APPLICATION OF GPS RECEIVER TO ROAD TESTS OF AUTOMOBILE

Hubert Sar, Janusz Pokorski, Piotr Fundowicz, Andrzej Reński

Warsaw University of Technology
Institute of Vehicles
Narbutta Street 84, 02-524 Warsaw, Poland
tel.: +48 22 2348410, fax: +48 22 8490303
e-mail: hubsar@wp.pl, jpk@simr.pw.edu.pl.
pfundow@simr.pw.edu.pl, arenski@simr.pw.edu.pl

Abstract

The article presents the assessment of the possibilities of applying GPS receiver for the measurement and acquisition of the longitudinal velocity of automobile in the investigations of longitudinal dynamics of automobile. For many years for the measurement of the longitudinal velocity Correvit-L sensors are applied. Major simplification of the measurement of the velocity with the GPS receiver, compared with correlational-optical sensors Correvit-L is giving the possibility to faster prepare the automobile for examinations. The more so as only recently GPS receivers with 10 Hz sampling rate are available. In the paper is shortly described the software specially designed for the measurements that makes it possible to simultaneously measure both the longitudinal velocity signal from GPS receiver and from Correvit-L sensor in real time. Furthermore, the application of the measurement of the velocity is presented on the basis of such road tests as the attempt of accelerating through the following gears, the attempt of free deceleration and the attempt of braking according to ECE 13 Regulation. On the basis of the mentioned manoeuvers the characteristics of the vehicle's acceleration and dynamic coefficient, rolling and air drag coefficient and the braking deceleration were determined. The paper shows also some problems connected with applying GPS receiver to measure longitudinal velocity of the automobile.

Keywords: *automobile dynamics, air drag coefficient, rolling drag coefficient, ECE 13 Regulation, road transport*

1. Introduction

The article discusses the judgement of the perspectives of application of GPS receiver for the measurement of the longitudinal velocity for the needs of automobile longitudinal dynamics investigations. Since many years for measuring longitudinal velocity Correvit-L sensors are used. Significant simplification of the measurement thanks to GPS receiver, in comparison to correlative-optical sensors Correvit-L allows to more rapidly preparing the automobile for the investigations.

GPS technology [2, 3] makes it possible to apply GPS receiver for the measurement of the longitudinal velocity of the vehicle with sampling frequency up to 10 Hz (in the past suitably 5 Hz and 1 Hz). In the references is shown the article [4] of other researchers, which tested the functioning of simple navigational devices with the possibility of acquisition the information about the velocity in text format with 1 Hz frequency for the needs of traffic accidents reconstruction.

Signal of the velocity was further applied to determine decelerations according to ECE 13 Regulation and differentiated in order to determine the characteristics of accelerations and the air and rolling drag coefficients.

2. Methodology of the research

In order to perform the research with simultaneous acquisition of automobile velocity using both correlative-optical Correvit-L sensor and GPS receiver, it was necessary to prepare the measurement-acquisition system and software for Correvit-L sensor, configure the GPS receiver and its software. Correvit-L sensor was used to verify the results of the measurements through GPS receiver.

As part of the work the following road tests were performed:

– attempt of braking – in order to investigate braking properties of automobile (determining braking deceleration according to ECE 13 Regulation,
– attempt of automobile accelerating – in order to obtain dynamic characteristic and acceleration characteristic of automobile [1, 5, 6],
– attempt of free decelerating – in order to determine air and rolling drag coefficients c_x and f_0 [1, 5, 6].

The object of research was Ford Transit 2.5D (1994).

3. Measurement-acquisition system\

For investigations measurement-acquisition PCI_EPP system [7] communicating with PC computer through Centronix-type interface was used. The research was conducted using the software that was specially designed in order to synchronize the measurement of velocity applying Correvit-L sensor (communication with PC computer through Centronix interface) and GPS receiver (comminication via USB port).

a)

b)

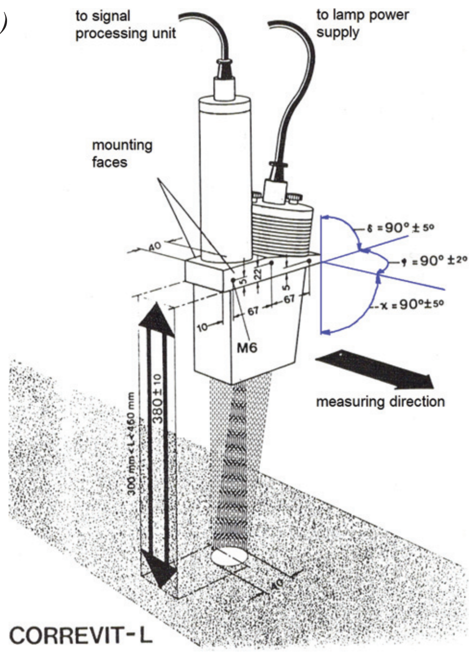

Fig. 1. Possibilities of measuring longitudinal velocity of automobile: GPS Qstarz 818XT 10 Hz receiver (a), and correlative-optical Correvit L sensor (b) [8]

Besides the above mentioned synchronization of acquisition velocity from Correvit-L sensor and GPS receiver, the software also determined according to ECE 13 Regulation the values of deceleration of automobile, using the signal of brake pedal pressed.

Figure 2 shows the window of observing automobile velocity from GPS receiver, both in numerical and oscilloscope form.

4. Results of road tests

4.1. Investigations of braking properties of automobile

The attempt of braking was based on automobile braking on even, horizontal road, with constant, increasing or decreasing brake pedal pressing. Based on this attempt the values of decelerations relative to the time and road were determined.

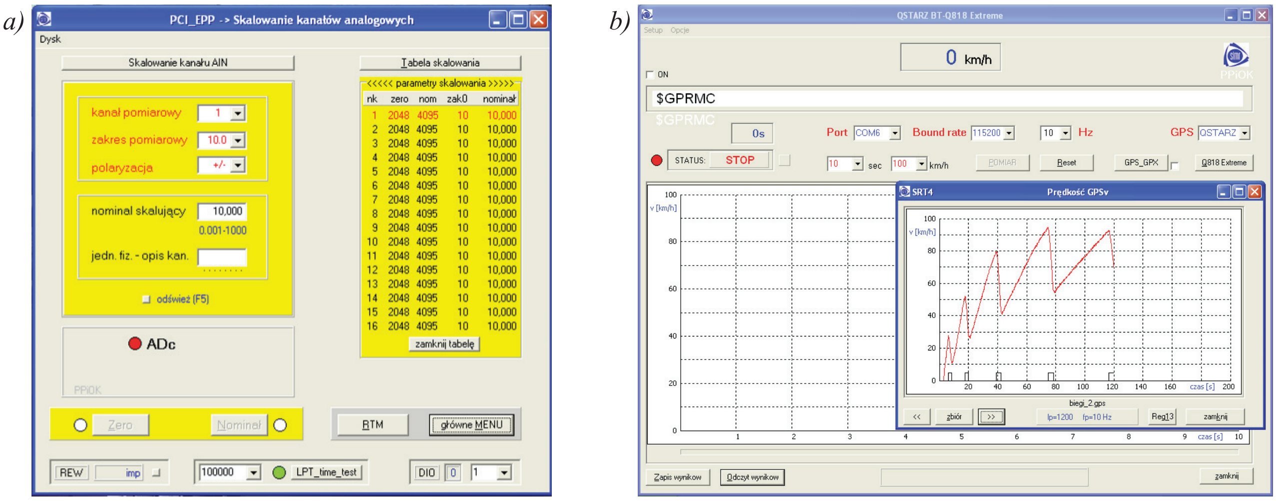

Fig. 2. Management software for PCI_EPP measurement-acquisition: window for analogue signals scaling (a), and window for configuring and observation of velocity from GPS receiver (b)

Figure 3 shows exemplary course of automobile velocity for brake test and obtained automatically, according to ECE 13 Regulation, values of braking decelerations from equations (1) in relation to time and (2) to road.

$$a_t = \frac{V_{80} - V_{10}}{\Delta t}, \tag{1}$$

$$a_s = \frac{V_{80}^2 - V_{10}^2}{2 s_{80-10}}, \tag{2}$$

where:
V_{80} – value of velocity equal to 80% of initial braking velocity V_{bra},
V_{10} – value of velocity equal to 10% of initial braking velocity V_{bra},
Δt – period of time between velocities V_{80} and V_{10},
s_{80-10} – distance covered between velocities V_{80} and V_{10}.

Tab. 1. Values of braking decelerations obtained during the attempts of braking (measurements only by GPS receiver)

Attempt No.	V_0 [km/h]	a_t [m/s^2]	a_s [m/s^2]
1	87	5.6	5.3
2	83	5.0	4.7
3	68	5.6	5.4
4	81	5.1	5.0
6	78	4.8	4.8
7	81	5.4	5.4
8	79	3.3	3.4
9	79	5.5	5.1
10	80	5.8	5.4
11	77	3.4	3.6
12	74	5.6	5.3
13	76	5.6	5.3
14	79	5.3	4.9
15	76	5.1	4.9
16	80	5.3	5.0

a) b)

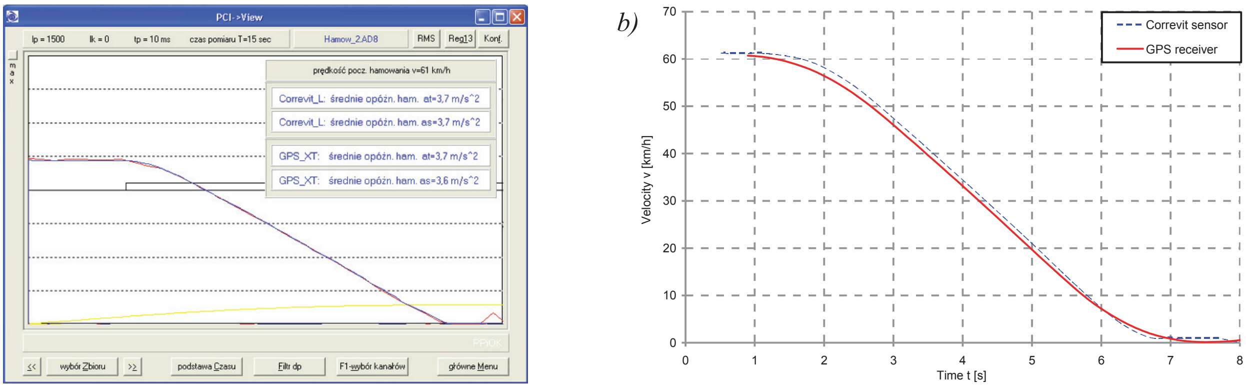

Fig. 3. Results of recording automobile velocity during braking test (measurements using Correvit-L sensor and GPS receiver): window of oscillogram with exemplary course of automobile velocity recorded during the attempt of braking (a), and comparison of automobile velocity in time domain during the attempt of braking (b)

Figure 3a presents the oscillogram of automobile velocity and automatically obtained, according to ECE 13 Regulation, values of braking decelerations. Also the marking of brake pedal pressed, necessary in case of research procedure according to ECE 13 Regulation can be seen.

In Figure 3b to compare are presented the courses of automobile velocity in time domain measured by Correvit-L sensor and GPS receiver.

4.2. The attempt of accelerating

The attempt of accelerating was based on increasing velocity of automobile with acceleration pedal maximally pressed (engine working on external characteristic) on even, horizontal road. On the basis of this test dynamic and accelerations characteristics are obtained.

This road test was also based on accelerating through the gears. Intentionally before changing each of the gears the short braking was taking place, that made it possible to cover as high range of velocity on each gear as possible (see Fig. 4). When accelerating, the acceleration pedal was pressed maximally.

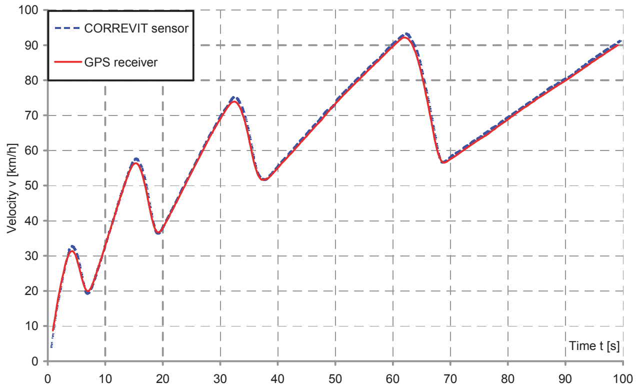

Fig. 4. Courses of automobile velocity in time domain during accelerating through the gears with braking before changing the gear

On the basis of differentiating velocity from Fig. 4, the courses of accelerations as a function of automobile velocity for different gears were made. In Fig. 5 suitably measurement points and approximations (fourth degree polynomials) of these measurements are shown, both for Correvit-L sensor and GPS receiver.

Similarily to the accelerations, the results of calculating dynamic coefficient are presented in Fig. 6. Dynamic coefficient was calculated according to equation (3), resulting from the balance of drive force and drag forces.

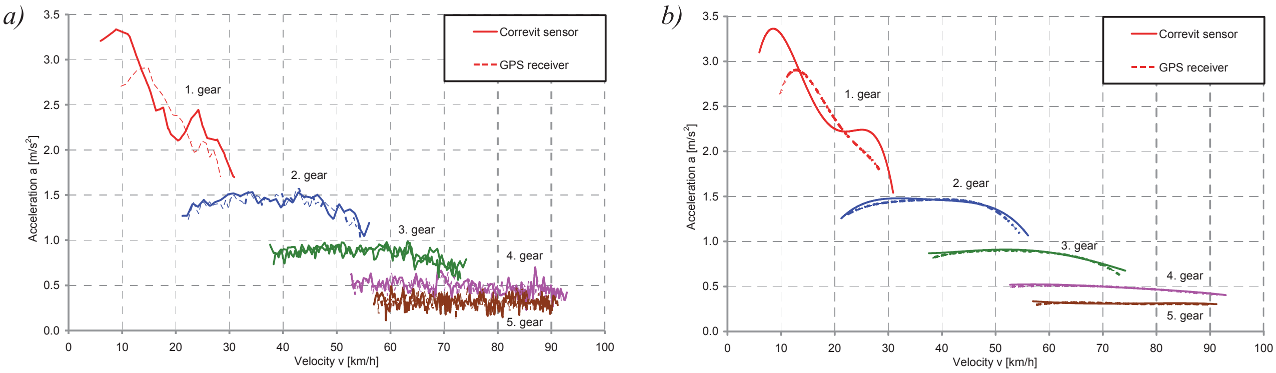

Fig. 5. The courses of accelerations for each of gears: results of the measurements (a), and approximations of the measurements (fourth degree polynomials) (b)

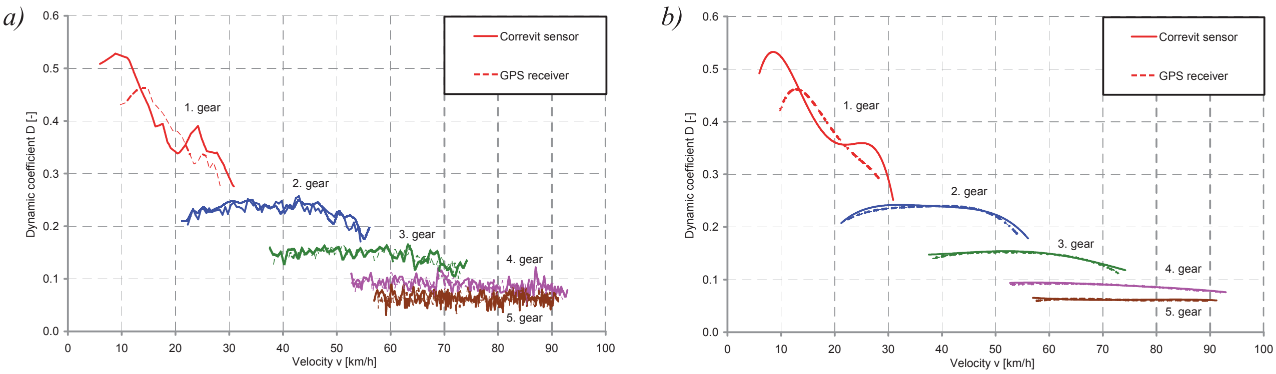

Fig. 6. Dynamic coefficient for each of the gears: results of the measurements (a), and approximations of the measurements (fourth degree polynomials) (b)

$$D = \lambda f_O + \frac{1}{g}\frac{\mathrm{d}v}{\mathrm{d}t}(\lambda + \delta_S i_b^2 + \delta_k)\,, \tag{3}$$

where:

δ_S – coefficient of rotating masses of the engine – $\delta_S = (I_s\, i_g^2\, \eta_m)/(m_c\, r_d^2)$, $\delta_S = 0.05$,

I_s – mass moment of inertia of rotating masses of the engine, $I_s = 0.8$ kg·m^2,

i_g – final gear ratio, $i_g = 4.11$,

i_b – gears ratios, $i_{b1} = 3.89$, $i_{b2} = 2.08$, $i_{b3} = 1.34$, $i_{b4} = 1.00$, $i_{b5} = 0.87$,

η_m – mechanical efficiency of the drive transmission, $\eta_m = 0.90$,

r_d – dynamic radius of the tyre, $r_d = 0.314$ m,

δ_k – coefficient of rotating masses of the wheels – $\delta_k = \dfrac{\sum I_k}{m_c r_d^2}$, $\delta_k = 0.02$,

λ – coefficient of automobile load – $\lambda = m / m_c$, $\lambda = 0.78$,

m – bare mass of automobile, $m = 2045$ kg,

m_c – allowable mass of automobile, 2620 kg.

4.3. The attempt of free decelerating

The method of free decelerating used for determining drag coefficients of moving automobile was based on concluding about the values of acting drag forces on the basis of deceleration of the vehicle, caused by the action of these drag forces. The investigations were performed on horizontal, even section of the road. The automobile was accelerated to high velocity and then the drive transmission was disconnected by putting the gear lever in neutral position and then the velocity was recorded as a function of time that made it possible to determine the values of drag coefficients.

Knowing the coefficients of rotating masses of the wheels δ_k related to the real mass of automobile:

$$\delta_k = 1 + \frac{\sum I_k}{m r_d^2}, \tag{4}$$

where:

I_k – mass moment of inertia of the wheel together with rotating elements of the brake, $I_k = 1.05\ \mathrm{kg{\cdot}m^2}$,

m – mass of the automobile, $m = 2045$ kg,

r_d – dynamic radius, $r_d = 0.314$ m,

in accordance to [1, 5. 6] the following equation can be written as below:

$$\frac{\delta_k}{g}\frac{\mathrm{d}v}{\mathrm{d}t} = f_0 + \frac{\rho A c_x}{2 m g} v^2, \tag{5}$$

where:

f_0 – coefficient of rolling drag,

ρ – air density, $\rho = 1.168\ \mathrm{kg/m^3}$,

A – field of the frontal cross section, $A = 4.1\ \mathrm{m^2}$,

c_x – coefficient of air drag.

Figure 7a presents the courses of the velocity measured both by Correvit-L sensor and GPS receiver for free decelerating. Fig. 7b shows the course of the function (5) for recording velocity by Correvit-L sensor and GPS receiver.

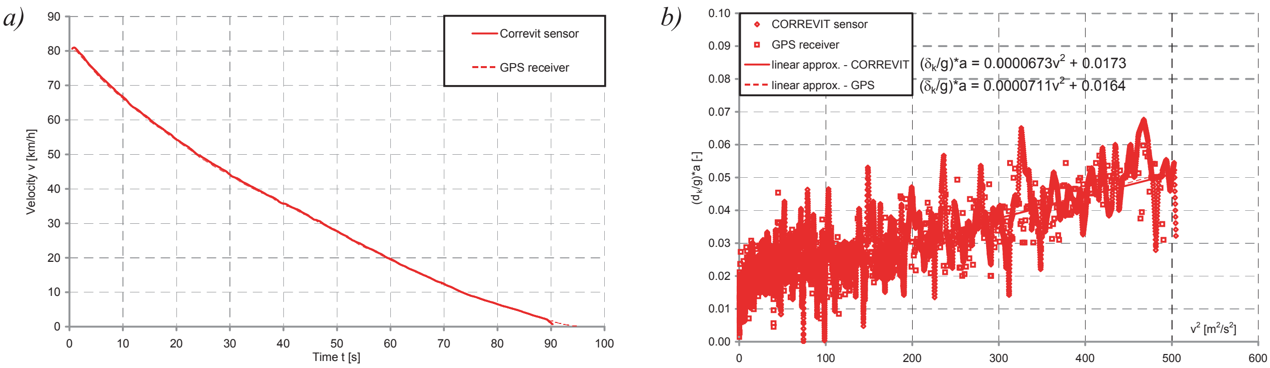

Fig. 7. The attempt of free decelerating: courses of automobile velocity in time domain (a), and supporting chart to determine the coefficients of rolling and air drag (b)

In accordance to the values in the equations of the linear functions, that were approximation functions of the measurements, the following values of air drag and rolling drag coefficients were obtained.

Tab. 2. Values of coefficients of air and rolling drag for the measurements using Correvit-L sensor and GPS receiver

Measurement of velocity	Air drag coefficient, c_x	Rolling drag coefficient, f_0
Correvit-L sensor	0.56	0.017
GPS receiver	0.57	0.017
GPS receiver – the average from three attempts of decelerating	0.54	0.017

5. Conclusions

5.1. The attempt of braking

Obtained results of the research show, that Correvit-L sensor can be substituted by GPS receiver with sampling frequency 10Hz. As Fig. 3 shows, the values of decelerations in relation to time and road can be regarded as practically equal.

5.2. The attempt of acelerating

In case of the attempt of accelerating it can be seen, that the analysis of accelerations or the dynamic coefficient on the first gear would be much difficult in case if the sampling frequency of GPS receiver lower than 10 Hz was applied. For the other gears (from the second to the fifth) can be seen the best agreement of obtained values of accelerations and dynamic coefficients.

5.3. The attempt of free decelerating

Obtained on the basis of the measurement using GPS receiver values of air drag coefficient c_x differ in wider range in comparison to the measurement using Correvit-L sensor, than the values of rolling drag f_0. However, in case of c_x coefficient the difference about 0.03 can be recognized as fully satisfying. In case of f_0 coefficient, its value is practically equal 0.017 both in case of Correvit-L sensor and in case of GPS receiver.

5.4. Problems with recording the velocity from GPS receiver

Recorded values of automobile velocity using GPS receiver can be affected by moving below the high voltage line. This influence is shown in Fig. 8.

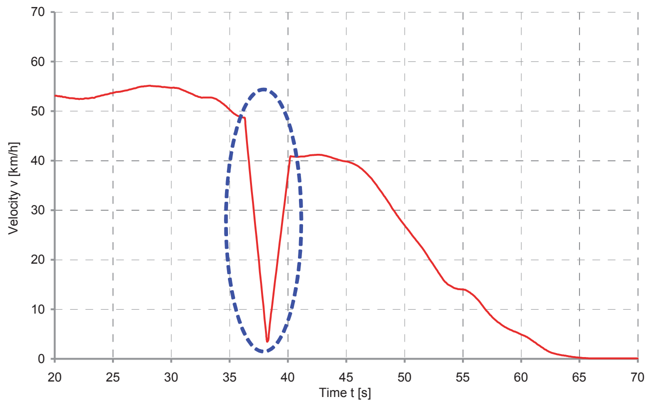

Fig. 8. The influence of moving below high voltage line on the course of the recorded velocity from GPS receiver

Besides this, the disturbances in recording automobile velocity from GPS receiver may occur also during moving below the bridge and on high-urbanized or forested areas.

In a few series of the measurements, there was also a problem of offsetting the signals from Correvit-L sensor and GPS receiver. The reason for this may be from the specifics of saving the data in GPS receiver buffer that is not recognized at all. This problem should be solved soon.

References

[1] Arczyński, S., *Mechanika ruchu samochodu*, Wydawnictwa Naukowo-Techniczne, Warszawa 1994.

[2] Braasch, M. S., van Dierendonck, A. J., *GPS Receiver Architectures and Measurements*, Proceedings of the IEEE, Vol. 87, No. 1, pp. 48–64, New York 1999.
[3] Enge, P. K., *The Global Positioning System: Signals, Measurements and Performance*, International Journal of Wireless Information Networks, Vol. 1, No. 2, pp. 83–105, 1994.
[4] Krzemień, P., Unarski, J., *Wykorzystanie możliwości rejestracyjnych odbiorników GPS w rekonstrukcji wypadków drogowych*, Paragraf na drodze – numer specjalny: Prawne i kryminalistyczne problemy ruchu drogowego, Instytut Ekspertyz Sądowych, pp. 199–219, Kraków 2011.
[5] Orzełowski, S., red., B*adania samochodów – Ćwiczenia laboratoryjne*. Praca zbiorowa, Oficyna Wydawnicza PW, Warszawa 1989.
[6] Orzełowski, S., *Eksperymentalne badania samochodów i ich zespołów*, WKiŁ Warszawa 1995.
[7] Pokorski, J., Bieliński, M., *System pomiarowy do badania stateczności ruchu pojazdu*, Zeszyty Naukowe Instytutu Pojazdów, 4 (51), pp. 17–30, Warszawa 2003.
[8] Technical documentation, *Datron Messtechnik, Correvit R EEP-2, Vehicle and Evaluation Computer, Operating Instructions*.