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ANALYSIS OF THE TEMPERATURE PULSATIONS OF THE EXHAUST GAS BEFORE THE THREE-WAY CATALYST

Böhm M.[*], Svída D.[**], Štětina J.[***]

Abstract: *When using combustion engine such as common gasoline engine, exhaust gas temperature pulsation due to dynamic changes in the operation condition often occurs. The most problematic point in designing the aftertreatment system is the light-off temperature of the three-way catalyst. The aim of this article is to describe the effect of the load and speed of the engine, which are the most problematic and frequently changing conditions during the real drive. A simulation of the exhaust gas temperature was carried out in order to investigate the impact on the effectivity of the catalyst. The simulated engine was inspired in turbocharged engine VW 1,5 TSI EVO. The exhaust gas temperature was calculated for full load steady state conditions, no load steady state conditions and real drive transient conditions. The results show that the effect of the dynamic changes of the load and speed of the engine is significant for determine the temperature pulsations in exhaust gas. These pulsations have major effect on the effectivity of the catalyst. Next research will be focused on remove these disadvantages with usage of heat storage system based on PCM materials inserted between the turbine and the catalyst.*

Keywords: **Gasoline, Combustion engine, Temperature pulsation, Exhaust gas temperature, Turbocharger.**

1. Introduction

Internal combustion engines are currently the most common type of engine in cars and trucks. This type of an engine has disadvantage in usage of the fossil fuels, whose combustion produces emissions and CO_2 in the exhaust gases. These negative components of the exhaust gasses are largely reduced thanks to the advanced aftertreatment systems and increasing overall efficiency of the combustion engines. But, in some operation conditions of the engine, these systems are not working under optimal conditions, and their efficiency is decreasing.

These processes have been intensively studied over the last decade due to the introduction of increasingly stringent emission limits, and especially today, as car manufacturers are preparing for the arrival of almost emission-free transport, this topic is becoming a major challenge.

For an optimal design and geometry of the aftertreatment systems (mainly three-way catalyst) it is necessary to know the actual temperature of the exhaust gas before it enters the system. During the operation of the engine, the temperature of the exhaust gas must reach in minimum the value of the light-off temperature of the three-way catalyst. This temperature depends on the design of the catalyst, but in common this temperature is around 630 K.

Determining the temperature of the exhaust gas due to running the engine in many different states and transient states is very demanding. Due to very fast and frequent changes in the engine operation conditions, large temperature pulsations of the exhaust gas occur. This article highlights the problem of the exhaust gas temperature pulsation before the entry into the three-way catalyst.

[*] Ing. Michael Böhm: Institute of Automotive Engineering, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, Michael.Bohm@vutbr.cz

[**] Ing. David Svída, PhD.: Institute of Automotive Engineering, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, Michael.Bohm@vutbr.cz

[***] Prof. Josef Štětina, PhD.: Institute of Automotive Engineering, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, Michael.Bohm@vutbr.cz

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2. Methods

The investigations presented in this paper were carried out by simulation. An GT-Suite model was developed to simulate the exhaust gas temperature behaviour and to perform the aftertreatment simulations. The model was created based on a 1,5 TSI EVO EA211 engine manufactured by VW. The model involved the turbocharged gasoline engine operated at different working points, simple aftertreatment system and thermocouple temperature sensor installed in the exhaust pipe right behind the turbocharger. The schematic of the set-up can be seen in Fig. 1.

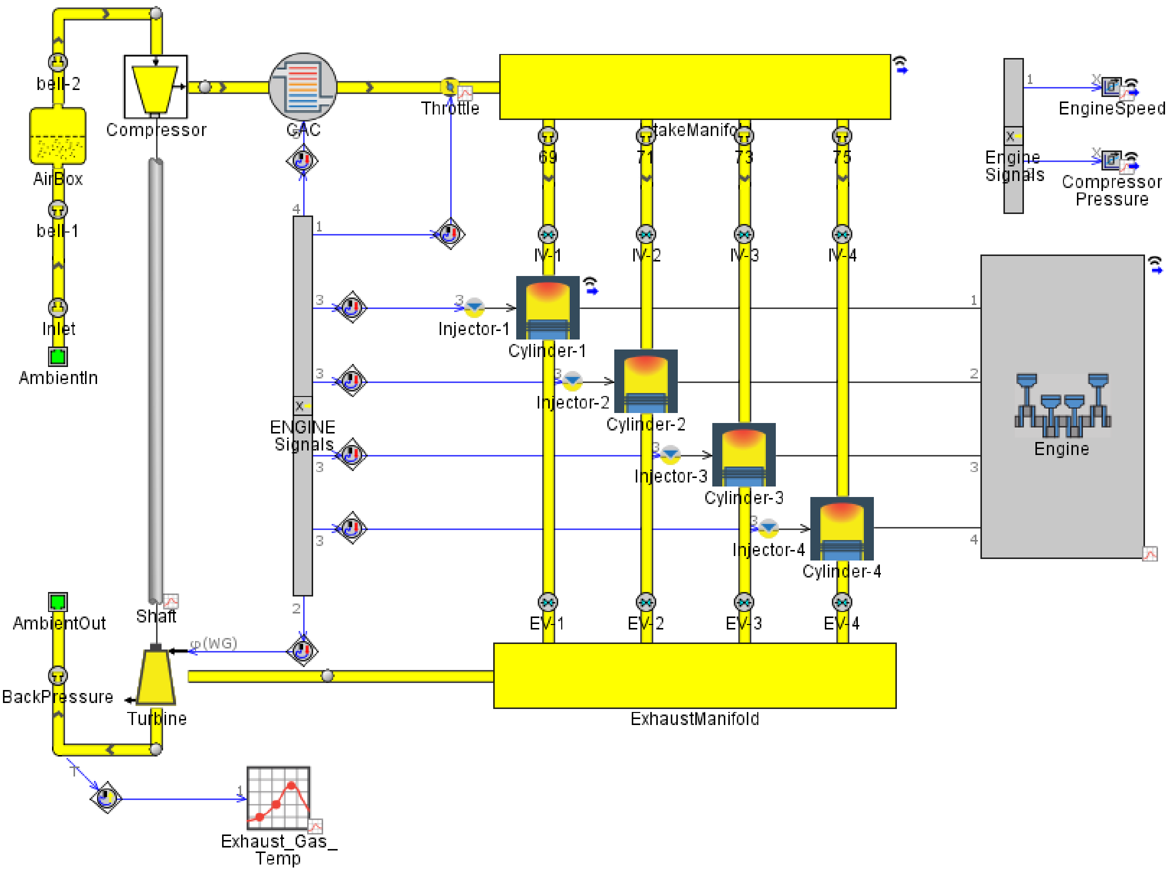

Fig. 1: Engine simulation model.

The internal conditions of the combustion in the engine were selected for the highest efficiency and stoichiometric mixture (intake pressure, intake temperature, air-fuel ratio). Adjusting the exhaust gas temperature by correcting some of these parameters, or other parameters of the combustion process, is possible, but it is disadvantageous because the process is set to optimal operating conditions, and therefore correcting the exhaust gas temperature in the combustion process would bring many negatives.

The simulation contained several different cases of engine operating conditions. In all cases, the exhaust gas temperature was measured as a function of time. The variable parameters of the simulation were the engine speed for steady states and the engine speed and load.

3. Results and discussion

The engine speed was prescribed directly, but the engine load was described by the throttle opening angle.

The first two cases were the engine performance characteristic and engine idling. This steady state cases were necessary to calculate the maximum and minimum exhaust gas temperature in the operation range of the engine. The temperature was calculated in 11 steps in the range of the engine speed 1000 – 6000 min^{-1}. The throttle was fully opened (t_{oA} = 90 °) and closed (t_{oA} = 0.5 °).

Tab. 1: Operation properties.

	Case 1	Case 2	Case 3
Simulation type	Steady state	Steady state	transient
Engine speed [min^{-1}]	1000-6000	1000-6000	Fig. 2
Engine load [%]	100	0	Fig. 2

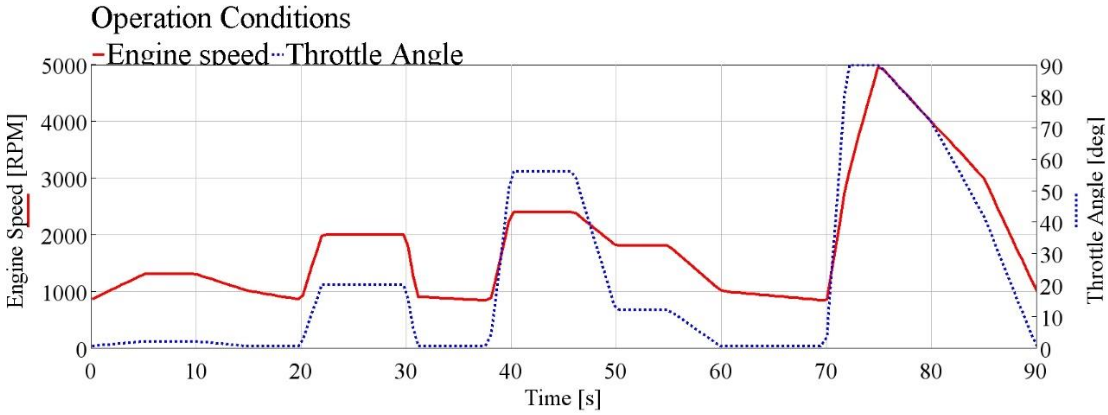

Fig. 2: Case 3 Operation conditions.

The third case represented conditions of the engine during real drive. These variables (speed and load) were chosen to correspond the dynamic and transient conditions.

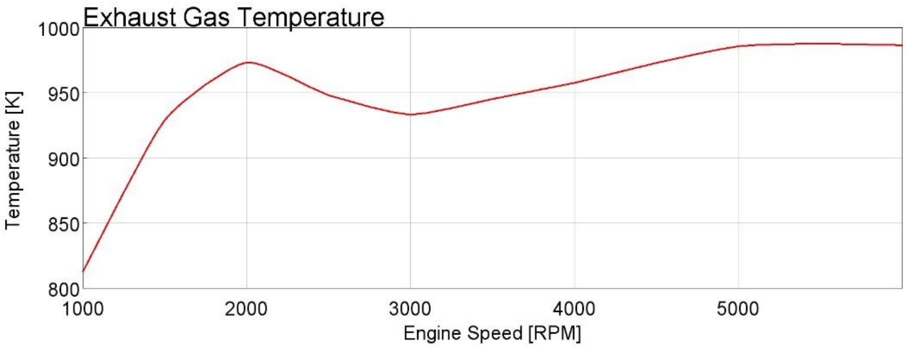

Fig. 3: The exhaust temperature for Case 1.

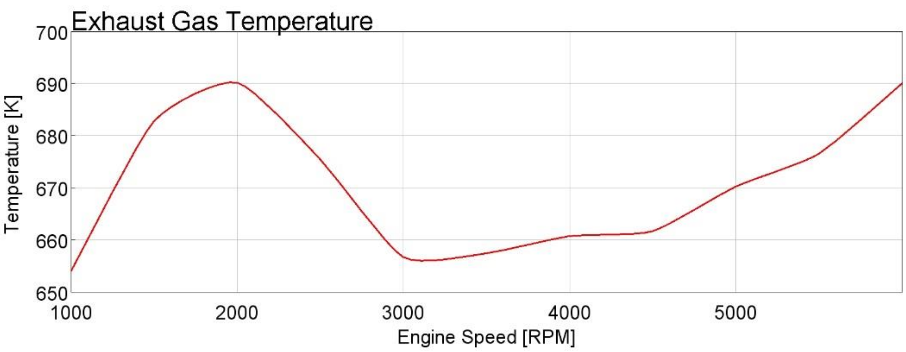

Fig. 4: The exhaust temperature for Case 2.

These two figures (see Fig. 3 and Fig. 4) shows the resulting exhaust gas temperature behind the turbine. However, it is almost impossible for the engine to reach these values of the temperature. These values only represent possible maximum values for chosen parameters.

The transient state of the engine shows (Fig. 5), that the temperature dynamically changes its value corresponds to the changes in the load and the speed of the engine. During the partial load (and full load) the temperature is high enough for efficient work of the catalyst. However, during the low speed and load conditions, the values of the temperature do not meet the basic condition of the effective work of the three-way catalyst:

$$T_{EXHAUST} \geq T_{CAT\_LO} \tag{1}$$

This causes a reduction in the efficiency of the catalyst and thus an increase in exhaust emissions.

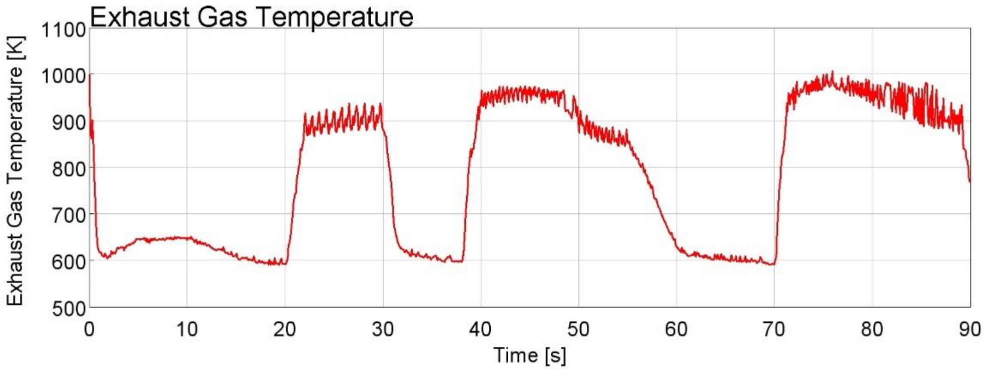

Fig. 5: The exhaust temperature for Case 3.

4. Conclusions

As described above, the changes exhaust gas temperature brings many pitfalls based on the dynamic changes in operation conditions. The condition of the combustion has effect on the exhaust temperature, but it is better to choose these variables for the highest possible thermal efficiency rather than for the optimal exhaust gas temperature. For this reason, it is necessary, as already mentioned, to calculate the exhaust gas temperature based on the engine speed and load.

The numerical model for an investigation of exhaust gas temperature behind the turbine was created. The VW engine EA211 1,5 TSI EVO was used as an engine for the simulation.

The results show that exhaust gas temperature has under the steady state conditions almost constant value and the trend of the temperature corresponds to the engine load and speed. However, during the transient conditions, which are more accurate for the real drive, the exhaust gas temperature pulsates. These pulsations reach in their minimum values temperatures, that are lower than the light-off temperature of the catalyst. The condition of the effective work of the three-way catalyst is not fulfilled and this causes a rapid reduction in the efficiency of the catalyst and increase the emissions.

Additional devices are currently used to remove these negatives. However, the thermal energy of the exhaust gas should be used to reduce the exhaust gas pulsation. The energy can be stored in heat storage based on the PCM materials. Due to this heat storage the overall efficiency of the engine and the efficiency of the catalyst will increase, and the production of the CO_2 and other emissions will decrease. Future research will be done in this area of heat storage systems which are not described in this paper.

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