ISSN 1392 - 1207. MECHANIKA. 2014 Volume 20(1): 108-112

The motion storage characteristics as the indicator of stability of internal combustion engine - receiver cooperation

D. Szpica*, J. Piwnik, M. Sidorowicz*****
**Bialystok University of Technology, Wiejska Str. 45C, 15-351 Bialystok, Poland, E-mail: dszpica@pb.edu.pl*
***Bialystok University of Technology, Wiejska Str. 45C, 15-351 Bialystok, Poland, E-mail: pivnic@pb.edu.pl*
****Bialystok University of Technology, Wiejska Str. 45C, 15-351 Bialystok, Poland, E-mail: macieks3@gmail.com*

crossref http://dx.doi.org/10.5755/j01.mech.20.1.6592

1. Introduction

The basic problem of the diagnosing process of operation state of drive sources, which are internal combustion engines, is to assume such diagnostic parameter or indicator, which can let the exact clarification of the stable work range and unstable work range. It is worth emphasising, that the internal combustion engine generates the torque at specified rotational speed, at given load. The representation of abilities of engine - receiver cooperation are individual torque values T_i and corresponding to them angular speeds ω_i (rotational n_i), from which it is able to designate the power of the engine P_i, kW at required points Eq. (1).

$$P_i = T_i \omega_i \; ; \; P_i = T_i 2\pi n_i \; . \qquad (1)$$

Having the power values, or torque, and hence the engine characteristics, it is hard to clearly estimate the correctness of the engine - receiver cooperation.

In final stage, the engine characteristics (external), given by measurement e.g. on the chassis dynamometer, can be the base to vehicle tractional characteristics designation (Fig. 1).

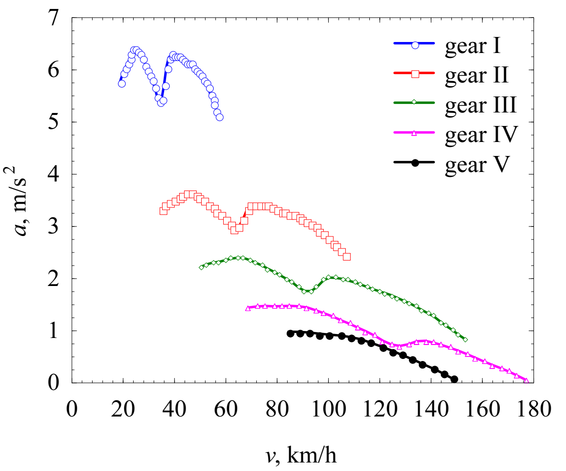

Fig. 1 Sample calculation tractional characteristics of the vehicle with LPG powered engine: *a* - acceleration, *v* - speed

As can be seen in Fig. 1, due to fluctuations of the torque generated by the engine, the vehicle dynamics is largely unstable. For now, the lack of the unambiguous coefficients characterizing the specific estimation of engine - receiver cooperation is occurred.

2. Basic parameters and coefficients of internal combustion engine

In the case of indicators such as power, torque, rotational speed, fuel consumption and exhaust gas composition, their estimation and compliance with values declared by manufacturer, or required by homologation regulations, concern mostly some ranges, largely only chosen points on the characteristics designated in research process.

The other indicator showing the vehicle tractive and operational abilities is elasticity coefficient E (Eq. (2)), which is the factor of the torque elasticity e_M and rotational speed elasticity (range) e_n [1]. In general case it shows the capability of adaptation to variable loads and rotational speeds.

$$E = e_M e_n = \frac{T_{max}}{T_{P\,max}} \frac{n_{P\,max}}{n_{M\,max}}, \qquad (2)$$

where T_{max} is maximum torque value, T_{Pmax} is torque value at maximum power, n_{Pmax} is rotational speed value at maximum power, n_{Tmax} is rotational speed value at maximum torque (Fig. 2).

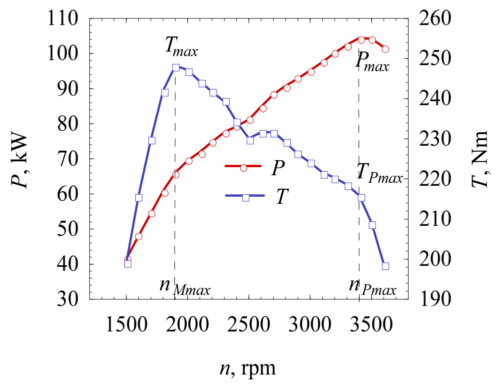

Fig. 2 Sample external characteristics of the Seat Toledo 1.9 TDi engine designated on the load chassis dynamometer ($E = 1.2891 \times 1.8279 = 2.356$)

The elasticity values of the petrol and older type diesel engines are showed in [2], while in [3, 4] there are newer generation engines, also alternatively liquefied petroleum gas (LPG) powered.

The fluctuations of angular (rotational) speed during experiments [5] can be significant parameter. They are result of the uniqueness of the various engine work circulation, characterized by run irregularity coefficient (Eq. (3)). In Fig. 3 there is the histogram of the engine run irregularity.

$$LU_j = \frac{\Delta\varepsilon_j}{\varphi}\,, \qquad (3)$$

where $\Delta\varepsilon_j$ is angular acceleration fluctuations, φ is crankshaft angle of rotation.

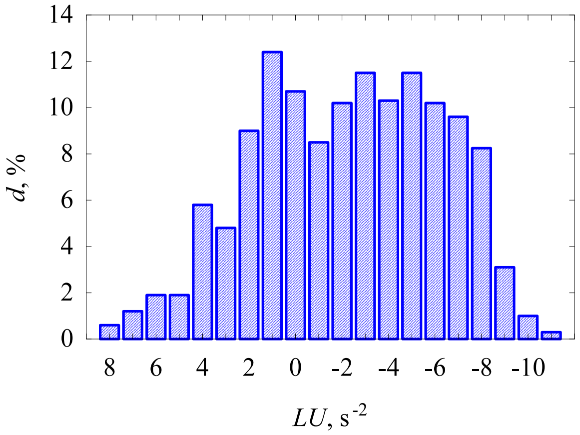

Fig. 3 The histogram of the engine run irregularity: d - distribution [5]

During whole vehicle consideration the acceleration times on various gears are designated, e.g. on IV gear from 60 to 100 km/h and on V gear from 80 to 120 km/h (at five-speed gearbox).

Presented in a comp way, selected specific quantities allow the diagnostic estimation of the engine, e.g. basing on the chassis dynamometer study during external characteristics designation. However, it cannot be excactly described, basing on them, the engine - receiver cooperation. That implies the attempt of adaptation the parameter, which is the motion storage characteristics, for purpose of diagnosing the engine - receiver cooperation at specified load and speed conditions.

3. Objects and methodology of the research

As research objects the sample internal combustion engines population representatives were selected, of various power systems: petrol, diesel and LPG. Basic technical data are set in Table 1.

The research was run on load chassis dynamometer with load balancing LPS 3000 Maha (Fig. 4), where the external characteristics were designated, i.e., full powercharacteristics, at full-open throttle, and partial speed characteristics as well. On dynamometer LPS 3000 working in load mode, continuous test, the cycle during the measurement is realized at constant acceleration, rad/s^2 assumption (Eq. (4)).

Fig. 4 Sample vehicle during designation of the external indicators on the LPS 3000 Maha chassis dynamometer

$$\varepsilon = \frac{d\omega}{dt} = const\,. \qquad (4)$$

Sample external characteristics (full power) designated on dynamometer LPS 3000 are presented below (Fig. 5).

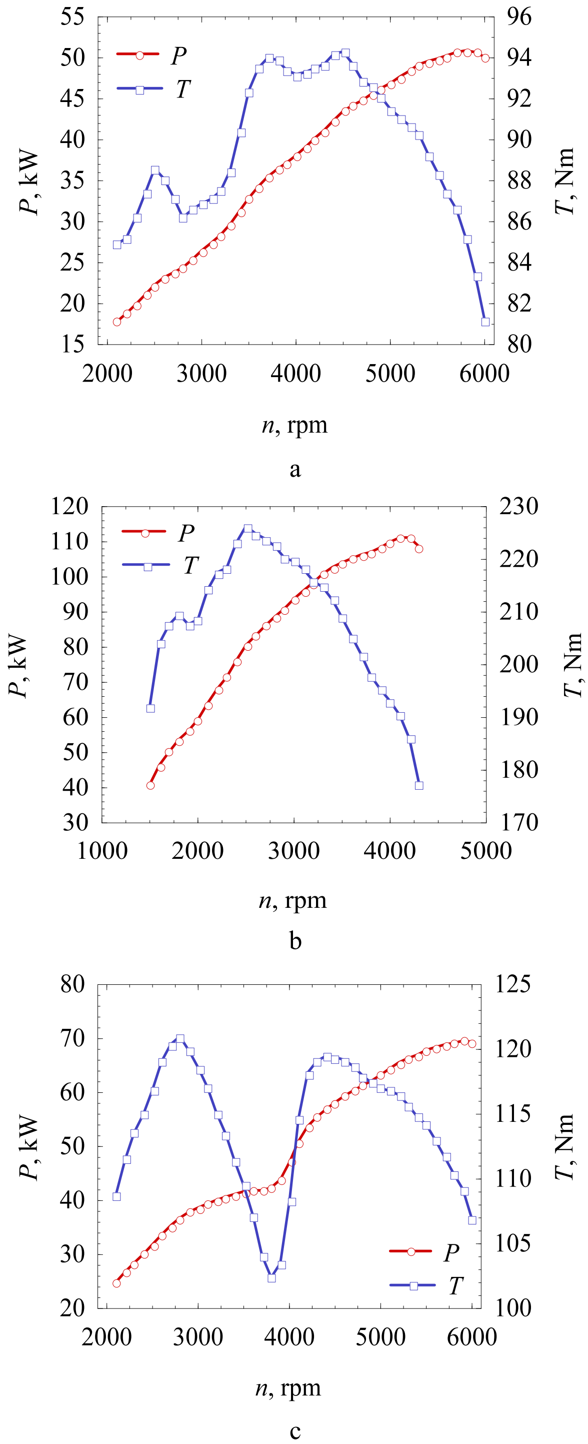

Fig. 5 The external characteristics designated on the LPS 3000 MAHA chassis dynamometer: a) Toyota Yaris 1.0 – petrol powered; b) Skoda Octavia 1.9 TDi –

diesel powered; c) VW Golf II 1.8 16V – LPG powered

Table 1

The setting of the analyzed vehicles and their data

Type model	Toyota Yaris 1.0 [6]	Skoda Octavia 1.9TDi [7]	Volkswagen Golf II 1.8 16V [8]
Displacement	998 cm^3	1896 cm^3	1781 cm^3
Maximum power/ rotational speed	51 kW/ 6000 rpm	82 kW/4150 rpm	102 kW/6100 rpm
Maximum torque/rotational speed	90 Nm/ 4100 rpm	235 Nm/ 1900 rpm	168 Nm/4600 rpm
Power system	multi-point fuel injection	unit injectors	LPG II generation
Charge	-	turbocharged	-
Catalytic converter	+	+	+
Mileage	15000 km	125000 km	280000 km

Designated characteristics are for comparing purpose, basing on them it can be estimated, whether the engine reaches values of such indicators as power and torque at specified speeds according to the manufacturer's declarations.

Basing on characteristics designated in such a way, it is hard to conclude the correctness of the engine – receiver cooperation (in this case – friction force of the braking rolls) throughout the whole range of the rotational speed and load range, which is represented by power and torque values.

4. The motion storage as a diagnostic parameter

The motion storage term, which up to now was used in bipedal human locomotion estimation [9, 10] was decided to be adapted to internal combustion engine conservative evaluation, taking into account the periodicity and complexity degree of processes occurring there, lated to mixture explosion, elements inertia, friction, etc.

In general case, the motion storage characteristics Z_i, kW/s can be defined as the product of instantaneous values of power P_i and corresponding to them rotational speed values n_i (5).

$$Z_i = P_i n_i \; . \tag{5}$$

Setting on one graph (Fig. 6) the dynamometer research results, there are differences visible in motion storage values for specified sorts of power system. This implies that motion storage can distinguish individual vehicle groups, what will be the topic of next stage in research in greater groups representing vehicles population.

The variability of motion storage values in rotational speed function was designated by linear regression (least squares method). In Eq. (6) as significant parameter, which can be the base to conservative analysis of engine, the slope coefficient a was considered.

$$Z_{im} = a n_i + b \; . \tag{6}$$

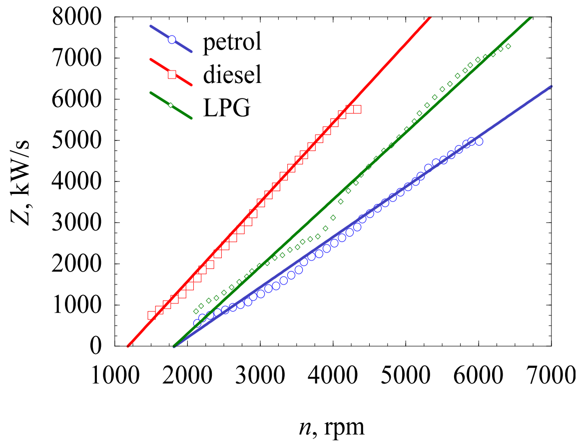

Fig. 6 The motion storage characteristics designated from external characteristics: Toyota Yaris 1.0 – petrol powered ("petrol" index), Skoda Octavia 1.9 TDi – diesel powered ("diesel" index), VW Golf II 1.8 16V – LPG powered ("LPG" index)

Comparing the values of elasticity of studied engines with motion storage characterizing coefficients, a correlation is visible (Table 2). The a coefficient, which states about the motion storage, is responsible for adaptive abilities of the vehicle during acceleration and related to this motion resistance increase. Otherwise, in the case of elasticity, where there are considered abilities to instantaneous load changes (Fig. 1, Eq. (1)), but also the external characteristics must be considered from the maximum power side – on the contrary.

The research showed that the diesel powered vehicle (Table 2) is characterized by the highest value of elasticity coefficient (2.335) and motion storage (115.565). However, the range of the rotational speed limits the field of the usage in relation to petrol and LPG powered engines.

Table 2

The setting of the elasticity calculations results and linear regression coefficients used for evaluation the motion storage for different fuel delivery systems

Sort of power system	Elasticity E	Motion storage		
		Slope a, kW	Regression coefficient $b \times 10^3$, kW/s	Coefficient of determination R^2
Petrol	1.427	73.222	-2.230	0.997

LPG	1.949	97.800	-2.280	0.999
Diesel	2.335	115.565	-2.959	0.994

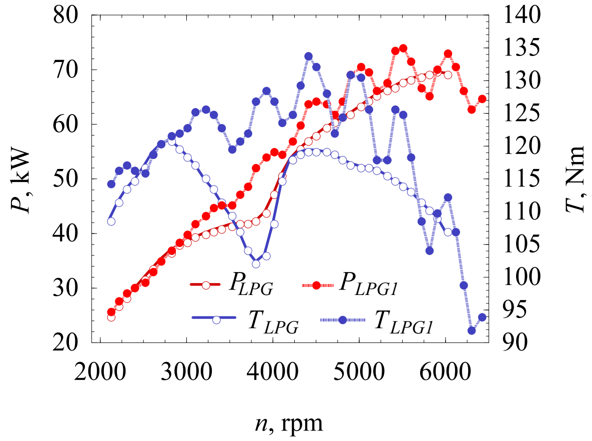

Fig. 7 The external characteristics of the VW Golf II 1.8 16V LPG powered engine, with LPG delivery system adaptation ("LPG" index), without LPG delivery system adaptation ("LPG1" index)

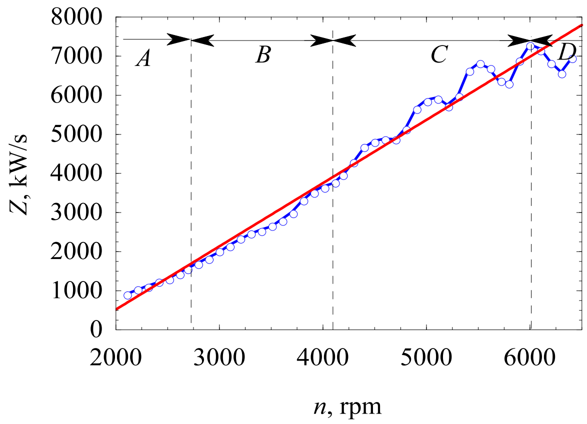

Fig. 8 The motion storage characteristics of the VW Golf II 1.8 16V – LPG powered

Additional tests were run, whose purpose was to show the motion storage characteristics applicability in conservative analysis. In the case of LPG powered engine (Fig. 7), beside the test described in Fig. 6 the additional test was run, i.e. without adaptation of LPG system (instant powering fuel change petrol-LPG and following test of external characteristics designation).

Analyzing the motion storage characteristics presented in Fig. 8 the significant dispersion over the model trend line is visible, which shows improper engine – receiver cooperation. In LPG powered engine motion storage characteristics (Fig. 8) the 3 areas of unstable (of different degrees) cooperation with receiver are visible. The first part (*A*) can be result of the chassis load adaptation in the beginning of the test and its initial regulation. Part *B* is the range of visible differences (instability) resulting in reducing the tractive abilities (jerking, irregular acceleration). Part *C* shows proper cooperation, in next stage in *D* range occurs "break of power", where due to safety considerations the test ends, for fear of power unit damage.

In this aspect it is seeking for capabilities of using motion storage characteristics in reference to engine – receiver cooperation estimation, especially in variable load conditions. It can be necessary to build and correction of special algorithms of engine control, and shows abilities of chassis dynamometer measurement in vehicle operational aspect. Besides the parameters given by manufacturers as

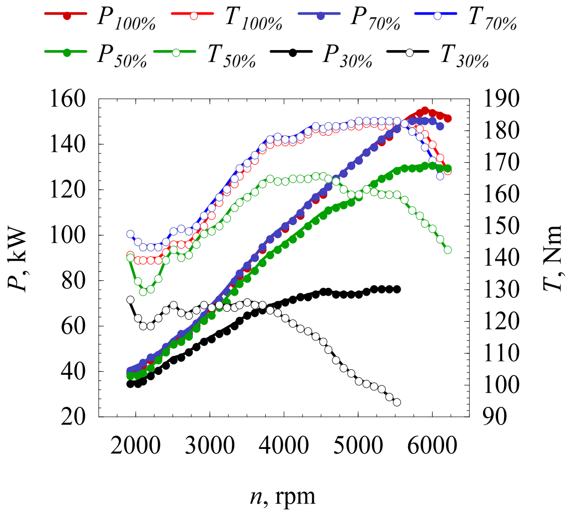

Fig. 9 Partial speed characteristics of BMW E36 vehicle engine (M50B20) at different power degrees (100, 75, 50, 30)%

normative, it can be considered by motion storage about correctness engine – receiver cooperation.

Also attempted to set the elasticity and motion storage coefficients values for simulated operational wear case. For this purpose the following partial speed characteristics were designated for BMW E36 vehicle engine (M50B20) at different power degrees (100, 75, 50, 30)%.

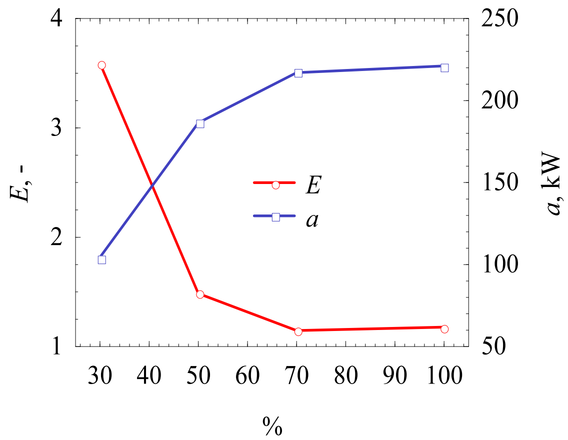

Fig. 10 Comparison of the elasticity and motion reserve coefficients of the BMW E36 vehicle engine (M50B20) at different degrees of powering (100, 75, 50, 30)%

Setting on one graph (Fig. 10) values of elasticity and motion reserve coefficients in simulated operational wear conditions, the diagnostic correctness of the second one was proved. By gradually lowering the powering degree of the engine the *E* values increase, while *a* decrease, so the usage of the *a* coefficient in conservative evaluation of the engine seems to be more reliable.

5. Conclusions

1. Presented method of motion storage characteristics usage in relation to engine – receiver cooperation estimation allowed the initial diagnosis. Basing on this, the sort of fuel powering can be distinguished and also the rotational speed ranges can be indicated, where the disturbance of traction stability can be predicted in vehicle equipped in studied engine. The legitimacy of the designation of the subject characteristics coefficient in evaluation the operational wear degree.

2. The following work will be run for clarification the formula describing the motion storage, because initially the slope was considered as the determinant of tractive abilities of the engine, but the basis of the engine – receiver cooperation evaluation in various load conditions was not defined.

3. The open question is to precise the motion storage parameter value in conservative evaluation of the engine, by inclusion the range over the model trend line. In following research the attempt of approximation the motion storage by additional formula based on coefficients related to the surface state, or uniqueness of internal combustion engines cycles will be run.

References

1. **Myslowski, J.; Koltun, J.** 2000. The Elasticity of the Piston Internal Combustion Engines, WNT. Warsaw. 184 p. (in Polish).
2. **Myslowski, J.** 1988. The Heat Calculations of Car Engines: (Exercise Guide), 2nd edition, Szczecin University of Technology Publishing. Szczecin, 78 p. (in Polish).
3. **Szpica, D.; Czaban, J.** 2010. The evaluation of the external and operational indicators of the LPG-powered engines, Combustion Engines 3: 68-75.
4. **Szpica, D.; Czaban, J.** 2010. The Leidemann dependence and the modern internal combustion engines constructions, Przeglad Mechaniczny 6: 24-29 (in Polish).
5. **Tichy, M.** 1994. The Engine Run Irregularity as input for an Adaptive System of Control System of gasoline engines, Slovak Technical University, Bratislava: 425p. (in German).
6. **Jex, R.M.** 2011. Manual Service and Repair, Toyota Yaris models 1999-2005 (1), WKiL. Warsaw: 26 (in Polish).
7. **Etzold, H-R.** 2010. Manual Repair Car Skoda Octavia, Models 1996-2004, WKiL. Warsaw: 22 (in Polish).
8. **Etzold, H-R.** 2012. Volkswagen Golf II i Jetta IX 1983 - VI 1992 (2), WKiL. Warsaw: 12 (in Polish).
9. **Jaworek, K.; Piwnik, J.** 2010. Locomotion description in biomass transport of a man into consideration of motion frequency, II International Scientific Conference: Transport Problems 2010, Silesia University of Technology Publishing, Katowice: 11-45.
10. **Jaworek, K.P.; Piwnik, J.; Patejuk, A.; Glebocki, M.** 2008. The storage-metric method of the multistepper bipedal man locomotion evaluation, Aparatura Badawcza i Dydaktyczna, No 1. COBRABID Publishing, Poznan: 11-12 (in Polish).

D. Szpica, J. Piwnik, M. Sidorowicz

VIDAUS DEGIMO, VARIKLIO SĄVEIKAUJANČIO SU APKROVIMO IR REGISTRAVIMO ĮRENGINIU, STABILUMO ĮVERTINIMAS PAGAL JO GALIOS GREITINĘ CHARAKTERISTIKĄ

R e z i u m ė

Straipsnyje aprašomas vidaus variklio, sąveikaujančio su apkrovimo ir registravimo įrenginiu, stabilumo vertinimas pagal jo galios greitinę charakteristiką. Remdamiesi važiuoklės dinamometro, pritaikyto įvairių galių jėgos sistemoms, išorinėmis charakteristikomis pabandyta pritaikyti pasiūlytąjį vertinimą. Pradinė analizė parodė, kad aptartos charakteristikos ypač naudingos išplėstą adaptacijos ciklą turintiems LPG (*liquefied petroleum gas* – suskystintosios dujos) varikliams. Be to, taikant tarpines greičio charakteristikas ir skirtingas variklio apkrovas, kurios imitavo eksploatacinį nusidėvėjimą, buvo nustatytos jo darbo stabilumo svarbiausios charakteristikos ir elastingumo koeficientas. Tai parodė, kad galios greitinės charakteristikos analizė yra tinkamas vertinimo kriterijus, jo kreivės nuolydis leido nustatyti variklio energinius parametrus, o kita vertus, įvertinti jo ir apkrovimo ir registravimo įrenginio sąveikos stabilumą.

D. Szpica, J. Piwnik, M. Sidorowicz

THE MOTION STORAGE CHARACTERISTICS AS THE INDICATOR OF STABILITY OF INTERNAL COMBUSTION ENGINE - RECEIVER COOPERATION

S u m m a r y

In the article the attempt of using the motion storage characteristics was showed, to estimation of internal combustion engine - receiver cooperation. Basing on the external characteristics designated on chassis dynamometer, for various variants of power systems, it was tried to apply for applicability of proposed indicator. Initial analysis confirmed the usefulness of subjected characteristics, especially in the case of alternatively powered by LPG engines with extended adaptation cycle. Additionally, by using partial speed characteristics of the engine by various power degree, which simulated degrees of operational wear, the significant parameter of the motion storage characteristics was set with commonly used in engine - receiver analysis parameter, which is elasticity coefficient. The setting showed the legitimacy of designation the motion storage characteristics, whose the slope lets on one hand to evaluate the energetic parameters, on the other hand - to assess the engine - receiver cooperation stability.

Keywords: internal combustion engine, characteristics, motion storage.

Received February 20, 2013
Accepted January 21, 2014