Determination Of Car Moving Resistance Using Double Coast-Down Deceleration Method

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ABSTRACT

In this paper is proposed the measuring of car deceleration, while the vehicle has been forced to coastdown, in two different loads (partially and fully loaded). Two equations of motion are used (considering load effect) to find out two unknown parameters – rolling resistance and aerodynamic resistance.

INTRODUCTION

For solving a variety of tasks in the theory of vehicle is necessary to know the rolling resistance and aerodynamic resistance. Rolling resistance is measured in special stands with large diameter drum, while the aerodynamic resistance is measured in the wind gallery.

Both these methods, are expensive ones and besides that give some results that are far away from real conditions of the car motion. It is well known the determination of total resistance that faces the car moving on a straight road, but to separate it's constituent components, it is difficult to set. Other methods require the use of complicated, special and expensive equipments.

However, some working practices often requires the simple and immediate calculation of resistance to motion, such as in case of accident reconstruction scenes, in determining fuel consumption etc. It is very interesting proposing this method that uses deceleration while the vehicle is coasting down in two load conditions [1]. This method is simple, does not require complex equipments and it is suitable for use in all real velocities of the vehicle (different from the pure conventional coast down method, described in [2]). The purpose of this paper is to verify the accuracy of this method and the use of it from almost every car driver.

DETERMINATION OF COEFFICIENTS

In a straight road, two coast down procedures are made, one with the vehicle fully loaded, and the other with partially loaded vehicle (with their masses m_1 and m_2 respectively). Intervals of times, during which the velocity drops occur are recorded, starting from a certain amount of speed, to a lower value (measured by the vehicle speedometer). For the average speed of motion V (in m/sec), are build up two equations with two unknowns - road resistance coefficient Ψ and aerodynamic factor kF ($k = \rho C_x/2$, where: ρ - is density of air, kg/m^3; p - is the atmospheric pressure, Pa; R - is the gas constant of air, that is 287.14 m^2/sek^2 K, T -

temperature, K; C_x - is the aerodynamic drag coefficient, F - is the area of frontal projection of vehicle, m^2), g - is the acceleration of free fall, 9.81 m/sek^2:

$$\begin{cases} m_1 \cdot g \cdot \Psi_1 + k_1 F \cdot V^2 = m_1 \cdot a_1; \\ m_2 \cdot g \cdot \Psi_2 + k_2 F \cdot V^2 = m_2 \cdot a_2; \end{cases} \qquad (1)$$

If we assume that Ψ and kF in both loading conditions, are the same, then:

$$\begin{cases} m_1 \cdot g \cdot \Psi + kF \cdot V^2 = m_1 \cdot a_1; \\ m_2 \cdot g \cdot \Psi + kF \cdot V^2 = m_2 \cdot a_2; \end{cases}$$

$$\Psi = \frac{m_1 \cdot a_1 - m_1 \cdot a_1}{(m_1 - m_2)g};$$

$$kF = \frac{m_1 \cdot m_2 \cdot (a_1 - a_2)}{\rho \cdot F \cdot V^2 \cdot (m_2 - m_1)}.$$

or

$$C_x = \frac{2 \cdot m_1 \cdot m_2 \cdot (a_1 - a_2)}{\rho \cdot F \cdot V^2 \cdot (m_2 - m_1)} \qquad (2)$$

We note here that in the above equations, the force of air resistance, that actually includes in itself the transmission losses in neutro position of the gearbox (motion for inertia), which do not depend on the load of the vehicle, are proportional to the square of the velocity and generally can be neglected because of the relatively small value. These losses are about 30 N for the speed 90 km/h [1].

EXPERIMENTAL PART

In spring 2010 is carried on the experimentation of Vw Jetta car and the results are presented in Tab. 1. Measurements were carried out on the road with asphalt layer in good condition, without wind, temperature 15^{o}C and atmospheric pressure 750 mm mercury column. Calculations according to formulas (2) give unsatisfactory results, especially regarding C_x coefficient. This is because of the assumption made for the coefficients, that do not depend on the load. For small cars tires, that have carcass made with metallic cords, when they are partially loaded, the rolling coefficient f' is smaller than the coefficient f for the full loaded tire that is given in the literature [3].

$$f' = f \cdot \left(1{,}3 - 0{,}3 \cdot \frac{G_{max}}{G_{act}}\right) = f \cdot K_{load} \qquad (3)$$

where G_{max}, G_{act} - is respectively the maximum permissible load and the actual load on the tire, in kg. For tires with carcass made with textile cords, coefficients within brackets are 1.5 and 0.5 respectively, while for the truck tires, these coefficients are 1.2 and 0.2 [1].

The vehicle that has been experimented has 175/80 R14 tires, that for the pressure 0.2 MPa can hold maximum load 485 kg, i.e. 970 kg per axle (bridge).

For partially loaded vehicle, the mass in the front axis is 735 kg, while in the rear axis is 485 kg.

On the fully loaded vehicle, the mass in the front axis is 790 kg, while in the the posterior axis 705 kg.

Per partially and fully loaded vehicle, using expression (3) are found these coefficients:

Partially loaded	$K_{p.load1}$ = 0,904	$K_{p.load2}$ = 0,7	$K_{p.load}$ = 0,8229
Fully loaded	$K_{f.load1}$ = 0,932	$K_{f.load2}$ = 0,887	$K_{f.load}$ = 0,9108

For the road with asphalt layer, road resistance coefficient Ψ, like rolling resistance coefficient f, depends on the load on the tire. Then (1) takes the form:

$$\begin{cases} m_1 \cdot g \cdot K_{f.load} \cdot \Psi + kF \cdot V^2 = m_1 \cdot a_1; \\ m_2 \cdot g \cdot K_{p.load} \cdot \Psi + kF \cdot V^2 = m_2 \cdot a_2; \end{cases} \quad (4)$$

from where

$$\Psi = \frac{m_1 \cdot a_1 - m_2 \cdot a_2}{g(m_1 \cdot K_{f.load} - m_2 \cdot K_{p.load})}$$

and

$$C_x \approx \frac{2m_1 \cdot m_2(a_1 K_{p.load} - a_2 K_{f.load}}{\rho F V^2 (m_2 K_{p.load} - m_1 K_{f.load})}. \quad (5)$$

According to these formulas, the value of the coefficient Ψ is closer to the real value (see Tab. 1), while the value of C_x coefficient is smaller than the value 0.44 given by literature for the standard load [4].

Tab. 1. Values of Ψ and C_x

Range of speed, km / h	*100-90*	*70-60*
Average speed, km/h	*95*	*65*
Coast down for fully loaded vehicle (m_1=1495 kg)		
Time, sec	*7,53*	*11,61*
Deceleration, in m/sec2	*0,3940*	*0,2482*
Calculation by formulas (5)		
Reduction coefficient of rolling resistance	*$K_{f.load}$=0,9108*	
	$K_{p.load}$=0,8229	
ψ	*0,02018*	*0,01563*
C_x	*0,34871*	*0,39336*
Calculation by formulas (7)		
Reduction coefficient of rolling resistance	*E=0,94*	
ψ	*0,01393*	*0,01233*
C_x	*0,45200*	*0,50987*
C_x mean	*0,480936*	
Calculation by formulas (7)		
ψ	*0,02246*	*0,02032*
C_x	*0,21128*	*0,16136*

Aerodynamic drag coefficient C_x depends from the ground clearance and the slope of the vehicle's cabin (Fig. 1 [5]).

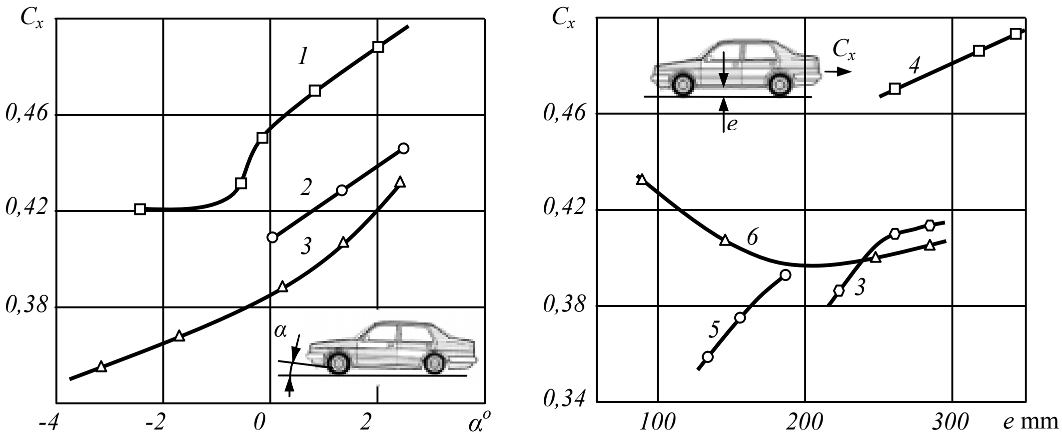

Fig.1. Influence of vehicle cabin inclination α and the ground clearance on the drag coefficient C_x [5]. 1 - Volkswagen; 2 - Audi 100, 3 - Ferrari F2-2, 4 - VW Transporter, 5 - Porsche 914, 6 - Citroen ID19.

For the vehicle in question, when it is fully loaded cabin slope is α = - 0.64°, and when it is partially loaded is α = - 1.27°.

The ground clearance in the vicinity of the front wheel, when the vehicle is fully loaded, is reduced 0.01 mm, while near the rear wheel, is reduced 0.03 mm, i.e. an average of 0.02 m (Fig. 2).

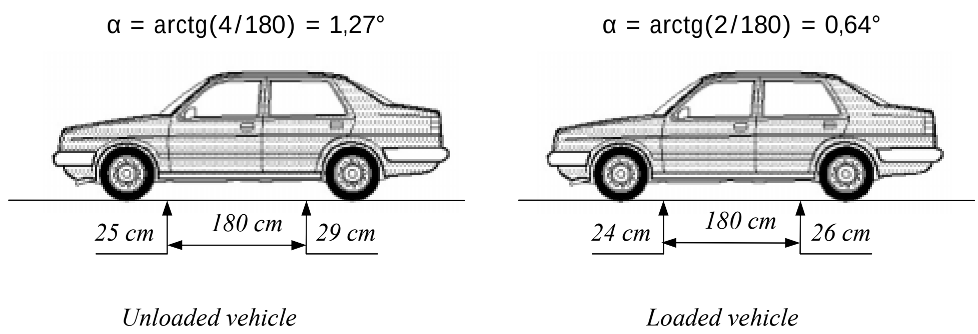

Fig. 2. Changing of the position of the vehicle cabin during loading

If we assume that the dependence between the coefficient C_x and ground clearance, is conforming the curve is 5, then we can write:

$$C_{xe} \approx C_x E_e; \qquad E_e \approx 1 - 1{,}7\Delta e$$

where Δe – is the change of vehicle ground clearance, in m.

The influence of vehicle pitching on the value of the coefficient C_x, can be obtained by using the linear parts of curves 1 and 2:

$$C_{x\alpha} \approx C_x E_\alpha; \qquad E_\alpha \approx 1 - 0{,}04\alpha$$

The simultaneous influence of vehicle pitching and ground clearance on the coefficient C_x, is calculated by the coefficient $E = E_e + E_\alpha$. Then the system of equations (4) takes the form:

$$\begin{cases} m_1 \cdot g \cdot K_{f.load} \cdot \Psi + kF \cdot V^2 = m_1 \cdot a_1; \\ m_2 \cdot g \cdot K_{p.load} \cdot \Psi + kF \cdot E \cdot V^2 = m_2 \cdot a_2; \end{cases} \quad (6)$$

From where

$$\Psi = \frac{E \cdot m_1 \cdot a_1 - m_2 \cdot a_2}{g(E \cdot m_1 \cdot K_{f.load} - m_2 \cdot K_{p.load})}$$

and

$$C_x \approx \frac{2m_1 \cdot m_2(a_1 K_{p.load} - a_2 K_{f.load}}{\rho F V^2 (m_2 K_{p.load} - E \cdot m_1 K_{f.load})}. \quad (7)$$

By changing the vehicle ground clearance to the extent of 0.02 m and the angle of inclination to the extent 1,27° − 0,64° = 0,63°, lowering coefficient of aerodynamic resistance is:

$$E \approx 0{,}94.$$

CONCLUSIONS

The method described for determining the resistance of the vehicle using double coast down with different loadings, gives results that match well with data published through the literature, that are derived by methods much more complicated. The experiment is simple, accessible from any driver and processing of results is equally simple. For using this method, should be checked in advance accuracy of speedometer and weighing of the vehicle at partial load and full load. Experiment is performed in a straight unclined road and without wind, but if so, that measurements should be performed making shuttle several times, to eliminate the influence of slope and wind. It should be noted here that the simple conventional coast down method [2], is very sensitive to measurement errors. Our goal was that of increasing the measurement accuracy without using complicated equipments. For more precision can be video registered the speedometer and after that processed on a computer.

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