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REDUCING FUEL CONSUMPTION USING A CALIBRATION STRATEGY FOR OBTAINING LEAN MIXTURES IN A GASOLINE M.P.I. ENGINE

George TRICĂ[1*], Alina TUȚĂ[1], Florian IVAN[2], Dinel POPA[2]
[1] Renault Technologie Roumanie, Romania; [2] University of Pitesti, Romania;

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Abstract: *It is well known that the engine spark-ignition (s.i.) must satisfy the extremely severe dynamic, performance, cost-efficient and environmentally friendly conditions. Meeting these demands requires complex operations of calibration using sophisticated research methods and techniques. The paper presents an s.i. engine calibration strategy for medium-class passenger cars. The developed strategy starts from the engine torque estimation based on the interdependence between the parameters: spark advance efficiency, efficiency of the mixture richness, efficiency of the engine filling. In the paper are presented the experimental results obtained on the test engines bench by applying this methodology. The validation of this calibration strategy is carried out in a first stage by a group of tests made on a vehicle at two characteristic speeds: 50 and 90 km/h. The purpose of the application of such calibration method is to highlight the available reserves of the engine to reduce fuel consumption and* CO_2 *emissions by burning lean mixtures.*

Keywords: Calibration, engine torque, engine filling, richness, ignition advance, lean mixtures.

INTRODUCTION

In its over 100 years of existence, the automobile, one of the most popular and complex creations of human genius has been developed and continuously improved. Currently, the increasing requirements for obtaining high dynamic performance and economic benefits in the context of increasingly stringent pollution standards require extensive research and great finesse. Account shall be taken of interdependence between multiple functional parameters of which engine parameter called richness (R= 1/λ – the inverse of the excess air coefficient) play a decisive role. Figure 1 shows the relationship between these parameter and pollutant emissions.

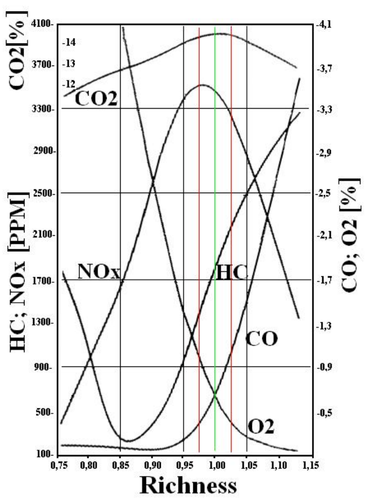


Figure 1. The link between richness, CO_2 and pollutant emissions.

[*] Corresponding author. Email: trica.george@gmail.ro

To meet the new requirements imposed by the pollution standards (e.g. EURO 6) we shall take into account the reserves related to lean combustion mixtures. To highlight such reserves it must be developed methods of calibrating engines enabling reaching an optimum compromise between dynamic, economic and ecological engine performance [1].
To burn mixtures with a low excess fuel coefficient we have to found a spark ignition advance which allows an efficient ignition. In the technical literature we find the correlation between richness and spark ignition advance, in other words we are limited by a maximum ignition advance before the detonation occurs or, where appropriate, optimal ignition advance for developing the maximum engine torque, and a minimum ignition advance imposed by the condition of incomplete flame propagation.
By applying these ignition limits for igniting the lean mixtures we are obtaining the qualitative diagram from Figure 2 in which we can find four characteristic areas.

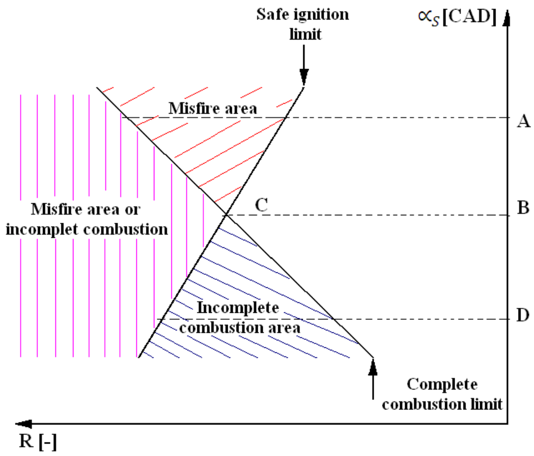


Figure 2. The stable ignition and complete combustion area according to the spark ignition advance (α_S) and richness (R).[2]

Stable combustion zone is found in the area between points A, D and C (without hatch area) and is characterized by a stable engine running with an ignition advance between point A, which represents the knock limit for s.i advance or optimal ignition advance for developing the maximum engine torque, and point D, which is the minimum ignition advance for which the complete combustion of the lean mixture occurs entirely before the opening of the exhaust valve.
From the area of stable combustion, for an ignition advance A it is to be noticed that through the progressive leaning of the mixture the safe ignition limit is exceeded and we are entering in the misfire area. In the same way, for an advance D, less than the advance A, gradual dilution of the mixture with air leads to the exceeding of the complete combustion limit and entering in the area of incomplete combustion. B advance allows us to burn very lean mixtures, a corresponding richness of point C located at the intersection between misfire area with incomplete combustion area.

CALIBRATION OF ENGINE TORQUE ESTIMATION

The calibration of the developed engine torque involves an assembly of adjustments and labels which allow the software from the electronic control unit (E.C.U.) to estimate the value of this parameter. The torque estimation is done by interpreting multiple operating parameters of the engine: the spark ignition advance, richness of the mixture, engine air flow rate and engine speed. In the analytical way the torque estimated value can be written:

$$M_{eest} = M_{i\,max} \cdot \eta_s \cdot \eta_R \cdot \eta_u + M_{PP} \quad (1)$$

Where:

- M_{eest} -effective engine torque, estimated by the E.C.U. software based on the values of the others engine parameters: η_s, η_R and η_u;
- $M_{i\,max}$ -maximum indicated engine torque, developed at a constant speed and charge;
- η_s -spark advance efficiency, can be written as:

$$\eta_s = \frac{\alpha_{apl}}{\alpha_{opt}} \quad (2)$$

Where:

- α_{apl} -applied s.i. advance for which we obtain the applied engine torque M_{α_apl} (calculated based on the advance parabola and α_{apl} for $R = 1$, $\eta_u = ct.$, and $n = ct.$);
- α_{opt} -optimal s.i. advance for which we obtain the maximum engine torque M_{α_opt} (retained in the cartogram for $R = 1$ $\eta_u = ct.$, and $n = ct.$).[3]

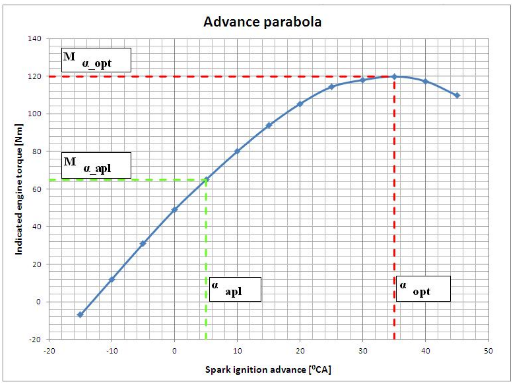


Figure 3. Determination of the indicated engine torque starting from s.i. advance.

- η_R -the mixture richness efficiency is expressed by the equation:

$$\eta_R = \frac{R_{apl}}{R_{opt}} \quad (3)$$

Where:

- R_{apl} -applied richness;
- R_{opt} -the richness for which the engine develop the maximum torque. After experimental tests we have seen that the optimum richness value is $R_{opt} = 1.12$.

In Figure 4 we can see the η_R determined keeping constant the values of α_S, η_u and n).

- η_u -engine filling efficiency, it can be written as:

$$\eta_u = \frac{u_{apl}}{u_{max}} \tag{4}$$

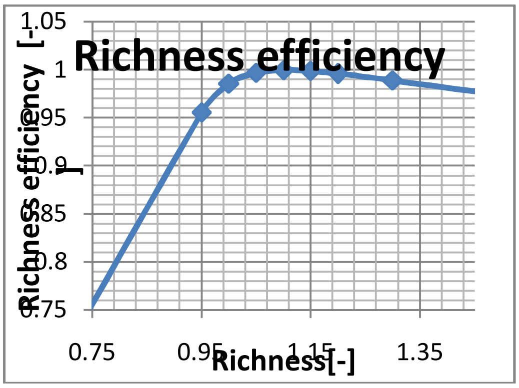


Figure 4. The influence of richness over the indicated engine torque.

Where:

- u_{apl} -represents the actual engine filling, or requested by driver, obtained by changing the position of the intake throttle;
- u_{max} -maximum engine filling in standard conditions (temperature 25^{0}C and pressure 1013 mbar).

For naturally aspirated engines the filling efficiency is $\eta_u = 0.96$ due to gas-dynamic losses through air intake.

- M_{PP} -represent the torque losses, which are calculated by the sum of the mechanical losses, pumping losses and auxiliary losses due to accessories.

We will use the relation (1) in order to illustrate the impact of richness over the engine effective torque. While maintaining constant effective engine torque, indicated torque, engine speed and torque losses, we change the richness efficiency highlighting the influence of this operation on the s.i. advance and filling efficiency (Figure 5).

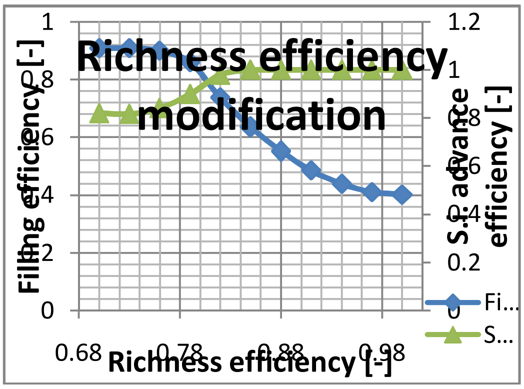


Figure 5. The influence of richness efficiency modification over the s.i. advance and filling efficiency, keeping $M_{eest} = ct.$

In Figure 5 we can see that for a small η_R the η_u has its maximum value and after that decreases exponentially. This behavior is explained by increasing the engine load (intake air) to compensate for the torque lost by reducing the richness efficiency. [4][5] The s.i. advance efficiency is at maximum value at small loads because the applied advance is at its upper limit, reaching the optimal advance value. At high loads, η_s decreases because the applied advance is limited by the occurrence of detonation, this s.i. advance is less than the optimal advance.

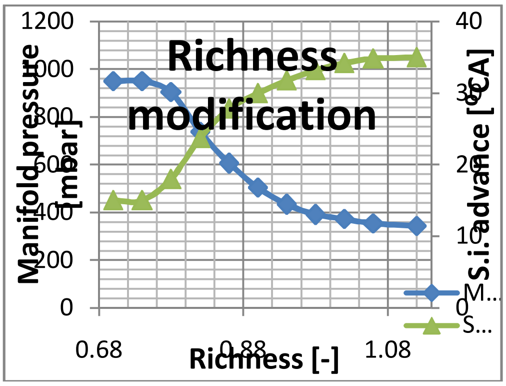
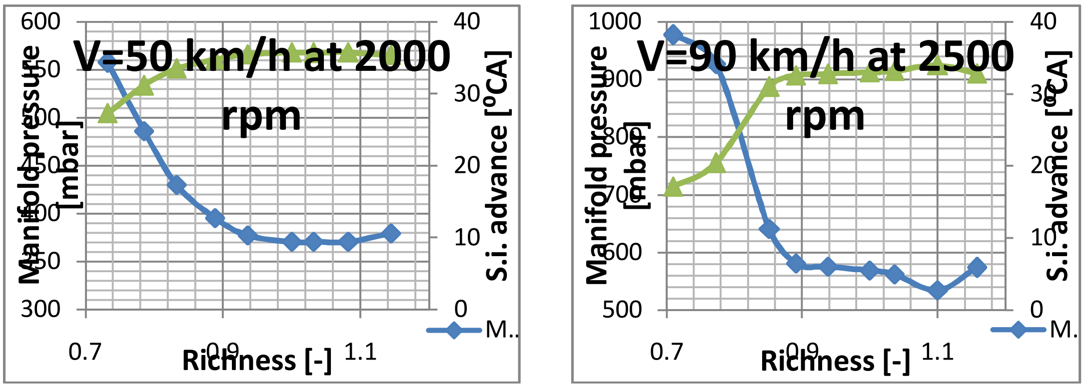


Figure 6. The influence of richness modification over the s.i. advance and filling ($M_{eest} = ct.$)

Figure 6 represents the transposition of the efficiencies from Figure 5 in actual physical parameters. It is to be noted that the manifold pressure (engine load) has the same allure as the filling efficiency. Regarding s.i. advance, it is obvious that it has an upward curve in close connection with the pressure from the inlet manifold, the advance increases as the inlet pressure drops. This behavior is explained by the calibration of s.i. advance at the knock limit based on the pressure from the intake manifold [6][7].

EXPERIMENTAL MEASUREMENTS ON THE VEHICLE REGARDING THE VALIDATION OF CALIBRATION IN TERMS OF REDUCING THE INJECTED FUEL.

In order to obtain an overview of the fuel gain by reducing the richness of the mixture, while maintaining a constant torque, we have realized a scavenging of R for two vehicle speeds: 50 km/h and 90 km/h. Experimental tests were performed on an average class K4M Renault engine with a total displacement of 1598 cm^3 equipped with a multipoint injection system. The main design parameters of the engine are 80.5 mm stroke, 79.5 mm bore and 9.8 compression ratio. The engine develops 82 kW at 6000 rpm and a maximum torque of 150 Nm at 4250 rpm.

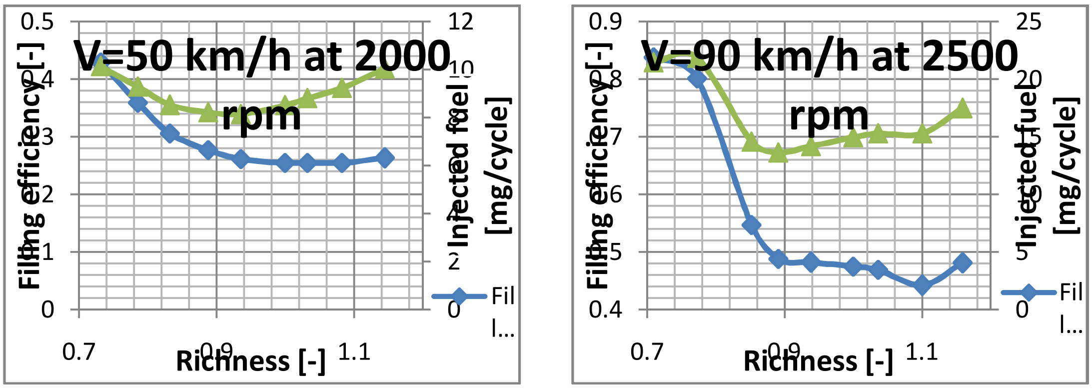


a) *b)*

Figure 7. Load and s.i advance depending on richness.

a) vehicle speed of 50 km/h; *b)* vehicle speed of 90 km/h

Has been kept a constant vehicle speed that allowed achieving a constant engine speed and torque at which we have change the richness. In Figure 7 we can see that the engine load increases as the R drops. This increase of load, represented graphically by the inlet manifold pressure, comes from the condition of keeping a constant engine torque for low combustion efficiency (low richness). At the same time, increasing the manifold pressure causes a shift from optimal s.i. advance, in partial loads (Figure 7.a.), to the knock limit advance at high loads (Figure 7.b. – for a manifold pressure greater than 700 mbar).

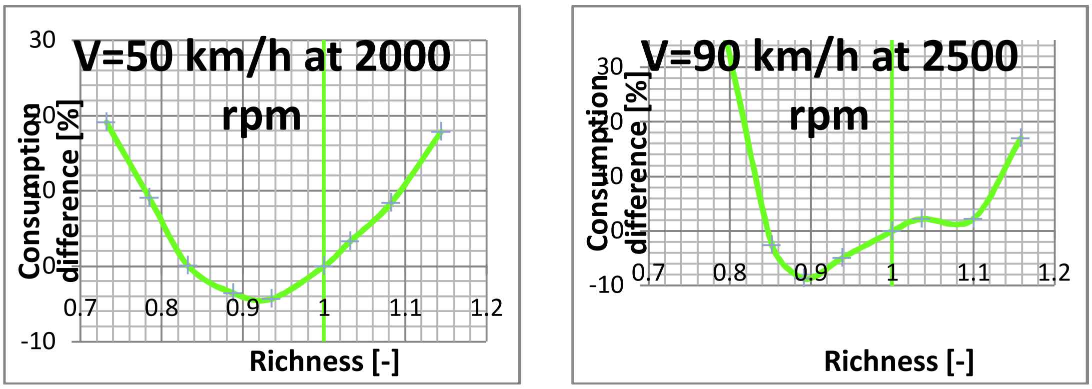


a) *b)*

Figure 8. Filling efficiency and injected fuel depending on richness.
a) vehicle speed of 50 km/h; *b)* vehicle speed of 90 km/h

By entering in the graph (Figure 8) the quantity of injected fuel according to the applied richness, it is observed that after R=0.9 the real fuel consumption begins to grow. This consumption growth is due to increased air flow admitted into the engine shown in Figure 8 through filling efficiency. Even if the richness decreases, the greater amount of air entering the engine also increases the injected fuel. For the injected fuel to decrease directly proportional to richness we must keep a constant air mass (constant load) admitted into the cylinder. This air mass can be constant only if the efficiency of combustion is constant, regardless of the richness value.

In order not to change the combustion efficiency of lean mixtures is necessary to implement stratified combustion technologies and more advanced ignition systems.



a) *b)*

Figure 9. The consumption difference depending on richness
a) vehicle speed of 50 km/h; *b)* vehicle speed of 90 km/h

This consumption difference represents the percentage ratio between the injected fuel for a given richness and the injected fuel for reference richness equal to 1.

With all that the engine used to obtain these results is limited in terms of stratification and ignition of lean mixtures it is to be noted that for a richness which value is around 0.9 the engine develops the same torque but using less fuel. At a speed of 50 km/h the fuel consumption is reduced by 4.3% for a richness of 0.93 (Figure 9 *a)*) and 8.7% for a richness of 0.89 and a speed of 90 km/h (Figure 9 *b)*).

CONCLUSIONS

After experimental research regarding the development of a calibration method using the estimate engine torque reveal:

- the calibration method developed allows obtaining an energy solution which will ensure a low level of fuel consumption, namely, a low level of CO_2 emissions.
- burning lean mixtures lead to a real reduction in fuel consumption even in the case of a multipoint injection s.i. engine, designed for working at an richness R = 1.
- the engine still has reserves of performance improvement only if we adopt special procedures of burning lean mixtures. We can use the following technical solutions:

- volumetric ignition - is represented by a heating system using micro-waves of a zone from the combustion chamber which allows the ignition of a mixture with a richness of at least 0.6.
- jet ignition – carried out the igniting of mixtures with an R= 0.6 using a plasma jet.
- the ignition with radio frequency plugs - enables the ignition of very lean mixtures (R=0.55) due to the presence of multiple sparks, as well as increasing the ignited volume from 1 mm^3 (ignition with a classical spark plug), to 1 cm^3, increasing significantly the possibility that a spark to reach an area of flammable mixture.
- laser ignition allows the ignition of lean mixtures (R=0,5) due to a high number of ignition areas [8].

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