Physics Factsheet

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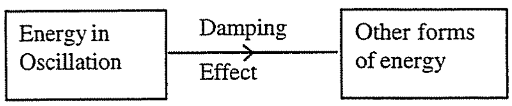
Practical Techniques for Damping Oscillations

Damping is primarily a method of absorbing energy from oscillations for the purpose of controlling or eliminating these oscillations. The kinetic energy of the oscillation can be transferred to kinetic, heat, electrical, magnetic or other forms of energy.

The transfer can be achieved through a variety of means – friction, elastic forces, electromagnetic induction, etc.



Sometimes we are dealing with resonance situations, sometimes with more steady oscillations. In this factsheet, we will look at some example situations where oscillations occur, and how they can be damped.

> *Exam Hint:* *Damping always involves the transfer of energy away from the oscillator. Look for the type of energy that is produced in the end (usually heat).*

Resonance:

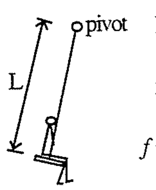
Resonance is a critical type of oscillation where an object oscillates at its natural frequency with greater and greater amplitude, sometimes until it destroys itself. These factors are required for resonance to occur:

(a) An object must have a natural frequency. It will vibrate at this frequency when disturbed e.g. a guitar string being plucked.
(b) A "force" applied regularly at the natural frequency. This could be a mechanical push, or in some cases a varying electrical emf.
(c) There must be a lack of energy loss (damping) from the oscillator. The energy of oscillation must be allowed to keep increasing.

How can resonance be limited? Sometimes by the natural frequency changing e.g. a pendulum only oscillates at a fixed frequency for small oscillations. Or the object might break as the amplitude increases. But we can often control resonance by introducing damping into the system.

> *Exam Hint:* *Resonance always involved the transfer of energy from an external source into the oscillator. The amplitude of the oscillation is directly linked to its energy.*

Playground swings



Pushing a child on a swing is an example of mechanical resonance. The swing has a natural frequency depending on its length.

$f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$ for small oscillations (measured in Hertz)

If you push at exactly the right time in each oscillation, the amplitude of the oscillations will increase. There is little natural damping.

> **Worked Example 1**
> **(a) Find the natural frequency of a child of mass 20kg on a swing of length 150cm.**
> **(b) Find the period of this oscillation.**
> **(c) Name two sources of damping in this oscillation.**
>
> *Answer*
>
> (a) $f = \frac{1}{2\pi}\sqrt{\frac{9.8}{1.5}} = 0.41$ Hz The mass has no effect (in theory).
> (b) T = 1/f = 2.4s
> (c) Air resistance and friction at the pivot. Both are relatively small.

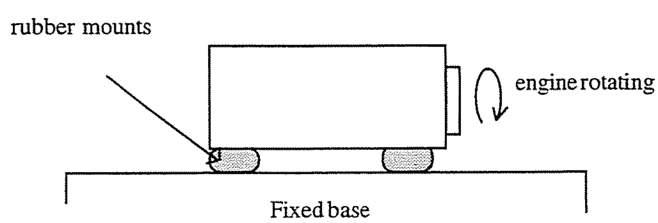
Motors

Many motors or engines rotate at varying speeds while in operation. Examples might be car engines or variable speed electric motors in industry.

Depending on the size, shape, and mass of different parts of the engine, it may have a natural frequency of vibration at a possible operating speed of the engine. This can also happen at multiples of the natural frequency.

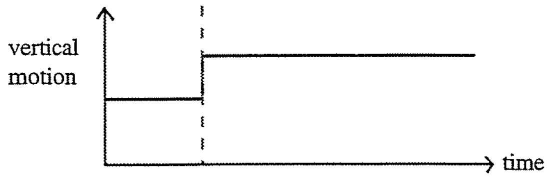
> **Worked Example 2**
> **An engine has a natural frequency of vibration of 1000rpm (revolutions per minute). Find possible angular frequencies of the engine that could lead to resonance.**
>
> *Answer*
>
> $\omega = 2\pi f = 2\pi \times \frac{1000}{60} = 105 \text{ rad s}^{-1}$
>
> (or multiples e.g. 210, 315, 420, etc)

A standard type of damping here is rubber engine mountings. The mechanical energy of vibration is transferred to heat energy through friction and the hysteresis effect in rubber. The vibrations are limited and the engine doesn't shake itself apart.

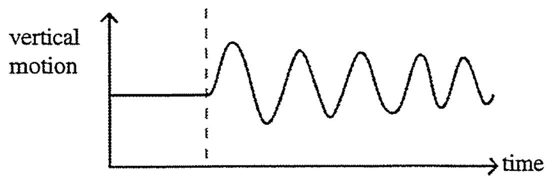


Car Suspension

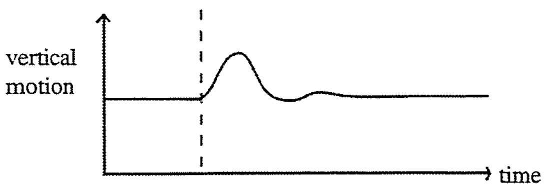
Damping does not always have to be involved with resonance. If a car had no suspension system, there would be a sudden jolt whenever the car hit a bump in the road.



To make the ride safer and more comfortable, springs are introduced into the suspension. The sudden jolt now sets up a more gentle oscillation.

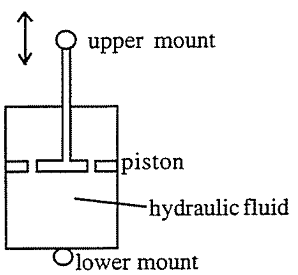


However these extended oscillations themselves are annoying and affect the handling of the car. Shock absorbers in the suspension system damp the oscillatory motion, changing kinetic energy into heat.



The oscillations are quickly eliminated.

How do these shock absorbers work?



Simply, as the upper mount moves up and down, hydraulic fluid is forced back and forth through the tiny holes in the piston. There is a great deal of turbulence and friction. The motion is restricted and kinetic energy is transformed into heat.

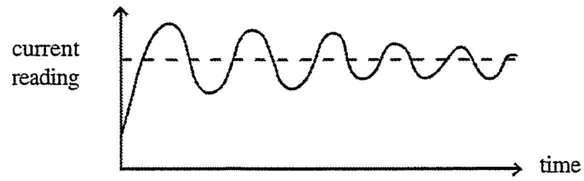
Worked Example 3
Traditionally large American cars have much less damping than sports cars. Can you suggest a reason?

Answer:
More damping gives a "harder" ride. However the car holds the road better with fewer oscillations and less leaning on bends.

Moving coil meters

This is in some ways similar to the situation with the car. Resonance is not involved, but sudden motion causes an unwanted oscillation. The magnetic force (when a current is applied) is opposed by a spring in the meter. The spring sets the needle of the meter oscillating about the correct current reading. Many seconds could pass before the needle settled down to display the reading.

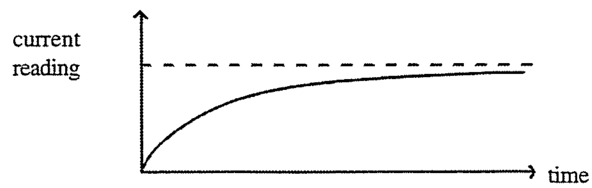
Natural Damping



However we can increase the damping by winding the coil onto a metal former. As the coil moves across the magnetic field, eddy currents are induced in the metal former. Kinetic energy is transferred to electrical energy in the eddy currents. Joule heating causes this energy to end up as heat.

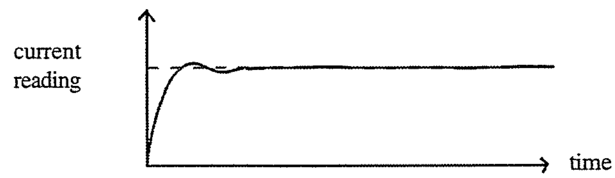
If we transfer kinetic energy too quickly into electrical energy, it takes too long for the meter to reach the correct reading.

Overdamping



If we design everything optimally, then the needle gives the correct reading quickly and accurately.

Critical Damping



The idea is very similar to the car suspension system, but KE is transferred by e.m. induction rather than friction.

Exam Hint: *In every case, damping is achieved by changing kinetic energy in the oscillator into some other form of energy. Keep clear in your mind the difference between the means of damping e.g. friction, and the energy transfer e.g. kinetic to heat.*

Worked Example 4
A galvanometer is overdamped. Suggest a way of redesigning it to decrease the damping.

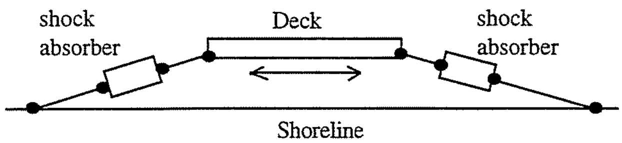
Answer
Use less metal in the former holding the coil. Or perhaps use metal of a different resistance. There are many ways of altering the strength of the damping.

The Millennium Bridge

The Millennium Bridge opened in the year 2000 in London. However it swayed so much when crowds walked across it, that it was closed to the public until major strengthening work took place. The culprit was resonance.

The bridge swayed slightly as people walked along it. This was expected. However this caused the pedestrians to step slightly side-to-side in order to keep their balance. As they all did this in time with each other, more and more sideways kinetic energy was transferred to the bridge and the oscillations became bigger and bigger. Resonance was occurring.

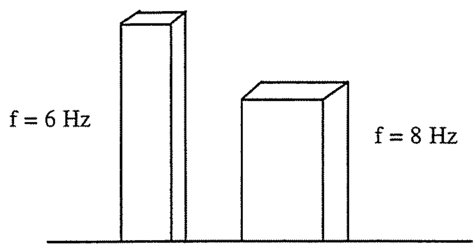
How was this cured?
By a number of techniques including shock absorbers (as used in car suspensions) on the shoreline.



As the bridge oscillates from side-to-side, the shock absorbers transfer kinetic energy to heat energy, reducing the oscillations to an acceptable amplitude.

Earthquake resistant buildings

Worked Example 5
Here are two buildings with different natural frequencies.



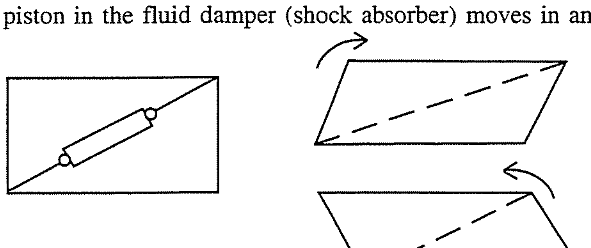
Which one is at risk from earthquakes?

The answer is that both are at risk. Earthquake vibrations arrive with a range of frequencies. Many buildings will be in danger of resonance occurring at their natural frequency.

Obviously buildings in earthquake zones should be built more strongly in general, but there are also techniques used to damp the oscillations. In every case, the dampers are designed to transfer kinetic energy from the oscillations into another form (usually heat). Types of dampers used are:

(a) Metallic dampers: These are metal braces designed to distort, then permanently deform during oscillations. This transfers kinetic energy to heat.
(b) Friction dampers: These have moving parts that slide over each other as the building oscillates. This friction transforms kinetic energy to heat.
(c) Viscous fluid dampers: These again are like shock absorbers in cars. As the building oscillates, kinetic energy is again transformed to heat.

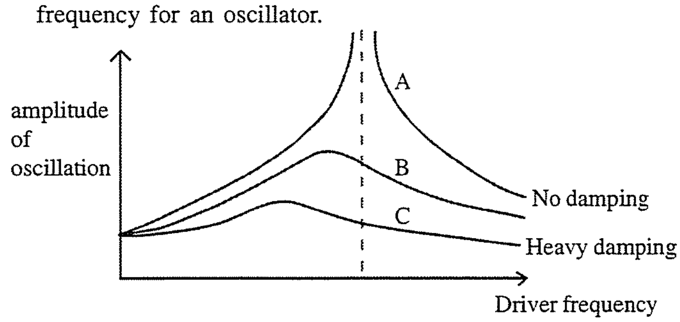
As the building twists clockwise, the diagonal shown increases. Then as the building twists anticlockwise, the diagonal decreases. The piston in the fluid damper (shock absorber) moves in and out.



Exam Hint: *Notice that all three methods result in the kinetic energy being transformed into heat. We spend a lot of time talking about heat as a form of waste energy. Transforming energy into heat can often be a valuable tool e.g. car brakes.*

Practice Questions:

1. A wall clock is driven by a pendulum of length 75cm.
   (a) Find the natural frequency of the pendulum.
   (b) How many times would it oscillate in one day (24hr)?
2. The steering wheel of my car vibrates as the car passes through 20mph.
   (a) What is occurring here?
   (b) How could you tell if the driving force for the oscillations came from the rotation of the engine or the wheels?
   (c) Suggest ways of reducing the problem.
3. Why should tall buildings have a lower natural frequency than shorter buildings?
4. Assume that a damped oscillator loses the same proportion of its energy of oscillation in equal time intervals. If a particular oscillator has 90% of its energy left after 5s, what proportion will be left (a)after 10s? (b)after one minute?
5. Look at this relationship between amplitude and driving frequency for an oscillator.



   (a) What occurs with no damping when the driver frequency matches the oscillator's natural frequency?
   (b) Name three results of increasing the damping.

Answers

1. (a) $f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$ = 0.58 Hz
   (b) $T = \frac{1}{f}$ = 1.72s , in one day $\frac{(24 \times 60 \times 60)}{1.72} = 5.02 \times 10^4$ oscillations
2. (a) Resonance.
   (b) Try driving at the same speed in a different gear (different engine speed). If the vibrations don't occur, the engine is the likely source.
   (c) Tighten the fixings for the steering wheel to reduce the oscillations. Clamp rubber or felt in the fixings to absorb energy. Ride a bicycle instead.
3. Think of the buildings as inverted pendulums. A longer pendulum oscillates more slowly. With the buildings the restoring forces would be tension rather than gravity, but the effect would be the same.
4. (a) 0.90 remaining after 5 seconds. So has $0.90^2 = 0.81$ or 81% remaining after 10s.
   (b) After 60 seconds, has $0.90^{12} = 0.28$ or 28% remaining.
5. (a) Resonance
   (b) Broader peak, lower amplitude at all frequencies, frequency of maximum amplitude oscillation decreases.

Acknowledgements:
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