New Way To Determine The Technical Condition Of Ball Joints

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Abstract. Among the multitude of vehicle suspension assemblies, the ball joint is one of the most important bearing assemblies, the operability of which directly depends on the operating conditions. Ball joints are used to connect the suspension and steering components and are kinematic interfaces that have three angular degrees of freedom when moving the working elements (levers). The reliability of the hinges has a significant impact on the safety of the car. In most cases, the ball joint is an indiscriminate node, which makes it difficult to determine the technical condition in a car service center. One of the methods of diagnosing are laboratory bench examinations of ball joints. To obtain reliable information about the wear of ball joints and the development of a technique for determining their technical condition in the conditions of an auto service company, a laboratory bench research area is needed. The completed research aimed at developing methods, tools and algorithms for determining the technical state of ball joints in the conditions of an auto service company. As a result of the research, the author's team developed a vibration method for determining the technical state of ball joints and a mathematical model for changing the technical condition of the ball joint of the front suspension of the MacPherson type of a car, in bench tests.

1. Analysis of test methods for ball joints

The efficiency of the hinges is determined by the gap in their interfaces. The excess of the permissible norms of these gaps is determined by the driver subjectively to the appearance of vibrations on the steering wheel, knocking and extraneous sounds from the suspension and running gear of the car, loss of controllability of the car while driving, but these signs also appear in the case of malfunction of other chassis and steering elements -blocks, bearings, steering rods and their tips, shock absorbers and hinges of their fastening). The above facts lead to a decrease in the durability of the suspension, increased wear of tires and wheel bearings. There is a decrease in active safety of the car [1].

One of the objectives of this study is to develop a method for diagnosing ball joints with varying degrees of wear, providing the most reliable information about their technical state [2].

Tests of ball joints, like any other devices, mechanisms and elements are divided into several types:
1. reliability, life, durability (cyclic resource tests);
2. for breaking, breaking, failure, resistance to maximum load (failure test);
3. on the definition of hidden gaps, magnitudes of defects, processes, composition (diagnosis).

For forecasting, as well as determining the installed service life of ball joints, as well as for determining their technical condition, automobile enterprises carry out various accelerated road, laboratory and bench tests and studies of suspensions [3,4].

Sometimes obtaining reliable information when carrying out road research on durability and reliability seems to be the most rational, since the approach of the loading regimes is the greatest when tested to operational conditions. However, the above presented method, for all its simplicity of the testability test plan, and comparability of results has drawbacks, such as high cost, complexity and duration of implementation [5].

The most effective way of investigating the ball joints is to reproduce it in the laboratory. At the same time, the accuracy of the reproduction of the process determines the completeness and reliability of the information.

Tests of the front suspension assembly simplify the testing of ball joints and can significantly reduce the additional difficulties that arise when creating the necessary test conditions, close to the real operating conditions. This allows you to obtain results with a high degree of certainty. The lack of such tests is the impossibility of obtaining reliable information about the changes in the parameters of individual suspension elements such as ball joints, etc. Negative moments are also unjustified costs (energy, time, material, etc.) for testing the suspension as a whole in conditions where it is necessary to obtain reliable information on the nature of the change in the parameters of a particular suspension element [6].

To obtain the necessary information on wear and the technical condition of the ball joints, bench laboratory tests are necessary. The test bench used to test the ball joints must fully reproduce the movements and loads that are hinged under real conditions.

In addition, to be able to fully trust the results of bench tests, it is necessary to verify them with data obtained in real conditions [7].

2. Determination of the basic parameters of the operation of the ball joints of the front suspension type "McPherson"

For ball joints of the front suspension of the McPherson type of a passenger car, the parameter characterizing its technical condition is the axial clearance h. Limit is the state of the ball joint, in which the axial and radial clearances reach 0.7 mm, when the axial and radial loads ± 981 H are applied to the finger. These values are valid for automotive ball pins with a diameter of incomplete sphere d = 25-35 mm.

The dependence of the axial clearance h can be represented as a function:

\[ h = f(F_L, F_{LAT}, F_V, N, \mu) \]  

where \( F_L \) – axial loads directed along the longitudinal axis of the car, \( H \); \( F_{LAT} \) – lateral loads inside the ball joint, \( H \); \( F_V \) – vertical loads inside the ball joint, \( H \); \( N \) – the operating time of the unit, is expressed in kilometers of car run; \( \mu \) – coefficient of friction.

The loads and their direction are determined in the spherical hinges of the front suspension of the "McPherson" type on the example of a small class "Daewoo Nexia" passenger car under various conditions.

The diagnostic feature characterizing the technical condition of the ball joint is the movement of the finger relative to the hinge body in the vertical plane in view of the presence of a gap between the polymer insert and the ball pin. This movement during the operation of the suspension leads to the development of a gap \( h \), which characterizes the appearance of vibrations in the hinge.
The mathematical model of changing the technical condition of the ball joint of the front suspension of the "McPherson" type of a passenger car under the conditions of bench research can be presented in the form of a differential equation:

\[ m_1 \dddot{x} + b_1 \ddot{x} + c_1 x + (\dddot{x} - \dot{y})b_2 + (x - y)c_2 = 0 \]  

where \( x \) – vertical mass transfer \( m_1, m \); \( \dot{x} \) – mass speed \( m_1, m/s \); \( \ddot{x} \) – acceleration of mass \( m_1, m/s^2 \); \( y \) – kinematic effect of mass \( m_2 \) (forced displacement of the "free-running part of the installation"), m; \( \dot{y} \) – the speed of the "free-running part of the installation", m/s; \( b_1 \) - viscoelastic resistance in the interface "lever-frame stand", m²/s; \( b_2 \) - viscous resistance in conjugation "finger head - polymer insert", m²/s; \( c_1 \) – coefficient of stiffness of interface "lever - frame of the stand", kg/s²; \( c_2 \) - coefficient of stiffness of interface "head of the finger - polymer insert", kg/s².

In the course of the study of the equation obtained, its mathematical transformation was carried out and it was reduced to a dimensionless form:

\[ \dddot{\xi} + \frac{\varepsilon_1}{\eta} \ddot{\xi} + \frac{\varepsilon_2}{\eta^2} \dot{\xi} = \frac{\varepsilon_2}{\eta^2} \cos \tau + \frac{\varepsilon_2}{\eta^2} \sin \tau \]  

Modeling the change in the technical state of the ball joint of the McPherson suspension of a passenger car in the Mathcad software environment made it possible to establish that the main parameters affecting the magnitude of the acceleration are: axial dimensionless gap \( \Delta \), and \( \varepsilon_1 \) and \( \varepsilon_2 \) are the damping factors in the lever and hinge coupling, respectively, \( g_1 \) and \( g_2 \) are the stiffness coefficients in the arm and hinge coupling, respectively, \( m_d \) (m) is the function, white noise simulation, \( \eta \) is the relative frequency.

3. Justification of the vibration method for determining the axial clearance in the ball joints of the suspension of cars

From the point of view of accuracy of measurement, informativeness, simplicity and speed of diagnosis of the ball joint, the most promising ones are diagnostic methods based on the use of capacitive vibration sensors installed on the investigated couplings of suspension and running gear. Their movement leads to the appearance of vibration in them, which leads to the formation of an electrical signal that can be converted into a gap size. Such methods of diagnosing in the conditions of service stations are most effectively used together with electro-hydraulic detectors [8].

The parameter studied, characterizing the technical condition of the ball joint, is the axial clearance \( h \). As the axial clearance increases to \( h = 0.7 \) mm or more, the hinge is unsuitable for subsequent operation [9,10].

The aim of the experimental studies is to obtain the dependences between the value of the axial clearance \( h \) in the ball joints and the readings of the vibration sensors installed on the working elements of the stand. On the basis of the results obtained, we develop a method for determining the axial clearance \( h \) in the ball joints installed on vehicles with vibration sensors, without disassembling and removing the hinges from the vehicle.

The presence of vibration is due to the presence of gaps between the spherical part of the ball joint and the polymer insert. Vibrations appear in the ball joint when the vehicle is moving, with the opposite loads appearing in the unit under consideration when the wheel is shifted, when it moves over the unevenness of the roadway, acceleration, deceleration and car movement during the turn [11].

The vibration displacement (vibration displacement) is measured with a low-frequency vibration with an upper boundary of the frequency components of 100-200 Hz. Vibration speed, the main parameter of vibration, it characterizes the vibrational energy. The amplitude of the components of the vibration velocity in a sufficiently wide frequency band (10 - 1000 Hz) is uniform, which simplifies the measurement and increases the reliability. Vibration acceleration characterizes the dynamic force action of the elements on each other inside the mechanism, which leads to the considered vibration. In our case, this is the interaction of the spherical part of the finger and the polymer liner in the ball joint. The
application of vibration acceleration is justified, since it does not need to be specially converted, it is measured in m/s².

4. Development of an experimental stand for diagnostic tests

The basis of the stand is one side of the modernized front suspension type "McPherson" car "Daewoo Nexia". During the work of the stand kinematics of motion and all loads in the ball joint remain, similar to the loads in the hinge of the car during its operation. As a source of reciprocating motion, a vertical double-acting hydraulic cylinder is used - 40x250-11-8811 (Figure 1a, 1b).

![Figure 1. General view of the stand for diagnosing ball joints: a) mechanical part, b) hydraulic part:](image)

| Maximum strength, [H] | Car «Daewoo Nexia» | Diagnostic stand |
|-----------------------|---------------------|------------------|
| Longitudinal, $F_L$   | 149                 | 12-355           |
| Lateral, $F_{LAT}$    | 1512                | 1591             |
| Vertical, $F_V$       | 179                 | 150-4063         |

The research method includes the installation of a hinge on the bench, the control measurement of the axial gap, the warming up of the stand, the installation of the test stand in the working position, the start and adjustment of the software, the launch of the stand, the reading of the vibration sensors. Then the stand stops, the data is checked and saved using the LabVIEW SignalExpress software.

The experimental substantiation of the method for diagnosing the technical condition of the ball joints of the vehicle suspension has been made, which will improve the safety of traffic [12-15]. The main purpose of the experimental studies was to obtain the dependences between the value of the axial clearance $h$ in the hinges and the readings of the vibration probes. These data are necessary for the development of a technology that allows the determination of the axial clearance $h$ in ball joints that are in real operation using vibration sensors, without disassembling and removing the ball joints from the vehicle.
5. Experimental research
For the experiment under laboratory bench tests, thirty ball joints were used, which have a gap in the range 0.1-0.9 mm with an interval of 0.13-0.2 mm. As a standard, the ball joint No. 1 was used, a new one, without using the car. The axial clearance $h$ of which was measured at the stand with the aid of a specialized device was 0.01 mm. The remaining hinges were dismantled from the suspension of the car at different mileage values.

\[ a = 120h^2 + 10 \]

where $a$ - dimensional acceleration, m/s$^2$.

As shown by the analysis of the joint graphs, the dependence is manifested when the gap is in the range from 0.01 mm to 0.9 mm, that is, for all hinges presented in the study.

The resulting equation has the form:

\[ h = \frac{\sqrt{a - 10}}{120} \]  \hspace{1cm} (4)

The error in measuring the value of the axial clearance by the vibration method in comparison with the measurement of the gap by the control device within the gap value of 0.1-0.9 mm does not exceed 10%.

The values of the maximum and average amplitudes of the vibration acceleration are an order of magnitude lower than the same characteristics obtained during bench laboratory studies. This is due to the fact that the vibrations that arise in the suspension of the car and its ball joints, in studies in the conditions of the car service are largely absorbed by the tires of the car. The obtained results can serve as a basis for the technique of diagnosing the axial clearance in ball joints.

6. Conclusions
The analysis of the front suspension of passenger cars was carried out, it showed that 80% of cars have a front suspension of the McPherson type and an analysis of the existing methods of determining the technical condition of the ball joints, which revealed their shortcomings - the complexity of the design, low measurement accuracy, and material resources for diagnosis. This confirms the relevance of the developed vibration method for determining the technical state of ball joints.

Scientifically-methodical approaches and a mathematical model of the technical condition of the ball joint of the front suspension of the McPherson type of a passenger car were developed, with bench research.

Experimental studies were carried out to determine the value of the axial clearance in 30 samples of ball joints using a vibratory method, numerical values of vibration acceleration and their correspondence to the value of the axial clearance:
- for laboratory bench tests from 1.4 m/s², which corresponds to the value of the axial clearance 0.01 mm, up to 95 m/s² - corresponds to an axial gap of 0.9 mm;
- for autoservice plant conditions from 1.0 m/s², which corresponds to the value of the axial clearance 0.01 mm to 2.8 m/s² - corresponds to an axial clearance of 0.9 mm.

On the basis of the analysis of the graphs of the dependence of the maximum amplitude of vibration acceleration a on the time of the experiment, in test samples with an axial clearance value of 0.01 mm, empirical relationships were obtained to determine the actual value of the axial clearance h.

Comparison of the graphs of the dependence of vibration acceleration on the magnitude of the axial clearance in mathematical modeling and in the experimental study showed that the greatest discrepancy between them does not exceed 10%. This confirms the adequacy of the developed mathematical model of the technical condition of the ball joint and its compliance with the bench research conditions.

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