

3. NOISE CONTROL

Once you have identified and measured the sources of noise, you are ready to consider what can be done to control the noise. Remember that the sound to be controlled is a form of energy. Your aim, therefore, is to reduce the amount of sound energy released by the noise source, or divert the flow of (sound) energy away from the receiver, or protect the receiver from the (sound) energy reaching him. In other words, all noise controls work at the noise source, along the noise path, or at the receiver.

The key to noise control is finding the control that is both effective and economical. You should know not only what controls can work, but also how costly the controls are to design and install. In this section, we present a systematic procedure for choosing among the available options, starting with controls that require the minimum amount of equipment modification and ending with those controls that require the most modification.

TECHNIQUES INVOLVING MINIMAL EQUIPMENT MODIFICATION

The kinds of noise controls listed below can be effective in reducing noise exposures, but do not involve machine or process design changes. The alternatives are not necessarily simple or cheap, but they should be considered first, before exploring more complex solutions. The controls are:

- Proper Maintenance
- Changing Operating Procedures
- Replacing Equipment
- Applying Administrative Controls
- Applying Room Treatments
- Relocating Equipment
- Simple Machine Treatments
- Proper Operating Speed.

Proper Maintenance

Malfunctioning or poorly maintained equipment makes more noise than properly maintained equipment. Steam leaks, for example, generate high sound levels (and also waste money). Bad bearings, worn gears, slapping belts, improperly balanced rotating parts, or insufficiently lubricated parts can also cause unnecessary noise. Similarly, improperly adjusted linkages or cams or improperly set up machine guards often make unnecessary contact with other parts and result in noise. Missing machine guards can allow noise to escape unnecessarily. These types of noise sources share one characteristic: Their noise emissions can be readily controlled, though there is no simple way to predict how much noise reduction can be achieved through proper maintenance.

Operating Procedures

The way an operation is performed can cause workers to be overexposed to noise. Some operations are monitored by workers stationed near a noise source. At times, the distance is more critical in terms of noise exposure than operational necessities. In other words, the operator can station himself at some other, quieter location without degrading his work performance. Some operations can be monitored or performed from inside an operator "refuge," a booth or a room. Sometimes, relocation of machine control systems can augment this type of noise control.

Noise reduction obtained by relocating operators can be estimated by measuring sound levels at the existing station and the planned new station. If an operator booth is employed, noise reductions can be expected to range from 10 to 30 dB, with the higher value for booths with good windows and doors, and the lower value for booths that are open to the environment on one or two sides.

Equipment Replacement

In some cases, the modification most readily available is quieter equipment that can be used to perform the same task. For example, several major manufacturers now sell quieted electric motors or quieted compressors. Other examples applicable to industry-specific manufacturing equipment also exist or are in various stages of production. Quieted versions of equipment typically sell for some premium over unquieted ones. Certainly, situations will arise when the purchase of different or newer equipment may be appropriate for production purposes, and these situations may be effectively combined with noise considerations. Be aware that new equipment may not necessarily be quieter, just because it's new. Noise specifications can play a significant role in quieting an environment when an upgrading or expansion program is undertaken, and they will be more important as pressure increases on equipment manufacturers to produce quieter equipment.

Administrative Controls

One possible form of noise control involves administrative control. One form of administrative control is to stretch your production so that the actual noise exposure is kept just below daily acceptable limits rather than allowing exposures to be high one day and low the next. Such noise control, however, is usually a remote possibility.

A second possibility is to rotate workers: Exchange those who work in noisy areas with those who work in quieter areas. This alternative administrative control has been used on occasion, but, because of different labor skills and wages, as well as worker resistance, the implementation of this form of noise control is not usual. Furthermore, rotating the workers means that more people become exposed to high-level noise. There is a trade-off between exposing few workers to high-level noise for long periods of time and exposing more workers to the high-level noise for briefer periods of time.

Room Treatments

As described previously, the presence of reflecting surfaces (walls, floors, ceilings, and equipment) in a workspace results in the build-up of sound levels in the reverberant field. By controlling the reflected sound (i.e., by preventing the reflections), reverberant field sound levels can be reduced by several decibels. Generally, the reflections are prevented by use of acoustically absorbent materials applied directly to wall or ceiling surfaces or suspended from the ceiling in the form of hanging baffles. The potential benefit of room treatment ranges anywhere from 0 dB (no benefit) to as much as 12 dB.

Equipment Location

The sound level drops off as one moves away from a noise source. Outdoors (i.e., in an acoustic free field), the sound level can be reduced by as much as 6 dB for every doubling of distance. Indoors, the effect of reverberation may limit the reduction obtainable by relocating equipment, but when workers are stationed close (within a meter) to noisy machines and where space permits, moving the noise sources (or the workers) may be beneficial. This situation is often encountered where manned production equipment is lined up in rows, and where a given operator may receive as much noise exposure from the machine behind him as from his own machine. If there is no room to spread out equipment, a likely alternative solution would be to shield the worker from the sounds around him (see Machine Controls section). Also, reverberant treatment may be of benefit. Refer to Figure 2.12.

Another form of equipment location would be to relocate machine service units that do not need constant attention, such as pumps, fans, drives, hydraulic systems, and air and steam flows, into unoccupied spaces.

Simple Machine Treatments

Vibration Isolation--

Airborne noise can be produced by any solid vibrating member of a machine. The vibrating member alternately pushes and pulls against the air, creating small pressure changes that tend to radiate in all directions. The vibrating member may be driven into vibration by contact with a primary moving part, or through some intermediate solid linkages in contact with the moving part. In such cases of "forced vibration," techniques of vibration isolation may be applicable. In general, all vibration isolation techniques aim at disassociating the vibrating member from the force causing it to vibrate, generally by interposing a slightly compressed "springy" material between the forces and the member. An example would be supporting a panel on a machine by means of bolts that pass through Neoprene grommets. Essentially, the panel is "suspended" from the machine by the Neoprene.

Close-fitted machine-mounted enclosures should be vibrationally isolated to prevent the enclosure panels from becoming important sound radiators.

Vibration Control--

Vibration control eliminates or reduces vibration at its source. In the discussion on maintenance, several vibration control techniques were mentioned, including the balancing of rotating components and the elimination of unnecessary component contact. Vibration control also includes mounting a vibration source on special supports. This type of vibration control, actually a form of vibration isolation, is considered separately because it deals with the vibration itself (which could be a motor-pump assembly, part of a machine, or the entire machine). Vibration control systems can employ springs, Neoprene, cork, felt, or glass fiber.

Vibration isolators are commercially available. They are selected by specifying the weight to be supported, the deflection required, and the lowest vibratory frequency of the unit to be isolated. They are made from elastomers (compressed or shear, ribbed Neoprene); other compressible materials (cork); fibrous mats (felt, glass fiber); and steel springs.

Basic isolation requires a knowledge of the lowest forcing frequency (f) of the machine to be isolated, as related to the natural frequency (f_n) of the isolator when supporting the machine and the weight on the footing to be isolated. The transmissibility of vibratory energy is greatest (and should be

avoided) when the ratio of $f/f_n = 1$. Isolation begins above $f/f_n = \sqrt{2}$. As a general rule, a machine on a heavy rigid foundation is well isolated when the resonance frequency is less than one-fifth of the lowest operating frequency. The latter is usually that of rotary unbalance in the slowest rotating part. If the machine is on a lightweight floor or is hung from a springy roof, the ratio should preferably be less than one-fifth. Vibrating pipes or suspended fans can be in this category. The isolator plus machine resonance frequency f_n is determined from $f_n = 0.5 \sqrt{d}$ or $f_n = 3.13 \sqrt{l/d}$, where d is the static deflection of the isolator under load in, respectively, millimeters or inches. This relation holds only when the deflection is strictly proportional to the load (linear systems).

To select spring isolators (Bell 1973)*

- Establish that part of the total weight that is on the footing in question.
- Determine the lowest forcing deflection required for degree of transmission percent required (see Table 3.1); 5% is normally adequate.
- Choose a suitable isolator that will sustain the load and have the proper deflection. Isolator manufacturers often list spring constants (lb/in. deflection).
- Ensure that the deflection is uniform for each footing.
- Ensure that the vibration isolation system is not shorted out by rigid connections (electrical conduit, mechanical supports, linkages, or pipe connections, etc.).

The selection of isolator pads follows the same general method, and data from the suppliers as to the recommended grade, material, and thickness are used. Many pads, however, are highly non-linear and cannot be selected directly on the basis of the above information.

A motor mounted on a platform is a typical isolation problem. This problem has a simple solution: Use four properly selected vibration isolators.

*Bell, L.H. 1973. Fundamentals of Industrial Noise Control. Harmony Publications, Trumbull, Connecticut.

Table 3.1 Required static deflection (inches) for common industrial speeds or forcing frequencies (base is assumed immovable).

Speed rpm	freq.	Vibration Transmission (percent)				
		0.5%	1.0%	5.0%	10%	25%
3600	60	0.55	0.27	0.06	0.03	0.01
2400	40	1.2	0.62	0.13	0.07	0.03
1800	30	2.2	1.1	0.27	0.12	0.05
1600	27	2.8	1.4	0.29	0.15	0.07
1400	23	3.6	1.8	0.38	0.20	0.09
1200	20	4.9	2.5	0.52	0.27	0.12
1000	17	7.1	3.6	0.74	0.39	0.18
800	13		5.6	1.2	0.61	0.28
600	10			2.1	1.1	0.49
400	7			4.6	2.4	1.1

Other vibration problems can be more complex, and knowledgeable suppliers should be consulted. Provide them with the machine weight, operating frequencies, weight distribution on footing, and test measurements, which should include acceleration, velocity, and displacement at machine footings and at other points on the machine, to aid in determining the isolator requirements. For example, machines with low forcing frequencies may require a heavy concrete inertia block, generally 1.5 to 2.0 times the weight of supported equipment. In addition, the inertia block and entire support structure could rest on spring isolators.

Another problem is a machine on a limber floor. Such designs and specifications call for special expertise. Complex vibration involving more than one plane requires specialized assistance from the suppliers or a qualified consultant. Under optimum conditions, the reduction in noise level (in dBA) should range from 2 dB for a machine with no vibrating panels, mounted on a very heavy inertia block, to perhaps as much as 14 dB for a heavy machine on a second-story, limber floor.

A special problem arises with punch presses or other sources of periodic impulse noise. Here the problem is to reduce the transmission of both the shock and the ensuing vibration. The optimum choice of vibration isolator is governed by the relation among three time intervals. First is t_1 , the effective duration of the exciting shock. Second is t_2 , the period (time for one cycle) of motion resulting from resonance between mass of the machine and the effective stiffness of the vibration/shock isolator. Third is t_3 , the interval between repetitions of the impulse. The isolator should be chosen so that $t_1 < t_2 < t_3$ to obtain near-optimum results. The value of t_1 for a punch press or shear is approximately the time between contact of the tool with

the workpiece and the completion of the cutting action. This can be determined from machine parameters; direct measurement with an oscilloscope gives more reliable data.

Surface Damping--

Frequently, lightweight metal (or plastic) parts are set into bell-like vibration by multiple impact (e.g., parts impacting on chutes) or by induced resonances caused by externally applied forces. The resulting "free" vibration can be effectively attenuated by application of externally applied damping materials. Damping treatments include application of specially treated aluminum tapes, application of troweled, painted, or sprayed-on materials, and application of constrained layer "sandwiches" of damping materials. In each case, the damping properties of these materials are dependent on temperature, humidity, and chemical exposure.

Other Simple Treatments--

At times, minor changes in the structure or functional design of a machine can reduce noise effectively. Prime examples of this technique are eliminating or softening (by padding) impacts at linkages and securing rattling parts. More sophisticated methods include changing the size or shape of main radiating structural components (making them smaller) and providing air "leaks" (perforations) in surfaces to make components less efficient radiators of sound.

These and similar modifications should be made only when a part has been clearly established as a main source of noise or vibration and when the ramifications of the proposed changes have been checked thoroughly.

TECHNIQUES REQUIRING EQUIPMENT TO BE ADDED TO EXISTING MACHINERY

Other forms of noise control may involve some kind of modification to the equipment. Some equipment changes that reduce noise exposure, however, can be accomplished without redesigning the equipment. Such modifications may change the machine noise emissions, may redirect the emissions, or may contain the emissions. In some cases, the noise controls may require some adaptation to new operating procedures - in effect, they may require some "getting used to." Humans, as you know, are reluctant to change everyday habits. You should therefore work closely with the people whom the control will affect. Let the workers say what design features they consider essential, and allow a reasonable time period before you evaluate the effects of the changes on operations.

Shields and Barriers

An acoustical shield is a solid piece of material placed between worker and noise source; it is often mounted on a machine. An

acoustical barrier is a larger piece of solid material, usually free-standing, on the floor. Both the barrier and the shield function by deflecting the flow of acoustical energy away from the worker. They are most effective when (1) the worker is close to the noise source (positioned in the near field of the noise source), and (2) the smaller dimension of the shield or barrier is at least three times the wavelength contributing most to the noise exposure received, and (3) when the ceiling and other nearby reflecting surfaces are covered with sound absorptive material. Shields or barriers can provide as much as 8 to 10 dB of improvement under these ideal conditions. The farther the worker is from the noise source, and the smaller the barrier, the less effective is the barrier.

Because most common construction materials used in shield and barrier designs provide considerably greater transmission loss than 8 to 10 dB, the treatment material is generally not critical. Material selection should be based on the (1) need for visual access to the problem equipment and (2) the expense involved. Typical materials used are light-gauge sheet metal, 1/2-in. plywood, 1/4-in. clear plastic, or safety glass.

For best results, and to minimize the addition of unwanted reflections, the machine side of a shield/barrier should be at least partly lined with an acoustical absorbent material, preferably oil-resistant and cleanable (see Noise Control Materials section). Handles and, if needed, casters can be provided for ease of moving. Hinged sections can also be incorporated in the design for physical access through the treatment, but care should be taken, in segmenting the treatment, to minimize acoustical leaks. Strips of Neoprene can minimize leaks at joints or hinges.

Shields can be used as replacements for less acoustically efficient machine guards in many cases. In such cases, the shield should be fitted carefully to cover all the noise leaks and should be properly vibration-isolated.

Enclosures

Partial Enclosures--

When a barrier is wrapped around a machine, with its top more or less open, it becomes a partial enclosure. Such an enclosure can be effective in reducing noise to workers nearby. The noise, however, escapes through the top and contributes to the reverberant sound in the workroom. In addition, specular (mirror-like) reflection from the ceiling can contribute reflected-path levels that can become obvious when the direct path is reduced by the enclosure, as shown in Figure 3.1.

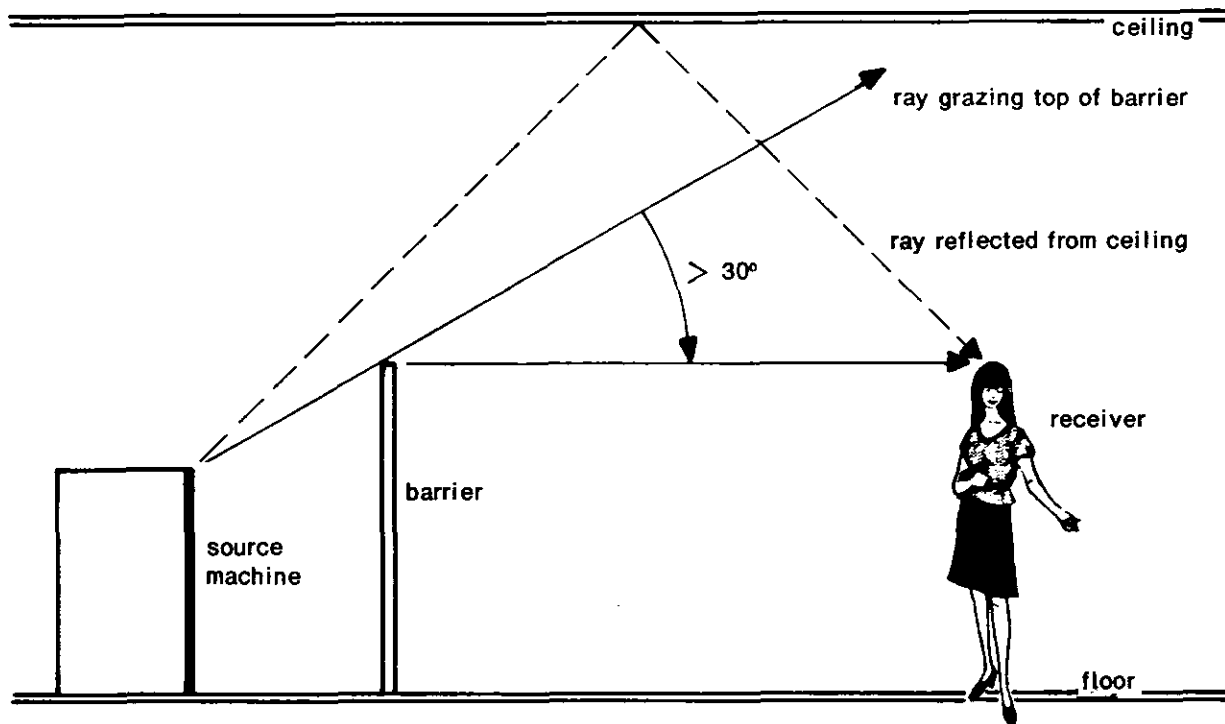


Figure 3.1. Source-barrier-receiver geometry. The angle into acoustic shadow should be greater than 30° for at least 10-dB attenuation. Ceiling reflection can offset barrier attenuation if ceiling height is less than 1.5 times distance from source to receiver.

These spill-over noise effects can be reduced by covering the inside of the enclosure with acoustically absorbent material. Also, suspended acoustically absorbent baffles may be placed over the openings to reduce the escaping noise. If all other machines in the workroom are quieted, the ceiling reflection may become apparent. Such reflections are usually specular, and the patch of ceiling at which the reflection takes place can be located geometrically on building plans. Acoustically absorbent material placed on the ceiling at this location will reduce the reflected sound.

Partial (and total) enclosures will usually need access for incoming material, product, scrap removal, operator, maintenance personnel, and vision. Doors, windows, and hatches will handle most access problems, but the usual precautions about avoiding leaks hold strongly at these openings. Hinged or sliding doors can use a gasket for a seal. A convenient material is the closed-cell foamed elastomer weatherstripping sold with a pressure-sensitive adhesive. Special acoustical gaskets, designed specifically for sealing leaks, are also available. For

less stringent sealing, the magnetic strip gaskets used on refrigerator doors supply both seal and positive closure. Hatches can be dogged down by quarter-turn latches.

Windows for visual access may need internal illumination to make visual monitoring easy. Heat build-up should be no problem with an open top in a partial enclosure. If necessary, ventilation openings (fitted with acoustically lined ducts or mufflers) can be provided through the enclosure walls. Noise reduction may remove acoustic signals that some workers use in evaluating the performance of a machine. Hence, if the reduction is too great, acoustic cues *may* have to be supplied separately, with a rugged microphone (at the site where the essential information is generated) feeding a small loudspeaker at the worker position.

Openings for workpiece, product, and scrap flow can permit noise to escape. Such openings should be in the form of tunnels lined with absorbent material. The length and unobstructed cross section of the tunnel determine the amount of noise attenuation obtainable. In the design, the acoustically absorbent material can be selected for maximum effect on the noise spectrum at that opening. Use of lined tunnels should be accompanied by some degree of automation. Examples of some partial enclosures, which can provide as much as 12 to 15 dB of noise reduction, are shown in Figure 3.2.

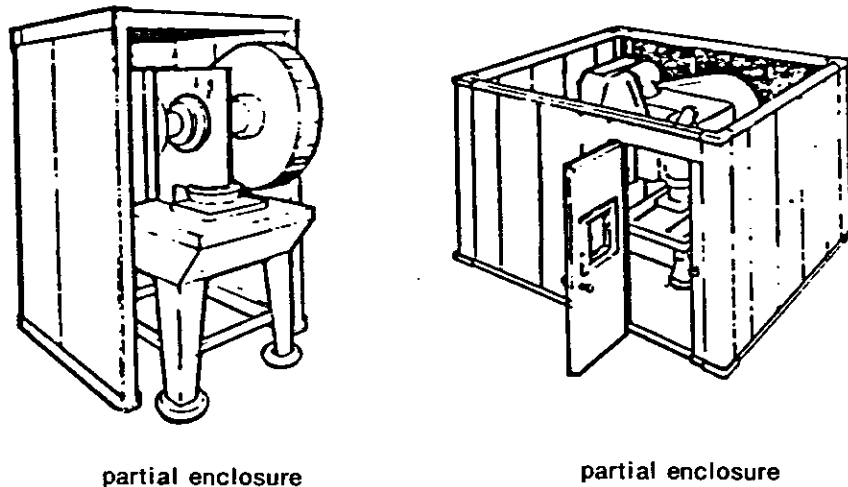


Figure 3.2. Examples of partial enclosures.

Total Enclosure--

If more than 12 to 15 dB of noise reduction are required, a total enclosure is needed so that noise is contained more fully.

By virtue of their design, total enclosures can cause a heat build-up problem. Heat build-up is handled by adding a ventilating blower, together with silencers for both supply and exhaust air. Some internal ducting may be needed if there are heat-sensitive components in the machine, but these ducts can also selectively supply cooling air and remove hot air. The minimum flow rate of cooling air, Q (in cfm), depends on W , the watts of heat generated, and on ΔT , the temperature rise permitted (degree F). For air cooling at sea level, $Q = 1.76 W/\Delta T$. More flow is needed at higher altitudes.

A total enclosure may require a change in work habits. The change can be more acceptable if the people most involved -- the workers and the foremen -- are given the opportunity to enter into the design discussions. Enclosures can also force consideration of modernizing equipment, for example, automatic feed by conveyor, which requires less personal attention to the machine. Such automation may also offset the difficulties that arise from less free access to the machine. In most instances, you will have little difficulty with the acoustical aspects of enclosure design. The chief job is to ensure an industrially viable design, taking account of the requirements for access, minimum change in productivity, and minimum installed cost. To meet these requirements, you, as the noise control engineer, must work closely with the industrial, plant, and process engineers, with foremen and workers, with maintenance crews, and with management.

As a general matter, enclosures should not touch any part of the machine and should be vibration-isolated from the floor. Nevertheless, the enclosure must be pierced for such services as electricity, air, steam, water, oil, or hydraulic power. These services can be regrouped, together with mechanical controls, to a convenient location and passed through a junction box that is later packed and sealed. Cables, pipes, and conduit can pass through cut-outs in metal cover plates for the junction box. If desired, an enclosure panel can be split and adapted for passage of services through the enclosure wall. See Figure 3.3. A resilient acoustical seal can then be made from two ring-shaped pieces of 1/8-in. (or heavier) Neoprene. Slot each piece at the pipe or conduit and overlap the two pieces with the slots facing away from each other. Seal the straight edges with strips of Neoprene or similar oil-resistant, heavy, resilient material.

For mechanical controls operating through an arc-shaped hole or slot in a panel, the seal can be of abutting multiple strips of Neoprene. The control lever should be as thin as possible. Where possible, replace the lever with a servo control operated from the outside.

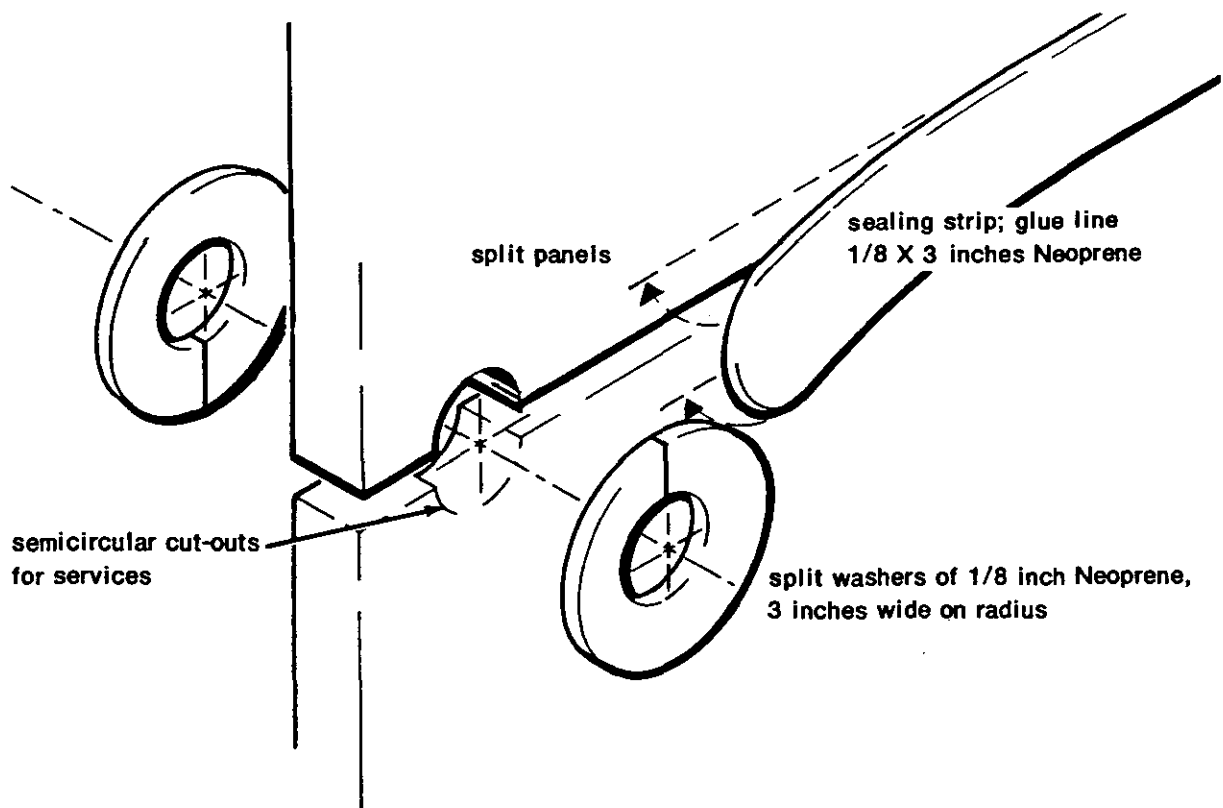


Figure 3.3. Split panels for services.

Many of the features of a convenient enclosure design are illustrated in Figures 3.4 through 3.10. The general design is based on panels secured (by quarter-turn captive screws) to an angle iron frame (see Figures 3.4 and 3.5). Thus, rapid access is provided for all types of servicing of the machine. This type of enclosure should be as close as possible to the machine. Up to 20 dB of noise reduction are usually easily obtained. The angle iron frame can be of bolted sections, to permit quick and complete disassembly and removal.

Machine vibration may still create a problem by vibrating the floor, which then acts as a resonant sounding board to vibrate the enclosure. This problem is handled by vibration-isolating mounts, using steel springs, or elastomers in shear (Figure 3.6). Special care in design is needed if the exciting force is of short duration but is repeated, as in a punch press. Not all vibration-isolator suppliers recognize the need for careful selection of isolators in this special repeated-impact situation. Be sure that you have enough data on the machines and the isolators to ensure an effective design. You will need data on three time scales: (1) duration of the impact, (2) time between impacts, and (3) the minimum period of oscillation of machine on a suggested isolator.

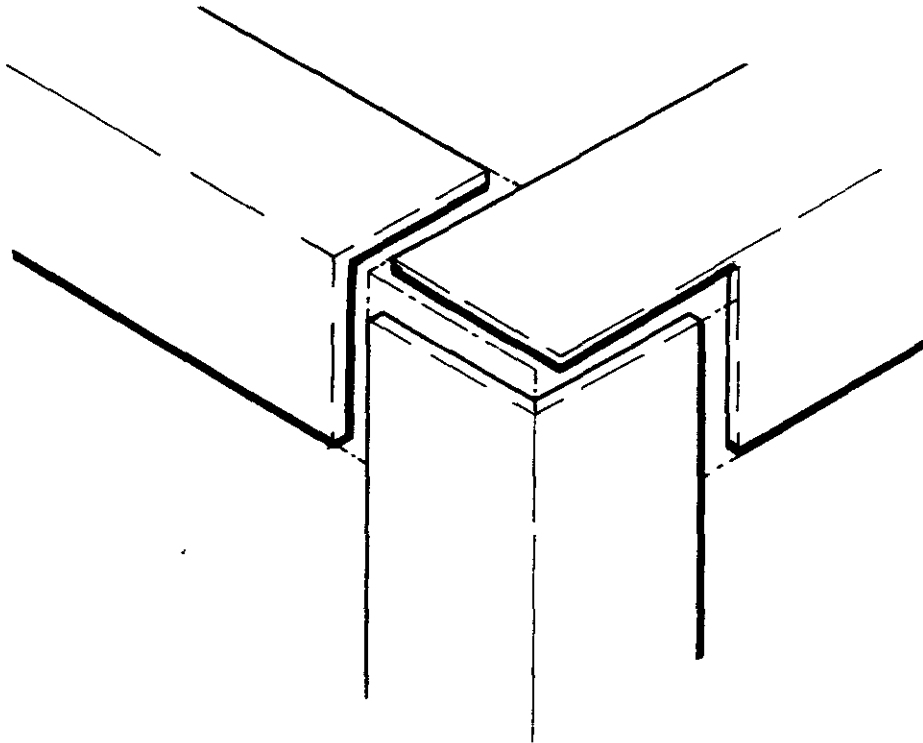


Figure 3.4. Welded angle iron frame. This frame can be welded in segments that are bolted together.

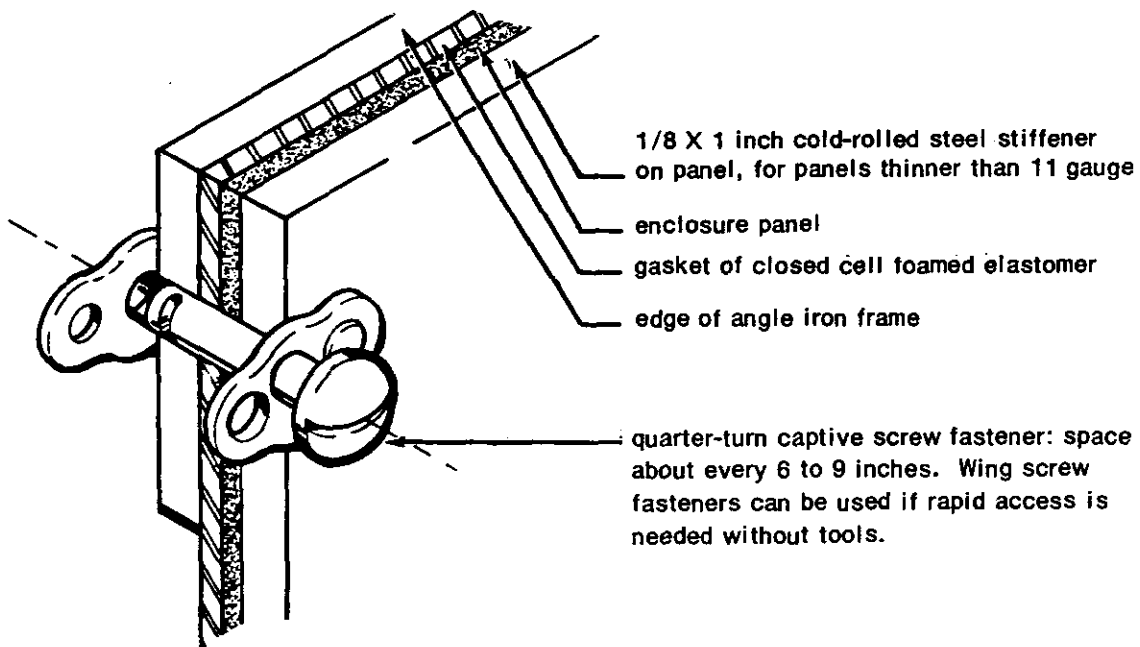


Figure 3.5. Enclosure panels secured to frame by quarter-turn fasteners.

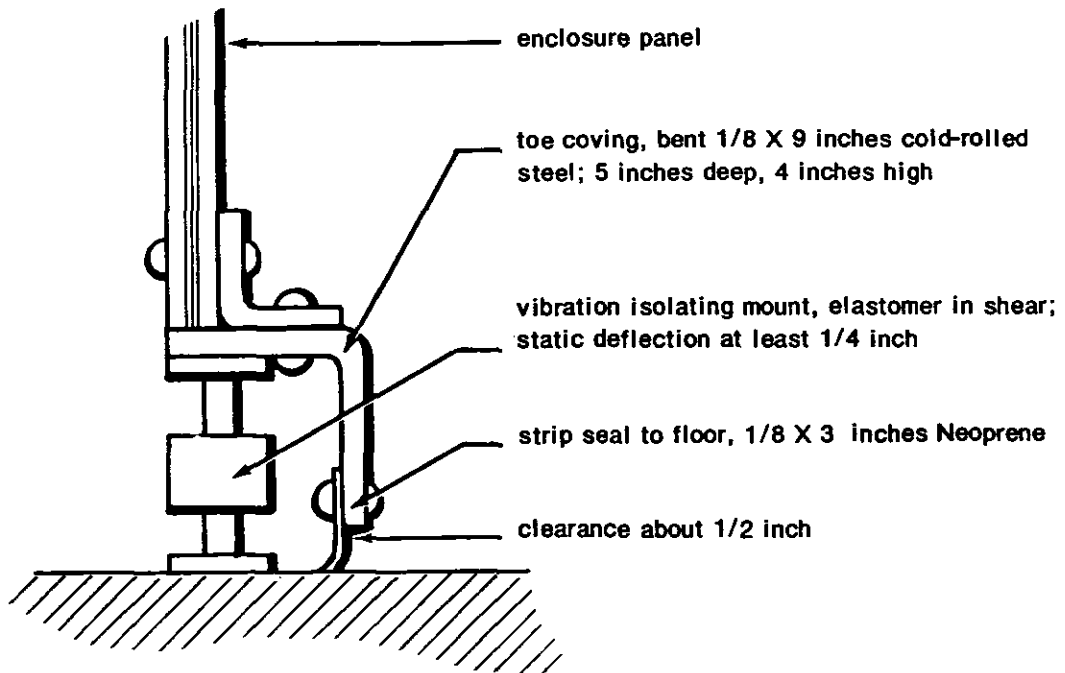


Figure 3.6. Vibration isolation and toe covering.

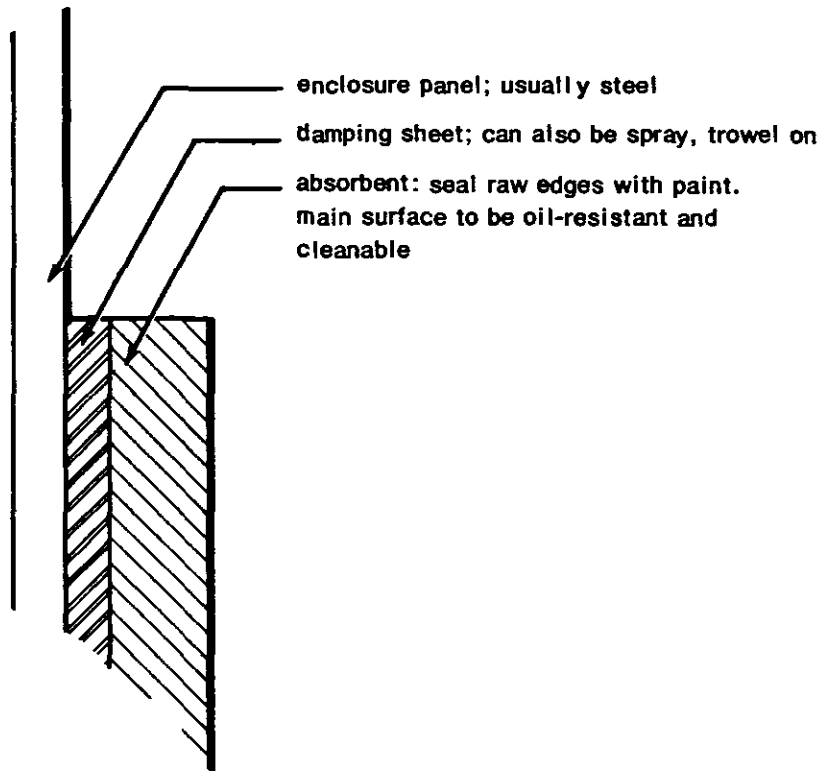


Figure 3.7. Enclosure panel interior treatment.

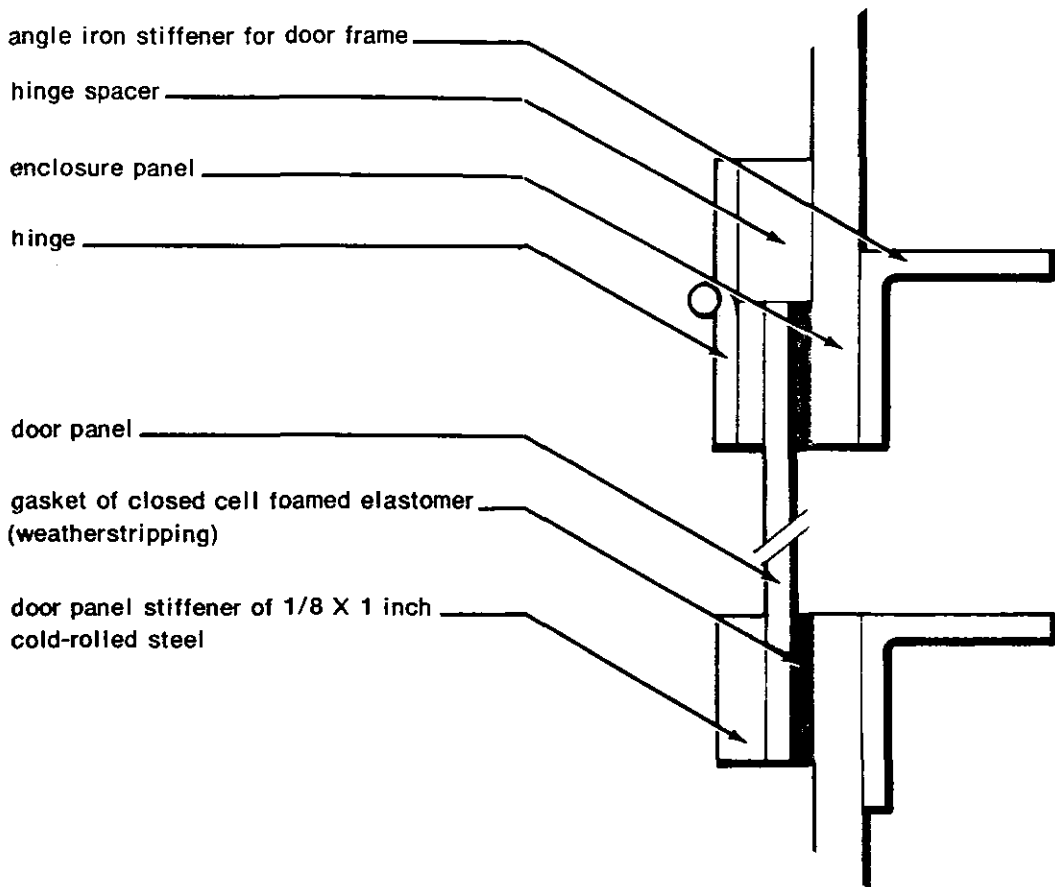


Figure 3.8. Door and hatch detail. Interior of doors and hatches have same acoustical treatment as enclosure panel. Secure doors by vibration-resistant latches or by quarter-turn fasteners. Doors and hatches must make airtight seal to enclosure panel.

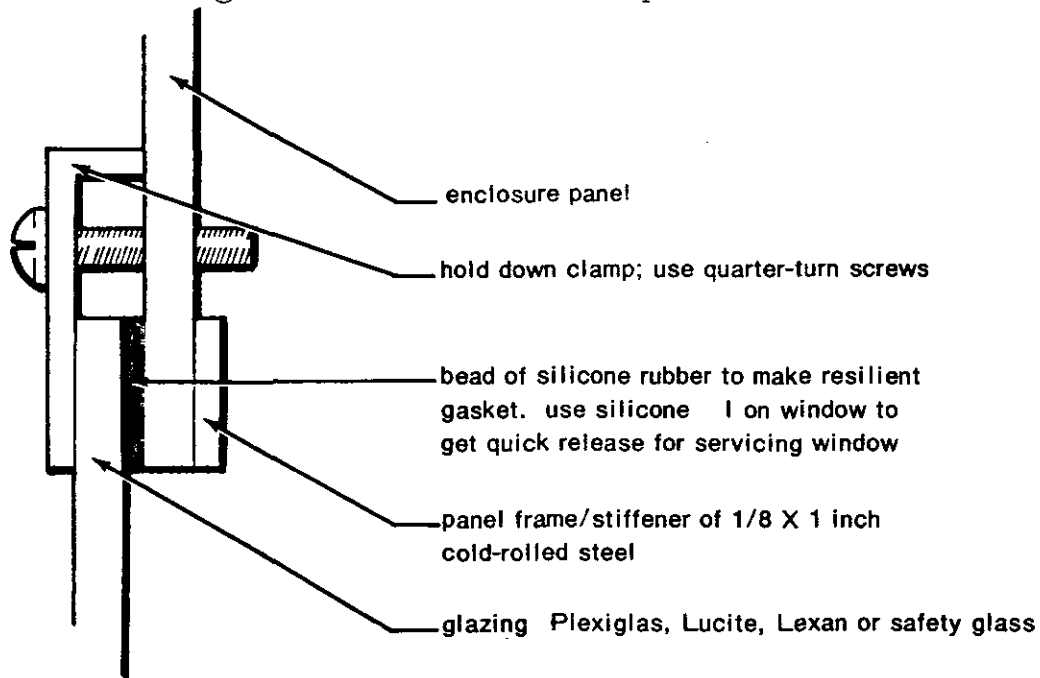


Figure 3.9. Window detail.

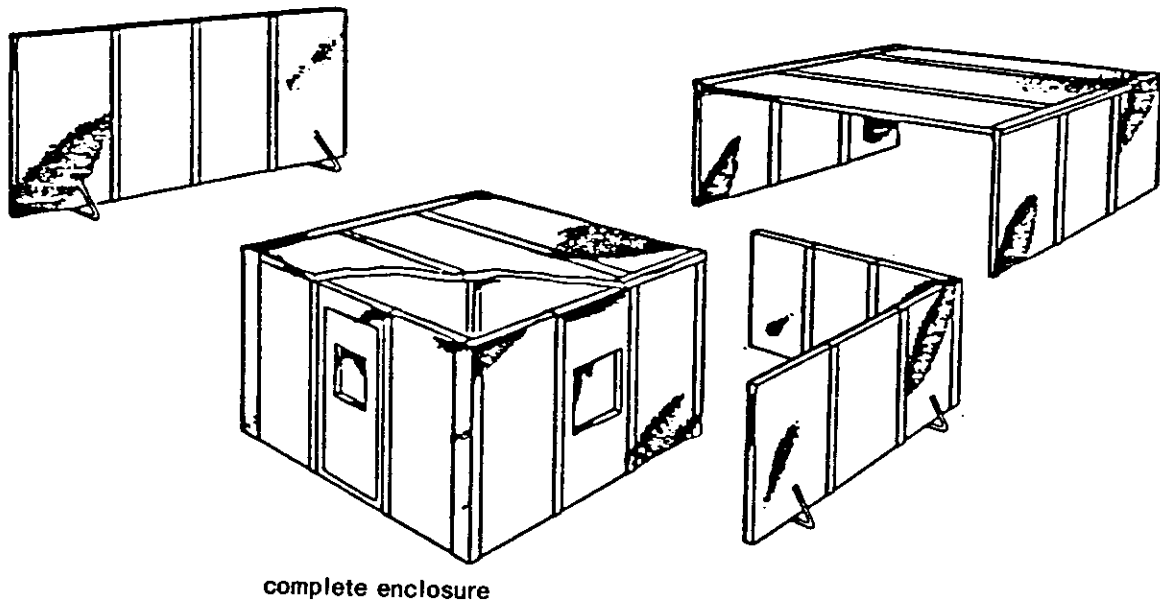


Figure 3.10. Examples of enclosures.

For any machine, the time comes when major repairs are due; additions or changes may also be called for. The enclosure designs suggested in Figures 3.2 through 3.10 afford some flexibility in this regard. The panels can be made separately and fastened in place with a gasket material (such as weatherstripping) to close off leaks. If the panel material is metal, its resonances can be distributed more uniformly in frequency if the panel is reinforced by bolted-on angle irons (bolting adds damping). The stiffeners should be placed so as to divide the panel into smaller areas, no two of which should be the same size and shape. Frames for doors, windows, and hatches can also be used as stiffeners.

Windows pose a special problem because they are an acoustical weak spot. Generally, if more than 20 dB of reduction are needed, double glazing must be used. The inside layer should be safety glass, because it must withstand rough handling and cleaning to remove oil, grease, and dirt. All panes should be set into soft elastomer gaskets. Room-temperature-setting silicone rubbers are useful. The visual access that windows provide should be carefully thought out in terms of the information needed by the operator. Glareless lighting of the components to be monitored is helpful. In extreme cases, closed-circuit video monitoring can be used.

A special adaptation of the total enclosure for the machine is a total enclosure for the operator when this is the more practical or economical approach. Such enclosures may require air intake and exhaust fans, with noise traps, lighting, heating, or, in some cases, air conditioning. As in machine enclosures, some inside absorption – such as an acoustic tile ceiling – is recommended, and special care must be taken in window and door design to avoid leaks. See Figure 3.11 for effect of leaks.

How can an enclosure be acoustically designed? First, establish how much noise reduction is needed for the equipment being enclosed at the location of interest outside the enclosure (typically the closest operator position). See Overall Noise Reduction Requirement and Noise Source Diagnosis sections. This machine-specific objective is termed the required "insertion loss" of the enclosure, and it should be expressed on an octave-band basis. Second, estimate the required "transmission loss" of the isolating wall of the enclosure, again on an octave-band basis.

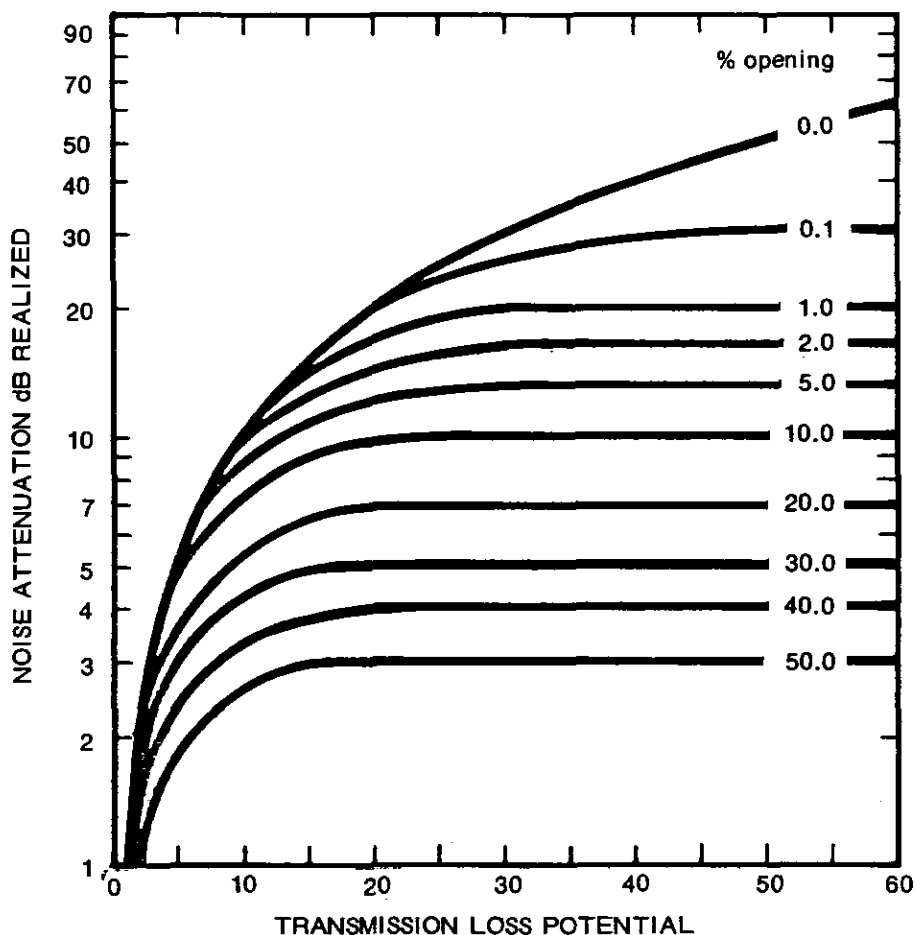


Figure 3.11. Effect of enclosure sound leaks on potential noise reduction.

For an enclosure that will be lined with sound-absorbing material, the estimated required transmission loss in each octave band is equal to the insertion loss plus 10 dB. For windows with bare interior walls, the estimated required transmission loss in each octave band is equal to the insertion loss plus 15 dB to 20 dB, depending upon how conservative you wish to be.* Third, find a suitable wall material that can provide the needed transmission loss in each octave band. (See Table 3.2.) Actual octave-band transmission loss information is also provided in advertising literature. There is a well-defined and accepted standard (ASTM E90-61T, or latest version) for measuring transmission loss, and you should verify that reported information is made in accordance with that procedure.†

A problem occurs in calculating the net transmission loss when the enclosure has panels, doors, hatches, windows, silencers, and leaks, each with its own area S_i and associated transmission loss L_{t_i} . A formula, however, that can be used is:

$$L_t = 10 \log S - 10 \log \sum S_i 10^{-L_{t_i}/10} \quad (3.1)$$

This formula amounts to adding up all the sound power that escapes and dividing by the total area. As an example, consider a machine control room that has ceiling-high walls that separate it completely from the rest of the shop, where the level is 100 dBA. The design of the wall is shown in Figure 3.12. The objective is to compare the performance of single- and double-glazed windows at a midrange octave band. We assume that there is negligible leakage through the roof and that all leaks have been well sealed.

The calculations are shown below for one octave band. In a complete analysis, calculations must be carried out for all bands.

*This estimation procedure is based on allowance for the build-up of sound that will take place inside an enclosure – a phenomenon that depends principally on the amount of absorption inside the enclosure.

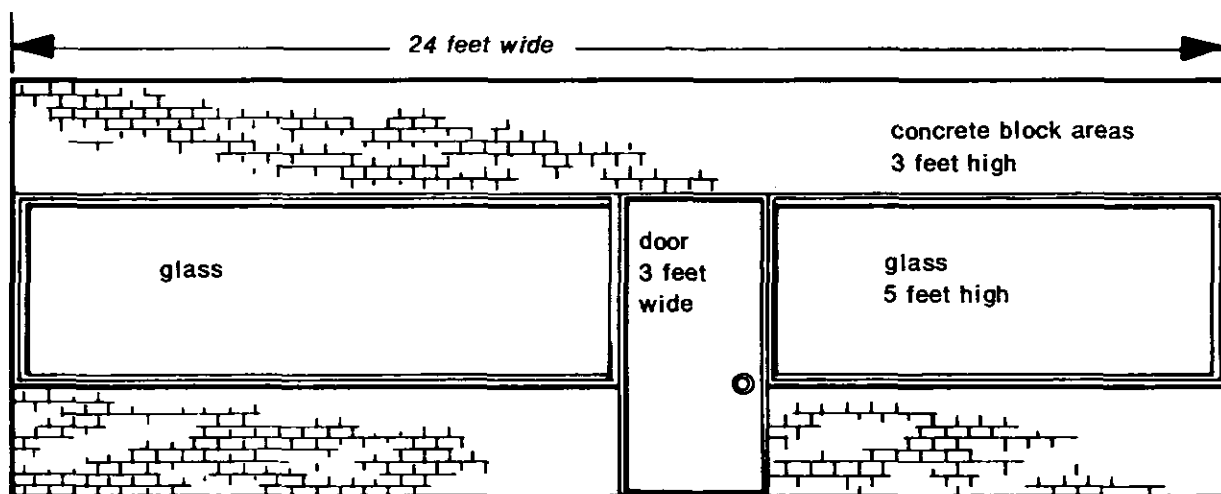
†Do not confuse transmission loss data with STC data, a related material performance measure that is often given in addition to or in lieu of transmission loss data in advertising.

Table 3.2. Transmission loss of common materials. The reader is referred to Beranek, *Noise and Vibration Control*,* and NIOSH's "Compendium of Materials for Noise Control,"† for general information on the behavior of noise-isolating material and the design of enclosure systems.

Material	lb/sq ft	Frequency						
		125	250	500	1000	2000	4000	8000
Lead								
1/32-in. thick	2	22	24	29	33	40	43	49
1/64-in. thick	1	19	20	24	27	33	39	43
Plywood								
3/4-in. thick	2	24	22	27	28	25	27	35
1/4-in. thick	0.7	17	15	20	24	28	27	25
Lead vinyl	0.5	11	12	15	20	26	32	37
Lead vinyl	1.0	15	17	21	28	33	37	43
Steel								
18-gauge	2.0	15	19	31	32	35	48	53
16-gauge	2.5	21	30	34	37	40	47	52
Sheet metal (viscoelastic laminated-core)	2	15	25	28	32	39	42	47
Plexiglas								
1/4-in. thick	1.45	16	17	22	28	33	35	35
1/2-in. thick	2.9	21	23	26	32	32	37	37
1-in. thick	5.8	25	28	32	32	34	46	46
Glass								
1/8-in. thick	1.5	11	17	23	25	26	27	28
1/4-in. thick	3	17	23	25	27	28	29	30
Double Glass								
1/4x1/2x1/4-in.		23	24	24	27	28	30	36
1/4x6x1/4-in.		25	28	31	37	40	43	47
5/8-in. Gypsum								
On 2x2-in. stud		23	28	33	43	50	49	50
On staggered stud		26	35	42	52	57	55	57
Concrete, 4-in. thick	48	29	35	37	43	44	50	55
Concrete block, 6 in.	36	33	34	35	38	46	52	55
Panels of 16-gauge steel, 4-in. ab- sorbent, 20-gauge steel		25	35	43	48	52	55	56

*Beranek, L.L. 1971. *Noise and Vibration Control*. McGraw-Hill, New York, N.Y.

†NIOSH Technical Publication No. 75-165. *Compendium of Materials for Noise Control*.



glass area	105 sq ft
door and frame	24 sq ft
concrete block	135 sq ft
total	264 sq ft

Figure 3.12. Example of isolating wall.

	S_i	L_i	$\frac{-L_i}{10}$	Values of S_i Single Glazing	$\frac{-L_i}{10}$ Double Glazing
Single Glazing	105	31	7.94×10^{-4}	0.0834	--
Double Glazing	105	45	3.16×10^{-5}	--	0.00332
Door	24	31	7.94×10^{-4}	0.0191	0.0191
Concrete Block	135	45	3.16×10^{-5}	0.00427	0.00427
Sums	264			0.1068	0.0267

$$10 \log 264 = 24.2$$

$$L_t (\text{single}) = 24.2 - 10 \log (0.1068) = 34 \text{ dB}$$

$$L_t (\text{double}) = 24.2 - 10 \log (0.0267) = 40 \text{ dB.}$$

Wrapping/Lagging

A special form of enclosure treatment is wrapping or lagging. This kind of treatment can be used to insulate already enclosed surfaces (e.g., piping or hoppers). The treatment consists of application of an absorbent material over the radiating or vibrating surface, followed by an outer coating of impervious material, such as sheet metal or flexible mass-loaded vinyl. Such treatments are less subject to problems encountered with box-type

enclosures, but are generally limited to use on regularly shaped surfaces that do not require constant maintenance. Some typical constructions and attenuations* are given below (in dB):

	<u>500 Hz</u>	<u>1000 Hz</u>	<u>2000 Hz</u>
1-in. glass fiber blanket with aluminum foil covering	1.5	4.8	13.8
1-in. glass fiber blanket with lead-impregnated vinyl	5.0	12.0	24.0
2-in. glass fiber blanket with lead-impregnated vinyl	4.0	13.5	26.0

Notes:

- Glass fiber is 4 lb/ft³ (64 kg/m³) density. Lead vinyl is 0.87 lb/ft² (4.25 kg/m²)
- Note low attenuation at 500 Hz, less at lower frequencies.
- Good seal at all joints is critical.
- Two layers of 2-in. glass fiber plus lead impregnated vinyl between layers plus a cover layer of lead impregnated vinyl would increase attenuation.
- Sheet lead of same weight/area could also be used.
- Sheet metal, plaster, or gunite (sprayed-on concrete) can be used for greater TL of the covering layer.

Silencers

There are many types of noise control devices that are termed "silencers." Duct silencers, for example, are cylindrical or rectangular structures fitted to the intake or discharge of air moving equipment. These "dissipative" silencers function by absorbing noise otherwise escaping from the intake or discharge. The duct silencers are internally lined with acoustical material.

Commercially available duct silencers are specified by the insertion loss (by octave bands) and by other specifications, such as velocity of flow, temperature, and allowable pressure drop. Large industrial silencers are also known as snubbers and are sometimes combined with spark arrestors. There is a great deal of art in silencer design. One difficult problem with dissipative silencers is fouling of the absorbent by particulate matter.

*Dear, T.A. 1972. Noise reduction properties of selected pipe covering configurations. In: the International Conference on Noise Control Engineering. P. 138. Washington, D.C.

Fans and blowers, when near or part of an operation, can be a major noise source. Fan types used are propeller, axial, and centrifugal. Blades on centrifugal fans may be radial, forward-curved, or backward-curved; backward-curved blades are the quietest. The resulting air noise is a combination of blade-pass frequency and harmonic peaks plus broadband aerodynamic noise and turbulence.

Reduced fan speeds will reduce noise, and replacement with lower noise level fans, such as backward-curved blade types, can be considered. If this is not practical or economical, the air flow noise can be reduced by commercial or custom-made silencers. Custom-made silencers, which can be constructed in maintenance shops, include acoustical labyrinths, parallel baffle silencers, acoustic-lined plenums, acoustic-lined ducts, and acoustic-lined bends.

If duct walls are lined with an absorbent with absorption coefficient, α , then an estimate of the decibel reduction obtained per foot of lined duct is given by:

$$\Delta L = 12.6 P \alpha^{1.4} / S ,$$

where ΔL = Change in sound pressure level

P = Acoustically lined perimeter of duct, inches

S = Cross section open area of duct, square inches

α = Coefficient of absorption (note that this is frequency-dependent, so octave-band data will be used to determine required insertion loss and length of duct to be treated). (3.2)

The above equation is applicable only for low frequencies (duct width/ λ < 0.1). Beranek, in *Noise and Vibration Control*,* provides other means for determining muffler performance.

Plenum chambers can also be lined with sound-absorbing material. An approximate relation for the reduction in level is:

$$\Delta L = 10 \log (\alpha S_p / S_b),$$

where α = Coefficient of absorption of liner

S_p = Area treated on plenum walls

S_b = Discharge area of blower. (3.3)

*Beranek, L.L. 1971. *Noise and Vibration Control*. McGraw-Hill, New York, N.Y.

An absorbent-lined bend should add about 5-dB attenuation, with length of treatment at about five times duct width. Commercial silencers are available for greater attenuation to fit any fan or duct size, and suppliers can give insertion loss at each octave band under varied conditions of flow. Note that noise travels both upstream and downstream, and silencers may thus be needed on both intake and delivery sides of the fan.

The "reactive" muffler is another type of silencer used along piping or ductwork systems or at engine exhausts. These devices are designed to reflect pressure disturbances back toward the noise sources, thus functioning in a different fashion than dissipative silencers.

Acoustic tunnels, fitted to the infeed or discharge of otherwise enclosed machinery, are another type of silencer. They are simply an acoustically lined passageway, dimensioned to accommodate the product flow. Here, sanitation details are likely to be more important than pressure losses caused by the use of the tunnel. Acoustic labyrinths, such as are used on ventilated enclosures, are a special form of acoustic tunnel.

In-line silencers are devices used in piping systems to smooth out pressure disturbances in the piping systems.

Two special categories of silencers are those fitted to pneumatic lines at pressure relief valves or exhaust ports on pneumatic equipment (exhaust mufflers) or to air wipes and parts blow-offs (parts ejection mufflers). These devices reduce the turbulence normally associated with the exiting stream of air.* These devices can serve as an inexpensive form of noise control for such frequently encountered noise sources. However, care must be taken to ensure that air flowing through these devices is reasonably clean, because the mufflers have a tendency to clog.

TECHNIQUES REQUIRING EQUIPMENT REDESIGN

Noise control at the source of the noise is highly desirable in many cases, especially when the need to retrofit or otherwise modify noise exposures is thereby eliminated. Usually, however, the expertise and resources necessary to redesign equipment on a large scale is beyond the means of the end user of a noisy product. Yet certain techniques may be useful to end users and may serve to eliminate the need for other forms of noise control.

*Jet noise is extremely sensitive to the air velocity. Noise reduction may therefore also be attained by simply minimizing supply pressure or increasing the cross section of the jet orifice. A reduction of jet velocity can result in a 20-dB or greater noise reduction.

In general, noise emissions caused by impact types of noise sources (e.g., hard parts on hoppers, cans on conveyors, etc.), can be reduced by "softening" or preventing the impacts. Thus, the plant should consider such treatments as:

- Placing internal baffles in hoppers to encourage the product to slide, rather than fall, onto hopper surfaces;
- Machining cam contours to prevent cam follower impacts;
- Changing chute slopes to encourage sliding rather than bouncing;
- Using soft material (e.g., Neoprene) or dashpot buffers to reduce mechanical impacts;
- Replacing metal conveyors at transfer drops with canvas units, or reducing the height of the drops;
- Lining conveyor sides with plastic railing;
- Using timing mechanisms to space out conveyor line product flows, thereby preventing product impacts;
- Applying damping to the underside of conveyors, chutes, hoppers, etc.

In other cases, it is possible to envision the use of alternative mechanisms to quiet noise emissions. Noisy hydraulic motors may be replaced with electric drives. Pneumatic parts ejectors may be replaced with mechanical mechanisms.

PERSONAL PROTECTION EQUIPMENT

There are basically three types of hearing protectors:

- Ear muffs, which are devices that fit around the ears and are supported either from a hard hat or from a head band that connects the individual muffs;
- Ear plugs, which are devices that fit within the ear canal;
- Canal caps, which are devices that rest on the ear canal opening and are supported by a head band.

Ear muffs come in a universal size and are available with foam- or liquid-filled cushions. Some devices fit only in one position (e.g., with the band over the head), while others are multi-positioned, and can be worn with the head band over the head, behind the head, or under the chin. Muffs cost more initially, but they are cleanable, and replacement parts are available.

Ear plugs come in many varieties. Disposable units (e.g., Swedish Wool) are worn once and discarded. Reusable units are cleanable. Some devices are made in several sizes to accommodate different-sized ear canals. Other come in one size that can be adapted by their natural expansion when inserted in the canal, or by removing one or more flanges on the unit. Some varieties are custom-molded, and these are supposed to provide the most comfortable and best fit.

Canal caps are available in only one size and configuration.

The laboratory-measured performance of the many brands and styles of hearing protectors is described in the "List of Personal Hearing Protectors and Attenuation Data," HEW Publication No. (NIOSH) 76-120. The publication also includes a method for determining the in-use performance of any device, on the basis of the frequency-by-frequency lab-measured attenuation and field-measured noise data.

Note: OSHA has always regarded use of hearing protectors as a secondary form of noise control, to be used only when engineering or administrative controls are infeasible or as an interim measure while other forms of noise control are being implemented.

In industrial plants, encouraging the use of protective equipment for employees and supervisors usually requires an educational program on ear protection. There should be continual follow-up by supervisors to see that the program is accepted and that ear protection is worn when needed. For reminders, place signs in areas where protective equipment is mandatory. Supervisors should be aware that if a plug or muff is uncomfortable, it may not be worn.

When they are used properly, hearing protectors can reduce potentially hazardous sound levels to nonharmful at-ear sound levels for most types of industrial noise environments. Laboratory measurements have shown that almost every hearing protector can provide 25 dB or more of attenuation. It should be recognized, however, that there may be significant differences between laboratory-measured performance and actual field performance.

Hearing protector performance is highly sensitive to fit of the device being used. Any acoustical leakage around the devices that may result from improper fit, broken seals from eyeglass frames or long hair, loss of pressure on cushions resulting from stretched supports, or improperly maintained cushions can degrade the hearing protector performance to the point that only 10 dB or less of attenuation can be obtained. Unfortunately, workers tend to use hearing protectors improperly because looser fitting devices are more comfortable.

To insure hearing protectors serve as intended, they should always be provided as part of a more comprehensive hearing conservation program which includes, at minimum, annual follow-up in the form of audiometric testing of individual hearing levels. Any successful hearing conservation program should also include education of the end users to the proper use of hearing protectors (as well as to the potential hazard of improper use) and should provide (1) professional advice as to proper fit and (2) a wide variety of hearing protectors of all kinds (to account for individual preferences and differences in ear sizes). In addition, the program should be supported by management, to ensure company-wide cooperation. Finally, it is important to be able to dispel some of the myths associated with the use of hearing protectors:

- Hearing protectors do *not* degrade a normal hearing person's ability to hear sounds or understand speech in high-noise environments. In fact, hearing protectors can improve listening conditions. When hearing protectors are worn, all sounds are attenuated, and the signal-to-noise ratio remains the same at each frequency. The only difference is that the *intensity* of the sounds is reduced. However, since different frequencies are attenuated by different amounts, the user will need to adjust to the alteration in the sounds he hears.
- Hearing protectors do not appear to cause hygiene problems. Reusable devices can be cleaned and disposable devices replaced as required.

There are certain problems associated with use of hearing protectors that should be acknowledged:

- The devices may be uncomfortable, especially when first worn and especially in hot environments, where perspiration can cause ear muffs to slip or to irritate.
- The devices do make it more difficult to hear in *low* noise environments (i.e., under 80 dBA) and, in intermittent noise environments, workers will naturally want to remove the devices during quiet periods.
- Workers with preexisting hearing impairment may lose some ability to hear certain sounds if the preexisting impairment complements the attenuation of the protector.
- Hearing protectors may make it difficult to localize a particular noise. That is, they can interfere with the ability to discriminate where a sound originates.