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Engine Calibration of Fuel Quality Adaptation Function with Intake Manifold Temperature Sensor

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ABSTRACT
Today different fuel qualities are taken into consideration at pre-injection and start-injection fuel mass. The nominal fuel mass with reference fuel to guarantee engine stability with minimum emissions, has to be increased to compensate low evaporation fuel. This paper presents engine calibration of fuel quality adaptation function(FQA) with intake manifold temperature sensor. In engine test benches, the first step is to investigate the temperature behavior in the intake manifold depending on fuels and the driving cycle, the load condition and the boundary conditions as engine rpm, MAF(Mass Air Flow), MAP(Manifold Absolute Pressure), TIA(Intake Air Temperature), TCO(Coolant Temperature). The further step is to investigate the possibility to detect a changing fuel quality in running after fill up the tank.
Keywords: Engine Calibration, Engine Test Bench, Fuel Quality Adaptation Function (FQA), Intake Temperature Sensor

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I. INTRODUCTION

Automotive engine manufacturers are under pressure to provide engines that tougher emissions regulations and increased customer expectations for durability, noise, performance and low fuel consumption. To meet these demands, the number of parameters for the engine control unit is constantly increasing. Current engines are using variable valve timing, EGR, multiple injections as well as advanced control strategies to achieve these demands. Control unit calibration for modern internal combustion engines is currently facing a conflict caused by the additional effort needed to calibrate increasingly complex engine data with a growing number of parameters, together with extremely ambitious objectives regarding the period time and the resources needed for calibration. This parameters are saved in the engine control and called engine calibration. The engine control functions based on a natural, physical description. As additional prerequisite values, especially at the interfaces of the individual functional modules, enable the adaptation of the whole system to the different strategies of emission and consumption reduction. The engine ECU provides, already during engine start, adaptive functions with self-learning algorithms allowing to HC emission up to 30%. For that conclusions on the actual fuel quality are drawn from the engine speed up when starting and thus the injected fuel quantity for the following start procedure is metered accordingly. This can be realized because the series setting so far had to include significant margins towards richer mixture in order to ensure the engine start even under unfavourable environment conditions and with poor fuel qualities. The adaptation of fuel quality or engine start allows to significantly reduce this margin. Four different fuels, a reference fuel, summer fuel, a winter fuel and station fuel were evaluated with 1.2L, 3 cylinder engine. A test series was carried out in order to examine the potential to detect different fuel qualities with an additional temperature sensor in the intake manifold. Due to the test 1 and test 2 with the fuel quality adaptation function it was shown, that different fuel leads to big temperature differences in the manifold due to different evaporation behaviors of the fuels.

II. ENGINE TEST BENCH SETUP

2.1 Engine dynometer

The experimentation is supported by Euro 4 production 3 cylinders 1.2L gasoline engine operated cold start condition on instrumented different sampling rates 10ms, 100ms, 500ms using intake manifold additional NTC temperature sensor as SAM 2000 application tool. The NTC temperature sensor is a modified TIA sensor with additional long connection cables in order to mount it in front of injector valve. This sensor is moistened by the fuel spray from the injector like shown in Fig.1. The temperature decrease as a result of the evaporation of fuel will be the measured signal. The electrical characteristic is shown Fig.2 together with the electric circuit of evaluation

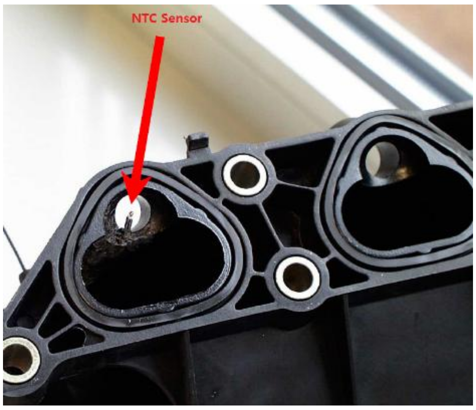


Figure 1 NTC sensor in the intake manifold

2.2 The NTC sensor

The general behavior of a moistened temperature sensor with fuel was already shown Fig.2. Fig.2 shows a diagram with measurements of three different fuels. A 1mm thermocouple K type was used to measure the temperature in the intake manifold. A significant temperature difference of the fuel can be seen already 1.0 sec after the start. There is a temperature difference of 15K after 3 sec between good vaporized winter fuel and bad vaporized summer fuel.

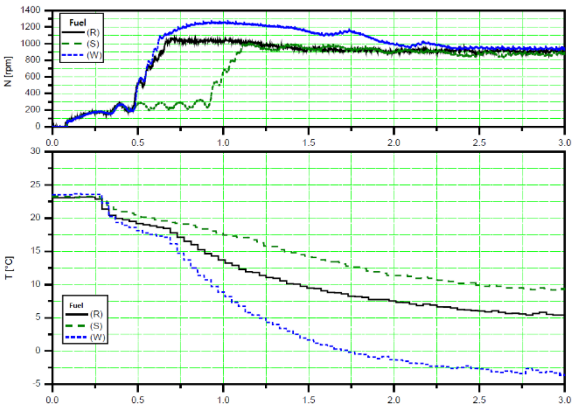


Figure 2 Temperature behavior of a moistened thermocouple

The NTC sensor was used and installed in the intake manifold in front of the injection valve. The NTC sensor itself has an approximate 1mm diameter and is moistened by the injector with fuel. Fig.3 shows temperature behavior T_{NTC} of the NTC sensor with station fuel of winter type for 3 times starts of the engine. There, the temperature decreases within 3sec for 22K from 15°C down to -7°C. This corresponds to the measurement results in Fig.3 which done with a thermocouple. This means that the NTC sensor is as fast as the thermocouples. The test evaluation was not considered the slope of changing temperature. The temperature of the NTC sensor do not correspond to the coolant temperature (TCO) when still no injection was at starting. The temperature of NTC sensor is 15°C at the coolant temperature 55°C. The intake manifold is made plastic with a bad heat conduct coefficient. The heat from engine will not directly and immediately warm up the manifold and sensor.

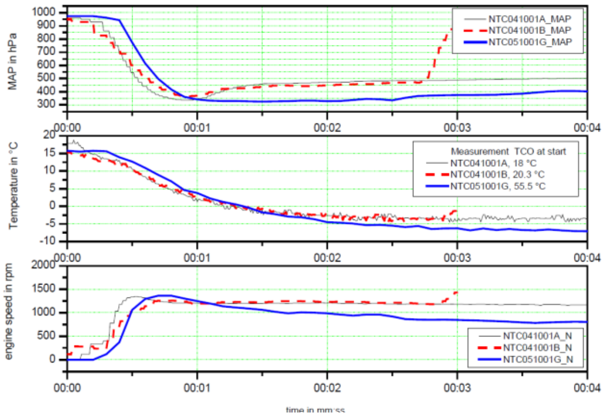


Figure 3 Temperature behavior of a moistened NTC sensor

2.3 Fuels

Fuels from the company Haltermann in Hamburg were used, see Table 1. Fig. xx shows the evaporation behavior over the temperature. At 40°C temperature the part of evaporated fuel of winter fuel amounts 10%, but the part of summer fuel amounts 0%. Therefore the difference is 100%. At 80°C temperature the part of evaporated fuel of winter fuel amounts 58%, but the part of summer fuel amounts 20%. Therefore the difference is 66%. For that reason it can be estimated that difference of the temperature drop due to the evaporation of different fuels will decrease at rising coolant and intake manifold temperature.

Table 1 Used fuels

	Reference fuel CE	Summer fuel	Winter fuel
ROZ	96.8	98.2	97.8
E70(Vol%)	22	15	50
E100(Vol%)	50	35	70
RVP(kPa)	56~64	35~40	90~95
VLI	714	455	1250
DI	1198	1312	837

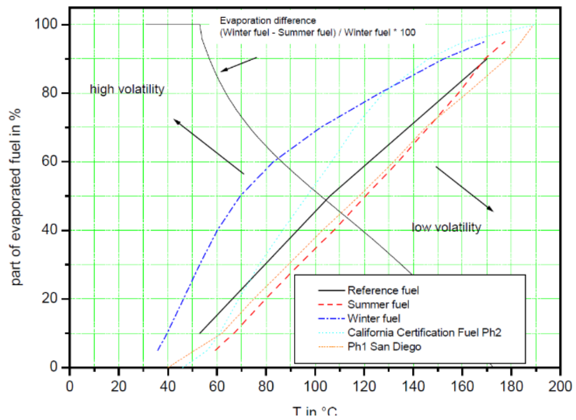


Figure 4 Evaporation behavior of different fuels

The test were carried out within one week. Each day other fuel was used in order to have as much variation as possible. In general the fuel was changed in the early afternoon by draining the old fuel from tank and from the fuel pipe. Only a little fuel amount from the common from the common fuel rail at the injectors rests in the car. After that the car was driven and at same time the temperature in the intake manifold measured. With this strategy it was possible to see the changing evaporation behavior of the fuel at a tank stop.

2.4 Driving Cycle

In order to get as much as possible information from the NTC sensor dependent on the engine load MAF and MAP, RPM, TCO and TIA a special driving cycle was defined and carried out with all fuels. This driving cycle takes about 18 min, including starts and stop cycles. Fig.5 shows the data of the above described driving cycle for station fuel. With this plot TCO rises from 18°C to 90°C and the temperature from the intake air rises from 18°C up to 37°C. The temperature T_{NCT} varies dependent on the engine operating states and TCO and TIA. The NCT temperature rises together with TIA. A temperature difference ΔT_{NTC} was calculated in order to reduce the influence of TIA to T_{NTC}. The temperature of the NTC sensor varies strong with the engine speed and of course with the load. Fig.6 shows all data of the previous driving cycle sorted by the engine speed. It ca be seen that only stable in range from 800rpm~1000rpm and reproducible temperature ±2°C are available. This means that strong filter conditions have to be fulfilled in order to evaluate the temperature behavior of the NTC sensor. For evaluation of the test filter conditions were defined in range from 800~1000rpm and ±20 rpm within 6 segments.

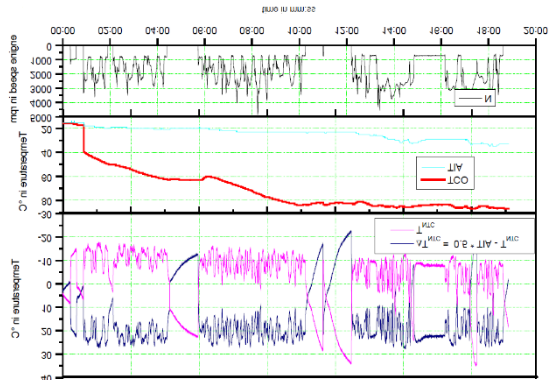


Figure 5 Driving cycle with station fuel

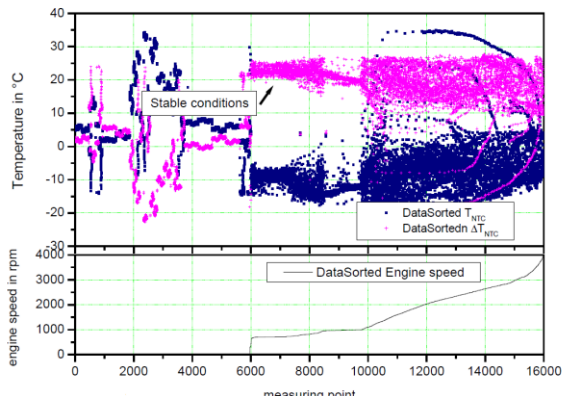


Figure 6 Sorted data wit station regions

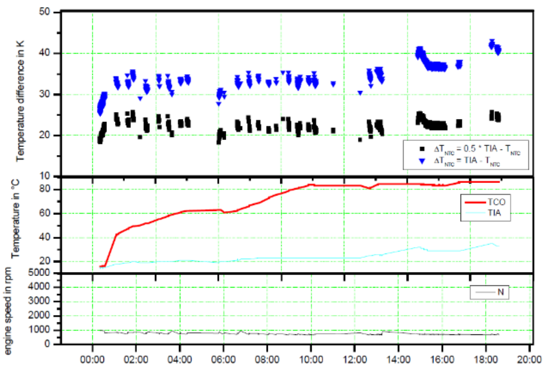


Figure 7 Filtered data of the driving cycle

The weighting factor 0.5 at the calculation ΔT_{NTC} was used in order to get the best result as representation of the influence of the intake manifold. The result of the driving cycle from Fig.5 after applying the calculation and the filters can be seen in Fig.7. A constant signal ΔT_{NTC} independent on TIA and TCO can be noticed.

2.5 Fuel Quality Adaptation Function

The purpose of the fuel quality adaptation function is to produce a correction factor for injection time calculation. The presence of bad fuel is detected by engine rpm gradient analysis during rpm-up. If the engine rpm-up is too low, then the correction factor is incremented step by step until idle speed set point is reached. The correction factor is used as an input for the different mass set points during start.

III. TEST EVALUATION

After carrying out all tests with the different fuels the data were filtered as mentioned above and place it in one data file. The temperature of the NTC T_{NCT} or temperature difference ΔT_{NTC} were plotted over different dependencies in order to find a parameter to clear distinguish the fuels. Fig.8 shows the temperature difference ΔT_{NTC} unsorted for all remaining measured points after filtering. With these data there are still the whole TCO temperature range from 15~90°C available. There are regions where a clear distinguishing between the fuels is possible and some where it is not possible. The summer fuel has the least temperature difference and winter fuel has the highest temperature difference.

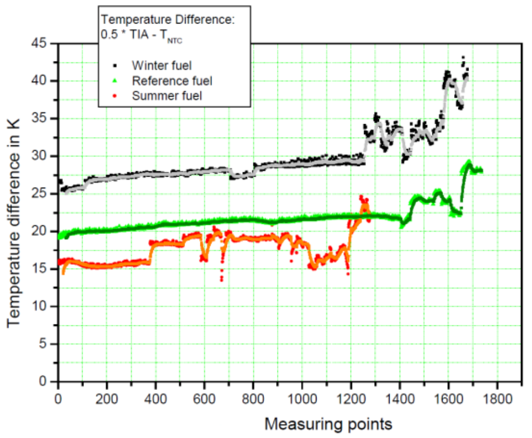


Figure 8 Temperature difference unsorted data

3.1 Temperatures dependent on MAF

Fig.9 shows the temperature difference ΔT_{NTC} depend on the mass air flow. The temperature difference rises with a falling MAF for all fuels. But the slop with winter fuel is even stronger than for summer fuel. In generally, the MAP is lower at lower MAF too. At lower pressure more fuel can evaporate and temperature difference is increased. But it can be noticed that will be no more possible to distinguish reference fuel from summer fuel at lower MAF values of 105 mg/stk.

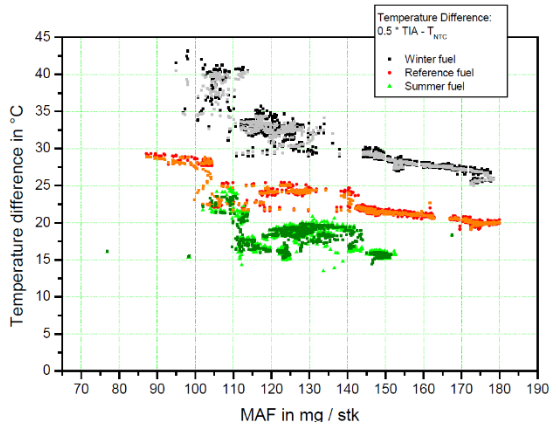


Figure 9 Temperature difference dependent on MAF

3.2 Temperatures dependent on MAP

Fig.10 shows the temperature difference on the MAP. As mentioned above this temperature difference ΔT_{NTC} should be strongly depend on the MAP due to the evaporation of the fuel. But this behavior can't be seen as clearly as thought. The detection of different fuels is even worse than at the evaluation of the MAF signal in Fig.9. The MAP values are not determined at the constant temperature of intake air and manifold due to driving cycle. In Fig.4, it was explained that at elevated temperature the relative evaporation and temperature difference of used fuels is lower than at lower temperatures. The temperature of intake air and coolant temperature has to be considered. The determination of the MAF signal takes into consideration the intake air temperature sensor, the difference of the used fuels can see more clearly than the evaluation of the raw MAP signal.

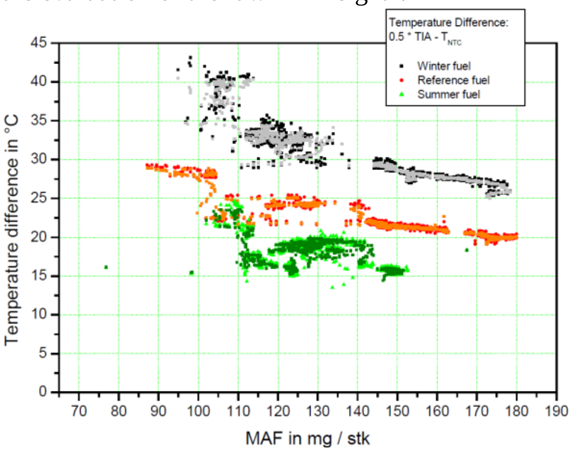


Figure 10 Temperature difference dependent on MAF

3.3 Temperatures dependent on TIA

Fig.11 shows the temperature difference ΔT_{NTC} dependent on the TIA. All conditions with the same MAP or MAF are represented with a colored bar. The winter fuel leads to the least temperatures of

-16°C at TIA 16°C. The summer fuel leads to the highest temperature. The temperature T_{NCT} at a certain TIA is quite stable and varies only for a deviation of approximately ±2K. The different fuel can clearly be distinguished because for each fuel a certain level on TIA be determined. It means that is possible to determine winter fuel because the difference between winter fuel and reference fuel amounts 8K or 4K under consideration of the deviation of ±2K. But it is not so easy to determine summer fuel because the difference of reference fuel and summer fuel amounts 5K or 1K under consideration of the deviation. At higher TIA 35°C the temperature difference between reference or summer fuel to winter fuel is even bigger than TIA value 15°C.

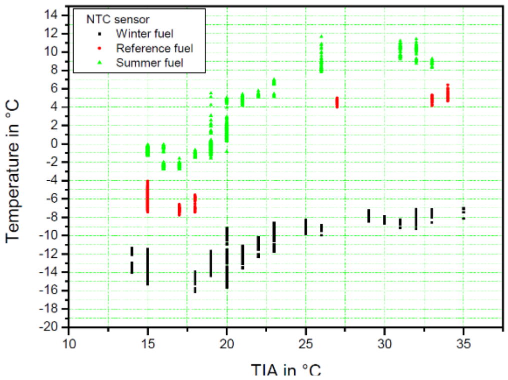


Figure 11 Temperature T_{NTC} dependent on TIA

3.4 Temperatures dependent on TCO

Fig.12 shows the dependent of T_{NTC} on the coolant temperature TCO. At lower TCO 15°C a clear separation of the used fuels is possible. The temperature difference between the fuels amounts the same values as TIA 15°C. This relation remains the same until TCO 55°C is reached. At more TCO 80°C level a separation between summer and reference fuel is hardly possible because the temperature difference the two fuels is nearly the same. There, the relative evaporation difference between summer and reference fuel will decrease. The relative temperature difference of the moistened NTC sensor and TCO will lower at higher TCO. At hot start after 10 min, the fuel in the rail was warmed up too. The temperature drop due to the moistened NTC sensor will have another behavior at a cold engine and cold fuel rail. In the Fig.11 T_{NTC} dependent on TIA is more than T_{NCT} dependent on TCO. It is the heat conductivity which warms up the intake manifold in the same manner as the fuel in the fuel rail.

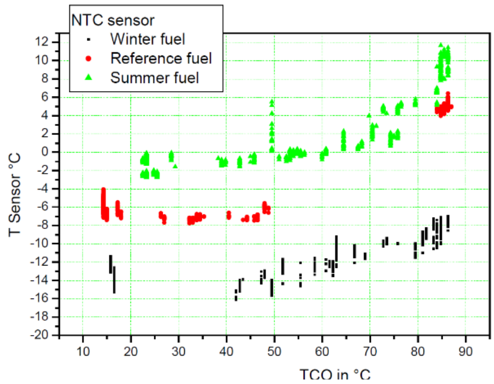
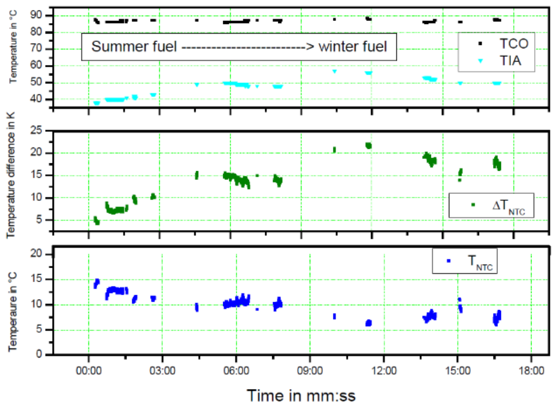


Figure 12 Temperature T_{NTC} dependent on TCO

3.5 Temperatures behavior at changing fuel

Fig.13 shows the behavior of the temperature at changing from summer fuel to winter fuel. The summer fuel was drained and afterwards filled up with winter fuel. So only the remaining fuel of fuel rail was summer fuel at engine start. The test was measured at a TCO 85°C and TIA 38°C, NTC 15°C. The temperature difference ΔT_{NTC} rises within the first 4 min from 5K up to 15K at a TIA 50°C and first 10 min from 5K up to 22K at a TIA 55°C.



In the case these results would be compared with an index table, which was created from the results presented in Fig. the changing fuel quality could have been determined in the running engine. The detected new fuel quality had to be written down in the non-volatile memory at engine stop in order to be available for next engine start. Then at engine start, the new fuel quality could be taken into consideration and injected fuel amount could be corrected by factor.

IV. CONCLUSION

With the presented determination method of fuel quality adaptation function, the calibration is provided with a universal tool for ECU function. It is bas been shown, the temperature different at cold start between the uses fuels is up to 5K after 1 sec and up to 15 K after 3 sec. A fuel quality adaptation function is to determine possibly at cold start. Filter has to be defined in order to evaluate stable operating conditions idle speed range of 800~1000rpm. The engine speed rpm must be stable and with 6 segments in a range of ±20 rpm. Only data are allowed where the engine operating state is idle. Under consideration of filter conditions it is possible to distinguish different fuel qualities even at hot running engine.

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