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The analysis of diagnostics possibilities of the Dual- Drive electric power steering system using diagnostics scanner and computer method

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Abstract. The article presents the analysis of diagnostics possibilities of electric power steering system using computer diagnostics scanner. Several testing attempts were performed. There were analyzed the changes of torque moment exerted on steering wheel by the driver and the changes of the angle of rotation steering wheel accompanying them. The tests were conducted in variable conditions comprising wheel load and the friction coefficient of tyre road interaction. Obtained results enabled the analysis of the influence of changeable operations conditions, possible to acquire in diagnostics scanners of chosen parameters of electric power steering system. Moreover, simulation model of operation, electric drive power steering system with the use of the Matlab simulation software was created. The results of the measurements obtained in road conditions served to verify this model. Subsequently, model response to inputs change of the device was analyzed and its reaction to various constructional and exploitative parameters was checked. The entirety of conducted work constitutes a step to create a diagnostic monitor possible to use in self-diagnosis of electric power steering system.

1. Introduction

Power steering system is at present used in all vehicle size classes. The aim of its use is to diminish the torque, the driver needs to turn the steering wheel in order to do a desirable maneuver. In some trucks, the application of the steering systems is enforced by legal regulations.

Hydraulic and electric power steering system solutions used contemporarily ensure the change of the value of steering feedback torque, what is particularly desirable during maneuvering at small travel speed and especially while parking the vehicle.

However, in some road situations the change of the level of vehicle steering effort tends to be seen negatively by the driver. Subjective feelings of the driver are of vital significance here, since based on them and the driver's earlier experience, they are able to predict the behavior of the driven vehicle in response to the steering wheel movements planned by them. At present, one can see increasingly stronger tendencies to broader use of electric power steering systems and moving from hydraulic power steering. That is why, with regard to the increasing number of vehicles with electric systems, the issues associated with the possibilities of proper diagnostics of work of these devices take on significance. In the paper, the attempt was undertaken to analyze the range of diagnostics possibilities of electric power steering system using computer diagnostics scanner. It was also evaluated how

changeable operational conditions can influence the parameters of electric power steering system obtained in car diagnostic scanner.

2. Electric power steering systems

Electric power steering systems have a lot of advantages. They are characterized by considerably smaller demand for power consumption in comparison to hydraulic power steering system and they are also smaller in size. The systems can lower steering wheel torque and improve the returnability [1,2,3]. These assets of electric power steering systems are the reason why they are used in almost all contemporary motor vehicles. Electric power steering systems began to be introduced to motor vehicles in the 90-s of the last century. Since then, they have been the subject of many studies and theoretical research papers. In systems of this type, electric motor is used, creating necessary torque and ipso facto fulfilling supporting functions [4,5,6]. The torque, the driver turns the steering wheel is registered by the torque sensor. On this basis, taking signals also from other sensors into account, assisting force is calculated, what in turn constitutes the basis for proper regulation of the current supplying the assistance motor [7,8,9,10]. In addition, one should notice that the steering stiffness resulting from the stiffness of the elements fixing the electric power steering device to the steering column has the influence on car steerability [10,11].

3. Driving and steering the vehicle

Both the driver's comfort and their safety depend on the operation and the regulation of controlling the steering system assistance. While running the vehicle, the driver bases the decisions taken by them on the steering feel, that is why, the degree this feel is considered will decide on the further acting strategy [11]. Thus, the operation of the steering system decides on the driver's feelings [12]. Some authors [11] are inclined to assume that the steering feel depends only on the steering wheel torque. Also in the publication [13], the authors indicated the torque on the steering wheel and steering wheel rotation angle as factors which are most clearly felt by the driver, therefore they are the most significant stimuli from the point of view of the steering feel. There are various ways of influence the steering feel. This can be the choice of shifting the steering gear, change of the length of the steering arm or change of the diameter of the steering wheel [14].

The steering torque is associated with steering effort [2,3,12]. Friction between tire surface and ground influences the steering wheel torque. The intensity of this influence depends on the concrete solution of constructional steering system [15]. During parking manoeuver or turning back, higher values of shifting in the steering system are beneficial. The value of steering effort is influenced by the type of tires, their stiffness coefficient and the tire pressure. It is assumed, that two factors influence in the most significant way the subjective evaluation of the facility of running the vehicle. Namely, the steering effort or steering wheel torque and the time of vehicle reaction to the steering wheel. Beneficial steering feel influences the reassurance of safe and convenient driving comfort [6,17,21].

The dependence of the vehicle reaction in the form of vehicle yaw rate and its lateral acceleration in response to the action of the driver expressed with the change of steering wheel rotation angle and the speed of this change has to be predictable for the driver and should not undergo too violent hesitations. Only then, the driver has the feeling of full control over the vehicle [18,19,22,23].

4. Experimental procedure

On the first stage of the experimental analysis, the essential torque applied by the driver of the vehicle during turns of the steering wheel to the right and left side range was determined. It was made in a maximum range, possible to attain for steering system construction reasons. The manoeuver was performed three times. In turn, with power steering system turned off and subsequently on both levels of reinforcement – i.e. in normal mode and 'city' mode. The measurement was made on dry asphalt surface. The courses of the changes of the steering wheel rotation angle and the torque obtained from diagnostic tester were juxtaposed in figure 1.

As one can observe from the obtained courses during the manoeuvers performed with power steering system turned off, the maximum registered torque applied by the driver exceeded 28 Nm. This value was achieved very quickly after starting the manoeuver and maintained during it, despite increasing the angle of wheel turn. This is a maximum value, possible to be read from system control unit by SolusPro tester. With power assistance steering system turned off, the total steering wheel torque required to realize a specific turn is applied by the driver. With power steering system turned on, based on the torque measured on the torsion bar, control unit of the system controls the torque of the electric motor, supporting the movement of the wheels of the vehicle. The torque of the electric motor is transmitted to the lower part of the torsion bar, allowing to diminish the torque on the steering column, resulting from the turn of the steering wheel. The torque recorded by the tester is lower. The controlled torque of the electric motor is higher for the city mode. Only after reaching the extreme angular position of vehicle wheels one can observe the increase of the torque on the steering wheel.
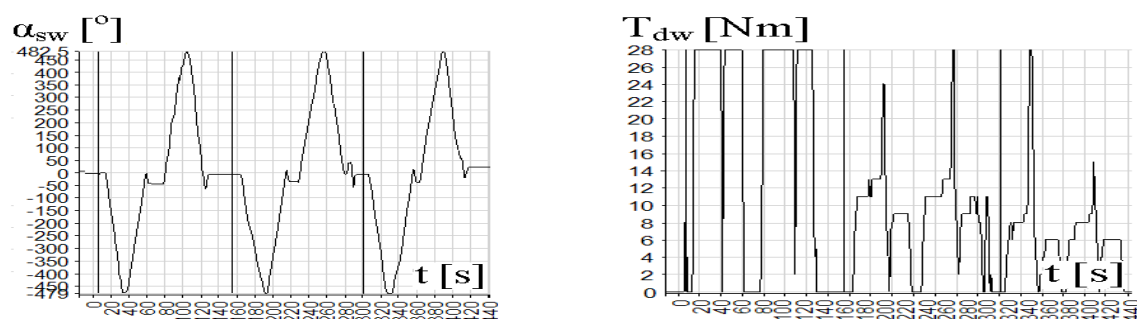

Figure 1. The course of the changes of the torque on the steering wheel during turns to the right and left on dry asphalt.

This can be seen on both modes i.e. normal mode and city mode. The controlled level of the assistance of the power steering system is corrected with the signal from the torsion bar. The torque on the rotor of electric motor helps to obtain the angle of wheel turn indispensable to perform a manoeuver. The torque on the wheels constitutes the sum of the components of the electric motor torque and the one applied by the driver. On the presented diagram we can observe the course of the changes of the torque on the steering wheel. It is of vital significance from the point of view of the rate of the realization of driver's intentions. As one can observe, after turning on city mode, the torque is diminished by about 5 Nm.
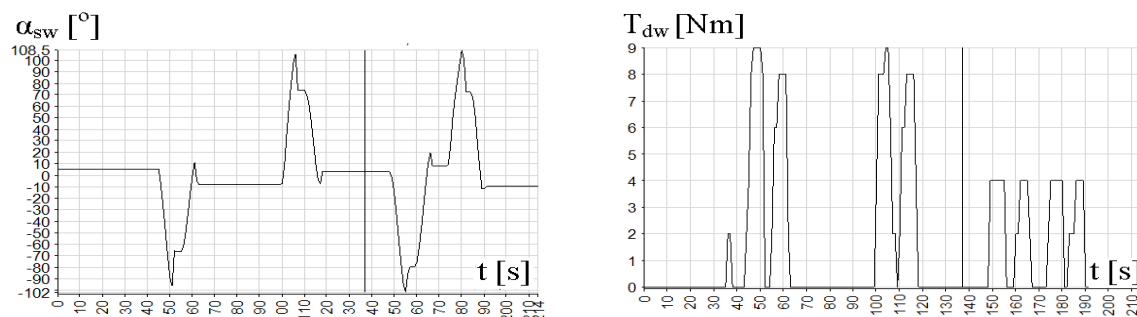

Figure 2. The changes of the torque on the steering wheel during turns to the right and left, manoeuvers performed on the asphalt covered with 5 cm fresh snow.

In order to evaluate the friction between tire surface and ground, tests were carried out on the asphalt covered with the layer of 5 cm of snow. Figure 2 shows the courses of the torque on the steering wheel

registered on the diagnostic tester. The following manoeuvers were performed: turn left, the return of the wheels to straight – ahead position, turn right, the return of the wheels to straight-ahead position. With the aim of precise determination of the influence of the conditions of interaction of the wheel with snowy surface, the test was repeated many times. Power steering system efficiency was compared on both levels of reinforcement i.e. normal mode and in "city" mode, which is characterized by higher assistance.

In real operating conditions, flexibility of suspension and the steering system as well as the coefficient of friction between tire surface and the ground affect the efficiency of control of the electric motor in the power steering system. In the analysed case, the highest attainable value of the torque amounted to 9 Nm. It was achieved during the phase of the steady turn of the wheels. The increase of the torque on the registered course is steep. This is why at every moment during the manoeuver, an optimal assistance of power steering system has to be ensured. The difference between "city" mode and normal one in the assistance torque, which can be seen in the figure 2 amounted to about 5 Nm i.e. about 50 %.

An analogous test, as described above was also made on wet asphalt. The obtained courses of the torque on the steering wheel were shown in figure 3. In comparison to the manoeuvers performed on snow, one can notice that the values of the torque are in this case higher by about 2 Nm, both in normal mode and in "city" mode.
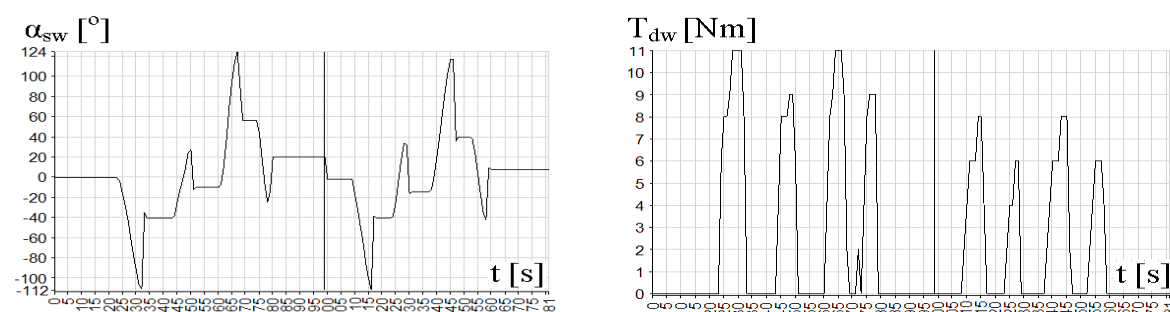

Figure 3. The changes of the torque on the steering wheel during turns to the right, left, manoeuvers performed on wet asphalt.

In order to check the reaction of the control unit of electric power steering system on any changes of the state of contact of the vehicle wheel with the surface, manoeuvers with the wheels were performed with changing the front axle load. The courses of the torque on the steering wheel with the load on the front axle of 7200 N, obtained in the tests were shown in figure 4, whereas the figure 5 shows the changes of the torque on the steering wheel with the load on the front axle of 4100 N. Comparing these courses one can notice that unloading the steering wheels of the vehicle influences considerably the resistance of the friction between tire and ground, what in turn decides on the torque on the steering wheel. This is visible with power steering system turned off. However, in such case, the level of controlling the assistance of power steering is only slight changed. We can observe this comparing the course of the torque both in normal mode and in city mode. The torque on the steering wheel changes maximally by 1 Nm with power steering system turned on.
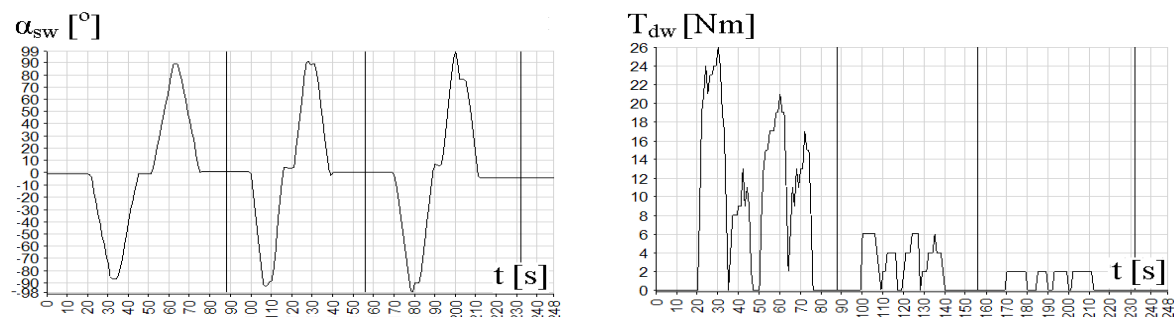
Figure 4. The changes of the torque on the steering wheel during turn right, left, manoeuvers performed with loading the front axle with 7200 N, subsequent manoeuvers were performed: with power steering system turned off, normal mode and city mode.
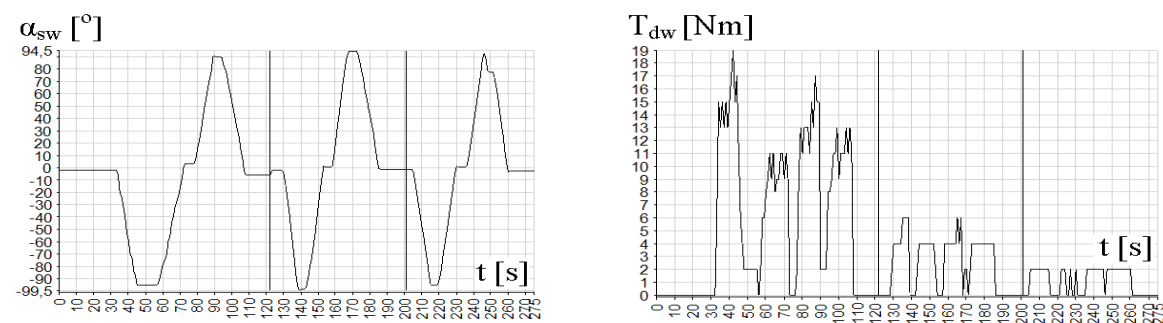

Figure 5. The changes of the torque on the steering wheel during turn right, left, manoeuvers performed with loading the front axle with 4100 N, subsequent manoeuvers were performed: with power steering system turned off, normal mode and "city" mode.

Apart from the manoeuvers described above, test rides were carried out on the same short section of asphalt surface at two various speeds. During each of these rides, manoeuver of the turn by 90° was performed twice. In given drive conditions, the test was made with normal mode and in "city" mode. The courses of the changes of the turning angle and the torque on the steering wheel during the ride on dry asphalt surface were presented in figure 6. On the basis of the obtained course of the change of the angle of turning the steering wheel versus time, one can single out particular phases of the test ride, i.e. starting to turn, then the return to straight drive and subsequently rapid turn.

In the phase of starting to turn, the torque on the steering wheel reached 10 Nm. During starting the second turn, the correction of the running track is visible, which was followed by a maximum turn of the wheels. From here, the change of the torque on the steering wheel is visible preceded by the achievement of extreme position. In case of "city" mode on the same ride route with analogous speeds, the torque on the steering wheel was about 40% lower.

Test rides, described above with the turns of the vehicle by 90° were repeated on the asphalt covered with snow. In case of these rides, the values of the torque on the steering wheel were slightly higher and reached from 8 to 10 Nm. However, in this case, higher range of the fluctuations of the torque was observed what could be the consequence of the changes of the resistance of rolling resulting from the presence of snow cap, over which the wheels were rolling. On the one hand, the coefficient of friction between the wheel and compacted snow was lower than on dry asphalt, on the other hand, as it was mentioned; the snow layer could be the cause of the increase of the rolling resistance of straight rolling.
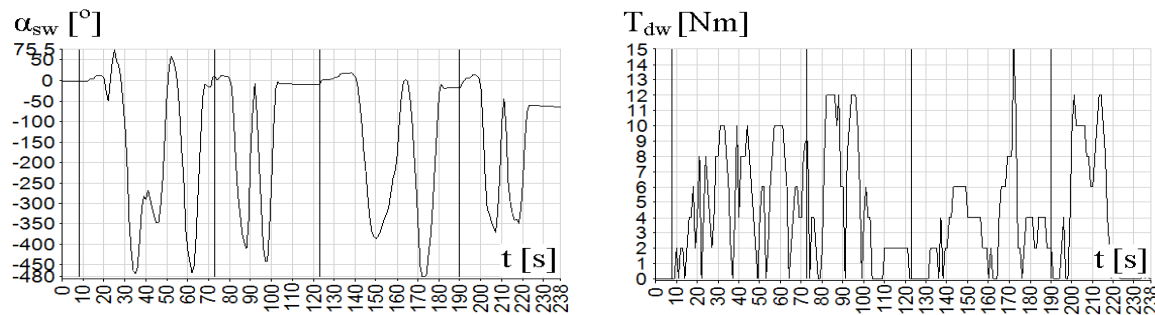
Figure 6. The changes of the torque on the steering wheel during the ride on dry asphalt; normal mode and "city" mode.
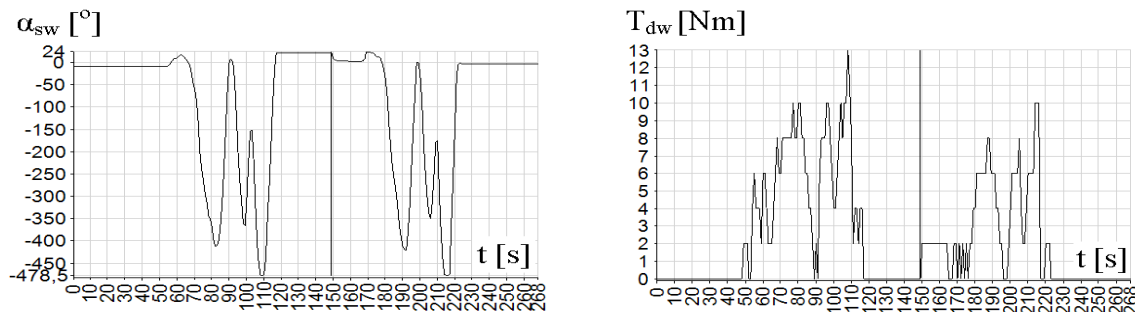

Figure 7. The changes of the torque on the steering wheel during manoeuvers; asphalt surface covered with snow, normal mode and "city" mode.

5. Model

The driver exerts the torque (T_{dw}) on the driving wheel (with the moment of inertia J_{sw}). The steering angle (α_{sw}), which is the result of the exerted torque, is measured with the use of the specified measuring equipment. The torque is transmitted from the steering wheel to the upper part of the steering column (with neglected stiffness and damping) and to the torsion bar with torsional stiffness c_{tb} and damping D_{tb}. The torsion bar allows to generate the signal for the control unit. The applied torque is calculated based on the signal. The torsion bar angular displacement is mechanically limited to a few degrees [4]. The power steering electric motor is coupled with the steering column via a worm gear. The worm wheel is joined to the steering column via elastic sleeve coupling (with stiffness c_{cl} and damping D_{cl}). The lower part of the steering column (with stiffness c_{lps} and damping D_{lps}) is placed under the worm gear assembly. The lower part of the steering column is coupled with the pinion of the rack and pinion mechanism (with neglected friction).

The formulated model doesn't include the steering system kinematics changes. The tire- road contact surface was modelled as the wheel with determined surface s. The surface s was constant during the simulation attempts. Thus, the tire's pliability on the tire- road contact area was neglected. The influence of the wheel suspension was also omitted. Normal load force F_l and the friction coefficient μ, included in the model are the tire-road contact parameters.
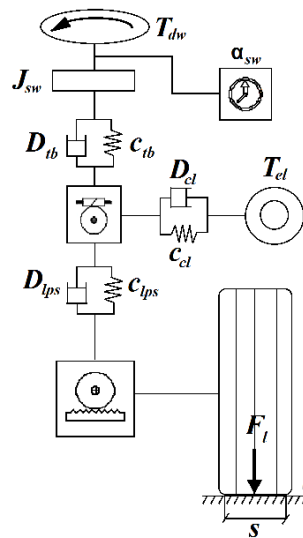
Figure 8. The formulated Matlab model.

6. Simulation analysis

6.1. Verification

The analysis of the results of computational calculations and the verification of a computational model were the next step of the work. The courses of the changes of the angle of the turn of the steering wheel, obtained from the calculations were related to those obtained during the measures made on the vehicle and registered with a diagnostic tester. Real technical data of the steering system were adopted for calculations. This allowed to obtain compatibility between the results registered during experimental research and computational calculations. Adopted parameters correspond to those established in the paper [4]. The values of the torque of the electric motor adopted in the simulation model both for "city" and normal mode of power steering system amounted to about 0.5 Nm.

Due to the flexibility of the collection of components of the steering system, the torque on the steering wheel showed fluctuations to some extent during repeated tests. The range of this variability was designated for obtained results both as a response of the real system and the results of computational calculations obtained based on the steering system mathematical model. So that the obtained results can be compared more easily, all the juxtapositions were examined as manoeuvers performed in two seconds' intervals of time. On the presented graphs one can see irregularities of the change of the angle of the turn of the steering wheel in the initial phase of the work of the system, what is the result of the slack in the steering system as well as steering stiffness and steering damping. Such a situation can be observed at the beginning of each of the manoeuver, since a constant torque of electric motor was adopted in calculations.

6.2. Influence of the change of the axles load

Both the operating conditions and malfunction which may occur can influence the work of the system and ipso facto its evaluation based on the read-outs registered by diagnostic tester. Simulation analysis was conducted in order to assess the influence of changeable operating conditions on the torque on the steering wheel.

The load on the wheels of the vehicle was the operating factor influencing the operation of the steering system, which underwent evaluation. The range of the change of the load by 1000 N, from 3922 N to 4922 N was analysed. The lowest load corresponded to unladen kerb mass of the vehicle burdened by a driver and one passenger with a joint mass of 150 kg. However, the biggest load corresponded to admissible gross vehicle weight rating. The analysis was made in conditions of interaction of tire with wet asphalt and normal mode of power steering system.
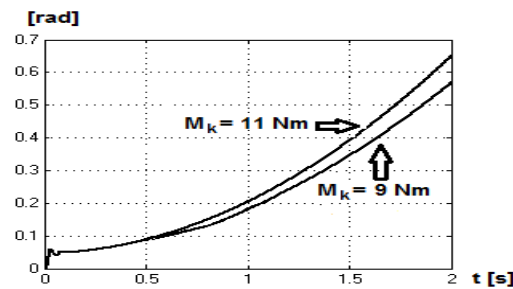
Figure 9. The range of fluctuation results obtained from computational calculations and measurement response of the real system.

The increase of the pressure causes in an obvious way the increase of the resistance of the movement during manoeuvers with the wheels of the vehicle. As one can observe on the courses shown on figure 10, in case of the lowest load, at a constant torque on the steering wheel and the constant torque of electric motor of the steering system, after two seconds of performing the manoeuver of the turn, the angle of the turn of 0,65 rad was obtained. However, in case of the highest load, due to higher resistance of the friction between tire surface and ground, the steering wheel was turned by 0,6 rad. The difference between these values is relatively small in view of the range adopted for the analysis of the change of the load. The change of the load by 1000 N causes the difference of the turn angle by 7%. This confirms a good optimization of the analysed solution.

6.3. Influence of the change of the friction coefficient between tire surface and the ground
Friction coefficient between tire surface and the ground was the next operating factor which was evaluated. The influence of its changes within the range from 0,3 to 0,9 was analysed. This corresponds to the range we can deal with on various surfaces; from the case of ice-covered and wet carriageway to dry, very adhesive asphalt. The results obtained from model simulations were shown on the figure 11.
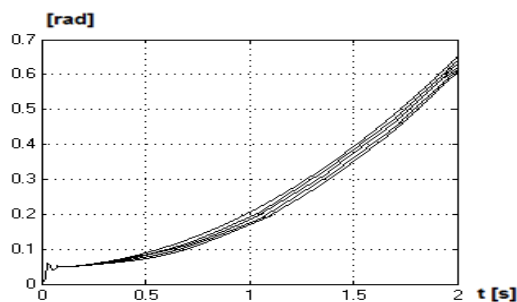

Figure 10. The influence of the change of the vehicle axles loads on rotation steering wheel angle at assumed constant torque on the steering wheel.
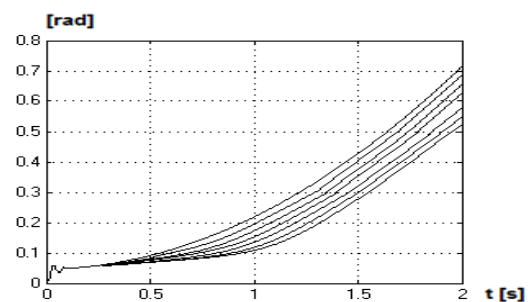

Figure 11. The influence of the change of the friction coefficient between tire surface and the ground on rotation steering wheel angle at assumed constant torque on the steering wheel.

For the adopted friction coefficient amounting to 0,3, i.e. the lowest examined resistance of the turn, after 2 seconds of the duration of the manoeuver, the steering wheel is turned by about 0,72 rad. However, in case of the friction coefficient amounting to 0,9, the steering wheel is turned by about 0,9 rad. The difference observed in the angle of the turn amounts to about 26 %. This shows considerably higher susceptibility of the system on the changes of the friction coefficient in comparison to the changes of the load on the vehicle axle. The abovementioned observations confirm the necessity to pay more attention to this factor during tests and diagnostic research of the system.

7. Conclusions

With regard to the increasing number of vehicles with electric systems, the issues associated with the possibilities of proper diagnostics of work of these devices take on significance. The following conclusions may be drawn on the basis of the experimental test performed and the analysis of their results:

1. Based on the formulated Matlab model of electric power assistance system, comparative analysis of the parameters of electric power steering system is possible.
2. Conducted measures enabled the evaluation of statistical dispersion of the values of the parameters of work of electric power steering system recorded by diagnostic tester.
3. The values of the angle of the steering wheel turn and the torque on the steering wheel decide about the steering effort, therefore they should be the parameters examined by diagnostic testers during electric power steering system evaluation;
4. The conducted evaluation of the influence of measurement conditions enables the determination of the range of variability of the records from the tester, which should be the basis to specify the guidelines of the range of allowed fluctuation of test conditions necessary for a reliable and valid measurement;
5. The entirety of conducted work constitutes a step to create a diagnostic monitor possible to be used in self-diagnosis of electric power steering system.

References

[1]   Liu Z, Yang J and Liao D 2003 *The optimization of electric power assisted steering to improve vehicle performance* Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering August 1 2003 217 pp 639-646

[2]   Parka T J, Hanb Ch S and Leec SH *2005 Development of the electronic control unit for the rack-actuating steer-by-wire using the hardware-in-the-loop simulation system* Mechatronics vol 15, Issue 8, October 2005, pp 899–918

[3]   Nogowczyk P 2009 *Kształtowanie charakterystyk układu kierowniczego, przy wykorzystaniu przyspieszenia poprzecznego pojazdu* PhD Thesis Kraków

[4]   Janczur R and Kuranowski A 2014 *Doświadczalna identyfikacja wybranych parametrów elektrycznego urządzenia wspomagającego układ kierowniczy* Logistyka Nauka nr 3 pp 2501-2508

[5]   Kuranowski A 2012 *Effect of the Variable Input Function Parameters on the Characteristics of an Electric Power Steering System* Automotive Safety Problems vol 1 Politechnika Świętokrzyska Kielce pp 53-61

[6]   Jaksch F 1979 *Driver-Vehicle Interaction with Respect to Steering Controllability* SAE Technical Paper 790740 doi: 10.4271/790740

[7]   Grzegożek W and Nogowczyk P 2008 *Analiza możliwości kształtowania charakterystyk wspomagania układu kierowniczego z wykorzystaniem wysiłku kierowania* Czasopismo techniczne z.8-M/2008 pp 55-62

[8]   Kuranowski A 2012 *Wpływ parametrów zmiennego wymuszenia wejściowego na charakterystyki elektrycznego urządzenia wspomagającego układ kierowniczy* VIII Międzynarodowa Konferencja Naukowo – Techniczna Problemy Bezpieczeństwa w Pojazdach Samochodowych Kielce Politechnika Świętokrzyska pp 175-187

[9]   Kuranowski A 2012 *Effect of Variable Input and Output on the Characteristics of a Steering System with EPS (Electric Power System)* Journal of KONES Powertrain and Transport vol 19 no 1 European Science Society of Powertrain and Transport Publication Warsaw 2012 pp 215-226

[10]   Kim J-H and Song J-B 2002 *Control logic for an electric power steering system using assist motor* Mechatronics vol 12, Issue 3 April 2002 pp 447–459

[11]   Yao Y 2006 *Vehicle Steer-by-Wire System Control* SAE Technical Paper Series 2006-01-1175 SAE World Congress 2006 Detroit Michigan April 3-6

[12]   Data S, Pesce M and Reccia L 2004 *Identification of steering system parameters by experimental measurements processing* Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering 08/2004 218(8) pp 783-792

[13]   Newberry A C, Griffin MJ and Dowson M 2007 *Driver perception of steering feel* Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering 04/2007 221(4) pp 405-415

[14]   Essma S 2000 Steering Effort Analysis of an Oval Racing Track Setup Champ Car *Newman Haas Racing 2000* International ADAMS User Conference

[15]   Toffin D, Reymond G, Kemeny A and Droulez J 2003 *Influence of steering wheel torque feedback in a dynamic driving simulator* DSC North America 2003 *Proceedings* Dearborn Michigan October 8-10 2003 (ISSN 1546 5071)

[16]   Nogowczyk P and Grzegożek W 2010 *Power steering adjustment considering lateral acceleration influence* Archiwum Motoryzacji Wydawnictwo Naukowe Przemysłowego Instytutu Motoryzacji no 2 pp 127-144

[17]   Janczur R and Kuranowski A 2014 *Obciążenia układu kierowniczego w granicznych stanach ruchu samochodu osobowego* Logistyka Nauka nr 3 pp 2509-2516

[18]   Amberkar S, Kushion M, Eschtruth K and Bolourchi F 2000 *Diagnostic Development for an Electric Power Steering System* SAE Technical Paper 2000-01-0819

[19]   Badawy A, Zuraski J, Bolourchi F and Chandy A 1999 *Modeling and Analysis of an Electric Power Steering System* SAE Technical Paper 1999-01-0399 doi:10.4271/1999-01-0399

[20]   Janczur R, Kuranowski A, Nogowczyk P and Pieniążek W 2015 *Badania eksperymentalne sił w drążkach kierowniczych* Archiwum Motoryzacji Wydawnictwo Naukowe Przemysłowego Instytutu Motoryzacji vol 68 no 2 pp 171-180

[21]   Bertollini G and Hogan R 1999 *Applying Driving Simulation to Quantify Steering Effort Preference as a Function of Vehicle Speed* SAE Technical Paper 1999-01-0394 doi:10.4271/1999-01-0394

[22]   Hai Chenguang Ji Peng and Yu Haifeng 2010 *Analysis of Influence of Steering System on Vehicle Straight Line* WASE International Conference on Information Engineering (ICIE) Beidaihe, Hebei 14-15 August 2010 vol 3 pp 336-339

[23]   Reinelt W, Klier W, Reimann G, Schuster W et al 2004 *Active Front Steering (Part 2): Safety and Functionality* SAE Technical Paper 2004-01-1101 doi: 10.4271/2004-01-1101