NEW DIAGNOSTIC METHODS OF ALTERNATIVE LPG/CNG INJECTION SYSTEMS

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Abstract

Diagnostic methods of gas alternative feeding systems were presented in this paper. Methods of validation for properly cooperation between OEM petrol systems and gas injection system were described. Procedures allowing the analysis of proper operation of both petrol and alternative feeding systems were presented. A detailed study has been done on sequential injection system, as a solution fulfilling restricted requirements of new SI engines.

Obtaining both satisfactory emission reduction level and minimal power drop for alternative engine gas operating is only possible with all diagnostic procedures especially ones connected with system prototyping phase being done with high precision equipment characterized by low inertia of transducers. Sensors output signals require acquisition with the use of more complex and faster systems. Proper choice of test equipment at each step, guarantees repeatability and what results also reliability of realized diagnostic procedures.

Influence of alternative gas fuelling systems on mixture adaptation, transfer function, diagnostic methods for prototyping phase, diagnostic procedures for alternatively powered vehicle operation, diagnosis of sequential gas injection system during normal system maintenance are presented in the paper.

Keywords: *CNG, LPG, SI engine, maintenance, fuel injection*

1. Introduction

Together with the introduction of oxygen sensor signal as an input for electronic control units in propulsion systems, A/F mixture ratio adaptation procedures have also been implemented [5]. Those adaptation procedures are subject of dynamic modifications, and are constructed in a way that makes it possible to provide faster and more precise control of air-fuel mixture.

Main purposes of adaptive functions are to provide stoichiometric air fuel mixture, by fast response and compensation of feeding system operating conditions variations.

The example of A/F regulation blockset has been presented on Fig. 1. Variations of fueling system operating conditions can be caused by different factors. We can mainly classify them in two groups. Physicochemical factors:

- fuel density and viscosity,
- calorific value,
- fuel temperature,
- fuel pressure,
- ambient temperature,
- atmospheric pressure,
- heat of vaporization.

Constructional factors:
- distance of injector nozzle from combustion chamber,
- injector maximum flow rate,
- distance of oxygen sensor from combustion chamber and from injectors,
- fuel injection quality, and fuel spray angle,

other factors may be also considered as creation of liquid fuel film in manifold ducts, influencing flow resistance due to friction during intake phase.

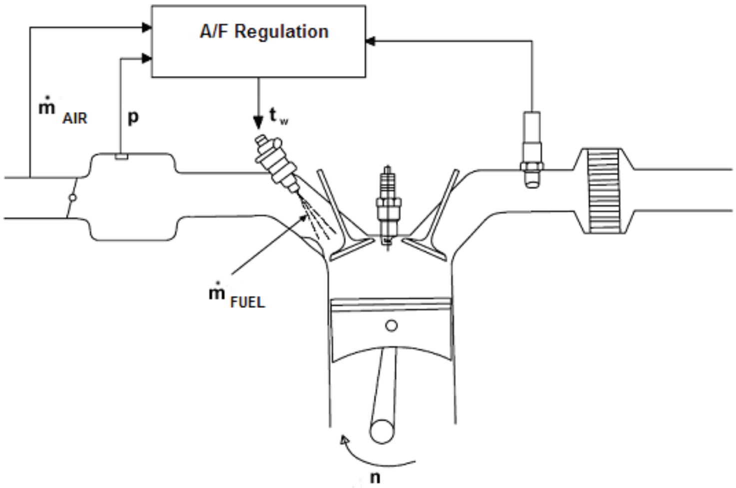

Fig. 1. Injection system with A/F regulation and adaptation blockset

2. Influence of alternative gas fuelling systems on mixture adaptation

The use of gaseous fuels characterized by different physicochemical properties compared to petrol makes it necessary to apply feeding system different construction. Differences between both OEM and alternative fueling systems are caused also by different aggregation state of gaseous fuels, which may be used both in liquid and gaseous state. Today's alternative fueling system is mainly a sequential injection, solution enabling fulfilling the emission regulations, and providing satisfactory performance by means of very low power drop compared to petrol operation.

Proper cooperation between petrol OEM and gas fuelling systems is very important aspect in case of sequential injection system, when considering of A/F mixture adaptation. That is because alternative gas fueling system remains in close cooperation with OEM petrol system. Block diagram, describing the idea of serial operation between petrol and gas system has been presented on Fig. 2. Electronic control unit which drives gas injectors actually translates the petrol injection duration in gas injection time.

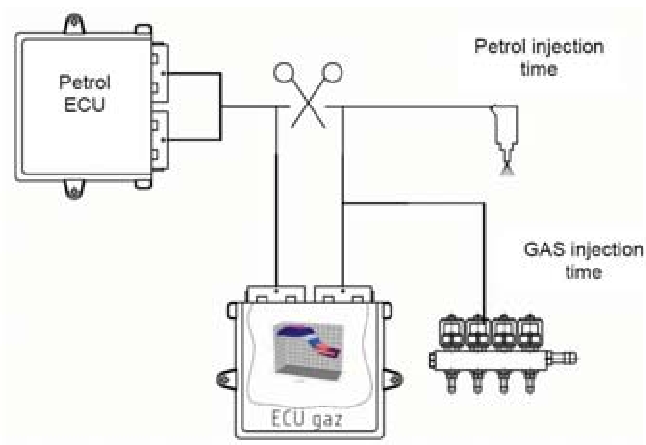

Fig. 2. Block diagram explaining operation principles of sequential injection system

Gas electronic control unit in this case is a sophisticated real time transforming unit, which considers:
- gas different physicochemical properties compared to petrol,
- different flow characteristics of petrol and gas injectors,
- different operating pressures for petrol and gas,

and transforms petrol injection time into gas injection duration.

3. Transfer function

Electronic control unit basing on transfer function realizes adjustment and transformation of injection duration for gas fuelling purposes. [2].

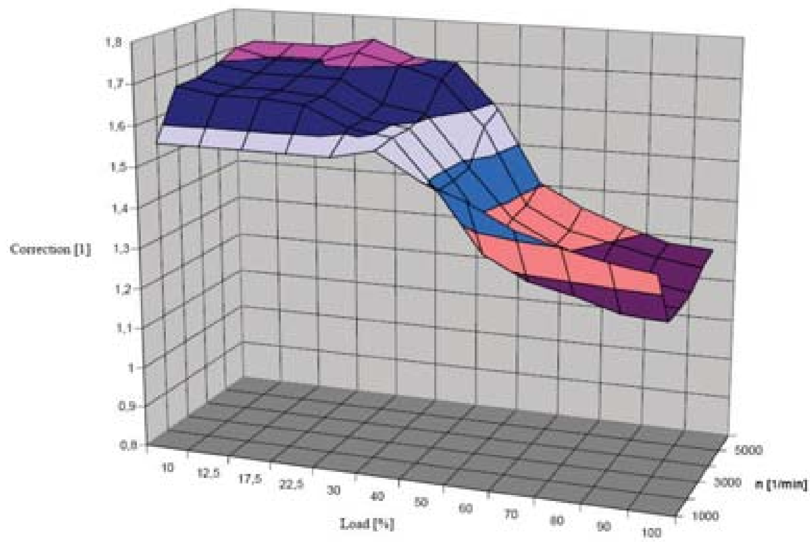

Fig. 3. Example of transfer function for Alfa Romeo 166 2,5 V6

Transfer function is the one that considers all factors mentioned above, and its proper definition is realized individually for each engine, allowing:
- minimized difference in engine performance on alternative gas operation compared to results obtained on petrol,
- important reduction of emission levels on gas operation,
- proper realization of adaptive and control procedures implemented in OEM ECU.

Example of transfer function for alternatively powered Alfa Romeo 166 2500 cc V6 engine has been presented on Fig. 3.

4. Diagnostic methods for prototyping phase

Introduction of a alternative feeding system on a market is forwarded by complex set of stand tests, which makes it possible to valuate overall performance of different engines powered with that system, especially:
- engine power and torque on gas,
- emission levels,
- fuel consumption,
- heat release during combustion process.

During stand tests, realized on braked benches, a detailed analysis of combustion process is carried on, with the use of piezoelectric pressure transducers.

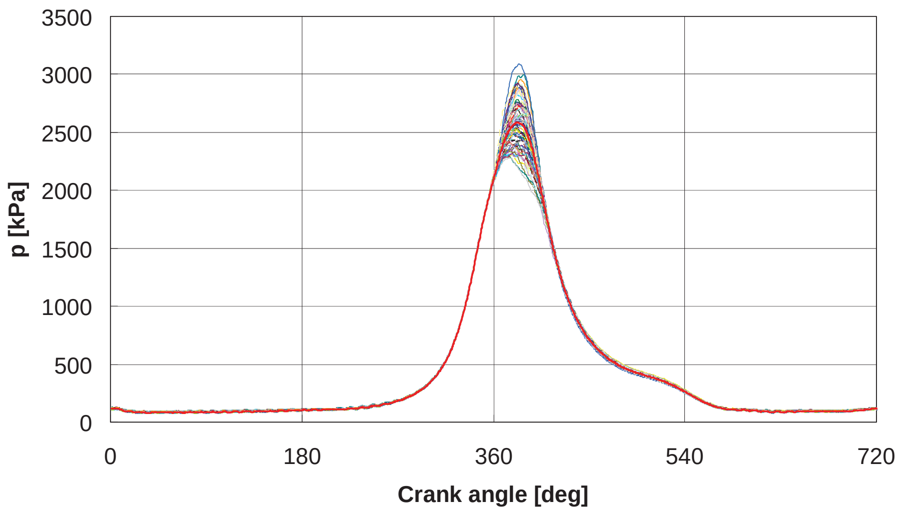

Fig. 4. In-cylinder pressure of X16SZR engine fueled by LPG

The use of information describing indicated pressure changes makes it possible to optimize fuel system configuration, what enables obtaining best engine performance results according to criteria defining the proper combustion process. Fig. 4 shows sample indicated pressure charts registered for X16SZR engine by OPEL, alternatively LPG powered by means of multipoint sequential injection.

Roller bench makes it possible to complete emission tests and to define fuel consumption based on carbon equilibrium.

Exhaust gases emission test results obtained in European driving cycle with hot start, for three different system configurations has been presented in Tab. 1. Emission levels are considered as one of very important factors which influence final system configuration.

Tab. 1. Emission tests results for different configuration of injection system

		Urban cycle	Extra urban cycle	Medium	Deterioration factors	Factored result
configuration 1	CO [g/km]	0.136	0.621	0.443	1.2	0.531
	NO_x [g/km]	0.051	0.009	0.025	1.2	0.030
	CH [g/km]	0.07	0.046	0.031	1.2	0.038
	CO_2 [g/km]	170.7	130.5	145.3		
configuration 2	CO [g/km]	0.266	0.233	0.245	1.2	0.294
	NO_x [g/km]	0.016	0.018	0.017	1.2	0.021
	CH [g/km]	0.027	0.010	0.017	1.2	0.020
	CO_2 [g/km]	172.2	131.8	146.7		
configuration 3	CO [g/km]	0.140	0.326	0.257	1.2	0.309
	NO_x [g/km]	0.016	0.007	0.010	1.2	0.012
	CH [g/km]	0.002	0.019	0.013	1.2	0.015
	CO_2 [g/km]	169.6	132.0	145.8		

5. Diagnostic procedures for alternatively powered vehicle operation

Tests completed directly on vehicle are an important supplement to test bench research. They are usually realized with the use of roller benches and directly on road. Main goal at this stage is to valuate system operation in transient states. A detailed study is carried on an OEM ECU adaptation blockset, valuating as well quality of cooperation between OEM and aftermarket system.

Test procedures realized with the use of serial diagnostic equipment allowing it to establish connection with OEM ECU, allows detailed analysis of mixture adaptation blockset operation in full range of engine load.

Switching from petrol to gas should not be recognized by OEM electronic ignition-injection control unit, and must not cause any changes in calculating, regulation and adaptation procedures.

In case where after switching from petrol to alternative gas operation OEM injection control unit registers changes in mixture preparation, it is considered important error in transfer function construction. Examples of injection time traces both of petrol and gas operation for proper and in correct setup are presented on Fig. 5.

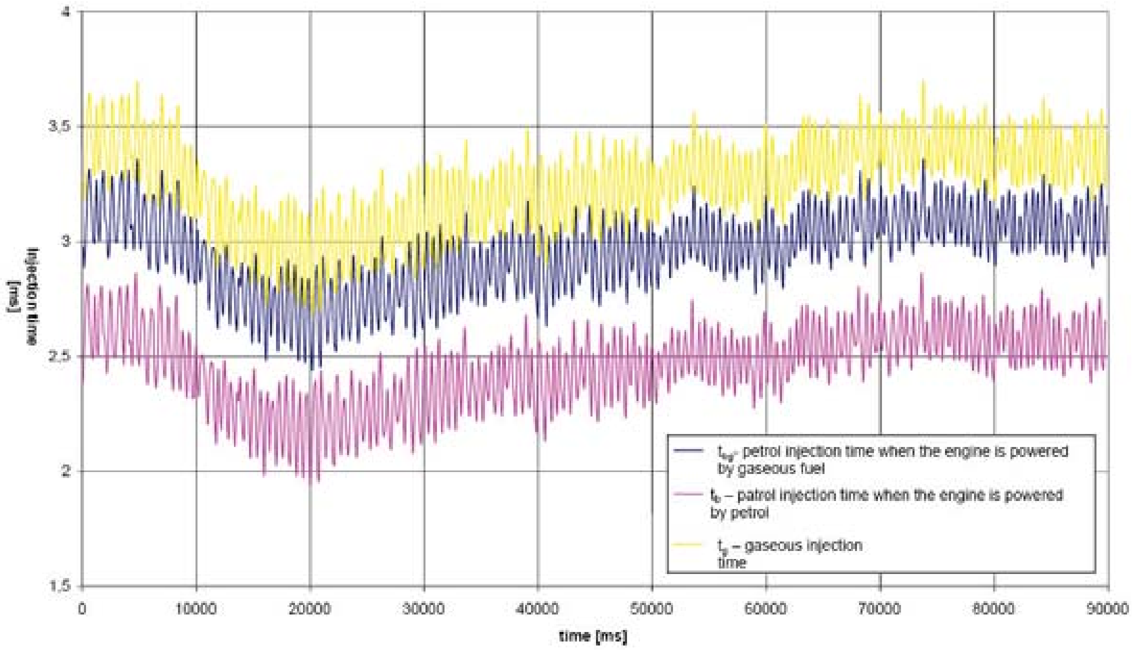

Fig. 5. Traces of injection times of petrol and LPG for both properly and not properly constructed transfer function

6. Diagnosis of sequential gas injection system during normal system maintenance

Stand tests characteristic for prototyping processes of feeding systems, together with supplementary tests done before introducing the system into production, are only giving the fuelling system only its initial shape.

Adaptation of IC engine to alternative gas operation in a standard workshop requires the use of much more simple and widely available verification methods. Proper operation of alternatively fuelling system and quality of its cooperation with OEM injection system is being tested according to following procedures:

- emission analysis with the use of stationary 4 gas analyzer at few points of engine operation without load,
- road test with the use of serial diagnosis equipment, allowing to dialog with OEM petrol injection ECU and follow precisely the operation of mixture adaptation blockset,
- eventual estimation of engine power and torque output fed both with petrol and alternatively with gas, with the use of accelerometer (Fig. 6).

Estimation of engine emission levels should be carried on with the use of fast response test equipment allowing registration of emission levels of nitrogen dioxides, hydrocarbons, carbon dioxide and dioxide and air-fuel ratio.

Serial diagnosis of electronic control units can be in most of cases realized on the base of normalized transmission protocols common for EOBD, OBD2 [1]. The use of that kind of diagnostic equipment makes it possible to follow operation of adaptation blockset thaks to fast and slow fuel trims variations.

Quality of realized at this stage diagnostic procedures in an important way defines cooperation between OEM petrol and gas systems, also influences alternatively gas powered engine performance. Improperly constructed transfer function of sequential injection system may significantly influence engine power output on gaseous fuel, what has been illustrated on Fig. 7 to 8. Those figures demonstrate differences in power and torque traces of 188A4000 engine by Fiat, alternatively CNG powered, for different transfer functions setups.

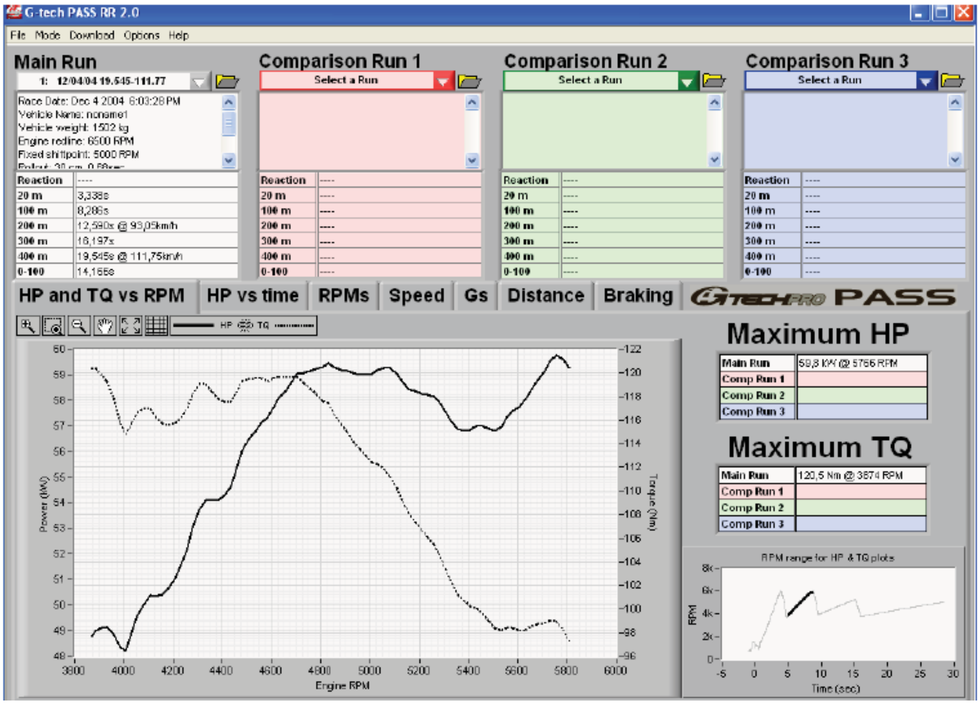

Fig. 6. Traces of engine torque and power

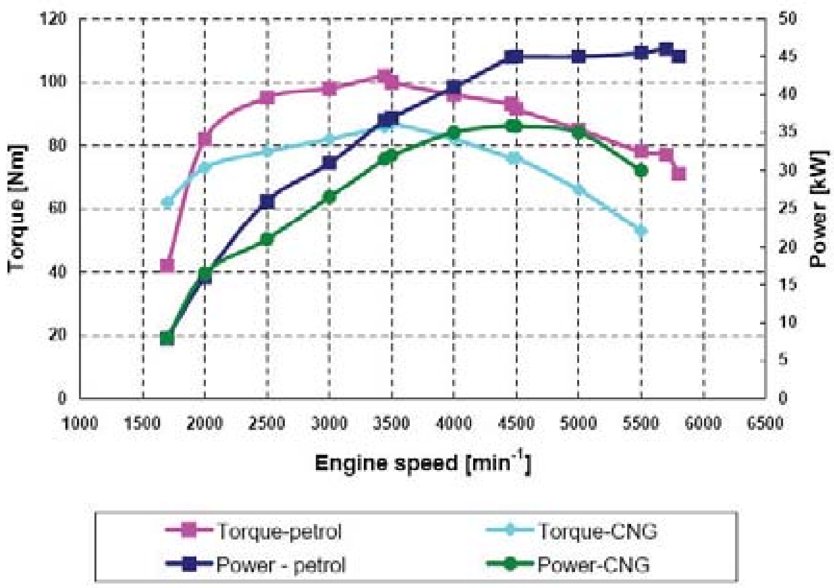

Fig. 7. Traces of power and torque for engine type 188A4000, fuelled by CNG for improperly constructed transfer function

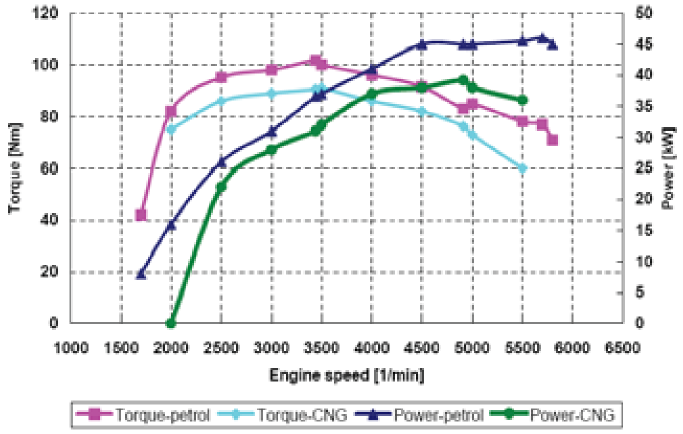

Fig. 8. Traces of power and torque for engine type 188A4000, fuelled by CNG for properly constructed transfer function

Fig. 9 shows the idea of automatic calibration of sequential injection system, for all solutions of OEM systems provided with oxygen sensor reference. K_4 is a discrete representation of injection transfer function consisting of 72 elements. S is a step matrix, defining the modification of map during calibration.

An example of both K_4 and S are presented below.

$$K_4 = \begin{bmatrix} 108 & 111 & 113 & 118 & 120 & 122 \\ 110 & 113 & 115 & 120 & 122 & 124 \\ 120 & 124 & 125 & 130 & 132 & 134 \\ 126 & 131 & 133 & 138 & 140 & 141 \\ 130 & 136 & 138 & 141 & 142 & 144 \\ 129 & 134 & 136 & 140 & 141 & 143 \\ 124 & 129 & 131 & 136 & 138 & 140 \\ 114 & 118 & 120 & 125 & 126 & 128 \\ 107 & 110 & 112 & 116 & 118 & 120 \\ 104 & 107 & 110 & 114 & 115 & 118 \\ 104 & 107 & 109 & 113 & 115 & 116 \\ 102 & 105 & 108 & 111 & 113 & 115 \end{bmatrix}, S = \begin{bmatrix} 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 \end{bmatrix}$$

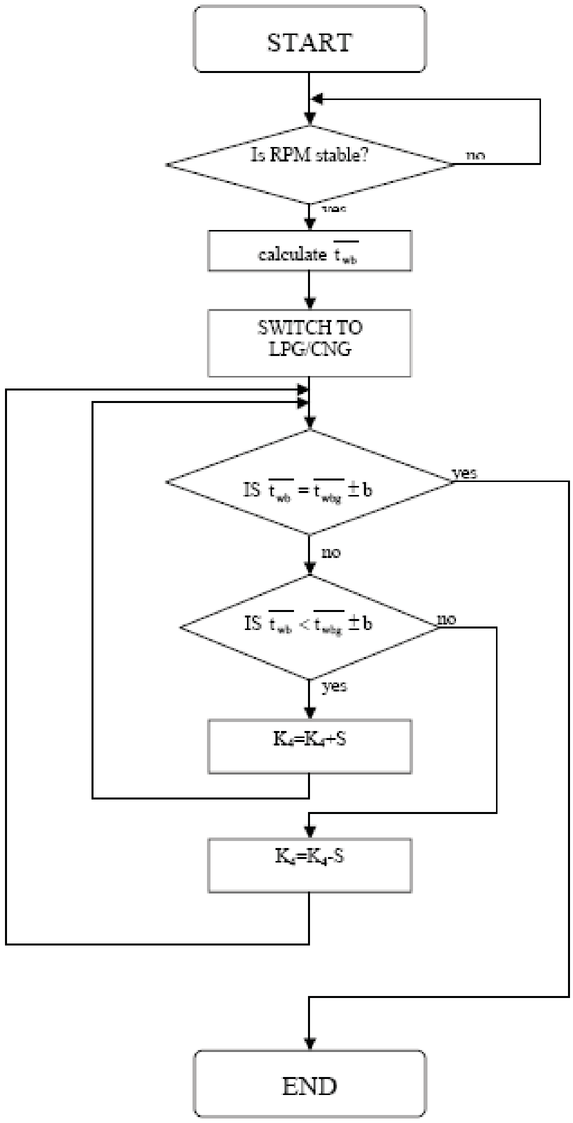

Fig. 9. Automatic calibration algorithm

Improper construction of transfer function, due to not correct operation of OEM petrol injection unit adaptive blockset can influence emission. Results obtained for two different setups of transfer functions, as traces of real time NO_x emissions registered in ECE driving cycle are have been on Fig. 10.

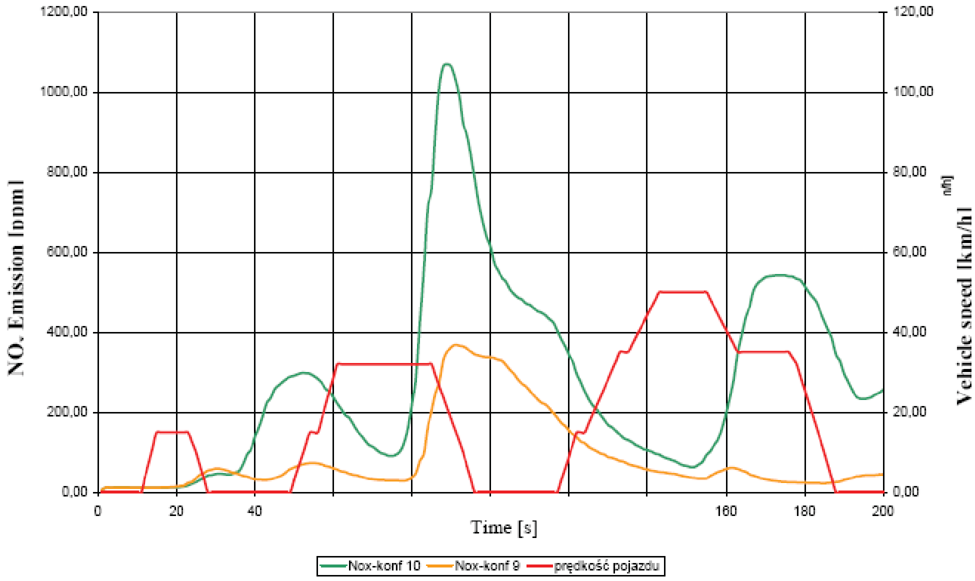

Fig. 10. Traces of NO_x emission for two examples of configurations

7. Conclusion

Obtaining both satisfactory emission reduction level and minimal power drop for alternative engine gas operating is only possible with all diagnostic procedures especially ones connected with system prototyping phase being done with high precision equipment characterized by low inertia of transducers. Sensors output signals require acquisition with the use of more complex and faster systems. Proper choice of test equipment at each step, guarantees repeatability and what results also reliability of realized diagnostic procedures.

Last step – diagnosis done in standard workshop, defines necessary equipment, underlining the obligatory supplementation with tools that allow complete it to the verification procedures according to algorithms mentioned above.

References

[1] Flekiewicz, B., *Zasilanie paliwami gazowymi a system OBD cz. 2*, Zeszyty Naukowe Politechniki Śląskiej, seria Transport, Z. 48, s. 225-232, 2003.

[2] Flekiewicz, M., Flekiewicz, B., *Funkcja przejścia w systemach sekwencyjnego fazowanego wtrysku paliwa gazowego*, Czasopismo Techniczne z. 6-M/2004, T.1 Silniki Spalinowe, Konmot Autoprogres, s. 143-148, 2004.

[3] Flekiewicz, M., Flekiewicz, B., *Diagnostyka układów regulacji przepływu gazu w klasycznym układzie zasilania LPG i CNG,* Materiały konferencyjne IV Konferencji Diagnostyka Pojazdów Samochodowych, T. 1, s. 233-237, Katowice 2000.

[4] Flekiewicz, M., Flekiewicz, B., *Nowe metody diagnostyczne systemów zasilania LPG i CNG w pojazdach samochodowych,* Materiały konferencyjne V Konferencji Diagnostyka Pojazdów Samochodowych, T. 1, s. 263-266, Katowice 2001.

[5] Wendeker, M., *Sterowanie wtryskiem benzyny w silniku samochodowym,* Lubelskie Towarzystwo Naukowe, Lublin 1999.

[6] Wendeker, M., *Sterowanie napełnieniem w silniku samochodowym.* Lubelskie Towarzystwo Naukowe, Lublin 1999.