EXHAUST GAS DOSE UNIFORMITY IN MODERN DIESEL ENGINES

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Abstract

Currently, the environment protection challenges the designers and manufacturers of combustion engines due to the fact that the engine emits toxic compounds, which are hazardous to the life organisms. Increasingly strict regulations concerning emission of the exhaust gases forces application of the innovative technologies or improvement of the presently used. One of systems, which reduce the toxicity of the exhaust gases, is the Exhaust Gas Recirculation (EGR) system. This solution reverse part of the exhaust gases back into the manifold and mixes it with fresh inlet air. In consequence, the combustion temperature decreases. Less oxygen reacts with nitrogen and more connects with carbon and hydrogen. Presently there are two types of EGR system i.e. internal and external. In case of the first one part of the exhaust gases remains in the combustion chamber after the combustion but its construction is not complicated. The external EGR system uses one valve of the exhaust gas recirculation system located on the manifold. This location can result of the uneven portion of exhaust gases directed to the combustion chamber. In consequence, the decrease on the temperature is also uneven and therefore different portion of nitrogen oxide in the exhaust gases.

Keywords: *EGR, exhaust gas recirculation, environmental protection, NOx*

1. Introduction

Exhaust gases recirculation systems (EGR), together with catalytic reactors, are commonly installed in modern piston combustion engines. Their purpose is to reduce the amount of nitrogen oxides (NOx) emitted in fumes. The need for this reduction takes its source in constantly more rigorous EURO norms, treating about maximum levels of NOx, HC and particulates produced as a side effect of engine's operation. Applied exhausts recirculation circuits can be characterized by a fact, that part of exhaust gases is redirected (through a cooler) and reaches a special valve. This valve, respectively to engine's current load and speed, drives more or less exhaust to suction manifold.

Beginnings of EGRs are reaching early seventies. The first EGR systems were crude, resembling an orifice jet between the exhaust and intake tracts, which admitted exhaust to the intake tract whenever the engine was running. They could be characterized by difficult starting, rough idling, also reduced performance and fuel economy. Further development lead to an EGR valve, which was controlled by manifold vacuum, opened or closed to admit exhaust to the intake tract only under certain conditions. Chrysler's system of 1973 utilized a coolant temperature sensor that blocked vacuum to the EGR valve until the engine reached normal operating temperature. This prevented driveability problems due to unwanted exhaust induction. The aim of research was to allow more precise constraint of EGR flow to only those engine load conditions, under which NOx is likely to form. Other example of improvement in EGR valve control was that, it was triggered by reference to vacuum within the carburettor's venturi. Later backpressure transducers were added. In newest constructions control is performed by an electronic unit [1].

Apart from external EGR valves, also internal recirculation systems are used. Solution bases on special construction of valve timing system and shape of exhaust system. Exhaust valves, during suction stroke, are closed with some latency, while in parallel intake valves are opened. This results in leaving some fumes in the cylinder.

2. Characteristics of the EGR system

Formation of toxic compounds is strongly related to burning temperature of fuel-air mixture. Inside cylinder, in high temperatures and pressures, nitrogen reacts with oxygen, creating nitrogen oxides. The heaviest impact on NOx particles creation has the type of the fuel-air mixture. It can be characterized by λ coefficient (1).

$$\lambda = L / Lt, \tag{1}$$

where:

L – the real (physical) dry air mass, in which fuel burns,

Lt – theoretical need for dry air for optimal (complete) burning.

In diesel engines it is typical to observe an excess of air in the fuel burning process (lean mixture). Therefore λ indicator is always greater than 1.2 ($\lambda > 1.2$). Lowering the burning temperature, and as a result, reducing NOx emission, is possible by replacing part of the cylinder inlet air by exhaust. Oxygen particles are then more likely to react with carbon and hydrogen rather than nitrogen. Amount of desired recirculated flow depends on engine working conditions, its load and speed. When considering idling diesel engine, typically an EGR valve is wide-open, delivering exhaust reaching 60% of sucked air mixture. The greater engine's load is, the smaller doze of fumes is provided, up to the complete closure of the valve. Recirculation is also deactivated when engine is heating-up and during very low atmospheric pressures (for example in mountain conditions) [2]. Estimation of optimal recirculation ratio can be done using formula (2).

$$\%EGR = ms / ms + mp, \tag{2}$$

where:

ms – mass of exhaust gases that were redirected to combustion chamber, in kilograms,

mp – air mass delivered to combustion chamber, in kilograms,

mp + ms – total weight of air and internally or externally re-circulated exhaust, in kilograms.

However, it is necessary to maintain certain burning conditions. Oxygen mass must be higher than the oxygen mass present in stoichiometric equations (for every 1kg of fuel – 14.6 kg air). This condition is a must, because of strong correlation between formation of nitrogen oxides and particulate matter (sooth). Too heavy exhaust flow reduces the overall gain from NOx reduction as amount of produced particulate matter starts to grow exponentially [3].

Not only the amount of re-circulated exhaust, but also its temperature shall be considered. Providing cooled exhaust to the intake system results in NOx reduction, but it also increases the emission of particulate matter. Introduction of electronic control in EGR systems enabled more precise regulation of their actuators. Modern combustion engines are equipped with single recirculation valve, placed just before the intake manifold (in terms of flow).

This positioning easies mixing of sucked fumes with fresh, turbo-loaded air, which is next transported (sucked) into each of the cylinders. Former research activities were focused on effectiveness of different EGR systems by measuring average NOx level in exhaust collector. However, the quantity of exhaust gases that is reaching each cylinder can be negatively dependent on EGR valve physical position in the circuit. Upper schemes are illustrating how, theoretically, the flow can be constantly uneven. Lack of this uniformity can effect with uneven slowing down

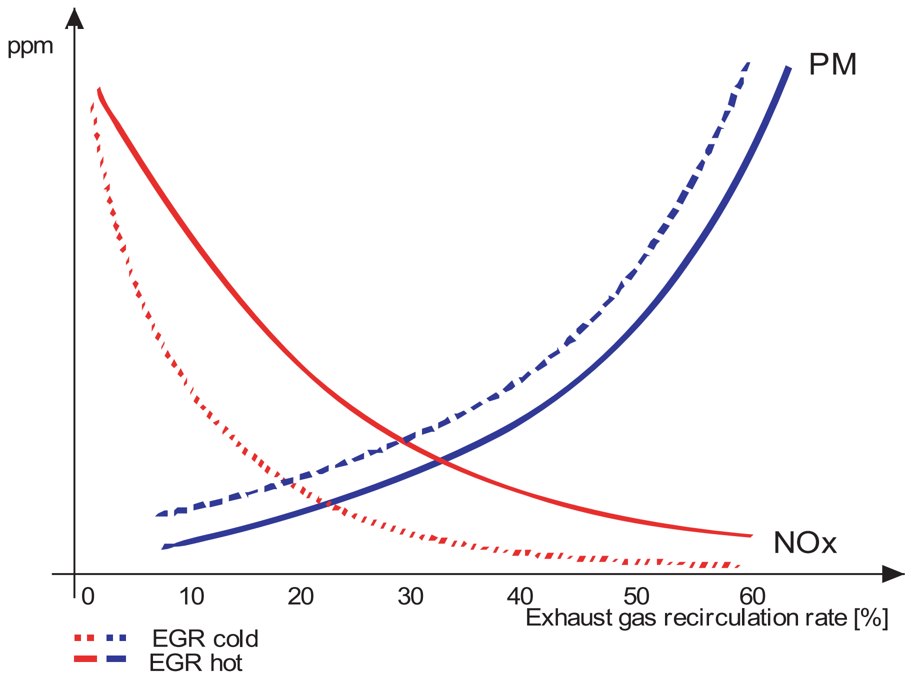

Fig. 1. Dependency between formation of nitrogen oxides and particulate matter

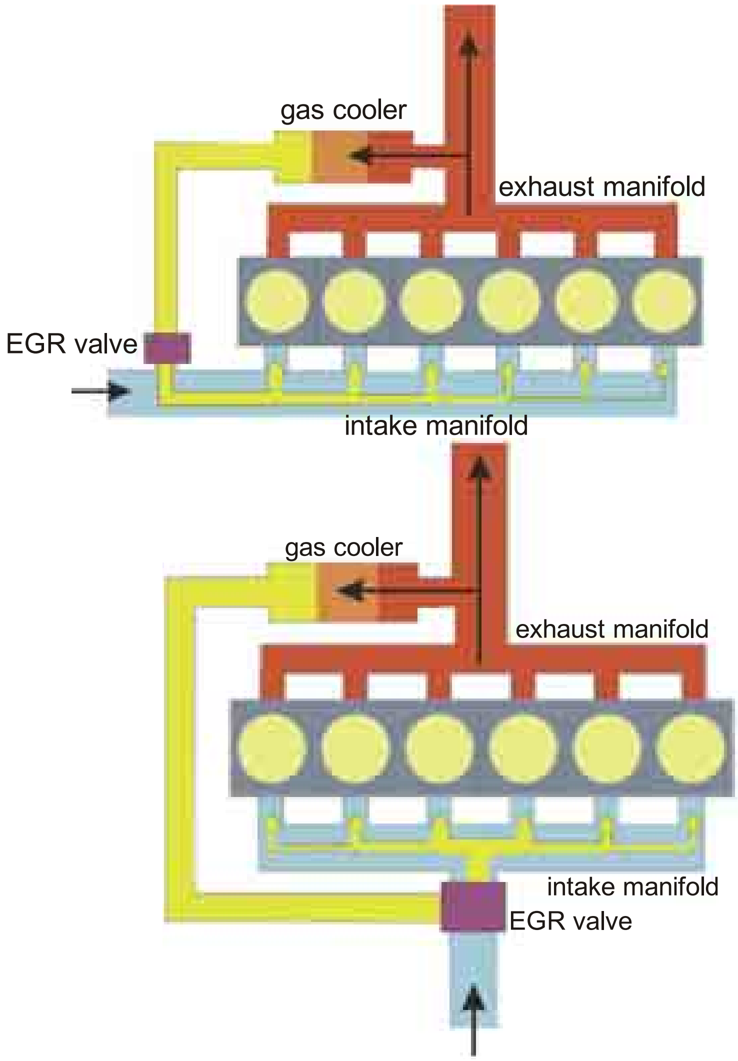

Fig. 2. Influence of the EGR valve location on the amount of gas supplied to the combustion chambers

the burning process, and therefore have impact on:

– nitrogen oxides emission,
– presence of particular matter in fumes,
– engine's torque and vibration,
– fuel dosing.

For analysis and verification of that thesis new research will be conveyed. They will be performed on Volkswagen turbocharged diesel engine with 1963ccm capacity. For measuring nitrogen oxides level, independent for each cylinder, a chemiluminescent analyzer will be utilized.

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