Experimental research of the electromechanical steering system

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Abstract
The development of advanced driver-assistance systems (ADAS) is a global trend. One of the types of ADAS are systems that control the movement of a vehicle in a lane, preventing unintended departure from the lane. When implementing the lane keeping assist system, one of the most important functions is the implementation of external steering control. This article presents tests of the electromechanical steering system with the possibility of external control. Conducted experimental research of the developed system. Based on the test results, conclusions were made on the system’s compliance with the requirements of GOST 31507-2012, and recommendations were given on the applicability to vehicles of the GAZ Group, in particular, the lane keeping assist system.

Keywords: ADAS, electromechanical steering system, lane keeping assist system, light commercial vehicles

1. Introduction
The implementation of driver assistance systems (ADAS) helps to improve the road safety of vehicles. The lane keeping system is a type of ADAS that prevents unintentional lane departure. When designing a lane keeping system, one of the most important functions is the implementation of external steering control.

The lane keeping system is planned for installation on vehicles of the GAZ Group, which are equipped with a rack-and-pinion steering gear with hydraulic booster. It was proposed to use a steering mechanism with an electromechanical power steering. The development of this steering mechanism is presented in [1].

To control the electromechanical power steering, algorithms, software, and a control unit have been developed [2]. The algorithm of the control unit allows to implement three operation modes of the steering system:
- electric power steering mode;
- external steering mode;
- emergency mode (manual control mode).

The developed steering mechanism with an electromechanical power steering, the software and the control unit were installed on the GAZelle Next prototype and a number of tests were carried out on the compliance of this steering with the requirements of GOST 31507-2012 standard [3].

2. Description of vehicle’s tests
The tests were carried out according to the developed program and test methodology of the prototype with the possibility of external control. The purposes of the tests were: verification of the design and circuit decisions of the developed steering, confirmation of the final decisions made on the basis of assessing the functioning of the steering control on the car. As a testing venue, the GAZ Group’s test site was used. The test conditions correspond to those specified in paragraph 5.2 of GOST 31507-2012. The test location is shown in Figure 1.
The first parameter to be determined is the steering force. PCAN-USB X6 CAN-FD (CAN Adapter) is used to read data from the vehicle’s on-board network [4]. As the measuring equipment, the Racelogic VBOX 3i RTK multifunction speed meter kit [5] and the CORRSYS-DATRON measuring steering wheel with MSW / S sensor and ZUB-MSW adapter [6] were used. The connection diagram of the measuring equipment is shown in Figure 2.

During the tests, following parameters were recorded: vehicle location coordinates (speed); steering wheel angle on CAN bus; CORRSYS-DATRON measuring steering wheel angle with MSW / S sensor; torque applied to the measuring steering wheel on the driver's side; steering wheel speed; time. The location of the measuring equipment on the vehicle is shown in Figure 3.

At the first stage, the steering force was measured on a stationary vehicle with the electric power steering running. Before starting the test, the position of the measuring steering wheel was calibrated relative to the position of the steering wheel, during the tests the discrepancy between the values of the sensor for the position of the steering wheel and the sensor for measuring the steering wheel did not exceed 1°.
Figure 3. Location of the measuring equipment inside the vehicle

To determine the effort on the steering wheel with a stationary vehicle, the steering wheel was slowly turned from neutral to the extreme right position, and then to the extreme left position, the maximum value of the steering angle was 612 °. From the graph shown in Figure 4 it can be seen that the maximum force exerted on the steering wheel by the driver does not exceed a value of 50 N, based on which it can be concluded that the object passed the test. In this case, the peak forces in the extreme positions of the steering wheel were not taken into account, since the effort on the driver’s side increased without turning the steering wheel.

Figure 4. Steering effort graph

2.1. Determination of the effort on the steering wheel (with a working power steering: entrance to a turn with a radius of 12 m at a speed of at least 10 km/h)

The next stage of the tests was the determination of the effort on the steering wheel during the “turn-in” maneuver. On a flat horizontal platform, a circle with a radius of 12 m was marked using road cones (Figure 5).
During this test, the speed of vehicle’s motion clockwise and counterclockwise around a circle with an internal radius of 12 meters was not lower than 10 km / h, which is confirmed by the graphs presented in figures 6 and 7.

**Figure 5.** Circle marked by road cones with a radius of 12 m

**Figure 6.** The graph of the change in vehicle speed during clockwise motion
To determine the indicators of effort on the steering wheel, the test driver accelerated the car to a speed of at least 10 km/h. At the entrance to the test section, the steering wheel was rotated at a constant angular speed alternately: to one side to the extreme position, and then to the other side also to the extreme position. The value of the steering speed was set in such a way as to ensure the transition of the car within 4 seconds from a rectilinear movement to movement in a circle whose overall radius is 12 meters. According to GOST 31507-2012, the test object is considered to have passed the test if the measured values of the effort on the steering wheel of the vehicle do not exceed the nominal values of 150 N. Figures 8 and 9 show the change in effort on the steering wheel when moving clockwise and counterclockwise, respectively. According to these graphs, we can conclude that the maximum effort on the steering wheel does not exceed 65 N when moving clockwise and 50 N counterclockwise.
2.2. Determination of effort on the steering wheel (inoperative power steering: entry into a turn with a radius of 12 m at a speed of at least 10 km / h)

At the second stage, the same test site was used as at the first stage (the circle with the radius 12 m). During this stage, the vehicle speed was also not lower than 10 km/h. Pictures with test fragments are shown in Figures 10 and 11.

Indicators of effort on the steering wheel were determined using the methodology described in the previous paragraph, except that there were simulated a malfunction of the power steering by disconnecting the power supply of the electric motor. According to GOST 31507-2012, the force on the steering wheel without the power steering must not exceed 300 N. The graphs of the changes in the force on the steering wheel without power steering are shown in Figures 12 and 13.
3. Steering stabilization when leaving a circle with a radius of 50 m

At the third stage of testing, the vehicle was located on a flat horizontal surface. At this stage, the test driver accelerated the vehicle to a speed of 51 km/h, after which the car was switched from straightforward movement to circular motion, the overall radius of which is 50 meters, with the vehicle leaving the circular path after the steering wheel rim is free of efforts exerted by the test driver. The speed was constant with an error of ± 2 km/h (Figure 15) until the rotation of the steering wheel were stopped within 6 seconds, after which braking was performed until the vehicle stopped completely.

From the obtained results, it can be concluded that the force on the steering wheel does not exceed 250 N when moving counterclockwise and clockwise.
After 6 seconds after the steering wheel was released, its angle from the neutral position was recorded. Three runs were made in each direction with the steering wheel turning clockwise and counterclockwise. Figure 16 shows the average value of the angles of the position of the measuring steering wheel based on the results of all six runs. The position of the steering wheel was determined by the readings that were transmitted to the CAN bus from the steering wheel position sensor (SAS).

![Figure 16. The average angle value of the steering wheel during tests](Image)

The graphs show that after the driver has released the steering wheel rim, the steering wheel returns to the neutral position without going through the neutral position and without oscillatory processes. The residual value of the steering wheel position is 6 degrees, which is 7.5% of the position value at the moment the steering wheel is released (80 degrees). The difference between the values of the angles of the position of the measuring wheel and the position of the steering wheel according to the SAS sensor are in the range of 1 degree.

4. Tests of external control mode

During the fourth test stage, to determine the steering angle in the external control mode, the vehicle was located on a flat horizontal asphalt surface. Correspondence of the steering wheel angles of the vehicle to the control signal of the data bus was made by recording the readings of measuring equipment synchronized in time with a log file recorded using a CAN adapter connected to the Racelogic VBOX 3i RTK and the measuring steering wheel CORRSYS-DATRON with MSW / S sensor and ZUB-MSW adapter, according to the diagram in Figure 2. At this stage, the vehicle speed was zero.

The angle of rotation of the steering wheel (wheels of the steered axis) was determined as follows: on a stationary car there was a turn of a steering wheel from a neutral position to the right with angle of 360 degrees, a turn was made by sending CAN messages; then the position of the steering wheel was fixed, then on a fixed car a turn of the steering wheel was made from the right position equal to 360 degrees, to the left position of the steering wheel equal to -360 degrees. To exclude the influence of external factors, after each turn of the steering wheel, the vehicle was moved 0.4-0.6 meters forward. The test was performed three times.

From the graph of the correspondence of the angle of rotation of the steering wheel to the control signal are shown in Figure 17. It can be concluded that the deviation during the test of the set and actual value of the angle is not more than 1 degree.
Figure 17. A graph of the correspondence of a given and measured position of the steering wheel

Steering wheel speed in the external control mode (stationary car)

To analyze the time when the power steering reaches the required value of the angle of rotation of the steering wheel, after processing the results obtained earlier, the time interval was fixed from the moment the control signal was sent to the data bus until the steering exited to the specified value of the angle of rotation. As a result of the tests, the average steering speed was 173 deg/s, the maximum turning speed was 245 deg/s. Also, during the processing of test data, it was found that in the steering there is practically no delay in the reaction of the actuator to the control signal via the CAN bus, and is less than 0.005 seconds.

5. Conclusion

Based on the results of these tests, it can be concluded that the developed electromechanical power steering with external control meets the requirements of GOST 31507-2012.

Namely, the forces exerted on the steering wheel in motion do not exceed the maximum permissible value both with a running power steering 65 N, with a permissible 150 N, and in emergency mode without an electric power steering 250 N, with a permissible 300 N. And in a static position the force does not exceed a value of 50 N, with a permissible 60 N.

Also at the exit from a turn with a radius of 50 meters and when the steering wheel rim is released, the steering wheel returns to a neutral position without going through it and oscillatory processes. The residual angle value does not exceed the value of 8% with a permissible 30%.

Regarding external control, it can be concluded that the turning speed of the electric power steering is sufficient for the entire range of operating speeds of the vehicle. A delay in the reaction of the actuator to control commands in 0.005 seconds will allow the system to quickly make adjustments to the motion path if necessary.

Thus, we can conclude that the developed steering is applicable for the implementation of driver assistance systems [7] on GAZ Group vehicles of the NEXT Gazelle family.

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