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Measuring of Traction and Speed Characteristics as Well as of Fuel Economy of a Car in Road Conditions

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Abstract. This article is devoted to the identification of traction and speed characteristics as well as of fuel economy of motor vehicles in road conditions. Among common variants of measuring of the above stated values, the preference was given to the immediate gaining of factors by means of a computer-aided measuring system. There is a theoretical justification given to the suggested approach as well as methods and results allowing to provide a practically sufficient solution accuracy of the problem.

Introduction

Vehicular transport is widely used in various areas of national economy. The utilization efficiency of vehicles affects production costs as well as delivery performance of passengers and cargos. It is also significantly defined by the type and the characteristics of internal combustion engines (ICE). The most widespread type of engines is diesel engine (over 90% in freight transport, and a constantly growing ratio among cars).

In practice, the lack of possibility to constantly control the technical conditions of vehicles results in the fact that they are often used with defects which are invisible to the driver but provoke the growing fuel consumption, raise transportation costs as well as increase the content of harmful substances in exhaust gases. Fuel economy as well as traction and speed characteristics of a motor vehicle are very important performance indicators that designate the exploitation efficiency of vehicles [1]. That is why a well-timed control, including diagnostics, is a vital task.

State-of-the-art.

Following measuring methods of motor vehicle parameters have been considered in road conditions:

1. Data acquisition by means of GSP/GLONASS technologies [2]
2. Recording of a data log by using a dealer scanner with subsequent data transfer onto an external medium [3, 4]
3. Immediate measuring of parameters by means of a computer-aided measuring system

The usage of satellite-assisted technologies and fuel consumption monitoring by fuel level in the tank are not suited for the given task because they deliver quite averaged data, while, in our case, during diagnostics, the process is considered to be very fast flowing. The second variant provides with quite exact data, however, these still need to be processed after being saved in a log. As for the fuel consumption registered by an on-board system, the calculation of fuel economy parameters can bring inaccurate results because of the difference between actual and expected injection rate. Taking into consideration all the above mentioned facts, it was decided to use the third variant with computer-aided technologies. The concept of this approach is depicted in the publication [5].

Mathematical model

Theoretic preconditions. We shall start to define the vehicle motion parameters by making up an analytical model of forces and moments that affect the motor vehicle (fig. 1) when accelerating uphill.

We shall define current net torque that is spent for the overcoming of motion resistance moment at every integration step on the basis of a force balance equation of a motor vehicle:

$$M_{ei}=M_{am}+(F_w+F_f+F_i\pm m_{eq}\cdot j_a)\cdot r_k/(i_t\cdot\eta_t) \quad (1)$$

where M_{am} is the moment spent for the gearing of auxiliary machinery, N·m

F_w is air resistance force, N

F_f is rolling resistance force, N

F_i is the force that affect the motor vehicle on the road inclination, N

m_{eq} is the equivalent mass of the motor vehicle, kg

j_a is the acceleration rate of the motor vehicle, m/s^2

r_k is the radius of rolling circle, m

i_t is the gear transmission ratio

η_t is the transmission efficiency factor

We shall admit that there is no crutch skidding and the crutch is rigidly closed, while the motor vehicle has elastic tires subject to force and speed deformation.

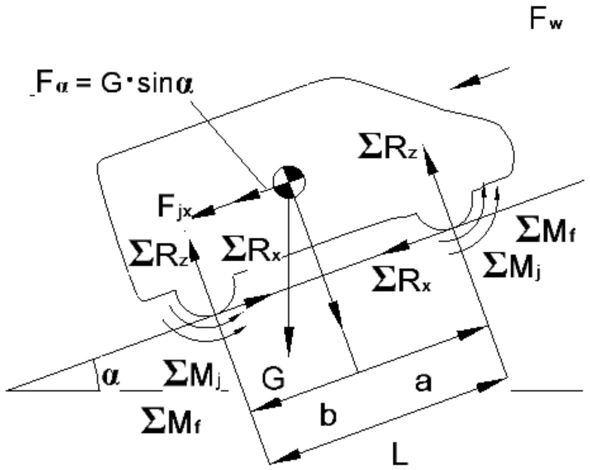


Fig. 1: Analytical model of forces and moments that affect a motor vehicle when accelerating uphill

The equivalent mass of the motor vehicle is defined taking into account the rotational inertia coefficient δ, by means of *a* familiar equation:

$$M_{eq}=m_a\cdot\delta=G\cdot\delta/g \quad (2)$$

where G is the weight of the motor vehicle, N
g is the gravitational acceleration, m/s^2.
In its turn, we shall define the rotational inertia coefficient the following way:

$$\delta=1+I_e\cdot i_t^2\cdot g\cdot\eta_t/(r_k^2\cdot G)+\Sigma I_k\cdot g/(r_k^2\cdot G)= 1+(I_e\cdot i_t^2\cdot\eta_t+\Sigma I_k)\cdot g/(r_k^2\cdot G) \quad (3)$$

I_e is the deduced inertia moment of the engine
I_k is the inertia moment of a car with a tire
Thus, taking into account equations (1-3), we shall write down the equation of motion of a motor vehicle:

$$j_a=(g/(\delta\cdot G))x$$

$$x(((M_{ei}-M_{am})\cdot\eta_t\cdot i_t/r_k)-G\cdot f\pm G\cdot sin\alpha-(c_x\cdot\rho\cdot S_x\cdot V_a^2)/(2\cdot 3.6^2)) \quad (4)$$

ρ is the air density
c_x is the aerodynamic drag factor
f is the coefficient of rolling resistance
α is the road inclination
S_x is the maximum mid-section of the motor vehicle
The speed of the motor vehicle at the ith step shall be calculated by means of numerical computation methods of differential equations. In our case, we used Euler's method:

$$V_i= V_{i-1}+j_a\cdot\Delta t \quad (5)$$

where V_{i-1} is the speed of the motor vehicle at the previous counting step, m/s
Δt is the counting step, c
The rotational rate of the crankshaft shall be defined on the basis of the current speed taking into account all made admittances:

$$n_{ei}= 2.65\cdot V_t\cdot i_t/r_k \quad (6)$$

Let us esteem the overall loss of capacity in the tires of leading wheels [6]. In a general case, the overall efficiency factor of a tire η_k is defined by the following equation:

$$\eta_k=\frac{N_m}{N_k}=\frac{R_x\cdot V}{M_k\cdot\omega_k}=\frac{M_k-M_f}{r_{ko}}\cdot\frac{V}{M_k\cdot\omega_k}=\frac{M_k-M_f}{M_k}\cdot\frac{r_k}{r_{ko}} \quad (7)$$

where N_k and N_m are the delivered and the withdrawn power of the wheel respectively; ω_k and V are the angular rate of the =resistance moment of the tire; R_x is the direct-axis reaction in the contact patch; r_k and r_{ko} are the rolling radius and the rolling radius in the conducted mode; M_k is the drive torque delivered to the wheel.

The efficiency factor of leading wheels depicts the loss of capacity and speed in the process of rolling. The efficiency factor of the tires of leading wheels η_k is the product of two multipliers:

$$\eta_k=\frac{M_k-M_f}{M_k}\cdot\frac{r_k}{r_{ko}} \quad (8)$$

The first multiplier reflects the friction force loss (hysteresis loss) of capacity in the tire while rolling. This component of capacity loss is calculated quite easily and exactly. There are usually no difficulties with its computation.

The second multiplier depicts speed losses of capacity connected with tangential elasticity of a tire, i. e. it takes into account the fact that the number of rotations made by a wheel as well as the covered distance do not always fit together exactly. The most of the hardships arise namely when determining the value of this multiplier. These complications are based on the definition of the kinematic radius r_k (the rolling radius of a wheel with an elastic tire):

$$r_k = \frac{V}{\omega_k} \tag{9}$$

The diagram below shows the dependence of the efficiency factor of tires (and in particular of every component of this) on the moment M_k delivered to the wheel.

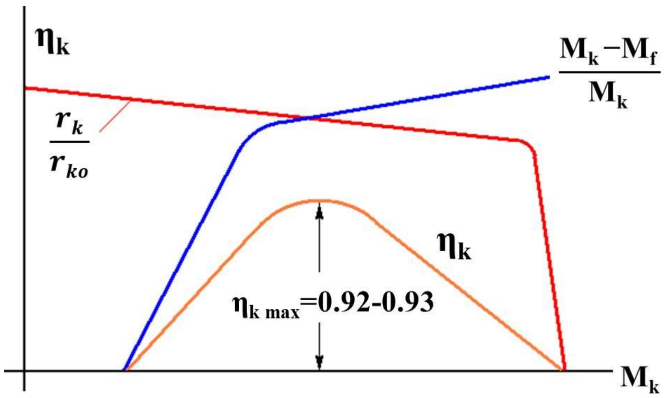


Fig. 2: The dependence of the efficiency factor of leading wheels of a motor vehicle on the value of the moment M_k delivered to the wheels (traction mode)

The maximum efficiency factor of tires of light vehicles, when the wheels are rolling in the conducted mode, tops $\eta_{k\ max}$≈0,92÷0,93. That means that at least 6…7% of engine capacity is lost in the tires of a light vehicle *for hysteresis and speed losses*. The maximum efficiency factor of tires of freight vehicles equals to $\eta_{k\ max}$≈ 0,90…0,87. It is obvious that the capacity loss in the tires of freight vehicles amounts to at least V 10…13% of engine capacity.

Thus, if we are given the parameters of the motor vehicle, the road type and its inclination, while measuring the speed of the motor vehicle, we find the drive torque that affects the axle tree and the capacity.

The given task can be solved by continuous measuring of the speed of the wheel(s) that work in a conducted mode.

Experimental procedure

The experiments were conducted on the motor vehicle "Sobol" (GAZ 2217) equipped with a diesel engine ISf 2.8 Cummins with Common Rail fuel injection system. The experiment was held on an even, dry road segment in a fine windless weather; the journey was made in two opposite directions. The method included the measuring of factors in the acceleration mode up to 100 km/h with a fully-pressed control pedal of fuel injection. The measuring system (fig. 3) consisted of an analog-digital converter to the input of which there were impulse signals delivered from the ABS wheel sensor of the front wheel, as well as of fuel flow meters mounted in the direct and in the reverse fuel-delivery lines. When calculating the fuel economy, the consumed fuel was determined as the difference between the direct and the reverse (returned into the tank) flow.

The data delivered to the input of the analog-digital converter were identically processed for fuel consumption as well as for the determination of the distance and the speed of the motor vehicle, because the signals are represented by rectangular pulses (fig. 4).

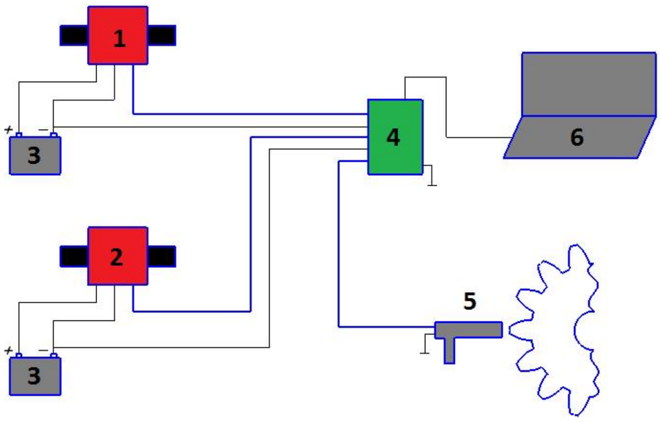


Fig. 3: Function chart of the instrumental complex
1 - fuel-flow sensor (delivery); 2 - fuel-flow sensor (return); 3 - accumulator batteries; 4 - analog-digital converter module; 5 - ABS sensor of the front right wheel; 6 - laptop

In order to facilitate data processing, there was a special script written, the essence of which is clarified in fig. 4. With a certain number of impulses given, the time of passing these intervals is registered, while the previous point is considered to be the initial point for the next interval.

Below, there is an example of equation for the calculation of line speed of a motor vehicle:

$$V_i = z_{ii}/(3600 \cdot k \cdot \Delta t_i) \quad (10)$$

where z_{ii} is the pre-defined number of impulses, imp

k is the calibration value, imp/meas. unit (for speed calculation of the motor vehicle GAZ 2217 there was the value assigned of 482 imp/km

Δt_i is the passing time of z_{ii}, s.

In order to measure the direct and the reverse flow, there were volume-flow rate sensors used with oval gears Microstream OF05ZAT by Aichi token (Japan) which are characterized by a high reproducibility of results and a practically sufficient measurement accuracy.

The metrological evaluation of the system allowed to conclude that the relative tolerance of line speed measurement of a motor vehicle and the angular rate of the wheel does not exceed 2.4%; the tolerance of fuel consumption does not exceed 3.8%.

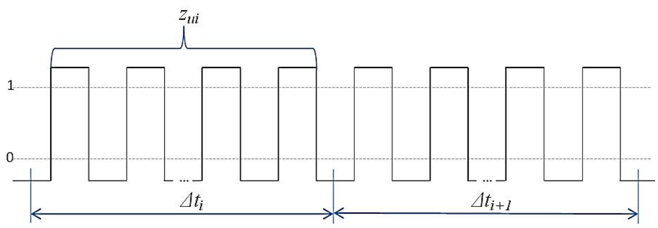


Fig. 4: The processing of measuring results

Results and discussion

The measurement and data processing results are represented in fig. 5, and 6. The dependence of speed of a motor vehicle on the time (fig. 5) was received when moving at each of the five gearings of the motor vehicle.

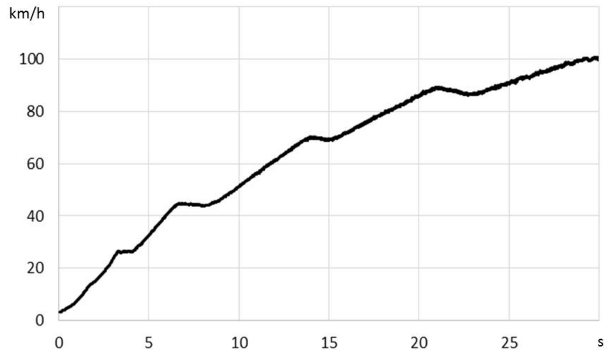
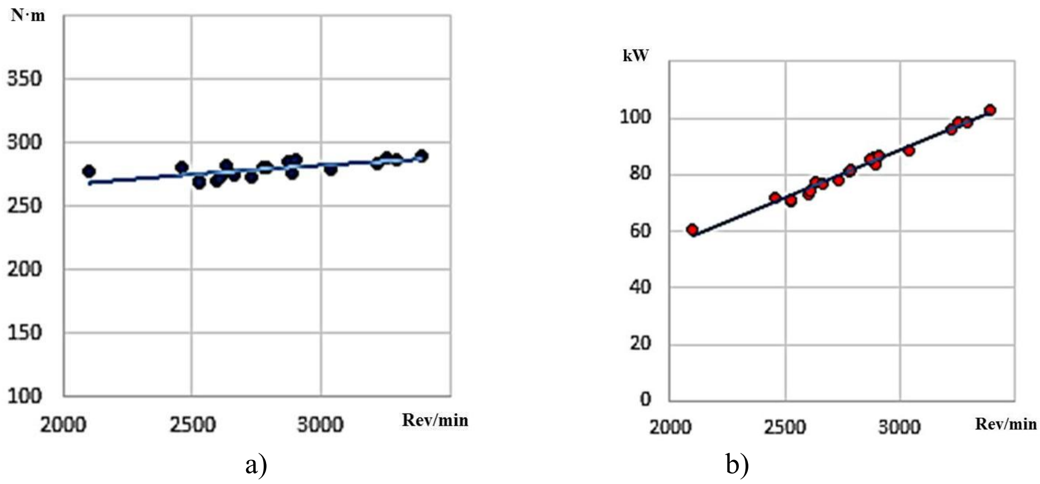


Fig. 5. The dependence of the speed change on the time when accelerating the motor vehicle GAZ 2217 up to 100 km/h

These data were used for the calculation of the effective drive torque and the effective capacity by means of an external velocity performance. There is a fact coming under notice that, on the basis of the given motion conditions (acceleration up to 100 km/h), there were points fallen out of the consideration which lie under 2000 rpm (fig. 6).

The calculated data available from experiments accord well with passport full-load curve of this diesel. In particular, the true values of an effective drive torque in the range of 2000-3500 rpm differ to 6.5% (in the initial specification, the maximum drive torque amounts to 310 Nm in the range of 2000-3500 rpm). The mentioned circumstance is not based on the calculation tolerance but on the difference in the versions as well as testing and exploitation conditions.



a) b)

Fig. 6: Estimated data of the full-load curve of the motor vehicle GAZ 2217 with a diesel engine ISf 2.8 Cummins a – effective drive torque; b – effective capacity

The conducted research led to the following conclusions:

1. The elaborated computer-aided system for the measuring of traction and speed characteristics as well as of fuel economy of a motor vehicle in road conditions helps to estimate the acceleration, the

speed, and the distance covered by a motor vehicle with a practically sufficient accuracy (relative tolerance equals to 2.4%).

2. In order to collect the data of traction and speed characteristics of a motor vehicle, it is most viable to use a regular sensor of angular rate of the antilock braking system for a wheel working in a conducted mode. In the case of usage of a sensor of angular rate of the conducted wheel, it is necessary to take into account speed and force losses in the tire.

3. In common rail fuel injection systems, it is rational to use the engine fuel consumption method as the difference between the direct and the reverse flow, because they grow the number of diagnosis information about the technical state of fuel injection system by themselves.

References

[1] Head I M 1996 Reserves and methods of fuel saving in transport of goods by road. (Irkutsk: ISTU) 214 p
[2] Khudyakov D A 2015 Diagnostics of the technical state of vehicles on fuel consumption on the basis of information system (Irkutsk: Car for Siberia and the far North. Design, operation, Economics : Publishing house of ERNITA) pp 71-77
[3] Molev Y I, Moshkov P S, Sokolov D A, Tikhomirov A N, Shcherbakov V V 2015 Method of determining the fuel consumption of a vehicle using data diagnostic Protocol OBD II (Moscow: FUNDAMENTAL RESEARCH) pp 74-78
[4] Krivtsov S N, Zimin V G, Malashkin I V 2015 Using dealer diagnostic software to collect data about the operation of the vehicle with diesel engine (Irkutsk: Publishing house of ISTU, Tr. students and teachers of the Institute of Avialesookhrana and transport) pp 29-33
[5] Krivtsov S N 2009 The creation of a device for diagnosing diesel engines on the basis of computer technology (Novosibirsk: AGROINFO-2009) pp 172-176.
[6] Fedotov A I, Vlasov V G, Krivtsov S N 2012 Calculation of speed loss in the tires of the car in operation (Moscow: The automotive industry N. 9) pp 44-45
[7] Korchuganova M, Syrbakov A, Tkachev A, Zorina T 2015 Research of the pre-launch powered lubrication device of major parts of the engine D-240 (Published under licence by IOP Publishing Ltd: IOP Conference Series: Materials Science and Engineering,Volume 91, conference 1)
[8] Glasberger T, Peroutka Z, Janda M, Majorszký J 2012 Traction Drive with PMSM: Frequency Characteristics Measurement (Transactions on Electrical Engineering, Vol. 1) pp 13-18
[9] Xu Z. L., Yao Z. Y. 2013 Research on Control Methods of Speed Stability by AR Model Based on Linear Ultrasonic Motor" (Applied Mechanics and Materials, Vols. 385-386) pp 777-780
[10] Du X. 2012 The Kinematic Analysis and Simulation of the Large-Scale Linear Vibration Screen (Applied Mechanics and Materials, Vols. 215-216) pp. 726-729