ISSN 1392 - 1207. MECHANIKA. 2013 Volume 19(5): 600-605

Drive test system to be used on roller dynamometer

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crossref http://dx.doi.org/10.5755/j01.mech.19.5.5542

1. Introduction

Contemporary motor-vehicles are furnished with both spark-ignition and compression ignition engines. The tests on such vehicles are usually carried out on a four-wheel chassis dynamometer. The essence of the dynamometer is the replacement of static driveway with a running track or roller(s) so that the vehicle remains immobilized while the tractive resistances to drive are being simulated [1, 2].

This type of test benches are often located indoors, which makes the test result independent of weather effects.

Modern four wheel chassis dynamometers are furnished with brakes for fluent resistance generation, which enables tests in static and dynamic conditions. The devices enable fuel consumption tests in the conditions of simulated drive and fuel composition measurements. The MAHA LPS 3000 (Fig. 1) is an example of such roller dynamometer.

The LPS 3000 roller dynamometer, in its standard software version, enables the measurement of the engine's power and torque, simulation of load (constants: tractive force, engine speed, cruising velocity), road cruise simulation, determination of engine dynamics, speedometer and odometer control [3].

However, it is not possible to carry out dynamic drive tests in this version and the addition of another module would generate high expenses. Therefore, we have attempted to develop such module ourselves.

Fig. 1 View of vehicle tested on the LPS 3000 MAHA roller dynamometer

2. Drive test specification

The control tests on roller dynamometers now applicable are most frequently made according to the ECE R83 and FTP75 cycles. Fuel consumption and exhaust gas component emissions are determined in this test.

The test cycle pursuant to the ECE 83 regulation [4] is applicable in Europe. It comprises the control drive repeated four times, pursuant to the ECE 15 regulation (Urban Cycle) and the Extra Urban Cycle follows right after.

During the vehicle tests carried out pursuant to the above regulations, the four-wheel chassis dynamometer generates appropriate tangential forces depending on the cruise velocity. The values of such forces are calculated, according to the ECE 83 Regulation. The person carrying out the test tries to maintain the drive speed set according to the run displayed on the computer screen [4].

The continuous recording of selected values, such as: engine power, torque, fuel consumption, etc. is possible during the drive test. The selection of values to be recorded depends on the type of testing apparatus connected to the dynamometer, e.g. fuel flow meter, exhaust gas analyzer.

Regulation ECE 83, in relation to the realization of the driving cycles, recommends using a chassis dynamometer that can reflect the total driving resistance in the speed range from 10 to 120 km/h. If there is no such possibility, other methods of calibration of the absorbed forces during the tests are admitted. The absorbed force is composed of the force absorbed by internal friction and the force absorbed by the power absorber, excluding the differences in the friction of the rollers with and without the vehicle on the chassis dynamometer. The internal friction of the free roller has been omitted.

Another method that is not recommended is rating of the braking distance through a measurement of the absolute pressure in the intake manifold at the speed of 80 km/h (not applicable for diesel engines). The regulation admits a replacement method, in which the coefficient of the load parabola is given for different vehicle masses. This method can be used upon consent of the manufacturer [4].

The chassis dynamometer manufacturers develop their own methods of identification that allow an accurate reflection of the curve of the total driving (rolling) resistance on the dynamometer. Yet, the algorithms are not included in the literature as they are mostly developed at the request of the manufacturer of the chassis dynamometer and these algorithms are included in the control software. The same pertains to the systems that are the topic of the study.

The idea of the solution developed is based on the use of the existing dynamometer for generation of traction resistances and recording particular values. The vehicle's traction resistances are generated by standard dynamometer software described by the expression [3]:

$$F = \frac{W_A}{v_{ref}} + \frac{W_B v}{v_{ref}^2} + \frac{W_c v^2}{v_{ref}^3} + (m - m_{rol})\frac{dv}{dt} + (m\,g\,sin\alpha), \qquad (1)$$

where W_A is constant component of rolling resistances power for reference velocity v_{ref}, W_B is linear component of rolling resistances power for reference velocity v_{ref}, W_C is air resistances power for reference velocity v_{ref}, v_{ref} is reference velocity $(25\,\mathrm{m/s})$, v is vehicle velocity, m is vehicle mass, m_{rol} is dynamometer rollers mass (rollers moment of inertia reduced to translational motion), g is gravitational acceleration, α is elevation angle.

The expression enables the simulation of driving on the road. Stating appropriate values of particular coefficients, we can assure testing conditions that comply with the ECE 83 Regulation.

The particular values of resistances power W are as follows [3]:

$$W_A = \mu_t m g v_{ref}\,; \qquad (2)$$

$$W_B = \mu_w m g v_{ref}\,; \qquad (3)$$

$$W_C = 0.5 \rho c_x A_p v_{ref}^3\,, \qquad (4)$$

where μ_f, μ_w are rolling resistances coefficients, m is vehicle mass, ρ is air density, c_x is head resistance coefficient, A_p is front surface.

The coefficients W_A, W_B, W_C can be determined experimentally while testing the vehicle on the road in coastdown trials or assuming the technical specifications provided by the manufacturer. In the second case the method should be deemed as simplified.

3. Drive testing device

The idea of the dynamic drive testing device has been presented in the block diagram (Fig. 2).

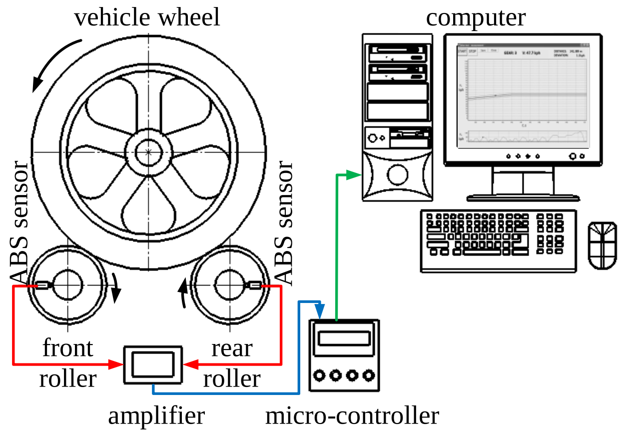

Fig. 2 The idea of drive cycles performance on the four-wheel dynamometer

The device is composed of:

– two ABS sensors;
– signal amplifier;
– measuring system with micro-controller;
– computer with software.

The ABS system sensors were used to determine the rollers rotational velocities. They cooperate with the toothed gears the dynamometer is furnished with (Fig. 3, a). The reinforcing system was made due to the ABS sensor tension characteristics (Fig. 3, b).

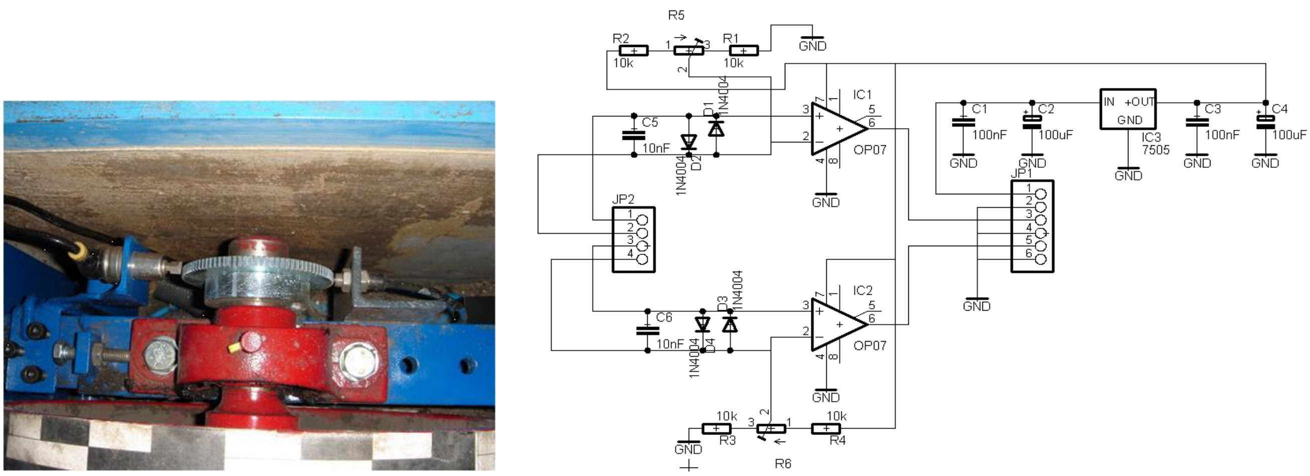

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Fig. 3 View of rotational velocity sensors distribution and amplifier's circuit diagram: a - velocity sensor, b - circuit diagram

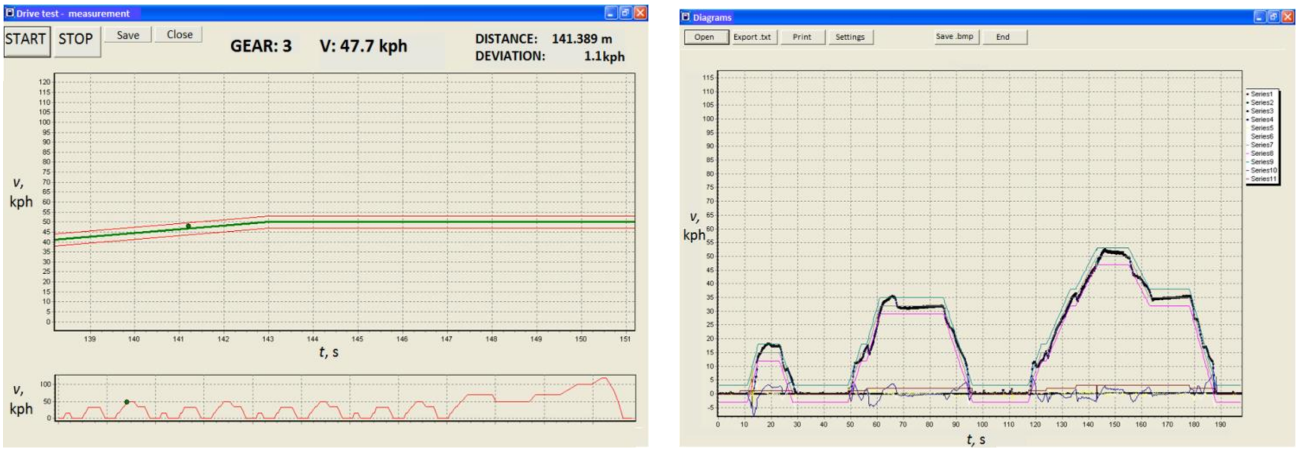

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Fig. 4 Examples of dialog boxes of the system developed: a) the main application window; b) diagrams

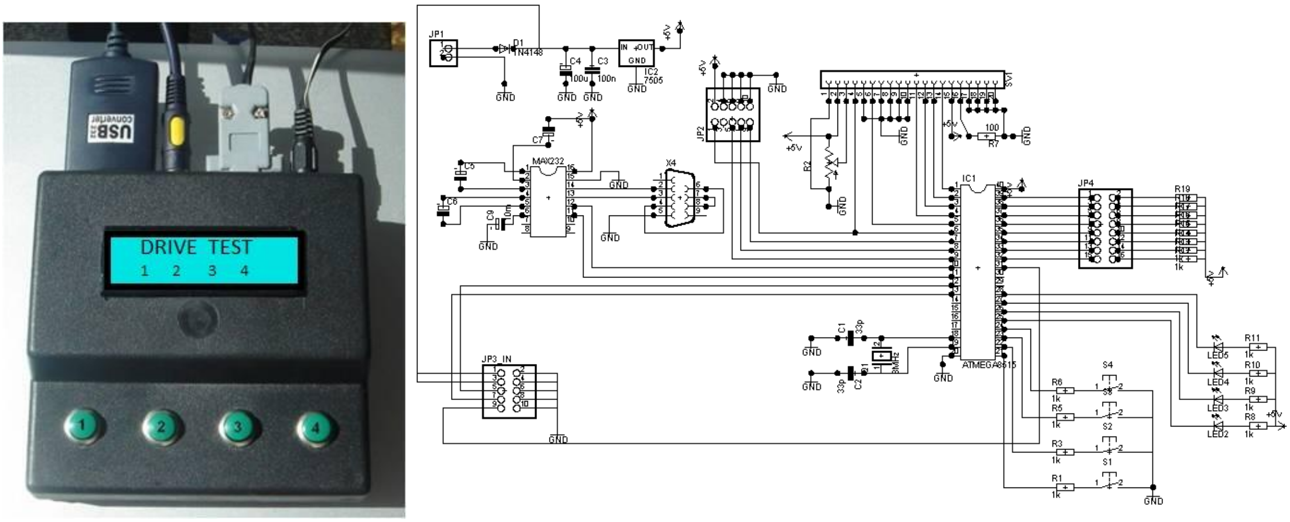

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Fig. 5 View of the micro-controller and the circuit diagram: a) micro-controller; b) circuit diagram

The task of the micro-controller (Fig. 5) is the preliminary processing of signal transmitted from the ABS sensors, i.e. calculation of the distance passed by a given vehicle, its velocity and acceleration [5]. Upon transmitting the questions to the transmitter, the computer receives data on the current parameters of a given vehicle's motion. On the other hand, the computer utilizes the reference dynamic drive test and displays it in the form of a velocity graph. The real velocity obtained from the micro-controller is simultaneously plotted onto the master graph in the form of a point. The driver must "drive" on the dynamometer in such a manner that the point's location fits within the tolerance range (Fig. 4).

The computer system developed allows for the performance of standardized velocity runs and for importing individual ones recorded by means of other software under real traffic conditions.

The communication system with the driver (Fig. 4) displays current prompts which gear should be used in the vehicle at a given moment and the "wandering" point means the velocity scope up to the standardized range. In addition we obtain information on the distance passed and velocity deviation displayed on the screen. In the bottom part of the screen there is the full record of the velocity run of a selected test with a marked point informing on the performance progress. The Delphi programming environment has been used for creating the system [6].

The view of the finished micro-controller and its circuit diagram are presented in Fig. 5.

The micro-controller was based on the AtMega8515 system and programmed in the Bascom AVR system [7].

4. Preliminary tests

The preliminary tests on two vehicles were carried out to assess the usefulness of the system developed. The first vehicle was Seat Cordoba [8]. Due to the Bosch Monomotronic Single Point Injection, it was impossible to apply the fuel flow meter (built-in fuel pressure regulator with overflow tube), therefore, the engine's exhaust gas emissions only were assessed. The other vehicle: BMW E30 [9], was assessed in terms of economic indexes thanks to the Bosch L-Jetronic Multi Point Injection. Table presents the technical characteristics of both vehicles tested.

Table

The technical characteristics of vehicles tested and the coefficients determined based on them, to initiate load modeling by the LPS 3000 MAHA roller dynamometer

Characteristic parameter	Seat Cordoba I 1.6i [8]	BMW E30 320i [9]
Body:	sedan	sedan
- height width l [m]	1.424	1.380
- width b [m]	1.640	1.645
- air resistance coefficient c_x [-]	0.33	0.32
- tire rolling resistance coefficient μ_r [-]	0.015	0.015
- tire rolling resistance coefficient μ_w [-]	0.00	0.00
- admissible vehicle mass m_c [kg]	1511	1580
- unladen mass m_w [kg]	955	1060
- eference mass m [kg] (laden mass increased by a uniform figure of 100 kg)	1055	1160
Engine:	R4, 8V, gasoline	R6, 12V, gasoline
- engine displacement V_s [cm^3]	1598	1990
- max. power N_{max} [kW] / at engine speed n_N [rpm]	55 / 5500	92 / 5800
- max. torque M_{omax} [N·m] at engine speed n_M [rpm]	125 / 2600	170 / 4000
- injection system	Monomotronic	L – Jetronic
- fuel-air mixture composition regulation	two-level control process lambda probe	-
Mileage[km]	98000	230000
Year of manufacture	1997	1984
Chassis dynamometer:	LPS 3000 MAHA [3]	
- air density [kg/m^3]	1.1	
- elevation angle [deg]	0	
- dynamometer rollers mass [kg]	200	
- constant component of rolling resistances power W_a [kW]	3.88	4.27
- linear component of rolling resistances power W_b [kW]	0	0
- air resistances power W_c [kW]	6.62	6.24

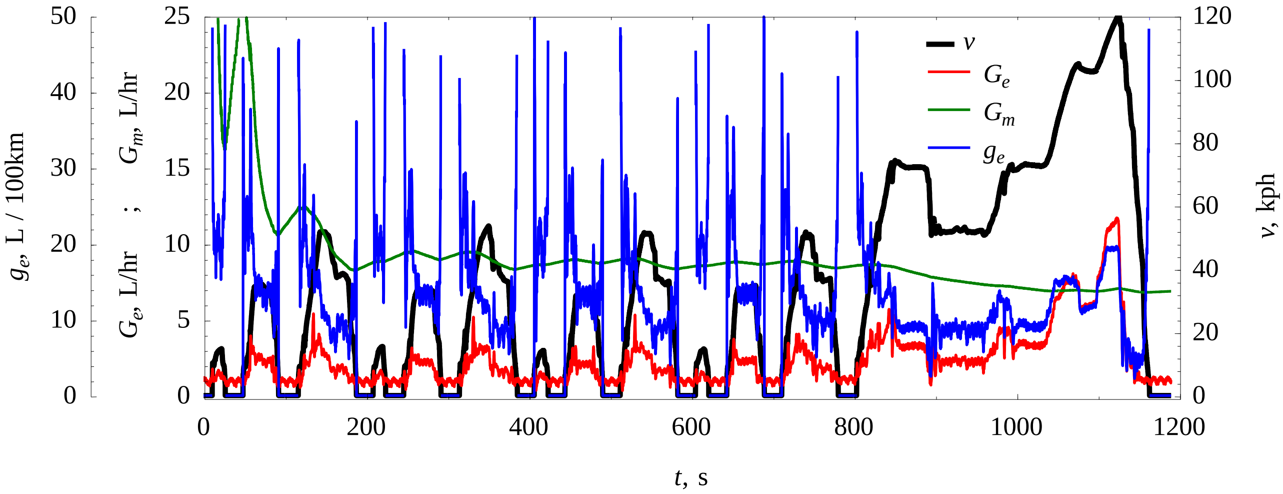
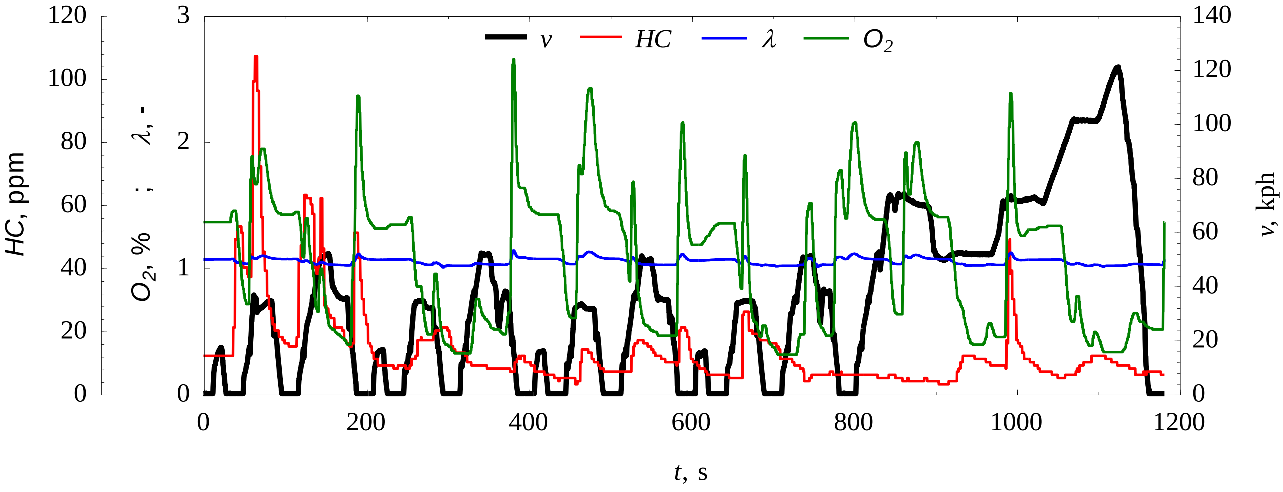


Fig. 6 The economic coefficient runs recorded during the drive test on the dynamometer, with the use of the AIC 1204 HR 2000 fuel flow meter (BMW E30 320i): v - speed, G_e - hourly fuel consumption, G_m - average fuel consumption, g_e - specific fuel consumption

The BMW E30, despite its age (year of manufacture: 1984), and mileage over 230 thousand km, upon the overall summary, consumed in average ca. 7 L/hr (Fig. 6), which should be acknowledged a very good result. It is conspicuous (Fig.6), that in the test of part 4 x ECE 15 the hourly fuel consumption did not exceed 6 L/hr, however in the EDUC part, it goes up to 12 L/hr, even [10]. One should remember, however, that the engine works on the idler gear for more than 30% of the test duration. Upon analysis of the unit fuel consumption , the maximum value observed can reach 40 L/100 km, while the average of the whole test is 6 L/100 km.

A disadvantage of the fuel flow meter used is the application of pressure regulator with constant pressure difference value in its measuring system, which is of crucial importance to the fuelling systems without feedback of the combustion mixture composition regulation (BMW E30) and may affect the fuel consumption and the external indexes of the engine.



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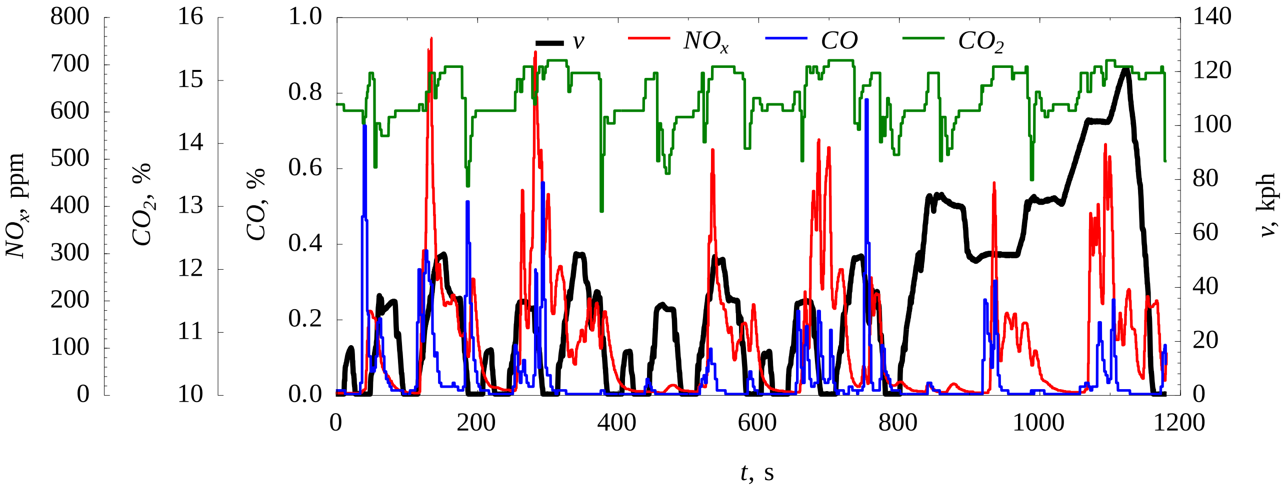

b

Fig. 7 The concentrations of the particular exhaust gas components and the air excess coefficient determined based on them with the use of the MGT 5 MAHA analyzer during the drive test on the dynamometer (Seat Cordoba I 1.6i): a) diagrams: v - speed, HC - hydrocarbons, O_2 - oxygen, λ - air-fuel ratio; b) diagrams: NO_x - nitrogen oxides, CO_2 - carbon dioxide, CO - carbon monoxide

In case of the Seat, as mentioned above, the composition of the exhaust gas emissions was analyzed. The MGT5 analyzer in the four-component version [11], cooperating with the LPS 3000 dynamometer, enabled recording of the concentration of the particular components, as presented in Fig. 7.

It is difficult, however, to compare the results to the manufacturer's data or regulatory requirements as they are defined in g/km, not in % or ppm, like in this case. However, a special exhaust gas dilution system is required (so that the reactions could occur in ambient conditions) together with a weighing system for particular components (measuring bags), although it is not the only method. Upon analysis of the air excess coefficient λ, determined from the concentration of the particular components (Fig. 7), some oscillations above 1 are visible. This may be the result of excessive reduction of the fuel/air ratio or leakage in the exhaust system of the vehicle tested. The leakage occurred in the section between the catalytic converter and the exhaust system, which had no effect on the operation of the oxygen sensor, however, the air "sucked" into the exhaust system could deform the measurement.

The preliminary tests carried out confirmed the correctness of the system developed, enabling the performance of dynamic drive tests on the LPS 3000 dynamometer, competitive to the expensive manufacturer's software.

During the tests on the LPS 3000 MAHA roller dynamometer, however, certain deficiencies were observed in the dynamometer's operation during the drive tests. The focus on the power transmission system load only during the test brings about the necessity to correct velocity through the change of engine admission extent on the one hand and the use of the brake system, on the other. Therefore, carrying out drive tests on four wheel chassis load dynamometers is burdened with a certain error. This is due to the fact that there is no simulation of the vehicle inertia in motion, which is possible on the so-called industrial engine test houses. The simulation of the car's inertia during a short switch of the brake's operation from the position "generator" to the position "engine" is possible in such test houses, their cost often exceeding 10 times that of dynamometers. This kind of engine test houses, however, is part of the equipment of automotive corporations and companies dealing in the homologation and vehicle tests, including without limitation ITS, TUV, DEKRA and the scientific research [12-17].

5. Conclusions

1. The suggested device is a supplement to the standard software of the roller dynamometer with low expenses on the purchase of its particular components.

2. The software developed enables the performance of standardized drive tests and the performance of customized velocity profiles.

3. The run research of the fuel consumption showed the average value on the level 7 L/hr, which should be acknowledged as a very good result (BMW E30, 1984, mileage over 230 thousand km).

4. The exhaust gases composition measurement (Seat Cordoba I, 1997, mileage 98 thousand km) showed just an instantaneous increased nitrous oxides emission, to what the two-level control process lambda probe contributed.

5. The low fuel consumption value, so as the level of the exhaust gas components emission, are the result of driving in most part of the test (ca. 70%) at a low speed on a high gear.

6. The showed measuring system by using adequate software can be applied in chassis dynamometer to inert mode of power measurement.

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RITININIO DINAMOMETRO TAIKYMAS AUTOMOBILIO BANDYMAMS

R e z i u m ė

Straipsnyje aprašoma įrenginio, leidžiančio atlikti automobilio dinaminius važiavimo bandymus naudojant ritininį dinamometrą. Sukurta sistema leidžia atlikti standartizuotus ir norimo greičio bandymus. Išmetimo dujų analizatoriaus ir degalų tekėjimo matuoklio kartu su ritininiu dinamometru panaudojimas leido įvertinti degių dujų sudėtį bei degalų sąnaudas esant tam tikroms bandymų sąlygoms.

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DRIVE TEST SYSTEM TO BE USED ON ROLLER DYNAMOMETER

S u m m a r y

The paper presents the concept of a device enabling the performance of dynamic drive tests on the roller dynamometer. The system developed enables the performance of standardized tests as well as individual speed tests. The use of the exhaust gas analyzer and the fuel flow meter, with the roller dynamometer, allowed for the assessment of fuel gas components as well as the fuel consumption of a selected drive test configuration.

Keywords: roller dynamometer, internal combustion engine, drive tests.

Received October 10, 2012
Accepted October 10, 2013