UDC 621.777.06

DOI: http://dx.doi.org/10.17580/cisisr.2017.01.09

NUMERICAL MODEL OF THE FORMING PROCESS FOR INTEGRAL ASSEMBLIES OF BALL JOINTS USING PLASTIC DEFORMATION VIA ROLLING-UP

I. G. Gun[1], I. Yu. Mezin[2], I. A. Mikhailovsky[2], D. A. Pesterev[1], E. G. Kasatkina[2]

[1] *"BelMag" Scientific and Production Corporation (Magnitogorsk, Russia)*
[2] *Nosov Magnitogorsk State Technical University (Magnitogorsk, Russia)*

E-mail: pesterev@belmag.ru

AUTHOR'S INFO

I. G. Gun, Dr. Eng., Prof., General Director;
I. Yu. Mezin, Dr. Eng., Prof., Head the Chair of Automobile Technology, Certification and Service;
I. A. Mikhailovsky, Dr. Eng., Associate Prof., the Chair of Automobile Technology, Certification and Service;
D. A. Pesterev, Leading Product Design Engineer, Design Engineering Dept.;
E. G. Kasatkina, Cand. Eng., Associate Prof., the Chair of Automobile Technology, Certification and Service

Key words: ball, joint, assembly, connection, plastic deformation, rolling, mathematical model, geometrical shape, pull-out force.

ABSTRACT

The modern companies manufacturing products for automotive industry more and more often use innovative methods of mathematical simulation. Such methods allow to cut essentially temporal and financial expenses for designing of constructions and corresponding production technologies, as well as to minimize risks of fabrication of reject products [1–4]. Especial attention is paid to the processes and operations forming functional and technological parameters of manufactured products, as well as safety characteristics [5, 6]. Forming of an integral assembly mainly using plastic deformation via rolling-up is considered as such operation applying to production processes of ball joints.
This direction is examined not very good, despite its relevance. Review of open-access sources has revealed presence of the one mathematical model for forming of integral assembly [7]. This well-known mathematical model has several substantial disadvantages that can be removed taking into account up-to-date level of scientific knowledge in the field of simulation. Thereby the aim of the current work can be formulated as follows: development and verification of the mathematical model for forming of integral assemblies of ball joints using plastic deformation via rolling-up.

Theory of the problem

Calculating algorithm of the well-known mathematical model for forming of integral assemblies of ball joints using plastic deformation via rolling-up is built of the finite element method (FEM) [7]. Geometric form of the detail that is intended for search of solution of differential equations is loaded in software medium. These differential equations are subjected to consequent approximation on finite quantity of elements with the simplest geometric form [8, 9]. Interaction between the objects is described by the theory of plastic flow and the theory of deformation ductility. The solution is presented as determination of function values in the points of the elements with the simplest geometric form.

Practical application of the existing mathematical model is connected with udsge of the following restrictions:

• rheological properties of material are described by bi-linear stress-strain diagram;

• deformation of linear scanning of shell collar is examined;

• one-pass deformation of shell collar is considered.

Usage of bi-linear diagram during execution of mathematical simulation is a wide-spread case of setting rheological properties of materials. Diagram building is conducted by numerical values of yield strength, tensile strength, elasticity modulus and relative elongation at breaking.

Usage of shell linear scanning is connected with introduction of variations in the kinematic scheme of rolling-up roll motion. The motion route of rolling-up roll in simulating process of integral assembly forming is described by the following simplest simultaneous operations: progressive motion along the axis of shape-forming tool (rolling-up head) and self-axis rotation. The route applied in the well-known mathematical model [7] implies replacement of rotating motion around the axis of shape-forming tool (rolling-up head) by progressive motion in the direction perpendicular to the observing axis.

It should be mentioned that process simulation for shell scanning does not take into account difference in the values of critical force for shell in usual state and in scanning state. Critical force is understood as the minimal force value when the initial equilibrium form becomes unstable. The fact when the critical force value for rotating bodies exceeds the critical force value for bodies in scanning state (for the same cross section) is known [10].

Confirmation of realization of the requirements preset to the integral assembly is one of the problems that is still not elucidated in the existing mathematical model. Quality of the integral assembly has direct influence on safety parameters, namely ball stud tear-out force from shell [11, 12]. Discrepancy on this single quality parameter is unacceptable.

Mathematical models for determination of ball stud tear-out force from shell [13, 14] are known. However, these models are applied separately using geometric shape of an integral assembly as initial data. Possibility of integration of the existing mathematical model in the model for forming of an integral assembly is absent, thereby the questions to precision of transfer of formed geometric shape of an integral assembly are left.

Up-to-date level of software provision in the field of mathematical simulation allows to exclude the part of restrictions and to rise thereby precision of obtained results. The suggested mathematical model for forming of integral assemblies of ball joints using plastic deformation via rolling-up is realized during two stages. The first stage includes forming of an integral assembly, and the second stage — calculation of force for its destruction.

Motion kinematics in the mathematical model is described by a rolling-up roll, while the components of assembled ball joint are motionless. Rolling-up roll rotates around the shell axis with the speed corresponding to the speed of rolling-up ball rotation in the simulating process; at the same time rolling-up roll rotates around its own axis. Rotation of a rolling-up roll can be considered as "passive", i.e. it rotates owing to its interaction with a shell, not having its own rotation speed. Transfer of the rolling-up roll along the shell axis can be realized in accordance with one of the following routes:

- rolling-up roll is subjected to the force corresponding to the force acting on the roll in real process;
- rolling-up roll is transferred with the speed corresponding to the transfer speed in real process.

Number of rolling-up rolls in the mathematical model corresponds to the number of such rolls envisaged by construction of the rolling-up head.

The suggested mathematical model for forming of integral assemblies of ball joints using plastic deformation via rolling-up is realized with the following restrictions:

- shell geometrical shape is presented by deforming collar;
- rheological properties of accessories are described by bi-linear stress-strain diagram;
- rolling-up rolls are recognized to be absolutely rigid (non-deformed) bodies. This allowance is based on the most than five-time excess of the yield strength of the rolling-up roll material in comparison with the yield strength of the shell material.

Detailed description of the experimental technique

Approbation of the mathematical model of the process of forming of integral assemblies of ball joints using plastic deformation via rolling-up has been realized on ball joints in automobiles of "Gazel NEXT" series (**fig. 1**).

Volumetric mathematical models of shell, thrust washer and rolling-up rolls are executed using CAD programs. These programs are based on numerical values of dimensions obtained as a result of actual measurements. The formed models are integrated for calculations in the software medium.

In simulating process the constant force acts of rolling-up roll; its value corresponds to this process. Stopping of forming process of an integral assembly occurs by time.

The stud tear-out force from shell is determined for geometrical shape of an integrated assembly formed during mathematical simulation. Depending on obtained destruction scheme of an integral assembly, we understand the following explanation for tear-out force:

Fig. 1. External view of a ball joints in automobiles of "Gazel NEXT" series

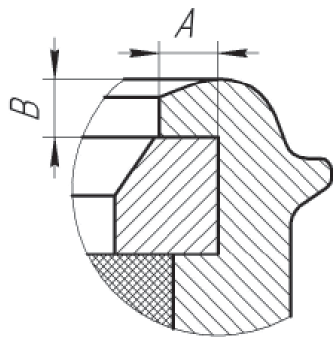

Fig. 2. Evaluated geometrical dimensions of an integral assembly

- maximal force value when ball stud or ball stud with thrust washer are disconnected from shell;
- maximal force value when ball stud is disconnected from a thrust washer.

Description of materials and analytical methods

Geometrical shape of an integral assembly is determined by dimensions *A* and *B* presented on the **fig. 2**. Actual values of these dimensions are determined on the empiric ball joint using microscope after segment removal as the preparing operation. Determination of the same dimensions on the ball joint manufactures via mathematical simulation is conducted by programming. Precision of geometrical shape of mathematically simulated integral assembly is evaluated via calculation of percent deviation from the empiric results.

Determination of precision of the values of the stud tear-out force from shell obtained during mathematical simulation is conducted in the same way - via calculation of percent deviation from the empiric results. As soon as it is impossible to use a ball joint after segment cutting for measurement of the stud tear-out force from shell, the new ball joint should be manufactured. Measurements of geometrical shape of shell and thrust washer as well as diameter of ball stud sphere are conducted before forming of the empiric assembly. The new volumetric models are created based on the results of these measurements; calculated value of the ball stud tear-out force from shell will be determined for these models in the future.

Discussion of the results

The integral assemblies obtained via empiric way and mathematical simulation are resented on the **fig. 3**. The measurement results of geometric shape of the integral assembly (see fig. 2) are displayed in the **tab. 1**.

Deviation between the values obtained by empiric way and via mathematical simulation is not more than 6.8%. Thereby we can conclude that the suggested mathematical model has less error in geometrical dimensions of forming integral assembly in comparison with already known model [7].

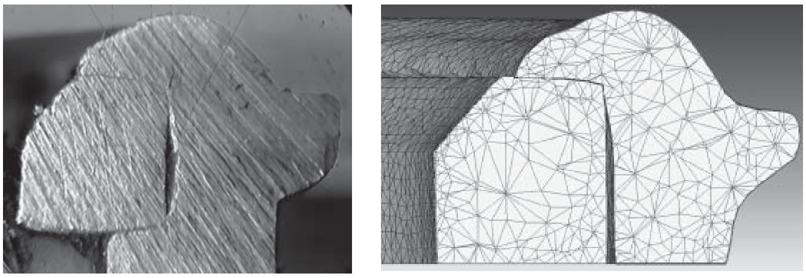

Fig. 3. Measurements of integral assemblies obtained by empiric way (*a*) and mathematical simulation (*b*)

Table 1. **Measurement results of geometric shape of the integral assembly**

Controlled dimension	Control results, mm		Error, %
	Integral assembly obtained by empiric way	Integral assembly obtained via mathematical simulation	
A	2.80	2.61	6.8
B	2.04	1.94	4.9

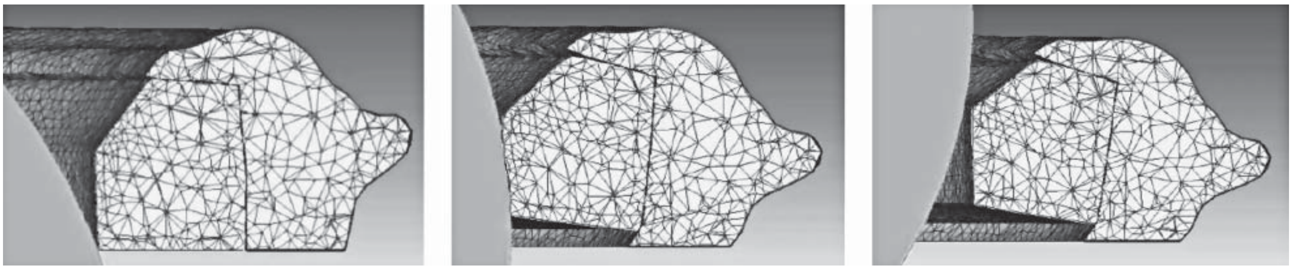

Fig. 4. Deformation of the integral assembly in the simulating process for determination of the ball stud tear-out force from shell

The control results have displayed that the stud tear-out force for an integral assembly obtained by empiric way made 46.6 kN, while the same parameter obtained via mathematical simulation made 40.8 kN (fig. 4). Deviation between the force values for empiric and simulated techniques constituted 12.4%.

Conclusion

The suggested mathematical model for forming of integral assemblies exceeds the already known model [7] in precision. Precision of geometrical form based on the obtained results is characterized by the error not more than 6.8%, while precision of determination of the tear-out force has the error not more than 12.4%.

REFERENCES

1. Lee H. M. Applying fuzzy set theory to evaluate the rate of aggregative risk in software development. *Fuzzy Sets and Systems*. 1996. Vol. 79.
2. Reid R. D. Automotive Quality Management System Evolves. *Quality Progress*. 2002. Vol. 35. No. 1. pp. 98–101.
3. Feigenbaum A. V. Total Quality Control. New York : McGraw-Hill Prosessional, 2004. 896 p.
4. Mikhailovskiy I. A. Mathematical simulation of assembly of ball joint of front suspension mount of a motor car by pressing. *Chernye metally*. 2011. No. 6 (Special issue). pp. 72–75.
5. Fecht N. Automotive Chassis Technology. Fundamentals, concepts, processes and trends. Munich : SV corporate media, 2004. p. 57.
6. Fecht N. Komponenten für Fahwerk und Lenkung. Landsberg / Lech : Verl. Moderne Industrie. 1997.
7. Gun E. I. Development of the investigation technique for metal products quality with determination of the key technological operation based on the method of hierarchies analysis : Dissertation ... of Candidate of Engineering Sciences. Nosov Magnitogorsk State Technical University, 2016.
8. MSC/DYTRAN User's Manual. The MacNeal-Schwendler Corporation, 1997.
9. MSC Nastran 2012 Quick Reference Guide. The MacNeal-Schwendler Corporation, 2011.
10. Lukyanov A. M., Lukyanov M. A., Marasanov A. I. Calculation of compressed rods for stability and longitudinal-transversal bending: methodical recommendations. Moscow : MIIT, 2012. 48 p.
11. Kalmykov Yu. V., Mikhailovskiy I. A., Salnikov V. V., Pesterev D. A. Analysis of the existing methods for forming of assemblies and the main quality requirements during assembly of ball joints for the automobile front suspension. *Vestnik Magnitogorskogo gosudarstvennogo tekhnicheskogo universiteta im. G. I. Nosova*. 2009. No. 4. pp. 47–50.
12. Mikhailovskiy I. A. Methodology of provision of products quality based on regulation of the complex of requirements to the processes of their fabrication. *Vek kachestva*. 2011. No. 2. pp. 49–51.
13. Kalmykov Yu. V. Improvement of the pressing process in order to improve quality level of ball joints for the automobile front suspension. Dissertation ... of Candidate of Engineering Sciences. Nosov Magnitogorsk State Technical University, 2010.
14. Salnikov V. V., Mikhailovskiy I. A., Gun I. G. Simulation of destruction process for ball joints for the automobile front suspension during axial loading. *Zhurnal avtomobilnykh inzhenerov*. 2011. No. 2 (67). pp. 51–53.