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METHODOLOGY FOR DYNAMIC TUNING OF THE HEV FUEL FLOW MEASURING SYSTEM

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Abstract: *The new requirements of modern automobiles become more stringent corresponding to power, torque, fuel economy, and ecology legislations [1]. The main factor in this area is the automotive engine fuel system, which is controlled by the electronic control unit (ECU). The electronic control of the Spark Ignition Engines (SI engines), as well as the Direct Ignition Engines (DI engines) is based on the certain sensors signals, program maps and management algorithms. In hybrid electric vehicles (HEV), the traction electric motors can operate independently or in association with the IC engine to power the wheels depending on the type of vehicle architecture [2]. One of the main HEV characteristics is the fuel consumption, which varies dynamically according to the work conditions. The advanced automotive scientific research centers and automotive manufacturers design and develop a specialized laboratory, stationary and movable test benches, and train complex for researching and testing of automotive energy efficiency, which is mainly depends on the fuel consumption. The dynamic measuring of the fuel consumption relates to all the work parameters as throttle angle or engine load, revolutions per minute, engine temperature, engine acceleration etc. Moreover, the continuous fuel flow circulation is also taken in consideration. This paper renders the methodology of dynamic tuning the Fuel Flow Measuring System EFMS100 on the test bench SKAD-1 for computer management of gasoline injection ICE with support of the standardized metering glass.*

INTRODUCTION

The hybrid electric vehicles or simply hybrid vehicles use both electric motors and an SI engine for delivering the propulsion power [3,4]; these vehicles have lower emissions compared to a similarly sized conventional vehicle, resulting in less environmental pollution. The ICE used in a HEV is, of course, downsized compared to an equivalent vehicle engines. The SI engine in combination with the electric motor and an energy storage unit battery provide an extended range for HEV and bring down pollution. The HEV serves as a compromise for the environmental pollution problem and the limited range capability of today's purely electric vehicle (EV). The HEV energy efficiency is the main factor for its advantage and evaluating. This efficiency depends directly from the HEV fuel consumption. It is very important to measure the fuel consumption in correct manner and with suitable equipment to obtain the correct results. Meanwhile, the fuel consumption metering equipment must be calibrated and adapted to the current tests.

STRUCTURE

The metering equipment of fuel consumption is usually a specialized set of fuel sensors, metering units and display units. In accordance with the fuel to use there is a different kinds of metering equipment. In this case the EFMS100 [5] metering system is used. Because of fuel flow circulation the system layout is consists of two sets of fuel sensors, metering units and display units (fig.1). One set is used for the fuel delivered and the other is used for the fuel returned.

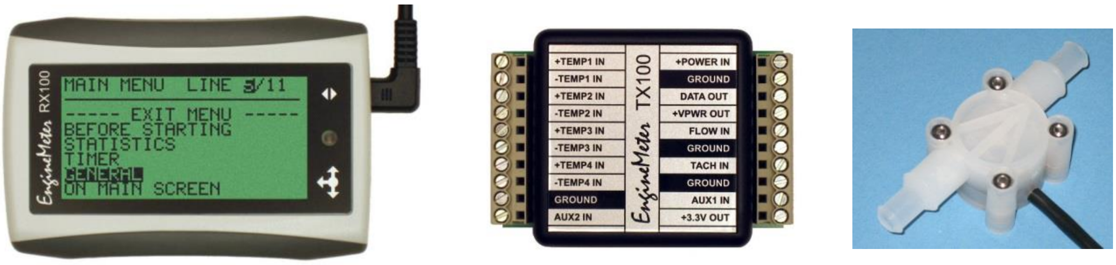

Fig.1 EFMS fuel flow metering system [7]: 1- display unit RX100; 2- metering unit TX100; 3-fuel flow sensor

The fuel metering system must be tuned, or calibrated, according to the amount of the fuel flow in the current application. A static calibration [6] is very important for the base adjustment, but to achieve real results the dynamic tuning, or calibration is essential. In the case of dynamic calibration, it is very useful to apply test benches. Very suitable is the test bench SKAD-1 [7] for Computer Control of Automotive Gasoline Injection Engine (fig.2). The test-bench can be programmed and managed by the Flowcode 7 software [8], which ensures adjustment to the real work mode of the fuel injectors in the modern automobiles and HEVs.

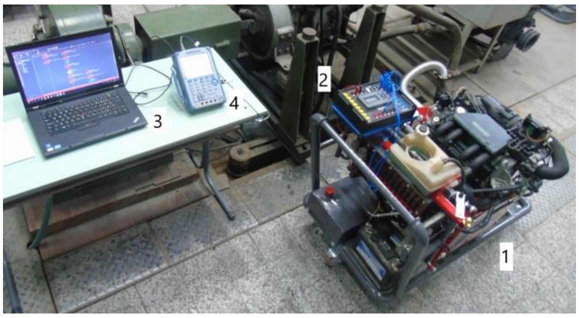

Fig.2. Test bench SKAD-1: 1-engine; 2-controller MI0245 [8]; 3-computer equipment; 4-measuring equipment

METHODOLOGY

The EFMS100 equipment is connected to the test bench SKAD-1. The fuel sensors are connected to the delivery line and return line. The fuel to use is gasoline, which is in store in the standardized metering glass metering glass according to the ISO 4788:2005 [9]. The two lines are connected to the metering glass. The controller MI0245 *2* (fig.2) manages the operating of the engine. The controller may be used for direct control of the engine by the Flowcode 7 software, but in this case is used the OEM engine control module Marelli to achieve results close to identical automotive conditions.

The metering glass is used to measure the fuel consumed from the test bench engine. The metering glass is A class according to the ISO 4788:2005. The quantity of consumed fuel is metered with the metering glasses and is compared to the quantity registered by the EFMS100 system.

The two fuel sensors are metering the fuel flow in the delivery line and the return line. The measured values of the sensors are registered in the metering units and displayed on the display units. The difference between measured values is the real fuel quantity which is essential for the calibration. The dynamic tuning, or calibration is carried on by the differential values, derived from the difference between the delivery fuel quantity and the return fuel quantity.

The dynamic calibration is performed in the four modes, which is close to main hybrid and automotive application, especially in the city traffic conditions. These modes are:

1) Idle mode – the throttle is closed;
2) Partial load at middle rpm;
3) Partial load at high rpm;
4) Full load.

The quantity of fuel consumed and metered in the metering glass is set to be 50 ml. After that, the test bench SKAD-1 is paused and is performing the comparison between the metered and registered fuel quantity. Then is performed the EFMS100 adjustment if required. The adjustment is made by the EFMS100 menu, which gave the access to the parameter *PVR* – pulse/volume ratio. This parameter is calculated the by the formulae:

(1) $PVR = \frac{FPC}{Q_f}$, pulse/l

where *FPC* is the fuel flow pulse count, which is the number of revolutions of the flow sensor turbine to the measured fuel quantity;

Q_f. – the measured fuel quantity, l.

Then the calculated *PVR* is set in the EFMS100 menu.

RESULTS

The following results is obtained after the performed experiments, which are displayed in graphic diagrams. The fig.3 displays the fuel metering results during the Idle mode. In this case the engine throttle is closed. The characteristic shows equal dependence between metering glasses and calibrated EFMS100 system. The characteristics deviation has proportional fluctuations. The maximum engine rpm at this mode are 730 min^{-1}. The measurement coincidence is observed at the experiment 5, which is achieved at the above-mentioned procedure.

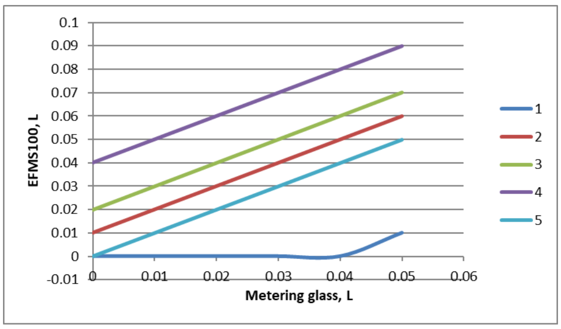

Fig.3 Fuel flow metering characteristic at Idle mode: 1,2,3,4,5-number of experiments

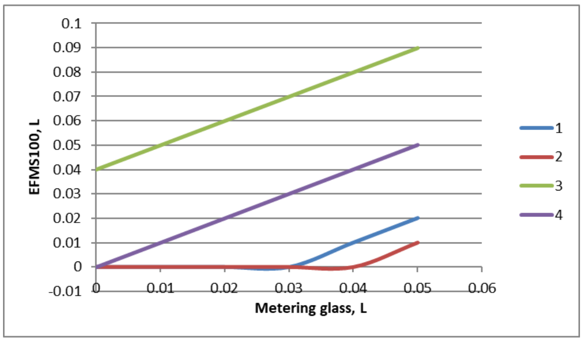

Fig.4 Fuel flow metering characteristic at Partial load mode with low rpm

The optimum PVR_d for delivery line is default value of 7000 pulse/l and for the return line PVR_r= 7230 pulse/l. The PVR values for the other modes are shown in the Table 1 and 2. At the next fig.4 is displayed the fuel flow characteristic during the Partial load mode with middle rpm. The maximum engine rpm at this mode are 2000 min^{-1}. The measurement coincidence is observed at the experiment 4.

The Partial load mode with high rpm is displayed on the fig.5. The characteristics shows equal dependence. The maximum engine rpm at this mode are 4000 min^{-1}. The measurement coincidence is observed at the experiment 4.

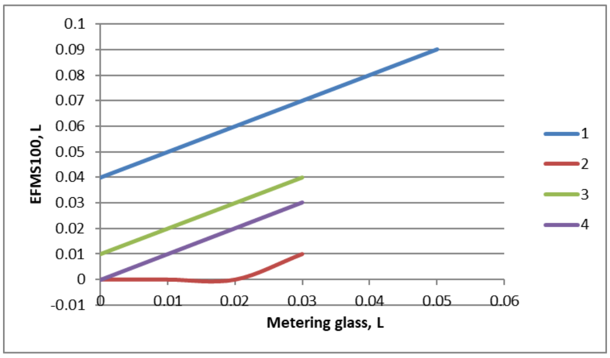

Fig.5 Fuel flow metering characteristic at Partial load mode with high rpm

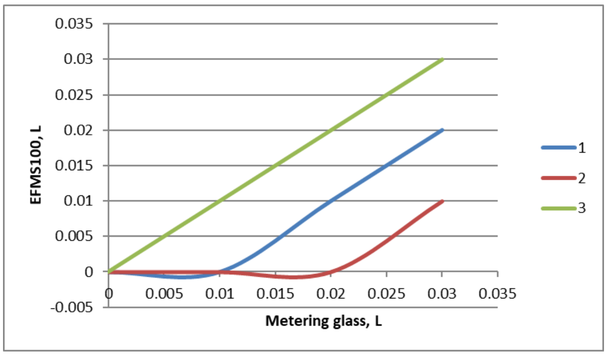

Fig.6 Fuel flow metering characteristic at Full load mode

The last diagram shows Full load mode. The maximum engine rpm at this mode are 8000 min^{-1}. The measurement coincidence is observed at the experiment 3.

As can be seen, all the fuel flow characteristic has approximate dependence, which is essential to the dynamic tuning, i.e. dynamic calibration of the calibrated fuel metering system. As can be observed the Idle mode is critical to the adjustment of the measuring equipment.

CALIBRATION

During the experiments at the previous point can be seen that the general measurement deviation has proportional dependence. To achieve the comparative characteristic of the calibration or calibration characteristic it is important to compare the *FPC* values with the fuel quantity values during the four modes. The values for the Idle mode and Partial mode at middle rpm is represented in the Table 1 and the values for the Partial load mode at high rpm and Full load mode – at Table 2.

Table 1: Comparative values for the Idle mode and Partial load mode with middle rpm.

Idle mode			Partial load at middle rpm		
Q_f, L	*FPC* delivery line	*FPC* return line	Q_f, L	*FPC* delivery line	*FPC* return line
0.01	2190	2178	0.01	600	589
0.02	4381	4356	0.02	1200	1178
0.03	6571	6535	0.03	1799	1768
0.04	8762	8713	0.04	2399	2357
0.05	10952	10891	0.05	2999	2946
PVR	7000	7230	*PVR*	7000	7700

Table 2: Comparative values for the Partial load mode at high rpm and Full load mode.

Partial load mode at high rpm			Full load mode		
Q_f, L	*FPC* delivery line	*FPC* return line	Q_f, L	*FPC* delivery line	*FPC* return line
0.01	271	266	0.01	116	103
0.02	543	531	0.02	232	207
0.03	814	797	0.03	348	310
0.04	1086	1062	0.04	464	414
0.05	1357	1328	0.05	580	517
PVR	7000	8200	*PVR*	7000	10000

The values in the tables are represented on the fig.7 and fig.8. As was mentioned above the Idle mode is critical for the adjustment and calibration.

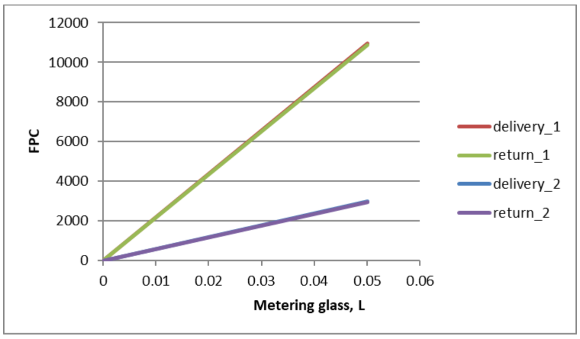

Fig.7 Calibration characteristic at Idle mode and Partial load mode at low rpm

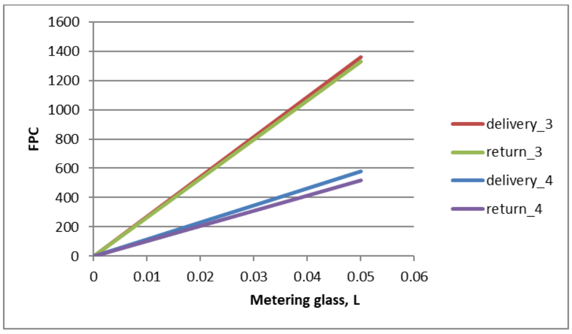

Fig.8 Calibration characteristic at Partial load mode at high rpm and Full load mode

As it is shown on the fig.7 and fig.8, analogical to static calibration [6] there is critical area in the range of Idle mode, i.e. at the little fuel quantities. This area is more likely to be the reason for incorrect fuel flow measurements. So, the dynamic calibration must be performed in accordance with this area and the area of Full load. The average value is the most practical solution.

The correct dynamic calibration consists the following:

1) Setting up the PVR_d and PVR_r to the default values.
2) Performing the control measurements for the Idle mode and Full load mode.
3) Comparing the values of consumed fuel quantity Q_f by the metering glasses and by the display of calibrating system. If there is difference between the readings the parameter PVR_r must be updated, according to below:
4) Reading the values of consumed fuel quantity Q_f by the metering glasses and the values of the parameter *FPC* of the returned line;
5) Calculating the PVR_r parameter by the (1);
6) Setting up the updated PVR_r value in the menu of the calibrated system;
7) Repeating the experiment and comparing the readings

After the correct dynamic calibration, the fuel metering system is ready to use with the real HEVs or automobiles for the accurate evaluation of fuel efficiency.

CONCLUSION

Dynamic tuning or calibration must be made in the little fuel flow quantity modes to achieve the accurate tuning of calibrated system.

The methodology of dynamic calibration of the fuel metering system for the evaluating the HEV fuel traffic city efficiency is proposed.

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МЕТОДИКА ДИНАМИЧНО КАЛИБРИРАНЕ НА СИСТЕМА ЗА ИЗМЕРВАНЕ НА РАЗХОДА НА ГОРИВО НА ХИБРИДЕН АВТОМОБИЛ

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Ключови думи: *хибридни автомобили, разход на гориво, измерване методика*

Резюме: *Новите изисквания към съвременните автомобили стават по-строги, съответстващи на нормативните изисквания за мощност, въртящ момент, икономия на гориво и екология [1]. Основният фактор в тази област е горивната уредба на автомобилните двигатели с вътрешно горене (ДВГ), която се управлява от електронния блок за управление (ЕБУ). Електронното управление на двигателите с искрово запалване (SI двигатели), както и на двигателите с директно запалване (DI двигатели) се основава на определени сигнали от сензори, програмни карти и алгоритми за управление. В хибридните автомобили (ХА) тяговите електрически двигатели (ЕД) могат да работят независимо или във връзка с ДВГ чрез механичен разпределител (МР), за да задвижват трансмисията в зависимост от типа на архитектурата на ХА [2]. Една от основните характеристики на ХА е разходът на гориво, който се променя динамично в зависимост от условията на работа. Съвременните научноизследователски центрове за автомобили и производителите на автомобили проектират и разработват специализирана лаборатория, стационарни и подвижни изпитвателни стендове и развиват комплекси за проучване и тестване на енергийната ефективност на автомобилите, която зависи главно от разхода на*

гориво. Динамичното измерване на разхода на гориво се отнася до всички работни параметри като натоварване на ДВГ, честота на въртене, температура на ДВГ, ускорение на ДВГ и др. Освен това непрекъснатата циркулация на гориво при системите за впръскване на бензин също се взема предвид. Настоящата статия представя методиката за динамично калибриране на измервателна система EFMS100 за разход на гориво с помощта на стенд SKAD-1 за компютърно управление ДВГ с впръскване на бензин и стандартизиран измервателен цилиндър.