RELIABILITY FUNCTIONS OF ELECTROMECHANICAL POWER STEERING

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ABSTRACT

The vast majority of new cars are equipped with electromechanical power steering (EPS) because of its clear advantage as compared to hydraulic and pneumatic devices. At the same time, the question of the technical operation of the unit has not yet been fully studied, as the combination of electronic and mechanical systems in which does not allow the full use of existing methods and means of monitoring operability of a vehicle, its actual technical condition. In this regard, development of standards for control over a technical state on the basis of diagnostic information, systematization of scientific achievements in this field, the problems of increasing reliability of EPS in operation are particularly relevant. The results of the conducted research will help in creation of a method for controlling reliability of the unit.

Keywords: car, steering, electromechanical power steering, technical state control, reliability, operation.

Background. *In the world's automotive industry, there is a growing trend towards the use of electromechanical systems for various purposes in the construction of cars. Among the variety of such devices, the most widely used are antilock braking system, electromechanical brake, climate control, starter generator, the system for adjusting the position of mirrors, seats, glasses, etc. [1].*

Objective. *The objective of the authors is to consider reliability functions of electromechanical power steering.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, evaluation approach, scientific description.*

Results.

Typology and general characteristics

So, the priority today belongs to electromechanical power steering systems (EPS), whose main tasks are [2–4]:

– adding the compensating torque M_c to the steering shaft when the input torque M_{in} is applied to the steering wheel (depending on speed of movement, the ratio M_c/M_{in} can reach 0,5–7);

– provision of optimal for ergonomic conditions loading and speed characteristics of SS;

– ensuring rectilinear movement of a car when tires or suspension are damaged;

– preservation of a possibility of driving in case of amplifier's failure;

– maintaining stabilization of the wheels (keeping them in a neutral position when exposed to various disturbing factors);

– reduction of the driver's energy costs and, as a result, improving the comfort of driving;

– reduction of reaction time and improvement of road safety.

Modern electromechanical power steering is produced in various configurations, which differ in the place of application of the auxiliary force [2, 5]:

– the force from the electric motor is applied to the steering shaft – this is the most common type of layout for cars of small class (Column Drive EPS);

– the force from the electric motor is transmitted to the gearbox of the steering gear – this layout is used for middle class cars (Pinion Drive EPS);

– the force from the electric motor through the ball screw pair is transmitted to the steering rack – this layout is used for large passenger cars and light trucks (Rack Drive EPS);

– «control by wire», or a tracking system with two matched electric drives on the steering wheel and the steering rack, not having a mechanical connection (Steer-By-Wire).

At the same time, it should be noted that the most widely used actuators are Column Drive EPS, which have been used in serial production of cars for more than 10 years by such world's auto manufacturers as Renault, Citroen, Opel, Fiat, Toyota, Honda [6]. And the first mass car, equipped with electromechanical power steering, was Suzuki Cervo in 1988 [7].

Depending on the design of the electromechanical drive, the actuators of the column type can be divided into geared and gearless.

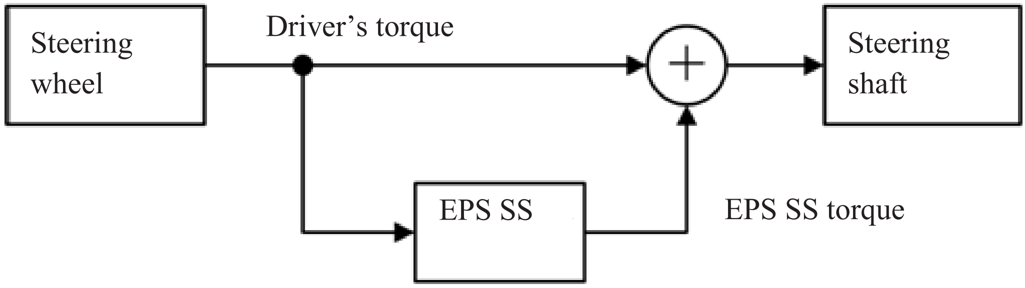
In the geared EPS, the actuating electric motor through the reducer, which is a worm gear that is designed to convert the rotational motion of the worm shaft into the rotational motion of the steering shaft [8], is connected to the steering mechanism. In such designs, a considerable rotational speed of the motor's rotor is required, but the requirements to the developed force are reduced [9].

The gearless actuator is a system based on a contactless low-speed, high-torque, direct-action electric motor, which has a simpler design than a geared EPS and, as a consequence, has high reliability in addition to improved dynamic qualities. The absence of a gearbox gives a number of advantages, in this design there is no additional friction in the mechanical part, which leads to an additional variable moment of resistance, which in turn leads to implementation of a more sophisticated control algorithm with compensations for dry and viscous friction in the gearbox. The speed of reaction of the gearless actuator when changing the direction of rotation of the steering wheel, as well as the speed of rotation of the steerable wheels can significantly exceed the same indexes on the geared electromechanical power steering. However, the main problem with the creation of gearless EPS remains the use of special motors that develop a significant force (torque) at low speeds of rotation [2, 10].

Schematically [11], the use of an electromechanical power steering of a column type in the steering design is shown in Pic. 1.

The presented scheme emphasizes the role of EPS of steering wheel as an auxiliary mechanism that does not break the connection between the driver and the road and does not interfere with driving in the disconnected state.

In the domestic automotive industry, the concept of building an electromechanical steering system such as the Column Drive EPS has been developed, the main advantage of which is a minimal change in the design of the steering device as a whole.



Pic. 1. Scheme of application of a column EPS in the steering design.

Analyzing the chronology of the introduction of Russian power steering [12, 13], it should be noted that the first work on the design and subsequent launch of the unit in the serial production was conducted in Novosibirsk in 1999 [14], and, unlike foreign analogues, a gearless EPS design was selected.

One of the initial developers of electromechanical amplifiers of a geared type was NPK Energia (Voronezh). However, the node designed there existed only at the stage of prototypes until 2003 and was not accepted for mass production.

The creation of gearless EPS for Lada Kalina and Lada Priora vehicles was carried out by JSC DAAZ (Dimitrovgrad) between 2005 and 2007, and then (2008–2010) the prototypes were handed over to PO «Sever» (Novosibirsk) but here the new unit was not launched into mass production.

The electromechanical actuator designed by OJSC Aviaagregat (Makhachkala) was produced serially from 2004 to 2009 and was installed on Lada Kalina cars. The design included a worm gearbox with a gear ratio of 15, 5:1.

Modern EPS developments are related to the activities of JSC Concern KEMZ (Kizlyar), which was considered as an alternative supplier of electromechanical actuators for Lada Priora cars. But the designed prototypes again did not go into mass production.

Now in Kaluga JSC Avtoelektronika produces a range of EPS that are installed on Lada Kalina and Lada Priora cars, and from 2011 on Lada Granta. Table 1 presents the technical characteristics of the units produced [15].

We add that the alternative supplier of EPS of JSC AvtoVAZ since 2008 is the manufacturer Mando Corporation (Korea). The units of this enterprise are installed on cars Lada Kalina and Lada Granta. The structural difference from the actuators of JSC Avtoelektronika is a worm gearbox with a gear ratio of 15, 33:1.

Principle of operation of gearless EPS

According to [9, 16], the power of the gearless actuator in all modes is carried out from the vehicle's on-board network via power cables. The current consumed by the actuator in the «compensation» mode, when the motor generates an additional force, can reach a considerable value of 55 A, which is why on most cars the work of EPS on an operating engine is impossible or limited due to the danger of excessive discharge of the battery.

The operation of the actuator is controlled by a controller (electronic control unit – ECU). Turning the key in the ignition switch activates ECU, which in turn starts the initialization and error detection operations. Detection at this stage of any malfunctions entails the transition of the actuator to the «failure» mode, and assistance to the driver in driving will be absent. After receiving a tachometric signal that determines the stable operation of the car engine, the controller switches the actuator to the main «compensation» mode.

In the «compensation» mode, when the steering wheel is turned by the driver, there is a moment on the input shaft, there is a mismatch between the input and output shafts. Located between them an elastic element – the torsion is twisted by an angle proportional to the magnitude of the input torque. The angle value is determined by the torque sensor and, in turn, is transmitted to the EPS motor control system. By receiving and processing signals, the control unit generates information about the magnitude and direction of the force applied by the driver (the input torque). When the value of the torque on the input shaft exceeds the specified minimum value the ECU of an electric motor generates a power control signal to generate the required compensating torque on the steering gear. The value of the signal on the stator winding of the electric motor is formed taking into account the signals of the rotor position sensor. In addition, the controller receives signals from the speed sensor and the engine crankshaft rotation sensor.

The dependence of the output compensating torque on the input is usually set in such a way that it is sufficient for the driver to exert a force on the steering wheel not more than a certain comfortable minimum (5–7 Nm), regardless of the type of the pavement.

As the speed of the car increases, the coupling properties between the wheels and the road surface decrease, and therefore, it is necessary to reduce the value of compensating force to create a «heavy steering» and to provide a «sense of the road». This requirement is met by obtaining by an ECU information on the speed of the vehicle through a separate input. As the speed of the vehicle increases, the value of the compensating torque decreases. This dependence is not linear and in most cases is determined experimentally for a particular brand of car [9].

Comparative analysis of amplifiers

Our comparative analysis [4–5, 17–19] of gearless EPS with geared and hydraulic actuators (HA) allows us to identify a number of advantages and disadvantages of the node under consideration.

The main advantages of gearless EPS over hydraulic power steering:

– manufacturability, adaptability and compactness of installation (the actuator is mounted on the car by

Table 1

Technical characteristics of EPS produced by JSC Avtoelektronika

Applicability	For cars VAZ-2170 «Priora» with a steering rack 4.1.	For cars VAZ-1118 «Kalina» and VAZ-2190 «Granta» with a steering rack 4.1.	For cars VAZ-2170 «Priora» with a steering rack 4.1.	For cars VAZ-1117 «Kalina» and VAZ-2190 «Granta» with a steering rack 3.1.
Serial number of the manufacturer	121.3405010–05	122.3405010–02 A	121.3405010–04	122.3405010–02
Serial number of JSC AvtoVAZ	2172–3450008–02	11186–3450008–02	2172–3450008–02	1117–3450008–02
Operating supply voltage, V	13,5			
Current consumption, A	not more than 55			
Compensating torque at a steering wheel speed 360°/s, Nm	28 ± 1	24,5	28 ± 1	28 ± 1
Overall dimensions	440 x 203 x 162			
Weight, kg	not more than 9,3			

one unit without intrusion into the engine compartment);

– simplicity of design and maintenance;

– installation time – not more than 1,5 h;

– high reliability (there are no hose pipes, belts, pulley housings, filler blocks, liquids);

– providing passive safety in case of impact;

– presence of the built in system of self-diagnostics;

– absence of friction parts and, as a result, wear;

– independence from the engine crankshaft rotation speed;

– independence from temperature fluctuations;

– environmental friendliness, affordability and energy saving (EPS consumes power only when maneuvering, which significantly reduces energy costs and leads to fuel saving);

– information content (the ability to easily change the degree of assistance to the driver when changing the car's speed);

– ease of adjustment in operation.

The disadvantages of gearless electromechanical power steering as compared with HA are:

– limited range of values of the compensating torque (not more than 28 Nm);

– low coefficient of efficiency;

– complexity and necessity of using special equipment for maintenance;

– non-repairability (in case of failure it is changed by a single node, thereby increasing the cost of technical impacts on transport);

– possibility of overheating of the windings of the electric motor;

– need for more complicated software;

– application of special algorithms and EPS control unit;

– use of a synchronous motor forces the use of the rotor position sensor in the design.

The main advantages of gearless over geared EPS:

– reliability (providing a direct transfer of the torque applied to the SS, on the shaft of the steering mechanism, in contrast to the gear version where the gear is present);

– response time (providing a high degree of reaction from the steering wheels to changing the position of the steering wheel);

– very low noise level;

– absence of a gearbox eliminates the need to compensate for dry and viscous friction, self-return in the EPS control algorithm, and also increases the safety of the steering system, there is no additional resistance moment on the steering column;

– compact size.

Disadvantages of EPS of a gearless type in comparison with a geared one:

– impossibility of obtaining large values of the compensating torque without significant increases in overall dimensions of the unit;

– low coefficient of efficiency;

– availability of additional sensors (rotor position sensor);

– greater heating of the electric motor.

The authors of the paper [20] who performed a comparative analysis of the effect of power steering on the consumer characteristics of VAZ-2170 by the expert poll, note that the gearless amplifier outperforms the hydraulic one in most parameters, yielding only to the vibration on the steering wheel and the sensitivity at small angles of rotation. According to the total expert evaluation, the amplifier system with electromechanical drive is 13 % ahead of the hydraulic drive.

Thus, it can be concluded that the most effective of the presented designs is an electromechanical amplifier of a gearless type.

The main requirements for EPS of cars of category M1

It is established [21] that the main requirements that the steering system must meet relate to:

– durability and reliability of units and major components during the entire life of the car;

– correctness and accuracy of turning of wheels;

– ease of control and ease of use;

– ability of a steering wheel to return to its original position and maintain the specified direction of the car;

– minimum transmission of back impacts on the steering wheel.

Since the electromechanical actuator is one of the steering elements, the technical condition of which has a direct impact on road safety, its faultless operation directly affects not only the trajectory stability and controllability of a vehicle, but also reliability of the entire system, as well as the risk of a road traffic accident. Therefore, strict requirements for safety, comfort and reliability of operation are imposed on EPS [1].

Analysis of the technical conditions formulated by the automobile plants VAZ, GAZ, UAZ for EPS of steering of private cars [22], and the results of the research [23] allows us to generalize the requirements for the actuator and determine the range of tasks that it must solve:

– provide a reduction of the steering effort applied by the driver to the steering wheel, up to 5–7 Nm at the steering wheel speed up to 1 s^{-1};

– provide a compensating torque within 0–28 Nm (with a steering wheel radius of ≈ 200 mm) for a car standing on a flat horizontal asphalt surface of the road with a full permissible load, with a steering wheel speed of 0 to 360 degrees per second;

– provide a smooth, without failures, change in force on the steering, depending on its angle of rotation;

– ensure a smooth change in the torque applied by the driver to the steering, depending on the car's speed;

– maintain the minimum possible level of oscillations on controlled wheels associated with transient processes in EPS;

– when the vehicle under dynamic passive stabilization moves, ensure an active smooth return of the steered wheels and steering to the central position (corresponding to the straight-line movement) when the control action is removed;

– do not allow active return of the steering wheel to the central position on the car standing still;

– carry out active damping of impacts and pulsations arriving at its driven shaft caused by interaction of automobile wheels with road irregularities;

– provide «awareness» of the driver in the process of driving at high speeds.

However, as noted in [24], the control system of the individual models of the EPS of the geared assembly is performed without feedback, i.e. the torque on the output shaft is not measured and not controlled. This shortcoming is significant and can cause some problems, including:

– appearance of static errors;

– occurrence of low-frequency pulsations of the torque, caused by features of the electric motor;

– loss of the driver's «road sense» due to the frictional forces of the gear mechanism.

(To be continued in the next issue).

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