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RESEARCH OF FUEL INJECTION DUTY ON A SPARK IGNITED ENGINE

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Abstract: *Using a spark ignited Mitsubishi engine, with a volumetric capacity of 1997 cm*^{3}*, this study presents the testing results of fuel injection duty and ignition advance in relation to the manifold pressure and throttle position. The later parameters are controlled by the driver's applied force upon the accelerator pedal. Displacement of the last one is digitally translated or encoded as engine's load. Peak value of the crank-shaft speed in this case study is close to 3000 rpm.*

Key words: *control, engine, fuel, injection, spark ignition*

1. INTRODUCTION

The last fifty years or so have been very significant in terms of fuel injection control and optimization both for spark ignition and other thermal engines. Fuel injection is one of the most important and influencing factors in engine's operation due to its mark upon performance and pollution. In the present scientific work is outlined a short overview on the testing protocol and experimental result from a rally spark ignited engine. Mitsubishi developed some of the most competitive power-trains for series models as well as motor-sport engines. In the present paper is studied the spark ignited engine in regard with fuel injection duty. Following trend-lines of fuel injection duty and other important parameters such as ignition advance, manifold pressure, crank-shaft speed, in specific regimes gives us the possibility to obtain a valuable insight on the relation between driver's request and throttle position, on one hand, respectively engine's operating regime and its performance on the other hand. The experimental research of actual values and their trends, beside the adjustment of the spark ignited engine, were made due to the necessity for a better understanding of mechanical effects given by extreme stresses in operation. Using digital control and a fast communication network there were acquired important actual values during a rally racing activity with a real Mitsubishi power-train equipped with modern systems for fuel injection and spark ignition. The opportunity of developing this experimental protocol in order to make measurements and record some real values in operation led the researcher to gain proper know-how for suitable and practical solutions in adjusting the spark ignited engine for competition and higher performances in term of increased efficiency. Fuel injection duty quantifies the amount of hydrocarbons introduced by the supply system in dependence with accelerator pedal position, throttle position, engine speed and temperature. Increased load upon accelerator pedal and low engine speed express on the power-train level the high resistant torque at the vehicle's wheels and finally at the crank-shaft. Optimally adjusting the fuel injection duty and the ignition advance will increase the engine operational efficiency. Applied measurements and advanced equipment for improving fuel efficiency and lowering pollution are widely used in current research [1, 2, 3]. Working fluids such as fuel and air are acting upon some of the most important parameters, such as temperature and pressure, which in turn dictate the engine speed and torque [4, 5].

Important advanced and applied methods for researching the engine's parameters and components were designed and used [6, 7, 8].

Highly digital and smart features are giving their support and assistance in managing both the production and later control in optimal operation as well as in servicing or technical investigations.

The main purpose of the paper is to present the fuel injection duty as a function of throttle position, engine speed and manifold pressure as well as to comment on trend-lines. Specific objectives are to relate the fuel injection duty with all the available parameters of the engine and to highlight the practical opportunities.

2. MATERIALS AND METHOD

The present research is an experimental approach, using a specific power-train on the basis of predesigned methodology. Figure 1 shows the architecture of the spark ignited engine studied with the volumetric capacity of 1997 cm^3.

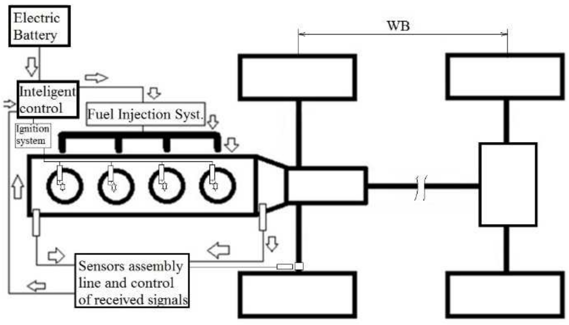

Fig. 1. Simple schematic of spark ignited engine

According to Figure 2 methodology of the study is pointing out the parameters which are considered in spark ignited engine *control procedure* that makes it easy to understand the importance of mechanical values and mathematical modelling.

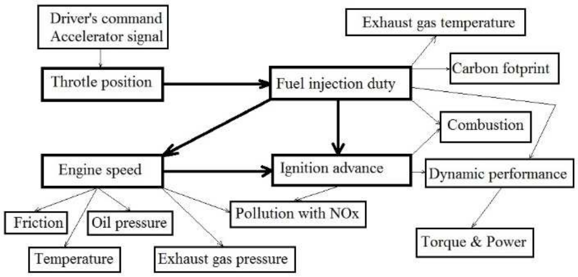

Fig. 2. Methodology of the fuel injection duty control

Figure 3 presents the evolution of first set of recorded parameters, such as engine speed and temperature.

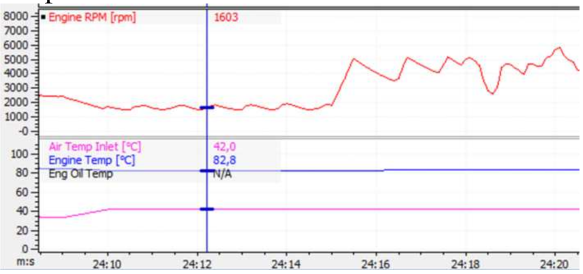

Fig. 3. Engine parameters screen shot from Motec

In Figure 4 real values are considered individually alongside the recording timeline.

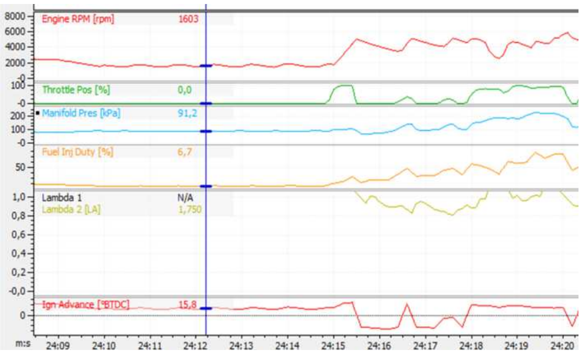

Fig. 4. Fuel injection duty variation besides other actual values in the recorded time frame

3. MATHEMATICAL MODELS

Fuel injection duty in relation with throttle position is given by polynomial equation (1):

$$F_{inj.duty} = -\frac{1}{10^4}\cdot T_p^{\,2} + 0.0983\cdot T_p + 7.21 \text{ , [\%]}. \quad (1)$$

where: $F_{inj.duty}$ is fuel injection duty in %; T_p – throttle position, expressed in %.

The excess air available is correlated with fuel injection being expressed by equation (2):

$$F_{inj.duty} = -316.1\cdot\lambda^2 + 984,7\cdot\lambda - 747.4 \text{ , [\%]}. \quad (2)$$

where: λ – excess air coefficient, in [-].

4. RESULTS AND OBSERVATIONS

Applied results are mainly concentrated toward the fuel injection duty representation versus throttle position, engine speed and other important parameters, according to figures 5-9.

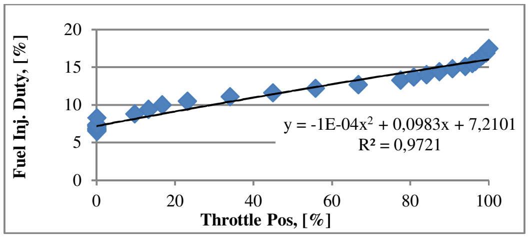

Fig. 5. Fuel injection duty versus throttle position

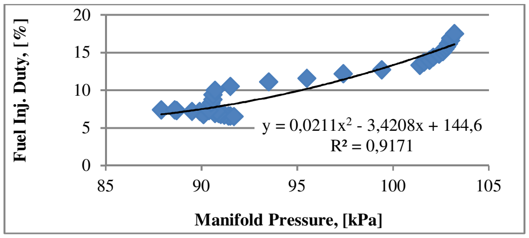

Fig. 6. Fuel injection duty versus manifold pressure

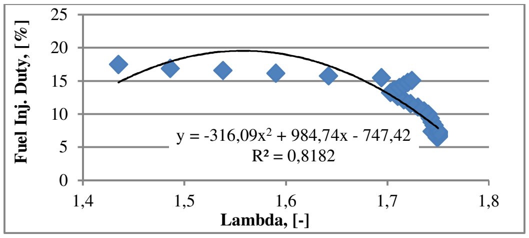

Fig. 7. Fuel injection duty versus lambda

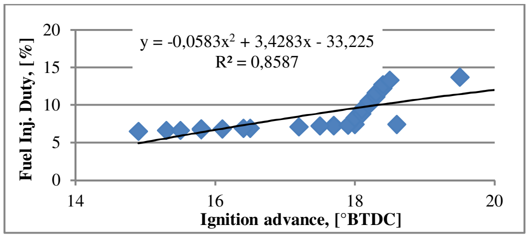

Fig. 8. Fuel injection duty versus ignition advance

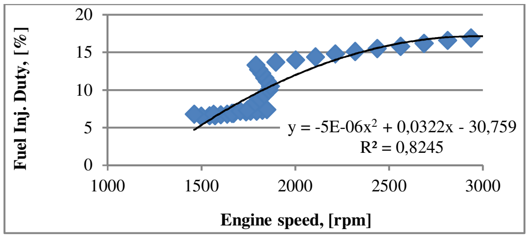

Fig. 9. Fuel injection duty versus engine speed

Figures 10-14 show the values vs. speed.

Engine speed is beside the throttle position one of the most important operational parameters which dictates the performance of the power-train, especially power output. Thus it is a good opportunity to study its effect upon other secondary actual values during operation.

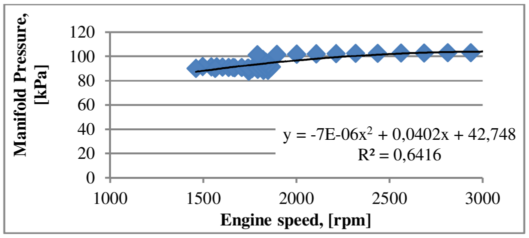

Fig. 10. Manifold pressure versus engine speed

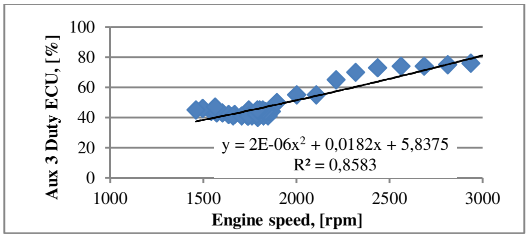

Fig. 11. Aux duty ECU versus engine speed

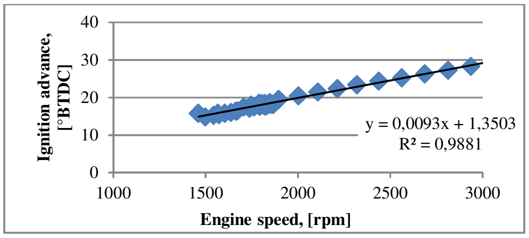

Fig. 12. Ignition advance versus engine speed

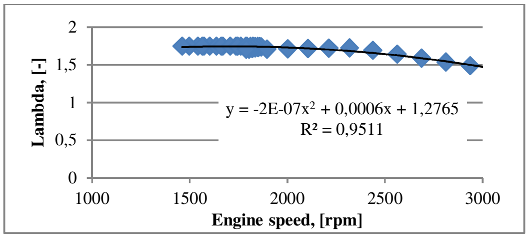

Fig. 13. Lambda coefficient versus engine speed

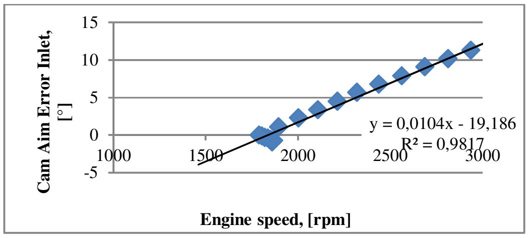

Fig. 14. Cam (shaft) aim in relation to engine speed

Cross-values are recorded in Figures 15-28.

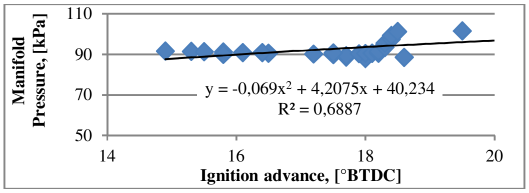

Fig. 15. Intake manifold pressure versus ignition angle

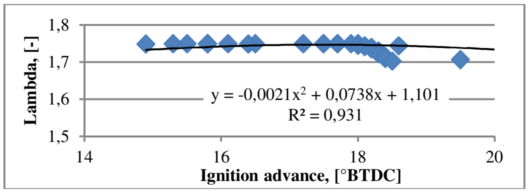

Fig. 16. Lambda coefficient related to the ignition angle

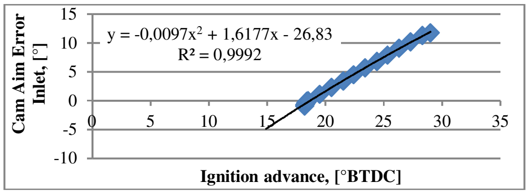

Fig. 17. Camshaft aim inlet versus ignition advance

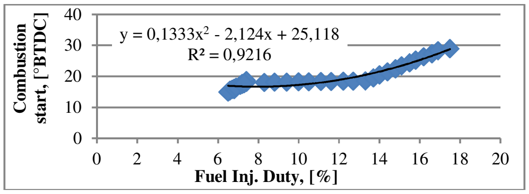

Fig. 18. Combustion initiation vs. fuel injection duty

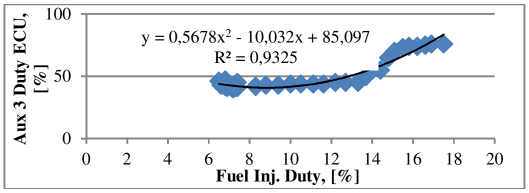

Fig. 19. ECU auxiliary duty versus fuel injection duty

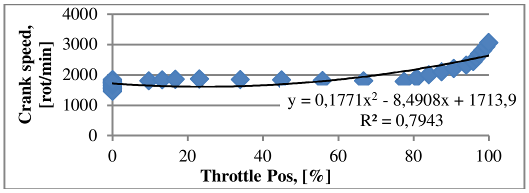

Fig. 20. Crank-shaft speed correlated to throttle position

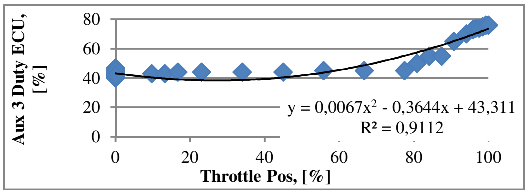

Fig. 21. ECU auxiliary duty vs. throttle position

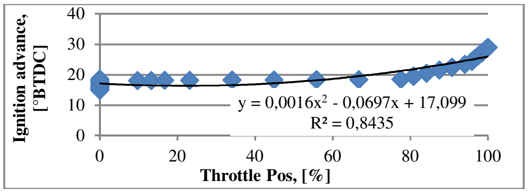

Fig. 22. Injection advance versus to throttle position

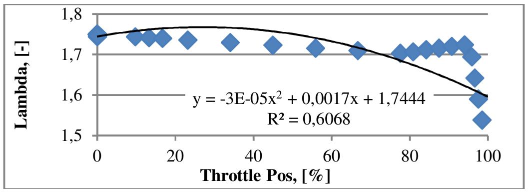

Fig. 23. Excess air coefficient related to throttle position

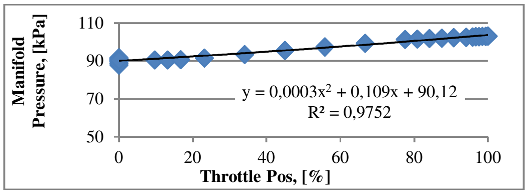

Fig. 24. Intake manifold pressure versus throttle position

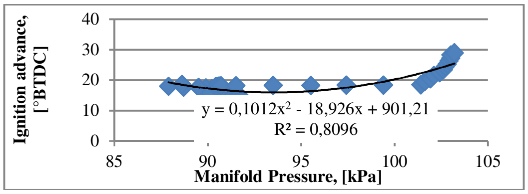

Fig. 25. Ignition advance in relation with intake pressure

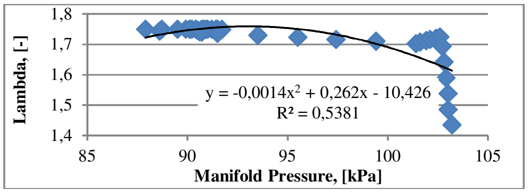

Fig. 26. Lambda coefficient versus manifold pressure

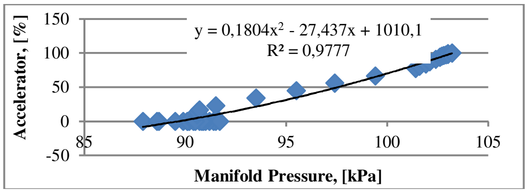

Fig. 27. Accelerator versus manifold pressure

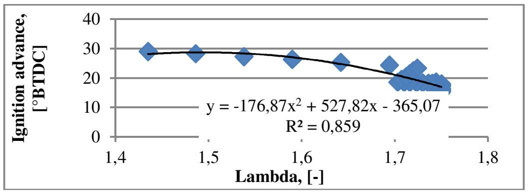

Fig. 28. Ignition advance correlated to lambda coefficient

The practical measurements were taken on a Mitsubishi Lancer Evo9 with technical data presented in Table 1.

Table 1

Spark ignited engine technical data

Index	Real Value	UM	Notes
Year	2011	-	working
Series	CT9A	-	developer
Capacity	1997	cm^3	-
Transmission	6-speed	gear	mechanical
Wheelbase	2625	mm	modified
Car length	4492	mm	-
Car width	1771	mm	-
Car height	1450	mm	modified
Car weight	1350	kg	modified

Observing the practical measurements and their trend-lines on each graph is possible to issue few conclusions on the specific matter.

5. CONCLUSION

Fuel injection duty being the hydrocarbon loading presented as a percent from maximum amount of liquid fuel introduced in a cylinder during a stroke, gives an expression of stress and fluid dynamics at a specific time.

The pick *fuel injection duty* (at 100% throttle position) was determined at 3062 rpm. At this moment of the operating regime the lambda value was 1.435, meaning that the excess air made a quite lean combustion. Practical recording shows at the same instance that manifold pressure was exactly 103.2 kPa leading us to assume the turbo charger boosted already. A minimum of 6.6 % fuel injection duty was measured zero accelerator position and with the lowest combustion starting angle recorded at 15.3 °BTDC.

The peak manifold pressure (at 103.2 kPa) was recorded for the 100% accelerator position and 29 °BTDC combustion start angle, respectively the lowest value of air intake pressure has been 87.9 kPa at 18 °BTDC spark advance.

Lowest fuel injection duty recorded at the 82.8°C engine temperature and 1.75 lambda coefficient, respectively the highest fuel injection duty has been correlated with a small increase (of 0.5 %) in engine temperature.

Mapping the fuel injection duty in relation with other operating parameters gives the opportunity of better understanding the engine's calibration and adjusting procedures. Injection process is quite significant and gives effects on consumption, fuel efficiency, pollution and carbon footprint. Fuel injection duty also dictates the qualitative level of air-fuel composition and thus influences the combustion phase of the engine's cycle.

Testing the car in real environment allowed the possibility to validate the assumption of interdependence between fuel injection duty and turbo charger operation as well as the mapping of the optimal operation pole. Most appreciated output performance at the testing moment was at 23.4 °BTDC ignition angle and 2319 rpm due to momentary optimal values stored with a 15.1 % fuel injection duty, respectively 83 °C engine temperature.

The air intake temperature was 42 °C and barometric pressure was 97.8 kPa. Throttle position for this step was 94 %. Due to the fact that the spark ignited engine is installed on a competition vehicle involved in motor-sport races the usual operating regime is above 80 % throttle position. Even in this case it is well seen to consider the fuel efficiency and even environmental impact.

Developing a well balanced operational map with the most refined efficiency means to have better digital control. Further measurements will be made as on board recording is available and easy to use in other investigations.

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CERCETAREA SARCINII INJECŢIEI DE COMBUSTIBIL PE UN MOTOR CU APRINDERE PRIN SCÂNTEIE

Rezumat: Utilizând un motor Mitsubishi cu aprindere prin scânteie, cu o capacitate volumetrică de 1997 cm^3, acest studiu prezintă rezultatele testării sarcinii injecţiei de combustibil şi a avansului la aprindere în raport cu presiunea din galeria de admisie şi poziţia clapetei. Aceşti din urmă parametri sunt controlaţi prin forţa aplicată de către şofer asupra pedalei de acceleraţie. Deplasarea acesteia din urmă este codificată sau tradusă digital ca sarcină a motorului. Valoarea de vârf a turaţiei în acest studiu de caz este apropiată de 3000 rpm.

Cuvinte cheie: *control, motor, combustibil, injecţie, aprindere prin scânteie*

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