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Catalysts Efficiency Evaluation by using CC Analysis Test

The study emphasizes the necessity of the catalysts efficiency testing. Diagnosis systems using lambda probes are based on the capacity of the catalyst oxygen storage. Comparing the lambda probe signals upstream and downstream of catalyst provides an indication on catalyst activity, although the correlation between oxygen storage capacity and catalyst efficiency is still difficult. Diagnosis for the 1.4 Renault Clio Symbol was accomplished in the Road Vehicles Lab at the Politehnica University of Timisoara using AVL Dicom 4000. The tests showed that the engine worked with lean mixture being necessary a fuel mixture correction calculated by the control unit ECU. A compensation of 0.14 % vol is required for the engine correct operation and emissions integration within permissible limits.

Keywords: *catalyst, fuel mixture, lambda sensor, diagnosis, pollutant emissions*

1. Introduction

There are millions of cars on the road that are potential sources of air pollution. In a major effort to reduce vehicle emissions, carmakers have developed an interesting device called a catalytic converter, which treats the exhaust gases before they leave the car and reduces the pollution [4].

In order to reduce emissions, modern cars have been designed to carefully control the amount of burning fuel. The goal is to keep the air-fuel ratio very close to the stoichiometric point, which is the calculated ideal ratio of air to fuel. The fuel mixture actually varies from the ideal ratio quite a bit during driving.

The main car engine emissions are:

Nitrogen gas: Air contains 78 percent nitrogen gas, and most of this passes right through the car engine.

Carbon Dioxide: This is a combustion product. The carbon in the fuel bonds with the oxygen in the air.

Water vapor: This is another product of combustion. The hydrogen in the fuel bonds with the oxygen in the air. Generally, these emissions are not poisonous (although carbon dioxide emissions are believed to contribute to global warming), however because the combustion process is never perfect, some smaller amounts of more harmful emissions are also produced in car engines:

Carbon monoxide: A poisonous gas that is colorless and odorless.

Hydrocarbons or volatile organic compounds (VOC' s): Produced mostly from unburned fuel that evaporates.

UV radiation breaks these down to form oxidants, which react with nitrogen oxides to cause ground level ozone, a major component of pollution.

Nitrogen oxides: Contributes to smog and acid rain, and also causes irritation to human mucus membranes. These are the three main regulated emissions, and also the ones that catalytic converters are designed to reduce [1].

2. Lambda Probe Presentation in Terms of Design and Operation

The lambda sensor is an electrical sensor mounted inside the exhaust system which can measure how well the combustion is occurring inside the engine. The amount of fuel allowed into the engine is controlled by the engine fuel injection computer or ECU (Electronic Control Unit). The object of the sensor operation is to permit the engine ECU to adjust the amount of fuel allowed into the engine for best economy and lowest emissions.

The sensor has to endure harsh conditions in hot exhaust gases, and in time it will wear out, just like other vehicle engine components wear out, such as spark plugs [5].

Lambda probes are important components and are essential for proper operating and achieving emission levels within permissible limits.

There are two main types of lambda sensors [5]:

- Tubular. The main particularity of this sensor type is the ceramic element in rod shape. It is equipped with a separate heating element to achieve a 350°C minimum temperature required by control action. The sensor body located at the end of the exhaust pipe is fitted with a protective tube in order to protect sensor elements against waste fuel of the exhaust gases.
  a) Zirconia - the oldest and most common type (Fig. 1a)
  b) Titanium - Used on some BMW, Volvo and Vauxhall models with Siemens ECU, during the 90's (often Called Titania) (Fig. 1b)
- Planar - represents a more advanced shape of the probe tube. It is a wideband sensor, found on the latest generations of engines from the 2000's onwards (Fig. 2). Measuring cell and heating element are both integrated into the plate, so the

sensor can reach operating temperature more quickly. Planar probe is fitted with a double-walled protective tube.

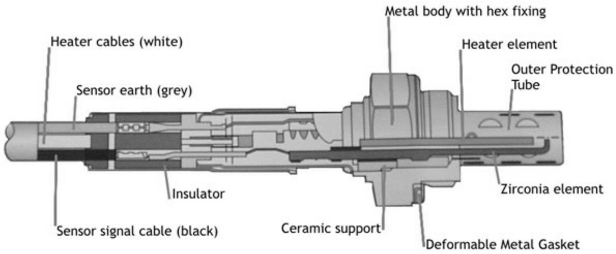

Figure 1a. Zirconia Lambda sensor

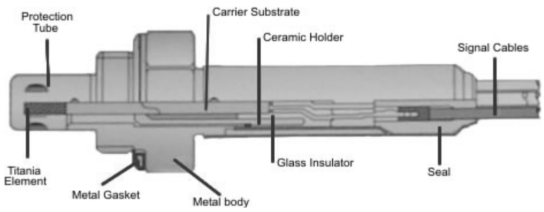

Figure 1b. Titania Lambda sensor

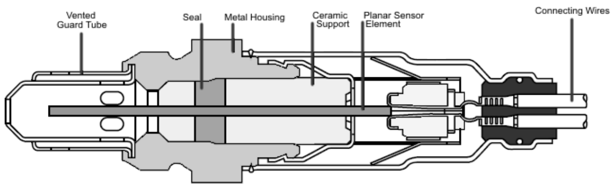

Figure 2. Planar wideband sensor

Lambda probes are located before and after the catalyst, a part of the electrode sensor is exposed to exhaust gases, while the other is in contact with ambient air which is used as a benchmark for measuring the oxygen amount in the flue gas.

A schematic diagram of adjustment sensor location (before catalyst) and diagnosis sensor (after catalyst) is presented in Fig. 3.

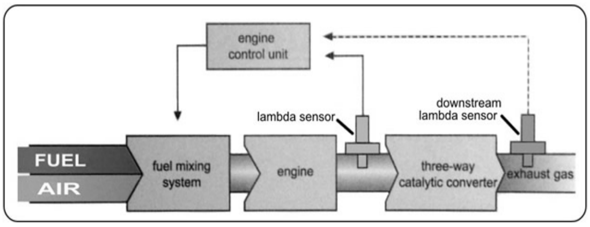

Figure 3. Lambda control loop

Cable mounting for measuring sensor voltage is accomplished with crocodile clips (Fig. 4).

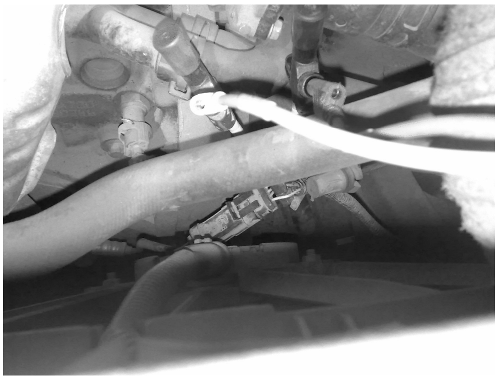

Figure 4. Cable mounting for sensor voltage measuring

The Lambda diagnosis sensors are not used to adjust the engine mixture but simply to identify the catalytic converters performance. Under ideal circumstances they should show a constant output indicating that CATs are working as intended.

The adjustment sensors (pre-CAT) monitor the engine mixture and report back to the EEC-V which then adjusts the mixture accordingly. CATs work best when the mixture varies between lean and rich every few seconds.

Lambda probe measures the residual oxygen amount in the exhaust gas. At the operating temperature (350ºC) it generates a voltage approximately between 25 and 900 mV corresponding to the oxygen amount in the exhaust gas, and compares the residual oxygen amount in the exhaust gas with the oxygen volume in ambient air. It also detects the transition from rich mixture (air deficiency) to lean one (air excess) and vice versa.

2. Lambda Probe Operation Mode

ECU control unit detects the mixture composition (rich or lean) with Lambda probe. This controls the fuel injected amount, so that an optimal mixture to be provided (λ=1), creating ideal conditions for catalytic exhaust gas treatment.

Oxidation reactions (1) determine the unburned HC and CO conversion, while relations (2) are the NOx reduction reactions [2], [3].

$$\begin{cases} C_mH_n + (m+n/4)O_2 \Rightarrow mCO_2 + n/2H_2O \\ CH_n + 2H_2O \Rightarrow CO_2 + (2+n/2)H_2 \\ CO + 1/2O_2 \Rightarrow CO_2 \\ CO + H_2O \Rightarrow CO_2 + H_2 \\ CO + NO \Rightarrow 1/2N_2 + CO_2 \end{cases} \tag{1}$$

$$\begin{cases} C_mH_n + 2(m+n/4)NO \Rightarrow (m+n/4)CO_2 + n/2H_2O \\ H_2 + NO \Rightarrow 1/2N_2 + H_2O \\ SO_2 + 1/2O_2 \Rightarrow SO \\ SO_2 + 3H_2 \Rightarrow H_2S + 2H_2O \\ 5/2H_2 + NO \Rightarrow NH_3 + H_2O \\ 2NH_3 + 5/2O_2 \Rightarrow 2NO + 3H_2O \\ NH_3 + CH_4 \Rightarrow HCN + 3H_2 \\ H_2 + 1/2O_2 \Rightarrow H_2O \end{cases} \tag{2}$$

During this process is also taking into account the engine load degree. For rich mixture (λ<1) the fuel quantity should be reduced and, for lean mixture (λ>1) it should be increased. Diagnosis probe tests if the adjustment probe is optimally functioning. The ECU control unit can calculate the required compensation in order to correct any possible deviations.

The lambda sensor measures the combustion efficiency by measuring the oxygen amount in the exhaust gas, giving a voltage output which represents this amount.

At the most efficient combustion point, the voltage takes a large step down, which signals to the ECU that this so-called 'stoichiometric point' has been passed through. The lambda voltage can be seen from the uninterrupted line on the graph. (Fig. 5) [5]. The graph also shows how the catalytic converter efficiency is affected by the mixture (dotted lines). A lambda sensor correct operation will allow the voltage to cycle up and down around the central point. (This range of movement is represented by the bands at the centre). This gives the catalyst favorable conditions to do its job properly.

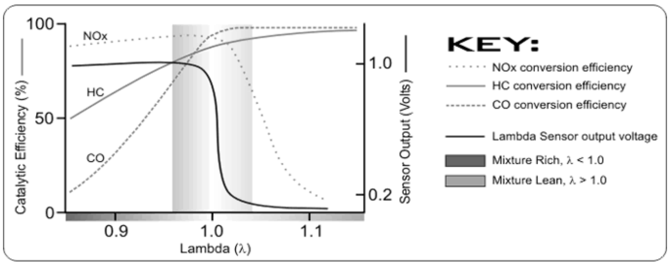

Figure 5. Quality fuel-air mixture effects on Lambda voltage and CAT efficiency

Any malfunction in the sensor operation will have a negative effect on engine performance, and ultimately could lead to catalyst damage. In practice, while the lambda sensor is being used in closed loop mode, the sensor output voltage value will oscillate, a few times every second. This process is influenced by the ECU using the lambda sensor output to continuously vary the mixture, from rich to lean and back again in order to provide the optimum conditions for the catalyst correct operation. The output voltage of the sensor has a very large step around the stoichiometric point, performing like a switch (Fig.6).

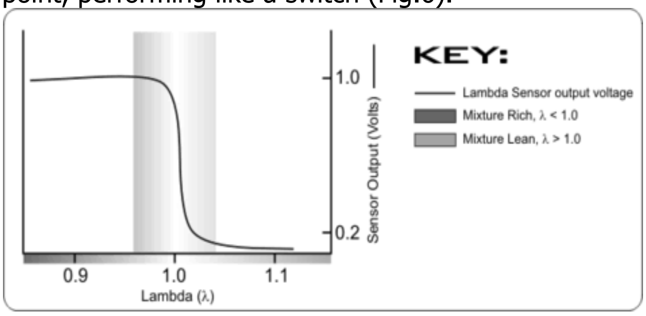

Figure 6. Lambda sensor voltage output curve

A malfunctioning, degraded, or worn out sensor will have this central point in the wrong place, or its response time will be sluggish rather than fast. A new sensor will switch in about 0.2 seconds. A worn out sensor may take as long as 1.5 seconds to switch. This will confuse or mislead the ECU and the result will be the engine poor running [5].

3. Experimental Results

In the Road Vehicles Lab at the Politehnica University of Timisoara, by using AVL Dicom 4000 analyzer, Lambda test was performed on the 1.4 Renault Clio Symbol vehicles (spark ignition engine) with the following characteristics:

Volume capacity: $V = 1390\ cm^3$
Power: $P = 72\ kW$
Speed at maximum power: $n_P = 6000 rot/min$
Torque: $M_m = 127 Nm$
Speed at maximum torque: $n_M = 3750\ rot/min$

Lambda test aimed to check the catalyst and fuel-air mixture efficiency [6].

The catalyst analysis was performed after stabilization testing and residual oxygen measurement (Fig.8).

Figure 7. Vehicle test

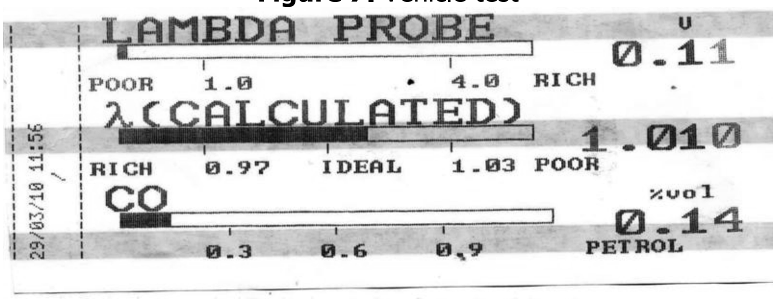

Figure 8. CC Analysis Test

Taking into account the recommended intervals for optimal engine operation, in Fig.8 it can be observed that for the tested vehicle, the fuel mixture is lean ($\lambda = 1.01$), so that the lambda sensor suggests the necessity of a supplementary oxygen quantity (SO = 0.14 < 0.3). ECU calculates the required compensation for deviations correction, thus an optimal operation requires the fuel quantity correction.

4. Conclusions

From the experimental research it is observed that the engine operates with lean mixture, so that a fuel mixture correction calculated by the control unit ECU is required. A compensation of 0.14% vol is imposed for the engine proper operation and enclosure emissions within permissible limits.

Lambda probes optimal operating can be jeopardized by several factors:

- The influence of external factors (salt and dirt);
- Fluctuations in temperature;
- Low quality fuel;
- Calamine and oil residues from the exhaust gases.

In order to prevent possible engine failures and fuel consumption increase which leads to CO_2 emissions increase, lambda probes should be tested after 30,000 kilometers of attending as a precautionary measure and replaced at recommended intervals.

Diagnosis systems using lambda probes are based on the capacity of the catalyst oxygen storage. As a consequence of oxygen storage capacity, an efficient catalyst will be able to absorb oxygen fluctuations in the exhaust gas when the vehicle is stable operating. Comparing the lambda probe signals upstream and downstream of catalyst provides an indication on catalyst activity, although the correlation between oxygen storage capacity and catalyst efficiency is still difficult [3].

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