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EXPERIMENTAL DETERMINATION OF DYNAMICAL CHARACTERISTICS OF STEERING WHEEL JOINT SHAFT

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Abstract: *Increasing demands in vehicle safety highlight the importance of complex examination of its every single element and factor. Participation of steering wheel and its joint shaft as causes of injury point out the importance of experimental determination of joint shaft properties. Furthermore, functional ability and working characteristic of whole steering system largely depends on dynamical characteristic and reliability steering wheel joint shaft as its element. This paper deals with experimental determination of dynamical characteristic of the steering wheel joint shaft as main factor for working properties, prediction of working life, safety and reliability so as its acting in accident. The experimental procedure was done by rapid approach and includes checking of joint shaft twisting resistance, fatigue resistance and torque destruction test. Experimental investigation was done on real elements of steering system. The obtained results of the experimental procedures showed that all tested samples satisfied the requirements of national and internal standards and technical normative. The results of experimental investigation shown in this paper gives important information about function ability on steering wheel join shaft. Developments of new methodology definitions as aspect of safety improvements are pointed out.*

Key words: *vehicle safety, steering wheel, joint shaft, dynamical characteristic*

1. INTRODUCTION

This paper considered experimental examination of the dynamic characteristics of joint shafts, which are used in the steering mechanisms of the motor vehicles. Steering mechanism is one of the basic mechanisms for providing the desired direction vehicles movement and to ensure appropriate active and passive safety. Share of steering mechanism defects in a total sum of accidents causes is at the very top, immediately after the braking system defects. These facts cause that the testing methodology of joint shaft used in direction control systems must be defined with great care.

Joint shaft, as an element of the vehicle steering system, must fully meet all legal and other normative acts required characteristics, and is subjected to regular checks and examinations to determine the technical properties of the vehicles. Elements of steering system, which includes joint shaft, must provide specified safety and reliability, as well as to ensure specified working life without failure. Dynamical characteristics of joint shafts have great influence on properties, conditions, features, security and reliability of the entire steering system, and represent an important aspect of joint shaft experimental testing.

2. SUBJECT, METHODOLOGY AND RESEARCH OBJECTIVES

Existing methods of calculating joint shaft working life do not considered a large number of construction, exploitation and technological factors. This leads to essential predicted working life defined by data from exploitation and laboratory examinations. That is why, the development of the methodology for experimental evaluation of joint shaft qualitative characteristics is very important issue. Examined joint shafts in this paper are part of the steering mechanism of delivery vehicles, made from Č1221 according to national standard. All four hinges of joint shaft are made from Č0363 while its cross is made of Č5421. The shape of the investigated joint shaft is shown in Figure 1.

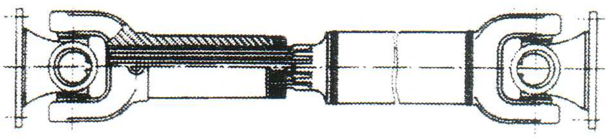

Fig. 1. Examined joint shaft.

Examined joint shafts were accepted for installation in vehicles, so they meet the technical requirements. All examined joint shafts during this exploitation characteristics analysis has passed the previous examinations of general characteristics and exploitation tests that are the base testing procedures of functional characteristics analysis. The procedures order in the analysis of functional characteristics of joint shaft in the vehicles steering mechanisms is shown in Tab.1.

Examined joint shafts, as a component of vehicle steering systems must provide the required functionality in a normal exploitation within temperature range of -35 ° C to +70 ° C. Elements of the joint shafts must be free from fractures, squashes, remaining materials, cracks or other defects that could put at risk their characteristics, operation, security and reliability. Marking elements, surface protection, dimensional control, and identifiable paint must be brought to the internal standard, manufacturers and obligatory national standard. Joint shafts that were investigated passed exploitation characteristics testing according to Tab. 1.

Tab.1. Procedures in analysis of functional characteristic.

		Control title
1	General characteristics	Visual control
2		Marking control
3		Material
4		Surface protection
5		Dimension and tolerances
6		Sliding force control in alignment of toothed joint
7		Angle gap control
8		Control of joints angles
9		Joints torque control
10		Seal control
11	Exploitation characteristics	Joints twisting resistance testing
12		Fatigue resistance testing
13		Fatigue testing of axial sliding
14		Seal control in dynamic conditions
15		Destruction torque with axial alignment
16		Maximal load tension / compression

3. EXPERIMENTAL PROCEDURES OF DYNAMICAL INVESTIGATION OF JOINT SHAFTS

Dynamical investigation of joint shafts enclosed the procedures of joints twisting resistance testing, fatigue resistance testing and fatigue testing of axial sliding, seal control in dynamic conditions, testing of destruction torque with axial alignment and maximal load testing to tension / compression. All test procedures ware done on existing devices in factory quality control center.

Joints twisting resistance testing was done by loading the joints with hinges axial alignment with torque of 200 Nm in 10 s. Permanent deformation was not allowed and dimensional and shape stability must be satisfied. Testing device provide load torque measuring by the means of force measuring and known radius of force applying, which is shown in the Fig.2.

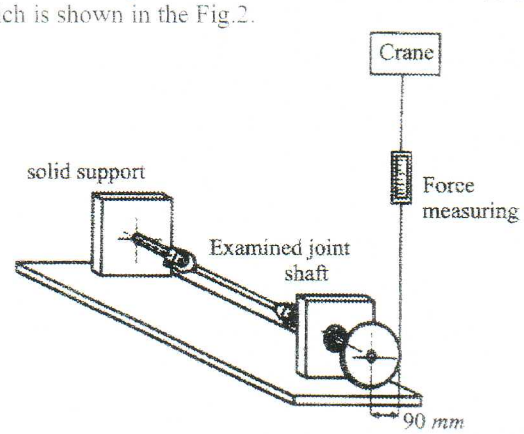

Fig.2. Schematic representation of test device for twisting resistance investigation.

The testing was carried out in a series of six shafts that were subjected to visual control, joints angle control during rotation and functional torque of collar control. After the load relieving, visual control ware done and no permanent deformation and damages are detected. Joint angles controls during rotation were done by placing one joint in maximum allowable transmission angle and subjecting rotation to joints shaft. The testing was conducted on the device that is shown schematically in Figure 3.

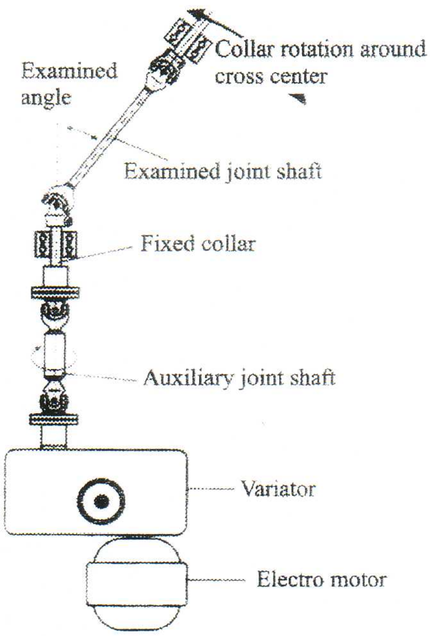

Fig.3. Test device for joints angle control

4. EXPERIMENTAL RESULTS REPRESENTATION

Using the listed methods and devices, experimental determination of dynamical characteristic of steering wheel joint shaft was done. Obtained results were represented in tables and diagram. Joints angles controls during rotation have great importance. Rotation speed is not critical factor in those test procedures. Exceeding allowable joints functional angles provoked occurrences of significant noises and permanent damages. Three-phase electric motor with power of 2.2 kW equipped with variator, outgoing RPM speed of 1 to 15 min^{-1} is used to drive test device. The transfer of power and rotation is further achieved by the auxiliary joint shafts, which have dimensions much larger than the dimensions of the investigated joint shaft. Test device supporter allows placement of the investigated joint shaft in the appropriate positions for test procedures. Obtained the results of joint angles in rotation is shown in Table 2.

Tab.2. Joints shaft angles in rotation control

Sample	1	2	3	4	5	5
Angle value, °	36	36	38	36	36	38

All tested joint shafts meet the requirements in respect of resistance to twisting. Obtained results of the functional torque of collar control are shown in Table 3.

All obtained results of the functional torque of collar control were not within the limits of technical conditions, that amount from 0.1 to 0.3 *Nm*, but were acceptable due to variations for less than 0.1 *Nm*, which was value of torque set during installation in the vehicle to joint shaft hinges to be mounted steadily.

Tab.3. Functional torque of collar control

Sample		Functional torque of collar, *Nm*	Sample		Functional torque of collar, *Nm*
1	1^{I}	0.1	4	4^{I}	0.07
	1^{II}	0.03		4^{II}	0.03
	1^{III}	0.25		4^{III}	0.10
	1^{IV}	0.15		4^{IV}	0.15
2	2^{I}	0.09	5	5^{I}	0.2
	2^{II}	0.20		5^{II}	0.10
	2^{III}	0.15		5^{III}	0.05
	2^{IV}	0.07		5^{IV}	0.15
3	3^{I}	0.07	6	6^{I}	0.25
	3^{II}	0.20		6^{II}	0.10
	3^{III}	0.25		6^{III}	0.08
	3^{IV}	0.15		6^{IV}	0.07

Resistance to fatigue test was carried out by the shaft with joints subjected to alternate rotation angle greater than 360 °, in following conditions: Joints must be set so that the corresponding axis of hinges forms at the ends the working angles to the shaft axis with respect to the real conditions the assembly in the vehicle. The fatigue test is performed according to the program with 100,000 cycle ± 2 revolutions of steering wheel and alternating twisting torque of 125 Nm. After load procedure, total angular backlash must be less than 0.75 ° with torque of 3 Nm and not permanent deformations of the elements are allowed. Test resistance to fatigue in the investigation of dynamic characteristics was performed by rapid laboratory tests principle on stationary test device, operating at normal temperatures. Test device is realized as an open system for the transfer of power. Test device for resistance to fatigue is shown schematically in Figure 4.

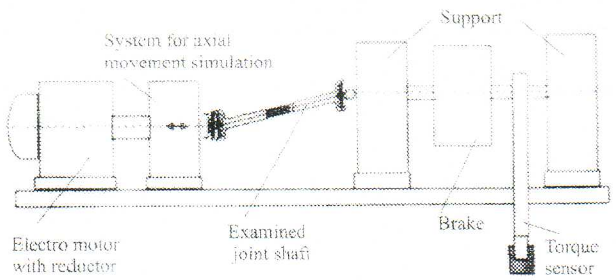

Fig.4. Test device for resistance to fatigue control

The test procedures was done on the series of nine joint shafts and obtained experimental results are shown in Table 4, while automatically registered diagram of torque signal is shown in Fig. 5.Obtained experimental results of the number of load cycles to failure are consistent and within the range between 5700 and 7100 cycles, may be concluded that all tested joint shafts meet the required criteria to fatigue resistance.

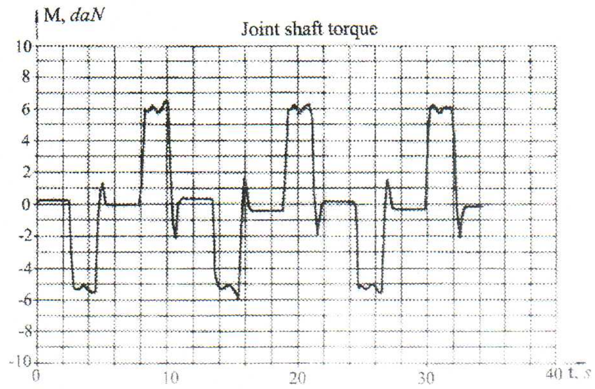

Fig.5. Diagram of torque signal

Tab.4. Resistance to fatigue obtained results

	Number of load cycle to failure, *N*	Failure description
1	5825	Unallowable backlash of bearing and hinges
2	7071	Unallowable backlash of bearing and hinges with collar damage
3	6500	Unallowable backlash of bearing and hinges
4	6832	Crack of hinge base
5	7003	Unallowable backlash of bearing and hinges
6	5930	Unallowable backlash of bearing and hinges with collar damage
7	7100	Crack of hinge base
8	5700	Crack of hinge base
9	10418	Unallowable backlash of bearing and hinges

Destruction torque with axial alignment tests were done with one of the two hinges blocked in the torque sensor and the second was placed, at a distance specified in the assembly of the vehicle, with axes aligned. Test device for destruction torque control is schematically presented in Figure 6.

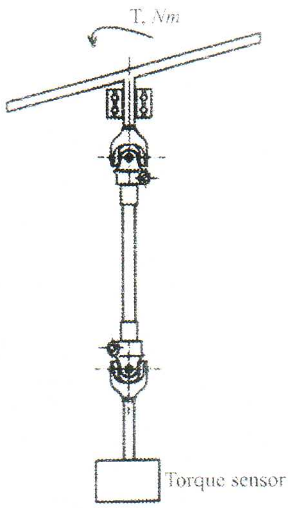

Fig.6. Test device for destruction torque control

The destruction torque value, according to technical condition, must be greater than or equal to 450 *Nm*, however, according to the exploitation conditions and security requirements appropriate torque of destruction is greater than or equal to 220 *Nm*, so that value was taken as a reference. Series of three joint shafts of vehicle steering system were tested and obtained the results are shown in Table 5.

Tab.5. Destruction torque value with axial alignment

Joint shaft number	Destruction torque, *Nm*
1	315
2	340
3	310

As on all tested joint shafts destruction occurred at torques higher than 300 *Nm* is concluded that the tested joint shafts meet the criteria of torque destruction with axes aligned.

5. CONCLUSIONS

Based on the obtained experimental results on series of 15 factory produced joint shafts may be concluded that them meet the internal factory and obligatory national standards. Test results are grouped and displayed in the test protocol. Based on the results of measurements and tests, the following conclusions may be imposed:

- Joint shafts meet the criteria set out by technical requirements (all tested shafts meet the test of geometric and kinematic accuracy, as well as all dynamic testing);
- New construction design of vehicle suspension and steering systems, especially construction with servo control, greatly reduce the functional load and relive working conditions of joint shafts;
- Development of road network, reducing the share length of road without of asphalt vehicle working life, also reflect positively on the working life of joint shafts;
- There is a need for defining a new methodology, with far more relaxed regime of quality verification, but for the verification of that new methodology far more number of tests should be done.

Security requirements for the steering systems and joint shafts, as their element, are quite complex and wide range of tasks should be addressed in order to achieve better design solutions and optimization. The existence of the request for reduction in dimensions and weight of the steering system, while improving reliability and functionality on the one hand, improving comfort and safety of steering on the other hand, with limitations set by technology development, require detailed research. To examine the characteristics, properties and functions, as well as the resistance of joint shaft in dynamic testing, in relation to various factors such as quality of materials, loading and applied technology development is necessary to conduct experimental tests with defined methodology. New testing methodologies must be derived from the needs and demands that are put on tested elements of the steering system. Improving the methodology of experimental testing of joint shaft in the vehicle steering system must be done within the framework of extensive research with respect to any claims of safety and reliability.

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