Analysis of behavior of car stabilizer bushing

Jakub Javorik, David Samek, and Ondrej Bilek

Abstract—The goal of this work is to create numerical model, which will be used for design and optimization of a rubber bushing for stabilizer bar. Thanks this model we are able to predict the mechanical behavior of the bushing. To get material constants for the model, the material of bushing (rubber) was tested in special deformations modes. A hyperelastic material model was set and it was implemented into the numerical model of the bushing. Critical points in the construction of bushing were reveled by the analysis of the numerical model.

Keywords—bushing, hyperelasticity, numerical model, stabilizer bar.

I. INTRODUCTION

The stabilizer bar is an important part of a car suspension. It is intended to force each side of the vehicle to lower, or rise, to similar heights, to reduce the sideways tilting of the vehicle on curves, sharp corners, or large bumps. One of the factors which influence the function and behavior of the stabilizer bar is a way in which it is connected with the car frame. This connection must be able to absorb quite large deformation of the stabilizer bar. Therefore the rubber bushings are commonly used to clamp stabilizer bar and to fasten it to the car frame. To design this bushing properly we need to predict the bushing behavior accurately. The numerical model of the bushing was created and the analysis of its behavior is described in this paper. Main goal of the work was to analyze the radial stiffness of the bushing.

II. MATERIAL AND METHODS

A. Geometry of Bushing

The scheme of half cut stabilizer bar bushing is shown in the Fig. 1. The bushing consists of three parts: two rubber parts (a) and (b), and steel clamp (c). Rubber parts are mounted on the stabilizer bar (d) and then together with the stabilizer bar they are fixed by the steel clamp (c) to the car frame. Both rubber parts of the bushing are reinforced by the aluminum core (e). There are eight holes in each core plate for better fixation of the core in the elastomer.

B. Material

We need to characterize two materials of bushing: - material of elastomer: NR 60±3 Sh A - material of bushing core: EN AW-AlMg3-H46

Material of the core (EN AW-AlMg3-H46) is standardized type of aluminum and we can get data from common material databases. Elastic modulus of this material is E=70000 MPa and Poisson ratio μ=0.3. Contrary to the core, to characterize the rubber, from which the elastomer part of the bushing is made, we need to test the mechanical properties of this material. This material was tested in three basic deformation modes that are used to characterize a hyperelastic material. These tests are: uniaxial tension, equibiaxial tension and pure shear [1]-[4].

C. Numerical Model of the Bushing

An advanced nonlinear "Finite Element Method" (FEM) system was used for numerical model creation and analysis [5]. With regard to the symmetric shape of the bushing and to the symmetry of loads and boundary conditions (which will be described bellow) we can reduce the geometry of the numerical model to one quarter of original shape (Fig. 2). First plane of symmetry is normal to the axis of stabilizer bar and it...
is placed in the center of the bushing. Second symmetry plane coincides with the stabilizer bar axis and is perpendicular to the first plane (Fig. 2). Model has four parts: bottom bushing part, top bushing part, stabilizer bar and clamp. Aluminum cores are positioned inside the top and bottom bushing parts (they are not shown in the Fig. 2).

In the model, the rubber parts and aluminum core were created of the "Four Node Tetrahedron FEM Elements" [6]. The stabilizer bar and top clamp are created as rigid bodies. Elastomer and core share nodes on their boundaries and therefore they are fixed together.

Material constants of aluminum are given above. For elastomer an appropriate hyperelastic material model had to be set [7]-[12]. Using results from uniaxial tension, equibiaxial tension and pure shear tests of elastomer, material constants of some hyperelastic models were computed. The closest agreement with experimental data (i.e. minimal error) showed a "2nd Order Invariant" hyperelastic model [13]. The strain energy density function $W$ [14] of this model is as follows:

$$W = c_{10}(J_1^{-3}) + c_{01}(J_2^{-3}) + c_{11}(J_1^{-3}) (J_2^{-3}) + c_{20}(J_1^{-3})^2$$ (1)

where $J_1$ and $J_2$ are first and second invariants of right Cauchy-Green deformation tensor [15]. There is the comparison of this model and experiment in the Fig. 3. Material constants of this model are: $c_{10}=0.23264$ MPa, $c_{01}=0.16711$ MPa, $c_{11}=-0.0060978$ MPa and $c_{20}=0.01475$ Mpa.

To be as close as possible to reality, the loads are applied in two steps. The first step can be considered as a "Mounting of bushing on the stabilizer bar". During this step some deformation and stress of the bushing occurs and the model is in the state of initial "preload" at the end of the first step. During the second step required load is applied to the stabilizer bar.

All three degrees of freedom of displacement were constrained on surfaces of bottom part of elastomer, shown in Fig. 4, because these surfaces are fixed to the car frame. A symmetry conditions are set on symmetry planes (shown in Fig. 2) as a null displacement in planes normal directions. There is a contact defined between two rubber parts of bushing, between these parts and the stabilizer bar, and between these parts and clamp. No friction is defined between contact bodies.

The bushing mounting is done by the displacement of the clamp. The Clamp is moved down against to bottom part of bushing (i.e. radial direction). During this motion the clamp touch the top part of bushing first, and then shift it to the
stabilizer bar. Stabilizer can move only vertically (other two displacements are not allowed), and thus it is pushed into the bottom part of bushing and is clamped from the top by other part of bushing and by clamp.

Second Load Step

At the beginning of this step, "glue" contact type is defined between rubber parts and the rigid stabilizer bar. It means that stabilizer bar is fixed on the surfaces of the bushing during whole second step. It should be in accordance with reality when bushing is fastened on stabilizer bar. Vertical radial force \( F=2000 \) N is gradually applied on the stabilizer bar during second step. It should be remembered that this force is applied only to quarter model and thus the load of full model is four times larger (8000 N). Rigid clamp will remain in its final position from the first step and will not move during the second step.

III. RESULTS AND DISCUSSION

The main result is "Radial Stiffness" of the bushing. To compute this parameter the "loading radial force / radial displacement of stabilizer bar" relation was monitored (Fig. 5). The stiffness was determined in the range of loading from force \( F=4000 \) N to \( F=8000 \) N (as well as in the practical tests of a real bushing). Values of force above are given for the whole bushing (i.e. 1000 N and 2000 N for the quarter numerical model). The final value of the Radial Stiffness of the model is 11168 N/mm. Average value from the practical tests of a real bushing is 11190 N/mm.

In Fig. 6 there is a Von Mises equivalent of strain in the model shown. The deformation of the bushing at the end of the first load step (time=1.0) is shown in the first picture (a) and the deformation under the final radial loading of \( F=8000 \) N at the end of the second load step (time=2.0) is shown in the second picture (b). We can see critical point with the maximum strain of \( \varepsilon=0.71 \) at the end of first step.

Contrary the strain, the stress distribution is absolutely different. Stress is concentrated on the aluminum core and in its vicinity (Fig. 7). But because the stresses in the aluminum core do not reach the strength of the material, the core is excluded from the Fig. 7 and we can analyze the stress distribution in the elastomer only. Thus, we can see that the extreme stresses in the rubber part are located in the spaces of the core holes and that the stress values are very high here even at the end of first load step (time=1.0).

The reason of this is that the elastomer has no space where to run out during the loading (it is closed in the core hole). Similar situation occurs on the core surfaces where the
deformation of the elastomer is constrained by the aluminum core. It means that the critical point of the bushing is the surface of the core (especially in the holes) where the stress is concentrated during the loading, and therefore there is a high risk of tearing off the rubber from the core. Next risk, resulting from this issue, is the fact that this defect of bushing is closed inside the device and can not be observed from outside. Thus we need special diagnostic methods to find such failings.

IV. CONCLUSION

Based on the tests of material the appropriate hyperelastic model of elastomer was determined and the material constants were computed. Using this model, we are able to predict the behavior of the bushing under the radial loading. Even next modes of loading can be analyzed by this model and these analyses were carried out but they are outside the scope of this article and they will be published later. The suitability of the numerical model was approved by close agreement with the experiment of real bushing. Analysis of the model revealed the critical points of the bushing and its results will be used to future shape optimization of the product.

REFERENCES