2.5.Vibration Isolation

MECH 463: Mechanical Vibrations

A. Srikantha Phani
srikanth@mech.ubc.ca

Suggested Readings:

1. Topic 2.5 from notes package for detailed derivations.
2. Section 9.10 from the course textbook.

Learning Objectives

1. Know the working principles involved in vibration isolation.
2. Apply SDOF vibration theory to deduce vibration transmissibilities.
3. Design simple SDOF isolators.
4. Appreciate the design trade-offs.

Fill in the class

Design Choices — # 1

1. Appropriate design of restoring (spring) and inertial (mass) elements of a mechanical system. Here, our goal is to avoid resonant frequencies by suitably choosing the spring constants and mass.
2. **We can isolate the source of vibration from the sensitive components we wish to protect**. In the case of a car, vibration from unbalance in engines and from the roughness of the road can be prevented from being transmitted into the passenger cabin. We achieve this using vibration isolators. **We shall study isolation system design in this topic**.
3. Equally applicable is the notion of absorbing vibration energy from a vibrating component. This can be accomplished by channelling away the energy into a secondary device, such as a vibration absorber, effective at selected tuned frequencies. We shall study vibration absorbers later.
4. Somewhat related to the above ideas is the notion of applying an external force (using actuators) to counter vibrations. This method of active vibration control is outside our scope as a detailed knowledge of control theory and actuator and sensor technologies is needed.

Design Choices — # 2

Q: Can you list a few situations, other than the car example, where vibration isolation may be useful? p.138 in NP

Fill in the class

2.17 SDOF Isolation (T9.10+NP) — # 1

The goal of vibration isolation is to reduce the transmitted vibration from a vibrating source to other parts of the system, by **decreasing** the natural frequency of the whole system compared to the disturbing force frequency. This is accomplished by inserting resilient elements (spring mounts, damped spring mounts, pneumatic rubber mounts) between the source of vibration and the object to be protected.

2.17 SDOF Isolation (T9.10+NP) — # 2

The effectiveness of an isolation system is quantified using a non-dimensional parameter called Transmissibility. It can be defined as a ratio of transmitted to applied force, or transmitted to applied displacement. Thus we have

$$\boxed{TR = \frac{F_t}{F} \text{ (force transmissibility); } TR_d = \frac{X}{Y} \text{ (displacement transmissibility)} \qquad (1)}$$

where F_t, F, X and Y are respectively, transmitted force, applied force, transmitted displacement, and applied displacement.

2.17 SDOF Isolation (T9.10+NP) — # 3

Q: What are the assumptions inherent in the definition of TR or TR_d? Describe situations where one is a better measure than the other. What is the ideal value for a TR?

Fill in the class

2.17 SDOF Isolation (T9.10+NP) — # 4

Q: Which of the following designs may be better? Why?

Fill in the class

Example 20 — # 1

Q: Show that the force and displacement transmissibility of a SDOF system is given by $TR = \frac{F_t}{F} = \frac{\sqrt{k^2+(c\omega)^2}}{\sqrt{(k-m\omega^2)^2+(c\omega)^2}} = \frac{\sqrt{1+(2\zeta r)^2}}{\sqrt{(1-r^2)^2+(2\zeta r)^2}}$ *(force transmissibility) ; and*
$TR_d = \frac{X}{Y} = \frac{\sqrt{1+(2\zeta r)^2}}{\sqrt{(1-r^2)^2+(2\zeta r)^2}}$, where $r = \frac{\omega}{\omega_n}$. (p.141 in NP)

Fill in the class

Example 20 — # 2

Fill in the class

Example 20 — # 3

Fill in the class

Example 20 — # 4

Fill in the class

Example 20 — # 5

Fill in the class

Example 20 — # 6

Fill in the class

Example 21 — # 1

Q: Using the result from example 20 discuss the transmissibility characteristics of an undamped spring mounting; damped spring mounting and a rigid connection of a machinery to a foundation. (p.143 in NP)

Fill in the class

Example 21 — # 2

Fill in the class

Example 21 — # 3

Fill in the class

Example 21 — # 4

Fill in the class

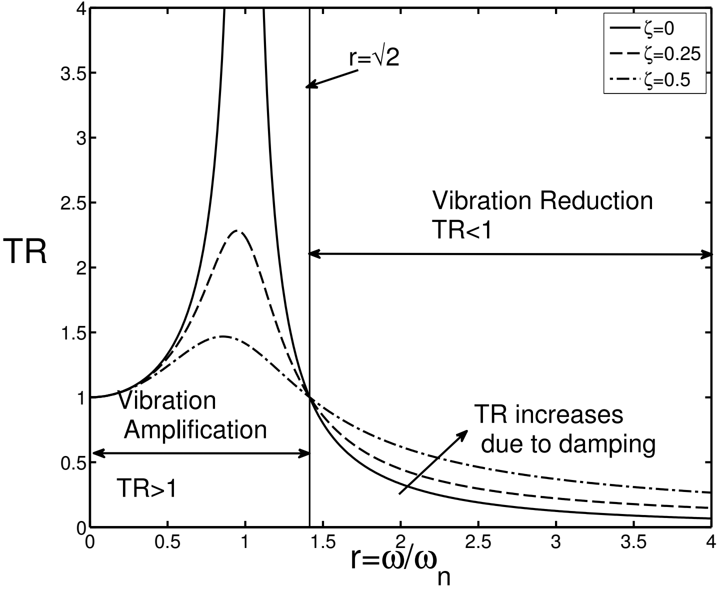
Example 21 — # 5

Fill in the class

Example 21 — # 6

Fill in the class

Isolation Design Curve — # 1



Isolation Design Curve — # 2

The following are worth noting

1. For a given operating frequency, say ω, we can choose $r = \frac{\omega}{\omega_n}$ in the above curves by suitably choosing the isolator's spring constant k. If we choose k such that $r > \sqrt{2}$, that is, the natural frequency of the combined system is well below the forcing frequency, then we obtain $TR < 1$ or less force is transmitted. Thus we obtain isolation by making the dynamics of the whole system with the isolator slow compared to the forcing frequency ω.
2. If spring constants are chosen such that $r < \sqrt{2}$, then vibration is amplified and hence more force is transmitted.
3. The above two points suggest that softer springs are better and stiffer springs are undesirable. Thus rigid mounting is the worst case in terms of force transmissibility.
4. Maximum transmissibility occurs around $r \approx 1$. A spring mounted system (or stiffness only isolator) has infinite force transmissibility around $r \approx 1$. Damping helps to reduce the TR dramatically around resonance.
5. There is an increase in the TR value above $r = \sqrt{2}$ due to the damper.

Isolation Design Curve — # 3

Q: Discuss the practical consideration in the choice of k and damping ζ of an isolator? How will you use the TR curve in practice?

Fill in the class

Example 22 — # 1

Q: An electronic instrument panel is to be isolated from a panel that vibrates at frequencies ranging from 25 Hz to 35 Hz. It is desired to have at least 80% vibration isolation in order to prevent damage to the instrument. If the instrument has a weight of 85 N, determine the necessary stiffness of a spring mounting. What is the limitation of this design? (p.148 in NP)

Fill in the class

Example 22 — # 2

Fill in the class

Example 22 — # 3

Fill in the class

Example 22 — # 4

Fill in the class

Example 22 — # 5

Fill in the class

Example 23 — # 1

Q: An exhaust fan, having a small unbalance, weighs 800 N and operates at a speed of 600 rpm. It is desired to limit the maximum transmissibility to 2.5 throughout the operation of the fan including the start-up. In addition, an isolation of 90% is to be achieved at the operating speed. Design the isolator for the fan. (p.150 in NP)

Fill in the class

Example 23 — # 2

Fill in the class

Example 23 — # 3

Fill in the class

Example 23 — # 4

Fill in the class

Example 23 — # 5

Fill in the class

Example 23 — # 6

Fill in the class

Summary

1. Isolation is a measure used to reduce the transmitted displacements and forces from a source of vibration in a mechanical system. It is quantified by a non-dimensional parameter called transmissibility (TR). An ideal isolator has $TR = 0$.

2. The force and displacement transmissibility of a SDOF system is given by $TR = \frac{F_t}{F} = \frac{\sqrt{k^2+(c\omega)^2}}{\sqrt{(k-m\omega^2)^2+(c\omega)^2}} = \frac{\sqrt{1+(2\zeta r)^2}}{\sqrt{(1-r^2)^2+(2\zeta r)^2}}$; and the displacement transmissibility is given by $TR_d = \frac{X}{Y} = \frac{\sqrt{1+(2\zeta r)^2}}{\sqrt{(1-r^2)^2+(2\zeta r)^2}}$, where $r = \frac{\omega}{\omega_n}$

3. Softer springs give lower ω_n and hence higher $r = \frac{\omega}{\omega_n}$ for a fixed forcing frequency ω. This takes the operating point above $r = \sqrt{2}$ giving isolation or $TR < 1$. However, the displacements are more. Thus the maximum allowed displacement sets the limit on how soft the spring in a isolator can be.

4. Damping increases TR above $r = \sqrt{2}$. However, this increase is tolerated as the system has to go through resonance in order to reach $r > \sqrt{2}$. Damping is desired to avoid resonance in the run-up to the operating point.

5. Note that $F = me\omega^2$ for a system subjected to a forcing due to a rotating unbalance.