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# Analyzing Bushing Model from Optimized Numerical Model Stiffness to Improve Vehicle Noise Performances

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**Abstract:** Bushings material described as a hollow elastomer cylinder connected to the suspension system and vehicle chassis which act as strain energy potential where it dissipates energy between the components. The increased demand of the road safety and riding comfortability in a vehicle design makes noise levels an important parameter when producing new commercial vehicles. In this study, the idea of the optimized bushing stiffness where its numerical model is modified were proposed initially. The method is by optimizing the numerical model through MATLAB quadratic optimization programmed by the previous researcher which were designed and analyzed to make a comparative study to the initial proposed design through a series of static and frequency (natural frequency) analysis in the Solidworks 2020. This study shows when a force of 800kgf is applied in the static analysis, the optimized rubber bushing produced better results where the stress and strain distribution on the model looked more stable. This result is supported by the natural frequency analysis where optimized rubber bushing (model 2) produce better vibration frequency and achieved higher frequency of vibrations where its axial vibration was 553.13 Hz and torsional vibration of 608.76 Hz. When compared to the initial design (model 1) it was measured that its axial vibration produced 474.66 Hz and torsional vibration of 578.04 Hz. Hence, it shows the reliability of the optimized rubber bushing in terms of vibrations and deformation results. Bushing stiffness alterations is one of the reliable methods in terms of costing and time consumption as it is only required the modification of the rubber bushing material stiffness in comparison to the other method when working to reduce the vehicle noises and improve riding comfortability.



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## 1. Introduction

Rubber isolator is extensively used in automotive engineering for vibration attenuation and noise reduction owing to its merits such as low cost, damping property to dissipate energy and simple structure [1]. The vehicle engine and chassis are subjected to various vibratory disturbance. Rubber bushing (isolators) are design specifically to overcome this problem where disturbance from road noise and vibrations are to be reduced. The increased demand of the road safety and riding comfortability in a vehicle design makes noise levels an important parameter when producing new commercial vehicles.

Therefore, bushing stiffness with improved numerical models is being investigated by many researchers to be applied in the current material and designs with the ambition of the industry to have better riding efficiency and comfortability. The analyzed bushing model from previous researcher where the modification of the numerical values in bushing was made is design and undergone the finite element analysis (FEA) of the model. The FEA is established as the universal accepted analysis in structural design which leads to the construction of discrete system of a matrix equation to represent the mass and the stiffness effects of the continuous structure [2]. Hence, in this study the proposed initial design and the optimized rubber bushing are design and made undergone simulations of FEA which will leads to the comparative study between both designs to show the influence of applying bushing stiffness method to the vibration study of the rubber bushing model which eventually leads to the reduction of the road noise.

### 1.1 **Rubber Bushings Model**

Basically, rubber bushings composed of hollow elastomer cylinder which built with inner and outer cylindrical steel sleeves. Components from suspension system are connected to the sleeves which forces are transmitted across the connection through the elastomeric material which reduces shock and vibrations [3]. The basis movement of the rubber bushings includes radial, torsional and combined radial-torsional deformations. The traditional method to characterize rubber material constitutive laws is evaluated through the sets of experimental data of different types of deformation. Uniaxial tension, planar tension and biaxial tension are common test as the recommendations to identify the model parameters [4]. Rubber bushings model or design needed to undergo the finite element analysis (FEA) to analyze it vibratory characteristics so that study could be done on that particular topic to further reduce the vehicle road disturbance or particularly road noises. The hysteresis loop contained by the loading and unloading curves in a stress–strain diagram represents the elasticity and capacity for dissipating vibration energy of rubber materials, which is represented in a stress–strain diagram by the hysteresis loop contained by the loading and unloading curves. In the past, there were several restrictions to representing rubber bushing dynamic stiffness in the frequency domain, such as amplitude difference [5]

### 1.2 **Optimization of Rubber Bushings**

In order to perform optimization, initial values and boundaries need to be addressed properly. First the design variables and objective function needed to be defined. The improvement of the vehicle noise can be defined by comparing initial acquisition noises data and after the optimized (dynamic stiffness) noise [6]. Equivalent shear modulus is needed to make the stiffness works which equivalent strains give total stresses made up from three components which are elastic, frequency dependent and frictional stresses. It is effective to change the stiffness of the rubber mounts between the suspension system and body in a transmission path of source vibration [7]. The important task of suspension design is to control elastic kinematics of the system and make a benefit improvement to the driving stability and both analyzes suspension kinematics and elastic [8] which can be done by the optimization of rubber bushing.

### 1.3 **Noise Reduction**

Rubber bushing stiffness provides many impacts, not just towards NVH levels but also the behavior of interactions between the vehicle components and also towards ride comfortability. The effects of suspension bushing stiffness in vehicle yaw response resulted to alteration of suspension kinematics elasticity which can improve driving direction stability [8]. Even with 5 to 10% of percentage stiffness optimization, the riding comfortability can be significantly noticed and vehicle noise can also be improved with optimization of rubber mount.

## 2. **Methodology**

This paper study the influence of the optimized rubber bushing numerical model shown through FEA analysis of the modified rubber bushing designs. The numerical model was optimized by previous researcher in MATLAB software while the FEA analysis of the rubber bushings is analyzed through Solidworks 2020. The initial design of rubber bushing was proposed and designed in the Solidworks 2020 followed by the design model of the optimized rubber bushing with specific shear modulus were implemented. The parameters of the proposed and optimized rubber bushing are shown in the Table 1 and Figure 1 shows the flowchart design of this simulation study.

**Table 1: Proposed model Structural Parameter Values & Optimal Values given by the Optimization [2]**

| Design Variables | | | |
|---|---|---|---|
| | Proposed | Optimized | |
| Inner Radius, a | 10 mm | 11.8902 | 11.9 mm |
| Outer Radius, b | 25 mm | 23.8979 | 23.9 mm |
| Length, L | 60 mm | 64.9193 | 65 mm |
| Shear modulus | 1 MPa | 1.1214 | 1.1 MPa |

The initial proposed design was selected as it was earliest design for vehicle bushing which only consist of inner radius and outer radius which then extruded in at 60mm and the optimized parameters generated were the best ones to study the multitargets vibrations. A comparative study can be made through two sets of simulations from the proposed and optimized design model of rubber bushings. The focused were to study the stress-strain and deformation of the model through the natural frequency analysis. The designs of both



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models were meshed by using standard meshing that usually tends towards finer course of meshing.

### 2.1 **Methods of FEA analysis**

The whole design was designed in the Figure 1, where two FEA simulations study in the Solidworks software. The static analysis of both designs was studied where the limitations of the designs were set the inner sleave as the fixed geometry and the outer sleave were to applied with 800kg of force on both designs. The stress-strain and the deformation studies of the model can be achieved with this method. Furthermore, the deformation of the models through natural frequency analysis was also done on both designs where the inner sleave and fillet part of the rubber bushings was made as fixed. The results to these simulations are to be discussed further.

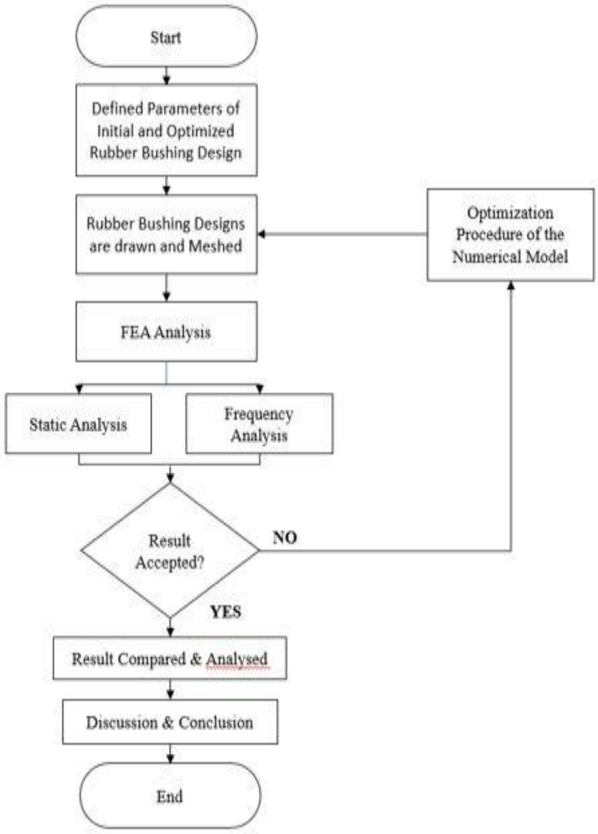


**Fig. 1: Flowchart of the Whole Simulation Study**

### 2.2 **Numerical Model Optimization Steps**

The optimization procedure required to use the quadratic optimization command provided in MATLAB R2021a. Initial boundaries values for bushing stiffness variables is defined properly with bushing stiffness and vehicle noise to be considered as design variables and objective function respectively. Taylor series expansion can be utilized in this study to estimate the numerical of the objective function which can help to predict the influence of the bushing stiffness on vehicle noises.

$$f(x,y) = f(x_0 y_0) + f_x(x_0,y_0)(x-x_0) + f_y(x_0,y_0)(y-y_0) + \frac{1}{2!}\left[f_{xx}(x_0,y_0)(x-x_0)^2 + 2f_{xy}(x_0,y_0)(x-x_0)(y-y_0) + f_{yy}(x_0,y_0)(y-y_0)^2\right] \quad (Eq. 1)$$

The subscript of x can be considered as a vehicle noise and y as bushing stiffness in the function, f. To save the computational cost, approximated of the Eq. 1 by using finite difference method could be used where it construct the objective function.

## 3. **Results and Discussion**

The results analysis of the simulations was collected and in this section. The designs of the rubber bushings were drawn according to the parameters proposed in Table 1. To achieve the objective of this study, the results of both design analysis were compared. As mentioned in the methodology sections the simulation design was applied during this analysis so we could measure and evaluate the static analysis and the frequency analysis through the vibration distribution on the axial and torsional of both designs.

### 3.1 **Static Analysis of Rubber Bushings**

The initial proposed design of rubber bushing and the optimized bushing were drawn and simulated in Solidworks 2020 and the results could be seen that the stress and strain output was increased respectively. Both the designs were meshed by using standard meshing. The minimum stress output generated by the initial design were 1.350e $N/m^2$ and 8.282e $N/m^2$ respectively. Meanwhile, for the optimized bushing design, the value of stress output was increased but lower in nodes where the minimum and the maximum stress were 1.870e $N/m^2$ and 1.089e $N/m^2$ respectively.

As for the strain analysis (ESTRN) of both designs, the maximum strain distribution of the designs was 1.526e-01 and 1.656e01 respectively. It could be seen that the stress and strain analysis on the optimized bushing designs was greater. However, the distributions were better and evenly distributed on this design as it can be proven through the analysis of displacement/deformation analysis on both designs. Figure 2 shows the results deformation of both design where the deformation on the initial design was greater in comparison to the optimized rubber bushings where it only deforms slightly at the edge of the outer sleave.


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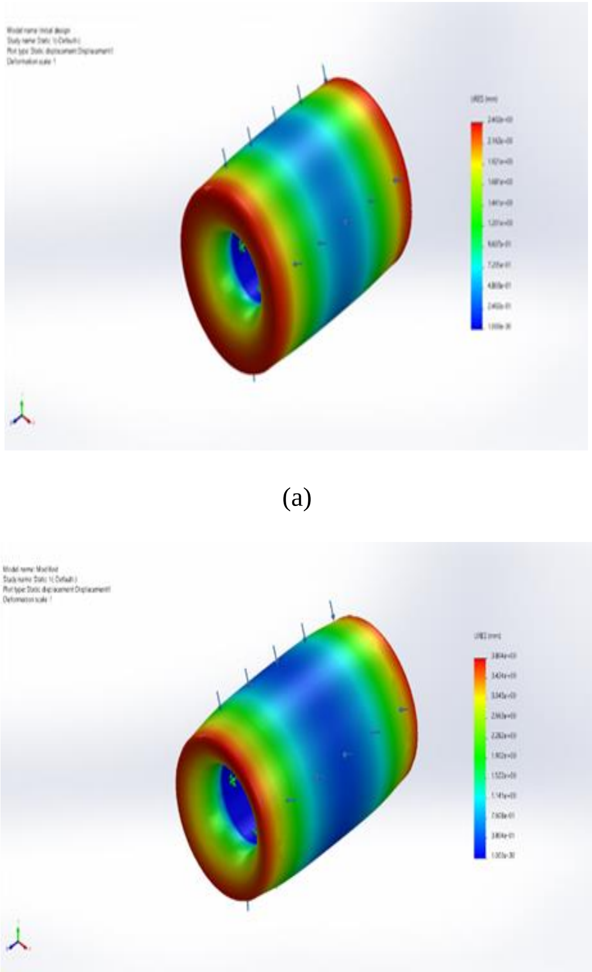
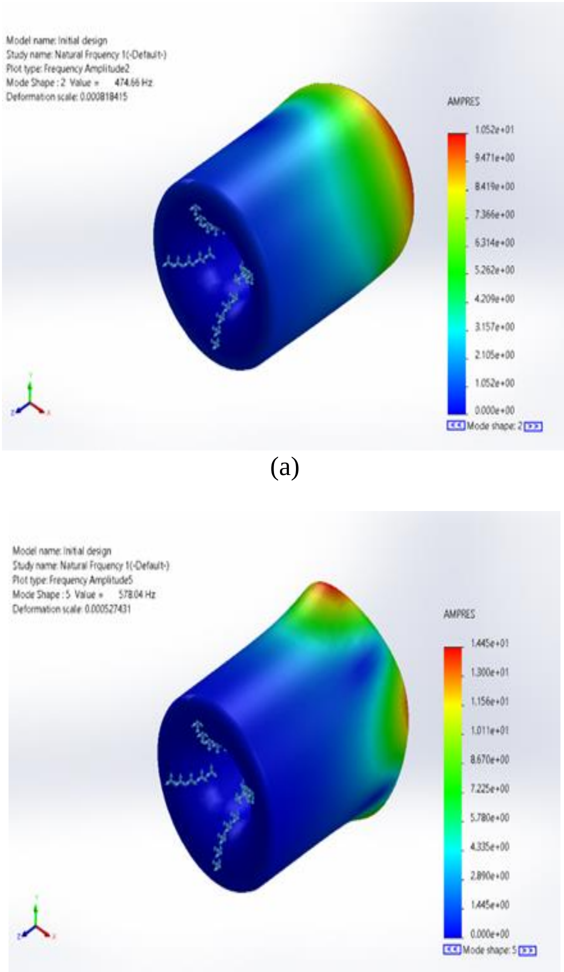


(a)

(b)

**Fig. 2: (a) The Deformation of the Initial Proposed Rubber Bushing Design (Model 1), (b) The Deformation of the Optimized Numerical Design of Rubber Bushing (Model 2)**




(a)

(b)

**Fig. 3: (a) The Axial Vibration of the Initial Bushing Design, (b) The Torsional Vibration of the Initial Bushing Design (Model 1)**

### 3.2 **Dynamic Analysis (Natural Frequency) of Rubber Bushing**

Dynamic analysis of the rubber bushings was done on both initial and optimized design. The amplitude study of this simulation was set at 5 different modes and the study made on this paper at two important vibration distribution which are axial and torsional vibration. The natural frequency of the rubber bushings was recorded, measured and compared. First, the geometry was set fixed for both design at the inner sleave and at the fillet side of the rubber bushings. The meshing used were standard meshing for both design where the total nodes for the initial and optimized design of rubber bushing were set at 10923 and 11951 respectively. Meanwhile, the total elements were 6959 and 7468 respectively. The study was also set to study at five different amplitudes and modes so that we could see the vibrations at different modes.

The frequency amplitude axial and torsional vibration of the initial bushing design were recorded at 474.66 Hz and 578.04 Hz respectively. For comparison to the optimized rubber bushing design it was analyzed that the frequency amplitude of the optimized version was higher measured at 553.13 Hz of axial vibration and 608.76 Hz of torsional vibration respectively. Because of the rubber characteristics, the static rigidity of rubber bushing is nonlinear. The difference in vibrations produced between both designs were different because both were different in geometry or parameters. Vibrations from the component can cause resonance to other components. Hence, larger natural frequency should be achieved by this component to improve the balancing between those components [9]. By this results it is safe to say that the optimized rubber bushing design produce better deformation distribution in comparison to the initial design. As shown in Figure 3, the axial and torsional deformation of the initial bushing design was seen greater compared to Figure 4 where the axial and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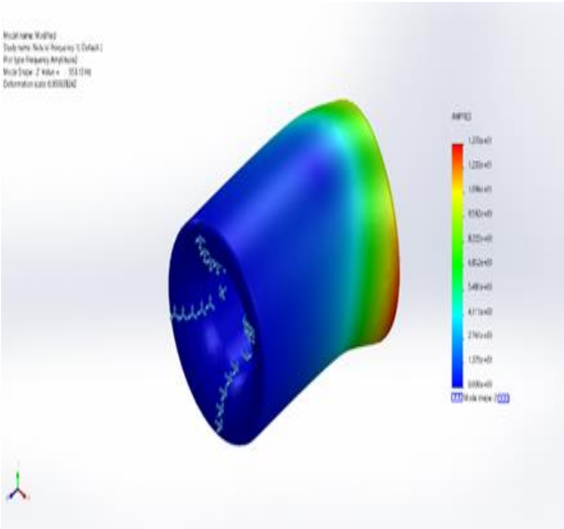
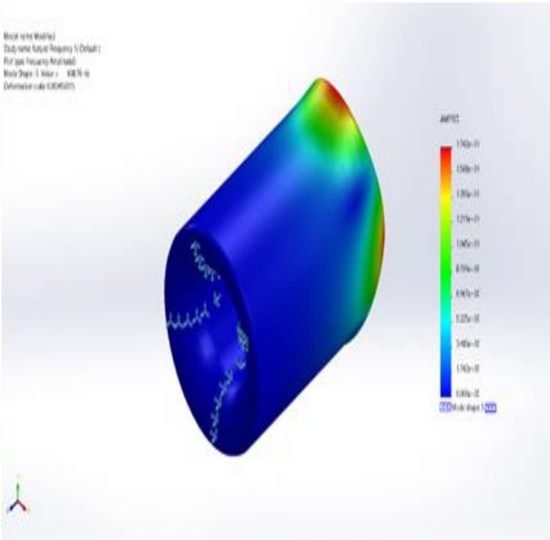
torsional deformation of optimized bushing lies. Hence, it shows that with optimized numerical model of rubber bushing the noise reduction in vehicle can be achieve.



(a)



(b)

**Fig. 4: (a) The Axial Vibration of the Optimized Bushing Design, (b) The Torsional Vibration of the Optimized Bushing Design (Model 2)**

## 4. Conclusion

In conclusion to the simulations done, the numerical optimization of rubber bushing can greatly support the idea of reducing vehicle noise and increasing riding comfortability. The results show that the static analysis of the optimized rubber bushing produced increasing stress and strain distribution values but better deformation results throughout the design when compared to the initial proposed design. The findings also indicated higher natural frequencies produced in optimized rubber bushing where its axial and torsional vibration produced shows better stability. Eventhough, the material used on both designs were the same which both static rigidities are nonlinear, the results of natural frequency vibrations produced should be larger in the optimized bushing model (model 2) where the resonance between components could be avoided or reduced. The study also could see that the deformation results were greatly seen on the initial proposed design (model 1). Hence, this shows rubber bushing stiffness optimization can greatly improved the vibrations and riding comfortability.

In the future, it is recommended to make a sequential of quadratic programming method on the numerical approximation optimization procedures with the increment of percentage as it is one of the global optimization procedures. As the optimization is done, it should be further studied onto vehicle model in any of the multidisciplinary structural analysis application such MSC Nastran to study the noise characteristics resulted onto vehicle model.

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