Effect of Hyper Elastic Property on Dynamic Behaviour of IC Engine

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Abstract— In this paper, concept of vibration absorber is discussed with its hyperelastic properties. Rubber pads are inserted between IC Engine and foundation. IC Engine with and without rubber pads are dynamically analysed using FEA software. Both modal and harmonic analysis are performed. The FRFs of two systems are compared for their vibration reduction. Natural frequencies and mode shapes are obtained by modal analysis whereas FRF is obtained by harmonic analysis in FEA software.
Key words: Hyper Elastic Property, IC Engine

I. INTRODUCTION

Vibration control and acoustics problem involves understanding its nature such as its originating source, vibration nature & direction and acoustics at location, transmission path & frequency content. It is followed by passive or active control methods. A passive control method modifies stiffness, mass & damping of the system. Damping can be increased by including highly damped polymeric material at specific location onto the structure. Structure and polymer can interact such that polymer can dissipate as much energy as possible [1].

Rubber is one of the most important materials included in pads and vehicle tyres. It can influence the dynamic behaviour of pad and vehicle tyres from its mechanical, elastic and hysteretic properties point of view. Rubber undergoes large strains so it becomes necessary to define rubber as a hyperelastic material [2].

When performing finite element method on rubber type material, their elastic properties are one of input parameters. These elastic properties are obtained by experiments on sample of rubber in form of stress-strain curve.

In this paper, elastic properties of rubber are obtained from FEA software as experiment results on sample of rubber is difficult for researchers to obtain from companies. Rubber pads are means of dissipating energy and acts as vibration absorber. IC Engine is founded with and without rubber pads.

II. THEORETICAL BACKGROUND

Materials is classified based on their deformation proportionality to load applied 1) Linear 2) Non Linear

A. *Linear Elastic Behavior (Hooke's Law)*

"As the extension, so the force" as suggested by Hooke, there exits linear relationship between force (stress) and deflection (strain). For a spring made of steel under small strain, the force is the product of the stiffness and the deflection or, the deflection can be obtained by dividing the force by the spring stiffness. As the spring remains linear elastic, this relation is valid up to the yield point. Applying twice the load, we obtain twice the deflection. For a linear spring, the typical force-displacement (or stress-strain) plot is thus a straight line, and the stiffness represents the slope [3].

B. *Hyperelastic (Neo-Hookean Law)*

A hyperelastic material is still an elastic material as it returns to its original shape after the forces have been removed. It is also is Cauchy-elastic, which means that the stress is determined by the current state of deformation, and not the path or history of deformation The difference to linear elastic Material is, that in hyperelastic material the stress-strain relationship derives from a strain energy density function, and not a constant factor. This definition says nothing about the Poisson's ratio or the amount of deformation that a material will undergo under loading However; often elastomers are modelled as hyperelastic. Hyperelasticity may also be used to describe biological materials, like tissue [4].

It is very instructive to view the stress-strain behaviour for rubber. If a tensile test is preformed on a synthetic rubber called EPDM (Ethylene Propylene Diene Monomer) cycled to 10%, 20%, 50% and 100% strain with each cycle repeated twice. The stress-strain behaviour of rubber is very different from Hooke's Law in four basic areas. First, as the rubber is deformed into a larger strain territory for the first time, it is very stiff, but upon recycling in this same strain territory, the rubber softens dramatically. This phenomenon is often referred to as the Mullins' effect. In most applications this one time very stiff event is usually discarded where it is assumed in these applications repetitive behaviour will dominate. Nonlinear elasticity has several stress and strain measures, however, it is most common to measure elastomeric experimental data using engineering stress and engineering strain measures, whereby the engineering stress is the current force is divided by the original area, and the engineering strain is the change in length divided by the original length. All test data will use engineering stress and engineering strain measures [3].

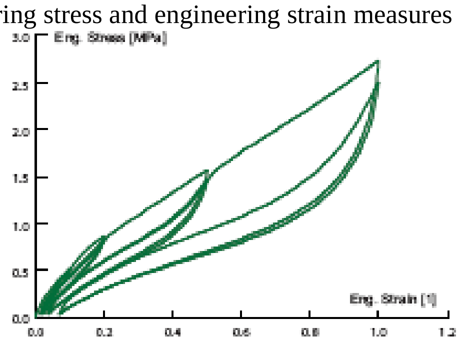


Fig. 1: Strain Vs Stress for Rubber like materials

III. MATERIAL MODELS FOR HYPER ELASTIC MATERIAL

As the material is incompressible, the deviatoric (subscript d or with 'bar') and volumetric (subscript V) terms of the strain energy function are separated. Hence, the volumetric term is a function of the volume ratio J only [4,5]

$$W = W_d(\bar{I}_1, \bar{I}_2) + W_v(J) \quad (1)$$

$$W = W_d(\bar{\lambda}_1, \bar{\lambda}_2\, \bar{\lambda}_3) + W_v(J) \quad (2)$$

So, W_d is the strain energy necessary to change the shape, W_V the strain energy to change the volume.

A. Polynomial Form

$$W = \sum_{i+j=1}^{N} C_{ij}(\bar{I}_1 - 3)^i (\bar{I}_2 - 3)^j + \sum_{k=1}^{N} \frac{1}{D_k}(J-1)^{2k} \quad (3)$$

The C_{ij} and D_k are material constants which have to be determined by tests. Here, the strain energy function is a polynomial function. Depending on its order, no (=single curvature), one or more inflection points in the stress-strain curve may appear. For the higher order functions, enough test data has to be supplied.

Hyperelastic material laws are:

1) *Neo-Hookean:*

$$W = C_{10}(\bar{I}_1 - 3) + \frac{1}{D_1}(J_e - 1)^2 \quad (4)$$

2) *Mooney-Rivlin:*

$$W = C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_1 - 3) + \frac{1}{D_1}(J_e - 1)^2 \quad (5)$$

B. Polynomial Form of Order

$$W = C_{10}(\bar{I}_1 - 3) + C_{20}(\bar{I}_1 - 3)^2 + \frac{1}{D_1}(J_e - 1)^2 + \frac{1}{D_2}(J_e - 1)^4 \quad (6)$$

Where I_1 is variant

IV. Finite Element Analysis

Components of IC engine are modelled with structure steel. IC engine is modelled with or without Rubber pad and meshed for finite element analysis. Modal and harmonic analysis are performed on both models. Neoprene Rubber is selected in material data. Hyper elastic property is obtained from FEA software. Neo-Hookean curve fitting method selected in FEA software environment and shear modulus and incompressibility parameter are obtained by Neo-Hookean.

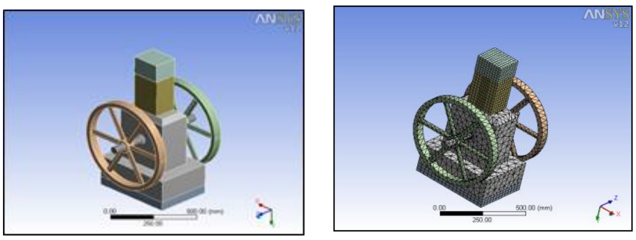


Fig 2: Case1: IC engine without rubber pad
(a) Solid and (b) FEM model

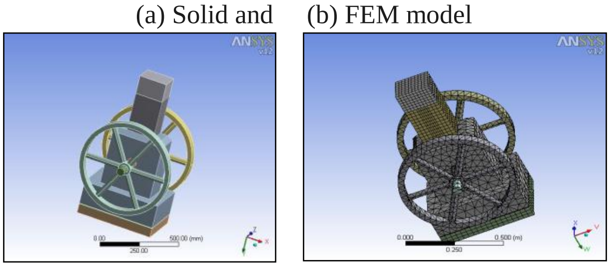


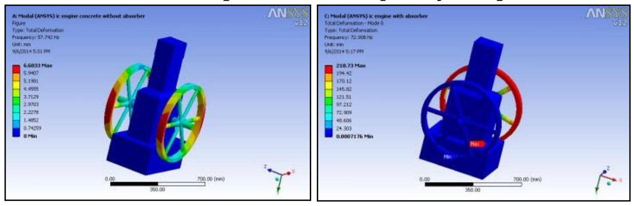
Fig 3: Case 2: IC engine with rubber
(a) Solid and (b) FEM model

V. Result and Discussion

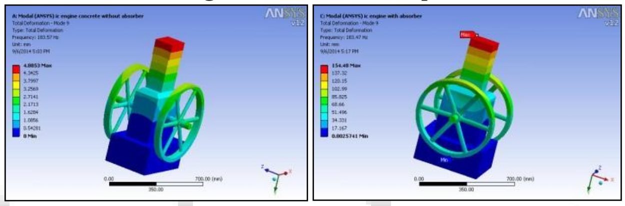
For both the cases, natural frequency is listed in Table 1 and mode shapes are plotted as shown in figure 4 to figure 6.

Frequency (Hz.)	Frequency Response (mm)		% age variation in Frequency Response
	Case 1 (Without Rubber pad)	Case 2 (With Rubber pad)	
73	1.31e-06	2.68e-7	-79.54
186	4.13e-6	4.59e-6	11.13
235	1.73e-4	5.55e-5	-67.91

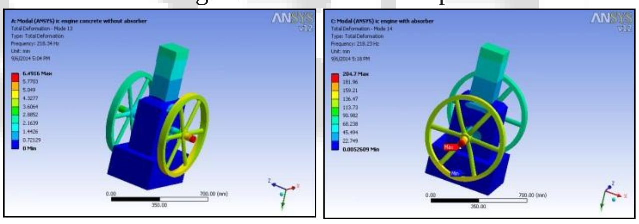
Table 1: Comparison of Frequency Response



(a) case 1 (b) case 2
Fig. 4: First Mode Shape



(a) case 1 (b) case 2
Fig. 5: Second Mode shape



(a) case 1 (b) case 2
Fig. 6: Third Mode shape

FRF for both cases are plotted in figure 7 and 8. In figure 9 and table 1, FRF and natural frequency for both cases are compared. It is evident from figure 9 that with addition of rubber pad, FRF changes. Also in percentage variation, negative sign indicates decrease in FRF while positive sign indicates increase in FRF.

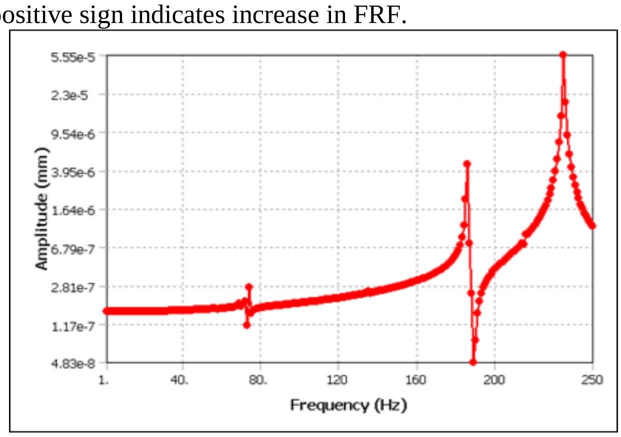


Fig. 7: FRF Vs Frequency plot (IC engine without Rubber Pad)

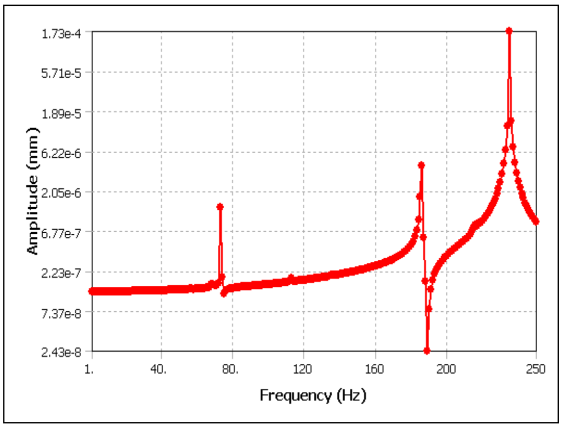


Fig. 8: FRF Vs Frequency plot (IC engine with Rubber Pad)

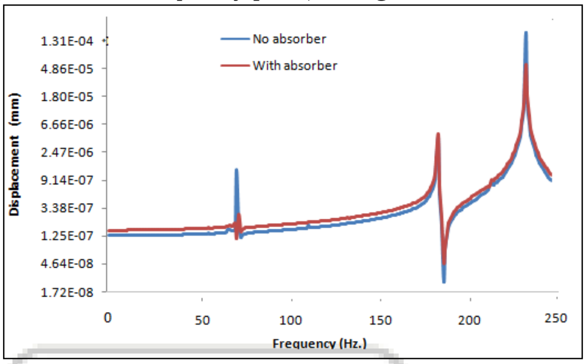


Fig. 9: Comparison of FRF Vs Frequency plot of both case

VI. CONCLUSION

The use of hyperelastic material like rubber can greatly reduce vibration in real application. By using FEA software, the effect of hyperelastic behaviour of material can be studied on dynamic behaviour of structures and FRF of the structures can be obtained with geometry of hyperelastic material verified for reduction of the vibration. Tuning various dimensions and thus obtained vibration behaviour, hyperelastic material can be incorporated as vibration absorber in structures of real applications. FEA results also further be used for comparison and validation with those obtained from experiment.

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