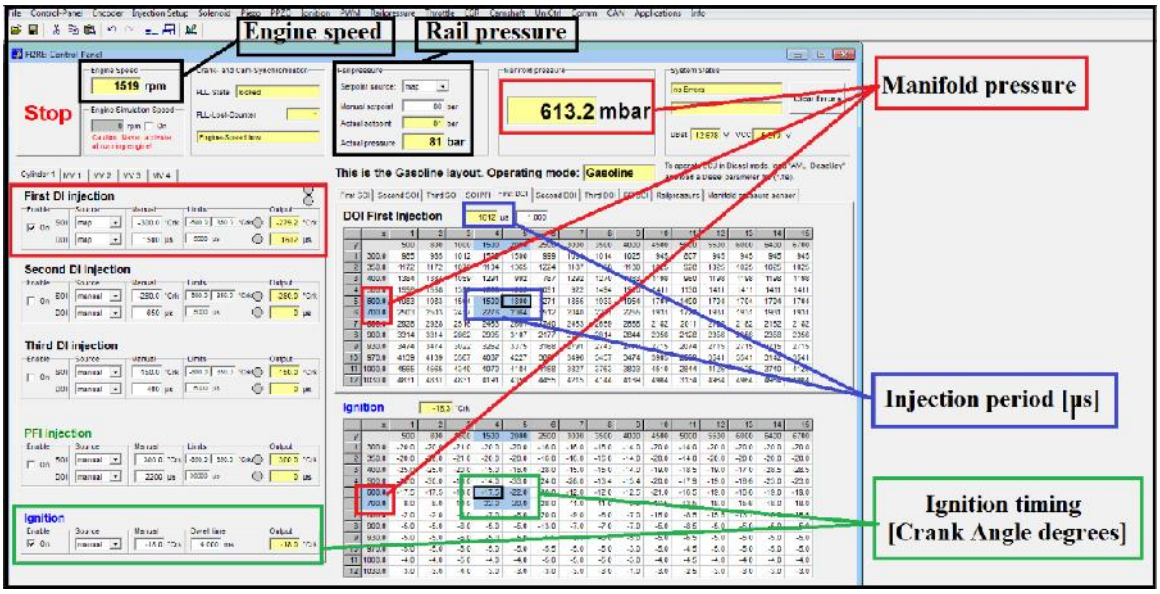

FIG. 8. AVL FI2RE menu - engine map parameters

The research can be extended to multi cylinder engines testing (engines that equip road vehicles). It seeks to improve engines processes and reduction of polluting emissions.

AKNOWLEDGMENT

We hereby acknowledge the structural founds project PRO-DD (POS-CCE, O.2.2.1., ID 123, SMIS 2637, ctr. No 11/2009) and Transilvania University of Brasov for providing the infrastructure used in this work.

REFERENCES

[1] A. K. Singh, A. M. Lanjewar, A. Rehman, Direct Fuel Injection System in Gasoline Engine - A Review, *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, ISSN: 2278-3075, Volume-4 Issue-4, September 2014;

[2] AVL - Tutorials and books for Engines Test Cell equipments usage, 2013;

[3] O. Fritz, GDI engine development according EU 6, *AVL Tutorials and books for Engines Test Cell*, 2013;

[4] P. K. Gajbhiye, S. P. Chincholkar, Review on Electronically Assisted Gasoline Direct Injection 4-Stroke Single Cylinder Engine System, *International Journal of Science and Research (IJSR)*, India Online ISSN: 2319-7064;

[5] W. Pulkrabek, Engineering Fundamentals of the Internal Combustion Engine, University of Wisconsin-Platteville;

[6] E. F., Obert, Internal Combustion Engines and Air Pollution. New York: Harper and Row, 1973;

[7] J. A. Gatowski, , E. N. Balles, K. M. Chun, F. E. Nelson, J. A. Ehchian, J. B. Heywood, Heat Release Analysis of Engine Pressure Data, *SAE paper 841359*, *SAE Trans.*, vol. 93, 1984;

[8] S. Ţârulescu, R. Ţârulescu, C.I. Leahu, Optimizing Combustion in an Single Cylinder GDI SI Engine, *Proceedings of the European Automotive Congress EAEC-ESFA 2015, Springer Cham Heidelberg New York Dordrecht London*, ISBN 978-3-319-27275-7 ISBN 978-3-319-27276-4 (eBook), DOI 10.1007/978-3-319-27276-4, Library of Congress Control Number: 2015955888 p. 395-404.

[9] J. B. Heywood, Internal Combustion Engine Fundamentals, ISBN 0-07-028637-X, printed McGraw-Hill, Inc., 2000 Edition.