PREVENT

Noise-induced hearing loss

Noise Control Tool

Concrete Actions and Specific Recommendations

Ontario · Health & Safety Ontario · Occupational Health Clinics for Ontario Workers Inc. · wsib Ontario

This document is intended to assist in the understanding of practical methods that can be used to minimize the causes of noise and prevent sound transfer in the workplace. It is a resource intended to be used in conjunction with other processes when planning the implementation of corrective action.

The contents are organized to complement the Noise Assessment Procedures & Resource Materials document and to facilitate in implementing a participatory risk management and control processes. This approach is recommended by the European Union SOBANE process based on the recommendations of a team headed by Jacque Malchaire of the Occupational Hygiene and Work Physiology Unit, Université catholique de Louvain, Brussels, Belgium.

This document utilizes many images from, or based on, images used by J. Malchaire's group to explain the SOBANE Process as well as many images based on images from resources of The Swedish Work Environment Fund both of which are in the public domain.

The material contained in this manual is for information and reference purposes only and not intended as legal or professional advice. The adoption of the practices described in this manual may not meet the needs, requirements, or obligations of individual workplaces.

Contents

Section 1: Summary of Control Methods

1. Reduce Vibrations and Mechanical Noise
2. Reduce Ground and Structural Transmission of Sound
3. Elimination or Reduction of The Shocks and Impacts
4. Metal Surfaces and Containers
5. Aerodynamic Noises
6. Ventilation Noise
7. Air Jets and Exhausting Compressed Air
8. Pure Tones/Resonance
9. Relocation of The Source or Worker
10. Acoustical Treatment of The Room
11. Preventive Maintenance
12. Acoustical Enclosure on Noise Source

1.1 – METHODS USED TO CONTROL NOISE

Summary of Methods used to Control Sources of Noise

(Section 2 provides more information on each of these topics)

1. REDUCE VIBRATIONS AND MECHANICAL NOISE
   - balance rotating parts to prevent imbalance vibration noise
   - use helicoidal gears instead of toothed gears in order to reduce the impacts associated with interlocking gears and the associated noise and vibration
   - install isolation dampers (springs, cork, etc.)
   - tighten parts or panels
   - use flexible connections for electrical, compressed air or hydraulic piping
   - use plastic (non-metal) materials
   - change the speed of rotating parts to minimize pure tones

2. REDUCE GROUND AND STRUCTURAL TRANSMISSION OF SOUND
   - install isolation dampers (springs, cork, etc.)
   - structurally isolate the source or other areas

3. ELIMINATION OR REDUCTION OF THE SHOCKS AND IMPACTS
   - reduce the falling distances of hard objects on hard surfaces
   - tilt the surface on which the parts are falling so that parts fall on an angle rather than perpendicularly
   - ease two objects into contact together before pushing one with the other (change work habits)

4. METAL SURFACES AND CONTAINERS
   - cover them with noise dampening material (resilient pads, old rubber belting)
   - dampen rotating blades on power saws
   - construct bins, conveyors and chutes with “noise-less” steel (resilient material such a rubber sandwiched between two sheets of steel)
   - construct with wood, plastic or other similar materials

5. AERODYNAMIC NOISES
   - reduce air pressures and velocity
   - design process (and/or change working habits) to avoid the impact of the compressed air stream on sharp edges or perpendicular to a surface

6. VENTILATION NOISE

- balance the rotating parts (see point1)
- isolate air handling units from building structure and ducting system (see point 1)
- place noise absorbing materials inside the ducts and inside air handling unit
- eliminate any unnecessary bends or sharp angles in ducting

7. AIR JETS AND EXHAUSTING COMPRESSED AIR

- find other ways to do the work without using compressed air
- use air guns specially designed to be quieter
- use a larger exhaust opening to reduce air speed
- place a silencer on the exhaust
- do not direct the exhaust directly towards a wall or other solid object

8. PURE TONES/RESONANCE

- Move the source away from the workers
- Dampen the object to break up or change the frequency
- Install a noise barrier between sources and workers

9. RELOCATION OF THE SOURCE OR WORKER

- Move the source away from the workers
- Install a noise barrier between sources and workers

10. ACOUSTICAL TREATMENT OF THE ROOM

- Add some absorbing materials if the room is highly reverberant
- Check noise transmission from adjacent rooms or the outside

11. PREVENTIVE MAINTENANCE

- ensure moving mechanical parts are serviced regularly
- ensure periodic overhauls are conducted
  - on a timely schedule (semi-monthly, annual...);
  - by a qualified person; and,
  - deteriorated parts are replaced before they break.

12. ACOUSTICAL ENCLOSURE ON NOISE SOURCE

An enclosure can be effective to reduce the noise only if:

- it is constructed of a sufficiently dense material,
- it is covered on the inside with a noise absorbing material,

- the openings are reduced to a minimum, and
- it is not directly connected to the machine (or, if connected it is made from, or covered, with a resilient material (plastic, rubber, noise-less steel, etc.).

Summary of Methods used to Control Transfer of Noise

(Section 3 provides more information on the following topics)

1. AIR FLANKING OF BARRIERS
   - avoid gaps around and through partitions and barriers
   - create gaps using flexible joint materials when using partitions
   - use flexible connections or gaps where ceilings and walls that meet particularly when they connect different work areas
2. PROVIDE SECTIONS OF FLEXIBLE JOINT MATERIALS
   - use flexible joint material between panels of hard materials
   - provide gaps or flexible joints at the junction of walls and partitions
   - provide a gap between walls and solid ceilings
   - construct walls of heavy materials
   - minimize internal connections between walls and wall mounted finishes or facing materials
   - install sound absorbent in or on ceilings
3. DECREASE BOUNCE AND REFLECTION
   - sound barriers, barrier walls and absorbent materials must be combined properly
4. VOICE AND OFFICE COMMUNICATIONS
   - ensure the room contains adequate absorbing materials either using the furnishings or by adding absorbents
   - check noise transmission from adjacent rooms or from the outside

Section 2: Examples of Noise Control at the Source

2.1 – MECHANICAL NOISE

General corrective actions:

- Tighten parts or panels.
- Cover them with a rubbery material.
- Use helicoidal gears instead of toothed gears.
- Use plastic materials.
- Balance rotating parts.
- Use flexible connections for electrical, compressed air and hydraulic connections.

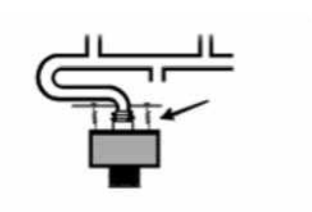
Reduce the surface area that's vibrating

Stopping the sound at its source is far better than having to deal with the sound after it has spread from the source. Dividing larger surfaces into a group of smaller components results in the creation of less noise at higher frequencies that is easier to prevent from radiating, or if it is radiated, to absorb.

Here are some examples:

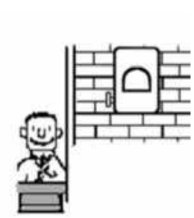
- a noisy furnace fan bolted not only to the furnace, but also onto the ducts, will cause the entire ducting system to radiate the sound of the fan
- a noisy cold water faucet connected to the cold water piping system will transmit noise through all the metal pipes throughout a building

The exhaust fan and ducts vibrate causing noise.



Flexible mounts and a flexible connection between the fan and the ducts prevents duct vibration and noise transmission.

Hand dryer transmits noise by vibrating the wall.

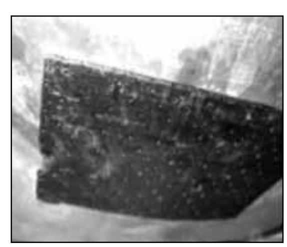


Isolate the dryer from the wall and move it to a better location if practical

Isolate the source

If a vibrating object is mounted to a large surface it should be either be moved to a different surface or isolated using flexible joints or mounts which will greatly reduce the noise carried from the source to other objects.

Attach absorbant pads or use other materials to add mass to the surface



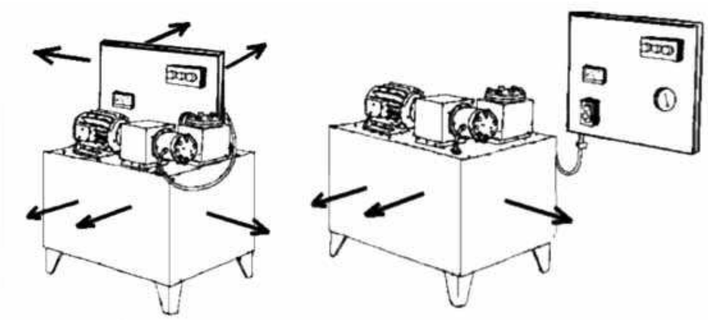
Attaching a pad constructed of dense material to a flat surface will dampen the vibrations that cause noise. Similarly some spray foams or sealants can be used.

For larger surfaces or stronger vibrations welding angle iron to the surface or using a magnet, magnetic pad or magnetic strips attached to the steel plate can reduce the noise level or change the frequency.

Avoid large panels that radiate noise from equipment vibration

Many control panels used for process control, shop or lab equipment have large flat surfaces that are ideal for radiating noise if they are integrated into the equipment (similar to a large base speaker) or attached to their surfaces like the ones shown:

When practical the control panels should be remotely located from the equipment, connected by flexible cables or piping and mounted to a solid surface. The equipment will still radiate noise but the large panel will not.



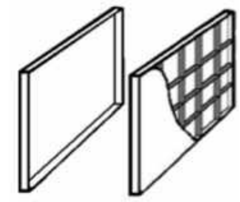
Increase the frequency (pitch) of the sound

BREAK UP LARGE VIBRATING AREAS INTO SMALL, EASILY DAMPED ONES

When a large area vibrates, it acts like a "piston", pumping the large volumes of air back and forward. This can sometimes be overcome as follows:

1. Replace a solid panel with a perforated one that lets air through, so there isn't a continuous surface to move the air.
2. Replace a single vibrating area with several smaller ones that will function just as well but will oscillate at a higher frequency and less strength than a single solid surface.
3. Replace noisy, square base plate supports on equipment and motors with by several, narrower strips that don't have a free oscillating centre.

For flexible objects bracing the object with a grid to create small sections whose frequency of resonance is much higher can end the effect. The higher frequencies that result are much easier to dampen using porous materials. Where breaking up a surface is not practical attaching weight or non-conductive pads to the object can have the effect of both decreasing and lowing the frequency of the oscillation and minimizing the problem.



A vibrating plate can be dampened by adding a grid or braces to stiffen the surface

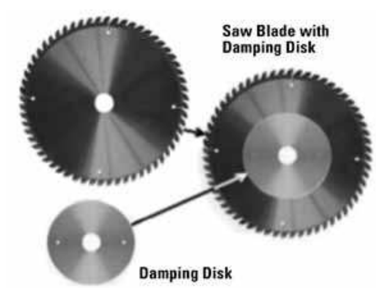
Use mesh or screens rather than solid panels

Another method that can be used is to replace large solid guard panels with an open screen or mesh that will not oscillate.

Solid guard will radiate vibrations and sound.

Open mesh doesn't oscillate so it doesn't radiate sound.

Use damping discs on flat rotating parts



CAUTION:

1. Do not use damping discs with portable tools unless they are specifically designed for the tool and approved by the manufacturer.

2. Ensure the damping disk will not interfere with the cutting action or depth clearance of the cutting tool.

A damping disk is a rigid disk that is mounted on a spinning machine component such as a cutting blade. The damping device will significantly reduce vibrations and oscillations of the spinning disk resulting in less direct noise and the minimizing of the transfer of vibrations that cause noisy vibrations of the main body or panels on the machine.

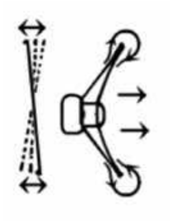
Free the edges to reduce low frequency noise

Free (unanchored) edges are important when low frequency sounds are being considered. Large plates, wall panels, sheet metal enclosures and similar structures are all major creators and transmitters of low frequency noise.

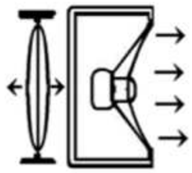
If the edges of a vibrating panel are not anchored, the panel will rock back and forward (oscillate) inconsistently, making it ineffective in moving the air and creating or transmitting sound.

If the same panel is secured around the edges, the rocking action is prevented, and the plate will bulge in and out at the middle, instead of the edges. The result is that more sound will emulate from the plate.

This is the principle is used in making speakers:



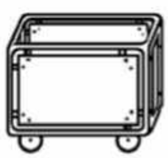
Free ends allow sound waves to see-saw back and forward reducing effectiveness and generating high frequency noise.



Fixed ends results in a push-pull action generation more low frequency sound.

The principle is applied in reverse to reduce sound. If, by freeing the edges, plates can be prevented from vibrating at the middle the noise will decrease.

Noisy carts with large flat surfaces.

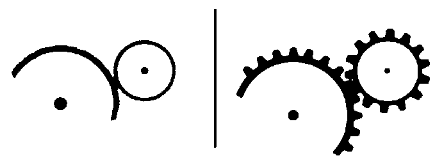


This alternative allows sound to self cancel.

The edges of many flat carts cannot be free. Solid panels, pads or braces mounted under a flat cart will decrease noies creating vibrations.

Lower the vibration to a less annoying frequency

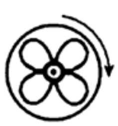
If the cause of the sound can be modified so that the object vibrates at a slower speed, the frequency of the noise will be reduced. This will make it less annoying to the human ear.



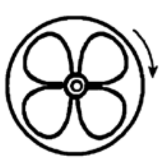
Reducing the number of gear teeth will lower the sound frequency. The teeth hit each other less frequently at the same rate of rotation.

Another example is where a pump, fan or propeller can replaced by a larger lower speed unit or modified to move more slowly while taking a "larger scoop" of air or liquid to achieve the same flow.

Lowering the frequency of vibration makes the noise less disturbing.

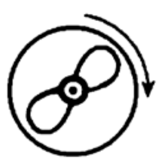


Small, high speed fans tend to be noisy.



Large, low speed fans are quieter.

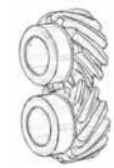
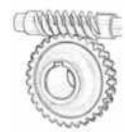
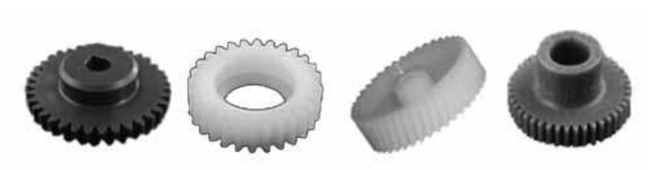
Lowering the frequency of vibration makes the noise less disturbing.



Small, high speed fans tend to be noisy.

More efficient fans can be operated at lower speeds

Substitute gears for quieter designs

Helical gears are quieter than toothed gears	Toothed Gears 	Toothed Gears 
Helical beveled gears are quieter than regular beveled gears	Toothed Gears 	Toothed Gears 
Plastic gears are quieter than metal gears but care must be taken in their selection since plastic is usually not as strong as metal and will usually wear faster.		

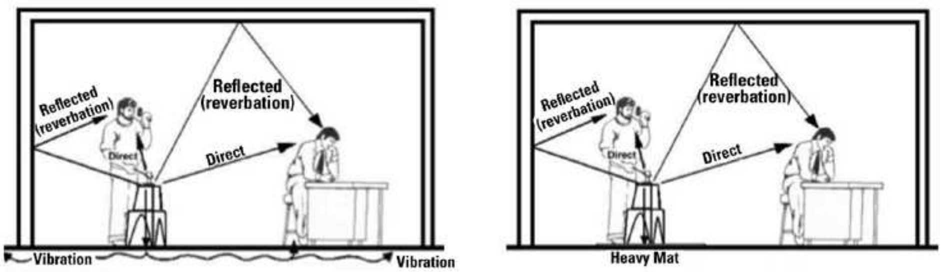
2.2 – GROUND AND STRUCTURAL TRANSMISSION OF VIBRATION

General corrective action:

- Install isolation dampers (mats, springs, cork, etc.).
- Structurally isolate the sound source from the rest of the structure.

Isolation of Work surfaces for hand and small power tools

The impact vibration from hand tool work and small machine tools can be minimized by heavy work mats. However the mats will not decrease either the direct or reflected noise.



Noise Transmission

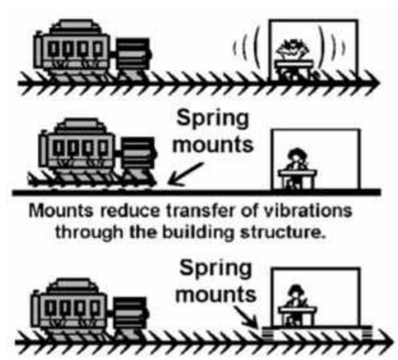
Anchoring heavy equipment

A large machine can transmit strong vibrations through the floor and walls, disturbing people in other rooms in the building.

The amount of disturbance can be greatly reduced by "disconnecting" the machine from the areas to be protected from the noise. This can involve any of the following methods:

- Mounting the machine on special pads or springs that do not carry the vibrations to the floor.
- Mounting rooms on special pads that will isolate them from the vibrating floor.

Heavy equipment that vibrates should be isolated using spring mounts or other special supports.



Sensitive equipment or areas can be isolated from the building structure to reduce vibration transfer.

Vibration-suppressing isolator materials

Materials that most successfully absorb the vibrations of heavy equipment are shown in the illustration:

These damping materials are placed between the machine and any solid surfaces that the machine makes contact with, usually between the machine and the floor.

Equipment that is anchored to the ceiling or mounted on a wall require isolators that are strong enough to both support the weight of the machine and to withstand forces that exceed those expected as a result of any machine forces including both the expected motion and vibrations from the machine starting and operating.

It is important to note that all springs and similar devices tend to oscillate at a particular frequency. If the motion or forces from the machine operating are at the same frequency it can actually increase the system vibrations. This is due to resonance. That is: at some frequencies, which will be different for different systems, the vibration may build up on itself, violently shaking to an extent that it creates very loud noises, or even the destruction of the mounts or the equipment.

Resonance may only happen briefly during the start-up or slow-down of the equipment, but even that short period can still be dangerous.

Some ways of overcoming this are as follows:

- use isolator materials to damp any violent bouncing of the mounts (springs etc.)
- replace problem springs with springs or other forms of mounts whose resonant frequency is very different from the equipment vibration frequency
- modify the equipment so that the vibration frequency or the resonant frequency is well above or below that of the mounts (springs)
    - add equipment weight
    - reposition parts
    - change the position of the supports or the number of supports
- use shock absorbers to dampen oscillations

Materials and devices used to minimize sound transmission

Rubber or plastic
- foam
- cellular
- solid

Cork

Mineral wool

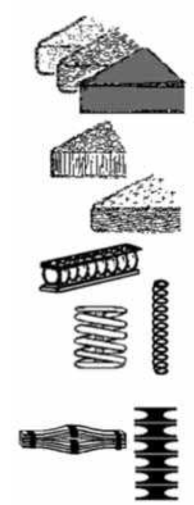
Horizontal coils

Long thin coils

Short thick coils

Leaf spring

Plate spring

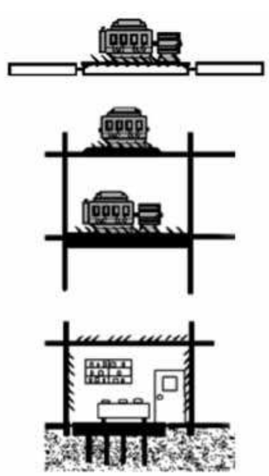


Structurally isolating can also be used to reduce vibration and noise.

This procedure can be used to isolate vibrations from machinery or to isolate specific areas where vibration or sound sensitive equipment is operated.

Some examples are shown below:

Strong floors that resist the transfer of vibrations



A separate base, joined to the main floor with flexible joints, provides excellent noise isolation.

A concrete pad or a extra thick floor greatly reduces flexing and noise

A separate base with ground anchors reduces transferred noise.

2.3 – IMPACTS OF PARTS ON A HARD SURFACE

General corrective actions:

- Tilt the plate on which the parts are falling.
- Cover it directly or in a sandwich with a rubbery (resilient) material.

Speed of impact, size of object affect noise

Reduce noise by reducing impacts.

Reducing any of the following factors will help:

- the distance an object falls or is thrown
- the weight and size of the object
- the speed of the impact:
  - minimize the steps in a fall by creating deflectors with heavy rubber materials
  - minimize the distance of the drop by using "spring mounted" transfer carts and surfaces that depress as the weight on them increases (this also improve the ergonomics when moving/lifting items off the surface)
  - cover the surface with a sound reducing mat

Discarding or transferring hard objects

Reduce noise by changing the distance and speed an object falls directly by using containers with flexible horizontal barriers.

Deflection barrier containment devices can be any size from bench top units to very large open bottom units (like a funnel) for use in industrial and construction work. The bottom of the large units should be just above the surface the materials are to be dropped onto and raised as the piles of materials raises so that the material's free fall distance is always kept as short as is reasonable for the process.

Discarding or dispensing materials

Deflectors in a small container

Material Into Container

Industrial/Construction unit

2.4 – AERODYNAMIC AND VENTILATION NOISE

General corrective actions:

- Avoid discontinuities (size changes, elbows and bends) or sharp edges.
- Use silencers or place noise absorbing materials in ducts, pipes and other conductors.

Noise reduction in pipes, ducts and chambers

Air, gas, liquids or dry powders flowing through a pipe will generate noise.

Part of the noise is a result of friction however most noise results from changes in the flow speed, obstacles or irregularities in the line or abrupt direction changes. In each case turbulence and some backpressure is created which can significantly reduce the systems efficiency and create noises such as bangs or roars.

Specific causes where the flow abruptly changes are:

- cavities, design of service ports
- bends, branching and turns
- bumps and irregularities in the path
- narrowing or widening, particularly if they are abrupt
- changes in the texture or density of walls

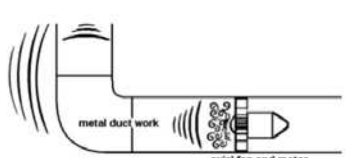
To reduce noise, ducts and pipes should be designed to minimize changes in the duct cross sectional area (size) and ensure changes in direction are gradual. Internal vanes can often be used to reduce the noise when irregularities or abrupt bends can't be avoided; however vanes can cause interference with the flow of many materials.

Fans will be quieter if they operate in smooth airflows

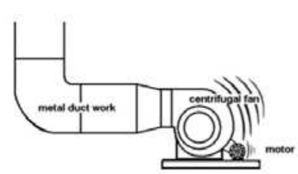
When air is disturbed in a duct, it behaves quite differently from smooth flowing air. The resulting noise levels depend on which of the following is true:

- the air is moving smoothly, with little or no turbulence – low noise
- the air is moving irregularly or there are obstructions or sharp turns in a duct - disturbed and noisy

The first consideration is the type of fan used. Different types of fans produce noise in different manners so the approach to minimizing noise levels will also be different:



Noise from an axial fan air supply system

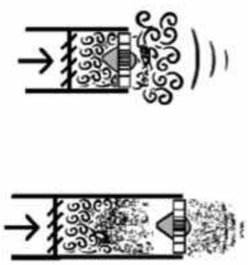


Noise from a Centrifugal fan air supply system

The second consideration is disturbances in the ductwork that result in air pressure changes causing both the air and structural components to oscillate creating audible noise. Any uneven fan load (variations in pressure in the duct) immediately before or immediately after the fan creates noise. These variations also change the load on the fan and the stationary fan mounting structures that can have the effect of amplifying the noise.

Vanes and dampers located in bends and at a distance of several times the duct diameter/size before a fan will calm disturbances in the airflow lowering the noise levels both in the duct and at the fan.

Rounded corners, guides and moving the fan away from the corner decreases the fan noise.

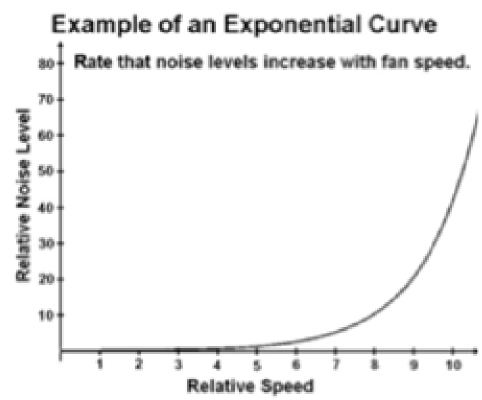


Disturbance of air flow in a duct makes fan noise worse.

Moving the control vanes further from the fan improves the noise levels.

Turbulence from corners makes fan noises worse.

Slow moving air flows and slower fans are quieter



A larger, slower fan will be quieter than a smaller, faster fan delivering the same airflow.

Reducing the fan rotational speed can have a significant impact on the noise created. Noise increases exponentially as fan speed increases. Slowing a fan by a small amount can made a large decrease in noise.

Similarly a lower air speed in a duct by using larger ducts will result in significantly lower noise levels.

Some other factors that should be looked at are:

- Straight ducts are generally quiet unless the air flow is excessive.
- Porous absorptive duct linings can be used to lower air flow noise.
- The type of air inlet and outlet openings and related grills or diffusers will affect the noise level.

Dissipative/Absorption mufflers for air supply ducts and equipment exhausts

The simplest dissipative “muffler” for a duct is simply an absorbent lining inside the duct. When higher sound levels are present specially designed absorption mufflers suitable for both low and high frequencies should be used. These “mufflers are constructed with multiple layers of sound absorbent materials alternated with air spaces. The size of the air spaces and the thickness of the absorbent materials determine the frequencies absorbed.

Thick absorbent layers with large air space layers are better for low frequencies.

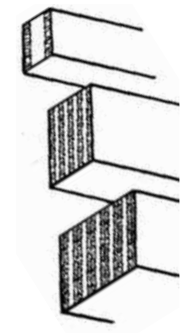
The material dissipates very little of the energy from low frequencies however the air space prevents low frequency energy from being transferred to the next layer since the air is accelerated slowly. For low frequencies greater distances are required to achieve the equivalent absorption that a shorter distance achieves with a higher frequency.

Absorption mufflers

For low frequencies:
- thick layers
- big space

For high frequencies:
- thin layers
- small gaps

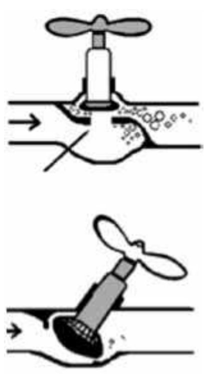
Forboth frequencies:
- thin spaces
- thick layers



Sudden pressure drop in fluids generates bubble noise

When a tap or valve is turned on fluids flow from a high-pressure area into a low-pressure area.

The sudden decrease in pressure can cause two effects that create noise.



Rapid pressure changes cause bubbles in liquids resulting in noise.

Sharp turns disturb the flow.

Larger valve seat allows a slower flow rate reducing bubbles and noise.

Smoother edges are quieter.

Air bubbles

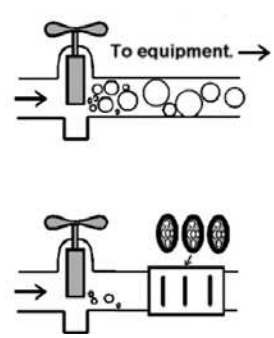
Air pockets in a fluid create small, noisy bubbles. The air molecules that are dissolved in the pressurized liquid come out of solution. The effect that is readily seen in glass of carbonated drinks (most soft drinks) will occur to some extent in any liquid that has not been degassed and can cause loud banging noises as bubbles form and then collapse within the pipes.

"Cavitation" (bubbling of the fluid itself)

Cavitation means that the liquid itself (not just the air dissolved in it) changes to a vapour because of a reduction in pressure.

Water boils at a lower temperature on a high mountain, because the air pressure (that presses down on the surface of the water) is lower on a high mountain.

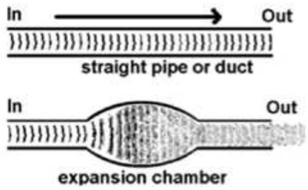
Similarly, if the pressure is suddenly and violently reduced inside a pipe, the liquid will "boil" even at room or lower temperatures. This is called cavitation, because it can cause large "cavities" (empty spaces in the pipe). The formation and collapse of these vapour pockets can create loud noises. Those voids can also seriously interfere with the functioning and damage pumps and valves that are designed to work only with liquids.



"Cavitation" occurs when fluid pressure drops so fast that the liquid changes into a gas as bubbles which later collapse.

Perforated plates limit the rapid changes of pressure.

Muffling sound in ducts and pipes



The expansion chamber allows the sound waves to expand and breaks the wave pattern lowering the transferred noise level.

Expansion chambers dampen low frequencies

When a low frequency sound travels along a pipe and encounters a bigger space, the sound wave pressure relaxes outwards into the space. The lowered pressure means less sound intensity as the sound wave emerges at the other end.

The larger the diameter of the chamber, the lower the frequency of sound suppressed.

Mufflers dampen ranges of frequencies

A muffler is a container designed specially to dissipate (weaken) sound. They are usually custom-designed for the specific range of frequencies that are to be suppressed.

Mufflers are commonly used to calm disturbed flows of exhaust gas from engines and exhaust air from compressed air tools.

The following principles are used in mufflers to eliminate sound:

1. **Absorption**

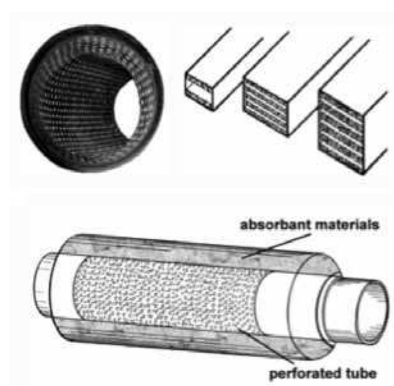
   a) Use of porous materials inside the muffler, where the sound energy bends fibers, converting sound energy into small amounts of heat.

   b) Use of columns of air that compress and expand, converting the sound into small amounts of heat. This is principle used in both household "anti-hammer" devices and in well water pumps to eliminate the "bang" ("hammer") when taps are turned off and on.

2. **Reflection:**

   Designed spaces in the muffler maximize reflection of sounds back onto themselves (so that reflected sound pressure waves partly cancel the originating waves).

Absorption muffler



As previously mentioned this type of muffler minimizes changes in air flow direction because the air travels straight through the muffler.

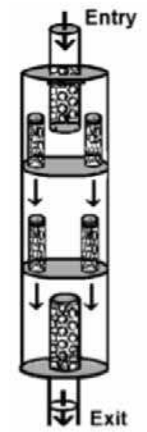
- this type of muffler has a low resistance and little interference to airflow
- noise control is best in the mid to high frequency range (above about 500 Hz)
- This type of muffler is commonly used as ducting in general ventilation, air supplies or exhausts for noisy equipment and is often combined with reflective mufflers for engine exhausts.

Reflection muffler

This type of muffler is especially suited where

- the range of frequencies to suppress is fairly narrow
- the sound is mainly comprised of low frequencies

To extend the range of frequencies several chambers can be combined one after the other. Each chamber is a different size to suppress different frequency ranges.



A reflection muffler forces sound to...

bounce between partition plates losing energy as it travels through the gas...

change direction 90˚ as it passes through perforated tubes to escape...

expand into a larger space which releases the pressure of the confined entry tube

2.5 – AIR JETS AND EXHAUSTING COMPRESSED AIR

General corrective actions:

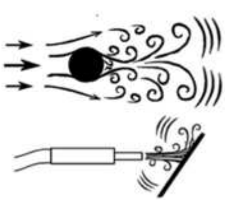
- Use exhaust mufflers for decompression air jet.
- Use special air guns.
- Reduce the air velocity of the jet.
- Avoid directing air jet on a sharp edge or perpendicular to a surface.

Airflow over objects causes "wind tones"

We have all heard the whirring sound of a skipping rope when it was turned very fast, or the sound of strong wind in power wires. This sound is a result of the fact that whenever air passes very fast over a very regular-shaped object such as an iron bar or a tall chimney, a moaning sound called a "Karman tone" may result.

The solution is to make objects located in air flows irregular in shape, so that the air movement is broken up into smaller, mixed currents of air that cancel each other out.

Noise from Air Tubulence



The fast flow of air past an object or through an opening disturbs the air flow resulting in noise from the sudden air pressure changes.

Projections on either the leading or trailing edges will break up the air flow pattern eliminating most noise.

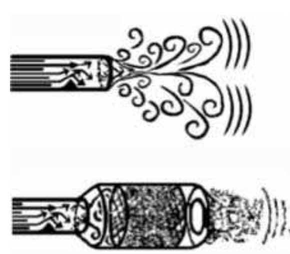
The diagram above illustrates two methods of reducing the noise. The first method, using projections, works best when the air flow direction is random. The second method, using a trailing edge is preferred when the airflow is from a constant direction like on the roof racks of a vehicle.

Gases/air exiting a pipe

The noise can be decreased if the disturbed flow is smoothed both by minimizing changes in the speed of the flow and the turbulence before the exit.

The mufflers on compressed air tools are examples of this principle.

Although the air supply may be smooth (from a pressurized reservoir) the tools have pistons and valves that abruptly stop and start the flow. When the sudden pressure changes in the gas emerge into the normal air, these pressure changes are heard as noise.



When a fast jet of air strikes an obstacle turbulence and noise are created.

In line mufflers constructed of a gauze mesh or other porous sound absorbing materials will reduce the noise.

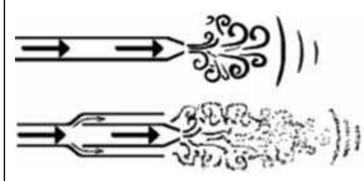
A gas jet can be muffled by surrounding it with another slower airflow

A "jet" stream is a flow of air moving faster than 100 m/s (325 ft/sec).

Compressed air tools including compressed air guns used for cleaning pieces of equipment often produce a jet stream.

As the air emerges from the nozzle, it collides with immobile air and cavities in the equipment parts. The enormous pressure difference produces strong air vibration, and very loud hissing sounds.

High speed air jets make load noise.

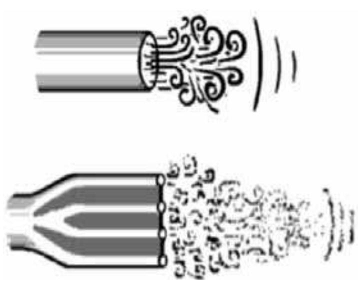


Surrounding the primary jet with a slower air stream will break up the noise flow and decrease the noise.

A way of reducing the noise is to allow some of the jet to escape around the nozzle. It forms a buffer of slower air to surround the fast jet for some distance until the sound level has fallen to a safer level.

Large air jets:

Vibration from the air flow in large pipes or ducts causes low frequency "jet" noise.



Breaking the air flow into smaller streams creates higher frequency sounds that dissipate more quickly in air.

The noise level can be lowered by converting large air jets to smaller, more easily muffled jets.

The larger the diamveter of the jet pipe, the lower the frequency of noise produced at the exit. As mentioned before, lower frequencies are more difficult to suppress.

The exit can be modified so that the flow emerges from several smaller jets. The noise will be at a higher frequency. The sound will lose its energy as soon as it starts to travel through the air or any other material. The effect is a result of the ability to transfer higher pitched sound wave energy (vibrations) to the air much faster than low pitch noise can be transferred.

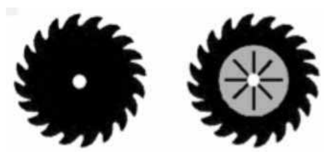
Another example of this principle is in mufflers (described in the aerodynamic/ventilation section) where perforated metal plates force a wide airflow through many holes to create a large number of very small streams of gas instead of just one.

2.6 – PURE TONES/RESONANCE

General corrective action:

- Move the source away from the workers.
- Dampen the object to break up or change the frequency.
- Install a noise barrier between sources and workers.

Dampen objects to change their resonance



Eliminate resonance caused by a machine operation by using dampening disks or attaching dampening pads.

Dampening pad

For almost all objects there is a particular frequency where the vibrations in the object can build up on themselves. The specific frequency will depend on the frequency of the noise combined with the characteristics of the object. The effect is a result of sound "bouncing" off solid objects and causing objects to vibrate at the same frequency as the sound source. The effect is called "resonance".

The effect is similar to a ball bouncing at a particular rate combined with a force being added to the ball on each bounce. The ball will begin to bounce higher and higher. Another analogy is the sloshing of water in a bathtub when a person adds an additional push in synchronization with each slouch until the water runs over the end.

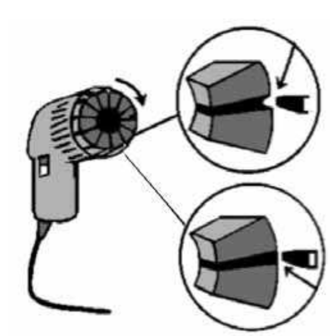
At particular speeds many mechanical devices like rotating cylinders, drums or circular cutting tools, like the blade of a circular saw, may start to roar or ring deafeningly. Similarly the speed of the machine's motor or drive train can cause structural components, such as metal panels and work surfaces to start oscillating and clatter loudly.

The frequency of the source of the vibration may not be readily changed, but the object can be modified so that it resonates at frequencies different from the source frequency. This does not lower the noise from the working edge but will lower the frequency of the noise created and keep resonance from occurring.

Open cavities or evenly spaced holes resonate

If you blow across the top of a bottle at certain speeds, you will generate a musical note. This illustrates how any open cavity can resonate.

If air is captured in fast-moving evenly spaces holes or cavities in parts of any moving object, unwanted noise may result. If the holes/cavities are all the same size and evenly spaced the noise from each hole will be the same tone and add to the noise from all the other holes resulting in a very loud noise.



Rotor pieces in a power tool pass a depression in the casing. The turbulence in the air caused by the presence of the cavity generates noise.

Few or no irregularities equals ower noise!

This is a common problem with rotating drums and machines or tools with rotating parts inside a ventilated case.

The solution is to ensure cavities are filled or covered so that the air does not flow over an open air space. When a drum requires perforations to perform the task it is designed for the perforations should be in an irregular pattern.

If the operation of the equipment requires high speed rotation with open holes or cavities the entire machine should be enclosed or the operator should be in a sound proof control area.

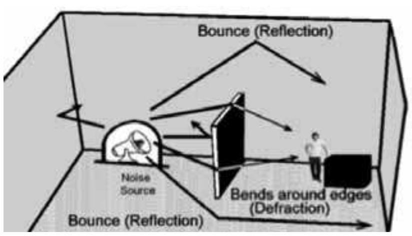
2.7 – RELOCATION OF THE SOURCE OR WORKER

General corrective action:

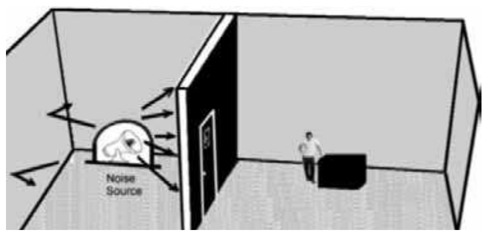
- Move the source away from the workers.
- Install a noise barrier between sources and workers.

Noise barrier between source and worker

Barriers can be effective in reducing noise levels - particularly high frequency sounds. Generally barriers should only be used when the noise reduction required is less than 15 dB. The barrier should be at least twice the height from the floor as the height of the noise source or when serving as a general room noise barrier when multiple sources are present over 2 metres high. Barriers are generally good solutions for noise reduction in the 10 to 15 dB range. For more information see the section on acoustical treatments.



A solid noise absorption barrier or moving the noise source to an isolated area are the best solutions when practical.



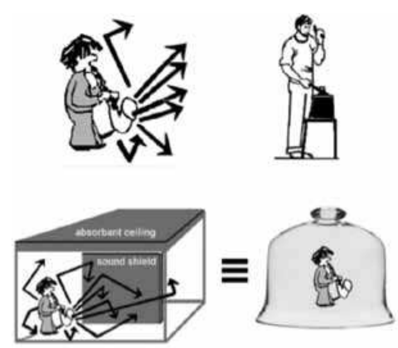
Solid enclosures must be used if the decrease in sound required is over 15 dB.

Isolate the source or the worker

When moving the source is not practical due to the type of operation being performed the workers should be located in sound proof control areas, cabs or offices that isolate them from the source.

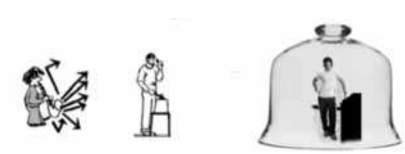
Enclosures must be totally enclosed (airtight) and be constructed of solid materials such as a concrete or steel outer casing lined with damping materials and acoustic mineral wool. The enclosure must not make direct contact with the machine or other noise source.

As an alternative to enclosing equipment the workers can be located in a soundproof enclosure. Size and cost dictate whether the machine or its operator should be enclosed.



Isolate the noise when possible.

OR



Isolate the workers

2.9 – ACOUSTIC TREATMENT OF THE ROOM

General corrective actions:

- Add some absorbing materials if the room is highly reverberant.
- Check noise transmission from adjacent rooms or from the outside.

Use Sound Absorbent Surfaces and Room contents

Wall coverings, soft floor materials and mats will all contribute to reducing noise.

Panels to absorb or reflect noise

The behaviour of porous panels

As mentioned earlier, an absorption panel uses absorbent material that vibrates within the panel. As the sound waves make the material bend, stretch and relax as the sound energy is converted into heat.

The most effective porous materials are those that allow air to be pushed right through them so that the vibrating air is exposed to the maximum amount of absorbent material.

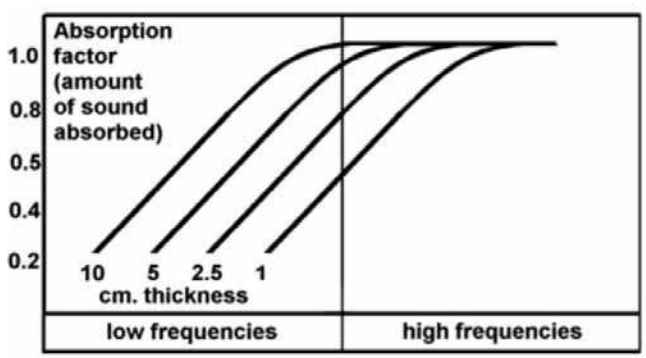
Surface-only pores are not very effective

Porous materials that only have pores near the surface are not nearly as effective because at the microscopic level, very little material actually flexes to dissipate the energy as heat.

Thin absorbent panels are only good for high frequencies

Note: Some of the newer high technology panel designs using nano and micro technology can absorb or eliminate unwanted sounds using thin panels for lower frequencies; however these newer panel designs are not readily available at the time of publishing.

The graph below shows how the thickness of absorbent panels affects the amount of absorption.



High frequencies

For high frequencies, thin porous materials are adequate because they aggressively vibrate the fibers. In the graph above, the 1-cm layer suppresses most of the higher frequencies.

Low frequencies

For low frequencies, much thicker layers are necessary. The flexing of the fibers is slower and gentler dissipating less energy. Notice that in the graph above, the 1-cm layer suppresses very little of the low frequency noise.

Below 100 Hz the thick layers may not be effective enough. Instead, it may be better to have a double wall of absorbent material with an air gap.

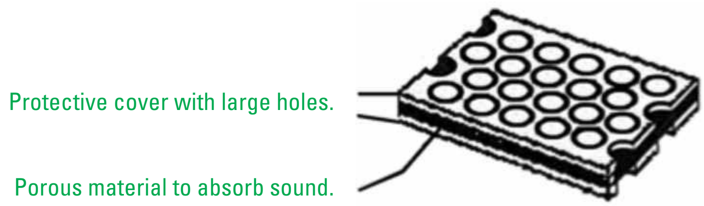
Inside that space, the low frequency sound waves will weaken by reflecting back and forward losing energy by compressing and relaxing the air.

For mixed low and high frequencies

Thick layers of porous material will absorb a wide range of frequencies.

Sheathing material in a perforated sleeve does not affect absorption

Fragile porous materials can be sandwiched between stronger layers that have large holes.

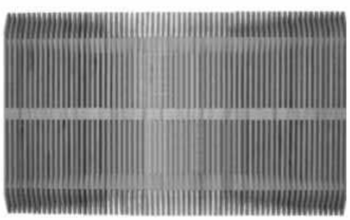


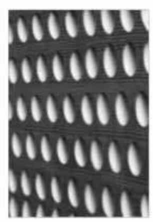
Porous material is often soft and fragile. It is often preferable to enclose it between protective outer layers of stronger material rather than leave the materials exposed where they can be damaged or deteriorate.

As long as the holes in the outer layers are large, the sound-absorbing characteristics of the porous materials are unaffected. A properly constructed panel will have the same effective absorbency as the uncovered material.

Cover hard walls and ceilings

Use sound absorbent wall coverings





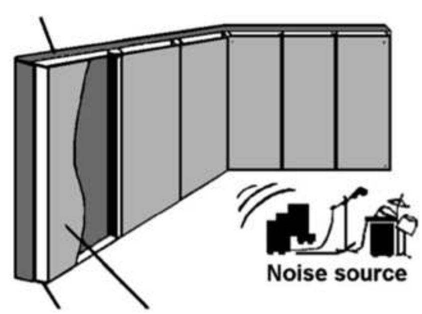
Absorbent wall coverings and acoustical panels absorb low frequencies and decrease resonance.

The problem in many rooms is not too much noise but too much resonance. A large amount of echoing in a room makes communications very difficult even if there is not hearing loss. Poor communications means instructions and warnings may not be heard.

Add a stud and panel wall to a hard wall

To absorb low frequency sounds install a sound-absorbing wall made up of studs (the vertical supports) and the panels of sound-absorbing material (the cladding of the wall).

This is effective, but only over a small range of frequencies.



Sound absorption can be improved for specific purposes as follows:

- increasing the gap between the hard wall and the panels improves the lower frequency range suppression by the panels
- the bigger the distance between the studs, the lower the frequency range suppressed
- the thicker the actual panel is, the broader the range of low frequencies it suppresses

2.10 – ACOUSTIC ENCLOSURE ON THE MACHINE

General corrective actions:

- Use hermetic enclosure covered with rubbery materials.
- Install sound absorbing materials inside the cover.

Totally sealed enclosures are the best choice for containing noise

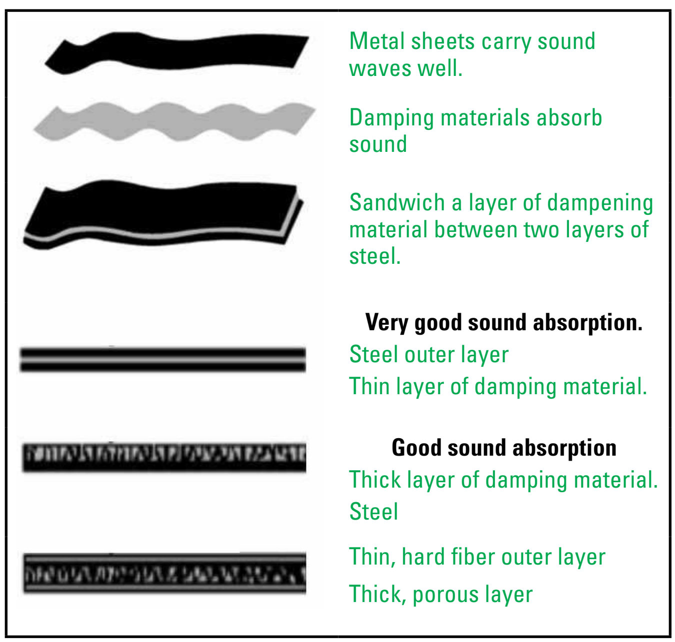
Any openings will allow sound to escape. The following shows how the amount of containment affects the decrease in sound escaping into the work area. The enclosure must have both internal damping and sound absorbent (normally acoustical mineral wool) to be effective.

Amount of enclosure	Noise reduction
full enclosure	60 dB
0.1% open	30 dB
1% open	20 dB
5% open	13 dB
10% open	10 dB
30% open	5 dB
50% open	3 dB

Panel and plate noise - internal dampening

Most solid materials are very "elastic" when vibrated by sound waves. The sound waves can cause the materials to oscillate creating distinct noises or allowing transfer of noise through the material without being weakened by the work of bending portions of the material. The whole mass of the material may chime or ring (like a bell), shriek (drums), buzz or clatter (metal panels), or roar (pipes.).

Other materials such as lead, rubber or fibrous substances only respond very sluggishly to impact or vibration. The energy of the impact or vibration is immediately consumed by bending the material, and is converted into very small quantities of heat instead of noise. This effect is known as "damping". These materials either generate a small thud or rumbling sound while allowing very little noise to travel through them.



Dampening materials are often attached to the surface of panels; however to increase the effectiveness of the noise reduction they can be sandwiched between layers of the structural materials.

The best way is ordering equipment properly.

When ordering any new equipment that could create noise always specify that sound enclosures and dampening be provided.

Some examples are:

< A pile driver is one of the noisiest machines used in urban areas..... yet they can be purchased with sound absorbent casings:

(picture – US Environmental Protection Agency)

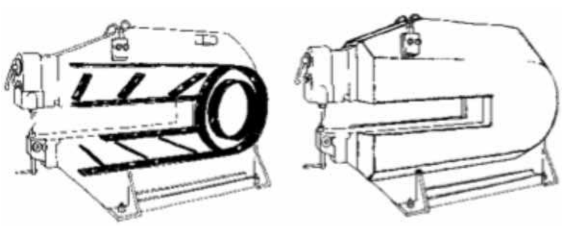
Many other tools and machines can be purchased enclosed to minimize noise or if necessary noise containment can usually be custom built.

< Shredder with sound dampening and sound reduction panels

< Shop tools such as this mill can also be purchased or modified with sound dampening and sound reduction panels

Modifying equipment can include encasing; sound dampening attached to vibration components; adding bracing to either change the sound frequency or eliminate vibration; filling cavities as well as many other changes that will vary depending on the actual piece of equipment.

Shown are some examples of possible modifications to a band saw:



Section 3: Examples of Methods of Controlling Noise Transfer

3.1 – AIR FLANKING OF BARRIERS

General corrective actions:

- Avoid gaps around and through partitions and barriers.
- Create gaps using flexible joint materials when using partitions
- Use flexible connections or gaps where ceilings and walls that meet particularly when they connect different work areas.

Air "Flanking" of noise

Even small cracks and holes leak a large amount of noise.

Fill cracks and holes in walls and sound barriers.

Cracks and holes can seriously reduce the effectiveness of a noise barrier. Here are some examples from a series of tests carried out by H.L.Blachford Ltd; a Canadian company specializing in noise control:

- in a wall that reduces noise by 40 dB(A), a one square inch (6.5 cm2) hole in a wall can pass as much noise as almost 100 square feet (9 m2) of the wall
- in the same wall, a 12 ft. long (3.7 m) crack that is only a hundredth of an inch (0.25 mm) high can double the perceived loudness of the noise coming through a wall (Crack area is 1.44 square inches (9 cm2).

Structural "Flanking" of sound

A barrier or wall is usually attached at right angles to other walls. If those walls are thin, they may vibrate in response to sound and radiate the sound to adjacent areas which results in the sound bypassing the barrier. This noise transmission is called "flanking".

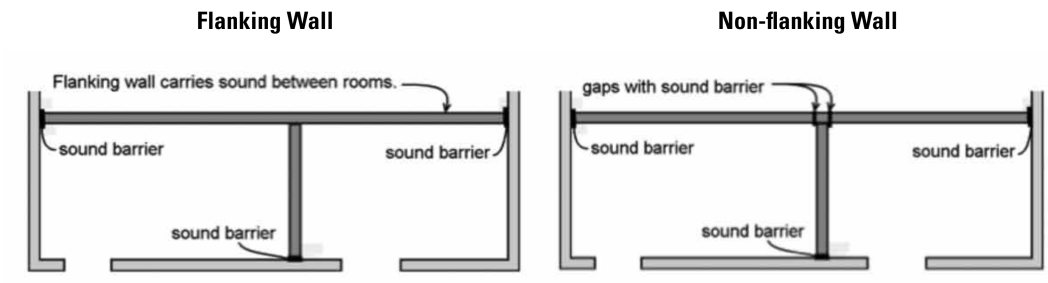
Similarly sound can bypass a wall or barrier through a ceiling, floor and other structural components.

Effective solutions are as follows:

- create gaps where solid materials exposed to noise meet other solid components to prevent sounds from being carried
- rest the wall on flexible mounts that do not leak sound either through the wall or to the floor
- cover the walls on the noisy side with sound absorbent materials.

Flanking can be particularly severe where a wall is connected to thin metal panels or partitions. The panels will rattle creating noise in the area they are located even though they are at right angles to the wall they are fixed to.

Metallic structural components of the building can also cause flanking of noise to areas they run through. If there are solid plates or mechanical devices attached to the components they can radiate noise in a manner similar to having a speaker mounted on the component. This effect often occurs in smaller buildings built using concrete or cement blocks when steel bracing is used in the walls or ceilings. The steel braces will also transfer other low and frequency vibrations (ultrasound and infrasound.)



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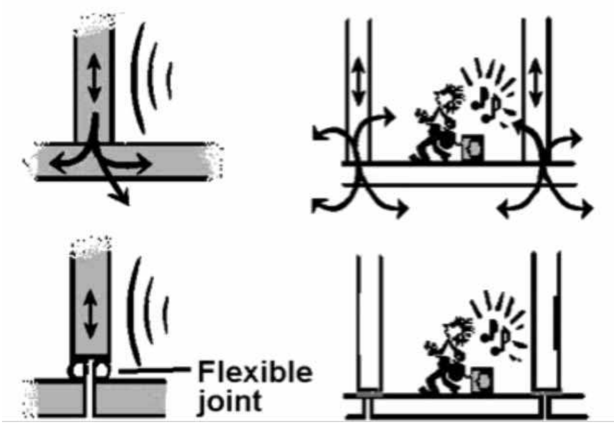

"Flanking noise" is reduced by replacing solid connections and joints with flexible materials.

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3.2 – WALLS AND CEILINGS THAT REDUCE SOUND

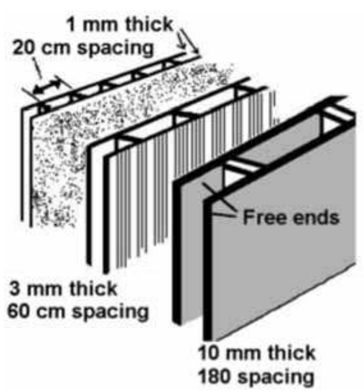
General corrective actions:

- Construct walls of heavy materials.
- Minimize internal connections between the wall facing materials.
- Install sound absorbent in or on ceilings.

Creating walls to block sound

Construct walls in noisy areas with materials as heavy as practical. The transmission loss of a wall is calculated from the weight of the material used to build and clad the wall. In other words, a wall whose surface layer is made with a lead cladding will stop noise far more than a wall with a plasterboard surface. A concrete wall will block far more sound than a frame wall.

The thicker the wall the greater the distance required between the studs.



A single-layer wall has a resonant frequency. That is, at a particular frequency, the vibrations will build up on themselves, causing noise to be retransmitted on both sides of the wall.

Some suggestions to minimize or overcome this problem follow:

- replace a wall with a double wall
- install bracing on the surface material which will make the natural resonant frequency much higher
- add absorbent material to each section of the wall

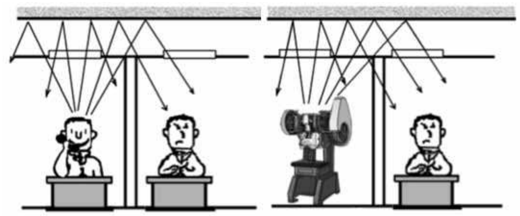
Wall rigidity also helps reduce sound. Try to choose heavy, solid materials like solid concrete (rather than cinder block), steel rather than aluminum, and thick glass.

Lightweight, double walls with an air gap are more effective than single, heavy walls. As the gap size increases (up to about 15-cm) the transmission loss increases. The same success can be achieved as could be achieved by building a wall that was five to ten times heavier. Adding a thick layer of sound absorption material inside the wall will increase the effectiveness even more.

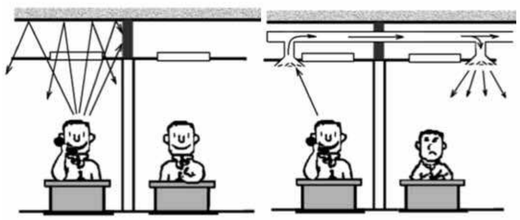
The closer together the studs are spaced between double walls, the less effective the sound-blocking effect will be. There should be as few gap-bridging connections as possible between the two outer surfaces. Thick walls lose their effectiveness if the studs are not spaced far enough apart.

If wall panels have free edges low frequency sound transmission is less. (That means - do not put the studs at the very ends of the walls.)

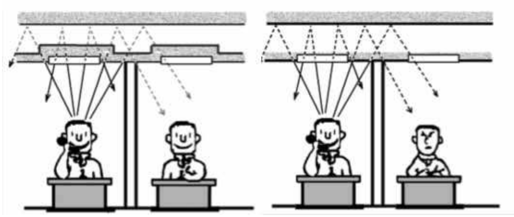
Creating ceilings to block sound



Sound transfer often occurs through the ceiling or by following paths of service ducts or conduits.
If an area has a suspended (false) ceiling with an open space above, sound is readily transferred.



If the wall between rooms is extended above the false ceiling to the roof sound will be blocked; however the sound will bypass the barrier if there are openings such as ductwork present.



Sound absorbent in the ceiling can also be used to prevent the transfer of sound. When sound absorbent is placed in the ceiling it must be both of an adequate thickness and continuous to be effective. Often sound absorbents are installed with thinner areas around lights or sensors which defeats the purpose of the barrier.

3.3 – DECREASE BOUNCE AND REFLECTION

General corrective actions:

- Sound barriers, barrier walls and absorbent materials must be combined properly.

Reflected sound can be reduced or eliminated in most rooms by covering surface areas with sound absorbent materials. If low frequency sounds predominate sound absorbent panels with air spaced either behind them or between them must be used. These coverings can be as simple as using curtains (be sure they are fire resistant) or as complicated as custom designed panels. What is required depends on the room use and sound levels.

Too much absorbent material, or the use of inappropriate absorbents, can make the room unpleasant to be in. If there is no reflected sound or reverberation, or if the absorbent eliminates some frequencies of sound and not others, the room well be acoustically "dead". People feel very uncomfortable and can have difficulty communicating in acoustically dead room. Acoustically dead rooms can cause difficulties in performing some activities creating other hazards or health effects.

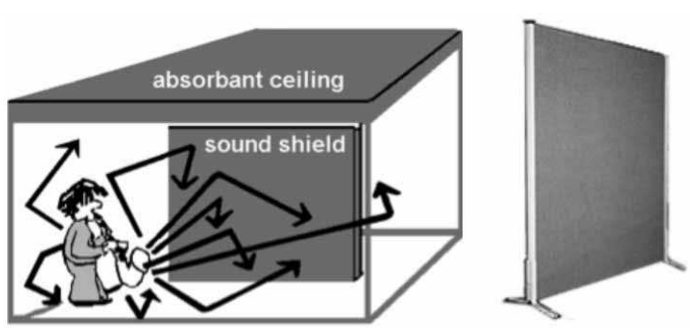
Another consideration is that the use of absorbents and barriers does not decrease the amount of sound that travels directly between the source and people in the room. Absorbent materials are not a method of eliminating noise at its source. Absorbents should only be used when the noise cannot be controlled at the source, controlling the noise is not desirable or when controlling noise at its source creates more serious problems.

For more information see the section on Section 1.9 - "Acoustical Treatment of the Room"

Place a barrier wall in the path of the sound

Noise can be reduced by using a sound shield (barrier) that absorbs the sound or reflects it away from the areas to be protected.

A sound shield reduces the amount of sound that reaches the protected area.



The taller and wider the sound barrier is, and the nearer to the sound source, the more effective the absorbance and shielding will be.

Block and absorb sound in the upper areas of rooms

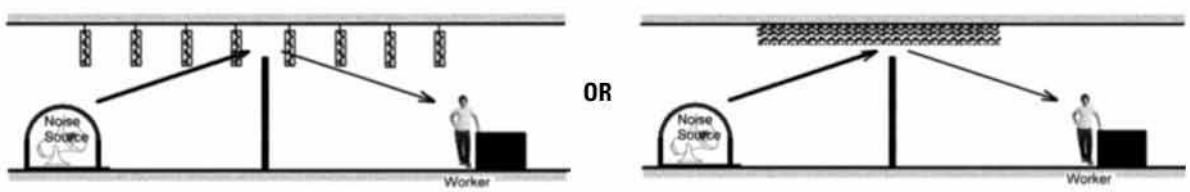

Example of baffles in the ceiling of a machine shop.

Rooms with high ceilings that are constructed using hard materials will have a lot of echo and reverberation making communications difficult particularly if any object is present that creates a lot of noise. Think of talking or turning on music in an empty gym.

An effective method for reducing the reflected noise is to cover the ceiling with sound absorbent materials. A more effective method that can be used for large and open areas are sound absorbent panels suspended in the upper areas of the room as shown in the picture below. These suspended panels are more effective in reducing reverberations, echoes and to some extent direct sound than ceiling tiles or flat absorbent coverings.

Consider the whole room

Using a combination of ceiling and wall coverings, appropriate selection of the room contents and upper area treatments should be considered. Adding sound absorbent to the ceiling (or walls) will decrease or eliminate sound transfer from reflection off the ceiling (or walls):



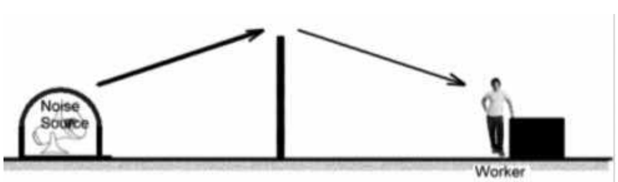
Consideration also needs to be given to the impact of noise that can be directly transferred to adjacent areas. While suspended panels are less expensive, usually easier to install and more effective in a contained area. A flat layer of insulation, with air spaces behind, is better for preventing the transfer of noise to adjacent areas.

A music room with both ceiling and wall sound absorbent panels that have an airspace between the panel and the building structure behind them:

Limitations on the use of barriers

The following explanations apply equally to walls and other hard surfaces as well as ceilings.

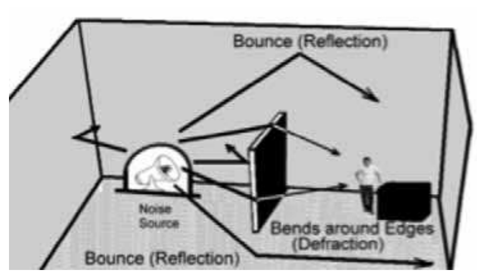
Previously the use of barriers to decrease noise was suggested when the amount of decrease required was under about 15 dB.



This statement ignores other room factors that can actually cancel out the benefits of a barrier.

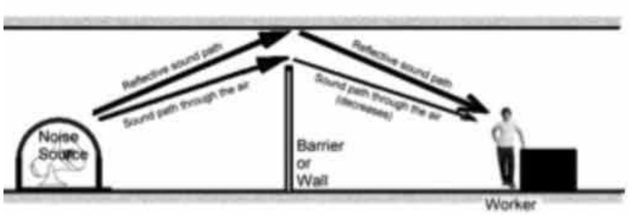
- barriers only cut down directly transmitted noise but have little impact on reflected noise
- a barriers can be effective for high frequency noises but have a small impact on not low frequency noises – particularly at a distance
- if the barrier doesn't extend the width and height of the room the noise that will be transmitted both above and to the side have to be considered when determining its effectiveness barrier.

If the room has a hard reflective ceiling or hard reflective walls the noise from the sound source will bounce off both the ceiling and the walls defeating the benefits of the barrier.

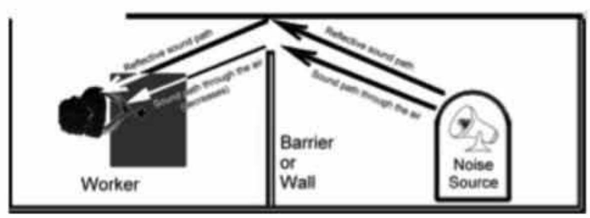


The actual decrease in the noise levels reaching the worker in the example illustrated above can be estimated using the formula illustrated in the following illustration. These estimates should only be carried out by individuals familiar with the characteristics of the room, measuring sound frequencies and limitations of the technical math calculations involved. This simple presentation of determining the effectiveness of a barrier ignores all other room and equipment factors that could actually defeat the barrier.

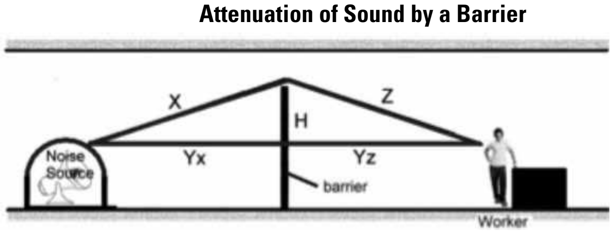
Reflection of sound by a ceiling



Reflection of sound by a barrier or wall - top view



Attenuation of Sound by a Barrier



all measurements in metres
Attenuation=(X+Y+Z)f/170 Y=Yx+Yz
H= barrier height above line between source and worker
f= sound in DBA at the specific frequency being considered

Notice that the benefit of the barrier depends on the frequency of the noise. If the frequency of the noise cannot be measured barriers should be used with caution in areas with high noise levels.

3.4 – ROOMS - OFFICE AND MEETING

General corrective actions:

- Ensure the room contains adequate absorbing materials either using the furnishings or adding absorbents.
- Check noise transmission from adjacent rooms or from the outside.

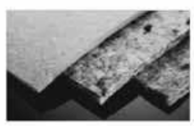
Communications and Concentration

Offices, training rooms and meeting areas rarely have sound levels that could cause hearing loss. However noise can have a major impact on the activities taking place and communications not understood can lead to errors in planning and accidents because of information or warnings not heard or misunderstood.

In general:

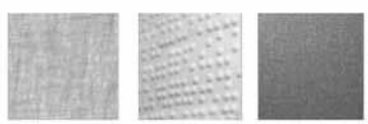
- a person's voice has to be about 15 dB louder than the background noise to be understood
- noises generated by a person's personal activities are annoying to people around but usually not to the person performing the activity
- unusual, unexpected or intermittent noises are more distracting and disturbing than a constant noise
- speech/loud voices affects people more than random noise

Use Sound Absorbent Surfaces and Room contents



Carpets and underlays in office and work areas will reduce noise transfer through the floor.

Furniture.



… and wall coverings or curtains also reduce reflected and transferred sounds.

Install acoustical ceiling tiles …

and dividers or barriers that both absorb sound and decrease reflected sound.

Section 4: Understanding Noise and Noise Control Principles

1. How Objects Cause Sound
2. Basics
2.1. Definition
2.2. Speed, Echoes, Resonance and Reverberation
2.3. Pitch/tone and Frequency
2.4. Loudness
2.5. Levels of Intensity (loudness)
2.6. Adding and Subtracting Sound
2.7. Continuous, Fluctuating and Intermittent Noises
2.8. Adding and Subtracting Sound
3. Impact Of Frequency
4. Terms And Basic Principles
4.1. Absorption
4.2. Barrier
4.3. Damping
4.4. Distance Effect on Loudness Reduction
4.5. Noise Reduction (NR)
4.6. Transmission of Sound
4.7. Transmission Loss
4.8. Resonance
4.9. Best positioning of source

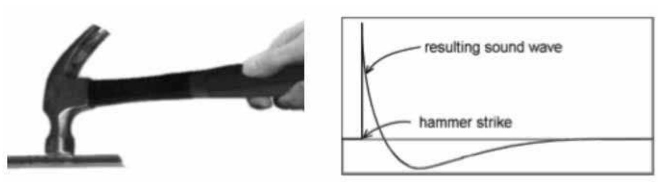
4.1 – HOW OBJECTS CAUSE SOUND

Changes of force, pressure and speed

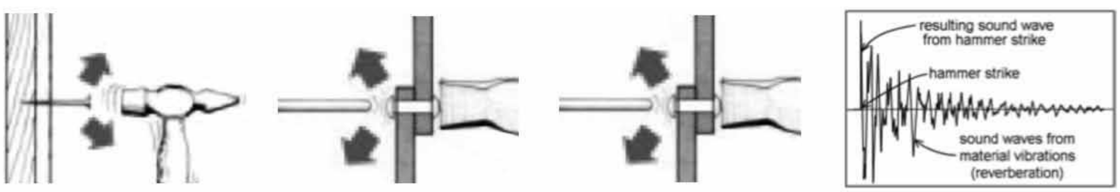
The speed and force of a change to physical objects determine how much vibration occurs and how much sound is generated.

EXAMPLES:

1. When a hammer strikes a solid object like a bar to straighten it, the bar and any connected objects vibrate strongly and rapidly as shown in the graph to the right. Since the bar is solid "ringing" will be minimal.



2. When a hammer strikes a hard object that can vibrate the struck object and any connected objects vibrate strongly and rapidly on the initial impact and then continue to vibrate and generate noise after the impact. This effect is called reverberation.



3. The evenly spaced teeth of objects like a circular saw blade strike and vibrate the blade and the edge of a piece of being cut creating a loud noise illustrated in the graph on the left below. Since the noise repeats with each tooth contact the effect is like a siren as shown on the graph on the right.

Blades have a noise effect similar to a siren

4. Turning on a tap or valve causes very high-pressure liquids or gases to escape into a much lower pressure area so that the gas or any gases (air) compressed in the liquid explodes into bubbles, vibrating the liquid, the pipe and the faucet. These vibrations can travel long distances through air or solid materials like pipes and wall beams.

Both Impact and continuous noise can cause damage to a persons' hearing however the very intense sounds from impact noises can cause immediate damage to the ear and, if loud enough, cause immediate irreversible hearing loss. Impact sounds result in an immediate (acute) risk to hearing unlike most other noise sources that cause hearing loss gradually, over time (chronic risk).

NOISE CONTROL IS THE USE OF PRACTICAL METHODS TO ELIMINATE THE CAUSE:

Change the system to reduce the causes of noise - impacts, pressure changes and speed changes.

For example:

- instead of using impacts, use bending force to work metal
- use tools with mixed or irregular cutting teeth arrangements or that have resonance suppressing slots cut into the cutting blades
- install partial barriers in the flow path of a fluid to reduce sudden changes in pressure
- isolate the source of the sound by:
  - enclosing it so the sound cannot escape
  - using flexible, rubber like, pipe joints that are sound-absorbing rather than rigid materials
- pad objects so they will not readily transmit sound
- anchor noise sources to solid and immovable surfaces or other large heavy objects so that they cannot vibrate readily

4.2 – UNDERSTANDING NOISE

Definition:

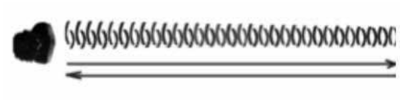
Noise is unwanted sound because it can cause annoyance, interfere with speech or communication and/or cause hearing impairment. Noise (sound) begins with a vibrating source. These vibrations get transmitted through the air (or other materials such as steel, water, etc.) to the hearer.

Speed, Echoes, Resonance and Reverberation

Noise travels in air at a speed of 340 meters per second (1224 km/hr). When sound hits a solid surface it bounces similar to the way a ball acts when it hits solid surface.

- When sound is reflected off a relatively smooth surface (wall, canyon, or other hard surface) the reflected sound is called an echo. Echoes are usually the same as the original sound except with a lower intensity (loudness). In an enclosed area because of the speed sound travels echoes that seem instantaneous. In open spaces there is a very easily perceived delay.

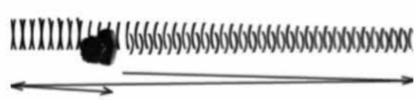
sound bounces off solid surface



ECHO

Echoes off a single hard surface are usually clear reproductions of the original sound with a lower volume and a time delay.

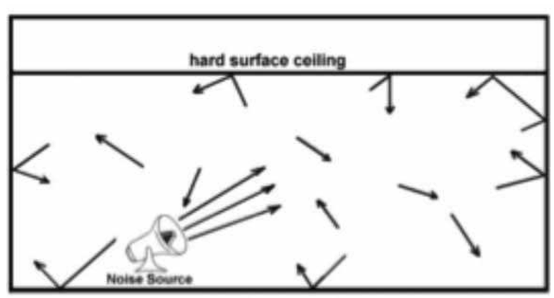
sound bounces between solid surfaces



"Flutter" ECHO

Flutter echoes are a result of echoes bouncing off two surfaces. The result is heard as an unclear sound or 'ringing'/'buzzing' that can be confusing or make speech unintelligible.

- If the reflected sound is in an enclosed area the reflected sounds add to the sound being generated in the area. This has the effect of increasing and extending the life of the original sound. When noise is reflected off the walls, floor and ceiling of a room in such a way that the original sound is distorted and gradually tapers off, we call this "reverberation". Some reverberation is normal in most enclosed areas giving voices and noises a "natural sound" to the listener and is normally considered good. Too much reverberation makes an area seem "noisy" making individual voices and sounds difficult to separate and understand. Areas with too little reverberation seem acoustically "dead" and can have people straining to detect expected sounds that aren't present.
- This is the simplest form of "resonance" a term that refers to the additive effects of the sound that "bounces back" with the sound generated. (see the next section "Explanation of Some Terms and Basic Principles"- "Resonance and Coincidence" and Section 1.6 – Pure Tones/ Resonance for more details)



Reverbation

Pitch/Tone and Frequency

In non-scientific terms sound is considered to have has two aspects: pitch/tone and loudness.

1. Tone

The term "tone" is generally used in sound to indicate the quality of the sound. Music and voices usually considered regular tones and have a fairly constant frequencies and pitch. A mix of frequencies and pitches usually indicates that the sound is "noise" meaning it is undesirable sound.

- ***Pure Tone:*** A noise that is dominated by a single frequency (tone).

2. Pitch

The term "pitch" when referring to sound can have several different meanings. The term is used (and defined) in music as the frequency of notes A to G. The term is also used as a general term to describe the variation of sounds with frequency as follows:

- ***Low Pitch***: The sound of a diesel engine, a truck or a compressor. These are so-called "low frequency" noises, which are difficult to dampen in an enclosed space and they also are easily transmitted by vibration through floors and walls.
- ***Mid Range Pitch***: These are the same frequencies as the sounds generated by the human voice (generally female slightly higher than male), therefore, noise in this frequency range can be a problem for hearing conversation.
- ***High Pitch***: The sound like a circular saw or a small high speed fan. These noises are particularly damaging to the ear and can cause hearing loss quickly.
- ***Very High Pitch***: Shrieking noise like a high pitched whistle.
- ***Sonic range (Hearing range)***: the range of frequencies (pitches) that can be heard.

When sounds are beyond the range of sounds that we can hear we refer to them as:

- ***Infrasound***: for the very low frequencies (low frequency vibration)
- ***Ultrasound***: for the very high frequencies (dogs can hear these sounds).

Loudness

Loudness refers to the volume or the physical intensity (strength) of the sound wave when it reaches the ear. Loudness is affected by the frequency and the tone. Passively determining the actual loudness of a sound can be difficult because pleasant sounds are often perceived as not being as loud as the same level of sound when it is unpleasant.

Levels of Sound Intensity (Loudness)

The following table illustrates the differing levels of sound intensity:

Voice Level: at one meter away	Normal	Raised voice	Loud	Very Loud	Shouting	Maximum Shouting
Noise Level (in dBA)	50 to 60	70 to 75	80	85	90	100
Risk Level	None	Distracting, Annoying, No risk of Hearing Loss	Annoying, Unpleasant, Slight Risk of Hearing Loss	Some Risk of Hearing Loss Ontario regulated level.	Medium Risk of Hearing Loss	High Risk Of Hearing Loss

Continuous, Fluctuating and Intermittent Noises

- some sounds are constant (continuous) Example: a fan
- others fluctuate (a constant background with regular louder levels of noise) Example: using a table saw to cut pieces of wood
- still others are intermittent (on and off) Example: airplanes taking off at an airport.

This time characteristic of the noise may be important when making precise noise measurements, however, in general these distinctions are seldom useful.

Adding and Subtracting Sound in Decibels

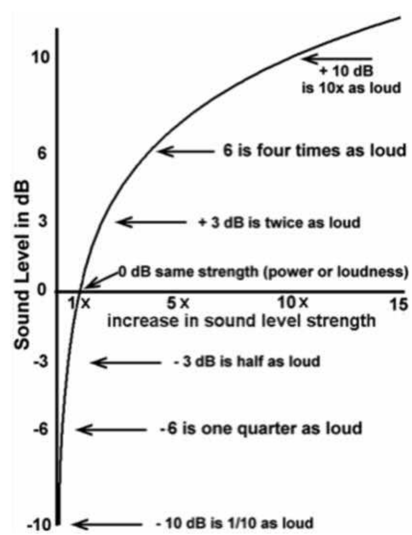
Sound levels are added by adding the individual decibel levels. However adding values using decibels is not straight forward and can be difficult (the scale is logarithmic). In order to add and subtract noise levels precisely, one must be familiar with the mathematics of logarithms and the definition of the decibel. This requires some specialized training.

For example, when you add two identical 60 dB sounds together, the total noise is 63 dB, not 120 dB. In other words every increase by 3 dB is a doubling of the sound level.

If a third noise source of 60 dB is added, the total noise is about 65 dB. Not 66 dB!

Another difficulty in determining subjectively what sources need to be added in the workplace is the fact that the additional noise of the third source (and more) would be difficult to distinguish from the combined noise of the other two sources.

Differences in Sound Strength as the dB level Changes



The logarithmic nature of the decibels scale means that:

- for noises with identical frequencies, the sound from one source can be completely masked (unable to be heard) if the source is approximately 10 dB louder; and
- when a noise source is reduced or removed, other noises which were previously masked and not being considered can appear.

Differences in Behavior of High and Low frequencies

THE SLOWER THE REPETITION, THE LOWER THE FREQUENCY WILL BE

Frequency means "often-ness", that is, how often an event happens.

- If you run your hand along a picket fence fast, the frequency of the sound made will be greater than if you did it slowly.
- Similarly, if an engine has parts that move round (or back and forward) fast, the frequency will be high, but slow moving engine parts generate low frequencies.

By designing equipment to lower the rate of repetition of movements the noise frequency can be lowered, lessening the disturbance to humans.

AIR WEAKENS HIGH FREQENCIES MORE THAN LOW FREQUENCIES

Because high frequencies oscillate (accelerate) air (or any other material) much more quickly than low frequencies, it consumes much more of its energy as it travels through the air or material. The result is that high frequency sound loses energy faster and weakens sooner than low frequency sound.

LOWER FREQUENCY AUDIO NOISE IS LESS DISTURBING THAN HIGHER FREQUENCIES

Note: frequencies at or below the lower limits of the human hearing range can be either very annoying or have other adverse effects on the human body even if they can't be heard..

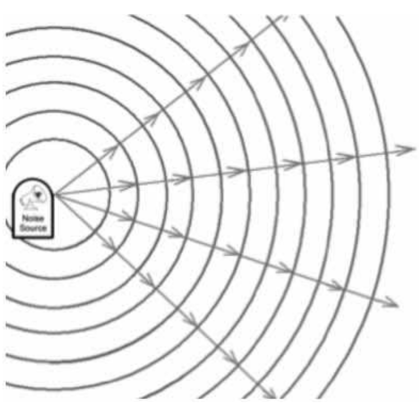
Again, because high frequency sound accelerates things much faster than low frequency sound, even at the same sound pressure level, it is more exciting to the ear, and more annoying.

As sound frequency increases, the characteristics change. The explanations are as follows:

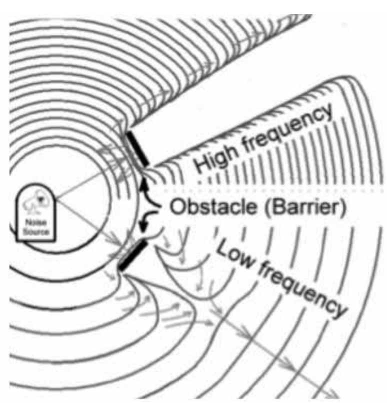
- high frequency is a rapid vibrating pressure rather than a slow "push-pull".
- high frequency sound travels straight out from the source rather than "bending" around corners. Low frequencies will carry around corners and through doorways.

THE HIGHER THE FREQUENCY THE MORE "DIRECTIONAL" SOUND IS
(REFLECTS BACK, DOESN'T FLOOD AROUND OBJECTS)

Radiation of Sound from a Single Source



Effects of an Obstacle on Sound Radiation



When high frequency sound encounters an object, there is less time for the air to be pushed aside, around the object, than with lower frequency sounds. Lower frequencies encountering the same object will build up pressure. The air is pushed to either side of the object, flooding the vibration around and beyond the object.

Low frequency sound can therefore "flood like water" round corners and through holes while high frequency sound is more like a light beam. It reflects back from an object, or travels straight through openings in the object

4.3 – EXPLANATION OF SOME TERMS AND BASIC PRINCIPLES

Absorption

Sound is a vibration and therefore involves the use and transfer of energy. During the transmission of sound, the air or other materials are forced to vibrate, that is, to bend backward and forward. This bending consumes energy, weakening the vibration. The loss of energy into the air or material is called absorption.

A good absorption material vibrates within itself when subjected to sound. Most are fibrous or sponge-like material with thousands of thin filaments each of which oscillate as sound waves pass. The result is that each filament uses some of the energy. As the sound waves make the filaments bend, stretch and relax, very small amounts of heat are generated. The result is that the sound energy is converted into heat energy.

In air, a similar process occurs. The sound squeezes and relaxes the air causing small amounts of heat to be generated that gradually consumes the sound energy.

The greater the quantity of material (or distance in air) that the sound goes through, the more absorption occurs. However for economic and practical reasons solid sound-absorbing materials are usually selected to absorb about 70% of the sound that strikes them.

Barrier

A sound barrier is a wall or plate that scatters, absorbs or bounces most of the sound back towards the source instead of allowing it to pass through.

Damping

When the vibration of an object is reduced or stopped by placing it in contact with another object that absorbs or prevents the vibration, the effect is called "damping".

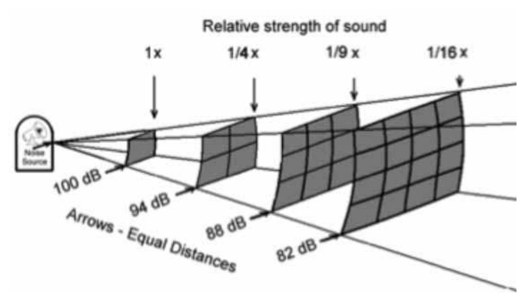
For example:

- placing one's hand on a ringing bell to make it quieter
- adding a layer of carpet on a floor so that footsteps will be quieter
- attaching a pad under a metal sink to quiet the noise of the water impact

Loudness Reduction by Distance

- As sound travels, it mechanically vibrates the air or other material that it is moving through. The further sound travels, the more of its energy is expended, and the weaker the sound gets.
- In open air (no walls) sound levels steadily decreases as the sound waves travel away from the source. A quarter of the original sound remains for every doubling of distance from the source.

Decrease in sound with distance.



Sound pressure decreases by -6 dB for every doubling of the distance. Pressure decrease = 10 $\log_{10}(1/2^{2})$

- In an enclosed area, like a room, the loudness does not diminish as much because the sound reflects back towards the source off surfaces like the walls (reverberation) adding to the sound levels being created in the room.

Noise reduction (NR)

The reduction of loudness achieved by installing a barrier or enclosure is called noise reduction, it is measured in dB(A). There are 3 types of noise reducing (NR) materials:

1. Noise Absorbing Material:

Examples: mineral wools, non rigid foams, expanded wood, porous materials

- used to reduce the reverberation (echoes) inside of rooms
- surface of the material must be porous to absorb noise
- porous materials are better for absorbing high frequency noise than low frequency noise

2. Noise Insulating Materials:

Examples: concrete, bricks, plaster, high density materials

- prevent the noise from passing from a room to the other areas
- these materials block noise (prevent transmission) but do not absorb noise well (solid concrete absorption coefficient = 0)
- material must be dense enough not to vibrate:
    - rigid foams are very light and do not insulate well
    - heavy materials are better at dampening high frequency noise (some low frequency vibrations are transmitted through heavy insulating materials)

3. Vibration Damping Materials

Damping material must be resilient*; not compressed or crushed. Stiff materials, like concrete, don't stop sound transfer; an impact against a wall can be heard all along the wall. Stiff foam plastics are not effective damping materials.

Examples: rubber, many soft plastics, springs, flexible air filled devices

- Materials or devices that prevent mechanical vibrations:
    - these materials stop items from emitting or transferring vibrations and noise
    - damping materials could include pre-formed materials such as PVC or rubber like sheets that stick onto the surface or are held by a magnet, sealers, sprayed on dense materials or heavy flexible finishes that are painted on.
- In some cases, thin vibrating surfaces can be dampened by simplying apply duct tape.
- Materials that return to their original shape (resilient* materials) after being bent, stretched, or compressed:

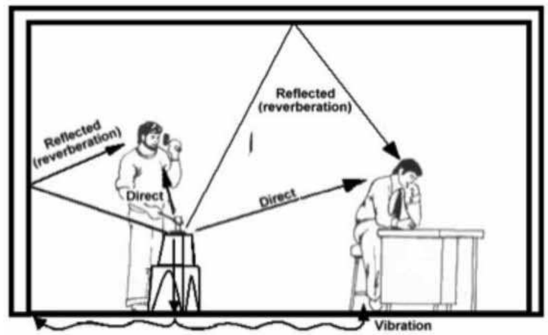
* Resilience refers to the physical property of a material. Resilient materials absorb energy/forces by changing shape - compressing, bending, or stretching – without being destroyed. When the applied force on the material is removed the resilient material will return to its original shape releasing the energy. These materials are often referred to as "rubber like" materials. Examples: a rubber ball, elastic bands, many springs, heavy floor mats, etc

- resilient materials are better at absorbing high frequency than low frequency vibrations
- Shock absorbers:
  - These are usually air or resilient material filled cylinders or spheres that change length or size as a load is applied or removed.

Transmission of sound

This refers to the travelling of sound from a source to the person that hears it.

Noise travels (is transmitted) through or into a work-space by direct transmission, reverberation, and vibration transmission. Each mode requires a different control method. Exposure is the sum of these three transmission paths – if all three noise transmission paths are present it can be difficult to determine the actual source of the noise.



Noise Transmission

1. Direct Transmission

Noise travels directly, in a straight line from the source to the worker's ear. In this case the loudness (intensity) depends on how close the worker is to the source. One can reduce exposure to noise transmitted directly by:

- placing a barrier between the source and the worker (e.g. noise barriers along highways)
- moving the worker further away from the source

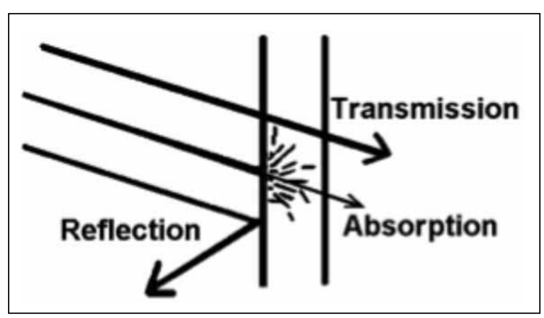
2. Reverberation

Noise is bounced off walls, ceilings, floors and other large objects and reaches the worker's ear along indirect paths. The solution to reverberated sound is to decrease the reflections by covering noise reflective surfaces with sound absorbing materials. Suspending noise absorbing baffles from the ceiling is often helpful.

3. Vibration Transmission

Vibrations travel along structures and floors to surfaces which emit noise into the work space when they vibrate (e.g. rattling fan cover). The transmission of vibrations can be absorbed by vibration isolating/damping materials.

Transmission loss (TL)



When sound strikes a wall or other barrier:

- some sound is reflected back off that barrier
- some sound is absorbed - it compresses and relaxes the impacted object, converting the sound energy into very small amounts of heat
- some sound will emerge on the other side of the barrier

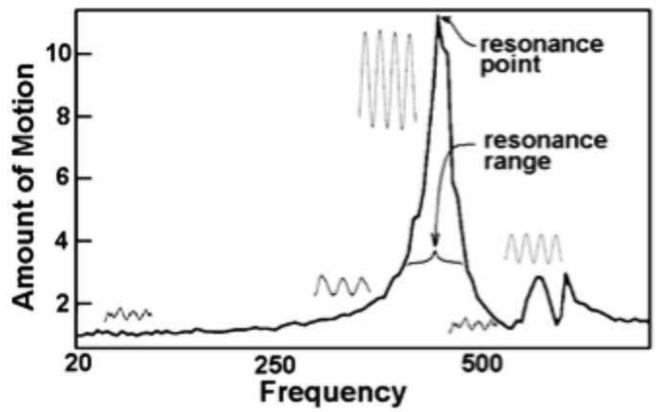
The decrease in the sound that passes through a barrier is called the transmission loss (TL) of the barrier. It is a fixed characteristic of the particular barrier. It is the ratio of the strength of the sound transmitted to the strength of the original sound measured in dB(A).

Resonance and Coincidence

1. Resonance in an object or space

A characteristic of hard objects and rooms with smooth hard walls is that at some frequency(ies), sound waves will bounce backward and forward, adding onto each other and growing much louder. The bouncing can occur within a solid object or within the airspace between solid objects. Even a small vibration or sound at the "frequency of resonance" can quickly build up to a deafening noise. The resonance characteristics of the object or room depends on its size, how it's anchored and what materials it's constructed with.

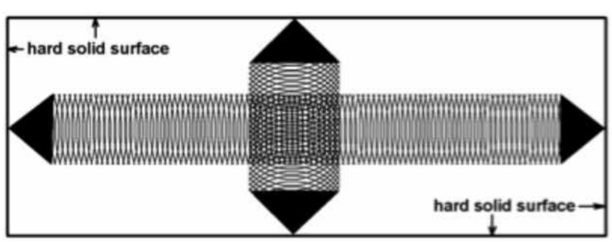
An example of the relative change in the surface movement of an unanchored/undampered solid at different frequencies. These movements generate noise.



All rigid solid objects with a fixed size have natural frequencies at which they will vibrate more readily than at other frequencies. These vibration frequencies depend on the size and the thickness/circumference of the object. Flat materials that are anchored at the edges will vibrate the most. These vibrations create sound waves if they are in the audio range. This form of resonance is the basis of most musical instruments where a surface or a component vibrates when struck, rubbed or air passes over it creating specific frequencies (musical tones). In the workplace these vibrations can cause very loud noises.

If a surface vibrates at the resonance frequency of another sound source (flat surface or tube), the second surface will also start to vibrate. This effect can lead to both mechanical failures in the object being vibrated and/or an increase in the total amount of noise in the area.

Resonance Between Solid Objects

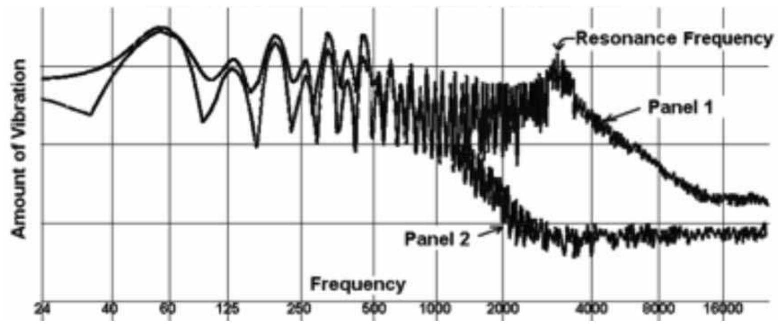


Resonance occurs when sound waves bounce between two hard parallel surfaces without being absorbed and reverberation does not occur. The effect is that the waves add and add to the waves from the sound source. The fequency that resonance occurs depends on the distance between the solid surfaces.

In a room with parallel walls sounds are louder and sustained longer at range of frequencies which are determined by the size and construction of the room. These are the room's resonance frequencies. Resonance associated with rooms usually occurs at low frequencies (bass ranges) and give the building space an "echo" or "boomy" quality. If the area is constructed with panels that resonate within the human voice range human voices can become the source of high noise levels or background noises interfering with vocal communications.

The following graph shows readings in a room where resonance interferes with communications. Panel 1 resonates within the human voice range due to the panel size and the method used to anchor the panel. A panel constructed of the same materials but of a different size and/or different method of anchoring (panel 2) will not vibrate.

Effect of Resonance on the Vibration of a Solid Panel



2. Coincidence and Sound Transfer between spaces

Similar to resonance that occurs within a space or object, materials can vibrate at what are referred to as "critical frequencies" and become effective at transferring sound. This is referred to as Coincidence.

Coincidence occurs when the natural flexing (bending) of a material matches the frequency of a sound source. The material will flex in synchrony with the sound source effectively becoming "transparent" to the sound and become an efficient transferor of sound energy along its length and from one side of the material to the other. If the material is a wall or barrier intended as a sound barrier it will carry and retransmit the sound rather than block it.

Coincidence occurs most commonly in thin materials such as thin wood panels, sheet metal and glass. In the graph above the resonance point of panel 1 would also be the coincident point for the panel.

Best positioning of sound sources

A sound source positioned close to a solid surface like a wall will reflect the sound off the entire surface. To prevent this, sound sources should be located away from solid surfaces when possible.

Sources of sound located near the junction of two solid surfaces such as two joining walls, a wall and floor, or ceiling and wall will reflect more than those just adjacent to a single solid surface.

Corners are the worst place to position a noise source because two walls and the ceiling or floor will reflect it back into the area.