4th INTERNATIONAL CONFERENCE
TRANSPORT SYSTEMS TELEMATICS TST'04

ZESZYTY NAUKOWE
POLITECHNIKI ŚLĄSKIEJ 2004
TRANSPORT z.55, nr kol. 1657

ITS, weight in motion systems, in-car computers, dynamic weighing of vehicles torque, forward thrust on the wheels, running resistance

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IN-VEHICLE WEIGHT IN MOTION SYSTEM

The paper deals with the current research and development results in area of weight in motion systems using the processing of in-vehicle data together with other measured data like acceleration, whether condition, etc. The described data processing results in the determination of vehicle weight that can be used for weight in motion applications (overloaded vehicles on roads and highways), evaluation of public transport line occupancy, etc.

CIĘŻAR POJAZDU W SYSTEMACH RUCHOMYCH

Referat opisuje bieżące badania i wyniki opracowań w obszarze ciężaru w systemach ruchomych wykorzystując dane pojazdowe wraz z innymi danymi zmierzonymi takimi jak przyspieszenie, warunki pogodowe itp. Przetwarzanie opisywanych danych pozwala na określenie wartości ciężaru pojazdu, jaki może być użyty jako ciężar w zastosowaniach ruchowych (przeciążone pojazdy na drogach i autostradach), oceny zajętości publicznych linii transportowych itp.

1. INTRODUCTION

Overloading of transport is causing enormous problems in road transportation. It is not easy to manage and manoeuvre an overloaded vehicle. Such vehicles are therefore a danger to road traffic. In addition, overloaded vehicles wear away the roads due to progressive pressure on the road surface. This leads to an un-proportional increase in the road rehabilitation costs.

This paper presents a technical elaboration of conditions and the relations needed for a continuous weighing of vehicle unit during travel. The telematic system that is contained in the patent application [1] is used. The principle of the patent application is the following quote: "the motive-derived dynamic data is recorded during travel, therewith as a component,

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together with all the external recorded forces and other factors acting on the vehicle, are assessed together with the oncoming corrections of external or implemented data in the onboard computer that is mounted in the vehicle according to law of inertia and other laws of nature, whereas the obtained data of the vehicle is input into the onboard computer telematically and/or supervisory or by means of a master system and/or digital speed recording indicator and/or into the system of electronic toll and/or into the management of transport telematic system etc. for further decision making and/or for the optimising of operation driving parameters of the vehicle unit", end of quote.

2. AN EXAMPLE OF EXPERIMENTAL WEIGHING

The readings and calculations in this article are based on the passenger vehicle – SKODA FAVORIT 136 L. Specifications: - engine type 781.136, - service weight 840 kg, - payload 450 kg, - tyres 165/70 R 13 with OR 37 design. The authors had all the essential data that was needed for continuous weighing of the vehicle during travel. The data was acquired as part of a broad collection of measured data meant for wide range special purpose experiments. This example is being presented as a model that is based on the application of the respective laws of nature, which are in principle applicable to all types of road vehicles.

2.1. THE BASIC DATA OF MEASURED VEHICLE

The torque characteristics were taken from the homologation report and purpose report that had been modified through the technical inspection of the vehicle.

The characteristics show the continuous dependence of engine effective torque M [N.m] on engine speed [revs per min].

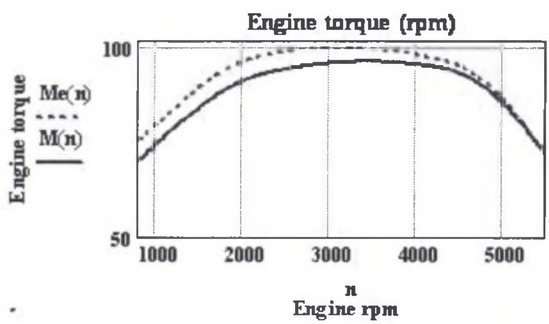

Fig.1. External characteristics showing the dependence of engine effective torque, (y-axis), on engine speed, (x-axis). The standard sound engine is represented by the dotted curve M' (n). For the measured worn engine, a full curve is used M (n).

The given characteristic M (n), signifies an extraordinary data input into the calculations thereinafter, because it is the only predefined component. Given its size it compensates all the passive resistances, mainly the resistance that is dependent on the weight under study. Figure 1 shows the so-called external torque characteristics at full throttle. In principle, once we take into account the relationships of other independent variables, namely the position of the accelerator pedal, it is possible to arrive at a continuous definition of the corresponding trends in torque characteristics and realise a random measuring of system to determine prevailing fuel supply. In comparison to the given external characteristics, for any type of torque characteristics the value of its torque in relation to engine speed in all cases could be only lower; from the analysis given below we can deduce that this less used values have always a negative impact in the form of poor measuring preciseness. It is possible to state that the resulting errors of dynamic measuring of vehicle weight according to the above cited registered invention, if carried out at half throttle there is roughly a twofold increase in errors, in comparison to the full throttle case.

For rational use of the given method, only a suitable choice and processing of random vehicle regimes can be recommended. This should be done under full throttle. This full throttle can even be short term, having duration of few seconds required for stable transition feature of fuel supply. The next analysis of the given problematic therefore results from given advantageous prerequisite. If this prerequisite is not respected, it will lead to a decrease in the input torque characteristic that will unproportionally increase the resulting test error. This is also linked to the recommendations in the invention report that says that tests should not be carried out in first gear because in this case there is a higher probability that full fuel supply causes big high slip, which is unacceptable for measurement reasons.

The other problem that is connected to the given torque characteristic M (n) is the precision of its update within the framework of the supposed modifications of the measuring procedures during technical inspections of the vehicle. In figure 1, the torque characteristics were updated just before the experiment. The car had undergone normal wear at 150.000 km mileage. The effective torque in this case decreased mainly at low engine speed. This was a manifestation of a partial loss in compression pressure resulting from the wear of pistons and cylinders. This phenomenon that is irreversible and mechanically nonadjustable must be registered during technical inspections and the all the affected characteristics should be entered into the updated engine database.

From the viewpoint of degenerative changes in the mechanical components of any type of vehicle that are related to use, the given changes in the characteristics M (m), will always be negative. If case they are updated at technical inspection intervals of an average 100 000 km mileage, we can, based on the earlier experiments recorded by the authors, suppose that the relative minus diversion will not be greater than –3%. For the rest of torque changes, which are random, and those that can be corrected through maintenance, it is imperatively in the interest of the user that they be corrected. This is due to the fact that any minus or plus diversions from the standards given by the manufacturer will almost always lead to worsening economic, dynamic, driving and safety conditions of the vehicle. In spite of this it is necessary to suppose that as a result of the given random phenomena, the characteristic M (n) can decrease roughly by another –7%, thus by a total of about –10% (see below).

For the given test requirements, the following data must be known for each type of vehicle. The concrete data has been taken from the test measurements carried out on a passenger car – FAVORIT 136 L:

Im = **0.142** [$kg.m^2$] it is the moment of inertia of a revolving component of an engine connected to the clutch, scaled on to the crankshaft.

Is = **0.002** [$kg.m^2$] it is the clutch dragged moment of inertia, including the whole transmission system. In the case of the method under investigation, **Is** does not enter the computations as an independent variable, but as a part of **Im.**

Ia = **0.901** and **Ib 0.901** [$kg.m^2$] gives the total moment of inertia of all driving wheels (a) and all driven wheels (a), including the complete system auxiliaries and their axis reduction.

ka = **0.118** [N/kg] gives the coefficient for all the constant components of rolling resistance for a standard surface.

kb = **0.003** [N.s/kg.m] it is the coefficient of linear dependence between the rolling resistance and vehicle speed on standard surface.

SP = **2.5** [m^2] is the front surface area of the vehicle car body.

cw = **0.32** is the aerodynamic resistance of the vehicle.

ρ = **1.202** [kg/m^3] is the air density. The value is updated from the database for above sea level height of a given section of the road.

$\mathbf{ip_s}$ = **4.935** is the total gear ratio between the crankshaft and the driving wheels in gear **s** = **3.**

up = **0.96** is the mechanical efficiency for energy transmission from the crankshaft to the driving wheels at a given nominal load and at standard road quality and running temperature of the oil.

2.2. DATA MEASURED DURING VEHICLE TRAVEL

As an example we have selected two readings on FAVORIT 136 L. During the first test, denoted by the index 1, the vehicle was loaded with three persons; it had the standard fittings including fuel in the tank. In the second test a person weighing 106 kg left the vehicle but the rest of the conditions remained the same; this test is denoted with index 2. In the two given evaluations I =1 and I =2, the following readings were taken:

$\mathbf{Mv_1}$ = **1209** and $\mathbf{mv_2}$ = **1103** [kg] is the static taken weight of the vehicle during 1 and 2 tests.

$\mathbf{n_1}$ = **2357** and $\mathbf{n_2}$ = **2501** [min^{-1}] the frequency of rotations for the crankshaft during 1 and 2 tests.

Ra = **0.274** [m] is the updated rolling radius of the vehicle drive wheels during travel.

v_1 = **48.78** and v_2 = **51.79** [km.h^{-1}] is the linear speed of the vehicle during test 1 and 2, which was determined from the frequency of drive wheel rotations (they can also be measured telematically).

a_1 = **0.959** and a_2 = **1.065** [m.s^{-2}] lineal acceleration of the vehicle during test 1 and test 2, which were determined through the derivation of speed $v_1 = v_2$ against time (It can also be measure using the gravity sensor).

vx_1 = **1.8** and vx_2 = **-2.5** [km.h^{-1}] it is perpendicular to the vector projection of speed along the longitudinal plane of the vehicle (it is measured using the anemometer and it is taken as the mean value for a given section of the road). The value is positive in the direction of the vehicle and it is negative in the opposite direction.

α_1 = **-1.1** and α_2 = **-1.1** [%] it is the elevation of a given section of the road expressed in %, i.e. 100.tangent.α. The value is positive uphill and negative downhill. (Measured using the inclinometer and taken as a mean value of the road section).

Figure 2 to figure 5 gives the measured data and the primary data computation of the given case.

2.3. COMPUTING THE DYNAMIC MEASURING OF VEHICLE WEIGHT

In random regime, all the forces acting on the circumference of the vehicle wheel are in equilibrium. Under conditions where all the insignificant components of the given forces e.g. the temperature effect of engine and transmission oil, pressure effect, temperature effect, air humidity effect, the effect of road surface adhesion properties etc., are neglected, we can derive the following relation for computing the dynamic weight of the vehicle:

$$m_i := \frac{\frac{ip \cdot up}{Ra} \cdot M(n_i) - a_i \cdot \left(\frac{ip^2 \cdot Im}{up \cdot Ra^2} + \frac{Ia + Ib}{Ra^2}\right) - \frac{0.5 \cdot \rho \cdot cw \cdot SP}{3.6^2} \cdot (v_i - vx_i)^2}{a_i + \left(ka + \frac{v_i}{3.6} \cdot kb\right) + 9.807 \cdot \sin\left(\operatorname{atan}\left(\frac{\alpha_i}{100}\right)\right)}$$

Each given input value was repeatedly measured with a higher degree of statistical compensation for all random errors and precisely rounded off to one decimal place. As a result upon substitution for the values in relation 2, we get relatively accurate results. The relative extreme error for dynamic determination of the vehicle is in this case roughly equal to 0.6%. It must be mentioned here that the torque M (n) was updated just before the experiment. This was done with the same precision as for quasistatic measuring 0.5%. This will evidently not be possible to realize under normal operational circumstances.

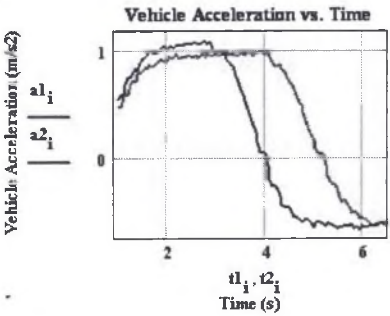

Fig.2. Linear acceleration a_1 and a_2 [$m.s^{-2}$] of the vehicle during the first measurement (lower value) and second measurement (higher value) in relation to time t_1 and t_2 [s].

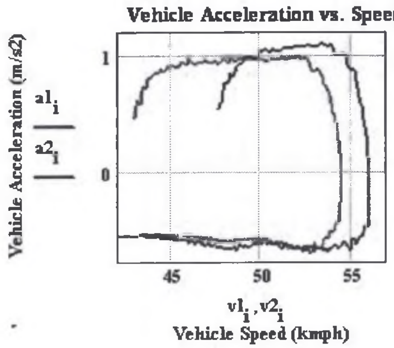

Fig.3. Linear acceleration a_1 [$m.s^{-2}$] of the vehicle during the first measurement and second measurement in relation to vehicle speed $\mathbf{v_1}$ and $\mathbf{v_2}$ [$km.h^{-1}$].

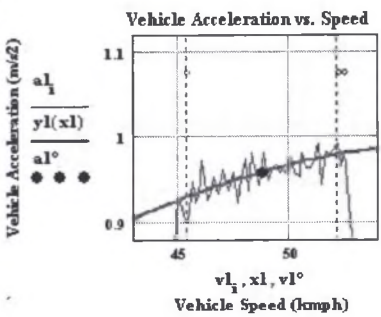

Fig.4. Details of linear acceleration a_1 [$m.s^{-2}$] of the vehicle interlarded with a regressive curve $\mathbf{y_1}$ and its mean value $\mathbf{a_1}$ for a measured road section.

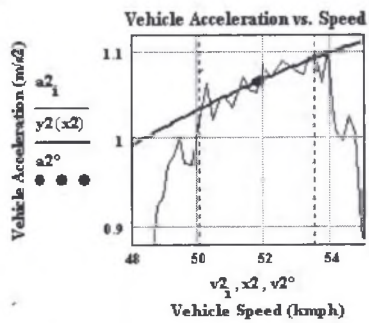

Fig.5. Details of linear acceleration $\mathbf{a_2}$ [$m.s^{-2}$] of the vehicle interlarded with a regressive curve $\mathbf{y_2}$ and its mean value $\mathbf{a_2}$ for a measured road section.

3. CONCLUSION

The repeatability of tens or hundreds of measurements has been proved. When running the verified model, for many of the input variables the same values or values of higher precision are obtained in repeated measurements – in some cases the results are better than the ones given in the example. For the torque characteristics M(m), statistical compensation does not help. From the computation point of view, the torque characteristic has an extraordinary importance. The torque characteristic is not only burdened by random error, but also by the systematic error. The systematic error is a result of a gradual increase in different engine faults and failures.

Based on the present measured data and experience, the authors suppose that the diversions of characteristics M (n) from the normal that are encountered in engine operations will, as a rule be negative. They will not be more than 10% of the standard value of the new run-in engine. The given limit of 10% is so big and it in general it would cause intolerable marked losses in power with its corresponding vehicle utilization; this would also cause an increase in fuel consumption that would be to the dislike of the user.

The results of the experiments have been used to show that according to [1], relative errors in dynamic measurements of vehicle weight can be expected to roughly reach 10%. The presented practical trials will be extended to other kind of vehicles under different measurement conditions. In-vehicle weight in motion system could be part of next on-board unit generation that will be connected to vehicle CAN bus and will contain all necessary components like GPS, GSM, accelerometer, etc.

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