

THE SYSTEM FOR ESTIMATION PARAMETERS OF INTERNAL COMBUSTION ENGINE IN THE ROAD TEST

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Abstract

Current internal combustion engine technology for road vehicles allows us to meet the existing and planned future standards for emission. However, the motion of a moving vehicle used in real operating conditions is frequent changes of the values of power in the powertrain. The analysis of the results of the road test through a measurement of parameters of engine in a passenger car proves, that the changes of parameters engine are frequent.

The paper presents method measurement parameters form system of data transmission CAN BUS and estimation is performed using measurement accelerometer car's chassis of parameters internal combustion engine determined on road test. Estimation of main parameters of internal combustion engine is made with use of measured quantities such as: car mass and acceleration collected in function of vehicle linear velocity. The most essential problems in this approach, considered as primary method errors, are minimization of underestimation of moment of inertia of rotating elements in drivetrain and efficiency of drivetrain itself. Moreover it is vital to determine as precise as possible vehicle acceleration and its linear velocity in presence of disturbances – mainly chassis movements and additional accelerations, which comes from pavement unevenness (roughness). In this article application of several sensors of different quantities for increase of accuracy of PAAF 2 (Power Acceleration And Force) device in relation to prototype device predecessor is taken into consideration.

Keywords: internal combustion engines, road test, system of data transmission CAN BUS

1. Introduction

The internal combustion engine is a dynamic object and its operation with variable speed is accompanied by energy accumulation processes. The most important processes of accumulation are connected with the flow of thermal and mechanical energy of movable masses of the crankshaft-piston assembly of the engine. The above-mentioned phenomena affect the changes of the operating parameters of engine in the powertrain of a vehicle in real conditions on the road. Since many years in Opole University of Technology carried out research on the measurement of internal combustion engine parameters in the test road. As a result of the work system was created for measuring and estimating the parameters of the engine with the name PAAF2. The problem is very complicated, especially in the process of acceleration of the vehicle. From a dynamic point of view, it is an extreme state of accelerated drive – from the start until attainment of a specified target speed and most often with devices controlling feeding of fuel into the combustion engine set to full dosing. According to literature [6, 10], the share of acceleration phase in normal operating conditions constitutes a considerable part of drive time, i.e. as much as 42% of the total time of urban driving and 26% of extra urban driving. According to change of the position of the UN actuators is made from 120 to 350 times per hour, which corresponds to 6-17 changes on average per one kilometre of drive. In official certification tests of vehicles adopted by the U.S. Environmental Protection Agency, according to EPA cycle, the acceleration phase constitutes 39.7% of the total drive time of a vehicle in urban conditions and 33% in extra urban conditions.

2. Variability of linear speed and driving conditions of a vehicle

During acceleration, when the powertrain is in temporary conditions (dynamic condition) and adopted constant values are variable (which relates to the traction coefficient, rolling resistance coefficient, variable dynamic radius, efficiency of the drive transmission system), the indicated momentary parameters of the engine in real conditions on the road have to be measured precisely and they differ from the parameters obtained in stationary conditions [2-4, 7, 10]. The situation is additionally complicated by the surrounding conditions that force constant changes of the engine power fed to the wheels, which is indirectly shown in the charts presented in Fig. 1.

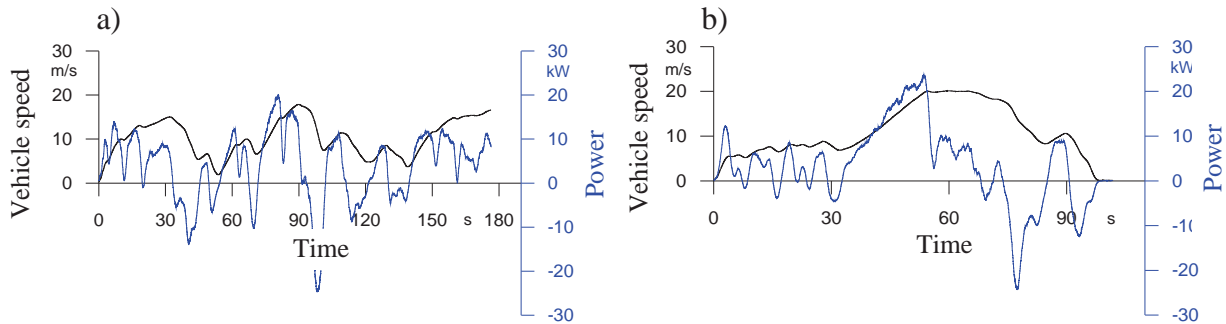


Fig. 1. The example temporary course of the speed and the power for the following traffic: a) urban, b) extra urban

Specifically they are: wind speed, humidity, temperature, road induced rolling resistance, suspension stiffness and mass distribution, road roughness potholes and bumps. Measurement of the operating parameters of the engine in variable speed conditions requires solving a lot of problems that relate, in particular, to the availability of all measured parameters in real time.

While the estimation of parameters such as engine power and torque from the drive system requires measurement in strictly defined conditions [2]. For determining the car's acceleration as well as powertrain driving force and power special road test has been developed, which speed profile is shown in Fig. 2.

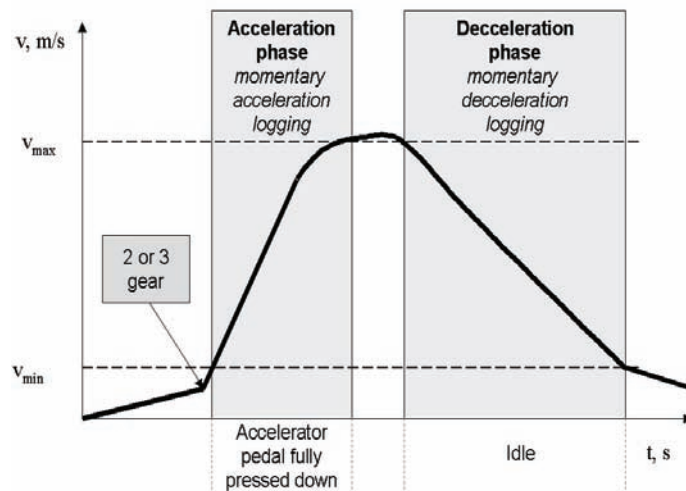


Fig. 2. Velocity profile of road test

In first phase car has to accelerate with highest intensity from v_{min} velocity to v_{max} . During this phase the longitudinal acceleration a_l of the car and other quantities are measured. The a_l value is relative to driving force. Furthermore driving force changes depends on engine characteristics and total car mass. The second phase occurs after the maximum velocity is reached. Then, with decoupled transmission, deceleration is realized. It is assumed that the measured acceleration is

negative and depends only on the total movement resistance. The test results were stored on mass memory. Further they can be used as input to MATLAB in order to perform additional processing and analysis.

3. Research

Due to diversified structure of engines in the powertrain of a vehicle, the Chair of Road and Agricultural Vehicles of the Opole University of Technology developed a portable measurement data recording system referred to as PAAF2 (*Power Acceleration And Force*). The system is used for recording of operating parameters of the engine and kinematic values characterizing the drive of the tested vehicle. The application was created with the use of LabView program. The main window of the application enabling the operation of the software is presented in Fig. 3a.

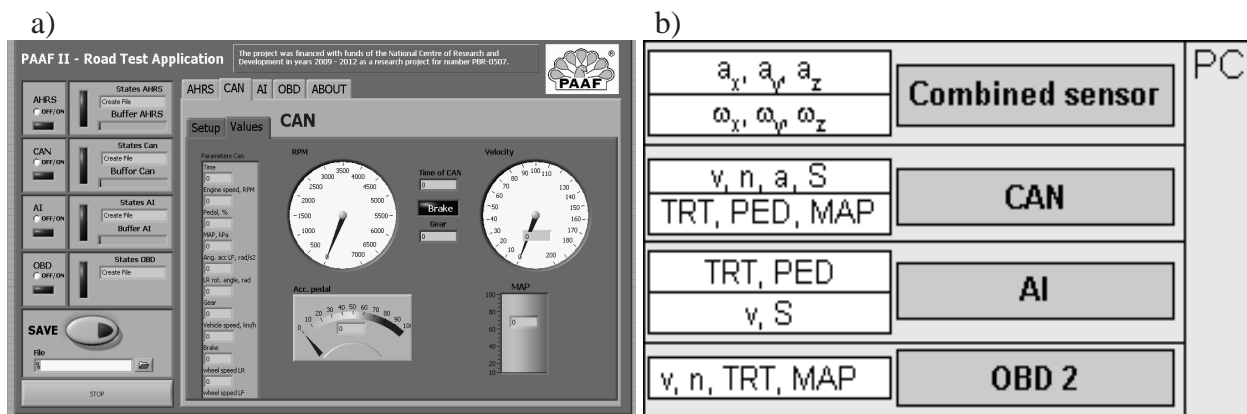


Fig. 3. The Main window of PAAF2: a) window of developed CAR.vi application, b) measurement system schema

The system enabled recording of operating parameters of the engine and kinematic parameters of the drive of a vehicle in the field of time from the measurement systems presented in Fig. 3b:

- from the diagnostic system OBD II (**OBD2**),
- from analogue and digital measurement card NI 6212 (**AI**),
- from the system of acceleration and multifunctional sensor 3DM-GX3-25 (**Combined sensor**),
- from the drive network of data transmission based on CAN BUS (**CAN**).

Owing to the flexible measurement system, PAAF2 application made it possible to select freely a method of recording of parameters depending on the testing vehicle used. Once configured, the readout of parameters from the OBD II system made it possible to read parameters, regardless of the tested vehicle [8, 9]. In road tests, various makes of vehicles were used and each of them was characterized by different structure of the engine and powertrain, i.e. Citroen C5 V6, Mercedes-Benz B180, Seat EXEO 2.0 TSI, Fiat Punto II 1.2 16V, Hyundai i35, Seat Ibiza 1.4 MPI.

3.1. Operating parameters of the engine

As it has already been mentioned, the process of acceleration with maximum intensity is an extreme operating condition of the engine and it is characterized by uniqueness and presence of random interferences. The figure below (Fig. 4) presents an example of the recorded throttle opening values during the acceleration of Citroen C5 passenger vehicle with PAAF2.

Differences between indications of throttle opening values (Fig. 4) are small in the case measuring of the AI and CAN method. However, the method of measurements based upon OBD II system is characterized by intermittence (step course) and time delay. The greatest opportunities as regards selection of parameters and transmitted quantities were offered by the method based upon recording of information transmitted between controllers of CAN BUS data transmission network.

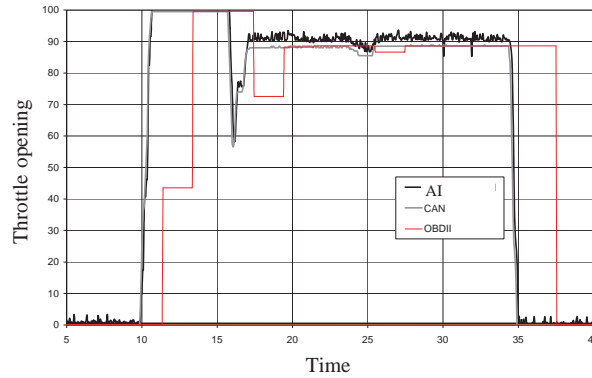


Fig. 4. Throttle opening profile of the on-road test

Below shows testing process by cross-acceleration registered with of CAN BUS data transmission network (Fig. 5) with maximum intensity test. The acceleration was realized from the engine speed of 1500 rev./min. and in the initial phase we may observe considerable growth of fuel consumption.

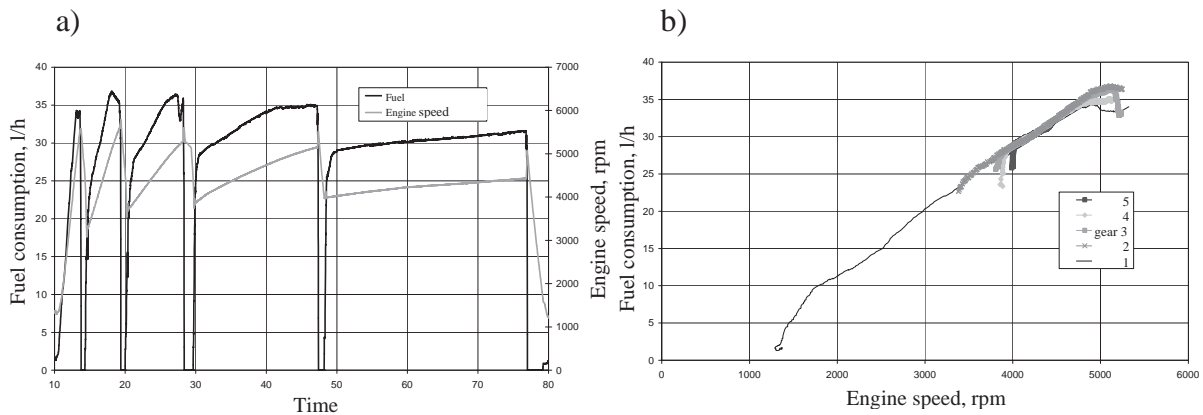


Fig. 6. The change of parameters the engine during on-road test for Seat Ibiza 1.4 MPi: a) consumption fuel and the engine speed, b) consumption fuel as a function of the engine speed during

In the case of acceleration of a vehicle using gears of maximum acceleration intensity, the throttle opening is set to maximum intensity and the value of the fuel consumed in time depends on the engine speed. Fuel consumption in time using of individual gears is directly proportional to the engine speed.

3.2. Estimation parameters of the engine

In a car’s powertrain there is a necessity of transforming engine torque (T_e) into driving force on the car’s wheels. Each of the components of a powertrain has an effect on the instantaneous value of the transmitted torque as well as the instantaneous value of the angular speed. As a consequence, the driving force is described by the following relation

$$F_d = \frac{T_e \cdot R_{DT} \cdot \eta_{DT}}{r_w}, \quad (1)$$

where R_{DT} – drive train ratio, η_{DT} – drive train efficiency, r_w – radius of the driven wheels.

Its characteristics are variable and the instantaneous value is difficult to determine. The above parameters indicate a complex nature and difficulties in the analytic statement of the internal and external conditions in a vehicle in motion. As a result, in this paper the focus is on the balance of

the longitudinal forces, which is the starting relation for the determination of the force and power of a powertrain, which determine the instantaneous car acceleration. The balance of the longitudinal forces in car under the assumption of a flat road can be defined as:

$$F_d - \sum F_{rm} - F_I = 0, \quad (2)$$

where:

F_{rm} - force of the resistance to motion of the car (rolling and drag),

F_I - force of the car inertia,

hence, the instantaneous longitudinal acceleration of a car (a_a) can be defined as:

$$a_a = \left(\frac{dv}{dt} \right)_a = \frac{F_d - \sum F_{rm}}{m + \frac{1}{r_w^2} \cdot \left(\sum_{i=1}^n I_w + R_{DT}^2 \cdot I_{DT} \right)}, \quad (3)$$

where:

m - weight of a car,

I_w - mechanical wheels inertia,

I_{DT} - mechanical drivetrain inertia,

v - car speed,

t - time.

From equation (3) it results that the measurement of the longitudinal acceleration can form the basis for the estimation of the value of inertia force, assessment of the driving conditions (drag) or vehicle mass [5, 7].

For the determination of the drag in a road test we applied the method of coasting, which involves the retarded motion of a car imposed by the deceleration resulting from drag for an engine disconnected from the driven wheels. During the coasting a flat road the motion drag is only overcome at the expense of the inertia force.

The balance of the longitudinal forces in during coasting can be defined as:

$$F_I - \sum F_{rm} = 0, \quad (4)$$

Hence, the instantaneous longitudinal drag of the car (a_r):

$$a_r = \left(\frac{dv}{dt} \right)_r = \frac{\sum F_{rm}}{m + \frac{1}{r_w^2} \cdot \left(\sum_{i=1}^n I_w + R_{DT}^2 \cdot I_{DT} \right)}. \quad (5)$$

From the equations of balance between the acceleration and coasting it results that the measurement of the longitudinal acceleration of a car for a given mass can form the basis for the estimation of the characteristics of the powertrain during a road test. The testing assumes that the prescribed procedures are conducted during a single session. On the basis of the above solutions the profile of the speed during the road test was defined as it is illustrated in Fig. 2.

As a consequence it applies a direct or indirect method of acceleration measurement and realizing algorithms, described in the works [1], enabling the estimation of the force and power of the powertrain with considerable repeatability regardless of the weather and road conditions. This was confirmed during original tests conducted in extremely variable weather conditions. The first measurement was conducted in favourable weather and followed by the same test conducted two weeks later during falling rain. The curves in Fig. 7 clearly indicate that the results of the test performed during unfavourable weather (marked WET) conditions display higher total value of the resistance of the car to motion (Trm). Despite that, the waveforms of force and power of the powertrain are similar in both cases.

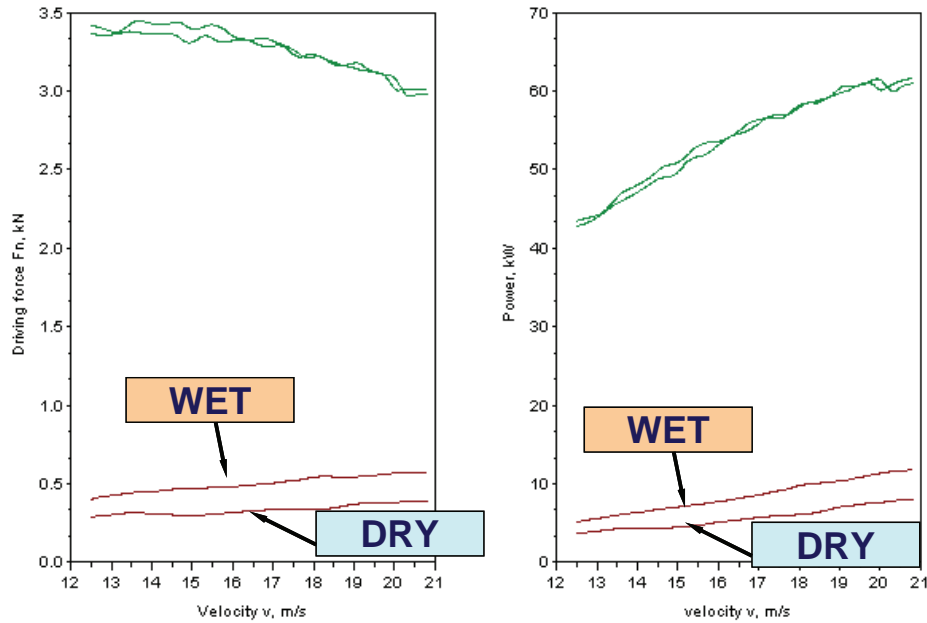


Fig. 7. Summary of the results of road tests indicating the changes in terms of force and power of the powertrain in the function of car speed for various weather conditions

The presented data indicate that the adopted methodology of estimation of the characteristics of the powertrain is not sensitive to atmospheric conditions of the drive test, which used to be a drawback of the previously applied similar devices.

On the basis of an input of the total car mass and registered acceleration during the acceleration and delay during the coasting it was possible to calculate the driving power and power of the powertrain in the function of the speed of the car. Subsequently, the values of the driving force in the function of the speed were transformed into the engine's rotational speed and its power on the basis of relations (6) and (7):

$$T_o = \frac{r_w \cdot F_d}{R_{PT} \cdot \eta_{PT}}, \quad (6)$$

$$P_e = T_o \cdot s_e \cdot \frac{2\pi}{60}, \quad (7)$$

where s_e is rotational speed of the engine, rpm.

For the purposes of calculations we took the values of the transmission ratio and axle ratio given by the manufacturer, i.e.: $R_f=3.562$, $R_{g1}=3.727$, $R_{g2}=2.052$, $R_{g3}=1.320$, $R_{g4}=0.966$. The dynamic radius of the wheels $r_w=0,266$ m was assumed on the basis of a test of car rolling with the load equal to the load of car during road tests [8]. The efficiency of the transmission for the particular gear was assumed on the basis of reference data [8, 9]: $\eta_f= 0.850$, $\eta_{g1}= 0.885$, $\eta_{g2}= 0.901$, $\eta_{g3}= 0.931$, $\eta_{g4}= 0.975$.

From the curves of the power (Fig. 8) for the particular gears it is clear that the curves for gear 2 and 3 are very similar, while their maximal values are highest of all gears and the maximum power at gear 2 is lower than the one in gear 3 by only 0.2 kW.

The curve of the power in gear 1 after accounting for the efficiency of the powertrain is flattened and much lower than the remaining ones. This comes as a consequence of the effect of both the changing dynamic radius and the higher transmission ratio in the powertrain, which can lead to exceeding the boundary value of the driving force in the wheels in terms of loss of tractive adhesion. The curve for gear 4 in the initial phase of acceleration occurs in the same way as in gear 2 and 3; however, for higher rotational speeds it tends to decrease. This does not come as a consequence of the changes in the engine's characteristics but results from the conditions of the

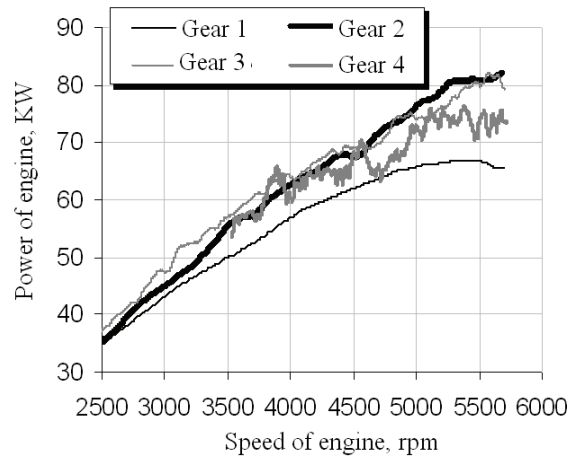


Fig. 8. Changes of estimation power of engine versus rotational speed at selected gears

test, as it was conducted at the speed exceeding 130 km/h. As a result, the sensor was subjected to strong vibrations originating from overcoming road bumps and the acceleration of the car lower than 0.5 m/s^2 .

4. Summary

It results from the operating parameters of the engine in real (dynamic) conditions on the road that it is possible to record the parameters from the data transmission network and CAN BUS and this method of recording has a lot of strong points. This method of recording may be used in various vehicles without the need of developing additional equipment or expensive apparatuses and the recorded parameters are characterized by good signal dynamics, which makes it possible to analyze them freely and involving the estimation of the power of a car engine on the basis of a road test. An important factor is associated with the fact that the measurement is performed in real time.

From the conducted original studies it results that the greatest repeatability of the results of engine power was gained for second and third gear. The differences noted for the first gear can come as a consequence of the fact of not eliminating the effect of the rotating masses of the powertrain and wheels beside the above mentioned ones. It was additionally assumed that the inertia of the rotating masses acts as an energy store and imposes resistance during the acceleration thus decreasing it, which is followed by energy released during the coasting of the car. However, for the first gear, where the angular acceleration forms the major component of the moment of inertia originating in the powertrain during the road test it plays an important role. Therefore, during the calculations of engine power its value is lower than the actual one. The value of the error results from the intensity of the effect and in particular from the ratio of the inertia of the rotating masses in the powertrain and inertia associated with the car in motion.

During the calculations of engine power one should also note the way of selecting parameters for calculations. First, the value of the dynamic radius of the wheel is not a constant value and increases inconsiderably in relation to the static radius determined during car rolling depending on the linear speed of the car. Secondly, the calculated value of the angular speed of the wheel should be adjusted in order to account for tire slip, which is relative to the type of tire as well as parameters of road surface. Thirdly, the efficiency of the ratios for particular gears are relative to various parameters, including the viscosity of the lubricants, construction of the elements of the drivetrain and powertrain as well as the technical condition of the car.

Therefore, during the estimation of engine power on the basis of measurement of the longitudinal car acceleration it is necessary to account for the above factors affecting the interference of the results and subsequently conduct the measurement several times and average the result.

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