Response of rubber based engine mounts with SBR as the core rubber.

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Abstract. Nowadays the most important and basic requirements of automotive industry are vehicle stability, driving ability, and passenger comfort; and all of these need the control of vibrations to some extent. Engine is main source of power to a vehicle but it produces vibrations, thereby reducing the performance of a vehicle. These vibrations can be eliminated by the use of engine mounts, using which an engine is mounted on the chassis of the vehicle. Its basic function is to rightly hold the engine and transmission system on chassis of the vehicle. A good engine mount should firstly isolate the engine vibrations caused by engine disturbances and next they should isolate the transfer of vibrations from engine to chassis and reversely. In view of this an attempt is made to study the performance of two elastomeric engine mounts of two separate origin with SBR (Styrene Butadiene Rubber) as their core rubber, laying main focus on their vibration isolation characteristics. The selected engine mounts are elastomeric mounts for a heavy commercial vehicle with rubber as core to resemble a sandwiched structure. In the present work firstly the damping properties and vibration isolation characteristics of SBR are identified by using a sandwiched structure. Then the engine mounts are modelled using this SBR as a Hyper-elastic rubber using the best fit Hyper-elastic material model. SBR is selected due to its wide range of applications in automobile industry. The performance of two engine mounts is studied for static, harmonic and time varying loads.

Keywords: Engine mounts; Elastomeric mounts; SBR; Hyper-elastic; Time varying loads.

1. Introduction

In a vehicle, engine which is the main source of power is a heavy mass which may vibrate due to reasons such as non-uniform gas pressure in the combustion chamber, unbalanced rotary and reciprocating parts of the engine. Therefore these vibrations can be reduced or eliminated by the use of engine mounts. An engine mount is placed between engine and the chassis and performs important functions such as supporting the weight of the engine, isolating the vibrations produced by engine to chassis and isolating the transmission of vibrations to the engine due to road surface excitation. To remove or reduce these kind of disturbances a low damping and low elastic stiffness is needed which can be obtained when the engine mount stiffness coefficient is low, which in turn can be achieved by incorporating rubber as their core element [2]. Different types of engine mounts have been developed till now such as elastomeric mounts, passive hydraulic mounts, semi-active and active mounts each
designed to fit desired applications. With modern vehicles a reality now, the vehicles have become lighter in weight but engine has become more power intensive and because of this there is still demand for improvement in engine mounting system.

2. Relevance of rubber in damping
Damping of vibration in automotive and other industrial fields has been an area of focus for improving the life of a particular component. The damping materials are usually made of natural rubber with some reinforcement because of its tendency of increased elastic modulus, tensile strength and hysteresis. The behaviour of this rubber is generally hyper-elastic which is characterised by large deformations and strains [4]. A no. of mathematical models has been developed by many researchers to model the hyper-elastic behaviour of rubber. Hyper-elastic is type of constitutive model for rubber like materials, and provides a method of specifying their behaviour which cannot be exactly specified by using linear elastic models. These Hyper-elastic models are based on strain energy density function that relates strain energy density of a material to its deformation gradient. Rubbers can withstand high strains without failing because they have long molecular chains and properties such as extensibility, resilience, and durability.

3. Objectives and methodology of the work
Following the trend in which physical prototyping is being replaced by virtual prototyping and numerical simulations, the main objective of this work is to study the performance of two separate elastomeric engine mounts with SBR as their core rubber and to identify the performance in terms of vibration isolation characteristics i.e. how these two mounts behave under static, harmonic and time varying loads with SBR as core rubber. As far as methodology is concerned, firstly the damping properties of SBR are identified by conducting simple experiments on sandwiched structures incorporated with SBR. Two cases are considered one is structural steel sandwiched between SBR, second is SBR sandwiched between structural steel, and Then static and impact analysis is carried out using different Hyper-elastic material models to identify the damping properties of SBR also to identify the best suited Hyper-elastic material model. Then the two engine mounts are modelled by considering their rubber part as SBR which is modelled as a Hyper-elastic rubber using Yeoh 1st order as the best fit Hyper-elastic material model. The modelling part was done using design software UG-NX and later imported to Ansys workbench 18.1 for analyses purpose.

4. Brief description of engine mounts considered.
In heavy vehicles with the help of engine mountings an engine is mounted on the chassis of the vehicle, they are made in such a way that they reduce or isolate the transfer of vibrations from engine to chassis and vice versa. In a heavy vehicle, engine rests on four engine mounts so ¼ of engine weight is taken by each mount.

4.1 engine mounting 1
The first engine mount considered is shown, it consists of two rubber cores sandwiched between structural steel to resemble a double sandwiched structure. These are designed to suit heavy commercial applications such as commercial trucks and busses.

4.2 engine mounting 2
The second engine mount considered is shown, it consists of a single rubber core sandwiched between structural steel resembling a sandwiched structure. These are also designed to suit heavy commercial applications such as commercial trucks and busses.
5. Experiments on sandwiched structures with SBR

A set of experiments are performed on sandwiched structures with SBR, the sandwiched structure is a cantilever beam with two different considered cases, one is structural steel sandwiched between SBR and second is SBR sandwiched between structural steel. The geometry is such that in 1st case a structural steel cantilever beam of \((l*b*h) = (100*10*10)\) cm is sandwiched or supported on top and bottom by a SBR layers whose thickness is varied as 0.5, 1 cm. In 2nd case SBR specimen whose thickness is varied as 8,9 cm is sandwiched by structural steel layers of \((l*b*h) = (100*10*1)\) cm. These geometries of sandwiched structures were inspired from the geometry of engine mounts itself.

5.1 Static Analysis.

The sandwiched structures without SBR and with varied thickness of SBR are subjected to static load of 100 N on the top face, and then deformation of sandwiched cantilever beams is noted in each case so as to get a clarity of how SBR damps static loads, it was observed that there was a considerable reduction in deformation when structural steel is sandwiched between SBR. It was also observed in the 1st case that with increase in thickness of SBR there was a reduction in deformation, but in the 2nd case varied results were observed due to the reason that since the rubber is occupying larger part of the structure it might have undergone a large amount of deformation.

Table 1. Deformation values (mm) for 1st case sandwiched structures for static loads.

| Solid without any protective layer : Displacement = 14.272 mm | Mooney Rivilin - 2 parameter. | Ogden 1st order. | Polynomial 1st order | Yeoh 1st order |
|--------------------------------------------------------------|-------------------------------|------------------|----------------------|----------------|
| 1. Solid + (0.5cm) sbr                                       | 7.8121                        | 12.618           | 7.8357               | 6.6313         |
| 2. Solid + (1 cm) sbr                                        | 5.6199                        | 10.987           | 5.7270               | 5.8400         |
Table 2. Deformation values (mm) for 2nd case sandwiched structures for static loads

| SBR without any protective layer | Mooney Rivlin - 2 parameter | Ogden 1st order | Polynomial 1st order | Yeoh 1st order |
|---------------------------------|-------------------------------|-----------------|----------------------|----------------|
| 1. Solid + (8cm) sbr            | 15.673                        | 17.41           | 19.35                | 17.279         |
| 2. Solid + (9 cm) sbr           | 17.008                        | 19.139          | 14.98                | 15.706         |

![Graph showing deformation values](image)

Figure 5. Variation of deformation in sandwiched structures for static loads.

5.2 Impact Analysis.
The sandwiched structures with and without SBR are subjected to dynamic loads to assess the behaviour of SBR under impact loading conditions, and see whether SBR has characteristics or properties to damp the structures in case of dynamic loading. Here the sandwiched cantilever beams are impacted with a structural steel sphere of 4kg, which is dropped from a height of 0.5m with velocities of impact varied as 10, 20 m/s. Different Hyper-elastic material models are considered during the analysis to identify the best fit Hyper-elastic material model.

Table 3. Deformation values (mm) of 1st case sandwiched structures for impact loads at 10 m/s.

| Solid without any protective layer | Mooney Rivlin - 2 parameter | Mooney Rivlin - 3 parameter | Ogden 1st order | Ogden 2nd order | Ogden 3rd order | Neo-Hookean 1st order | Yeoh 1st order | Yeoh 2nd order | Yeoh 3rd order |
|-----------------------------------|-----------------------------|-----------------------------|-----------------|-----------------|-----------------|----------------------|---------------|---------------|---------------|
| 1. Solid + (0.5cm) sbr            | 20.121                      | 20.338                      | 20.266          | 20.441          | 20.443          | 20.229               | 20.193        | 20.162        | 20.126        |
| 2. Solid + (1 cm) sbr             | 18.593                      | 19.202                      | 19.466          | 19.451          | 19.453          | 19.095               | 19.055        | 19.051        | 19.057        |
Table 4. Deformation values (mm) of 1st case sandwiched structures for impact loads at 20m/s.

|                      | Mooney Rivlin 2 parameter | Mooney Rivlin 3 parameter | Ogden 1st order | Ogden 2nd order | Ogden 3rd order | Neo-Hookean 1st order | Neo-Hookean 2nd order | Neo-Hookean 3rd order | Yeoh 1st order | Yeoh 2nd order | Yeoh 3rd order |
|----------------------|----------------------------|----------------------------|-----------------|-----------------|-----------------|-----------------------|-----------------------|-----------------------|----------------|----------------|----------------|
| Solid + (0.5cm) sbr  | 24.12                      | 24.131                     | 24.22           | 24.22           | 24.219          | 23.971                | 23.937                | 23.92                 | 23.913         |                 |                 |
| 2 Solid + (1 cm) sbr | 22.829                     | 23.173                     | 23.622          | 23.622          | 23.623          | 23.042                | 23.065                | 23.065                | 23.078         |                 |                 |

Table 5. Deformation values (mm) of 2nd case sandwiched structures for impact loads at 10m/s.

|                      | Mooney Rivlin 2 parameter | Mooney Rivlin 3 parameter | Neo-Hookean     | Ogden 1st order | Yeoh 1st order |
|----------------------|----------------------------|----------------------------|-----------------|-----------------|----------------|
| 1 8cm of Hyper-elastic rubber | 74.113                     | 69.906                     | 66.535          | 60.444          | 61.488         |
| 2 9cm of Hyper-elastic rubber | 77.298                     | 71.85                      | 67.752          | 63.693          | 61.821         |

Table 6. Deformation values (mm) of 2nd case sandwiched structures for impact loads at 20m/s.

|                      | Mooney Rivlin 2 parameter | Mooney Rivlin 3 parameter | Neo-Hookean     | Ogden 1st order | Yeoh 1st order |
|----------------------|----------------------------|----------------------------|-----------------|-----------------|----------------|
| 1 8cm of Hyper-elastic rubber | 77.141                     | 70.228                     | 70.081          | 75.198          | 68.777         |
| 2 9cm of Hyper-elastic rubber | 80.129                     | 73.362                     | 70.929          | 77.552          | 69.09          |

6. Analysis of engine mounts.
6.1 Static Analysis.
The objective is to study the deformation underwent by engine mounts with SBR, under static loading conditions. According to company specifications the weight of engine which rests on 4 engine mount may vary from 1.2 to 1.5 tones, therefore 1/4th of that weight will act on each engine mount.
∴ for static analysis the applied force/load was varied from 1tonne to 1.5tonne.
∴ 1tonne (1000 kg) / 4 = 250 kg (2500 N) will be acting on each engine mount.
The parameter calculated in static analysis is deformation with applied load varied from 2500N (1000kg/4) to 3750 N (1500kg/4) in intervals 50kg.

Table 7. Values of engine mount for static analysis.

| Load applied (N) | Total deformation of engine mounting 1 (mm) | Total deformation of engine mounting 2 (mm) |
|------------------|-----------------------------------------------|-----------------------------------------------|
| 2500             | 1.0691                                        | 0.98756                                       |
| 2625             | 1.1163                                        | 1.0323                                        |
| 2750             | 1.1634                                        | 1.0767                                        |
| 2875             | 1.2102                                        | 1.1209                                        |
| 3000             | 1.2568                                        | 1.1649                                        |
| 3125             | 1.3032                                        | 1.2087                                        |
| 3250             | 1.3495                                        | 1.2521                                        |
| 3375             | 1.3955                                        | 1.2953                                        |
| 3500             | 1.4413                                        | 1.3398                                        |
| 3625             | 1.487                                         | 1.3846                                        |
| 3750             | 1.5324                                        | 1.4293                                        |
6.2 Modal Analysis

The main objective is to observe and calculate the natural frequencies of the engine mountings, with SBR. In order to perform modal analysis we will need constraints or boundary conditions. The boundary conditions for engine mounts are, the bottom face of the engine mount will be fixed to the chassis and the top face will be connected to the engine.

Therefore the first natural frequencies for engine mounts are

1) First natural frequency for engine mounting 1 = 109.57Hz.
2) First natural frequency for engine mounting 2 = 151.92 Hz.
6.3 Harmonic response

The main objective is to calculate response of engine mountings having SBR as their core rubber, when subjected to harmonically time varying loads. In order to perform harmonic response it is needed to proceed with a harmonic load and specify a maximum range of frequency for which the load will act. Here harmonic response was calculated for the case when the engine runs and the engine Rpm being converted into frequency to be specified as the maximum range of frequency for varied intervals.

For the analysis part a load of 3000N was applied as a harmonic load, and since the case of running engine is considered harmonic response was calculated for two scenarios

1) Harmonic response for maximum torque of the engine.
2) Harmonic response for maximum power of the engine.

According to company specifications for a heavy commercial vehicles such as commercial trucks Lorries and busses such as made by Ashok Leyland and Eicher motors

Maximum torque = 615N-m @ 1600-1800RPM. (Engine speed)
Maximum power = 180BHP @ 2400RPM. (Engine speed)

To convert RPM into frequency we have, \[ 2\pi f_n = \omega \]
\[ \omega = \frac{2\pi N}{60} \]

For 1 RPM \[ \omega = \frac{2\pi (1)}{60} = \frac{\pi}{30} \]
\[ f_n = \frac{\pi}{60} = 0.016667 \text{ HZ.} \]

For 100RPM \[ f_n = 100 * 0.01667 = 1.6667 \text{ HZ.} \]

Harmonic response is calculated for a harmonic load of 3000N and engine speed varied in intervals of 100RPM. The parameters calculated are Maximum Amplitude of Deformation, Acceleration, Velocity, Stress, and Strain; whose values are tabulated in the tables below. With the S.NO’s 1-18 representing the values of harmonic response for maximum torque of the engine and the S.NO’s 1-24 representing the values of harmonic response for maximum power of the engine.

Table 8. Harmonic response of engine mounting 1 for maximum torque and maximum power of the engine.

| S.NO | Engine speed (Rpm) | Frequency (HZ) | Max amplitude of deformation (mm) | Max Amplitude of stress (Mpa) | Max Amplitude of strain (mm/mm) | Max amplitude of Velocity (mm/s) | Max Amplitude of acceleration (mm/s²) |
|------|------------------|----------------|---------------------------------|-----------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 1    | 100              | 1.6667         | 0.5022                          | 0.79141                     | 0.014605                        | 5.2592                          | 55.075                            |
| 2    | 200              | 3.3333         | 0.50222                         | 0.79143                     | 0.014606                        | 10.518                          | 220.3                             |
| 3    | 300              | 5              | 0.50226                         | 0.49148                     | 0.014607                        | 15.779                          | 495.71                            |
| 4    | 400              | 6.6667         | 0.5023                          | 0.79154                     | 0.014608                        | 21.04                           | 881.34                            |
| 5    | 500              | 8.3333         | 0.50236                         | 0.79162                     | 0.014609                        | 26.303                          | 1377.2                            |
| 6    | 600              | 10             | 0.50243                         | 0.79172                     | 0.014611                        | 31.569                          | 1983.5                            |
| 7    | 700              | 11.6667        | 0.50251                         | 0.79183                     | 0.014614                        | 36.836                          | 2700.2                            |
| 8    | 800              | 13.3333        | 0.50261                         | 0.79197                     | 0.014616                        | 42.106                          | 3527.5                            |
| 9    | 900              | 15             | 0.50272                         | 0.79212                     | 0.014619                        | 47.38                           | 4465.5                            |
| 10   | 1000             | 16.6667        | 0.50284                         | 0.79229                     | 0.014623                        | 52.657                          | 5514.3                            |
| 11   | 1100             | 18.3333        | 0.50298                         | 0.79247                     | 0.014626                        | 57.939                          | 6674.8                            |
| 12   | 1200             | 20             | 0.50312                         | 0.79268                     | 0.014630                        | 63.224                          | 7945.3                            |
| 13   | 1300             | 21.6667        | 0.50329                         | 0.79292                     | 0.014635                        | 68.515                          | 9327.4                            |
| 14   | 1400             | 23.3333        | 0.50346                         | 0.79314                     | 0.014642                        | 73.811                          | 10821.1                           |
| 15   | 1500             | 25             | 0.50365                         | 0.7934                      | 0.014645                        | 79.113                          | 12427.7                           |
| 16   | 1600             | 26.6667        | 0.50385                         | 0.79368                     | 0.014650                        | 84.421                          | 14145.9                           |
| 17   | 1700             | 28.3333        | 0.50406                         | 0.79398                     | 0.014656                        | 89.735                          | 15975.0                           |
| 18   | 1800             | 30             | 0.50429                         | 0.79429                     | 0.014662                        | 95.056                          | 17918.4                           |
| 19   | 1900             | 31.6667        | 0.50453                         | 0.79462                     | 0.014669                        | 100.38                          | 19973.9                           |
| 20   | 2000             | 33.3333        | 0.50478                         | 0.79497                     | 0.014676                        | 105.72                          | 22142.0                           |
### Table 9. Harmonic response of engine mounting 2 for maximum torque and maximum power of the engine.

| S.NO | Engine speed (Rpm) | Frequency (HZ) | Max Amplitude of deformation (mm) | Max Amplitude of stress (Mpa) | Max Amplitude of strain (mm/mm) | Max Amplitude of velocity (mm/s) | Max Amplitude of acceleration (mm/s²) |
|------|--------------------|---------------|-----------------------------------|-----------------------------|---------------------------------|---------------------------------|----------------------------------|
| 1    | 100                | 1.6667        | 0.46036                           | 0.48967                     | 0.013364                        | 4.821                           | 50.486                           |
| 2    | 200                | 3.3333        | 0.46038                           | 0.48968                     | 0.013365                        | 9.6421                          | 201.94                           |
| 3    | 300                | 5             | 0.46041                           | 0.48971                     | 0.013366                        | 14.464                          | 454.41                           |
| 4    | 400                | 6.66667       | 0.46046                           | 0.48975                     | 0.013367                        | 19.228                          | 807.93                           |
| 5    | 500                | 8.3333        | 0.46052                           | 0.48981                     | 0.013369                        | 24.113                          | 1262.5                           |
| 6    | 600                | 10            | 0.4606                           | 0.48987                     | 0.013371                        | 28.94                          | 1818.4                           |
| 7    | 700                | 11.6667       | 0.46069                           | 0.48994                     | 0.013373                        | 33.77                          | 2475.5                           |
| 8    | 800                | 13.3333       | 0.46079                           | 0.49003                     | 0.013376                        | 38.603                          | 3234                             |
| 9    | 900                | 15            | 0.46091                           | 0.49013                     | 0.01338                         | 43.439                          | 4094.1                           |
| 10   | 1000               | 16.6667       | 0.46104                           | 0.49024                     | 0.013383                        | 48.28                          | 5055.8                           |
| 11   | 1100               | 18.3333       | 0.46118                           | 0.49036                     | 0.013388                        | 53.124                          | 6119.4                           |
| 12   | 1200               | 20            | 0.46134                           | 0.49049                     | 0.013392                        | 57.973                          | 7285.1                           |
| 13   | 1300               | 21.6667       | 0.46151                           | 0.49063                     | 0.013397                        | 62.828                          | 8553.1                           |
| 14   | 1400               | 23.3333       | 0.46169                           | 0.49079                     | 0.013402                        | 67.688                          | 9923.5                           |
| 15   | 1500               | 25            | 0.46189                           | 0.49095                     | 0.013408                        | 72.554                          | 11397                           |
| 16   | 1600               | 26.6667       | 0.56211                           | 0.49113                     | 0.013414                        | 77.427                          | 12973                           |
| 17   | 1700               | 28.3333       | 0.56233                           | 0.49132                     | 0.013421                        | 82.306                          | 14652                           |
| 18   | 1800               | 30            | 0.56257                           | 0.49153                     | 0.013427                        | 87.193                          | 16436                           |
| 19   | 1900               | 31.6667       | 0.56283                           | 0.49174                     | 0.013435                        | 92.088                          | 18323                           |
| 20   | 2000               | 33.3333       | 0.5631                           | 0.49197                     | 0.013442                        | 96.991                          | 20314                           |
| 21   | 2100               | 35            | 0.56338                           | 0.49222                     | 0.013451                        | 101.9                           | 22410                           |
| 22   | 2200               | 36.6667       | 0.46368                           | 0.49245                     | 0.013459                        | 106.82                          | 24611                           |
| 23   | 2300               | 38.3333       | 0.46399                           | 0.49271                     | 0.013468                        | 111.75                          | 26917                           |
| 24   | 2400               | 40            | 0.46432                           | 0.49299                     | 0.013477                        | 116.7                           | 29329                           |

### 6.4 Transient response

The main objective is to study the response of two engine mountings modelled with SBR, when subjected to time varying loads. During the running of a vehicle there may be road surface excitation or in the cases of small disturbances on the road, the mount may experience changes. Transient response is used to calculate response of the engine mounts to such time varying loads. Response is calculated in terms of parameters deformation, acceleration, velocity, stresses and strains.

The loading patterns considered are mentioned below.

i) Load applied for 0.1s and removed for next 0.1s, and the excitation is maintained for next 1s, with response being calculated for time intervals of 0.1s.

ii) Load applied for 0.1s and removed for next 0.1s, and the excitation is maintained for next 5s, with response being calculated for time intervals of 0.1s.

iii) Load applied from 0.1s to 0.2s and removed for next 0.1s, and the excitation is maintained for next 5s, with response being calculated for time intervals of 0.1s.

The response of engine mounts in terms of parameters deformation, velocity, acceleration, stresses and strains with respect to time for above loading patterns are shown below in graphs.
Figure 10. Response of engine mounts in terms of considered parameters for loading patterns mentioned above. (a), (b), (c) for engine mounting 1. (d), (e), (f) for engine mounting 2.

7. Conclusions.
Firstly the characteristic properties of SBR with main emphasis on its damping properties and vibration isolation characteristics were identified by using two separate cases of sandwiched structures. In the impact analysis of sandwiched structures Yeoh 1st order was identified as the best suited Hyper-elastic material model for SBR, using which SBR was modelled and incorporated in two separate engine mounts. Using Yeoh 1st order the performance and behaviour of engine mounts was studied for static and dynamic cases by carrying out various analyses. If the comparison factor is taken into account, the engine mounting 2 is better than engine mounting 1; for the considered cases. And it
can also be concluded that SBR exhibits damping properties and it can be used in cases such as vibration isolation or reducing the transfer of vibrations.

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