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Vibration Isolation Using Various Isolating Material of an Air Compressor

M. Tech. Scholar Sutar Praveen S., Asst. Prof. Akhya Kumar Behra
G.H Raisoni College of Engineering and Management,
Wagholi, Pune.
akhya.behera@raisoni.net

Abstract- As for the increasing dependability of man on the machine, it seems necessary to strive for improvement of the performance of machines given that the dependent inputs are not changed drastically. In mechanical engineering terms, we are accustomed to working towards increasing the efficiency of a prime mover or core machine setup by developing methods to reduce wastage of energy and performance reducing factors can be eradicated. In machines vibration is the underlying factor that complies to carry out periodic maintenance, not working up to the full potential of the prime movers, limiting the working and output of the mechanical forces and thus resulting in reduced performances. Here we have conducted a brief review of this Vibration affects performance and how isolating it can result in increased efficiency and performance.

Keywords: Viration analysis, Compressor.

I. INTRODUCTION

The vibrations are available in all mechanical equipment. But the unnecessary vibrations occurring should be eliminated. But we cannot eliminate these but reduce the vibrations.

Various materials are available which can absorb these vibrations and isolate the vibrations from being transferred from the vibrating source to the structure or foundation [11]. Vibration isolation can be of two major types mainly passive and active isolation systems.

Passive isolation systems are making use of various materials to absorb the vibration and isolate the system from its base. We have the most widely used materials like springs, dampers, pads of isolating materials like rubber, cork, or felt, [14] also some pneumatic devices, and new smart materials are also being introduced for vibration isolation.

It's been used in households, vehicles, automotive applications, aircraft industries and buildings as well as infrastructures. Active isolation systems are including a feedback control that will use actuators to balance the vibration in the system as compared to the vibrations produced in the setup.

R.A.Ibrahim et. al., did an assessment of nonlinear and passive type of vibration isolators. On vertical vibration isolation using Euler spring isolator, analysis done for Euler beam. Various materials like smart material, viscous-elastic also composite type of springs and their characteristics and what is the transmissibility with regards to temperature and amplitude is concluded [1].

Chen Yang et. al, has used numerical analysis using computer and is compared with experimental data. It is concluded that using vibration isolator can reduce the transmissibility in between the Launch pad and spacecraft [2].

M. A. Salim et. al, have discussed on the transverse behaviour of vibration. A mathematical model is developed and accomplished to represent LRMS model's stiffness level at transverse vibration as to what will be actual value [14].

However, in this study we are proposing using sandwich pads of three materials rubber, felt, and cork and find out using harmonic analysis technique the transmissibility of using these as mounts for an air compressor.

II. PROBLEM STATEMENT AND OBJECTIVE

The purpose of this study 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.

We will use different combinations of rubber, cork and felt to reduce and achieve isolation of vibration to the foundation of an air compressor. Comparison of vibration without isolation to the one with isolation using sandwich of these combinations is carried out.

III. THEORETICAL ANALYSIS

The vibration isolation problem is being put forth by many authors. The most discussed and easiest will be a single DOF system, with dependencies on mass, stiffness and damping. A two DOF system can be devised as giving better-analyzed data with fixed inputs.

As per the review of Michel on both nonlinear and linear stability theory, feedback control can be said is linked to improved stability. Eigen values of the system can be used to examine results for stability of these systems and it will be stated if values found are negative.

When the damping or stiffness can be controlled by the system, it can be said that it contains tunable parameters. Various data is available on diminishing harmonic excitations. Vibration absorbers are widely used to reduce unnecessary disturbances [10].

In this section, we study the calculation using the theoretical method is proposed for identifying the effects of vibration isolation on the Machine [2]. Below is the basic equation we use for the calculation of the vibrating system [3]

m x+ c x+ kx = F(t).....(1)

Where;

- **x (t) =** vertical displacement
- **C =** viscous damping
- **K =** stiffness
- **F (t) =** excitation force
- **M =** mass of system

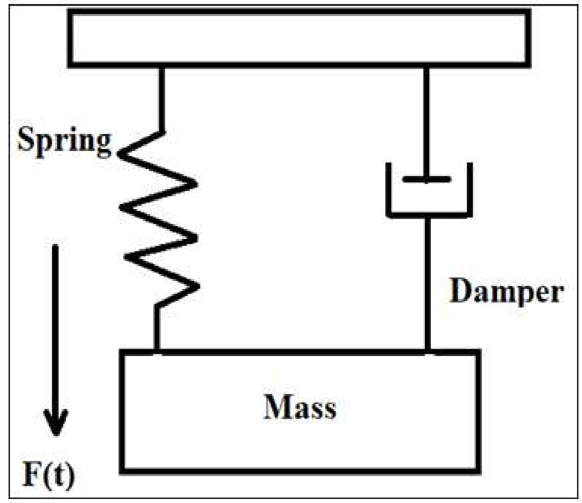

Fig 1. Schematic Diagram of Vibration System.

Where M-(mass), C-(damping), and K-(stiffness) are matrices, and F (excitation force's vector) which is shown in above Fig.3.1 [2].

By neglecting to damp, vertical motion occurred in the system, [3]

That is displacement is as below:

$$x(t) = \frac{Fo/k}{(1-r^2)} \quad \sin\omega t \;....(2)$$

Where:

$$r = \sqrt{\frac{\omega}{\omega_n}} \;....(3)$$

$$\omega_n = \sqrt{\frac{k}{m}} \;.....(4)$$

The system has a natural frequency; here it will give larger amplitudes, for a low force of input.

Natural frequency is as follows:

$$f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \;.....(5)$$

In RPM, critical frequency is as following

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$$RPM_{critical} = 60 f_n = \frac{60}{2\pi}\sqrt{\frac{k}{m}} \quad \ldots (6)$$

The force transmitted is:

$$F = kx \quad \ldots (7)$$

Transmissibility is nothing but transmitted force upon input force.

Transmissibility (T) is as below

$$T = \left|\frac{F_t}{F_o}\right| = \left|\frac{1}{1-r^2}\right| \quad \ldots (8)$$

The above equation can also be able to calculate the response of a machine X to the displacement of the foundation, Y.

The isolator's effectiveness (dB) is:

$$E = 10\log_{10}\frac{1}{T} \quad \ldots (9)$$

The isolator's effectiveness in percent is:

$$(1-T) * 100 = Percent\ Isolation \quad \ldots (10)$$

Calculation of Stiffness (K) For Single layer of Rubber:

Displacement for 5 Kg is 0.62 mm.

KR= 5/0.62 = 8.06 Kg/mm

KR= 8.06 x 9.81 =79.1129 N/mm.

KR=79.1129 x 1000 = 79112.9 N/m.

For Single layer of Felt:

Displacement for 5 Kg is 0.6 mm.

KF=81.750 x 1000 = 81750 N/m.

For Single layer of Cork:

Displacement for 5 Kg is 0.47 mm.

KC=104.3617 x 1000 = 104361.7 N/m.

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

Rubber- Rubber- Rubber (RRR)

$$\frac{1}{K_{RRR}} = \frac{1}{K_R} + \frac{1}{K_R} + \frac{1}{K_R} =$$

$$\frac{3}{K_R} = \frac{3}{79112.9} = \frac{1}{26370.96}$$

KRRR= 26370 N/mm

Similarly, we get values for various combinations in below Table 1.

Table 1. Stiffness of materials.

Sr.No.	Material Combination	K(Stiffness) in N/mm
1	FFF	27250
2	CCC	34787.23
3	RFR	26657
4	RCR	28684
5	FRF	26495
6	FCF	29371
7	CRC	31442
8	CFC	31850
9	RFC	29023
10	RRR	26370

Calculation of Damping Coefficient

Damping ratio of materials is R-0.075, C-0.06, F-0.06

Ɛ = C/CC

C = Ɛ x CC

For Rubber:

CC = 245.17Ns/m. CR = 217Ns/m.

CC = 245.17Ns/m.

Rubber- Rubber- Rubber (RRR)

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

Below Table 2 Contains damping value for all combinations.

Table 2. Damping of materials.

Sr.No.	Material Combination	C(Damping) in Ns/m
1	RRR	88.94
2	FFF	72.3
3	CCC	81.7
4	RFR	82.6
5	RCR	86.4
6	FRF	77
7	FCF	75.2
8	CRC	84
9	CFC	78.3
10	RFC	80.4

Calculation of Transmissibility Without Damping Effect

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

$$T_r = \frac{1}{|r^2-1|} \quad \ldots(11)$$

Where r = ω/ωn
ω = 2πN/60 = 2πx480/60 = 50.26 rad/s

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

$$T_r = \frac{1}{\left(\frac{\omega}{\omega n}\right)^2 - 1} \quad \ldots(12)$$

Rubber- Rubber- Rubber (RRR)

$$T_r = \frac{K}{101042.7 - K} \qquad K = 26370.96\,\text{N/m}$$

$$T_r = \frac{26370.96}{101042.7 - 26370.96} \qquad T_r = 0.3531$$

Similarly, for other combinations values are noted in below Table 3.:

Table 3. Transmissibility for materials analytical.

Sr.No.	Material Combination	Transmissibility (*Tr*)
1	RRR	0.3531
2	FFF	0.37
3	CCC	0.525
4	RFR	0.358
5	RCR	0.39
6	FRF	0.363
7	FCF	0.4
8	CRC	0.45
9	CFC	0.46
10	RFC	0.4

Calculation of Transmissibility with Damping Effect

$$T_r = \frac{\sqrt{1+(2\varepsilon r)^2}}{\sqrt{((1-r^2)^2+(2\varepsilon r)^2)}} \quad \ldots(14)$$

Where r = ω/ωn
ω = 2πN/60 = 2πx480/60 = 50.26 radX/s

$$\omega n = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{40}}$$

(m=40 Kg = mass of system)

$$\varepsilon = C/C_C,$$

$$C_c = 2\sqrt{Km}$$

$$T_r = \frac{\sqrt{1+\left(2\frac{C}{C_c}\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left[\left(\frac{\omega}{\omega_n}\right)^2-1\right]^2+\left(2\frac{C}{C_c}\frac{\omega}{\omega_n}\right)^2}}$$

$$T_r = \frac{\sqrt{1+\left(2\frac{C}{2\sqrt{Km}}\frac{\omega}{\sqrt{K/m}}\right)^2}}{\sqrt{\left[\left(\frac{\omega}{\sqrt{K/m}}\right)^2-1\right]^2+\left(2\frac{C}{2\sqrt{Km}}\frac{\omega}{\sqrt{K/m}}\right)^2}} \quad \ldots(15)$$

Putting the values of ω and m we have collected values for Stiffness, Damping and transmissibility for material combinations in below Table 4.

Table 4. Material values for r, K, C and Tr.

Material	r = (ω/ωn)	K (N/mm)	C (Ns/m)	Transmissibility	
				(Without damping)	(With Damping)
RRR	1.9276	26370.96	88.94	0.3531	0.3574
FFF	1.9233	27250	72.33	0.3692	0.3720
CCC	1.7034	34787.23	81.72	0.5250	0.5276
RFR	1.9470	26657.60	82.62	0.3583	0.3621
RCR	1.8768	28684.2	86.39	0.3964	0.4002
FRF	1.9363	26950.54	77.13	0.3637	0.3669
FCF	1.8547	29371.25	75.21	0.4098	0.4125
CRC	1.7927	31442.30	83.99	0.4517	0.4549
CFC	1.7811	31850.64	78.33	0.4603	0.4630
RFC	1.8658	29023.66	80.42	0.4029	0.4062

$$T_r = \frac{\sqrt{1+\left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left[\left(\frac{50.26x\sqrt{40}}{\sqrt{K}}\right)^2-1\right]^2+\left(\frac{50.26C}{K}\right)^2}}$$

$$T_r = \frac{\sqrt{1+\left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K}-1\right)^2+\left(\frac{50.26C}{K}\right)^2}} \quad \ldots(16)$$

Rubber- Rubber- Rubber (RRR)

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

Now 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, for other combinations Transmissibility is given in Table 5 below:

Table 5. Transmissibility for materils numerically.

Sr.No.	Material Combination	Transmissibility (*Tr*)
1	RRR	0.3574
2	FFF	0.372
3	CCC	0.527
4	RFR	0.362
5	RCR	0.4
6	FRF	0.3669
7	FCF	0.412
8	CRC	0.454
9	CFC	0.463
10	RFC	0.4062

Calculation of Effectiveness and Isolation The isolator's effectiveness in percent is:

% Isolation = (1-T)X100.

IV. NUMERICAL ANALYSIS

Analysis packages and software has been used for determination of the various levels of vibration and its isolation. This is done by developing the model in CAD (ANSYS 18.1) and applying the conditions as per the requirement.

Results are plotted as numeric values, curves and graphs. Harmonic Analysis in Ansys without Isolation.

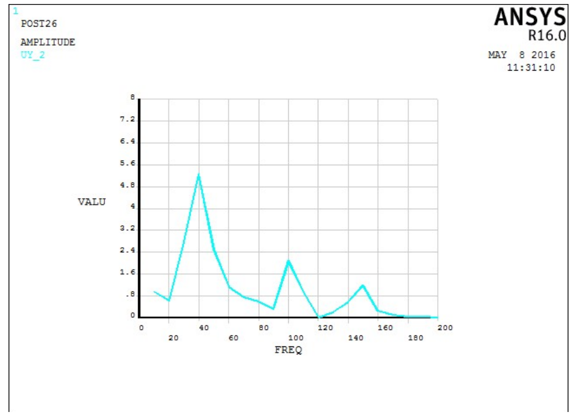


Fig 2. Amplitude Vs Frequency Plot without Isolation.

```
***** ANSYS POST26 VARIABLE LISTING *****

FREQ          899 UY
              UY_2
              AMPLITUDE        PHASE
 10.000       0.949291        180.000
 20.000       0.614929        180.000
 30.000        2.76321        180.000
 40.000        5.26623        0.00000
 50.000        2.49216        0.00000
 60.000        1.12657        0.00000
 70.000       0.752126        0.00000
 80.000       0.581264        0.00000
 90.000       0.311997        0.00000
 100.00        2.07926        0.00000
 110.00       0.918669        180.000
 120.00       0.138039E-01    180.000
 130.00       0.199091        0.00000
 140.00       0.567978        0.00000
 150.00        1.17109        180.000
 160.00       0.235820        180.000
 170.00       0.996159E-01    180.000
 180.00       0.184523E-01    180.000
 190.00       0.382260E-01    180.000

***** ANSYS POST26 VARIABLE LISTING *****

FREQ          899 UY
              UY_2
              AMPLITUDE        PHASE
 200.00       0.618507E-02    0.00000
```

Fig 3. Amplitude of Vibration without isolation.

Frequency of vibration from Ansys=50 Hz
The graphical representation of Amplitude vs. Frequency is shown in Fig 5.1

The amplitude of vibration without isolator= 2.49216 mm is taken from software output as shown in Fig.5.2 RRR.

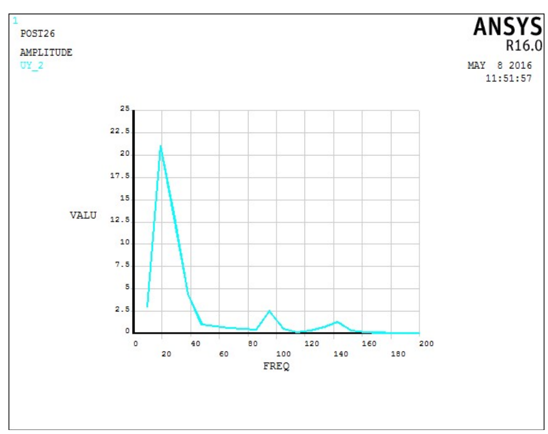
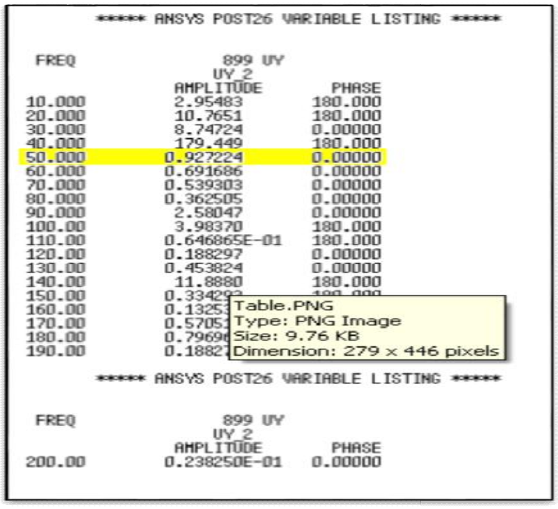


Fig 4. Amplitude Vs Frequency plot for RRR.



***** ANSYS POST26 VARIABLE LISTING *****

FREQ	899 UY UY_2 AMPLITUDE	PHASE
10.000	2.95483	180.000
20.000	10.7651	180.000
30.000	8.74724	0.00000
40.000	179.449	180.000
50.000	0.927224	0.00000
60.000	0.691686	0.00000
70.000	0.539303	0.00000
80.000	0.362505	0.00000
90.000	2.58047	0.00000
100.00	3.98370	180.000
110.00	0.646865E-01	180.000
120.00	0.188297	0.00000
130.00	0.453824	0.00000
140.00	11.8880	180.000
150.00	0.33429	[illegible]
160.00	0.13253	[illegible]
170.00	0.57051	[illegible]
180.00	0.79696	[illegible]
190.00	0.18827	[illegible]

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Size: 9.76 KB
Dimension: 279 x 446 pixels

***** ANSYS POST26 VARIABLE LISTING *****

FREQ	899 UY UY_2 AMPLITUDE	PHASE
200.00	0.238250E-01	0.00000

Fig 5. Amplitude of Vibration for RRR.

The amplitude of vibration with RRR= 0.9272 mm from Fig 5.4 Amplitude vs. Frequency Graphics represented in Fig.3.

$$\text{Transmissibility} = \frac{\text{Amplitude of vibration with isolator RRR}}{\text{Amplitude of vibration without isolator}}$$

$$= \frac{0.9272}{2.4921}$$

Tr = 0.3720

Similarly, values were calculated for all combinations using this numerical analysis method.

V. RESULTS AND DISCUSSION

Table 6. Comparison of transmissibility of Analytical (with and without Damping) to Numerical (Without Damping).

S.N.	Material	Analytical		Simulation
		Transmissibility (Without damping)	Transmissibility (With damping)	Transmissibility (Without Damping)
1	RRR	0.353	0.357	0.372
2	RFR	0.358	0.362	0.374
3	FRF	0.363	0.366	0.376
4	FFF	0.369	0.372	0.378
5	RCR	0.396	0.400	0.389
6	RFC	0.402	0.406	0.392
7	FCF	0.409	0.412	0.395
8	CRC	0.451	0.454	0.412
9	CFC	0.460	0.463	0.416
10	CCC	0.525	0.527	0.442

The value of transmissibility is shown in the table 6. A comparison of values received by using theoretical calculation is compared to the values received from Numerical simulation with harmonic analysis method.

The result of different composites shows the transmissibility of the combinations tested numerically and compared with the theoretical readings. Rubber has a better isolation property as the composites having rubber have less transmissibility which is 0.372.

The readings obtained by the theoretical, experimental and numerical methods are in close agreement with each other. Felt is the second best performer with transmissibility values as 0.374 and can be used for the heavier mass of setup.

The cork combinations is found to have the highest transmissibility and hence the least performance with transmissibility to be 0.442.

VI. CONCLUSION

Rubber is the best isolating material among the combinations for the air compressor followed by felt and cork. However, the application of the isolators depends upon the variables like the weight of the system, frequency of excitation, damping co-efficient and other factors.

The performance characteristics of isolators can be enhanced by using layers (composite) of these isolators. The performance can be further enhanced by bonding or gluing the isolators.

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