Vibration Isolation of an Air Compressor by using Sandwich Mount Isolators

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Abstract - *As per the recent trends in designing a light weight and more power output equipment's like compressor, automobile engines, aircrafts etc. are required which leads to excessive vibration on the system it can be a serious problem if resonance is occurs. The paper is intended to study and analyze the performance of composite isolators to minimize the vibration of air compressor. The composites of rubber, felt and cork are studied and analyzed. Rubber shows a least transmissibility whereas cork shows highest. From analysis it is seen that it is possible to enhance vibration characteristics by combining rubber with cork or felt.*

Key Words: Composite isolator, isolation transmissibility

1. INTRODUCTION

The unwanted motions of the system are always a nuisance. One of the simplest means to reduce the vibration is to use the pads of rubber felt, cork and other vibration absorbing material. These materials are widely used for this purpose. However, this study proposes the sandwich (composite) use of these materials to combine the advantage of the materials that can be obtained if they have been used separately.

2. PROBLEM STATEMENT AND OBJECTIVE

The purpose of this project is to determine the vibration caused by a compressor and then applying passive composite vibration isolators to reduce the transmissibility i.e., vibration transmitted to the base. The combinations of rubber, felt and cork have been used as isolators to reduce the vibration transmitted to the base of compressor. The vibration without isolation is measured and then again measured by using isolator. The ratio gives transmissibility theoretically. For theoretical analysis the value of stiffness, damping ratio and mass plays a major role while the acceleration is determined experimentally by using FFT analyzer with and without isolator. In numerical simulation the amplitude ratios are compared and the transmissibility is determined.

3. LITERATURE REVIEW

R. A. Ibrahim presented a paper "Recent advances in nonlinear passive vibration isolators". This paper postulates a comprehensive assessment of recent developments of nonlinear isolators in the absence of active control means. They are does not deal with other means of linear or nonlinear vibration absorbers. It is the basic concept and features of nonlinear isolators and inherent nonlinear phenomena. Specific types of nonlinear isolators are then discussed, including ultra-low-frequency isolators. In vertical vibration isolation, the Euler spring isolator is based on the post buckling dynamic characteristics of the column elastic and axial stiffness. Exact and approximate analyses of axial stiffness of the post-buckled Euler beam are outlined. Nonlinear visco-elastic and composite material springs, and smart material elements are described in terms of material mechanical characteristics and the dependence of their transmissibility on temperature and excitation amplitude. The article is closed by conclusions, which highlight resolved and unresolved problems and recommendations for future research directions. [1]

Chen Yang presented a preview study named "Study of Whole-spacecraft Vibration Isolators Based on Reliability Method". In this study they said that, a method for whole spacecraft vibration isolator design is studied by the author. The WSVI stiffness problem and response problems are discussed. On the basis of the results computed with reliability theory and the data obtained from experiment, the control method of WSVI stiffness and the coupling problem are studied. The VIE problem is also discussed. From the reliability aspect, the NF of WSVI can be controlled over a large domain to avoid the possibility of spacecraft being resonant with the launch vehicle. The effect of NFC and the reliability of vibration isolation can satisfy different launching requirements. In the first part, the stiffness feature of the WSVI is studied with reliability analysis and experimental data. In the second part, the problems induced by stiffness feature are discussed. The simulated and experimental data show that the transmissibility, which is coupled with stiffness, can be reduced by attaching the vibration isolator between the spacecraft and the launch vehicle. [2]

4. THEORETICAL ANALYSIS

Vibration isolation of a system means to reduce the vibration of the system by using suitable means of isolators between the system to be isolated and the exciter or the source of vibration. If we consider only the vertical motion, it can be described mathematically by a single degree of freedom.

$$mx + cx + kx = F(t) \quad (1)$$

Where:

m = mass of system
k = stiffness
c = viscous damping
x (t) = vertical displacement
F (t) = excitation force

If we are neglect damping, the vertical motion of the system, x(t) can express to be:

$$x(t) = \frac{F_0/_K}{(1-r^2)}\sin(\omega t)$$

Where: $r = \frac{\omega}{\omega_n}$ $\omega_n = \sqrt{\frac{k}{m}}$ (2)

The system has a natural or resonant frequency, at which it will exhibit large amplitude of motion, for a small input force. In units of Hz, this frequency, *fn* is:

$$f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad (3)$$

In units of RPM (revolutions per minute), the critical frequency is:

$$RPM_{CRITICAL} = 60\, f_n = \frac{60}{2\pi}\sqrt{\frac{k}{m}} \quad (4)$$

The force transmitted to the floor is: $F = kx$

The ratio of transmitted force to the input force is called transmissibility, T

$$T = \left|\frac{F_T}{F_O}\right| \quad (5)$$

Where:

F_T = Force Transmitted to the base

F_O = Excitation Force.

This same equation can be used to calculate the response of a machine **X** to displacement of the foundation, **Y**.

The effectiveness of the isolator, expressed in dB is:

$$E = 10\log_{10}\frac{1}{T} \quad (6)$$

The effectiveness of the isolator, expressed in percent is:

% Isolation = (1-T) *100

A. Calculation of Stiffness (K)

For Single layer of Rubber:

Displacement for 5 Kg is 0.62 mm.

K_R = 5/0.62 = 8.06 Kg/mm

∴ K_R = 8.06 x 9.81 =79.1129 N/mm.

∴ K_R = 79.1129 x 1000 = 79112.9 N/m.

For Single layer of Felt:

Displacement for 5 Kg is 0.6 mm.

K_F =81.750 x 1000 = 81750 N/m.

For Single layer of Cork:

Displacement for 5 Kg is 0.47 mm.

K_C =104.3617 x 1000 = 104361.7 N/m.

Using the above calculation, the values of stiffness are calculated.

1. Rubber- Rubber- Rubber (RRR)

$$\frac{1}{K_{RRR}} = \frac{1}{K_R} + \frac{1}{K_R} + \frac{1}{K_R} = \frac{3}{K_R} = \frac{3}{79112.9} = \frac{1}{26370.96}$$

$$\therefore K_{RRR} = 26370.96 \text{N/mm}$$

2. Felt- Felt- Felt (FFF)

$$\frac{1}{K_{FFF}} = \frac{1}{K_F} + \frac{1}{K_F} + \frac{1}{K_F} = \frac{3}{K_F} = \frac{3}{81750} = \frac{1}{27250}$$

$$\therefore K_{FFF} = 27250 \text{ N/mm}$$

3. Cork- Cork- Cork (CCC)

$$\frac{1}{K_{CCC}} = \frac{1}{K_C} + \frac{1}{K_C} + \frac{1}{K_C} = \frac{3}{K_C} = \frac{3}{104361.7} = \frac{1}{34787.23}$$

$$\therefore K_{CCC} = 34787.23 \text{ N/mm}$$

4. Rubber - Felt - Rubber (RFR)

$$\frac{1}{K_{RFR}} = \frac{1}{K_R} + \frac{1}{K_F} + \frac{1}{K_R} = \frac{2}{K_R} + \frac{1}{K_F}$$
$$= \frac{2}{79112.9} + \frac{1}{81750} = \frac{1}{26657.60}$$

$$\therefore K_{RFR} = 26657.60 \text{ N/mm}$$

5. Rubber - Cork - Rubber (RCR)

$$\frac{1}{K_{RCR}} = \frac{1}{K_R} + \frac{1}{K_C} + \frac{1}{K_R} = \frac{2}{K_R} + \frac{1}{K_C}$$
$$= \frac{2}{79112.9} + \frac{1}{104361.7} = \frac{1}{28684.2}$$

$$\therefore K_{RCR} = 28684.2 \text{ N/mm}$$

B. Calculation of Damping Co-Efficient (C)

Damping ratio (Ɛ) of materials is:

Rubber - 0.075; Felt – 0.06; Cork – 0.06

$\mathcal{E} = C/C_C$

$C_C = 2\sqrt{Km}$

$C = \mathcal{E} \times C_C$

For Rubber

$C_R = \mathcal{E}_R \times C_{CR}$

$C_R = 0.075 \times 2\sqrt{79112.9x40}$

$C_R = 266.83$ Ns/m.

For Felt

$C_F = \mathcal{E}_F \times C_{CF}$

$C_R = 0.06 \times 2\sqrt{81750x40}$

$C_R = 216.99 \approx 217$Ns/m.

For Cork

$C_C = \mathcal{E}_C \times C_{CC}$

$C_C = 0.06 \times 2\sqrt{104367.1x40}$

$C_C = 245.17$Ns/m.

1. Rubber- Rubber- Rubber (RRR)

$$\frac{1}{C_{RRR}} = \frac{1}{C_R} + \frac{1}{C_R} + \frac{1}{C_R} = \frac{3}{C_R} = \frac{3}{266.83} = \frac{1}{88.94}$$

$\therefore C_{RRR} = 88.94$ Ns/m

2. Felt- Felt- Felt (FFF)

$$\frac{1}{C_{FFF}} = \frac{1}{C_F} + \frac{1}{C_F} + \frac{1}{C_F} = \frac{3}{C_F} = \frac{3}{217} = \frac{1}{72.33}$$

$\therefore C_{FFF} = 72.33$ Ns/m

3. Cork- Cork- Cork (CCC)

$$\frac{1}{C_{CCC}} = \frac{1}{C_C} + \frac{1}{C_C} + \frac{1}{C_C} = \frac{3}{C_C} = \frac{3}{245.17} = \frac{1}{81.72}$$

$\therefore C_{CCC} = 81.72$ Ns/m

4. Rubber - Felt - Rubber (RFR)

$$\frac{1}{C_{RFR}} = \frac{1}{C_R} + \frac{1}{C_F} + \frac{1}{C_R} = \frac{2}{C_R} + \frac{1}{C_F}$$
$$= \frac{2}{266.83} + \frac{1}{217} = \frac{1}{82.62}$$

$\therefore C_{RFR} = 82.62$ Ns/m

5. Rubber - Cork - Rubber (RCR)

$$\frac{1}{C_{RCR}} = \frac{1}{C_R} + \frac{1}{C_C} + \frac{1}{C_R} = \frac{2}{C_R} + \frac{1}{C_C}$$
$$= \frac{2}{266.83} + \frac{1}{245.17} = \frac{1}{86.39}$$

$\therefore C_{RCR} = 86.39$ Ns/m

C. Calculation of Transmissibility without Damping Effect:

The transmissibility of a system without damping effect is given by the equation:

$$T_r = \frac{1}{|r^2 - 1|} \qquad (7)$$

Where $r = \omega/\omega_n$

$\omega = 2\pi N/60 = 2\pi x480/60 = 50.26$ rad/s

$\omega_n = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{40}}$ (m=40 Kg = mass of test rig)

$$\therefore T_r = \frac{1}{\left(\frac{\omega}{\omega n}\right)^2 - 1} = \frac{1}{\left(\frac{50.26x\sqrt{40}}{\sqrt{K}}\right)^2 - 1} = \frac{1}{\frac{101042.7}{K} - 1} = \frac{K}{101042.7 - K}$$

1. Rubber- Rubber- Rubber (RRR)

$$T_r = \frac{K}{101042.7 - K}$$

K = 26370.96 N/m

$$\therefore T_r = \frac{26370.96}{101042.7 - 26370.96}$$

$\therefore T_r = 0.3531$

Similarly, the calculated transmissibility of all above the combinations.

D. Calculation of Transmissibility with Damping Effect:

The transmissibility of a system without damping effect is given by the equation:

$$T_r = \frac{\sqrt{1 + (2\varepsilon r)^2}}{\sqrt{((1 - r^2)^2 + (2\varepsilon r)^2)}} \qquad (8)$$

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26c}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K} - 1\right)^2 + \left(\frac{50.26c}{K}\right)^2}}$$

1. Rubber- Rubber- Rubber (RRR)

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26c}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K} - 1\right)^2 + \left(\frac{50.26c}{K}\right)^2}}$$

K = 26370.96 N/m, C= 88.94 Ns/m

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26 \times 88.94}{26370.96}\right)^2}}{\sqrt{\left(\frac{101042.7}{26370.96} - 1\right)^2 + \left(\frac{50.26 \times 88.94}{26370.96}\right)^2}}$$

$$T_r = \frac{\sqrt{1+0.028}}{\sqrt{8.018+0.028}}$$

$T_r = 0.3574$

Similarly, the calculated transmissibility of all above the combinations.

The values of transmissibility for the composites are shown in the following table:

Material	r = (ω/ω_n)	K (N/mm)	C (Ns/m)	Transmissibility	
				Without Damping	With Damping
RRR	1.9	26370.9	88.94	0.3531	0.3574
FFF	1.9	27250.0	72.33	0.3692	0.3720
CCC	1.7	34787.2	81.72	0.5250	0.5276
RFR	1.9	26657.6	82.62	0.3583	0.3621
RCR	1.8	28684.2	86.39	0.3964	0.4002

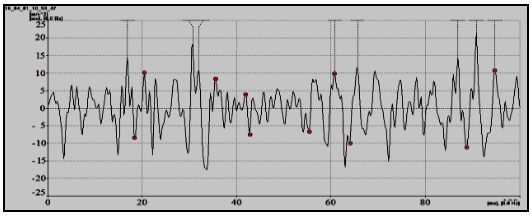
Table.1. Theoretical value of Transmissibility

5. EXPERIMENTAL TESTING

The composite of Rubber, Felt, Cork and material are having the low natural frequency for high loading and by these property vibrations are absorbed by the material. For the sake of comparing the frequency of pad, experimental results have to be checking. For that setup of unbalanced reciprocating mechanism is made with motor and belt transmission system. For experimentation FFT analyzer is use. The amount of vibration that machine is producing without any type isolation pad, and by using pads is being calculate by providing the signal receiving sensor at the top of the base plate and at the bottom of the isolator for all layers.

Fig.1. Experimental Setup

1. Acceleration Plot without isolation.



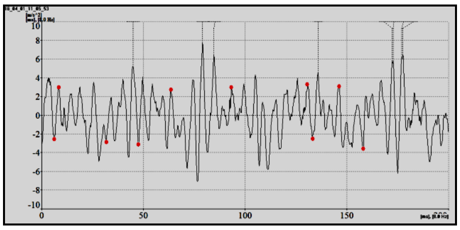
Graph.1. Acceleration Plot without Isolation.

Points	1	2	3	4	5
Positive Values	10	8	4	10	11
Negative Values	8	7	6	10	11

Table.2. Acceleration Points without Isolation

Average Acceleration without isolation = 85/10 =8.5 m/s²

2. Acceleration Plot for RRR



Graph 2. Acceleration Plot for RRR

Points	1	2	3	4	5
Positive Values	3	2.8	3.1	3.4	3.2
Negative Values	2.3	2.9	3.2	2.2	3.8

Table.3. Acceleration Points for RRR

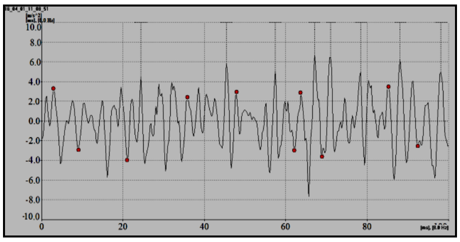
Average Acceleration for RRR = 29.9/10 =2.99 m/s²

$$\text{Transmissibility} = \frac{\text{Average Accelaration for RRR}}{\text{Average Acceleration wihout isolation}}$$

$$= \frac{2.99}{8.5}$$

$$\text{Tr} = 0.3517$$

3. Acceleration Plot for FFF



Graph.3. Acceleration Plot for FFF

Points	1	2	3	4	5
Positive Values	3.4	2.2	3.5	3.3	3.7
Negative Values	2.8	4	2.7	3.8	2.2

Table.4. Acceleration Points for FFF

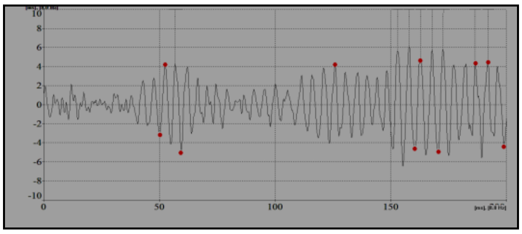
Average Acceleration for FFF = 31.6/10 =3.16 m/s^2

$$\text{Transmissibility} = \frac{\text{Average Accelaration for RRR}}{\text{Average Acceleration wihout isolation}}$$

$$= \frac{3.16}{8.5}$$

Tr = 0.3717

4. Acceleration Plot for CCC



Graph.4. Acceleration Plot for CCC

Points	1	2	3	4	5
Positive Values	4.2	4.3	4.7	4.4	4.5
Negative Values	3.3	5.1	4.6	4.7	4.5

Table.5. Acceleration Points for CCC

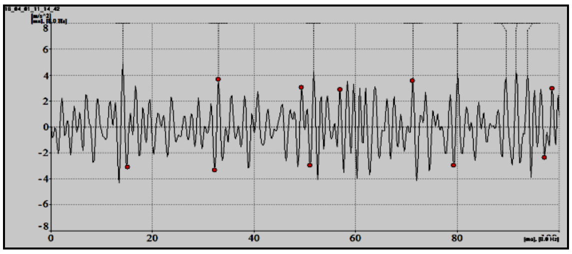
Average Acceleration for CCC = 44.3/10 =4.33m/s^2

$$\text{Transmissibility} = \frac{\text{Average Accelaration for CCC}}{\text{Average Acceleration wihout isolation}}$$

$$= \frac{4.43}{8.5}$$

Tr = 0.5212

5. Acceleration Plot for RFR



Graph.5. Acceleration Plot for RFR

Points	1	2	3	4	5
Positive Values	3.8	3.2	2.9	3.7	3
Negative Values	3.2	3.4	2.9	2.8	2.3

Table.6. Acceleration points for RFR

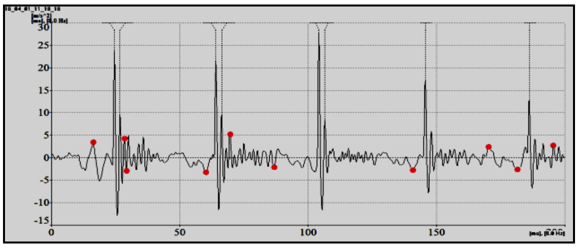
Average Acceleration for RFR = 31.3/10 =3.13 m/s^2

$$\text{Transmissibility} = \frac{\text{Average Accelaration for RFR}}{\text{Average Acceleration wihout isolation}}$$

$$= \frac{3.13}{8.5}$$

Tr = 0.3682

6. Acceleration Plot for RCR



Graph.6. Acceleration Plot for RCR

Points	1	2	3	4	5
Positive Values	4	4.8	5.2	2.5	2.8
Negative Values	3.4	3.6	2.3	3.2	2.6

Table.7. Acceleration Points for RCR

Average Acceleration for RCR = 34.4/10 =3.44 m/s²

$$\text{Transmissibility} = \frac{\text{Average Accelaration for RRR}}{\text{Average Acceleration wihout isolation}}$$

$$= \frac{3.44}{8.5}$$

$$\text{Tr} = 0.4047$$

6. RESULTS AND DISCUSSION

The Value of transmissibility is shown in the table:

Sr. No.	Material	Analytical		Experimental
		Without Damping	With Damping	With Damping
1.	RRR	0.3531	0.3574	0.3517
2.	FFF	0.3692	0.3720	0.3717
3.	CCC	0.5250	0.5276	0.5212
4.	RFR	0.3583	0.3621	0.3682
5.	RCR	0.3964	0.4002	0.4047

Table.8. Performance of Isolators

The result of different composites shows the transmissibility of the combinations tested experimentally, numerically and compared with the theoretical readings. Rubber has a better isolation property as the composites having rubber have less transmissibility. The readings obtained by theoretical, experimental and numerical method are in close agreement with each other. Felt is second best performer and can be used for heavier mass of setup. The cork combinations are found to have the highest transmissibility and hence the least performance.

7. CONCLUSION

The performance of rubber is found to be better than other isolators for the air compressor followed by felt and cork. However, the application of the isolators depends upon the variables like weight of system, frequency of excitation, damping co-efficient and other factors. It is advisable to use rubber with felt, cork or other material to enhance the vibration characteristics. The performance characteristics of isolators can be enhanced by using layers (composites) of these isolators.

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