Analysis of Vibration Transmissibility on a System using Finite Element Analysis

Rajesh Shukla[1] Akhilesh Lodwal[2]
[1]M.E. Student [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1,2]Institute of Engineering & Technology, Devi Ahilya Vishwavidhyalaya, Indore-452017 (M.P), India

Abstract— This paper deals with analysis of vibration transmissibility of a spring mass damper system. SDOF system had been solved by ANSYS workbench for natural frequencies and damped frequencies and its results are compared with theoretical calculation. Later on the harmonic analysis of damped forced vibration is also done and its results are compared with theoretical calculations. This paper also deals with the study, analysis and comparison of relations between stiffness and transmissibility and damping and transmissibility of isolation system.

Key words: ANSYS Workbench, Harmonic Response, Isolation, Base Excitation, Damping, Transmissibility

I. INTRODUCTION

Vibration is one of the major problem in industries. Most of the machines, Vehicle Engines, Pumps, Precision machines installed in workshops etc. are subjected to forced vibration due to operation of their own or nearby machines. If they are vibrating near the natural frequencies are prone to excessive amplitude and hence large stresses and strains which can cause failure of these machines, equipments and their parts and may affect their performance. In these cases stiffness and damping of isolator plays an important role.

The inertia force developed in a reciprocating engine, unbalanced forces produced in any rotating machinery and motion of a vehicle on rough road should be isolated from the foundation so that the adjoining structure is not set into heavy vibrations.

Effectiveness of isolation may be measured in Terms of

- Ratio of the Force transmitted to that in existence.
- Ratio of the motion transmitted to that in existence.

A. Vibration Transmissibility

When a machine is operating or a vehicle travelling on road it may be subjected to several time varying forces or movement, because of which it tends to exhibit vibrations. In this process some of these forces are transmitted to the foundation or passenger travelling. This is known as transmissibility which could have some harmful effect on the health of machines or equipment. The transmissibility is mainly of two types

B. Force Transmissibility

The term force transmissibility in case of force excited system is defined as ratio of force transmitted to the foundation to that impressed upon the system.

C. Motion Transmissibility

In forced vibration system the ratio of absolute amplitude of the mass to the base excitation amplitude is known as motion transmissibility.

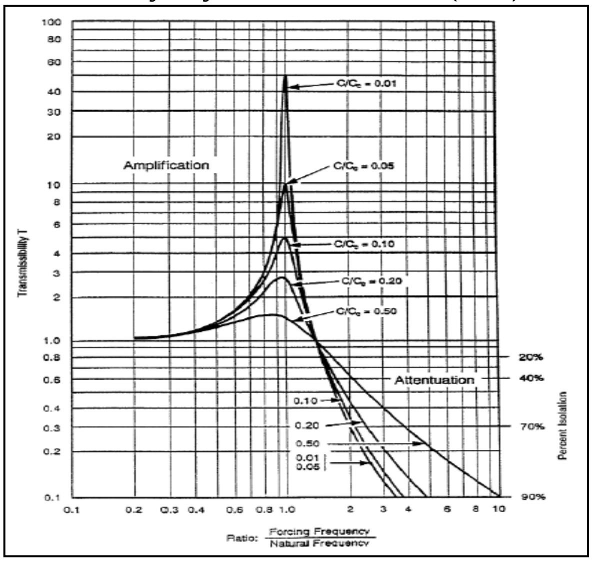

Fig. 1: Transmissibility V/s Frequency ratio for different amount of damping [6]

D. Vibration Isolation

It is the isolation of system from transmission of vibration of environment. It is reducing the transmitted vibration by vibration isolation. This is obtained by placing property chosen isolation material between the vibrating body and supporting structure.

E. Damping

This process of dissipation of energy is known as damping refers to the phenomenon by which energy is dissipated in a vibratory system. The consideration of damping becomes important for an accurate prediction of the vibration response of a system. A damper is assumed to have neither mass nor elasticity, and damping force exists only if there is relative velocity between the two ends of the damper.

II. LITERATURE SURVEY

Dr.Ashesh Tiwari & Amit Chandsarkar [1] in this paper comparison and analysis of various materials for vibration isolation is studied. Transmissibility and properties on different materials gives idea about getting maximum vibration isolation. Values of transmissibility have been taken for different materials. Writer studies to get a best possible solution for vibration isolation amongst materials under observation.

Chandradeep Kumar, Anjani Kumar sing, Nitesh Kumar and Ajit Kumar [2] in this paper FEA Modeling and analysis done of cantilever beam and natural frequencies are found using MATLAB and ANSYS software and obtained results are compared with theoretical calculation. Good agreement is found between all results.

Dr.C.M. Ramesha, Abhijit K.G., Abhinav Singh, Abhishekh Raj and Chetan S Naik [3] in this paper Modal analysis and Harmonic response Analysis of crankshaft done using Ansys software. Mode shapes and natural frequencies of two conditions are found and analysed. The variation of number of modes vs frequency has been plotted graphically. Harmonic response analysis has been studied. Variation of displacement amplitude (frequency response) with respect to frequency has been graphically plotted.

Clarence W. de Silva[5] Harmonic Excitation Method: If the input signal is sinusoidal (harmonic) with frequency, f; the output also will be sinusoidal with frequency, f; at steady state but with a change in the phase angle.

Galal Ali Hassan [7] in this paper study of transmissibility of SDOF system is done using an efficient technique to get optimal damping ratio to adjust transmissibility of vibrating system. Different objective function relationships are presented and the best one is assigned leading to the desired unit force transmissibility

Ivana Kovac, Zarko Milovanovic and Michael J. Brennan [8] in this paper a one degree of freedom passive vibration isolator system with a parallel combination of a stiffness and damping element subjected to harmonic base excitation is analysed. A study is conducted in order to investigate the influence of the system parameters on the relative and absolute transmissibility of the system to check for possible improvement of the transmissibility of a system with linear viscous damping.

J.M. Krodkiewski[9], if the equipment requiring isolation is the source of unwanted vibration. Conversely, if the equipment requiring isolation is a recipient of unwanted vibration, the purpose of isolation is to reduce the vibration transmitted from the support structure to the recipient. An isolator is a resilient support, which decouples an object from steady state or forced vibration.

T. K. Caughey and K.E.J.O'Kelly [11] in this paper an analysis is presented of the effect of damping on the natural frequencies of linear dynamic systems. It is shown that highest matural frequency is always decreased by damping, but the lower natural frequencies may either increase or decrease, depending on the form of the damping matrix

III. THEORETICAL ANALYSIS

A. *Free Vibration Analysis without Damping*

A vibratory system shown in fig 2 If the mass m is displaced from its equilibrium position and then allowed to vibrate free, it is said to have free vibration.

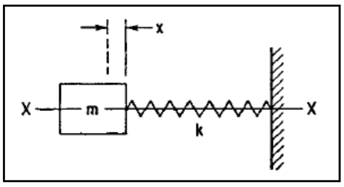

Fig. 2: Undamped single degree of freedom system [4]

Newton's Equation is written for the mass m.

$$m\ddot{x} + kx = 0 \qquad (1)$$

Where x = 0, solution of Eq. (1) is

$$x = A\sin\sqrt{\frac{k}{m}}\,t + B\cos\sqrt{\frac{k}{m}}\,t \qquad (2)$$

Where angular natural frequency defined by

$$\omega_n = \sqrt{\frac{k}{m}} \quad \text{rad/sec} \qquad (3)$$

The time interval to complete one cycle is the period:

$$\tau = \frac{2\pi}{\omega_n} \qquad (4)$$

The reciprocal of the period is the natural frequency:

$$f_n = \frac{1}{\tau} = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad \text{Hz} \qquad (5)$$

B. *Free Vibration Analysis with Damping*

Figure 3 shows a single degree-of-freedom system with a viscous damper.

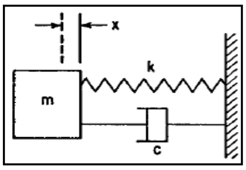

Fig. 3: Damped Single Degree of Freedom System[4]

The differential equation of motion of mass m

$$m\ddot{x} + c\dot{x} + kx = 0 \qquad (6)$$

The form of the solution of this equation depends upon whether the damping coefficient is equal to, greater or less than the critical damping coefficient c_c

$$c_c = 2\sqrt{km} = 2m\omega_n \qquad (7)$$

The ratio $\zeta = c/c_c$ is defined as the fraction of critical damping.

The damped natural frequency is

$$\omega_d = \omega_n(1-\zeta^2)^{1/2} \quad \text{rad/sec} \qquad (8)$$

$$f_d = \omega_d / 2\pi \ \ \text{Hz} \qquad (9)$$

C. *Harmonic Response Analysis of a Damped System under Harmonic Motion of Base*

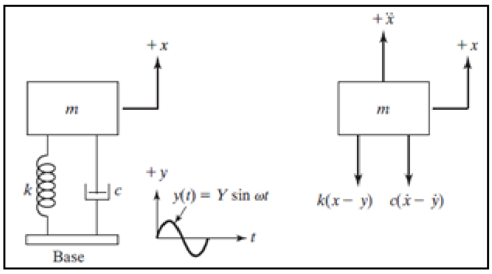

Fig. 4: Base excitations/Support Motion model[10]

Steady state response of mass $x_p(t)$ can be expressed as

$$x_p(t) = X\sin(\omega t - \phi) \qquad (10)$$

$$\frac{X}{Y} = \left[\frac{k^2 + (c\omega)^2}{(k - m\omega^2)^2 + (c\omega)^2}\right]^{1/2}$$

$$= \left[\frac{1 + (2\zeta r)^2}{(1 - r^2)^2 + (2\zeta r)^2}\right]^{1/2} \qquad (11)$$

$$\phi = \tan^{-1}\left[\frac{mc\omega^3}{k(k - m\omega^2) + (\omega c)^2}\right]$$

$$= \tan^{-1}\left[\frac{2\zeta r^3}{1 + (4\zeta^2 - 1)r^2}\right] \qquad (12)$$

IV. RESULT AND DISCUSSION

A. *ANSYS Result of Model Analysis*

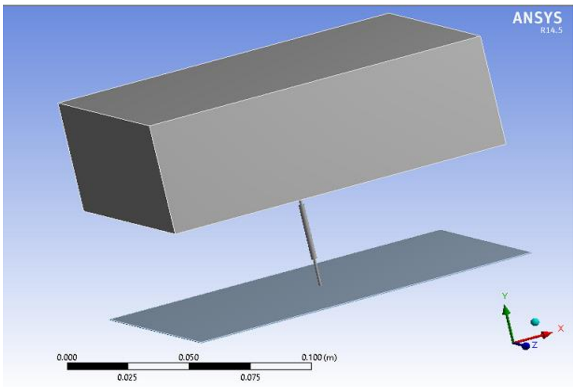

Fig. 5 ANSYS Model

B. *Undamped Free Vibration Analysis*

S. No.	k = Stiffness	fn= Natural frequency	
		Calculated	Ansys results
	N/m	Hz	Hz
1	40	0.414844	0.41486
2	60	0.508078	0.50809
3	80	0.586678	0.58669
4	100	0.655926	0.65594
5	120	0.718531	0.71854
6	140	0.776102	0.77611
7	160	0.829688	0.8297
8	180	0.880017	0.88003
9	200	0.927619	0.92763

Table 1: Comparison of natural frequencies

C. *Damped Free Vibration Analysis*

S. No.	k= Stiffness	C= Damping Coefficient	f_d= Damped frequency	
			Calculated	ANSYS Results
	N/m	N-s/m	Hz	Hz
1	40	10	0.39221	0.39222
2	60	10	0.48977	0.48977
3	80	10	0.57090	0.5709
4	100	10	0.64185	0.64186
5	120	10	0.70570	0.70571
6	140	10	0.76424	0.76425
7	160	10	0.81860	0.81861
8	180	10	0.86957	0.86958
9	200	10	0.91772	0.91773

Table 2: Comparison of damped frequencies

D. *ANSYS Result of Harmonic Analysis*

S. No.	ANSYS Displacement Output Results		
	Angle in deg.	Input displacement (m)	Output displacement (m)
1	0	0.00100000	0.0000102440
2	36	0.00080902	-0.0000620780
3	72	0.00030902	-0.0001106900
4	108	-0.00030902	-0.0001170200
5	144	-0.00080902	-0.0000786540
6	180	-0.00100000	-0.0000102440
7	216	-0.00080902	0.0000620780
8	252	-0.00030902	0.0001106900
9	288	0.00030902	0.0001170200
10	324	0.00080902	0.0000786540
11	360	0.00100000	0.0000102440

Table 3: ANSYS results of harmonic analysis

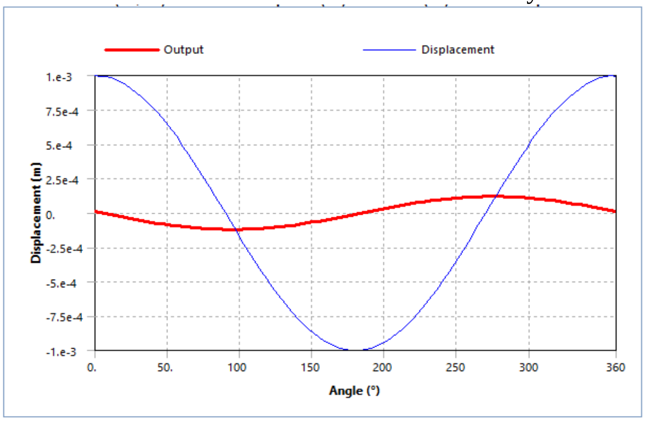

Fig. 6: Phase response of harmonic analysis by ANSYS as per table 3

S. No.	Theoretical calculations output results		
	Angle in deg.	Input displacement y(t)	Output displacement x(t)
1	0	0.001000000	0.000010244
2	36	0.000809017	-0.000062078
3	72	0.000309017	-0.000110689
4	108	-0.000309017	-0.000117020
5	144	-0.000809017	-0.000078654
6	180	-0.001000000	-0.000010244
7	216	-0.000809017	0.000062078
8	252	-0.000309017	0.000110689
9	288	0.000309017	0.000117020
10	324	0.000809017	0.000078654
11	360	0.001000000	0.000010244

Table 4: Theoretical results of harmonic analysis

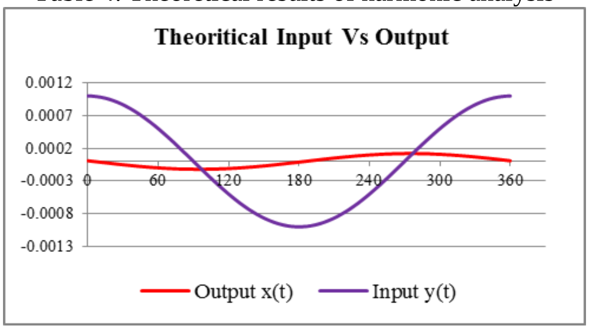

Fig. 7: Phase response of harmonic analysis by theoretical calculations as per table 4

S. No.	k = Stiffness	C = Damping Coefficient	Amplitude			Transmissibility	
			Input	Theoretical result	ANSYS results	Theoretical result	ANSYS results
	N/m	N-s/m	m	m	m	m	m
1	100	10	0.001	0.0000272002	0.0000272000	0.0272002	0.0272000

2	100	15	0.001	0.0000405066	0.0000405070	0.0405066	0.0405070
3	100	20	0.001	0.0000538457	0.0000538460	0.0538457	0.0538460
4	100	25	0.001	0.0000671779	0.0000671780	0.0671779	0.0671780
5	100	30	0.001	0.0000804851	0.0000804850	0.0804851	0.0804850
6	100	35	0.001	0.0000937557	0.0000937560	0.0937557	0.0937560
7	100	40	0.001	0.0001069805	0.0001069800	0.1069805	0.1069800
8	100	45	0.001	0.0001201512	0.0001201500	0.1201512	0.1201500
9	100	48	0.001	0.0001280247	0.0001280200	0.1280247	0.1280200

Table 5: Result of amplitude and Transmissibility of harmonic vibration at different damping coefficient

S. No.	**k = Stiffness**	**C = Damping Coefficient**	**Amplitude**			**Transmissibility**	
			Input	**Theoretical result**	**ANSYS Results**	**Theoretical Result**	**ANSYS Results**
	N/m	N-s/m	m	m	m	m	m
1	40	10	0.001	0.0000268538	0.000026854	0.0268538	0.0268540
2	60	10	0.001	0.0000269429	0.000026943	0.0269429	0.0269430
3	80	10	0.001	0.0000270584	0.000027058	0.0270584	0.0270580
4	100	10	0.001	0.0000272002	0.000027200	0.0272002	0.0272000
5	120	10	0.001	0.0000273680	0.000027368	0.0273680	0.0273680
6	140	10	0.001	0.0000275614	0.000027561	0.0275614	0.0275610
7	160	10	0.001	0.0000277801	0.000027780	0.0277801	0.0277800
8	180	10	0.001	0.0000280235	0.000028024	0.0280235	0.0280240
9	200	10	0.001	0.0000282912	0.000028291	0.0282912	0.0282910

Table 6: Result of amplitude and Transmissibility of harmonic vibration at different stiffness

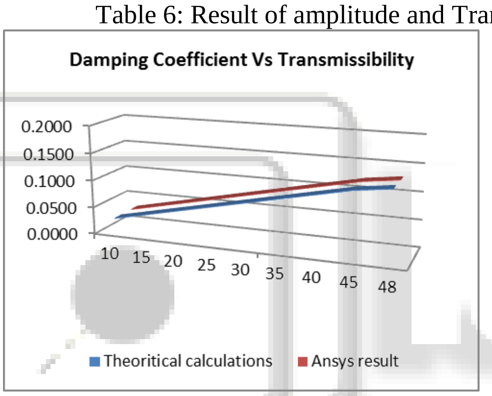

Fig. 8: Damping Coefficient vs Transmissibility Graph corresponds to table 5

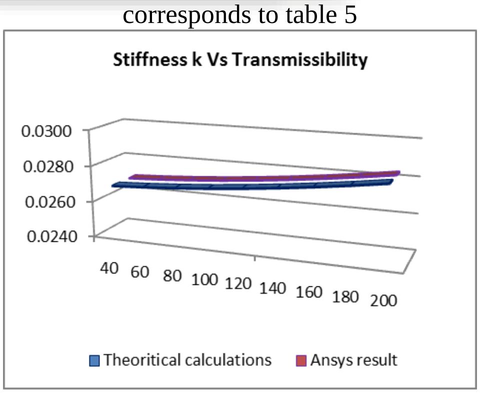

Fig. 9: Stiffness Vs Transmissibility Graph corresponds to table 6

V. Conclusion

In this project work the Forced vibration characteristics of a mass spring damper system is studied for free vibration, damped free vibration and harmonic vibration using Finite Element Analysis method. Three types of analysis are done and theoretical and ANSYS Workbench results were compared.

1) Modal analysis done free undamped and damped vibration and compared the results of ansys output with theoretical calculation.
2) Harmonic analysis done by given harmonic displacement to the base of the mass spring damper system and phase response taken on mass.
3) Transmissibility analysis with nine different values of damping coefficient keeping stiffness and mass value constant.
4) Transmissibility analysis with nine different values of stiffness keeping damping coefficient and mass value constant.

In the first analysis a good agreement is found between the ansys results and theoretical analysis.

In the second analysis the statement "If the input signal is sinusoidal (harmonic) with frequency, f ; the output also will be sinusoidal with frequency, f ; at steady state but with a change in the phase angle"[5] proven by analysis results. If we see the fig. 6 and 7 the input displacement given to the system is harmonic in nature and the response is also harmonic in nature with some change in phase."

In the third analysis a linear relation found between damping coefficient and transmissibility. As the damping coefficient increases transmissibility also increase a linear scale.

In the fourth above analysis a parabolic relation is found between stiffness and transmissibility. As the stiffness increases transmissibility also increases on a parabolic scale.

Acknowledgement

This work is supported by the Mechanical Engineering Department, Institute of Engineering and Technology Devi Ahilya Vishwavidhyalaya, Indore. Kind help and valuable guide from Mr. Akhilesh Lodwal (Asst. Professor) is acknowledged.

REFERENCE

[1] Dr. Ashesh Tiwari and sumit chandsarkar "Analyse the transmissibility of various material using vibrations analysis, ISSN: 2277-9655","International Journal of Engineering sciences and Research Technology", August 2014.
[2] Chandradeep Kumar, Anjani Kumar sing, Nitesh Kumar and Ajit Kumar " Model Analysis and Harmonic Analysis of Cantilever Beam by ANSYS" Global Journal for Research Analysis, Volume-3, Issue-9, Sept-2014 • ISSN No 2277 - 8160olume-3, Issue-9, Sept-2014 • ISSN No 2277 – 8160
[3] Dr. C.M. Ramesha, Abhijit K.G., Abhinav Singh, Abhishekh Raj and Chetan S Naik , " Modal Analysis and Harmonic Response Analysis of a Crankshaft" International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 5, Issue 6, June 2015
[4] Cyril M. Harris, Allan G. Piersol "Harris's shock and vibration handbook" Fifth Edition McGRAW-HILL (Book)
[5] Clarence W. de Silva "Vibration and Shock Handbook" Taylor & Francis Group (Book)
[6] FABRIKA "Vibration and Shock Control" Fabreeka International Inc. KTI GmBH,(FAB 3000-050), 08/200
[7] Galal Ali Hassan "Adjustment of the Force Transmissibility of a SDOF Vibrating System; PartII: Fraction Transmissibility" International Journal of Computer Techniques Volume 2 Issue 2, Mar – Apr 2015
[8] Ivana Kovacic , Zarko Milovanovic and Michael J. Brennan "On The Relative And Absolute Transmissibility Of A Vibration Isolation System Subjected To Base Excitation" Series: Working and Living Environmental Protection Vol. 5, No 1, 2008, pp. 39 – 48
[9] J.M. Krodkiewski "Mechanical Vibrations" copyright © 2008 by the University of Melbourne, Department of Mechanical and Manufacturing Engineering (Book)
[10] Singiresu S. Rao "Mechanical Vibrations", Fifth Edition, Prentice Hall (Book)
[11] T. K. Caughey and K.E.J. O'Kelly "Effect of Damping on the Natural Frequencies of Linear Dynamic Systems" THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA VOL,- 33, NUMBER-II NOVEMBER, 1961

