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New Designed Bushings for Reaching Intended Stiffness Values and Their Analysis in Torque Rod of Heavy Commercial Vehicles

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Abstract

The combination of various parts designed to absorb shock and vibrations in all motor vehicles constitutes the suspension system. The torque rod with the bushings at both ends, an important component of the suspension system, is the connecting element used in heavy commercial vehicles to connect the axle to the chassis. Providing defined movements and isolating noise and vibrations of the torque rod and other suspension components can be achieved by the proper combination of metal and rubber. Rubber-metal parts (bushings and joints) contribute to the damping of axial and torsional loads and increase driving comfort. In this study, the stiffness values of the bushings of the torque rods which are used in heavy commercial vehicles were provided to be in the desired range. Geometric dimensions of the metal component and amount of rubber of the bushing was modified in order to improve the axial, radial, torsional and cardanic stiffness values of the bushings. The analyses were performed with the aid of FEM and dynamic test devices.

1. INTRODUCTION

The suspension system is a main vehicle component which directly affects the driving performance and comfort of the vehicle. The combination of various parts designed to absorb shock and vibrations in all motor vehicles constitutes the suspension system [1]. The torque rod with the bushings at both ends is an important component of the suspension system that connects axle to the chassis in heavy commercial vehicles (Fig. 1).

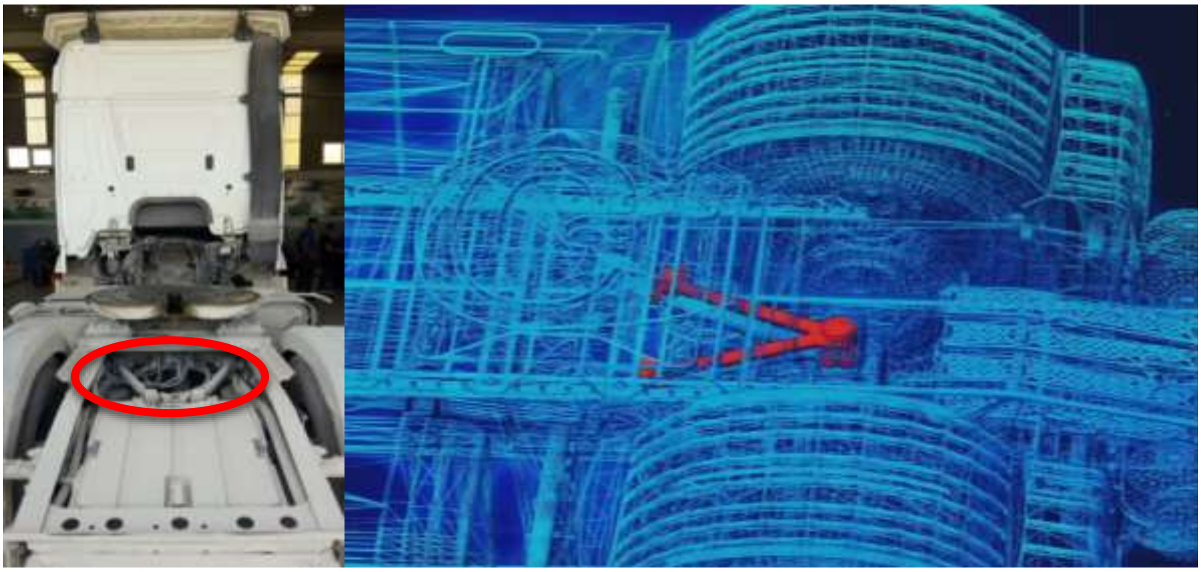

Figure 1. *Place of Use of the Torque Rods in Heavy Commercial Vehicles*

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The exerted forces from the road are transmitted by torque rod to the axle body. While some of these forces and vibrations are damped on the wheels, most of the vibrations are transmitted to the axle. The torque rod transforms these uncontrolled movements into the vehicle's body with low amplitude and limited oscillating movements, so as not to disturb the passengers' comfort. At the same time, the force produced by the engine, which gives the traction power to the vehicle, is transmitted to the wheels by means of the drivetrain. The inertia of the mass of the vehicle and the lateral forces caused by the negative effects of traction on the wheels and the cornering of the vehicle are transmitted to the vehicle body through suspension system and torque rod [2,3]. All forces shown in Fig. 2 are absorbed by transferring from the torque rod to the bushings in heavy commercial vehicles. Rubber-metal parts (joints and bushings) increase driving comfort contributing to the damping of axial and torsional load. Vibration of the vehicles can be improved with the proper combination of metal and rubber of torque rod [3,4].

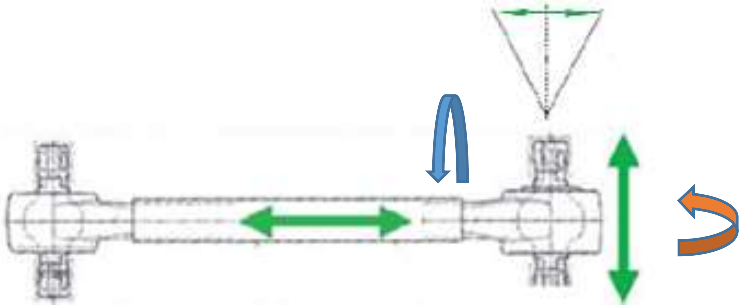


Figure 2. *General Forces on Torque Rods in Heavy Commercial Vehicles*

The bushing is a mechanical system which allows the two parts to move together without losing their mobility. The spherical bush can move at a certain angle in a cylindrical bearing [4, 5]. These bushings are widely used in many sectors such as defense and aerospace industry, automotive and rail systems. The bushing is to undertake the shocks that are transferred to the vehicle from the holes that a moving vehicle's wheels way fall into or bumps that they may come across. Thereby, bushing provides protection of the vehicle's mechanical parts and driving comfort [6,7].

There are different studies in the literature about the bushings. Öncü and Dova (2018) investigated the effect of calibration process on durability of rubber bushing. Finite element analysis was performed to determine the change of the static stiffness and calibration process in their study. The prototypes were produced to evaluate the accuracy of the material model used in the nonlinear analysis. The applied method was firstly tested radially under the analysis conditions and the results were compared. Durability test results show that durability performance gets improved when calibration ratio increases [8]. Güven et al. (2014) performed shape optimization of the rubber bushing's geometry used in vehicles. The bush geometries that provide the desired static stiffness curve were determined by shape optimization. In order to define the hyper elastic material model in the finite element model, material tests were performed and the hyper elastic material model was chosen. The bushing geometry is optimized through the function obtained with the experimental design method [9]. Uludamar et al. (2020) investigated the results of shortening of rod-end which was produced from C45+ N quality steel by comparing with the unmodified rod-end. For the comparison, fatigue test and Finite Element Analysis were performed. The results showed that the cropped part has almost no effect on the durability of the product. It is measured that the modification result with 0,082 kg weight reduction on each rod-end and 5 seconds shortening of machining process were observed by the modification on rod-end. As a result, weight reduction provides cost advantages by saving on machining time and raw material in their study [10]. Geren et al. (2017) developed for the parametric design of a ball joint using three dimensional (3D) modelling techniques to reduce design time and cost. The developed platform can be used for the design of part and assembly using top-down design approach. The major advantage of the proposed system is that the system can parametrically change assembly, part, part material, feature, geometry and dimensions in a programmable environment. This provides a wide range of alternative systematic solutions to design every parts of ball joints. Whereas, the current parametric systems, allow changes only in dimensions or parts of assembly in a library. The suggested approach and the platform have been tested to validate ball joint designs. The results demonstrated the practicability and validity of the proposed parametric system [11].

In this study, the stiffness values of the bushing of the torque rods used in heavy commercial vehicles were intended to be in the desired range. For this purpose, the distance between the radius centers of the metal bush part is reduced by 3 mm, so cross section of the metal bushing was reduced. The decreasing metal section was replaced by the rubber component, thus the rubber section increased while the metal section of the bushing decreased. The effect of changes in joint metal and rubber geometries and volumetric ratios on stiffness values were both analyzed by finite element method (FEM) and tested with dynamic test devices. Obtained results were investigated and compared.

2. MATERIAL and METHOD

In this study, the bushing was produced from DIN 41CR4 quality steel. Chemical composition of the steel was given in Table 1. Illustration of torque rod bushing which was evaluated through this study was shown in Fig. 3.

Table 1. *Obtained in Spectrometer DIN 41Cr4 Chemical Compounds*

C	Si	Mn	P	S	Cr
0.38-0.45	Max 0.4	0.6-0.9	Max 0.025	Max 0.035	0.9-1.2

Figure 3. *Torque Rod Bushing (Left) and Its Cutaway View (Right)*

Firstly, the steel part was placed in vulcanization die. Then, rubber was injected into die and waited for a certain time, and bushing is obtained with vulcanization process. After the deburring process, the molded bushings were subjected to torsional, cardanic, radial and axial stiffness tests as well as mechanical strength tests. The measurements were performed at Ditaş R&D test center. Test parameters to be applied are schematically shown in Figure 4 and test conditions were given in Table 2. Test setup for radial stiffness is also shown in Figure 5. Here, the bushing was mounted on the torque arm and the force was applied in the direction of the torque arm axis during test. All tests were performed with SincoTec high speed test machine with 250 kN and 50 Hz capacity at room temperature.

Table 2. *Reaction Rod Stiffness Test Conditions*

TESTS	CYCLES	AMP (KN/°)	FREQ (Hz)	WAVE FORM
CARDANIC STIFFNESS	Reading at 5 Cycles	10°	0.05	SINE
TORSIONAL STIFFNESS		10°		
AXIAL STIFFNESS		±50 KN		
RADIAL STIFFNESS		±50 KN		

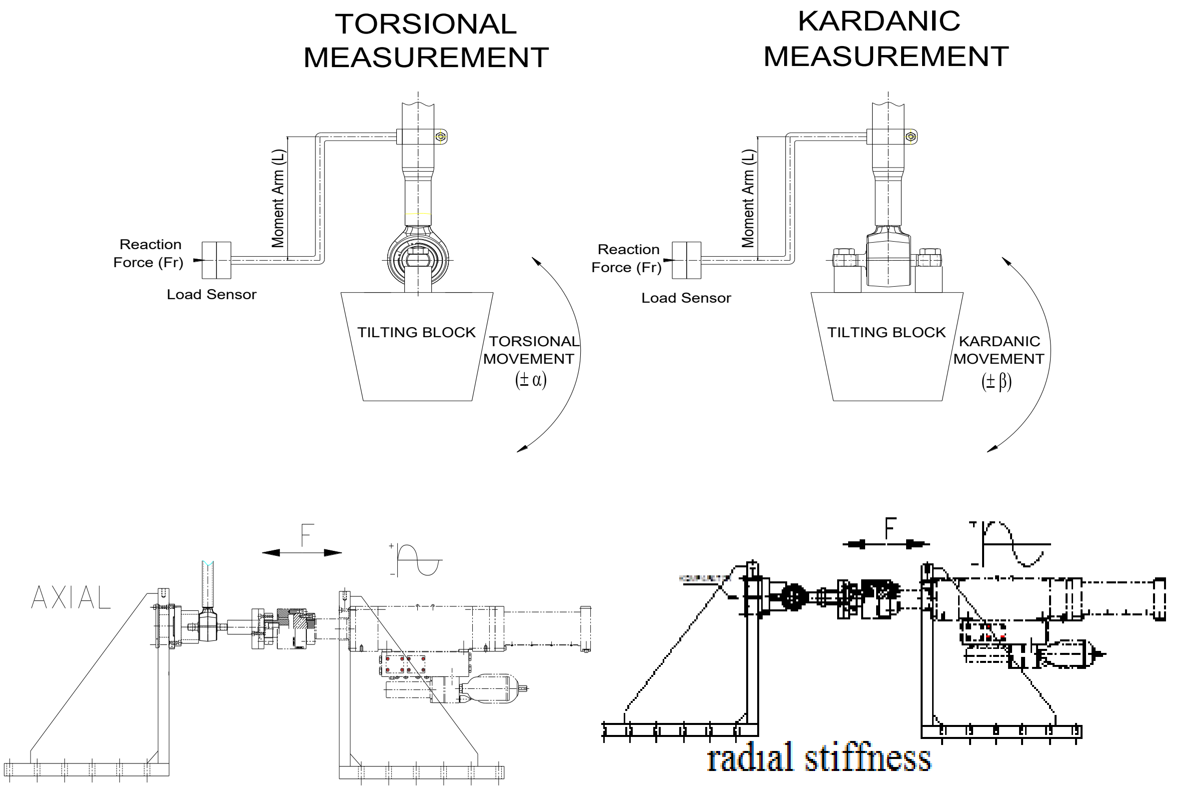
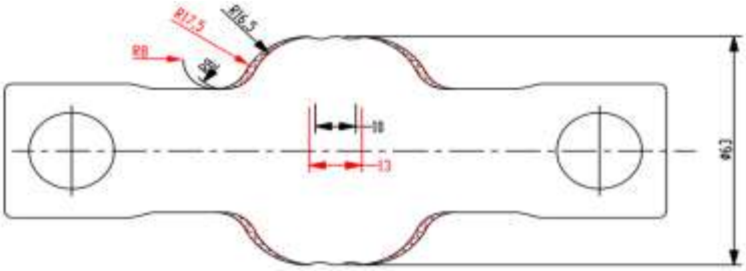


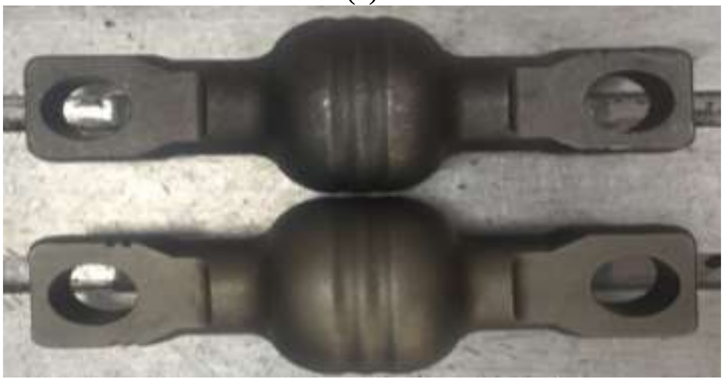
Figure 4. *Measurement Parameters of Reaction Rod Torsional, Cardanic, Radial And Axial Stiffnesses*

Figure 5. *Test Setup for Radial Stiffness*

In this study, two various design of bushing's metal component were compared. The names of the designs were named as new and old design. The designs were in Figure 6. Dimensional changes between old and new designs are shown in Figure 6.a. Also, old design metal bushing was illustrated as red colored. The distance between the radius centers of the metal bush part is reduced from 13 mm to 10 mm, and radius size of spherical region in metal bushing was changed from 17.5 to 16.5 mm, so cross section of the metal bushing was reduced as illustrated in Figure 6. In addition, the difference between the old and the new design is clearly shown at the Figure 6.b.



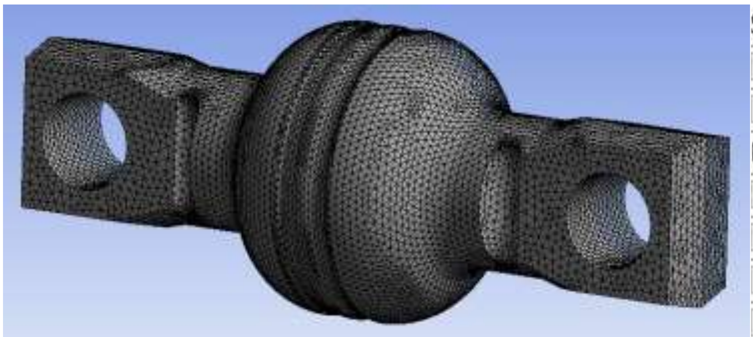
(a)



(b)

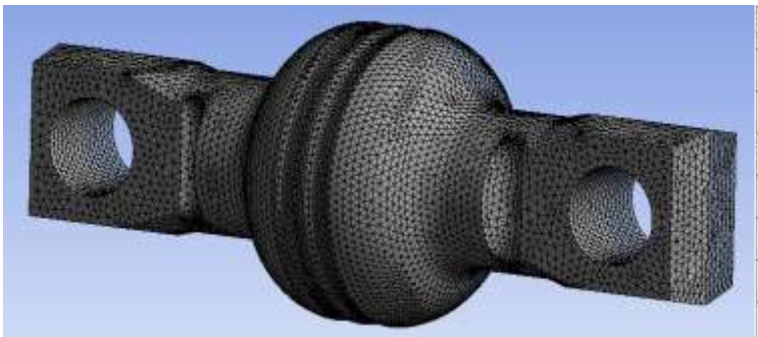
Figure 6. *a) Comparisons of Design Changes Made in Bushing Metal Component (Old design was shown as red colored) b) Its New Design (top) and Old Design (bottom)*

Proper meshing operation on geometry is an essential parameter for reducing error in numerical calculations. For the geometries that evaluated in this study, tetrahedral elements performed better result and reduced mathematical error. Properties of mesh were shown in Figures 7 and 8 for old and new design, respectively.



Statistics	
Nodes	762761
Elements	545596
Mesh Metric	Element Quality
Min	0,068140865137184
Max	0,999987386484088
Average	0,833111493599798
Standard Deviation	9,95119771993885E-02

Figure 7. *Structural mesh and element quality of the old design metal form of the bushing*



Statistics	
Nodes	744101
Elements	531711
Mesh Metric	Element Quality
Min	0,127529754035289
Max	0,999989819479412
Average	0,833413239167165
Standard Deviation	0,100218626474329

Figure 8. *Structural mesh and element quality of the new design metal form of the bushing*

3. RESULTS

Before the usage of finite element method (FEM), the mechanical properties of DIN 41Cr4 quality steel was revealed in order to enter the properties in FEM software. The result of Stress-Strain graph of the product was shown in Fig. 9.

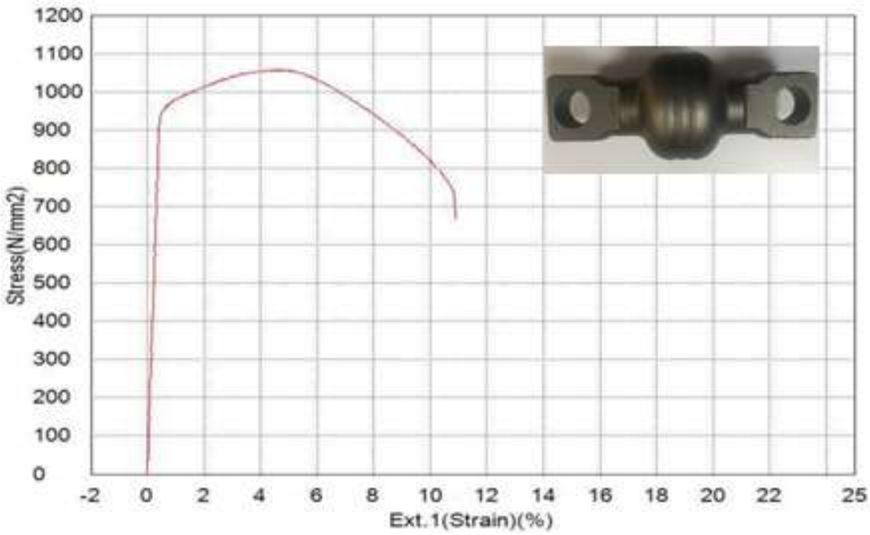


Figure 9. *Obtained in Tensile Testing, Stress-Strain (%) Graph of DIN 41Cr4 Steel Material*

After the properties were entered and mesh operation was performed, boundary condition of the bushing was applied as fixing from assembly holes and 50 kN tensile force from spherical form. Von-Mises stress distribution of old and new design was illustrated in Figures 10 and 11, respectively. According to results, stress concentration was occurred at notch areas as expected. 444 MPa was calculated as highest von-Mises stress on the geometry and 1,3877 was found as minimum safety factor. Also, the stress was occurred as 100 MPa in modified region. In addition, 671 MPa stress is not represent true von-misses value due to ANSYS calculation matrix error at the sharp corner which caused stress increment. Because of this reason, these nodal error locations on model are ignored.

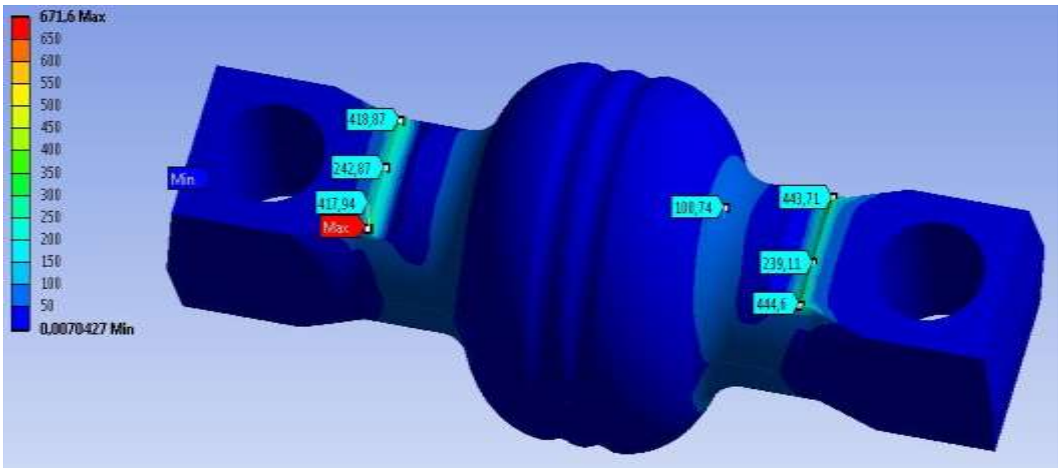


Figure 10. *Stress Distributions on Metal Part of the Old Designed Bushing*

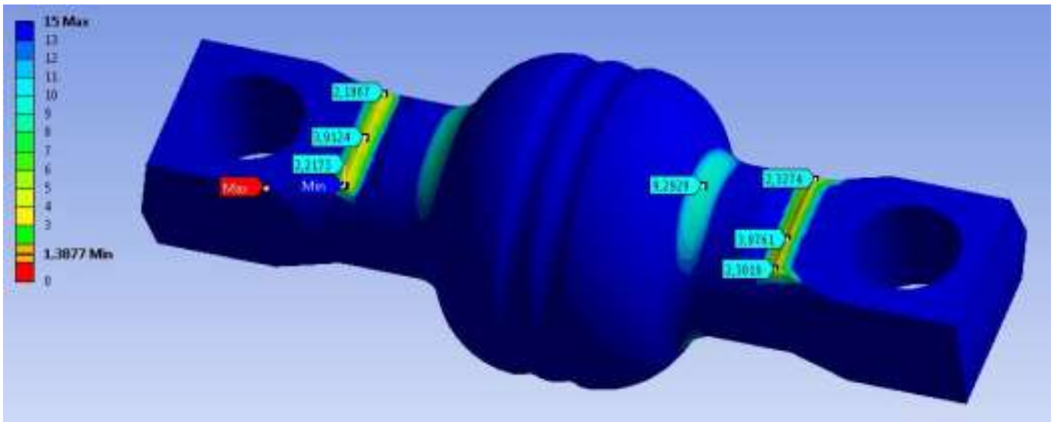


Figure 11. *Safety Factor Distributions on Metal Part of the Old Designed Bushing*

Von-Mises stress distribution of new design was given in Figure 12 and safety factor distribution was shown in Figure 13. Highest stress was found as 444 MPa in the new design. However, it was occurred as 120 MPa in the modified region. 20 MPa increment of von-Mises stress did not showed significant reduction on the safety factor. The calculation was verified with the physical tests which were performed in R&D test lab. By this means, stiffness values would increase without any significant reduction on the strength of the part.

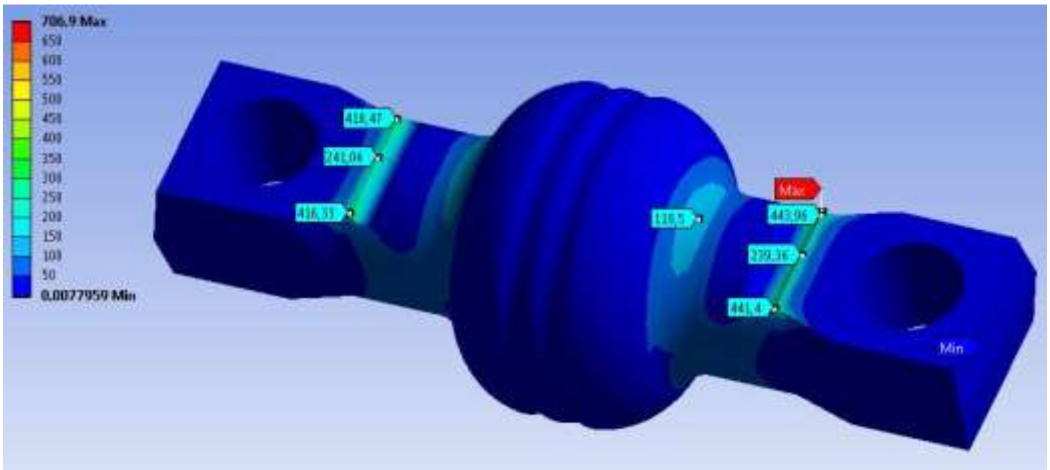


Figure 12. *Stress Distributions on Metal Part of the New Designed Bushing*

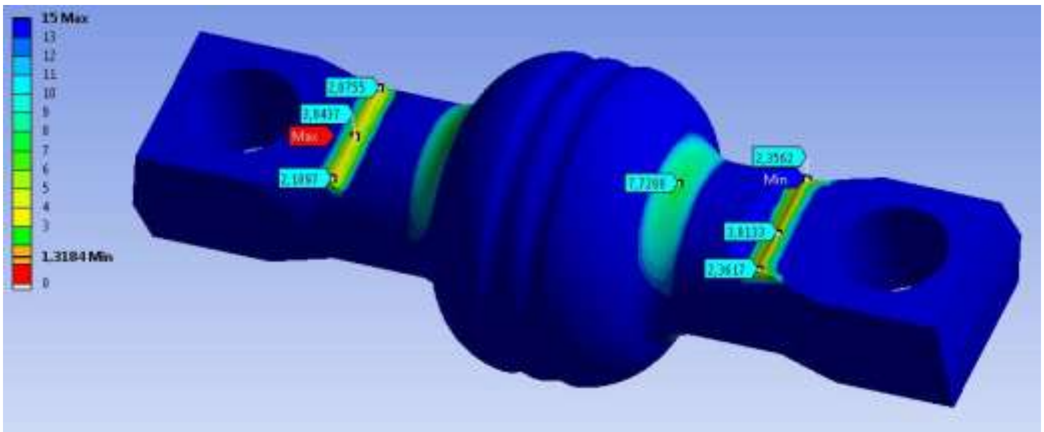


Figure 13. *Safety Factor Distributions on Metal Part of the New Designed Bushing*

Safety factor of both designs was occurred as close to each other at the critical region. This result indicates that the behavior of both designs was almost the same under applied force. Moreover, high stiffness values were obtained by modifying the geometry of bushing. The obtained stiffness values were given in Table 3. This 5% cross sectional change in the design reduces the cardanic and torsion stiffness values by 20% while reducing the radial stiffness value by 15%.

Table 3. *Stiffness Values of New and Old Design Bushings*

Part		Cardanic (Nm/°)	Torsion (Nm/°)	Axial (kN/mm)	Radial (kN/mm)
Old Design Bushing	1	60	57	24	88
	2	61	58	26	85
	3	58	58	24	90
	4	63	56	25	87
	5	60	57	24	86
	Avg.	60.4	57.2	24.6	87.2
New Design Bushing	1	52	40	25	77
	2	49	39	24	75
	3	48	38	23	74
	4	53	41	23	76
	5	51	40	23	76
	Avg.	50.6	39.6	23.6	75.6
	Target	47-53	37-43	22-28	72-78

4. CONCLUSION

In conclusion, the stiffness values of the bushings of the torque rods which are used in heavy commercial vehicles were provided to be in the desired range. Geometric dimensions of the metal component and amount of rubber of the bushing was modified in order to improve the axial, radial, torsional and cardanic stiffness values of the bushings. The analyses were performed with the aid of FEM and dynamic test devices. It was obtained that desired stiffness values have been reached without any significant change in the strength of bushing. As a result, the stiffness values of the bushings may increase and decrease depending on changes on the metal and rubber cross sections. With this study, changes in stiffness values were evaluated after design changes on the metal part of bushing.

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CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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