Master Thesis Notes

# Design of a Vibration Isolator:

Source: NPTEL “Vibration Control” Lectures Dr. S.P. Harsha

When designing vibration isolators, a few fundamental rules of thumb must be followed to ensure effective vibration isolation. These rules are:

1. **Isolator Stiffness (Static Stiffness):**

* The static stiffness of the isolator must be chosen such that the **highest mounting resonance** occurs at a frequency far below the **lowest exciting frequency**.
* This ensures that the isolator effectively reduces vibrations without amplifying any frequencies.

**2. Foundation Stiffness:**

* The mounting positions on the foundation should be as stiff as possible.
* A stiff foundation minimizes the risk of transferring vibrations from the isolator to the structure or vice versa.

**3. Coupling Stiffness:**

* The points at which the machine is coupled to the isolators should also be as stiff as possible.
* This ensures that the isolators can function properly without being affected by weak couplings.

**4. Internal Anti-Resonance:**

* The isolator should be designed so that its first internal anti-resonance frequency is well above the highest frequency of excitation.
* While effective, this is often challenging in practice. If this condition cannot be met, alternative rules (below) should be followed.

**5. Internal Resonances:**

* The isolator must be designed so that its internal resonances do not coincide with the strong components of the excitation spectrum.

**6. Foundation Resonances:**

* The isolator must also ensure that its anti-resonance frequencies do not coincide with the resonance frequencies of the foundation.

**Practical Constraints:**

In addition to the rules mentioned above, practical considerations such as geometric constraints, material strength, and stability concerns must be addressed.

**Example Use Case: Vibration Isolation in an Industrial Machine:**

**Scenario:** Consider a high-speed compressor installed in an industrial plant. The compressor generates vibrations at frequencies ranging from **20 Hz to 100 Hz**, and these vibrations can affect nearby equipment and structural components.

**Solution:**

1. **Choose a Soft Isolator:**
   * Select isolators with low static stiffness to ensure that the highest mounting resonance is below 20 Hz (the lowest excitation frequency).

Explanation:  
  
**Static stiffness** refers to the stiffness of the isolator material or structure under static (non-vibratory) loads. It is defined as:

Where:

* k: Static stiffness (N/m)
* F: Applied static load (force) (N)
* Δ: Resulting static deflection (m)

This is Why **Low Static Stiffness is Important** for Vibration Isolation

1. **Natural Frequency of the Isolator**: The natural frequency of an isolator is given by:
   * k: Stiffness of the isolator (N/m)
   * m: Mass of the supported machine (kg)

A **lower stiffness** (k) reduces the natural frequency (fn​) of the isolator. This helps to:

* + Shift the isolator's natural frequency below the operating frequency of the machine.
  + Ensure that the isolator achieves effective vibration isolation by operating in the isolation region (where excitation frequency > ​).

1. **Isolation Effectiveness**:
   * To isolate vibrations effectively, the isolator's natural frequency (​) must be much lower than the operating frequencies of the vibration source.
   * Low static stiffness helps achieve this by lowering​​.
2. **Deflection Considerations**:
   * While low stiffness improves isolation, it also leads to greater static deflection (Δ).
   * This requires balancing stiffness to avoid excessive deflection that could destabilize the machine.

**Example: Choosing Low Static Stiffness**

Suppose:

* A machine weighs 100 kg (m=100 kg).
* The operating frequency of the machine is 50 Hz.

To achieve effective isolation:

* The natural frequency of the isolator (​) should be much lower than 50 Hz, for suppose its consider the frequency to be **10 Hz**.
* Using the formula for ​​:

Substituting =10 Hz and m=100 kg:

A stiffness value of around **39,478 N/m** would give the required natural frequency of 10 Hz.

**Practical Implications of Low Stiffness**

1. **Improved Isolation**:
   * Vibrations at higher frequencies (e.g., 50 Hz and above) will be attenuated effectively.
2. **Static Deflection**:
   * A lower stiffness will result in greater deflection under the machine's weight:

For m = 100 kg and g = 9.81 m/s2

This deflection is acceptable in many cases but should be considered in the design.

1. **Stiffen the Foundation:**
   * Reinforce the floor slab beneath the compressor with steel plates or concrete to increase its stiffness.
2. **Ensure Proper Coupling:**
   * Use rigid bolts and plates to securely connect the isolators to the compressor base and the foundation.
3. **Avoid Internal Resonance Issues:**

Ensure that the isolator material and design do not amplify frequencies between 20 Hz and 100 Hz.

What does it mean?

* + Internal resonance occurs when the natural frequencies of the isolator’s components (such as rubber, springs, or internal structures) align with the excitation frequencies.
  + When this happens, vibrations are amplified instead of dampened, reducing the isolator's effectiveness.

**How to avoid internal resonances?**

* **Material Selection**: Use isolator materials with inherent damping properties (like viscoelastic materials) to suppress internal resonances.
* **Design Geometry**: Ensure that the dimensions, mass, and stiffness of the isolator are designed so that the isolator's natural frequencies lie outside the excitation frequency range. For example, if the excitation range is 20 Hz to 100 Hz, the isolator's natural frequencies should be below 20 Hz or well above 100 Hz.
* **Simulation and Testing**: Perform finite element analysis (FEA) or experimental modal analysis to identify the natural frequencies of the isolator. Adjust design parameters to shift these frequencies.

1. **Check Anti-Resonance Frequencies:**
   * Test the isolator system to ensure that its anti-resonance frequencies are well above 100 Hz (the highest frequency of interest).

**What is Anti-Resonance?**

* Anti-resonance is a frequency at which the response of a system is minimal due to destructive interference of vibrational energy.
* In vibration isolation, this refers to the frequency at which the vibration transmission to the foundation is nearly zero.

**Why is Anti-Resonance Important?**

* If the anti-resonance frequencies of the isolator align with the foundation's resonance frequencies, the vibrations can still amplify in the foundation, defeating the purpose of isolation.

**How to Avoid Anti-Resonance Issues?**

* **Avoid Matching with Foundation Resonances**: The foundation's natural frequencies should not overlap with the isolator's anti-resonance frequencies. This is done by analyzing the foundation's vibrational characteristics.
* **Tuning the Isolator**: Modify the isolator's design parameters (mass, stiffness, damping) to adjust the anti-resonance frequencies.

**Outcome:** This setup reduces the transfer of vibrations from the compressor to the surrounding structure and minimizes the risk of resonance amplification.