Motor vehicles’ problems with keeping the straight driving direction; analysis of selected case

T Pusty 1*, R Lewiński 1, H K Kowieski 1

1 Łukasiewicz Research Network – Automotive Industry Institute, Jagiellońska 55, 03-301 Warszawa, Poland
*tomasz.pusty@pimot.lukasiewicz.gov.pl

Abstract: The article presents issues related to the testing and verification of the keeping of straight driving direction by motor vehicles. The subjective feelings of drivers were assigned specific values of physical quantities describing the rectilinear path of motion, i.e. the steering wheel angle and the force vector applied to the steering wheel of the vehicle under test while driven along a straight path. This made it possible to determine the limit values enabling the assessment whether the object under test has a tendency to move straight ahead without any unusual steering corrections. The cases analysed relate to the situations where measurements of wheel geometry settings do not show significant deviations from the standard but, in spite of that, the vehicle requires unusual steering corrections by the driver to maintain a straight path.

Key words: vehicle dynamics, vehicle testing, steering wheel

1. State of the art

The maintaining of the straight driving direction is one of the elements of motor vehicle’s active safety. As stated by J. Wicher [4], the elements of kinematics of the road-vehicle system determine the vehicle’s path on a specific road. This means that the vehicle should keep the straight driving direction on a flat horizontal road when accelerating, moving with a constant speed, and braking.

According to authors’ experience, problems with maintaining the preset driving direction may happen even in the case of new vehicles; nevertheless, they occur much more often in result of operational damage. In most cases, they manifest themselves in a repeated and marked turn of the steering wheel when driver’s hands lie freely on it and, in consequence, in a change in vehicle’s direction of motion. Such a phenomenon may occur with different intensity at various driving speeds in vehicles of various types (passenger cars, off-road vehicles, motor trucks, buses, etc.); anyway, the matter of importance is its intensity, repeatability, and question whether it can affect the road traffic safety.

One of the requirements that must be met by vehicles’ steering systems (according to UN ECE Regulation No 79) is that the system shall ensure vehicle’s capability of traveling along a straight road section without unusual steering correction by the driver and without unusual vibration in the steering system at the maximum design speed of the vehicle. This means that the assessment whether the necessary steering corrections and the vibrations in the steering system are “unusual” or not has been left to discretion of the technical unit carrying out the tests. This work will make it possible to determine the limit values that will provide grounds for the assessment whether the vehicle has a tendency to travel straight ahead without any unusual steering corrections.

2. Assessment whether the vehicle can maintain the straight driving direction

2.1. Vehicle examination on test stands and at Vehicle Testing Stations

The assessment of current actual vehicle’s technical condition begins from vehicle identification and verification of its completion (set of components used) for conformity with the vehicle conformity
certificate issued by the vehicle manufacturer. This makes it possible to assess whether any design changes not meeting the specifications of the type approved have been made in the vehicle. Then, the tyre inflation pressure is measured and adjusted if necessary and the vehicle undercarriage is visually inspected with special attention being paid to the condition of vehicle’s rims and tyres, wheel guiding parts, and suspension spring and damping elements. The inspection also includes preliminary measurements of: wheel toe-in on a sideslip plate, shock absorber damping performance, tyre rolling resistance, and tyre tread depth. During the inspection, signs of mechanical damage and excessive plays in the suspension and steering systems are sought. The inspection should be carried out in compliance with the latest relevant guidelines provided e.g. in publication [1]. During the measurements, attention is particularly focused on toe-in measurement results, differences in the damping coefficients of the left and right shock absorbers, and differences in the left and right tyre rolling resistance.

When reasonable, vehicle wheels may additionally be balanced, including the “road-simulation test”, where the tyre-road contact is simulated during the balancing by means of a special roller pressed onto the tyre with a force of 5 kN. The complete balancing of all the wheels and appropriate selection of the location of individual wheels in the vehicle is to reduce the impact of tyres on vehicle sideslip.

As the next step, the linear and angular dimensions of the geometry of vehicle wheels and suspension components are precisely measured, i.e. the wheel toe-in, camber, castor, and kingpin inclination angles, as well as wheel track and wheelbase are determined. The measurement results are compared with the values specified by the vehicle manufacturer as acceptable. The parameters of particularly high importance for the vehicle stabilisation when driven straight ahead are the castor angle and the toe-in; however, the other parameters may indicate mechanical defects, such as damage to suspension components or, in extreme situations, to the undercarriage as a whole.

Then, the linear dimensions of the positions of the base undercarriage points, i.e. the main points of vehicle’s longitudinal members and points of fastening the suspension system in relation to the said main points, are measured. The measurement results are compared with the values specified by the vehicle manufacturer as acceptable.

For the above rig tests and measurements, the equipment of Vehicle Testing Stations or garages may be used. Such operations, not very much time and cost consuming, may provide grounds for formulating or rejecting some hypotheses as regards the reasons for a possible vehicle fault.

2.2. Road tests
The tests that enable quantitative verification of vehicle’s susceptibility to autogenous changing of the direction of motion are much more labour-consuming. They are carried out in specific dynamic road conditions, by means of specialist testing and measuring equipment to record the steering wheel angle and the value of the force vector applied to the steering wheel, referred to as a “dynamometer steering wheel” (or “strain-gage steering wheel”), Figure 1. In the tests described herein, an inertial and satellite navigation system RT 3000, installed and positioned in the vehicle in accordance with normative requirements, was also used. Less sophisticated test equipment, the application of which for tests of similar nature has been presented in publications [2] and [3], e.g. the VBOX Sport system to record time histories of accelerations and velocities in rectilinear motion as well as instantaneous locations in geographic coordinates or other apparatus to measure vehicle velocities, locations, and positions, may also be used.

It is recommended to carry out road tests on a dry, straight, flat and horizontal lane of a road section with bituminous or concrete surface, 300-500 m long, closed for public traffic. When analysing the measurement results, the direction and value of the slope of the road lane as well as the wind velocity should be taken into account. During the measurements, the side wind velocity should not exceed 5 m/s and the road slope should not exceed 2%; the impact of the possible occurrence of these factors should be compensated by driving the vehicle on the same lane and road section in the opposite direction. The vehicles’ ability to maintain the preset driving direction will vary depending on their body shapes, design of suspension and steering systems, and alignment of road wheels, especially in case of disturbances.
e.g. kinematic excitations caused by the road profile (surface roughness, cavities, etc.), or blasts of wind, translating into the necessity of steering corrections made by the driver.

![Dynamometer steering wheel installed in a vehicle under test. Photo: Ryszard Lewiński](image)

Tests of two types may be carried out in road conditions. In one of the types, the vehicle is driven along a rectilinear track and a force necessary for the vehicle to be kept on the predefined path is applied to the steering wheel (closed-loop tests). In the other one, the vehicle having entered the test road section moves without any correction of its driving direction, i.e. any deviation from its predefined path is made possible (open-loop tests). The tests are carried out at different constant total vehicle velocity values in both driving directions.

### 2.3. Analysis of road test results

When the road test results are analysed, the arithmetic mean value of the force applied to the steering wheel and the arithmetic mean value of the steering wheel angle are calculated for individual tests.

In the open-loop tests, not only the steering wheel angle and the force applied to the steering wheel are measured but also the vehicle’s deviation from the rectilinear trajectory (i.e. the distance between the vehicle and the preset vehicle path) is determined. In the analysis of the test results, special attention is paid to a possible predominance of the situations where a force has to be applied in a specific direction to the steering wheel for the desired straight driving direction to be maintained or where the vehicle autogenously deviated from the rectilinear path leftwards or rightwards. The authors of this publication make an attempt to establish specific numerical values of the steering wheel force and angle as criteria of assessment of vehicle’s capability of maintaining the straight driving direction based on subjective drivers’ opinions. The test results obtained for a selected case have been presented in Section 3.

### 3. Analysis of a selected case

The methodological approach described in the preceding Section was used for the analysis of a civil law dispute concerning a sport utility vehicle (SUV) of category M1G. The subject matter of the analysis was the ascertaining whether the vehicle had a physical fault that caused an autogenous change in the vehicle’s driving direction.

A visual inspection of the SUV did not reveal any marks of impacts, wheel rim deformations, or excessive plays in, or damage to, the suspension and steering systems. The tyre tread depth was uniform,
amounting to 6.3-6.7 mm and no dentation marks or cavities were noticed. The EUSAMA value (EV = the percentage of remnant vertical tyre-road contact force) for the left and right front axle wheels was 70 % and 75 %, respectively; for the rear axle wheels, it was 72 % on both sides. The values obtained did not show any malfunction of the suspension system. The tyre rolling resistance measured on a roller tester were: 310 N for the front left wheel, 210 N for the front right wheel, 130 N for the rear left wheel, and 150 N for the rear right wheel. The total tyre rolling resistance for the left wheels exceeded that for the right wheels by 80 N.

The difference found to occur between the left and right tyre rolling resistance forces, although quite small, was recognized as potentially capable of pulling the vehicle to the left. To verify this observation, the wheels were additionally balanced on a balancer supporting the “road-simulation test” function. This test did not confirm the differences indicated by the measurements carried out on the roller tester; on the contrary, the occurrence of a force of 30 N suggesting the possibility of pulling the vehicle in the opposite direction, i.e. to the right, was detected. The above discrepancies indicated that the total difference in the tyre rolling resistances detected by the roller tester at the Vehicle Testing Station came not from the wheels but, probably, from the power transmission or suspension system of the vehicle.

Measurements of the linear and angular dimensions showing the wheel alignment settings and locations of suspension system parts revealed some faults:

- The castor angle of the front left wheel was 318’ while the maximum acceptable value is 2’ 15’; for the front right wheel, the castor angle was 2’ 49’ (at the same acceptability limit of 2’ 15’).
- There was a difference between the steering angles of the front wheels: the values of the angles were 3’ 00’ for the right wheel and 2’ 45’ for the left wheel (at the acceptable value of 2’ 30’ ± 20’), i.e. the acceptability limit was exceeded for the right wheel.
- There was an excessive offset (of 10 mm) between the front wheel axes of rotation (the vehicle axles were not parallel to each other), while the tolerance is ± 8 mm.
- The maximum steering angle of the left wheel inwards (to the left) was 36’ 54’, at the acceptability limit of 35’ 30’. For the right wheel, the corresponding angle value was within the limit.

The excessive offset of the front wheels might have resulted from the difference between the castor angles of the left and right wheel or from incorrect fastening of the front axle to the vehicle body by means of the radius arms (reaction rods). The measurements of locations of the base undercarriage points did not reveal any deviations from the norm in the geometry of the vehicle body frame. During road tests carried out on a test road section on the Ułęż airfield apron to check the maintaining of the straight driving direction, a difference of 5.1 N was found to occur between the moduli of the arithmetic mean values of the forces applied to the steering wheel. This meant that a force of 5.1 N (leftward) had to be applied to the steering wheel for the vehicle to keep the straight driving direction on a flat horizontal road section. An example measurement result has been presented in Figure 2. An example of the measuring trajectory apparatus fastening point when the vehicle was driven westwards has been presented in Figure 3. This trajectory was determined from the moment when the resultant value of the force was 0 N.
Figure 2. Time histories of the force applied to the steering wheel (Fk) and the steering wheel angle (Kk) during a road test on a test road section: vehicle driven westwards

Figure 3. An example of the analysis results, a) time histories of the force applied to the steering wheel (Fk) and the steering wheel angle (Kk), b) the trajectory of the vehicle
On a flat horizontal road section 150 m long, the vehicle deviated from its initial position on the straight driving path by $0.76 \div 1.22$ m (this is the maximum and minimum difference between the moduli of the final and initial vehicle position coordinates measured in the lateral direction). Based on measurements of the force applied to the steering wheel and the steering wheel angle, the vehicle was found to have a tendency to turn autonomously the steering wheel by an angle of about $2.0^\circ \div 2.5^\circ$, which will translate into a considerable rightward change in the driving direction when the resultant force applied to the steering wheel is 0 N.

4. Summary

The assessment of keeping the straight driving direction is a complex issue, for which various measuring instruments must be used. The most reliable element of the tests is the finding that the vehicle when subjected to road tests shows a tendency to pull to one side. Such a finding should in principle be based on measurements of the forces acting on the steering wheel and the steering wheel angle.

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