

THE TRACTION SURVEY AND MONITORING OF A VEHICLE USING A SATELLITE NAVIGATION SYSTEM

Karol Cupiał*, Janusz Grzelka*, Adam Dużyński*, Piotr Grzelka**

*Institute of Piston Machines and Control Technology, Częstochowa University of Technology

**Faculty of Electronics, Branch Motion Telecommunication, Wrocław University of Technology

Summary. The paper presents the results of the traction survey of a vehicle by using a system incorporating satellite navigation receivers operating in the GPS system and a differential system operating with a reference station (DGPS) enabling recording of the momentary coordinates of the location and velocity of the vehicle under examination in the ellipsoid system (x, y, z – the WGS-84 system) at a frequency of 20 Hz., as well as other things. The results have been compared to the results of the vehicle survey using the so called „fifth wheel”. An application developed in the LabView environment is also presented, together with its practical utilization allowing the determination of the online location of an agricultural vehicle during field work by using the AVL method.

Key words: traction survey, external characteristic, fifth wheel, satellite navigation system, vehicle positioning

INTRODUCTION

In order to carry out complete diagnostic tests of a vehicle, the measurements of the transient motion of the vehicle during its acceleration and the assessment of its dynamic properties are required to be made. For these to be complete, the following should be measured: vehicle displacement, velocity, time, acceleration and vertical displacements. Using traditional techniques, taking advantage of the so called „fifth wheel”, this is practically not feasible. Also, advanced laser measuring systems being a substitute for the „fifth wheel”, operating on the LDA principle, are not able to take account of the difference in the height and vertical component of the velocity vector, and the knowledge of these quantities is essential for the correct verification and assessment of the traction surveys of a vehicle. A number of drawbacks of the traditional method of recording a vehicle's acceleration process and the development of satellite navigation systems, along with the construction of satellite receivers of high technical parameters, all create opportunities for the utilization of satellite telecommunication techniques for the examination of transient vehicle motion, and particularly a vehicle's acceleration process. The satellite navigation technique has developed sufficiently to allow the above-mentioned func-

tions to be implemented using signals from satellites, e.g. those of the NAVSTAR system.

The paper describes a test using the GPS system in a differential version for the traction survey of the vehicle acceleration process and the assessment of dynamic vehicle properties.

FUNDAMENTALS OF THE GPS SATELLITE NAVIGATION SYSTEM

After a considerable number of artificial Earth satellites have been put into orbit, new opportunities for their utilization, e.g. for navigation, have appeared. The NAVSTAR satellite system allows for the determination of not only the location of the observer, but also observer movement velocity and time in any location of the globe. It is composed of 24 satellites of the US Defense Department, deployed in six orbits, each of an inclination to the Earth equator plane of approx. 55° and a radius of 20183 km. The global character of this system manifests itself in the common availability of the GPS satellite signal round-the-clock in any corner of the world. At present, there may be up to 13 satellites above the horizon (with an average visibility of 8 satellites). In the case of dynamic measurements, the standard frequency of receiver location updating is approx. 1 Hz (with higher-class receivers attaining frequencies from 20 to 100 Hz).

THE DGPS SYSTEM USED IN INVESTIGATION

For vehicle traction surveys carried out at the Institute of Piston Machines and Control Technology (IPMCT) of the Częstochowa University of Technology the differential satellite navigation system was used (Fig. 1), incorporating satellite receivers supplied by NovAtel of Canada (type ProPak-G2- DB9-3151W with a 600-L1 antenna) of the following parameters:

- | | |
|--|------------------------|
| – number of channels | 11 plus 2GEO |
| – positioning accuracy: | |
| - GPS L1 | 1.8 m CEP ¹ |
| - SBAS L1 | 1.2 m CEP |
| - DGPS (L1, C/A) | 0.45 m CEP |
| - RT20 | <0.2 m CEP |
| – velocity determination accuracy | 0.03 m/s RMS |
| – measurement frequency | 20 Hz. |
| Reference station parameters: | |
| – radio modem by Satel, type 1870 | |
| – ERP = 0.153 W (equivalent radiation power) | |

¹CEP – Circular Error Probable – the radius of the circle within which the receiver is located with a probability of 50%

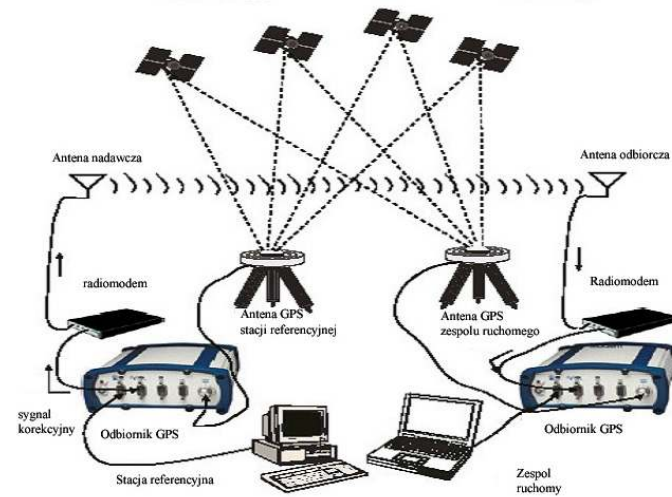


Fig. 1. Schematic diagram of the differential DGPS system used at the IPMCT [Cupiał *et al.* 2004a]

- the theoretical range of the reference station is contained within the radius of 7.15 km, whereas the practical range as defined by the limit of a good reception of the information signal (40 dB/1 μ V/m) is 1.2 km.

The elements of the system reference station and the system „moving” elements at the time of carrying out the investigation are given in [Cupiał *et al.* 2004 a and b].

THE SUBJECT OF TESTS

The testing of the acceleration process and the assessment of dynamic properties were carried out for the following vehicles of the main technical specifications shown in Table 1.

Table 1. The main technical specifications of the tested vehicles.

Parameter	Dimension	Passenger car no. 1	Passenger car no. 2	Agricultural tractor
Engine type	-	ZI	ZI	ZS
Cylinder capacity	cm ³	1389	1199	3908
Maximum power	kW	66	55	69
Torque	Nm	125	110	no data available
Complete vehicle weight	kg	1183	1055	4164
Wheel rolling perimeter	m	1.875	1.7502	4.824/3.498 (rear/front)
AC _x	m ²	0.67	0.87	no data available

Figures 2 and 3 show the elements of the subject of testing.

RESULTS OF TESTS

Surveys made using the GPS system

Surveys carried out over a section of the DK-1 national highway during normal vehicle traffic comprised measurements of the transient motion of car no. 1 (Table 1) with acceleration at the full opening of the throttling valve.



Fig. 2. One of the testing vehicles during road surveys made with the GPS system and the „fifth wheel”, respectively

The system recorded, at a frequency of 20Hz, quantities including the coordinates of testing car displacement in the WGS-84 (x, y, z) system, its displacement velocity (V_x, V_y, V_z), the standard deviation of the above-mentioned quantities and the remaining navigation information received from the satellite. Calculated quantities were recorded and subjected to numerical processing using the author's own software. The results are illustrated in Figs. 4–6.

In the case of the transient motion of a car over a flat surface the equation for the momentary value of an engine's shaft torque required to overcome the resistance of motion is defined by equation (1):

$$M = \frac{R_t}{\eta_n \cdot i_n} \left(\mu \cdot m \cdot g + \frac{AC_x}{2} \cdot \rho \cdot v^2 + e \cdot m \cdot \frac{dv}{dt} \right) \quad (1)$$

where:

- R_t – car wheel rolling radius,
- η_n – power transmission system efficiency,
- i_n – power system axle ratio,
- μ – rolling resistance coefficient,
- m – complete car weight,

g – gravitational acceleration,
 C_x – aerodynamic resistance coefficient,
 A – car face area,
 ρ – air density,
 e – whirling mass coefficient,
 v – linear car velocity,
 t – time.

Knowing the numerical values of the car parameters occurring on the right-hand side of the torque equation (1) and the variation of car motion velocity recorded as a function of time, the momentary value of engine torque can be calculated using this equation.



Fig. 3. An agricultural tractor during a traction survey

To enhance the accuracy of calculations of the momentary value of car acceleration dv/dt occurring in equation (1) and calculated by means of the numerical differentiation of the velocity variation curve obtained from measurements, it is usually approximated with a parabola equation of a not very high degree. If car acceleration was carried out on one arbitrarily chosen gear and at the full opening of the throttle valve, then the external characteristic of engine torque and power could be determined in this manner.

The comparison of the variations of motion resistance calculated from the relationships of car acceleration at different gears indicate that at low gears inertial forces prevail in the total motion resistance, with a small share of rolling resistance and aerodynamic resistance (at gear I – 4.5%, at gear II – 8.9%, at gear III – 21.3%, at gear IV – 31.5% and at gear V – 50%), and this is why any possible inaccuracies in determining the coefficient of rolling resistance and the product AC_x at low gears do not substantially affect the calculated torque value.

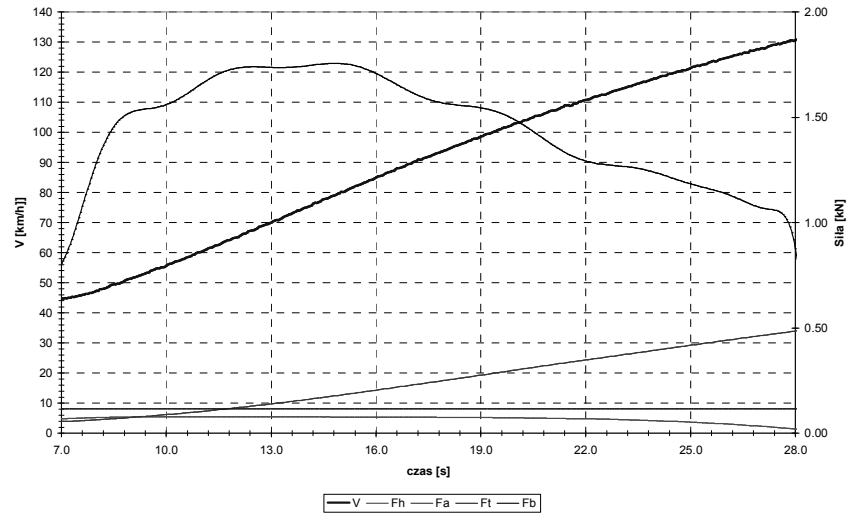


Fig. 4. Variation of velocities and forces during the passenger car acceleration process:
(F_h – ascent resistance force, F_a – aerodynamic resistance force, F_t – rolling resistance force,
 F_b – inertial force)

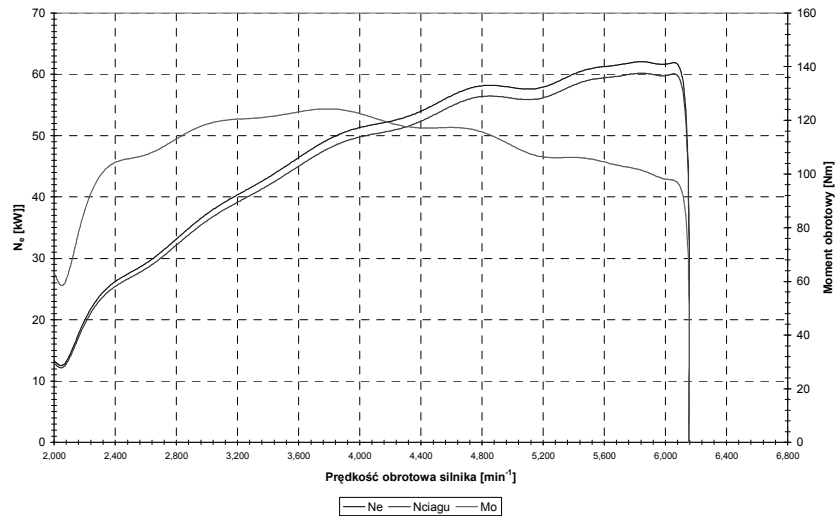


Fig. 5. External characteristics of the passenger car engine determined from measurements done
with the GPS system during car acceleration
(N_e – effective power, N_{thrust} – thrust power, M_o – torque)

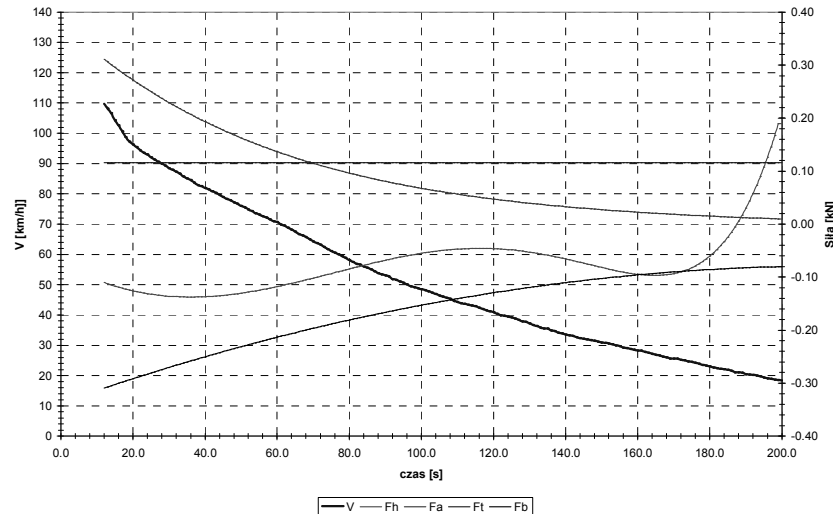


Fig. 6. Variation of velocities and forces during the free coasting of a passenger car

Comparative surveys using the fifth wheel technique

At present, the NAVSTAR system can be an alternative to the so called fifth wheel technique, whose basic drawback is the failure of accounting for variations in altitude when carrying surveys, which results in quite significant variations in the obtained results, as shown in Fig. 7, illustrating variations in external engine characteristic determined with ascent resistance having been (Ne-H), and not having been (Ne-NH) taken into account. These surveys were carried out on the apron of the aerodrome at Rudniki near Częstochowa by recording the velocity of motion of testing vehicle no. 2 (Table 1) using the DGPS system and the „fifth wheel” technique at the same time.

The fifth wheel system available at the IPMCT, composed of a 26” wheel operating with an inductive rotational speed transducer, a frequency–voltage converter and a 12-bit A/D converter assures a velocity recording accuracy in the range of 0.15–0.42 km/h (at a vehicle speed of 20–120 km/h), which gives a relative error below 1%. The basic drawback of each of the methods of vehicle velocity recording at a high sampling frequency are instantaneous fluctuations in vehicle velocity leading to an erroneous interpretation, particularly of the acceleration signal that is the result of vehicle velocity differentiation. Therefore, a need arises of approximating the vehicle velocity by a multinomial with the lowest possible degree. The approximation of the velocity signal by a multinomial of the 5th degree yields a correlation coefficient of $R^2 = 1000$. The effect of multinomial degree on the shape of external engine characteristic is illustrated in Fig. 8. During an engine operation with external characteristic within a rotational speed of 2–6 thousand rpm, a multinomial degree of 2–3 assures a correct approximation of the velocity variation. Approximation in a velocity range above the fuel dose cut-off velocity and the calculation of characteristic variation in that range are purposeless.

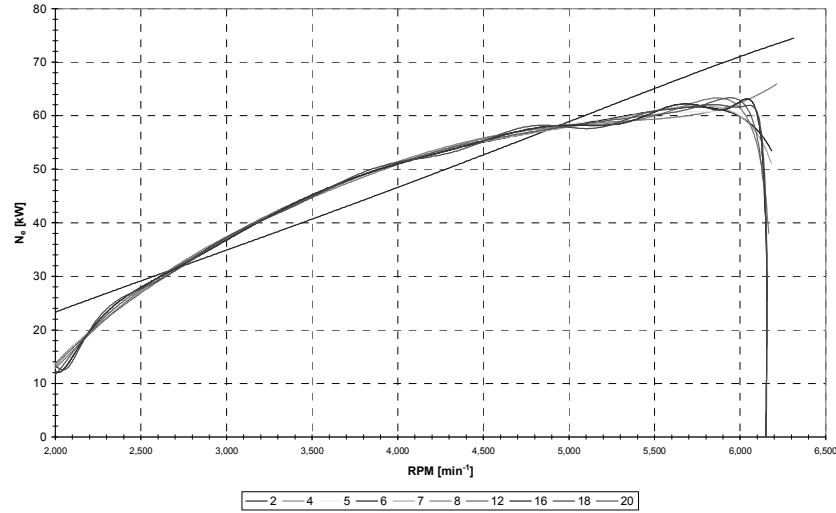


Fig. 8. Effect of multinomial degree on the variation of external engine characteristic – the numbers denote the degree of the multinomial approximating the measured variation of vehicle velocity at the third gear

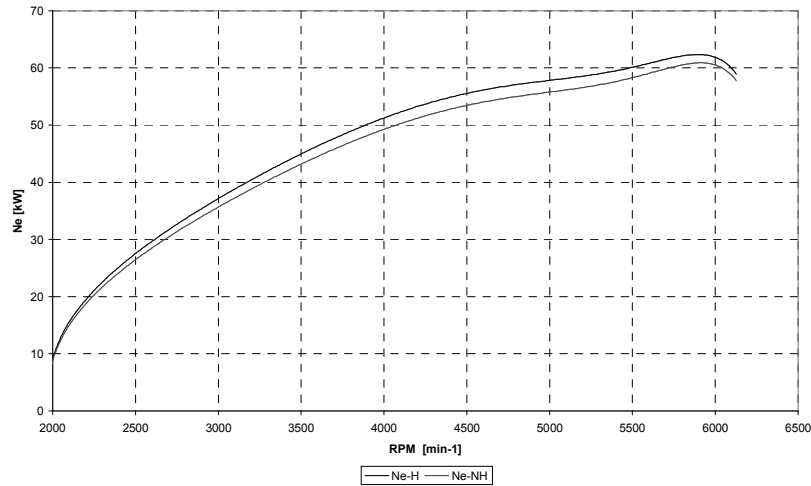


Fig. 7. Variations of external engine characteristic obtained from traction surveys, respectively, with and without accounting for the changes in the altitude of the moving vehicle

Satellite systems are also applied in other spheres – e.g. in agriculture for locating agricultural machines and controlling their operation [Deimert and Mailler 2004]. With this in mind, an application created in the LabView environment has been developed [Grzelka 2004], which allows the online location of an agricultural machine using the AVL (Automatic Vehicle Location) method during field work, as well as carrying out remote traditional traction measurements.

The use of the GPS for the survey of a tractor

Figure 9 shows the result of operation of this application during the testing of using the GPS system in agriculture. The surveys were conducted on Waldemar Plantowski's Arable & Animal Farm on a New Holland TL100 Deluxe tractor. Figure 10 shows the process of acceleration of the tractor and its free coasting.



Fig. 9. The AVL method applied to field work

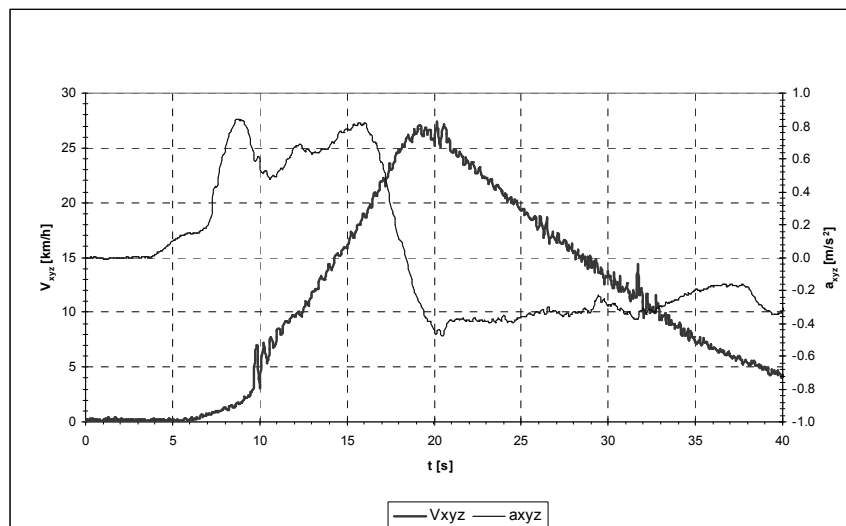


Fig. 10. The process of accelerating and free coasting of a TL100 agricultural tractor:
 V_{xyz} – velocity, a_{xyz} – acceleration

CONCLUSIONS

The dynamics of a vehicle can be evaluated using the GPS system, whose accuracy in determining the location is at the level of 1.8 m (CEP) and the velocity at approx. 0.1 km/h with a result recording frequency of min. 20 Hz. This system, as used to the measurement of the transient motion of a vehicle being accelerated, makes it possible to reach a vehicle displacement determination inaccuracy of 1.86–3.60% (with the standard deviations of position coordinates (acc. to WGS84) being $\sigma_x = 2.9$ m, $\sigma_y = 1.7$ m, $\sigma_z = 3.2$ m, and those of velocity 1.28, 0.73 and 1.4 km/h, respectively). The use of the differential DGPS system results in increasing the measurements of velocity and acceleration by 2–3 times, with a corresponding increase in the precision of determining the motion resistance and the engine torque and power of the vehicle, as calculated based on the signals from the NAVSTAR system. This is associated, however, with increased costs and the necessity of installing a reference station. The displacement determination inaccuracy is 0.7–1.7% (with the standard deviations of position coordinates (acc. to WGS84) being $\sigma_x = 1.5$ m, $\sigma_y = 0.8$ m, $\sigma_z = 0.85$ m, and those of velocity 0.65, 0.34 and 0.37 km/h, respectively).

The average „visibility” of the satellites during the performance of the test was (9–10 – the GPS measurement) and (7–8 – the DGPS measurement), with an average daily satellite visibility over the territory of Poland of 8 satellites. Conducting traction surveys in an urban area is difficult for obvious reasons, such as:

- a dense housing forming a natural „barrage” to the weak signal from the satellite, restricting at the same time the propagation of radio-waves transmitting correction allowances from the reference station;
- the road traffic that cannot be eliminated.

The traction surveys of different vehicles equipped with GPS receivers and operating with the DGPS reference station have shown that, based on measurement results obtained with the help of those satellites such parameters can be determined as the momentary horizontal and vertical position and the velocity and acceleration of the vehicle in the conditions of stationary motion and during acceleration at particular gears. Based on the analysis of the variation of vehicle acceleration at medium gears the variation of external engine characteristic can also be determined without having to use a chassis test bed, and this may have a significant importance in vehicle diagnostic testing, among other things.

The use of the differential DGPS system results in an increase in the accuracy of velocity and displacement measurements by two to three times, which correspondingly increases the precision of determination of vehicle velocity, acceleration and motion resistance and vehicle engine power.

At present, the NAVSTAR GPS system might be an alternative to the so called fifth wheel technique. A higher precision in determining vehicle motion parameters will be possible to be obtained, when the EGNOS location-aiding system attains its full technical performance, or when the Galileo system starts to operate over Europe, whose full technical performance is expected to be achieved in the years 2008–2010.

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