

# Methodology for static tuning of the HEV fuel flow measuring system

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**Abstract:** The modern automobiles are subject of more stringent requirements [1] corresponding to power, torque, fuel economy and ecology legislations, which is led to designing of new power sources and constructions, such as the hybrid electric vehicles (HEV). They are moving by the energy [2], which is ensured by the internal combustion engine (ICE) and the battery. The main factor in this area is the HEV fuel system, which is controlled by the electronic control unit (ECU) [1]. 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. The result in this electronic control is the management of the fuel injectors. The management of the fuel injectors consists in the start of injection, injection duration, number of injection events, injection advance, injection pressure etc. Moreover, the fuel consumption and fuel efficiency are the main factors, which are determining the HEV advances. The learning and measuring the HEV fuel consumption, as well as, the conventional automobiles, is the ground for achievement of quality results in the education of the automotive engineers, as well as for obtaining of scientific researching for developments and innovations. Significant meaning in this concept has the real, live and practical performance with the help of testing equipment and test-benches. This paper renders the methodology of static tuning the Fuel Flow Measuring System EFMS100 on the test bench SAV-1 with the support of controller Matrix MIAC MIO245 and Flowcode 7 software.

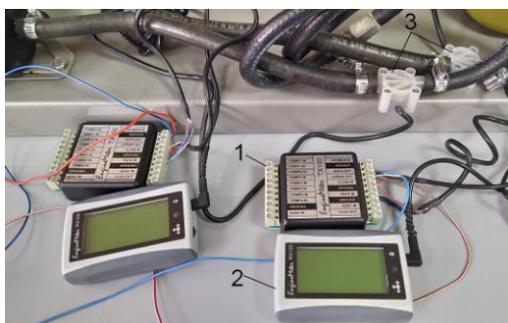
**Keywords:** HEV, FUEL FLOW, METERING, METHODOLOGY

## 1.Introduction

The hybrid electric vehicles or simply hybrid vehicles use both electric motors and an SI engine for delivering the propulsion power [3]; 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.

## 2.Structure

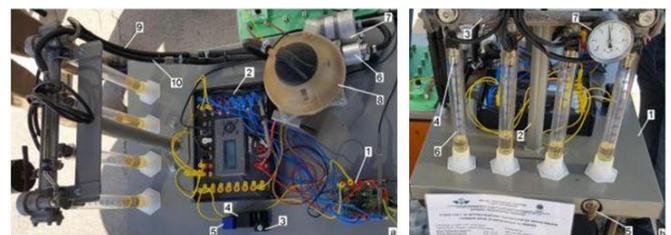
The fuel consumption metering equipment is specialized set of fuel sensors, metering units and display units. In accordance with the fuel to use there is different kind of sensors and metering techniques. In this case the EFMS100 [4] metering system is used. It consists from two sets of fuel sensors, metering units and display units (fig.1).



**Fig.1** EFMS fuel flow metering system [4]: 1-metering unit; 2-display unit; 3-fuel flow sensor

The fuel metering system must be calibrated according to the amount of the fuel flow in the current application. In the case of metering the HEV fuel consumption it is very useful to apply test benches, which can adjust and calibrate the equipment according to the flow range. Such test bench is the test bench SAV-1 [5] for automated management of the automotive gasoline fuel injectors

SAV-1 (fig.2). The test-bench can be programmed and managed by the Flowcode 7 software [6], which ensures adjustment to the real work mode of the fuel injectors in the modern automobiles and HEVs.



**Fig. 2** Common view of the test bench SAV-1 for automated management of the automotive gasoline fuel injectors: a) 1-control panel; 2-controller MIO245; 3-fuses; 4-fuel pump relay; 5-main relay; 6-fuel pump; 7-fuel filter; 8-fuel tank; 9-pump line; 10-return line b) 1-base plate; 2-fuel rail bar; 3-fuel rail; 4-fuel injector; 5-ignition key; 6-metering glass; 7-manometer

## 3.Methodology

The EFMS100 equipment is connected to the test bench SAV-1. The fuel sensors 3 (fig.1) are connected to the pump line 9 and return line 10 (fig.2a). The fuel to use is gasoline, which is in the fuel tank 9. The gasoline is pumped by the fuel pump 6 and is pressurized in the fuel rail 3 (fig.2b). The gasoline pressure is maintained by the fuel pressure regulator in limits of 3-4 bar. The gauge 7 measures the pressure. The controller MIO245 2 (fig.2a) manages the fuel injectors 4 (fig.2b). The Flowcode 7 software develops the management program.

The management program determines the opening and closing time of the injectors, i.e. the injection duration and injection advance.

The metering glasses 6 are used to measure the fuel sprayed from the injectors. The metering glasses are an A class according to the DIN 12680. The quantity of sprayed fuel in the metering glasses is compared to the quantity registered by the EFMS100 system. The whole equipment is powered from the 12V battery or by an adaptor from the electric set.

The two fuel sensors are metering the fuel flow in the pump 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 static tuning, or calibration is carried on by the values from the pump line fuel sensor. In this case the test bench is set to pump mode, i.e. the regulator does not permit the fuel to the return line. The dynamic

tuning is carried on by the values from the two sensors, i.e. by the differential value of the sensors. The results from this tuning is object of another researching.

The static calibration is performed in the four modes, which have main automotive application. These modes are:

- 1) Continuous – all injectors are activated and produce continuous spraying;
- 2) Simultaneous – all injectors are pulse activated and produce pulse spraying;
- 3) Semi-sequential – the injectors are pulse activated in groups and produce group pulse spraying;
- 4) Sequential – the injectors are individual pulse activated and produce individual pulse spraying.

The pulse has three parameters:

- 1)  $ON_{time}$  – the time in which the injector is opened;
- 2)  $OFF_{time}$  – the time in which the injector is closed;
- 3) Duty cycle D:

$$(1) D = \frac{ON_{time}}{ON_{time} + OFF_{time}} \cdot 100, \%$$

The timing of the  $ON_{time}$  and  $OFF_{time}$  are varying from 5 to 45 ms at the step of 5 ms, and D is varying from 10 to 90%. There are the following combinations, which are represented on the Table 1. These values are corresponding to the real injection automotive processes.

**Table 1:** Timing combinations.

$ON_{time}$ , ms	$OFF_{time}$ , ms	D, %
5	45	10
10	40	20
15	35	30
20	30	40
25	25	50
30	20	60
35	15	70
40	10	80
45	5	90

The quantity of fuel sprayed in the metering glasses is set to be 100 ml. After that, the test bench SAV-1 is paused and is performing the comparison between the sprayed 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:

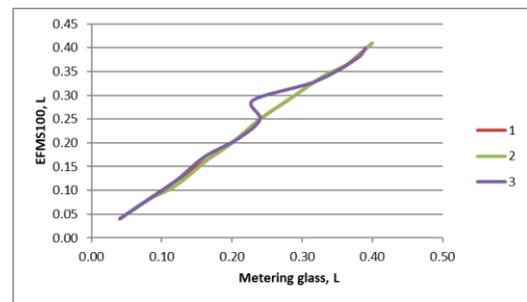
$$(2) PVR = \frac{FPC}{Q_f},$$

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.

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

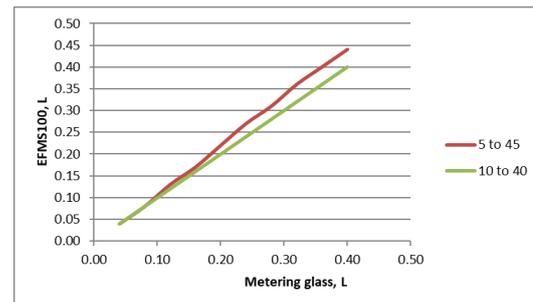
### 4.Results

After the performed experiments is obtained the following results, which are displayed in graphic diagrams. The fig.3 displays the fuel metering results during the Continuous mode. In this case the fuel injectors are spraying continuously. The characteristic shows equal dependence between metering glasses and calibrated EFMS100 system. The deviation of the experiment 3 is because of fuel flow fluctuations, which has chance character.



**Fig.3** Fuel flow metering characteristic at Continuous mode: 1,2,3-number of experiments

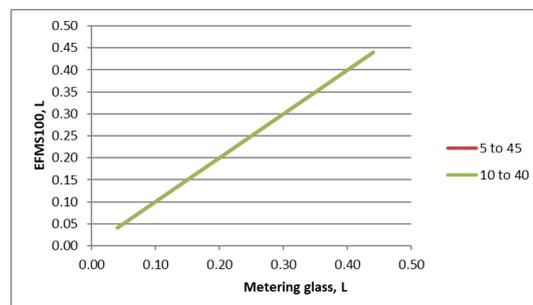
At the next fig.4 is displayed the fuel flow characteristic during the Simultaneous mode. At this mode, the injectors work at varying the  $ON_{time}$  and  $OFF_{time}$  timing as mentioned above.



**Fig.4** Fuel flow metering characteristic at Simultaneous mode

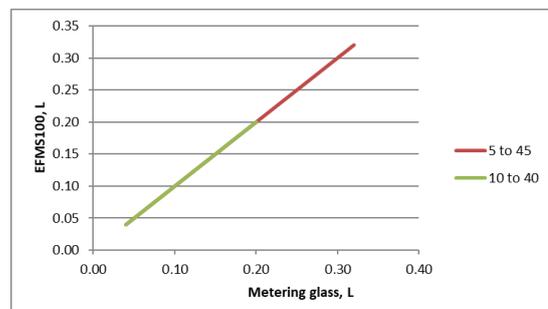
The remain combinations are the same with the second combination 10 to 40 ms.

The Semi-sequential mode is displayed on the fig.5. The timing of the  $ON_{time}$  and  $OFF_{time}$  is the same as previous Simultaneous mode. All the combination shows equal characteristic and are layered one above other.



**Fig.5** Fuel flow metering characteristic at Semi-sequential mode

The last and most modern automotive injection sequention is the Sequential mode. Its characteristic is shown on the fig.6 and the timing is the same.



**Fig.6** Fuel flow metering characteristic at Sequential mode

As can be seen, all the fuel flow characteristic has approximate dependence, which is essential to the static tuning, i.e. static calibration of the calibrated system.

### 5. Calibration

During the experiments at the previous point can be seen that the main difference is rendered at the little quantities of injected fuel, i.e. at the  $ON_{time}$  timing of 5 to 10 ms. 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 Continuous and Simultaneous mode is represented in the Table 2.

Table 2: Comparative value for the Continuous and Simultaneous mode.

Continuous		Simultaneous			
fuel, L	FPC	ON5ms, OFF45ms		ON10ms, OFF40ms	
		fuel, L	FPC	fuel, L	FPC
0.04	636	0.04	1411	0.04	975
0.08	1153	0.08	2721	0.08	1855
0.12	1770	0.12	4590	0.12	2729
0.16	2545	0.16	6008	0.16	3633
0.20	3134	0.20	7663	0.20	4502
0.24	3781	0.24	9323	0.24	5475
0.28	4425	0.28	10866	0.28	6361
0.33	5079	0.32	12352	0.32	7337
0.36	5656	0.36	13822	0.36	8172
0.40	6152	0.40	15168	0.40	9063

The values in the table and the remain values are represented on the fig.7. As was mentioned above the range of little fuel quantities is critical for the adjustment and calibration.

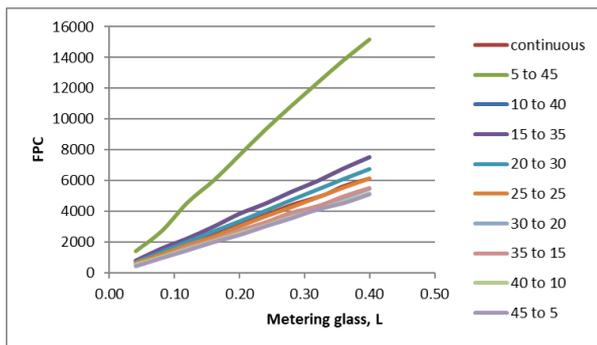


Fig.7 Calibration characteristic at Continuous and Simultaneous mode

The values for the Semi-sequential and Sequential mode is represented in the Table 3.

Table 3: Comparative value for the Semi-sequential and Sequential mode.

Semi-sequential				Sequential			
ON5ms, OFF45ms		ON10ms, OFF40ms		ON5ms, OFF45ms		ON10ms, OFF40ms	
fuel, L	FPC	fuel, L	FPC	fuel, L	FPC	fuel, L	FPC
0.04	2055	0.04	1340	0.04	2383	0.04	1783
0.08	4163	0.08	2604	0.10	6811	0.08	3783
0.18	9241	0.18	5626	0.20	13041	0.12	5895
0.30	15736	0.31	9808	0.28	18619	0.16	7970
0.20	7663	0.20	4502	0.32	22867	0.20	9914

The values in the table and the remain values are represented on the fig.8.

As it is shown on the fig.7 and fig.8, there is critical area in the range of little fuel quantities, i.e. at the little  $ON_{time}$  values. This area is more likely to be the reason for incorrect fuel flow measurements. So, the static calibration must be performed in this area.

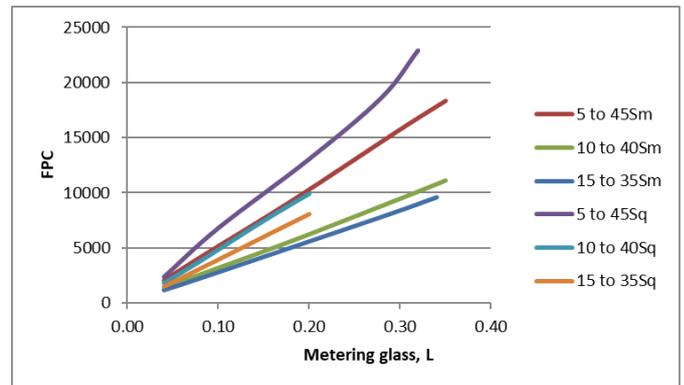


Fig.8 Calibration characteristic at Semi-sequential and Sequential mode

The correct calibration consists the following:

- 1) Setting up the timing to the minimal  $ON_{time}$  values (for example 5 ms)
- 2) Defining the control fuel quantity  $Q_f$  (for example 200 ml)
- 3) Performing the experiment
- 4) Comparing the values of sprayed fuel quantity  $Q_f$  by the metering glasses and by the display of calibrating system
- 5) If there is difference between the readings the parameter PVR must be update, according to below
- 6) Reading the values of sprayed fuel quantity  $Q_f$  by the metering glasses and the values of the parameter  $FPC$ .
- 7) Calculating the PVR parameter by the (2)
- 8) Setting up the updated PVR value in the menu of the calibrated system
- 9) Repeating the experiment and comparing the readings

After the correct calibration, the fuel metering system can be attached to the real HEV and can be made experiments to determine its fuel consumption during different driving modes in different areas. This will give the accurate evaluation of the HEV fuel efficiency.

### Conclusion

The experimental calibration of the fuel metering system for the HEV fuel consumption is needful and important factor for the correct fuel metering.

Static tuning or calibration must made in the little fuel flow quantity modes to achieve the accurate tuning of calibrated system. Thus, the fuel consumption during idle mode of the HEV will be accurately define, moreover the idle mode is very common during the city traffic conditions.

### Literature

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