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EFFECT OF VARIABLE INPUT AND OUTPUT ON THE CHARACTERISTICS OF A STEERING SYSTEM WITH EPS (ELECTRIC POWER SYSTEM)

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Abstract

The complexity of the process of controlling the steering system assistance causes that the assistance units, designed as the control systems, change their characteristics depending on the frequency and amplitude of the torque applied to the steering wheel as well as on the frequency and amplitude of the force applied to the gear toothed bar. The investigation aiming to indicate this effect involved designing a special test stand enabling differentiation of the frequency and amplitude of the input functions applied to the steering wheel or to the gear-toothed bar. The results of the investigation are the characteristics diagrams and numerically determined friction force and compliance values. The test stand allows carrying out the research in two operation modes of the assistance device – normal *mode and* city *mode as well as at simulated different driving speeds. The investigation permitted to identify the parameters of the model of a steering system with an electric assistance device. In the paper, the results of the investigation and their preliminary analysis are presented. The load input function from the side of the toothed bar showed a strong relationship between the frequency and the torque transmitted on the steering wheel. For example, high frequencies occurring during running fast through small irregularities of the road are strongly damped. The slow-variable runs are transmitted on the steering wheel as a feedback reaction.*

Keywords: *steering electric power system EPS, research*

1. Introduction

Electric power steering systems for the passenger cars have many advantages. They realize, for example, the demanded relationship between the steering wheel torque and the assistance torque and a standard relationship with the vehicle speed. Moreover, they provide an active vibration damping as well as a self-return of the steering system to the going straight position. The best-known producers are the firms: Delphi Automotive (assistance module at the steering shaft), TRW Automotive (assistance module at the steering gear), and Koyo Seiko Corporate.

The driver turns the steering wheel mainly in order to control the direction of the car movement, but also he uses the steering system as a sensor of the road forces acting on the steered wheels. In order to arrange appropriately the experimental research on the electric power steering system, the models of the studied system are used. The model of steering linkage, describing the transfer of the forces from the steering wheel knuckle to the rack, considering friction forces, is analysed. The model of the assisted steering gear describes its controlling the torque, measured using the torsion bar, taking account moment of inertia of the steering wheel and of the stiffness of the steering column.

Experimental research on the assisted steering system is done in two phases of a typical driving a car. The first phase corresponds to an entering into a turn from a straight driving, caused by the driver turning the steering wheel. Second phase occurs, when the car goes out from the turn and the system is set to go straight, the steering wheel being free, and the system action is automatically done by the car, because the vehicle tends to return naturally to the straight driving.

In the work [6], the attention was focussed on two functions of the electric mechanism assisting the steering system (EPS), namely, on the reduction of the driver's effort and on the forced by EPS self-returns of the steering system to the setting of wheels for driving straight. The authors proposed a new type of controller – without interfering in the secret controllers of the firms Delphi Automotive and TRW Automotive. One of the most important features of the proposed system is the application of the load torque mapping. The reference steering torque is constantly defined on the basis of the information about vehicle speed and steering wheel angle. The steering strategy aiming to achieve demanded self-return of the system to drive straight ahead was done by two algorithms. One is the algorithm, acting within the range of small frequencies, serving to return the steering wheel to the drive straight. The main function of this return controller is to bring the steering wheel to the drive straight setting quickly and precisely, which is especially important, when the inherent friction prevents the self-returning. The second algorithm, operating at higher frequencies, is the algorithm of "active damping", enabling the steering wheel to return to the drive straight in a mild damped way and avoiding the oscillation occurring usually at high speeds. Because of this, it is desirable that both return and damping control is applied in a simultaneous combination.

The work [14] presents the method of modelling EPS. The controller was modelled using Matlab/Simulink programs, and the EPS mechanism was modelled in a traditional way as the combination of mass elements, damping and elasticity. Next, the mechanical model of EPS was verified experimentally. During the experimental determining of the torsion bar stiffness, the assistance device together with the gear was fixed to the stand. The steering wheel was loaded by input torque and the EPS output shaft was immobile. During determining the friction force, the input function was applied to the output shaft, while the steering wheel was left without loading. Angular displacement of the input shaft within 0 - 450^o was achieved by driving the output shaft with the speed of 5 rpm. It was stated that the conformity of measuring and simulation results is satisfactory in both cases.

A negative effect of the steering system substitute flexibility on car steerability is discussed in the work [13]. A simplified two-wheel model of a car was used. It was demonstrated that it would be advisable to reduce excessive flexibility of the steering system – by increasing the stiffness of rubber elements fastening the electric assistance system to the steering column. Moreover, in the substitute flexibility of the system, low stiffness of fixing (with a rubber element) the steering gear support to the body must be taken into account.

The work [8] presents the methodology of stand investigation of power assisted steering in the car FIAT Punto. Kinematic input function was created by a harmonic rotation of the steering wheel in the ±15^o range at input function frequencies changing within the 0.5-1.5 Hz range. The loading was proportional to the toothed bar displacement within the range of the system elastic strain. Moreover, the variation of the torque on the steering wheel at three simulated driving speeds: 0, 25 and 100 km/h were discussed there as well. It was noticeable that the torque on the steering wheel increased almost twice at the speed of 100 km/h as compared to the torque developed in parking. At the *city* mode on, the torque on the steering wheel decreased of about 30%.

2. Construction and characteristic of the research object

An electricdevice *dual drive* of the firm Delphi assisting the steering system was chosen for the study on that account that it makes possible using different assistance strategies depending on needs and road conditions:

1. Principal action is generated by the driver applying a torque on the steering wheel. The controller of the device assisting the steering system according to the torque forced by the driver, measured by a sensor on the steering column, controls the motor, which, through a worm gear, assists the rotation of the steering column shaft, reducing the effort of the driver.

2. Other strategy it is a changing assistance depending on the driving speed. When the car speed increases, the assistance device, using the driving speed signal, reduces the value of the current supplying the assistance motor. The effect of the assistance is then decreasing.
3. The subsequent function of the assistance system is an active return to the driving straight ahead. The return phase means a rotation of the steering wheel to recover the neutral position after a turn. Owing to a suitable setting of front wheels, the steering wheel being released after a turn, a self-return to driving straight ahead happens. In this operation phase, the assistance device, depending on the driving speed, assists returning to the centre position. The purpose of this function is the acceleration of return to the neutral position, assisting the effect of setting the steered wheels. The correction of an active return changes in accordance with the drive speed and it is maximum at low speeds and minimum at high speeds. In addition, the effect of self-return assistance depends on the turning angle relative to the centre position. The larger is the turning angle, the higher is the assistance at returning to the drive straight position.
4. Next function of the electric assistance system is damping of pulsations occurring, when the steering wheel is returning to its central position. After turning and releasing the steering wheel, the pulsations are generated. As they last for a certain time, they may be tiresome and even dangerous. In the assistance system, the motor control is set to achieve the torque braking the rotation of the steering column shaft, reducing by this the pulsation amplitude during returning to the drive straight ahead.

Fig. 1. View of the electric power device assisting the steering system

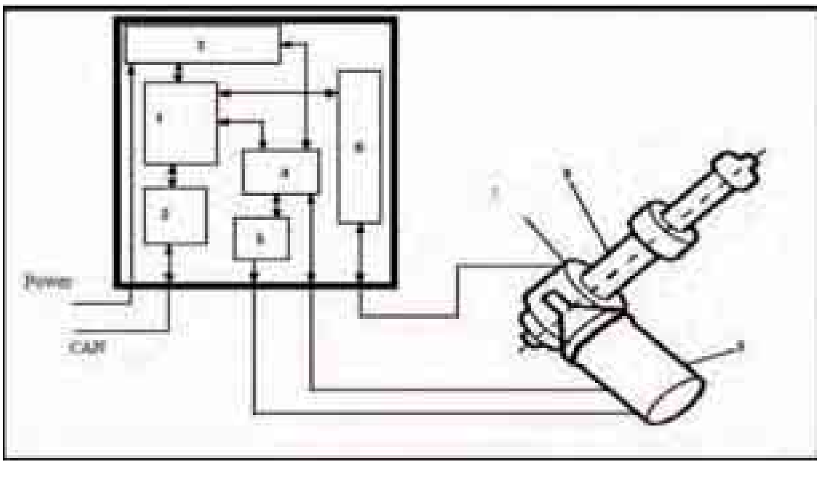

Fig. 2. Block diagram of a complete electric device assisting the steering system; 1 – microprocessor, 2 – CAN interface, 3 – power supply circuits, 4 – motor phases control circuit (EBMD), 5 – electronic power systems (FET), 6 – analog signal interface/interface of analog signals, 7 – position and torque sensor, 8 – assistance system/device, 9 – electric motor with a position sensor and transducer built-in

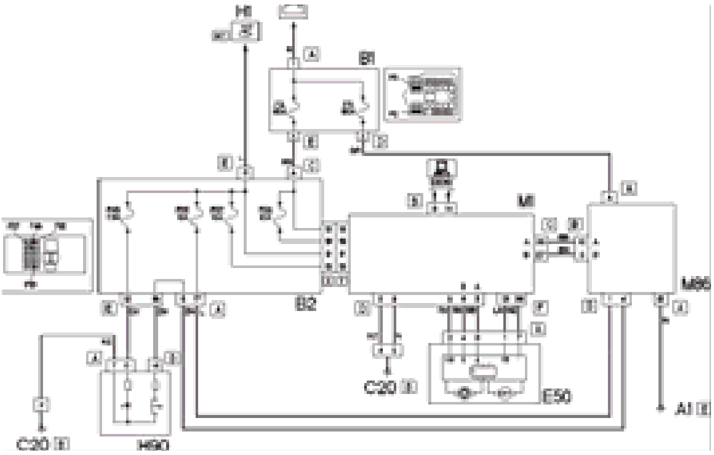

Fig. 3. Scheme of an electric assistance device for steering system of the car FIAT Punto II

3. Description of the measuring stand

The measuring stand allows performing high-speed variable input functions during a time both from the driver side and from the gear toothed bar side. Input functions from the driver side are of two kinds:

- to ensure a steady turning of the steering wheel within about 500° on the left and about 500° to the right, a gear with a cog belt and a worm gear were used. The installation was driven by two-speed commutation d.c. motor of 150 W, providing a steady turning of the steering wheel at two speeds – 0.2 rps and 0.1 rps. After a turn on a side, the limit switch automatically changes the direction of turning,
- for harmonic input functions, a slider-crank mechanism of the test bend was used. Because of its special structure, the mechanism ensures the input functions almost exactly sinusoidal within ±15° at controlled amplitude of 0-100 mm and at the frequency 0-5 Hz. During the tests, the frequencies 0.5, 1.0 and 1.5 Hz were used. The bend is driven by a d.c. motor, supplied from a thyristor system, ensuring 0.1 % accuracy of maintaining steady speed of input function. In the case of the input function from the driver – the toothed bar was loaded by elastic elements stretched by shifting slat. The same kinematic sinusoidal input function can be employed, in the future, in driving from the side of toothed bar (from the wheels). In such a case, the loading may be constituted by the inertia of the steering wheel itself, assembled in the factory. Every time, the force can be measured as well as the displacement of the toothed bar, the torque and the turning angle of the steering wheel.

Fig. 4. Measuring stand. View of the mechanical device forcing the steering wheel turning within ±500°

Fig. 5. Measuring stand. View of the connecting rod device forcing the steering wheel turning within ±15°

Measuring stand permits to perform input functions changing fast both on the driver's side and on the side of the gear-toothed bar.

Fig. 6. Measuring stand adapted to input function on the side of the gear-toothed bar. Examined toothed bar is in a vertical position

4. Measuring system

For measuring on the test stand, a special five-channel recorder has been designed. The measures were performed and archived by means of software operating the recorder installed in the PC computer. The only measuring, which cannot be done using this recorder is the digital signal of the main CAN, because its frequency is much higher than the recorder potential fitted to the other signals measured on the stand.

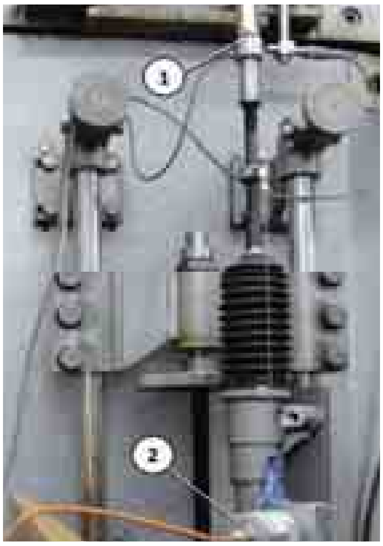

Fig. 7. Input function system; 1 – force sensor; 2 – cable sensor of the toothed bar displacement

Fig. 8. Measurement of the steering wheel rotation angle; 1 – cable sensor of the steering wheel rotation angle

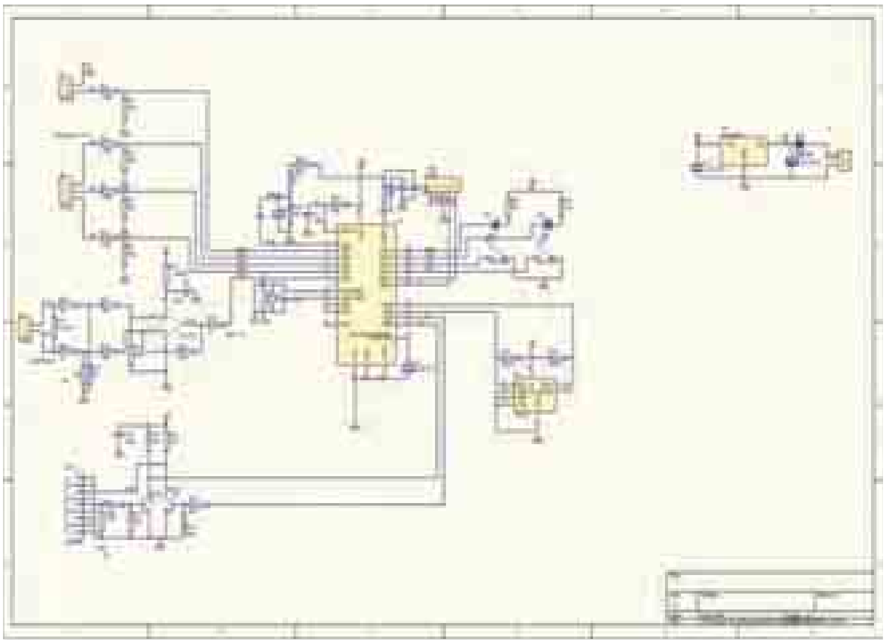

Fig. 9. Schematic diagram of a five-channel data recorder

From the recorder measurement, hoses come out of four voltage channels of the range 0-5 V. The fifth channel served to measure the motor current and it was integrated with the shunt. The shunt is included to the negative pole of the assistance controller supply.

This system allows to measure the current supplying the whole assistance device, but, as the power consumption by other assistance elements in relation to the motor is very small (about 1.5 A), we can admit that it is the intensity of the current supplying the assistance motor.

5. Results of stand research

Figure 10 shows the changes of the torque on the steering wheel measured for three cases of simulated driving speed – 0, 25, 100 km/h. It is visible that torque on the steering wheel increases almost twice at the speed of 100 km/h in relation to the torque developed during parking/stopping. By switching on the *city* mode, the torque on the steering wheel decreases of about 30% (Fig. 11).

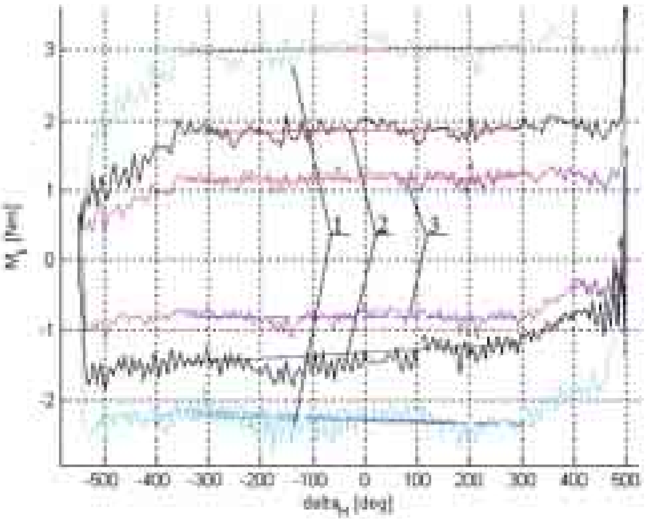

Fig. 10. Influence of the car speed on the value of the steering wheel torque. Steering wheel turning speed 0.2 rps; 1 – 100 km/h, 2 – 50 km/h, 3 – 0 km/h

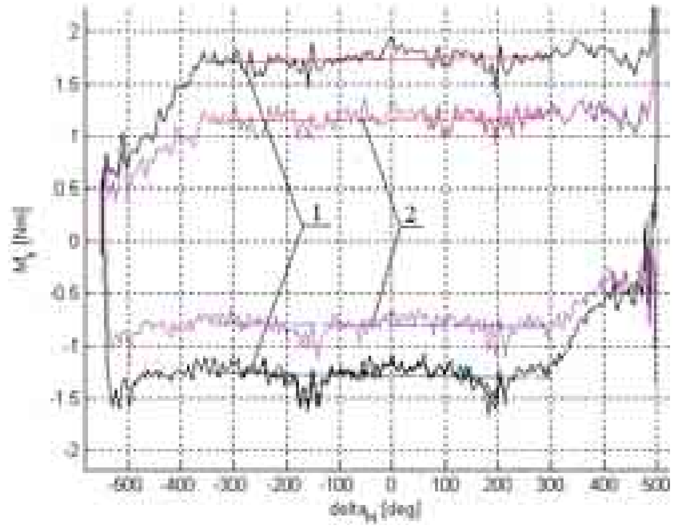

Fig. 11. Influence of the mode city on the value of the steering wheel torque. Steering wheel turning speed 0.2 rps; 1 – city off, 2 – city on

During the investigation, the gear was working without loading and the steering wheel was turned at the speed of about 0.2 rps. The simulated increase of the speed above 50 km/h caused automatically turning off the mode city.

Figure 12 shows the changes of the steering wheel torque at input function frequencies 0.5, 1.0 and 1.5 Hz. The mode city was on; the driving speed was 0 km/h. The gear, practically, did not change its characteristics in spite of different input function frequencies. At the same input function frequency, the speed of 100 km/h was simulated. The increase of the speed caused the increase of the torque of about 30%. The frequency changes did not sensibly influenced on the characteristics running (Fig. 13). In both cases, summary friction torque of the gear and of the assistance system was determined for the neutral position and was 0.75-1.0 Nm.

Maintaining steady input function frequency on the level of 0.5 Hz, step changes of vehicle speed were simulated as 0, 25, 50 and 100 km/h. At 50 and 100 km/h, runs are almost the same. It is so because the assistance is switched off automatically at higher speeds. As it was expected, the lowest steering wheel torque appeared at simulated speed 0 km/h. The variation of input function frequency did not disturb general regularity, namely – increase of the assistance torque on parking (Fig. 14).

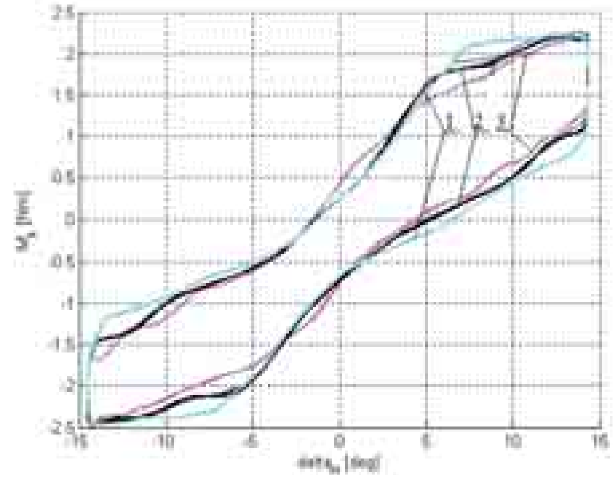

Fig. 12. Plot of steering wheel torque versus steering wheel angle at different input function frequencies. Vehicle speed 0 km/h; frequencies: 1 – 0.5 Hz, 2 – 1.0 Hz, 3 – 1.5 Hz

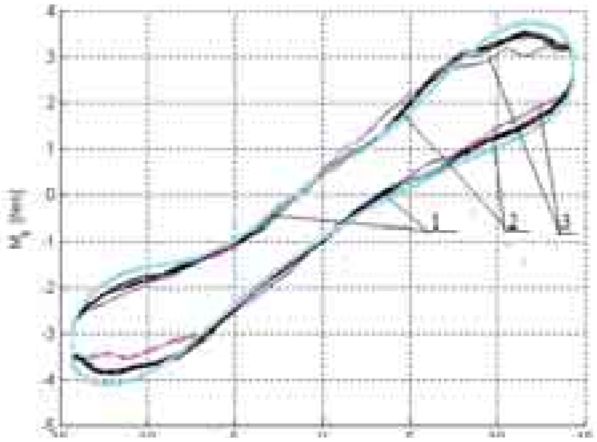

Fig. 13. Plot of steering wheel torque versus steering wheel angle at different input function frequencies. Vehicle speed 100 km/h; frequencies: 1 – 0.5 Hz, 2 – 1.0 Hz, 3 – 1.5 Hz

The investigation performed at the frequency of 0.1 Hz, when the influence of the inertia was negligible, showed that the friction in the gear – EPS system, in gear toothed bar terms, was about 0.5 kN. Independently of friction, the steering gear together with the EPS unit showed flexibility. The flexibility in gear toothed bar terms was about 0.075 m/kN. A very good repeatability of results was found; it is almost possible to distinguish successive meshes of the gear toothed bar (Fig. 15 and 16). The values of friction and flexibility did not depend on the assistance state – they were the same at the assistance on and different driving speeds and at the assistance off.

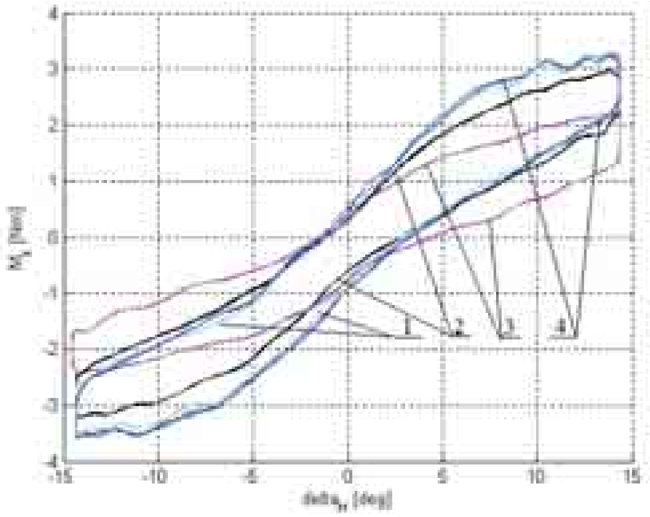

Fig. 14. Plot of steering wheel torque versus steering wheel angle at different driving speeds. Input function frequency 0.5 Hz; vehicle speed: 1 – 100 km/h, 2 – 50 km/h, 3 – 25 km/h, 4 – 0 km/h

Tab. 1. Friction and flexibility of a steering gear with EPS in gear toothed bar terms at the input function frequency 0.1 Hz

	Assistance off	Assistance on					
		Normal mode			*City* mode		
		0 km/h	30 km/h	60 km/h	0 km/h	30 km/h	60 km/h
Friction force kN	0.48	0.51	0.50	0.48	0.54	0.51	0.50
Flexibility m/kN	0.075	0.063	0.081	0.067	0.059	0.070	0.067

Variation courses of the force in the toothed bar versus the bar displacement turned to be definitely different from the previous ones, when the input function frequency was increased up to 1.0 Hz. Then, the inertia “smoothed” the courses and the value of the force (resultant of friction forces and inertia) increased five times up to the value of about 2.6 kN. At this input function frequency, the courses did not differ at the assistance on or off (Fig. 17 and 18).

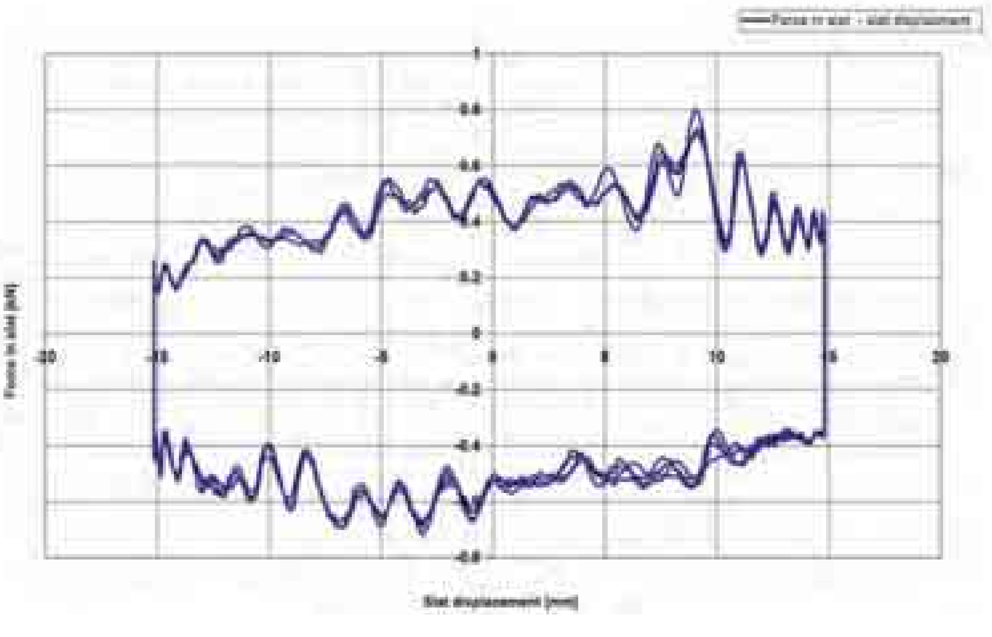

Fig. 15. Variation of the force on toothed bar versus displacement of the bar; input function frequency 0.1 Hz; assistance off

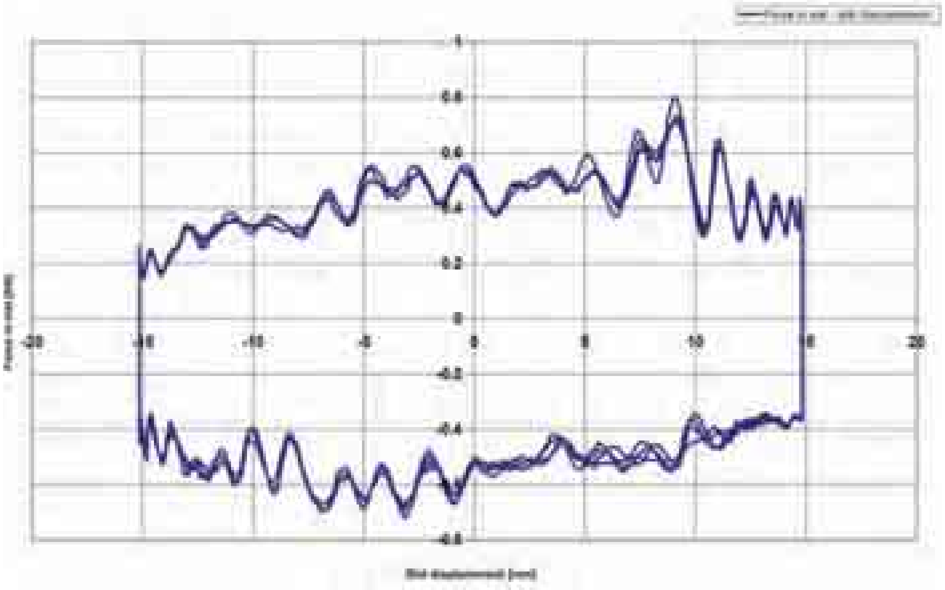

Fig. 16. Variation of the force on toothed bar versus displacement of the bar; input function frequency 0.1 Hz; assistance on; city mode; speed 30 km/h

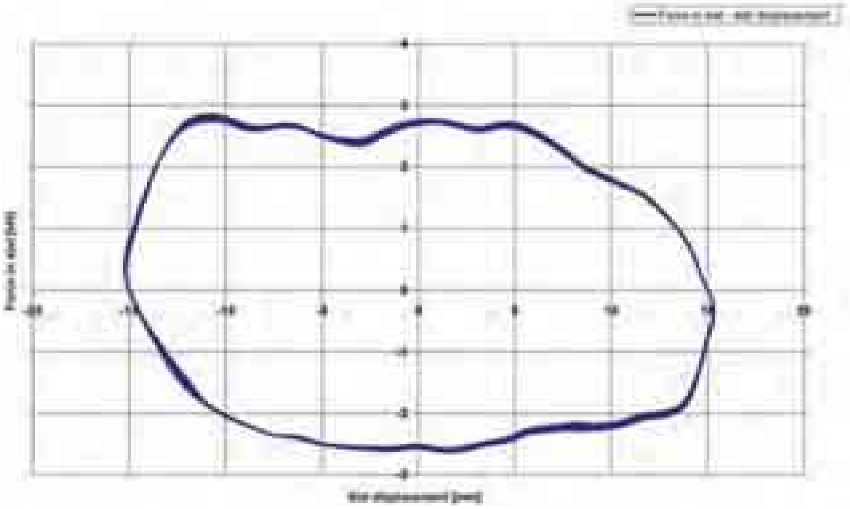

Fig. 17. Variation of the force on toothed bar versus displacement of the bar; input function frequency 1.0 Hz; assistance off

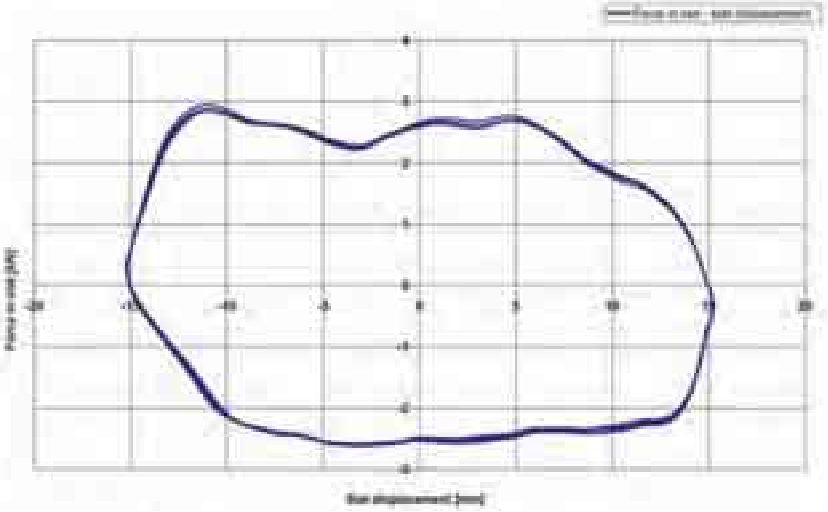

Fig. 18. Variation of the force on toothed bar versus displacement of the bar; input function frequency 1.0 Hz; assistance on; city mode; speed 30 km/h

Like in the case of low frequency input function – a very good repeatability of results was achieved.

6. Conclusions

The test stand designed for the investigation turned out to be sufficiently functional and the achieved characteristics runs showed multiple repeatability. In the future, this stand will be extended by the system of input function forces acting on the gear-toothed bar. It is to be expected that at such input functions, the steering wheel moment of inertia would be essential. Investigation results as far confirmed that the assistance effect during parking is about three times higher than the assistance effect at the speed of 100 km/h. In the case of turning the steering wheel within $\pm 15^o$, diversification of torques during parking and at the speed 100 km/h was twice lower.

Designed test stand allowed also analysing of the influence of the input function frequency on the assistance effect. This influence was not significant.

The loading input function on the side of the toothed bar showed a strong dependence between the frequency and the run character. High frequencies occurring, for instance, in driving through small irregularities of surface, are strongly damped in a real vehicle and this effect is visible in the research results. The runs varying more slowly – giving a road feeling – are not damped, but transmitted, as a feedback reaction, on the steering wheel. The stand tests confirmed this regularity. It is an advantageous feature of the EPS.

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