TP N°2 - Vibrations

Table of Contents

Introduction

When a dynamic system is subjected to a steady-state harmonic excitation, it is forced to vibrate at the same frequency as that of the excitation. Common sources of harmonic excitation are unbalance in rotating machines, forces produced by the reciprocating parts, or the motion of machine itself. The harmonic excitation can be given in many ways like with constant frequency and variable frequency or a swept-sine frequency, in which the frequency changes from the initial to final values of frequencies with a given time-rate (i.e., ramp).

If the frequency of excitation coincides with one of the natural frequencies of the system, a condition of resonance is encountered and dangerously large oscillations may result, which results in failure of major structures, i.e., bridges, buildings, or airplane wings etc. Hence, the natural frequency of the system is the frequency at which the resonance occurs. At the point of resonance the displacement of the system is a maximum. Thus calculation of natural frequencies is of major importance in the study of vibrations. Because of friction and other resistances vibrating systems are subjected to damping to some degree due to dissipation of energy.

Damping has very little effect on natural frequency of the system, and hence the calculations for natural frequencies are generally made on the basis of no damping. Damping is of great importance in limiting the amplitude of oscillation at resonance.

By that, we need to determine the resonance of Spring-Dashpot System in different damping conditions in order to analyses and understand the risks of resonance, the way to overcame it and manage it accordingly. That makes a lot of things safer for human usage and benefits afterwards.

Theory

In order to define the resonance of the system i.e. Spring-Dashpot System, we need to find the natural frequency of the system in free vibration state. By that, we may know theoretically value of the natural frequency. Next, the exciter will be used to give desired forced to the system. As we know exciter is capable to generate different type of forcing signal e.g. sine, swept sine, rectangular, triangular etc.

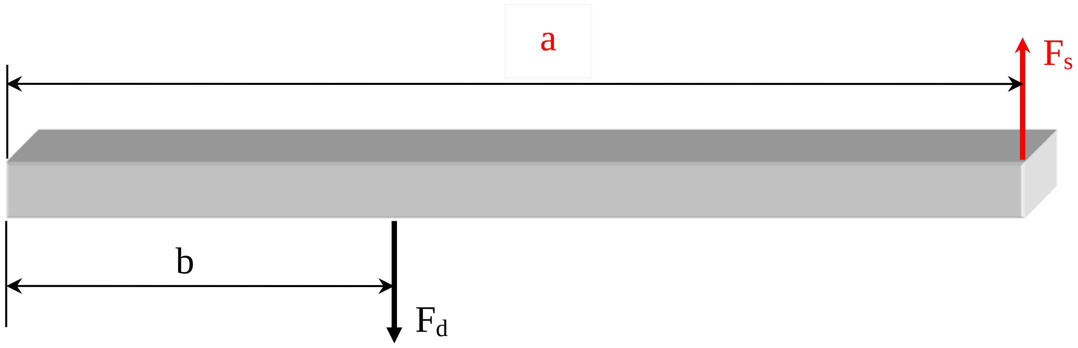
The effect of damping is to limit the maximum response amplitude and to reduce the sharpness of resonance, which can be defined as occurring when the drive frequency Ω equals the natural frequency of the system, ω.

Based on our learning of the resonance, this phenomenon only occurs if the frequency of the excitation coincides with the frequency of the system. As the reaction of the phenomenon's happen in a short time, we may need define a suitable frequency interval to record the amplitude that will occurs.

From the theoretical value of the natural frequency, we may generate the frequency of the system as we may need it for further progress of the experiment. Tabulate a table that consists of frequency i.e. input frequency through the control unit, as variable value and amplitude as responding values. From the data collected, analyses it and discuss the result in discussion part of this experiment. The calculation to determine the theoretical value of the system is shown in the next page.

The experiment will repeated with two conditions, both with closed damped condition but with different distance between the damper and the initial points of moments.

Objectives: - Determine the resonance of Spring-Dashpot System in different damping conditions.



Free-Body Diagram

$y = a\theta$; $F_s = ky$, $\dot{y} = b\dot{\theta}$; $F_d = -c\dot{y}$, $M_o = I_0\ddot{\theta}$; $I_0\ddot{\theta} = b(-cb\dot{\theta}) - a(ka\theta) = -cb^2\dot{\theta} - ka^2\theta$

$I_0\ddot{\theta} + cb^2\dot{\theta} + ka^2\theta = 0$ or, $\ddot{\theta} + \frac{cb^2\dot{\theta}}{I_0} + \frac{ka^2\theta}{I_0} = 0$

From the general equation: $\ddot{y} + 2\zeta\omega_n\dot{y} + \omega_n^2 y = 0$

Thus, $\zeta = \frac{cb^2}{2I_0\omega_n}$ $\quad \omega_n = \sqrt{\frac{ka^2}{I_0}}$

The natural frequency of system: $\omega_n = 2\pi f,\quad f = \frac{\omega_n}{2\pi}$

Total moment of inertia: $I_0 = I_{0beam} + I_{0exciter}$

$$= \left(\frac{1}{3}ml^2 + mk^2\right)_{beam} + \left(\frac{1}{3}ml^2 + mk^2\right)_{exciter}$$

Period, T: $T = \frac{1}{f_n}$

Unbalanced force,F_0 : $F_0 = m.a.\omega_n$

Damped frequency,ω_d : $\omega_d = \omega_n\sqrt{1-\zeta^2}$

Angular frequency applied, f_n: $\omega_n = f_n \times 2\pi$

Frequency ratio,r: $r = {}^{\omega_d}/_{\omega_n}$

Amplitude ratio,M; : $M = {}^{x}/_{F_0/k}$

Experimental Procedure

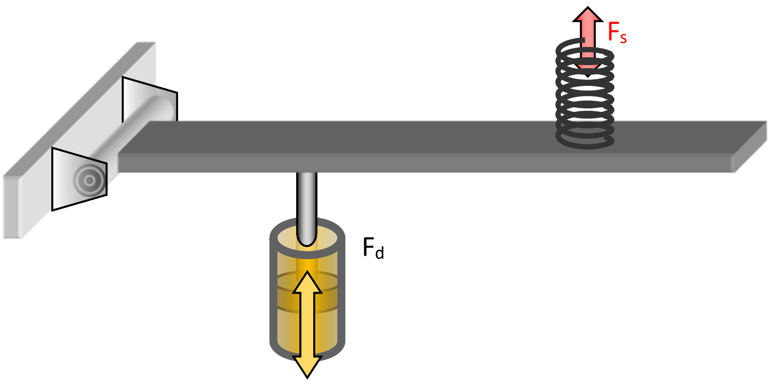


Figure 1 Universal Vibration System (TM155)

Apparatus: Universal Vibration System Apparatus (TM155)

1. Frame
2. Beam
3. Spring
4. Damper
5. Mechanical Recorder
6. Unbalance Exciter
7. Control Unit (TM150)

Procedure

1. Tabulate a table that consist value of the desire frequency and responding values, the amplitude. Plot a suitable frequency interval in order keep a good record keeping afterward.
2. Set the distance of the damper between the initial points to 150 mm.
3. Set up mechanical drum recorder on the Spring-Dashpot system for plotting the graph.
4. Switch on the control unit; adjust the desire frequency on the ten-turn potentiometer.
5. Switch on exciter with the frequency adjustable on the ten-turn potentiometer as the mechanical drum recorder record the graph plotted.
6. After the graph plotted, switch of the control unit and analyses the data on the graph to find the amplitude.
7. Repeat above step with distance between the damper and the initial points to be 550 mm.

Results

Table 1 Condition 1; 150mm

Frequency, Hz	Amplitude, x mm	Angular frequency, f_n $rad/_s$	Frequency ratio, r	Amplitude ratio, M
1.0	0	6.28	7.49	0
2.0	0.20	12.57	3.74	0.54×10^{-3}
3.0	0.40	18.85	2.49	1.08×10^{-3}
4.0	0.50	25.13	1.87	1.36×10^{-3}
5.0	0.70	31.42	1.49	1.90×10^{-3}
6.0	0.90	37.70	1.25	2.44×10^{-3}
6.5	1.10	40.84	1.15	2.98×10^{-3}
6.7	1.10	42.10	1.12	2.98×10^{-3}
6.9	1.20	43.35	1.08	3.25×10^{-3}
7.1	1.20	44.61	1.05	3.25×10^{-3}
7.3	1.30	45.87	1.02	3.53×10^{-3}
7.5	1.50	47.13	1.00	4.07×10^{-3}
7.7	1.50	48.38	0.97	4.07×10^{-3}
7.9	1.55	49.37	0.95	4.20×10^{-3}
8.1	1.60	50.89	0.92	4.34×10^{-3}
8.3	1.80	52.15	0.90	4.88×10^{-3}
8.5	1.95	53.41	0.88	5.29×10^{-3}
9.0	2.25	56.55	0.83	6.10×10^{-3}
10.0	2.30	62.83	0.75	6.24×10^{-3}
11.0	2.05	69.12	0.68	5.56×10^{-3}
12.0	2.00	75.40	0.62	5.42×10^{-3}
13.0	1.76	81.69	0.57	4.77×10^{-3}
14.0	1.30	87.96	0.53	3.53×10^{-3}
15.0	0.70	94.25	0.50	1.90×10^{-3}

Table 2 Condition 2; 550mm

Frequency, Hz	Amplitude, x mm	Angular frequency, f_n $^{rad}/_{s}$	Frequency ratio, r	Amplitude ratio, M
1.0	0	6.28	7.45	0
2.0	0.20	12.57	3.72	0.54×10^{-3}
3.0	0.25	18.85	2.48	0.68×10^{-3}
4.0	0.40	25.13	1.86	1.08×10^{-3}
5.0	0.50	31.42	1.49	1.36×10^{-3}
6.0	0.53	37.70	1.24	1.44×10^{-3}
6.5	0.60	40.84	1.15	1.63×10^{-3}
6.7	0.61	42.10	1.11	1.66×10^{-3}
6.9	0.62	43.35	1.08	1.68×10^{-3}
7.1	0.64	44.61	1.05	1.74×10^{-3}
7.3	0.65	45.87	1.02	1.76×10^{-3}
7.5	0.66	47.13	0.99	1.79×10^{-3}
7.7	0.66	48.38	0.97	1.79×10^{-3}
7.9	0.67	49.37	0.95	1.82×10^{-3}
8.1	0.68	50.89	0.92	1.84×10^{-3}
8.3	0.70	52.15	0.90	1.90×10^{-3}
8.5	0.71	53.41	0.88	1.93×10^{-3}
9.0	0.73	56.55	0.83	1.98×10^{-3}
10.0	0.72	62.83	0.75	1.95×10^{-3}
11.0	0.71	69.12	0.68	1.93×10^{-3}
12.0	0.70	75.40	0.62	1.90×10^{-3}
13.0	0.70	81.69	0.57	1.90×10^{-3}
14.0	0.69	87.96	0.53	1.87×10^{-3}
15.0	0.66	94.25	0.50	1.79×10^{-3}

Sample calculations

The moment inertia of the system:

$$I_0 = I_{0beam} + I_{0exciter}$$

$$= \left(\frac{1}{3}ml^2 + mk^2\right)_{beam} + \left(\frac{1}{3}ml^2 + mk^2\right)_{exciter}$$

$$= \left[\frac{1}{3}(1.680kg)(0.65m)^2 + (1.680kg)(350)^2\right] + \left[\frac{1}{3}(0.722kg)(0.02m)^2 + (0.840kg)(0.35m)^2\right]$$

$$I_0 = 0.575\ kgm^2$$

The natural frequency of the system:

$$\omega_n = \sqrt{\frac{(3000\ {}^{N}/_{m})(0.65m)^2}{0.575\ kgm^2}}$$

$$= 46.95$$

The frequency of the system: $\omega_n = 2\pi f, f = \frac{\omega_n}{2\pi} = \frac{46.95}{2\pi}$

$= 7.472\ Hz$

Period, T: $T = \frac{1}{f_n} = {}^{1}/_{7.472} = 0.1338\ s$

Unbalanced force,F_0 : $F_0 = ma\omega_n = (0.772)(0.65)(46.95)^2 = 1106.12\ N$

Condition 1: closed, b = 150 mm

Damper constant, c = 15 ${}^{Ns}/_{m}$, b = 150 mm , $\omega_n = 46.95\,{}^{rad}/_{s}$

Damping ratio, ζ: $\zeta = \frac{cb^2}{2I_0\omega_n} = \frac{(15)(0.15)^2}{2(0.575)(46.95)} = 6.25 \times 10^{-3}$

Damped frequency,ω_d : $\omega_d = \omega_n\sqrt{1-\zeta^2} = (46.95)\sqrt{1-(6.25 \times 10^{-3})^2}$

$= 46.95\,{}^{rad}/_{s}$

Condition 2: closed, b = 550 mm

Damper constant, c = 15 ${}^{Ns}/_{m}$, b = 150 mm, $\omega_n = 46.95\,{}^{rad}/_{s}$

Damping ratio, ζ: $\zeta = \frac{cb^2}{2I_0\omega_n} = \frac{(15)(0.55)^2}{2(0.575)(46.95)} = 84.04 \times 10^{-3}$

Damped frequency,ω_d : $\omega_d = \omega_n\sqrt{1-\zeta^2} = (46.95)\sqrt{1-(84.04 \times 10^{-3})^2}$

$= 46.78\,{}^{rad}/_{s}$

Sample calculations

Condition 1: closed, b = 150 mm

Damper constant, c = 15 ${}^{Ns}/_{m}$, b = 150 mm, $\omega_d = 46.95\,{}^{rad}/_{s}$

Angular frequency applied, (for $f_n = 10\ H_z$) :

$\omega_n = f_n \times 2\pi = (10)(2\pi) = 62.84\ H_z$

Frequency ratio,r: $r = {}^{\omega_d}/_{\omega_n} = {}^{46.95}/_{62.84} = 0.747$

Amplitude ratio,M; $M = {}^{x}/_{F_0/k} = {}^{(2.30 \times 10^{-3})}/_{(1106.12/3000)} = 6.24 \times 10^{-3}$

Discussion

In this experiment, we had to determine the resonance of Spring-Dashpot System in different damping conditions. By that, we need have the natural frequency of the system. From our theory, we had summarized some of the basic understanding about the objectives of this experiment and we come out with some several equations that may help to find the natural frequency of the system. The frequency calculated is 7.472 Hz.

We know that the resonance will occurs if the frequency coincides with the natural frequency of the system. Based on that, we had to calculate the theoretical value of the natural frequency of the system. By using that value, we manage to tabulate a table of data that consists the input frequency and the responding values i.e. the amplitude. The occurrence of the resonance happen such a short time. So, we decide that the value of input frequency given properly. By do that, we manage to record the resonance amplitude.

However the data that we have might be slightly differing from the theoretical values. This due to the several errors during this experiment conducted. The apparatus that recorded the amplitude in this experiment was no precise as it may lead to miscalculations of data. Other than that, the actual natural frequency may vary from our theoretical value. This is because the condition and surrounding may affect the system as well as experiment take place.

Apart from that, all the team members shift control the exciter and observe the recorded graph so that the result that we keen to have is possible. It will result a better understanding about the experiment especially the theory involved among the team members.

Perhaps all the data that we get is acceptable. We think this experiment is a success and I thanks to all members for giving full participation and our supervisor for their unforgettable help.

Conclusion

In this experiment, we need to understand the resonance phenomenon, the concept of the natural frequency, damped frequency and all the parameters involved in this experiment. We had to understand and do some revision about all the theory of this experiment before it conducted.

Based on our results, perhaps it does fulfill our objectives. The main important things are the understanding of the concept involve and how to practically in prefer way. The apparatus use for this experiment is well maintained for our use. Besides that, we use different angles in order to see the different result that we get.

Besides that, the data that we calculated may vary from the theoretical values. In future, a better understanding about the apparatus and theory involved is vital for getting precise and accurate result. Consider the surrounding that may disturb the natural frequency of the system. Other than that, time management is very important during this experiment conducted.

Nevertheless, all errors that occurred during this experiment lead to differing of real and theoretical results. So that, a deeper understanding on how to practically using the given formula is very important. Then, this experiment can be done successfully based on the procedure and help from the supervisor. We can conclude that this experiment had achieved the overall objectives and we had a better understanding about this topic.

The experimental approach that we have used is to apply the concept of natural frequency, resonance phenomenon and the damped frequency. We have decreased the increment value of frequency was start from 6.5 to 8.5 to get the resonance because the resonance occurs in a short time.

For the future studies, I think that the apparatus should more efficient and user friendly such as the marker pen and the graph paper or maybe we can use the computer recording data so that the data that we get is more exactly.

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