

International Union, United Automobile, Aerospace and Agricultural
Implement Workers of America (Ind.) Social Security Dept.

NOISE CONTROL



A Worker's Manual

edited by Dan MacLeod

Detroit, Feb. 1978

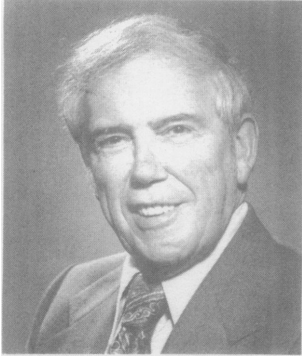
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The UAW's fight to have the noise levels lowered inside the workplace is being waged on many different levels. We are continuing to pressure the American and Canadian governments to enforce stricter standards. We have already taken steps to inform our UAW membership and the general public of the hazards of noise. We have raised the issue during collective bargaining negotiations and will continue to do so. In some cases, we have been forced to take strike action at the Local level to convince management that something must be done to control harmful levels of noise.

In the course of these efforts, we've learned it is not enough to state that noise damages hearing and causes other health problems. Management has often responded by agreeing that it is harmful, but then claimed there are no feasible ways to institute satisfactory noise control, saying nothing can be done.

Thus, we have found that we need to educate ourselves in the techniques of satisfactory control in order to convince management to reduce noise.

The purpose of this manual is to help spread available information on noise control techniques to wage our fight more effectively against noise. We have proven that much of the technology and know-how to control noise is available today and something can be done when management decides to go ahead.

I want to emphasize that it is not the job of the Union to find the exact engineering techniques to solve noise problems or to draw up the blueprints for the controls. Management has professional engineers available to do that.

It is the Union's job, however, to represent workers when managements say nothing can be done. The Union must evaluate every management plan of action in this important area. The Union will make every effort to have each management adopt a serious, professional approach taken in good faith to control noise.

In order to do this job, the Union needs to know more about the basics of noise control.

I should add that both the law and long-recognized standards of occupational health require management to engineer noise out, rather than merely hand out earplugs. It is the worker's right to have a quiet workplace and not to have to wear earplugs forever. There are many solid reasons to support this principle and the UAW has fought on many occasions to uphold it.

The management mentality which puts short-term profits before the health and comfort of workers is the major stumbling block in improving noise levels inside our shops. It is this "production-first" mentality which has made the earplugs available and neglected engineering controls, even though there is proof that some noise controls save money in the long run.

We have been convinced in recent years that noise is dangerous—far more dangerous than we thought in the past. Now we need to take action stronger than ever before in controlling the high levels of noise in many of our shops.

I believe this manual will better enable our Union members to wage that fight.

A stylized, handwritten signature in dark ink that reads "Douglas A. Fraser".

Douglas A. Fraser
President
International Union, UAW

“On the basis of more than one-third of a century’s experience and involvement in literally thousands of industrial noise control projects, I can say unequivocally:

“Effective engineering control measures are available for nearly any industrial noise problem. In most cases, such measures have been available for years; no ‘breakthroughs’ and no waiting for new technologies are necessary.”

**Lyle Yerges
Independent Noise Control Expert
in testimony at the
OSHA Hearings on the Noise Standard
Washington, D.C., July 1975**

Section I

How to Fight Noise



Noise can be reduced inside your shop. The information in this manual shows that technology can eliminate most noise problems.

However, in order to convince management to add the controls, certain steps often need to be taken:

Educate the Membership

Put an article about the effects of noise in your local union newspaper; raise the issue at Union meetings; put out a handbill in the shop. The information in the last section of this manual can be used for this education.

The Company should also provide noise education to all exposed employees. If controls have been applied to noisy machines, the Company should tell the workers why the controls are there and how to maintain them.

Give progress reports to the membership on the status of getting the Company to control the noise. Make sure all workers understand that the law requires management to engineer the noise out and not just put earplugs on workers.

Meet with Management

Set up special meetings with management on the noise problem. Get them to agree to adopt a comprehensive written plan of action to engineer the noise out.

Call in Government Agencies if Necessary

OSHA and the Canadian provincial agencies can often bring additional pressure on the Company to adopt a plan to control the noise. Remember that calling an inspector in is just the start of a long proceeding which the Union must be involved in each step of the way.

In the United States OSHA may cite the company for violation of the standard but will not offer engineering solutions. OSHA may require hearing protection for exposed workers and may require an abatement plan and progress reports from the company. Be ready to challenge abatement plans which are too long. Watch out that OSHA doesn't accept too easily company claims that the noise is uncontrollable. Company Progress Reports to OSHA and other such information are available for Union inspection and copying under the Freedom of Information Act.

In Canada the enforcement procedure differs by province, but involves the same basic idea as listed above.

More help is available from the International Union, Regional Offices, and National Bargaining Departments on how to handle these proceedings.

Use the Contract

Good contractual rights and Local Union action are the only guarantees of effective noise control. Many times even rights guaranteed by law should be nailed down in the contract.

Call UAW International

If you are having particular problems in getting action and improvements, International Representatives can let the Social Security Department know what the problem is and what has been done to solve it. The UAW Health and Safety Staff may be helpful.

Demand An Abatement Plan

One of the most important parts of the Local Union's fight is to get the Company to develop an effective "Abatement Plan."

Management is required by law to control noise through feasible engineering controls. When these controls are extensive such as controlling noise or putting in a ventilation system, the Local Union should demand an abatement plan, that is, a timetable and plan of action for installing the controls.

The plan must follow a systematic, professional approach to avoid exaggerated estimates or actual expenditure of large amounts of money for ineffective measures, as is often done either out of ignorance or out of a desire to make engineering controls look impractical.

The following questions may help you develop a good noise abatement plan.

General

—Is one person responsible for coordinating the noise abatement program?

—Are all audiometric test results, noise monitoring data, engineering survey and evaluation information made available to the local union?

—Has the Company hired noise experts to help them control noise?

Noise Surveys

—Has a floor plan of the shop been made with noise levels recorded at each work station?

—Is the Local Union involved in making these surveys?

—Is the noise survey organized according to jobs, not just to physical areas?

—Is the maximum noise level and the time history of exposure recorded for each job?

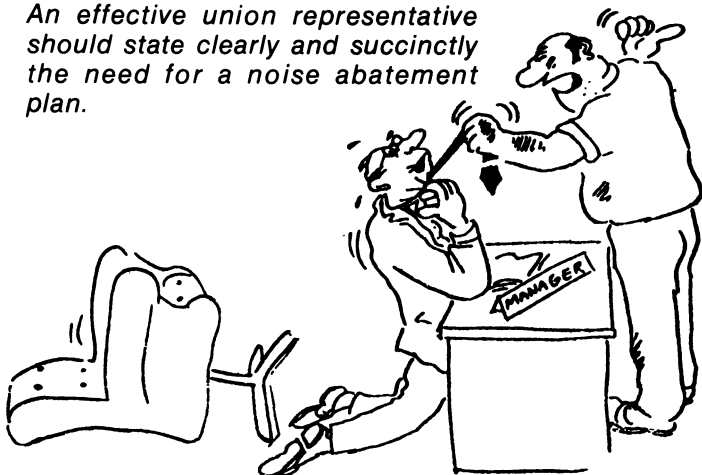
—Does the plan provide for a frequency analysis of the noise?

—Based upon the frequency analysis are certain areas earmarked for noise controls?

—Are impact noise peak levels and duration measured?

—Have you made a special informal survey of the plant yourself using only your ears to detect noise sources you may have taken for granted in the past and not really noticed?

An effective union representative should state clearly and succinctly the need for a noise abatement plan.



—Have workers in the plant been informed of their current (and past) exposure?

—Does the Local Union receive a copy of survey results, reports and recommendations?

Engineering Program

—Has a specific "Plan of Attack" been outlined so everyone knows what is supposed to happen?

—Are projected dates for completion of engineering controls been written down?

—Has any form of Progress Chart been placed on a wall so everyone can see it?

—Are priorities made for reducing the noise, such as the loudest and the most easily controlled noises first?

—Is the engineering program based upon the results of both the audiometric and noise surveys?

—Does the plan reflect implementation of available methods for controlling noise?

—Are competitive bids obtained where practical?

—Are the noise reduction expectations clearly spelled out for each intended control measure before implementation?

—Does the engineering plan direct itself to the most serious exposures as shown in the audiometric and noise surveys, that is, the loudest and longest exposures?

—After implementing a control measure, is another noise survey especially using a frequency analysis made to evaluate the effectiveness of the control measure?

Audiograms

—Does the Company administer pre-employment baseline audiograms and regular audiometric testing every six months?

—Are the audiometric tests correlated to work stations?

—Does the Company use audiometric test results and trends as a partial monitor of the hazard?

—Are audiometers calibrated regularly?

—Is the testing area qualified according to ANSI standards for background noise?

—Are audiograms made at least fourteen hours after noise exposure?

—Does the initial pre-employment baseline audiogram include a questionnaire about the subject's activities during the previous few hours? (Exposure to noise prior to testing can create a significant temporary hearing loss.)

Noise Maintenance Program

—Is a special machine maintenance program instituted to make sure worn, broken or damaged parts are replaced; machines properly adjusted and lubricated; and all loose connections tightened?

—Are maintenance personnel provided with instructions that any changes which will effect noise modifications must be reviewed with the Engineering Department?

—Is the additive noise effect of new machinery or machinery moved from one area of the plant to another determined before it is purchased and/or installed?

BACKGROUND: TWO UNITS USED TO EVALUATE NOISE

5

Two units are commonly used to evaluate noise for the purpose of developing engineering controls.

Decibels

Decibels (dB) measure the loudness of the noise. Decibels can be somewhat confusing to use, because they involve a mathematical shorthand which is based on multiplication rather than adding. Ninety decibels is 10 times louder than 80. Ninety-three decibels is twice as loud as 90.

This shorthand scale is used because of the tremendous range in power between quiet sounds and noisy sounds. Noise could, for example, also be measured in watts, since noise is basically just another form of energy.

A very soft whisper generates about one billionth of a watt (0.000,000,001 watt) of sound power. On the other end of the scale a jet engine can make one hundred thousand watts (100,000 watts) of sound power.

To write and talk about noise using this range of numbers would be very clumsy, so a "logarithmic" scale is used which compresses the numbers by multiplying them rather than adding them.

The following chart shows different noise sources measured both in decibels and in watts:

NOISE LEVELS

Noise Source	Sound Power	
	In Decibels	In Watts
Jet engine	140	100,000
Riveting on steel tank	130	10,000
Cutting Machine hardened tools	120	1,000
Pneumatic hammer	110	100
Pneumatic drill	100	10
Shouting to be heard a few feet away	90	1
	80	0.1
	70	0.01
Voice, normal conversation	60	0.001
	50	0.0001
	40	0.00001
Very soft whisper	30	0.000001
	20	0.0000001
	10	0.00000001
Threshold of hearing	0	0.000000001

Frequency

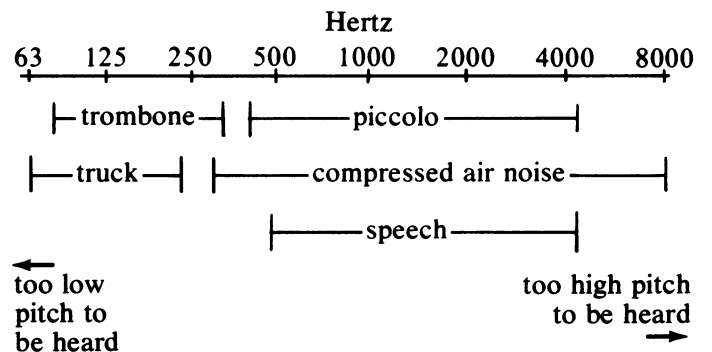
In addition to knowing how loud noise is, it is important in controlling noise to know the frequency (or "pitch") of the noise.

An example of a high frequency noise is a piccolo in a band or a compressed air jet in a plant. In lay terms we would call this a high pitched noise.

An example of a low frequency noise is a trombone or a large truck rumbling by. We could also call this low pitch.

Frequency is measured in Hertz (Hz). The higher the number of Hertz, the higher the frequency.

The following chart gives a rough idea of various frequencies of noise:



Frequency is measured both when analyzing the noise of a machine and when measuring hearing loss of the ear. Noise causes hearing to be lost first in the upper frequencies, especially around 4000 Hertz.

Measurements for Engineering Controls

A common way of measuring noise in order to plan for engineering controls is to measure the decibel level at each frequency, like the following example from a measurement of noise from a pneumatic wrench.

Hz Level	125	250	500	1000	2000	4000	8000
dB Level	66	69	90	100	90	80	70

A read out like this indicates whether most of the noise is high frequency or low frequency and thus helps determine the sort of engineering control needed.

Measurements for Compliance with Standards

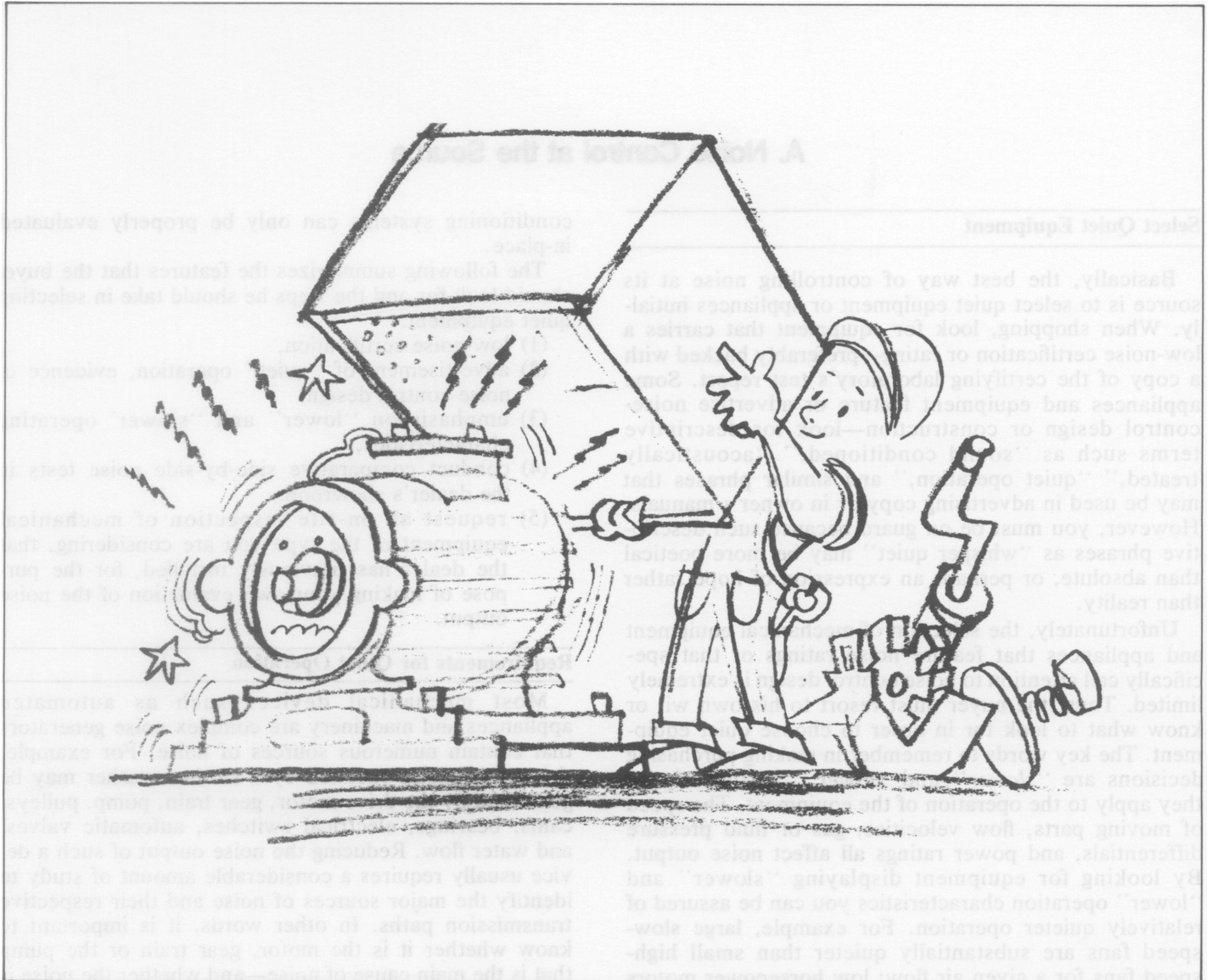
Usually when inspectors are measuring noise to see if standards are being violated, the different frequency measurements are lumped together (automatically by the noise level meter) to get one average reading.

Several different formulas or "scales" have been developed to do this averaging, each one for a slightly different purpose. These scales have been labeled as "A," "B," and "C." The "A" scale is usually used in standards since it reflects most closely how the human ear hears the noise.

Averaging out the noise measurements from the pneumatic wrench example above on the "A" scale (that is according to the "A" formula), the sum reading is 102 dB(A).

Section II

Basic Principles of Noise Control



Edited from
Quieting: A Practical Guide to Noise Control

U.S. Department of Commerce
National Bureau of Standards
(Publication No. NBS HB-119)
July, 1976

Source vs. Path vs. Receiver

If you have a noise problem and want to solve it, you have to find out something about what the noise is doing, where it comes from, how it travels, and what can be done about it. A straightforward approach is to examine the problem in terms of its three basic elements: i.e., sound arises from a source, travels over a path, and affects a receiver, or listener.

Solution of a given noise problem might require altera-

tion or modification of any or all of these three basic elements:

- (A) modifying the **source** to reduce its noise output.
- (B) altering or controlling the transmission **path** and the environment to reduce the noise level reaching the listener, and
- (C) providing the **receiver** with personal protective equipment (but only if the noise source or path cannot be controlled).

A. Noise Control at the Source

Select Quiet Equipment

Basically, the best way of controlling noise at its source is to select quiet equipment or appliances initially. When shopping, look for equipment that carries a low-noise certification or rating—preferably backed with a copy of the certifying laboratory's test report. Some appliances and equipment feature or advertise noise-control design or construction—look for descriptive terms such as "sound conditioned," "acoustically treated," "quiet operation," and similar phrases that may be used in advertising copy or in owner's manuals. However, you must be on guard because such descriptive phrases as "whisper quiet" may be more poetical than absolute, or perhaps an expression of hope rather than reality.

Unfortunately, the selection of mechanical equipment and appliances that feature noise ratings or that specifically call attention to noise control design is extremely limited. Thus, the buyer must resort to his own wit or know what to look for in order to choose quiet equipment. The key words to remember in making purchasing decisions are "*slower*" and "*lower*," particularly as they apply to the operation of the equipment. The speed of moving parts, flow velocities, gas or fluid pressure differentials, and power ratings all affect noise output. By looking for equipment displaying "*slower*" and "*lower*" operation characteristics you can be assured of relatively quieter operation. For example, large slow-speed fans are substantially quieter than small high-speed fans for a given air flow; low horsepower motors are less noisy than those with high horsepower ratings; likewise low-pressure, low-velocity air ventilation or fluid distribution systems are virtually noiseless compared with their high-pressure high-velocity counterparts.

Whenever possible, the buyer should conduct a side-by-side comparison noise test for various makes or types of appliances or equipment. This can best be done by dealing with a supplier who carries a wide selection of appliances or equipment made by several manufacturers and who is willing to demonstrate their operation in the show room. This, of course, is possible when shopping for small domestic appliances such as vacuum cleaners, window air conditioners, etc. However, large mechanical installations, such as central heating or air

conditioning systems can only be properly evaluated in-place.

The following summarizes the features that the buyer should look for and the steps he should take in selecting quiet equipment.

- (1) low-noise certification,
- (2) advertisement of "quiet" operation, evidence of noise-control design,
- (3) emphasis on "lower" and "slower" operating characteristics,
- (4) conduct comparative side-by-side noise tests in the dealer's showroom,
- (5) request an on-site inspection of mechanical equipment of the type you are considering, that the dealer has previously installed, for the purpose of making your own evaluation of the noise output.

Requirements for Quiet Operation

Most mechanical devices such as automated appliances and machinery are complex noise generators that contain numerous sources of noise. For example, the overall noise radiated by a clothes washer may be generated by the drive motor, gear train, pump, pulleys, cams, bearings, electrical switches, automatic valves, and water flow. Reducing the noise output of such a device usually requires a considerable amount of study to identify the major sources of noise and their respective transmission paths. In other words, it is important to know whether it is the motor, gear train or the pump that is the main cause of noise—and whether the noise is radiated directly from the source into the air as airborne noise, or whether it is transmitted structurally as vibration to other parts and surfaces of the machine which, in turn, vibrate and radiate the noise.

A thorough study of the cause of machine noise is important because the sound from major noise sources must be attenuated before reduction of the noise from secondary sources, such as surface vibration, will have any significant effect. The need for these investigations increases with increasing size and complexity of the machinery. In short, the larger and more complicated the machine, the more difficult it is to quiet.

Obviously, the most effective way of manufacturing quiet equipment is to incorporate good noise control techniques in the basic design stage.

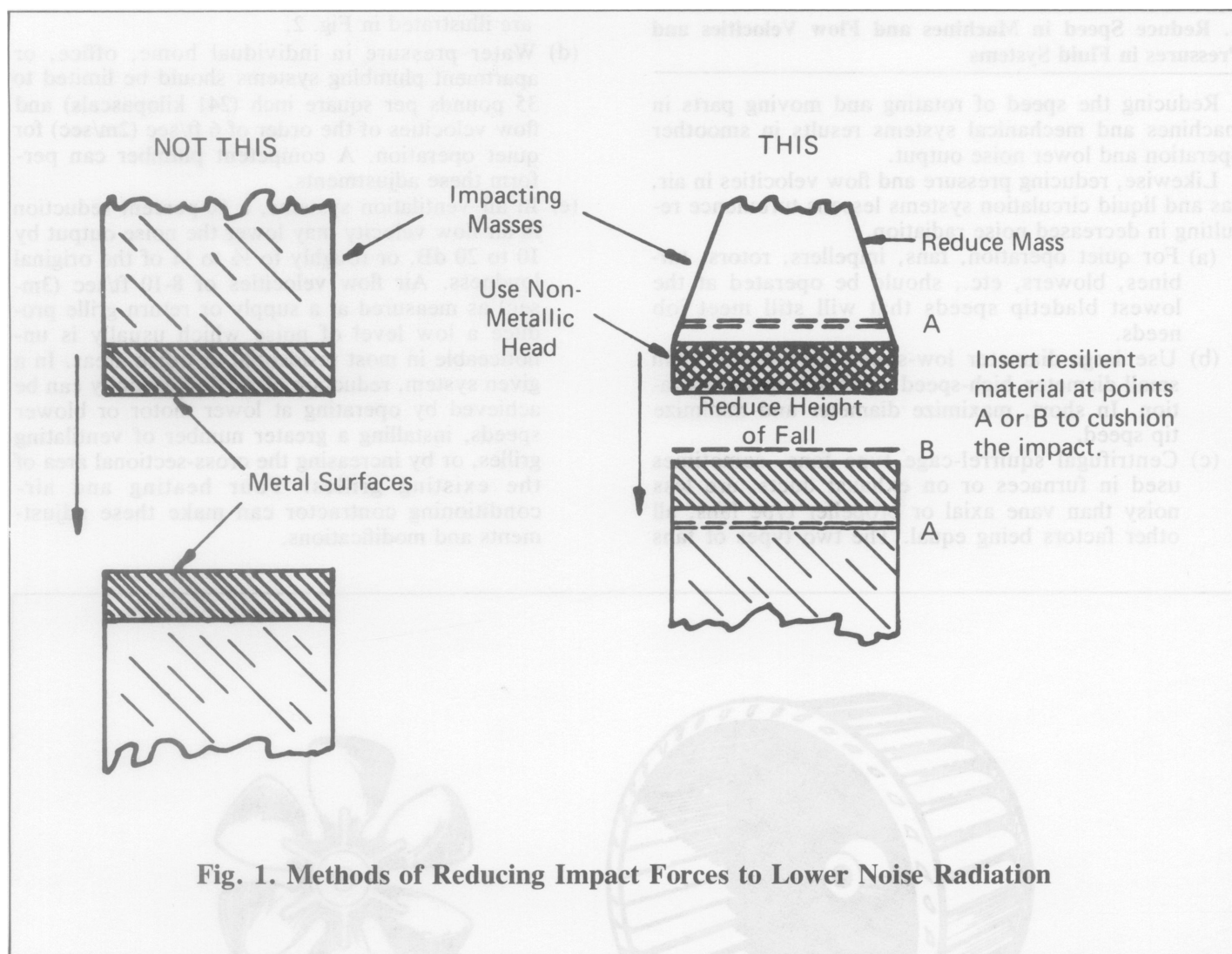


Fig. 1. Methods of Reducing Impact Forces to Lower Noise Radiation

1. Reduce Impact or Impulsive Forces

Many machines and items of equipment are designed with parts that strike forcefully against other parts, producing noise. Often, this striking action, or impact, is essential to the machine's function. A familiar example, is the typewriter—its keys must strike the ribbon and paper in order to leave an inked letter-impression. But the force of the key also produces noise as the impact falls on the ribbon, paper and platen.

Other common devices that produce impact noise include quick-acting cut-off valves found in washing machines and furnace humidifiers. The loud "thump" they often make can be startling, annoying, or in the case of some furnace controls, they can disturb sleep.

Several steps can be taken to reduce noise from impact forces. The particular remedy to be applied will be determined by the nature of the machine in question. Not all of the steps listed below are practical for every machine and for every impact-produced noise. But application of even one suggested measure can often reduce the noise appreciably. A knowledge of the principles underlying impact-noise reduction can also assist you in purchasing quieter equipment.

- (a) Reduce weight, size or height of fall of impacting mass.

- (b) Cushion the impact by inserting a layer of shock-absorbing material between the impacting surfaces. (For example, insert several sheets of paper in the typewriter behind the top sheet to absorb some of the noise-producing impact of the keys hitting against the platen.) In some situations, you may insert a layer of shock-absorbing material behind each of the impacting heads or objects to reduce transmission of impact energy to other parts of the machine.
- (c) Whenever practical, one of the impact heads or surfaces should be made of non-metallic material to reduce "resonance or ringing" of the heads. Figure 1 shows the application of measures a, b, and c.
- (d) Substitute the application of a small impact force over a long time period for a large force over a short period to achieve the same result.
- (e) Smooth out acceleration of moving parts; apply accelerating forces gradually. Avoid high peak acceleration or jerky motion.
- (f) Minimize overshoot, backlash, loose play in cams, followers, gears, linkages, etc. This can be achieved by reducing the operational speed of the machine, better adjustment, or by using spring-loaded restraints or guides. Machines that are well made, with parts machined to close tolerances generally produce a minimum of such impact noise.

10 **2. Reduce Speed in Machines and Flow Velocities and Pressures in Fluid Systems**

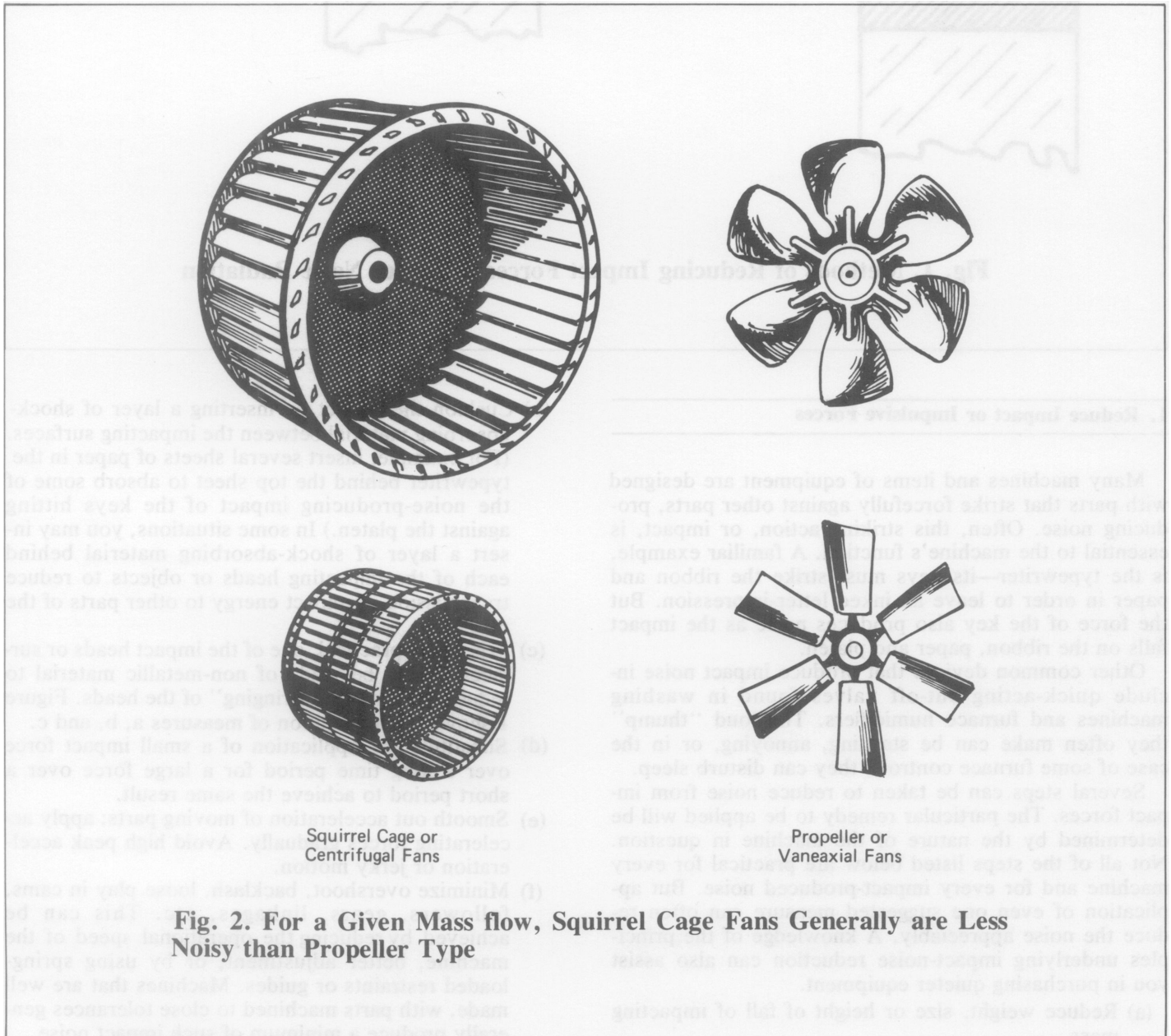
Reducing the speed of rotating and moving parts in machines and mechanical systems results in smoother operation and lower noise output.

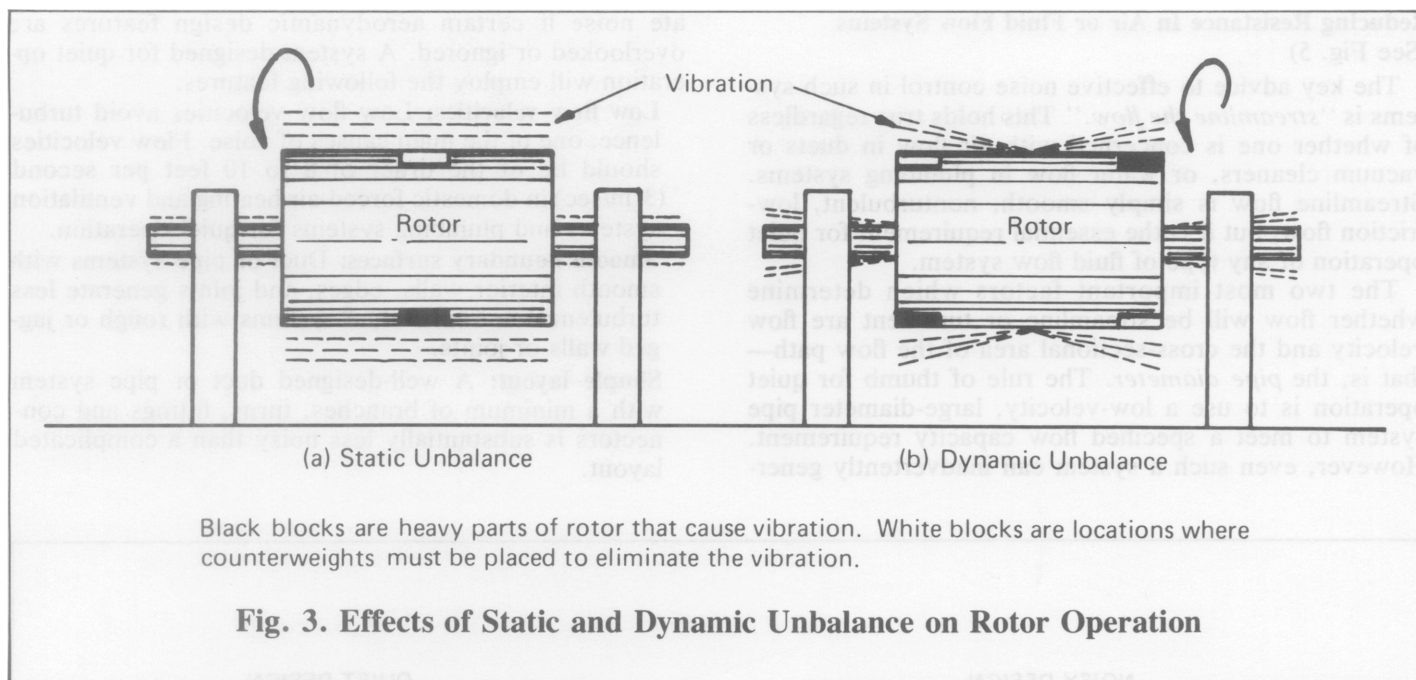
Likewise, reducing pressure and flow velocities in air, gas and liquid circulation systems lessens turbulence resulting in decreased noise radiation.

- (a) For quiet operation, fans, impellers, rotors, turbines, blowers, etc., should be operated at the lowest bladetip speeds that will still meet job needs.
- (b) Use large-diameter low-speed fans rather than small-diameter high-speed units for quiet operation. In short, maximize diameter and minimize tip speed.
- (c) Centrifugal squirrel-cage type fans, sometimes used in furnaces or on exhaust ducts, are less noisy than vane axial or propeller type fans, all other factors being equal. The two types of fans

are illustrated in Fig. 2.

- (d) Water pressure in individual home, office, or apartment plumbing systems should be limited to 35 pounds per square inch (241 kilopascals) and flow velocities of the order of 6 ft/sec (2m/sec) for quiet operation. A competent plumber can perform these adjustments.
- (e) In air ventilation systems, a 50-percent reduction in air flow velocity may lower the noise output by 10 to 20 dB, or roughly to $\frac{1}{2}$ to $\frac{1}{4}$ of the original loudness. Air flow velocities of 8-10 ft/sec (3m/sec) as measured at a supply or return grille produce a low level of noise which usually is unnoticeable in most residential or office areas. In a given system, reduction of air flow velocity can be achieved by operating at lower motor or blower speeds, installing a greater number of ventilating grilles, or by increasing the cross-sectional area of the existing grilles. Your heating and air-conditioning contractor can make these adjustments and modifications.





3. Balance Rotating Parts

One of the main sources of machinery noise is structural vibration caused by the rotation of poorly-balanced parts such as fans, fly wheels, pulleys, cams, shafts, etc. Measures used to correct this condition involve the addition of counter weights to the rotating unit or the removal of some weight from the units as indicated in Fig. 3. You are probably most familiar with noise caused by imbalance in the high-speed spin cycle of washing machines. The imbalance results from clothes not being distributed evenly in the tub. By redistributing the clothes, balance is achieved and the noise ceases. This same principle—balance—can be applied to furnace fans and other common sources of such noise. On some furnace blowers driven by a single belt, an unbalanced load may be applied if the blower pulley can move out of direct alignment with the motor pulley; if the load is applied symmetrically through a pair of belts driving pulleys on either side of the fan and the motor shafts, both shafts will tend to stay centered and the pulleys aligned, resulting in less noisy operation and reduced wear.

4. Reduce Frictional Resistance

Reducing friction between rotating, sliding or moving parts in mechanical systems frequently results in smoother operation and lower machine noise output. Similarly, reducing flow resistance in air, gas and liquid distribution systems results in less noise radiation. In most cases, applying any one or a combination of the following corrective measures should provide a noticeable reduction in noise output.

Reducing Resistance In Mechanical Systems

(See Fig. 4)

Lubricate: all rotating, moving, sliding, meshing or contacting parts should be lubricated with an appropriate lubricant for quiet operation.

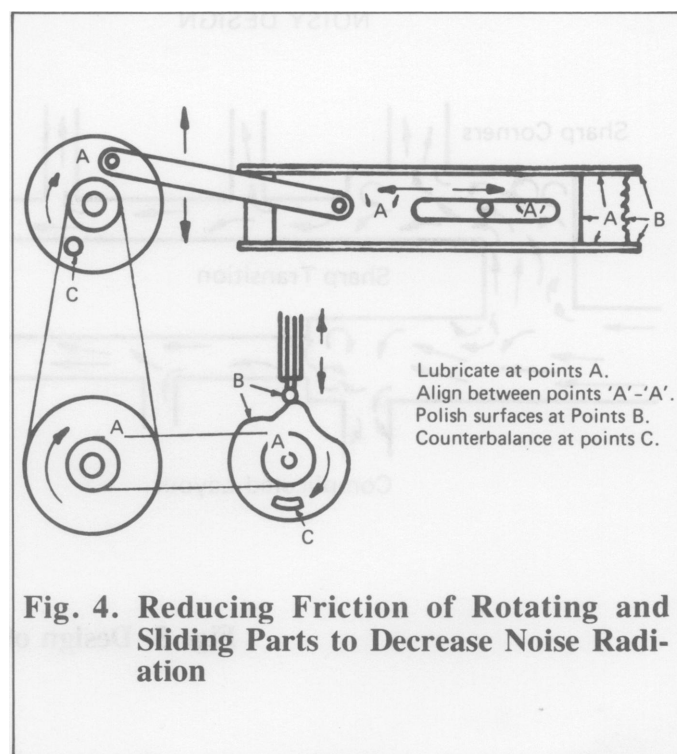
Align: Proper alignment of all rotating, moving or contacting parts results in less noise output. Maintain good axial and directional alignment in pulley sys-

tems, gear trains, shaft couplings, power transmission systems, bearing and axle alignments, etc.

Polish: Highly polished and smooth surfaces between sliding, meshing or contacting parts are required for quiet operation, particularly where bearings, gears, cams, rails, and guides, are concerned.

Balance: Static and dynamic balancing of rotating parts reduces frictional resistance and vibration, resulting in lower noise output.

Avoid eccentricity or out-of-roundness: Eccentricity or off-centering of rotating parts such as pulleys, gears, rotors, shaft/bearing alignment causes vibration and noise. Likewise, out-of-roundness of wheels, rollers, and gears causes uneven wear, resulting in flat spots which generate vibration and noise.



12 Reducing Resistance In Air or Fluid Flow Systems

(See Fig. 5)

The key advice to effective noise control in such systems is “*streamline the flow.*” This holds true regardless of whether one is concerned with air flow in ducts or vacuum cleaners, or water flow in plumbing systems. Streamline flow is simply smooth, nonturbulent, low-friction flow, but it is the essential requirement for quiet operation of any type of fluid flow system.

The two most important factors which determine whether flow will be streamline or turbulent are flow velocity and the cross-sectional area of the flow path—that is, the *pipe diameter*. The rule of thumb for quiet operation is to use a low-velocity, large-diameter pipe system to meet a specified flow capacity requirement. However, even such a system can inadvertently gener-

ate noise if certain aerodynamic design features are overlooked or ignored. A system designed for quiet operation will employ the following features:

Low flow velocities: Low flow velocities avoid turbulence, one of the main causes of noise. Flow velocities should be of the order of 8 to 10 feet per second (3 m/sec) in domestic forced-air heating and ventilation systems and plumbing systems for quiet operation.

Smooth boundary surfaces: Duct or pipe systems with smooth interior walls, edges, and joints generate less turbulence and noise than systems with rough or jagged walls or joints.

Simple layout: A well-designed duct or pipe system with a minimum of branches, turns, fittings and connectors is substantially less noisy than a complicated layout.

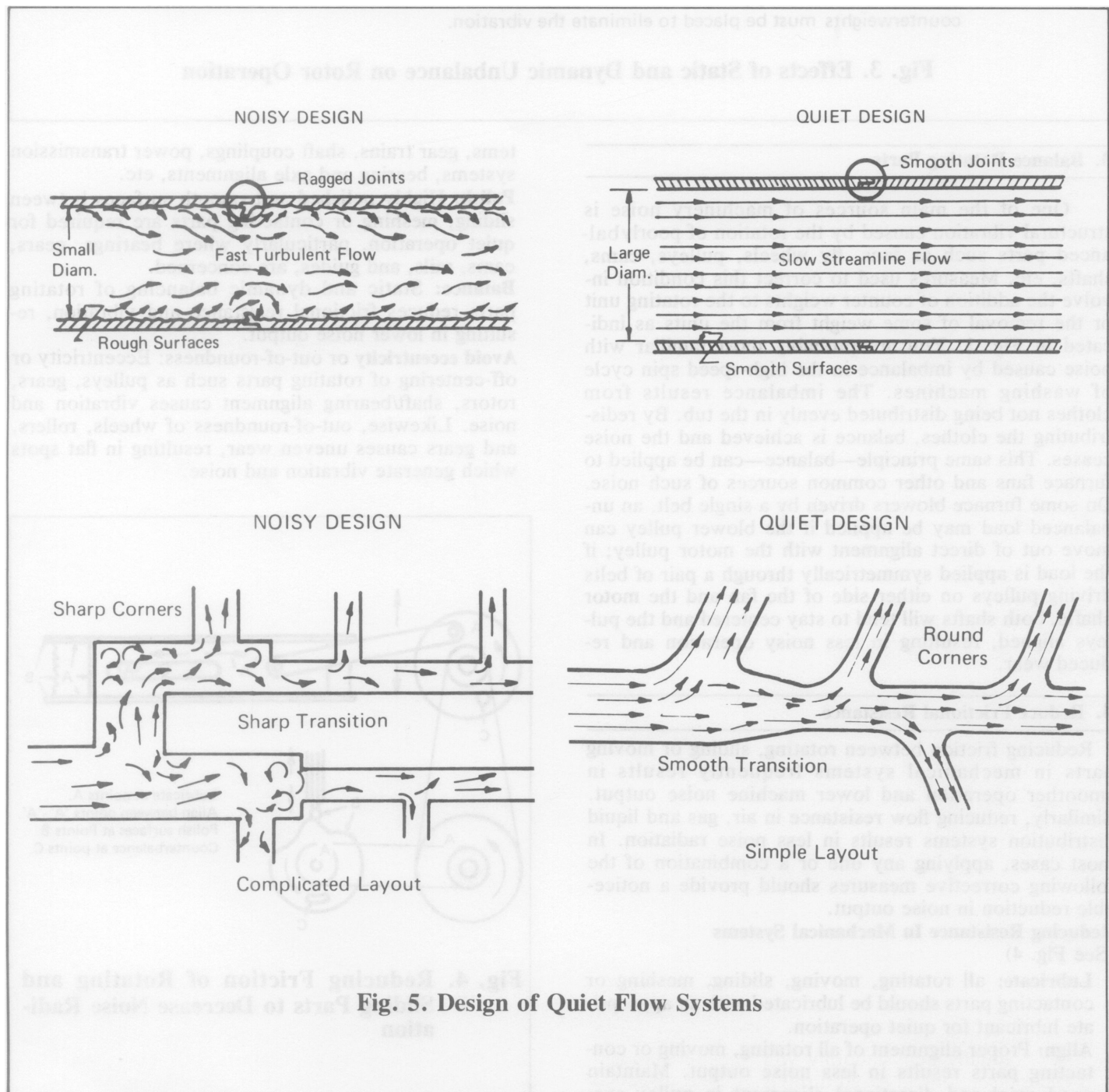


Fig. 5. Design of Quiet Flow Systems

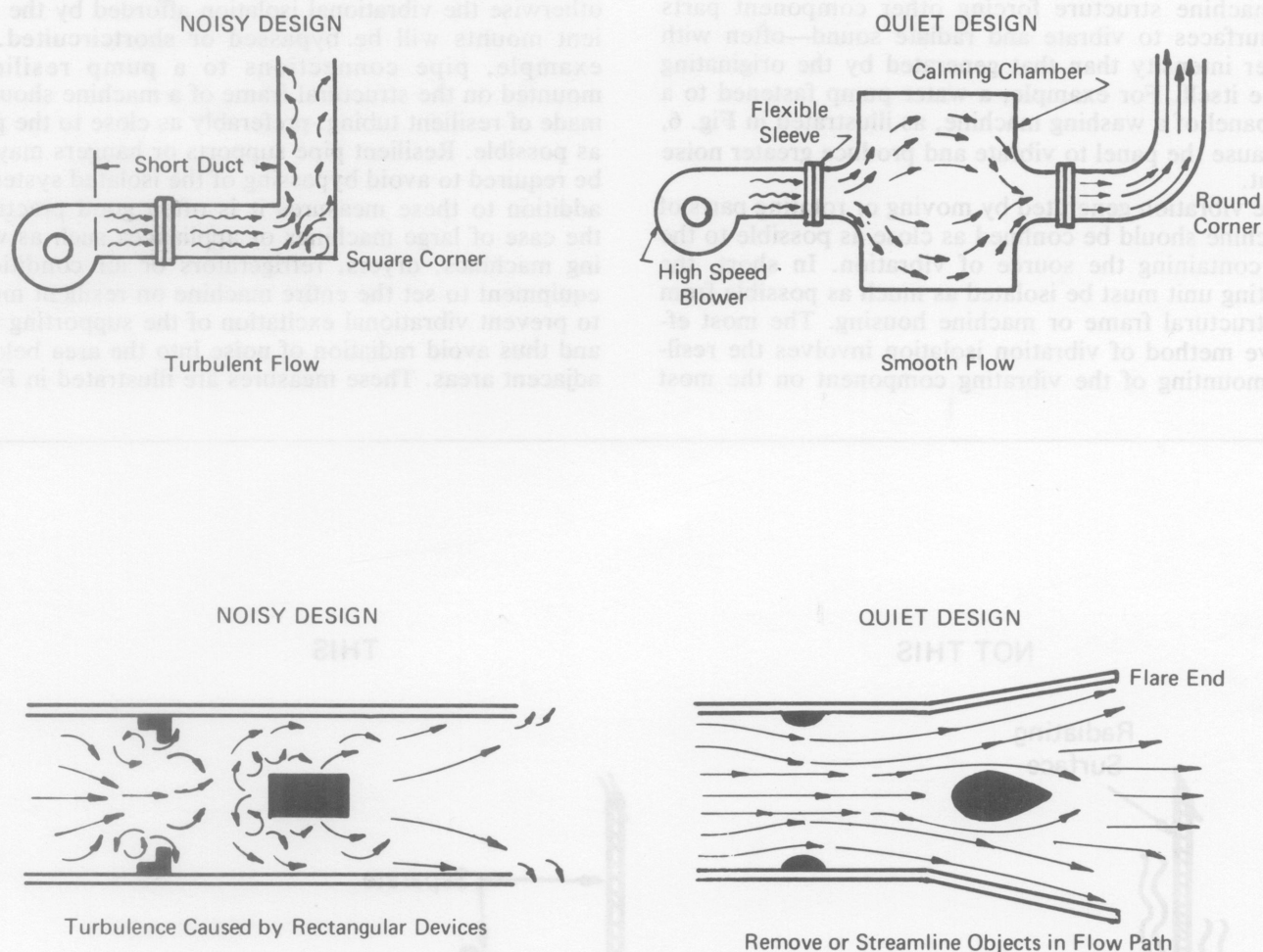


Fig. 5. Design of Quiet Flow Systems

Long-radius turns: Changes in flow direction should be made gradually and smoothly. It has been suggested that turns should be made with a curve radius equal to about five times the pipe diameter or major cross sectional dimensions of the duct.

Flared sections: Flaring of intake and exhaust openings, particularly in a duct system, tends to reduce flow velocities at these locations, often with substantial reductions in noise output.

Streamline transition in flow path: Changes in flow path dimensions or cross-sectional areas should be made gradually and smoothly with tapered or flared transition sections to avoid turbulence. A good rule of thumb is to keep the cross-sectional area of the flow

path as large and as uniform as possible throughout the system.

Remove unnecessary obstacles: The greater the number of obstacles in the flow path, the more tortuous, turbulent, and hence the noisier the flow. All other required and functional devices in the path such as structural supports, deflectors, and control dampers, should be made as small and as streamlined as possible to smooth out the flow patterns.

In other cases, parts with perforations, slots or other openings permit air leakage through or around the part as it moves, thus eliminating air pressure buildup, the chief cause of flexing and pulsation. Such action when there is no air leakage gives a popping sound—as the noise produced when squirting oil from an oil can.

5. Isolate Vibration Elements Within the Machine

In all but the simplest machines, the vibrational energy from a specific moving part is transmitted through the machine structure forcing other component parts and surfaces to vibrate and radiate sound—often with greater intensity than that generated by the originating source itself. For example, a water pump fastened to a side panel of a washing machine, as illustrated in Fig. 6, will cause the panel to vibrate and produce greater noise output.

The vibration generated by moving or rotating parts of a machine should be confined as close as possible to the area containing the source of vibration. In short, the vibrating unit must be isolated as much as possible from the structural frame or machine housing. The most effective method of vibration isolation involves the resilient mounting of the vibrating component on the most

massive and structurally rigid part of the machine. All attachments or connections to the vibrating part in the form of pipes, conduits, shaft couplers, etc., must be made with flexible or resilient connectors or couplers—otherwise the vibrational isolation afforded by the resilient mounts will be bypassed or shortcircuited. For example, pipe connections to a pump resiliently mounted on the structural frame of a machine should be made of resilient tubing, preferably as close to the pump as possible. Resilient pipe supports or hangers may also be required to avoid bypassing of the isolated system. In addition to these measures it is often good practice in the case of large machines or appliances such as washing machines, dryers, refrigerators or air conditioning equipment to set the entire machine on resilient mounts to prevent vibrational excitation of the supporting floor, and thus avoid radiation of noise into the area below or adjacent areas. These measures are illustrated in Fig. 7.

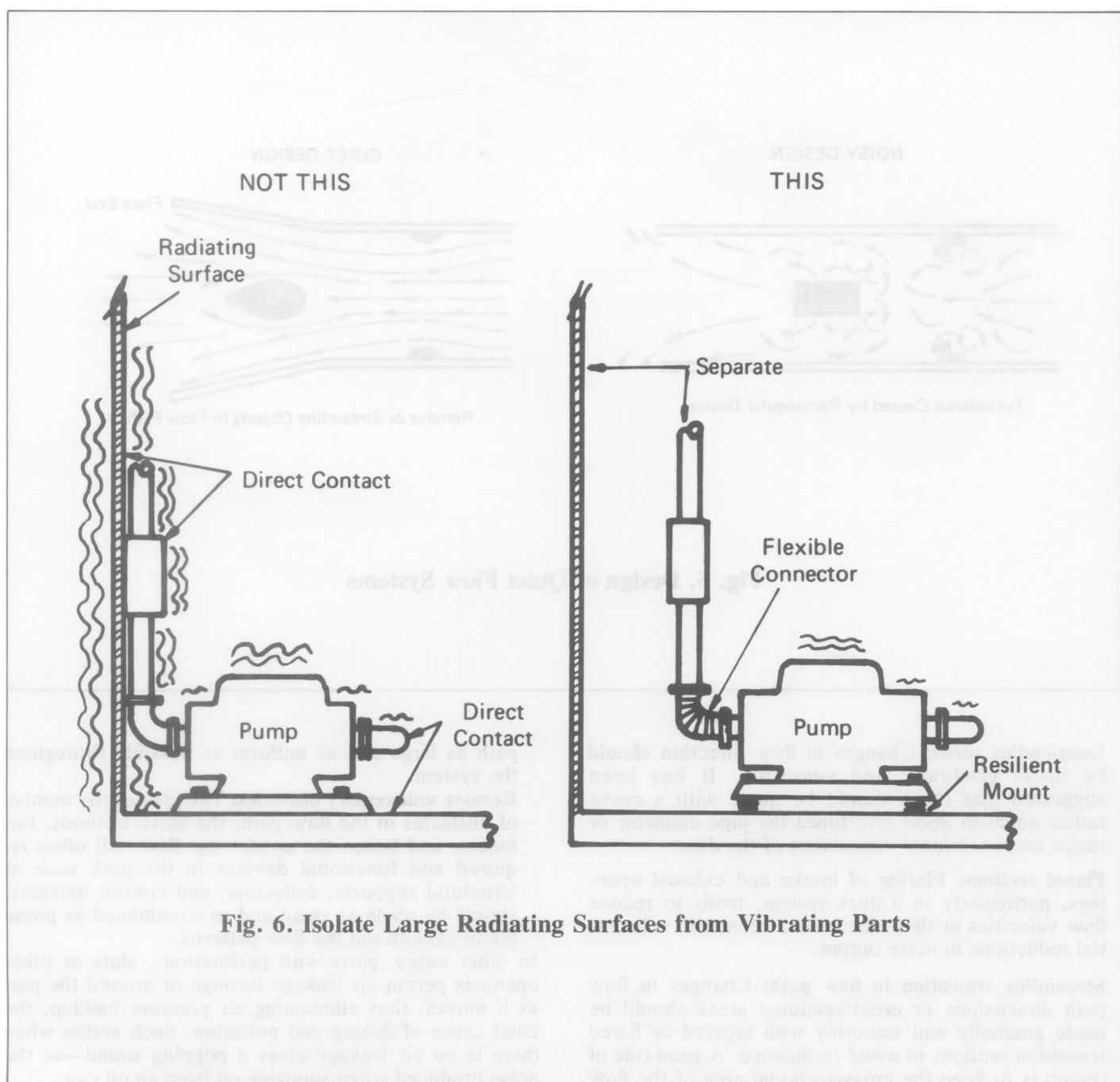
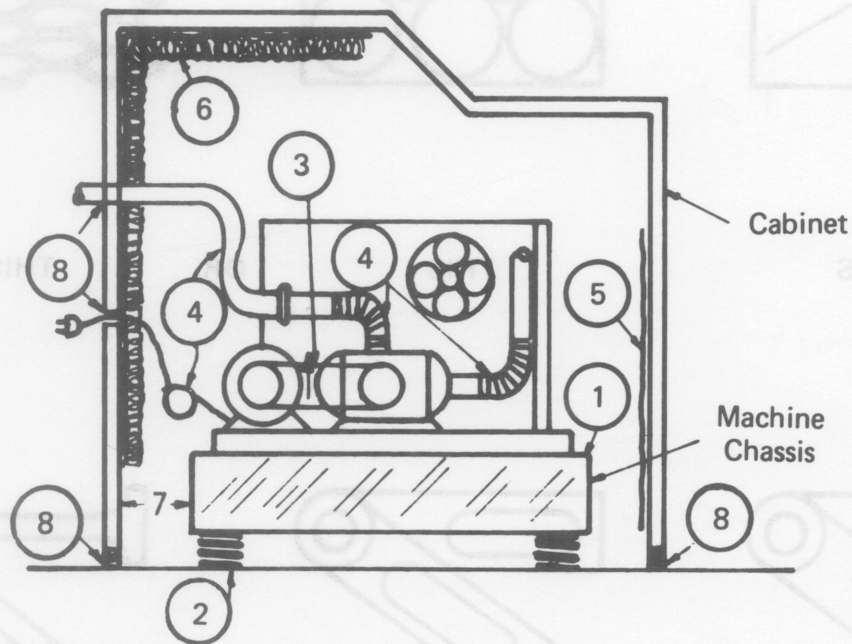


Fig. 6. Isolate Large Radiating Surfaces from Vibrating Parts



1. Install motors, pumps, fans, etc. on most massive part of the machine.
2. Install such components on resilient mounts or vibration isolators.
3. Use belt drive or roller drive systems in place of gear trains.
4. Use flexible hoses and wiring instead of rigid piping and stiff wiring.
5. Apply vibration damping materials to surfaces undergoing most vibration.
6. Install acoustical lining to reduce noise buildup inside machine.
7. Minimize mechanical contact between the cabinet and the machine chassis.
8. Seal openings at the base and other parts of the cabinet to prevent noise leakage.

Fig. 7. Techniques to Reduce the Generation of Airborne and Structure Borne Noise in Machines

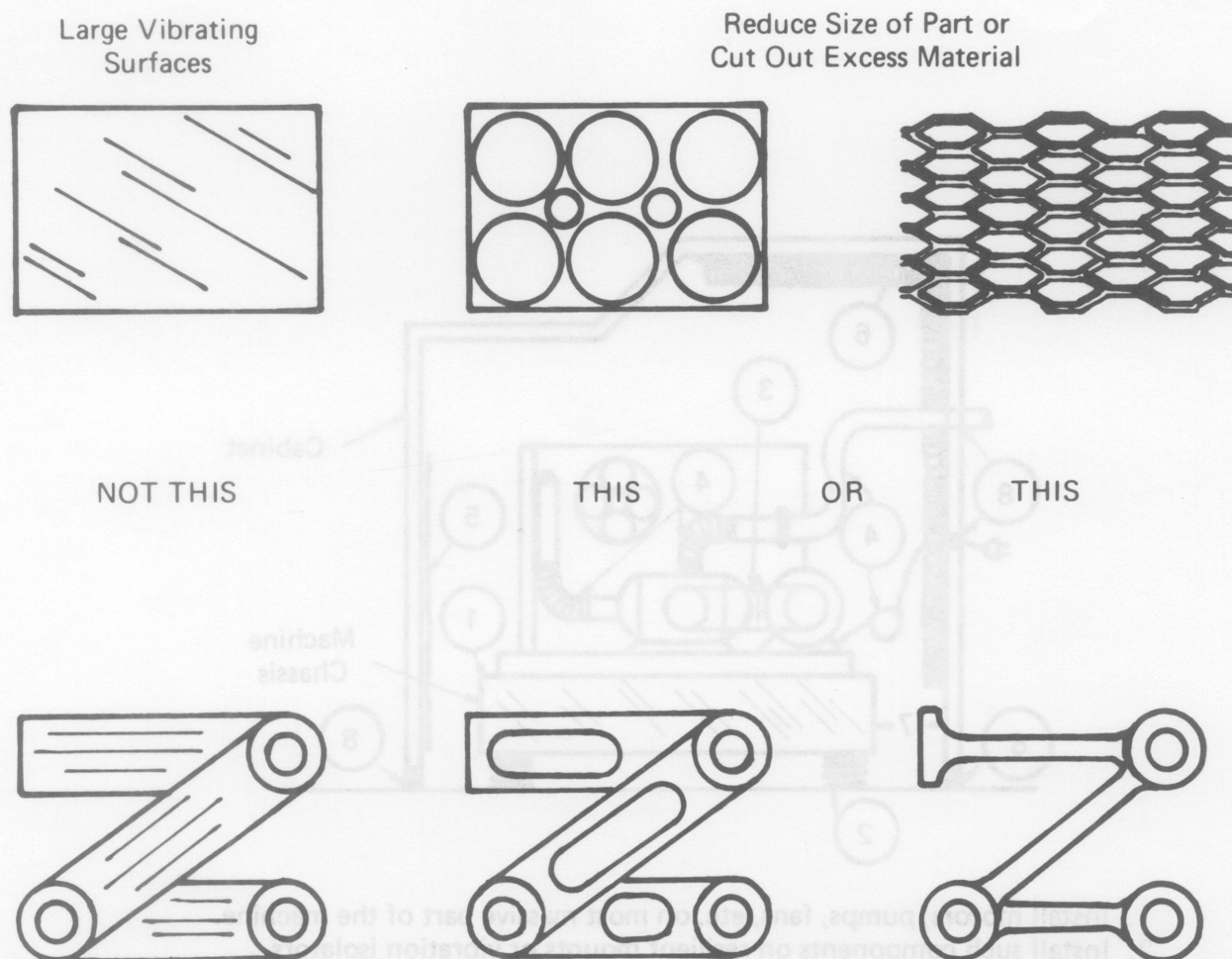


Fig. 8. Reduce the Area of Vibrating Surfaces to Lower Noise Radiation

6. Reduce Radiating Area

Generally speaking, the larger the vibrating part or surface, the greater the noise output. The rule of thumb for quiet machine design is to minimize the effective radiating surface areas of the parts without impairing their operation or structural strength. This can be done

by making parts smaller, removing excess material, or by cutting openings, slots or perforations in the parts. For example, replacing a large vibrating sheet metal safety guard on a machine with a guard made of wire mesh or metal webbing might result in a substantial reduction in noise, because of the drastic reduction in surface area of the part.

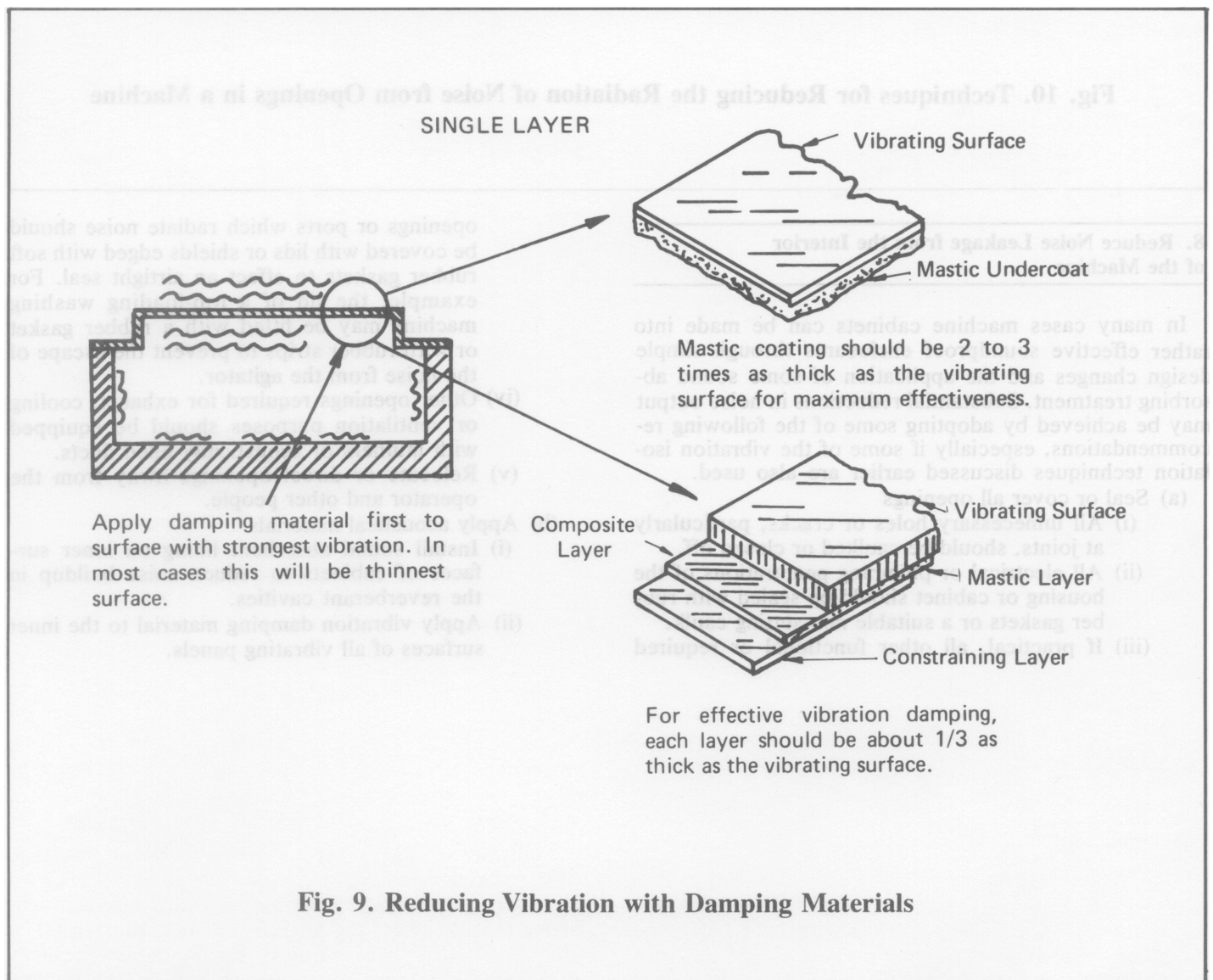
7. Apply Vibration Damping Materials

Since a vibrating body or surface radiates noise, the application of any material which reduces or restrains the vibrational motion of that body will decrease its noise output. Generally speaking, when such materials are applied to a vibrating body they dissipate the vibrational energy in the form of frictional heat which is generated by the flexing, bending and rubbing of the fibers or particles of the damping material. For example, these materials could be applied to surfaces of washing machines, dryers, refrigerators, room air conditioners, etc., to help control noise due to vibration. Of course, you would probably apply the materials to the inside surface to preserve the appearance of the appliance. Three basic types of vibration damping materials are available:

- liquid mastics which are applied with a spray gun and harden into relatively solid materials, the most common being automobile "undercoating";
- pads of rubber, felt, plastic foam, leaded vinyls, adhesive tapes or fibrous blankets which are glued to the vibrating surface;
- sheet metal viscoelastic laminates or composites which are bonded to the vibrating surface.

The type of materials best suited for a particular vibration problem depends on a number of factors such as size, mass, vibrational frequency and operational function of the vibrating structure. However the following guidelines should be observed in the selection and use of such materials to maximize vibration damping efficiency.

- Damping materials should be applied to those sections of a vibrating surface where the most flexing, bending or motion occurs. These usually are the thinnest sections.
- For a single layer of damping material, the stiffness and mass of the material should be comparable to that of the vibrating surface to which it is applied. This means that single layer damping materials should be about two or three times as thick as the vibrating surface to which they are applied.
- Sandwich materials made up of metal sheets bonded to mastic ("sheet-metal viscoelastic composites") are much more effective vibration dampers than single layer materials; the thicknesses of the sheet metal constraining layer and the viscoelastic layer should each be about one-third the thickness of the vibrating surface or panel of the appliance to which they are applied.



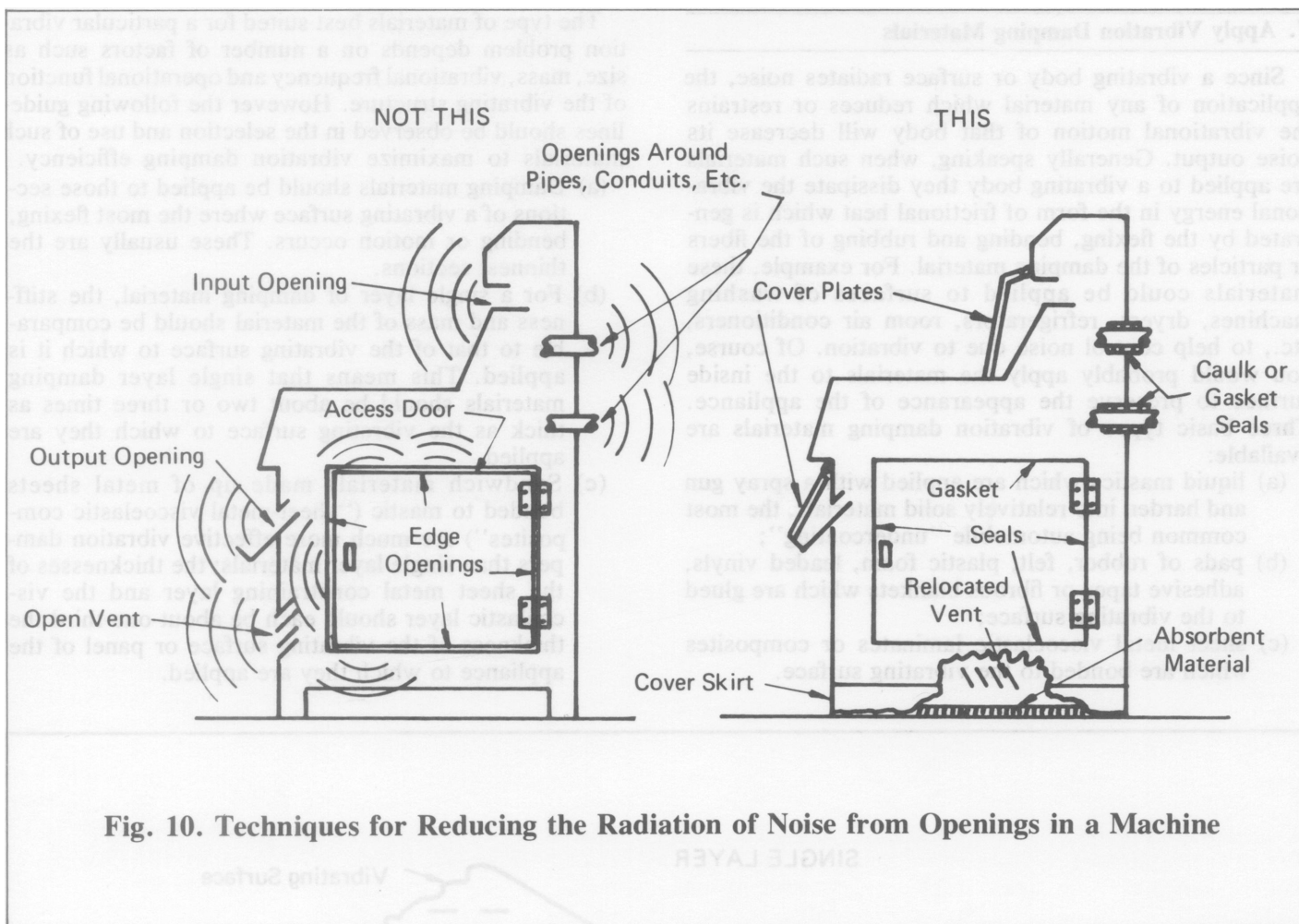


Fig. 10. Techniques for Reducing the Radiation of Noise from Openings in a Machine

8. Reduce Noise Leakage from the Interior of the Machine

In many cases machine cabinets can be made into rather effective soundproof enclosures through simple design changes and the application of some sound absorbing treatment. Substantial reductions in noise output may be achieved by adopting some of the following recommendations, especially if some of the vibration isolation techniques discussed earlier are also used.

(a) Seal or cover all openings

- (i) All unnecessary holes or cracks, particularly at joints, should be caulked or closed off.
- (ii) All electrical or plumbing penetrations of the housing or cabinet should be sealed with rubber gaskets or a suitable non-setting caulk.
- (iii) If practical, all other functional or required

openings or ports which radiate noise should be covered with lids or shields edged with soft rubber gaskets to effect an airtight seal. For example, the lid of a top-loading washing machine may be fitted with a rubber gasket or with rubber strips to prevent the escape of the noise from the agitator.

- (iv) Other openings required for exhaust, cooling or ventilation purposes should be equipped with mufflers or acoustically lined ducts.
- (v) Relocate or direct openings away from the operator and other people.

(b) Apply acoustical materials

- (i) Install sound absorbent lining on inner surfaces of cabinets to reduce noise buildup in the reverberant cavities.
- (ii) Apply vibration damping material to the inner surfaces of all vibrating panels.

After you have tried all possible ways of controlling the noise at the source, your next line of defense is to set up barriers or other devices in the transmission path to block or reduce the flow of sound energy before it reaches your ears. This can be done in several ways:

- you can absorb the sound along the path,
- you can deflect the sound in some other direction away from you by placing a reflecting barrier in its path, and
- you can contain the sound by placing the source inside a sound-insulating box or enclosure.

Selection of the most effective technique will depend upon various factors such as the size and type of source, intensity and frequency range of the noise, and the nature and type of environment. In addition one should have a basic understanding of the characteristics and behavior of sound that influence its propagation or travel through the air.

1. Separate the Noise Source and Receiver As Much As Possible.

Increasing your distance from a source of noise is a practical means of noise abatement, if you can manage it.

Indoors, the noise level generally drops from 3 to 5 dB for each doubling of distance in the near vicinity of the source. However, further from the source, reductions of only 1 or 2 dB occur for each doubling of distance, due

to the reflections of sound off hard wall and ceiling surfaces.

2. Use Sound Absorbing Materials.

Sound absorbing materials on ceiling, floor or wall surfaces can reduce the noise level in most rooms by about 5 to 10 dB for high-pitched sounds, but only by 2 or 3 dB for low-pitched sounds. Unfortunately, such treatment provides no protection to an operator of a noisy machine who is in the midst of the direct noise field. For greatest effectiveness, sound absorbing materials should be installed as close to the noise source as possible.

3. Use Sound Barriers and Deflectors.

Placing barriers, screens, or deflectors in the noise path can be an effective way of reducing noise transmission, providing that the barriers are large enough in size, and depending upon whether the noise is high-pitched or low-pitched. Wood or metal panels lined with acoustical materials and placed in front of or around some noisy machine might attenuate the noise reaching a worker on the other side by about 10 to 15 dB if the noise is high-pitched. For example, in a room relatively free of echoes, the noise from a card-punch machine, which has a fundamental frequency of about 3000 Hz, can be reduced in the shadow of a barrier which measures about 5 feet (1.5 m) on a side by at least 10 dB. Low-pitched noise, however, might be reduced by only 4 or 5 dB. (See Fig. 11.)

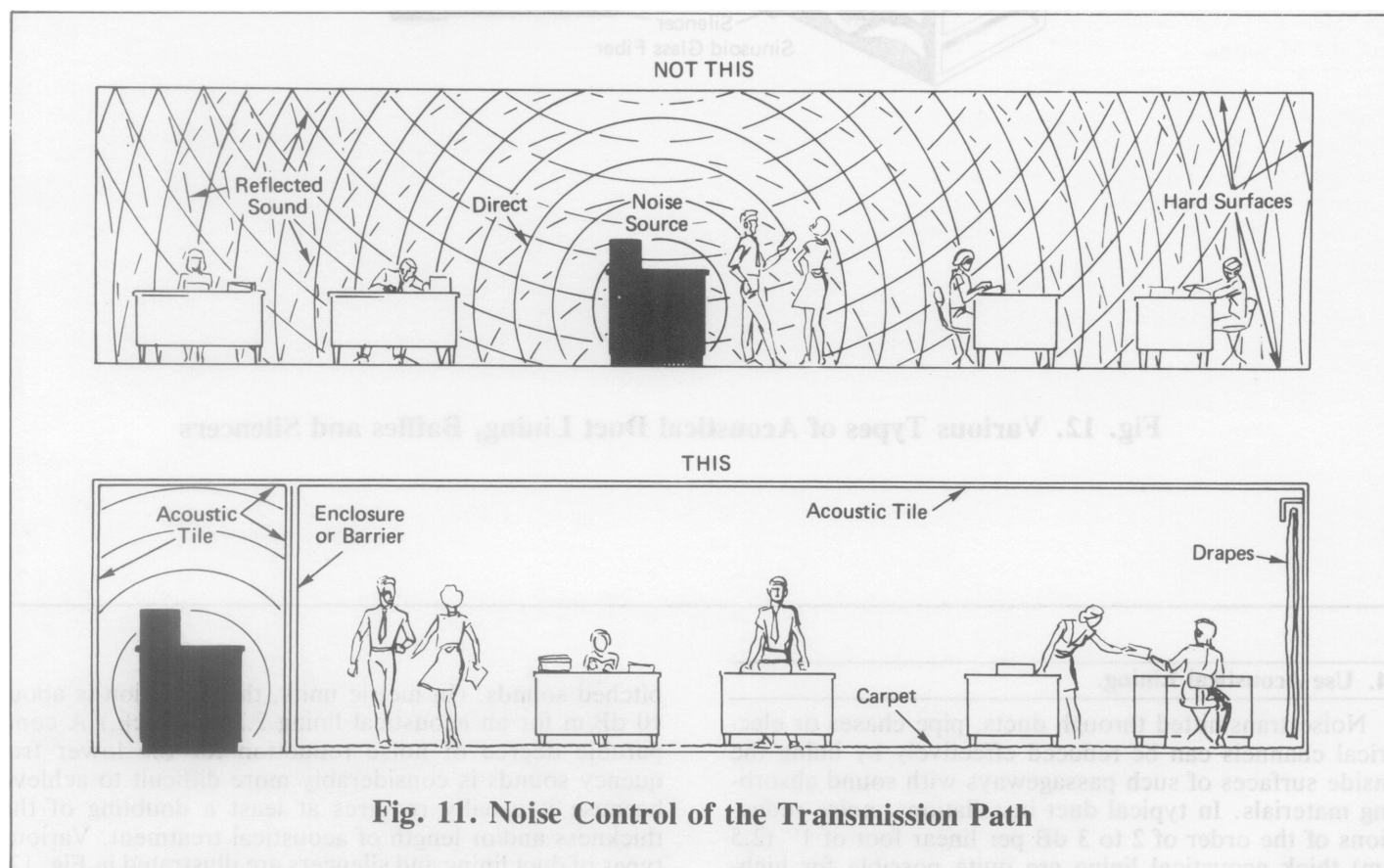


Fig. 11. Noise Control of the Transmission Path

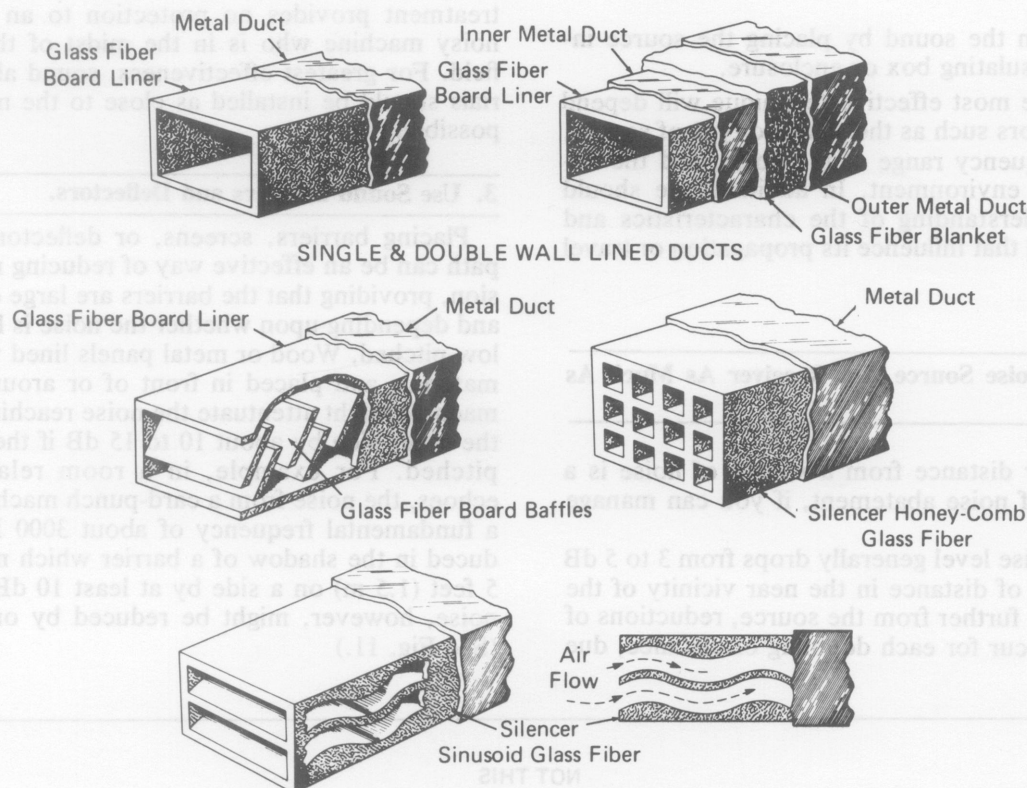


Fig. 12. Various Types of Acoustical Duct Lining, Baffles and Silencers

4. Use Acoustical Lining.

Noise transmitted through ducts, pipe chases or electrical channels can be reduced effectively by lining the inside surfaces of such passageways with sound absorbing materials. In typical duct installations, noise reductions of the order of 2 to 3 dB per linear foot of 1" (2.5 cm) thick acoustical lining are quite possible for high-

pitched sounds. (In metric units, the reduction is about 10 dB/m for an acoustical lining 2.5 cm thick.) A comparable degree of noise reduction for the lower frequency sounds is considerably more difficult to achieve because it usually requires at least a doubling of the thickness and/or length of acoustical treatment. Various types of duct lining and silencers are illustrated in Fig. 12.

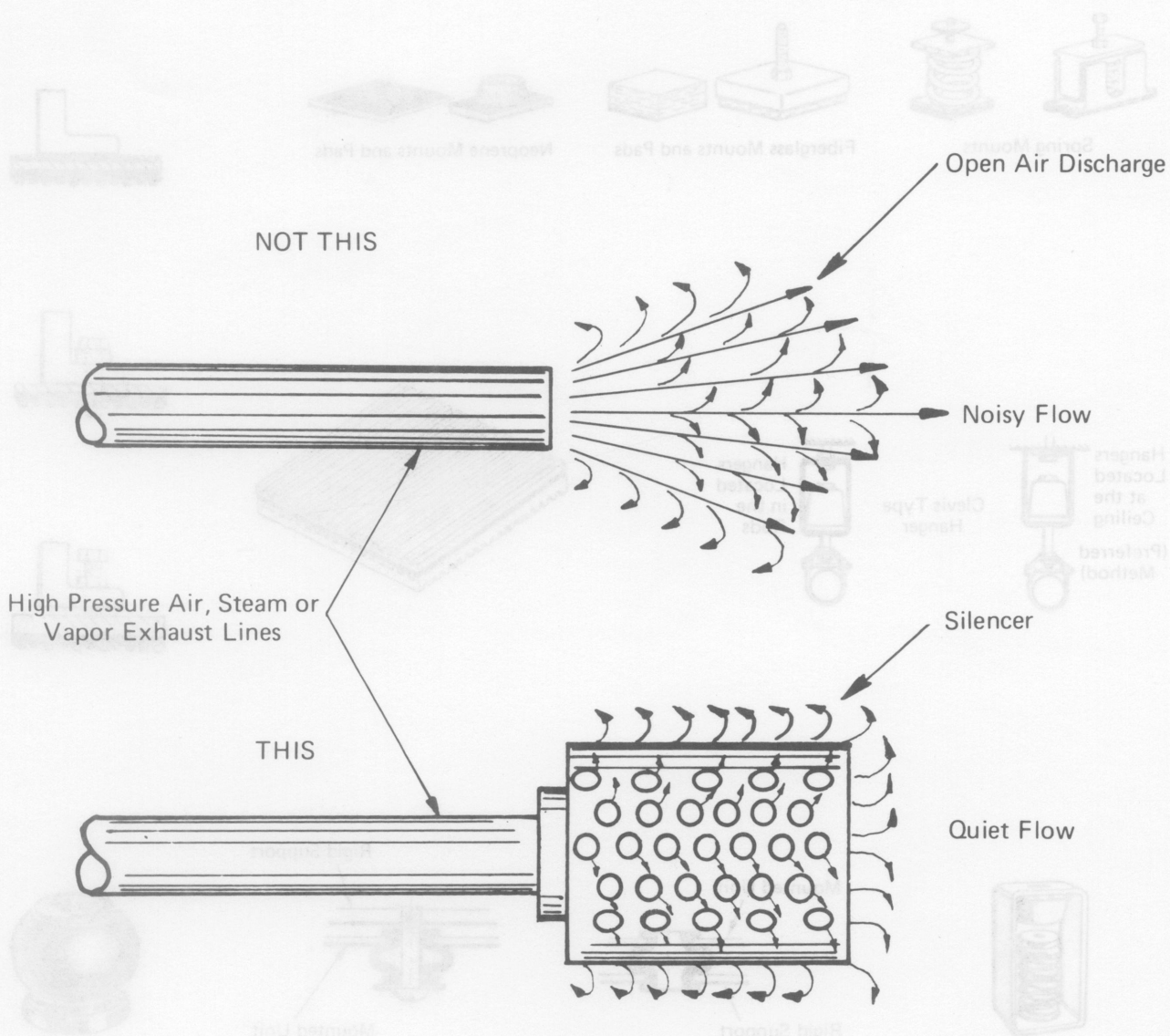


Fig. 13. Silencer for High Pressure Exhaust Line

5. Use Mufflers, Silencers, or Snubbers.

Mufflers or silencers should be installed on all gasoline or diesel engines, regardless of size, including those used in model airplanes, toys, power tools, etc.

Such devices should also be used in all installations in which large quantities of high-pressure, high-velocity gasses, liquids, steam or air discharged into the open air as illustrated in Fig. 13.

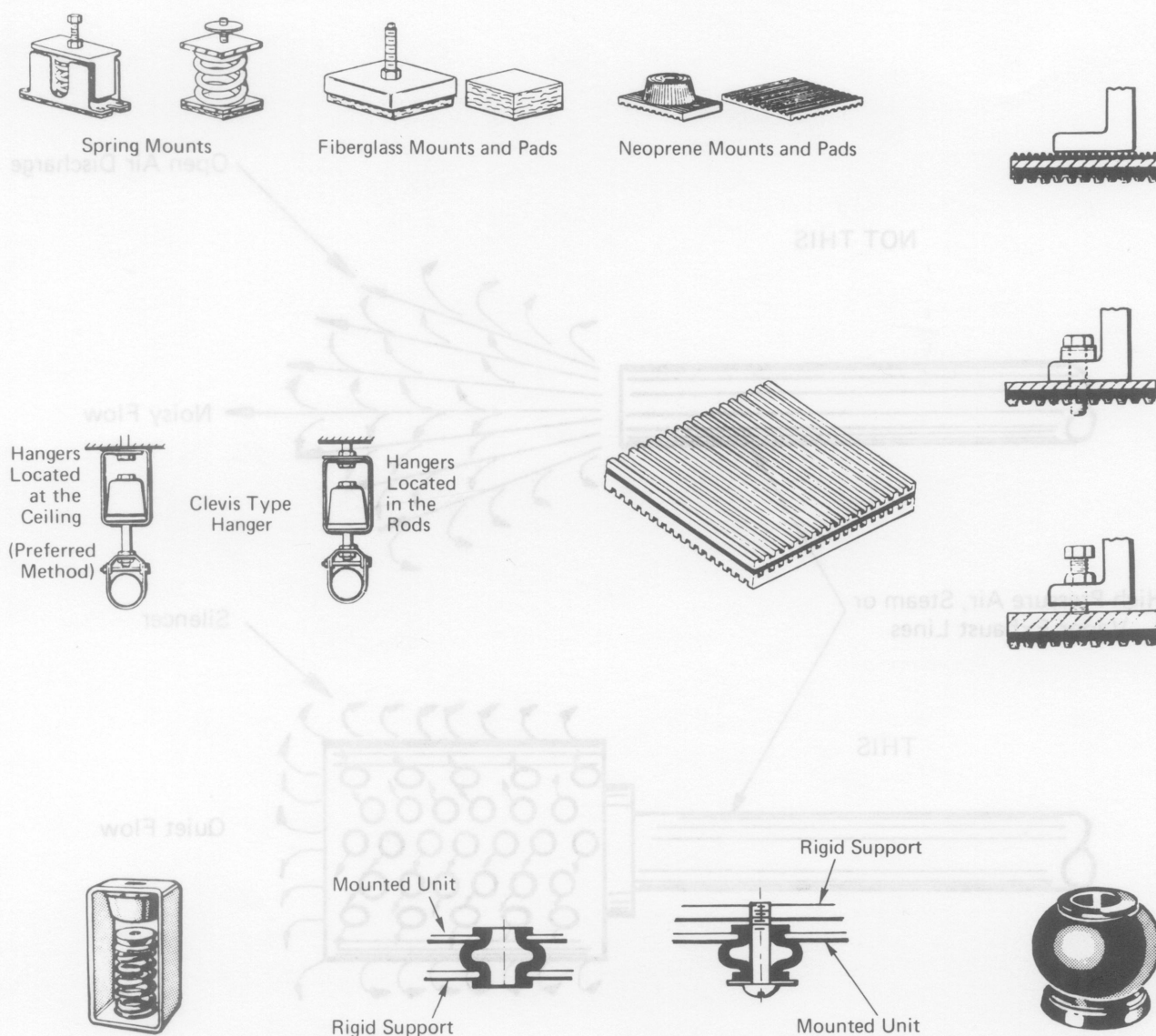


Fig. 14. Various Types of Vibration Isolators

6. Use Vibration Isolators and Flexible Couplers.

In cases where the noise transmission path is structure-borne in character, vibration isolators in the form of resilient mountings, flexible couplers, or structural breaks or discontinuities should be interposed between the

noise source and receiver. For example, spring mounts placed under an appliance or machine may prevent the floor from vibrating; or an expansion joint cut along the outer edges of a floor in a mechanical equipment room may reduce the amount of vibration transmitted to the structural frame or walls of a building. Such measures are illustrated in Figs. 14 and 15.

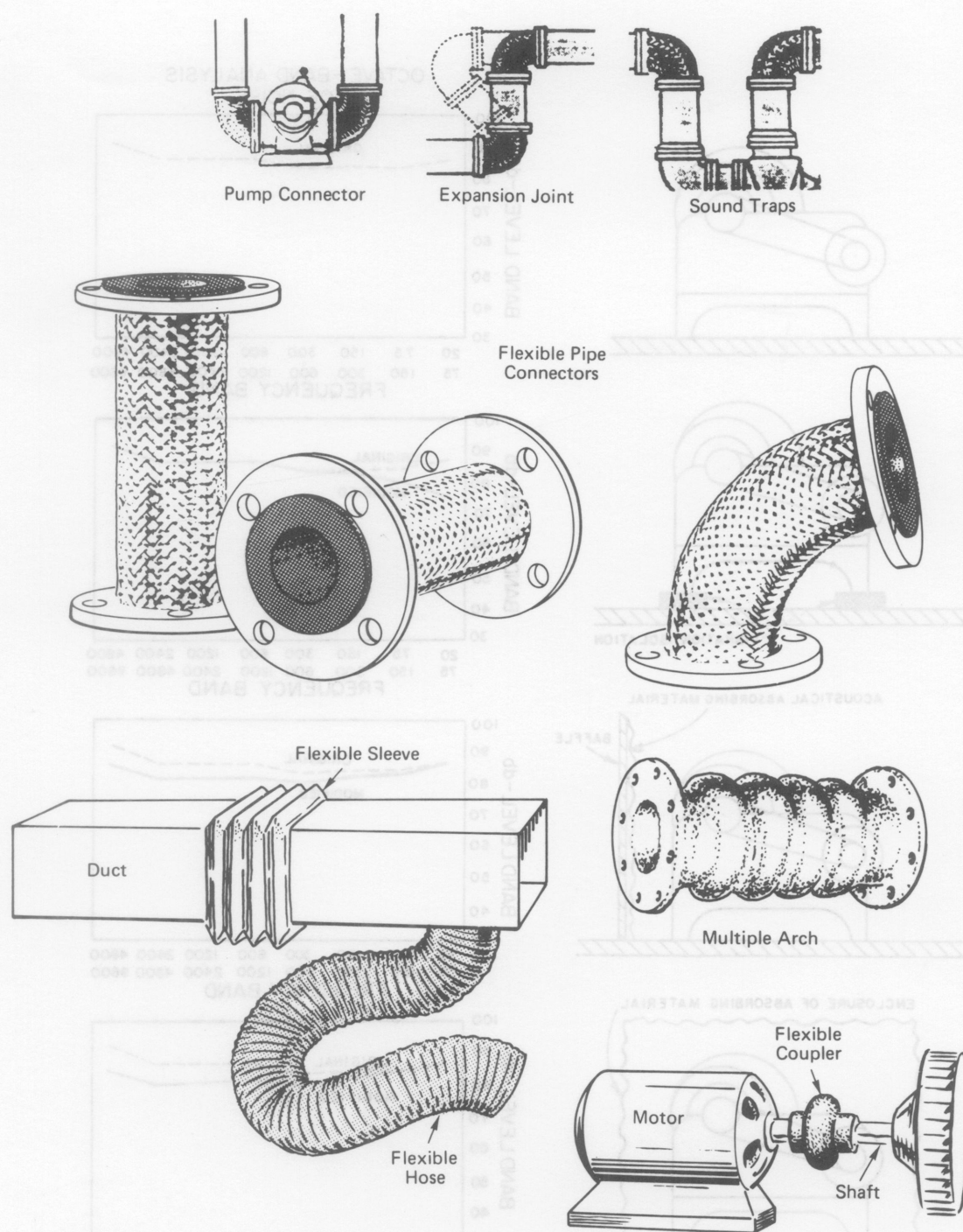


Fig. 15. Various Types of Flexible Connectors

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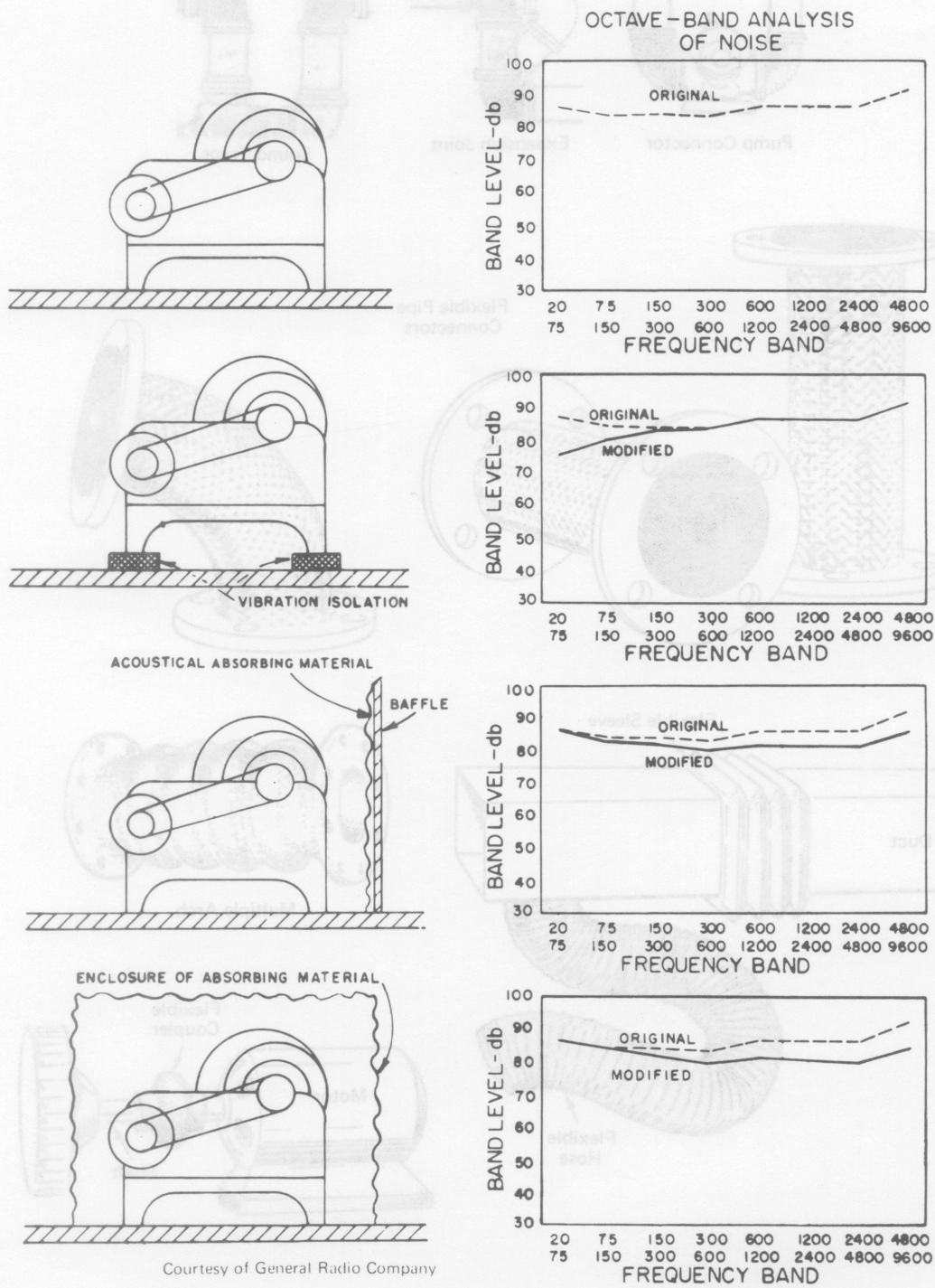


Fig. 16. Effectiveness of Various Noise Reduction Techniques

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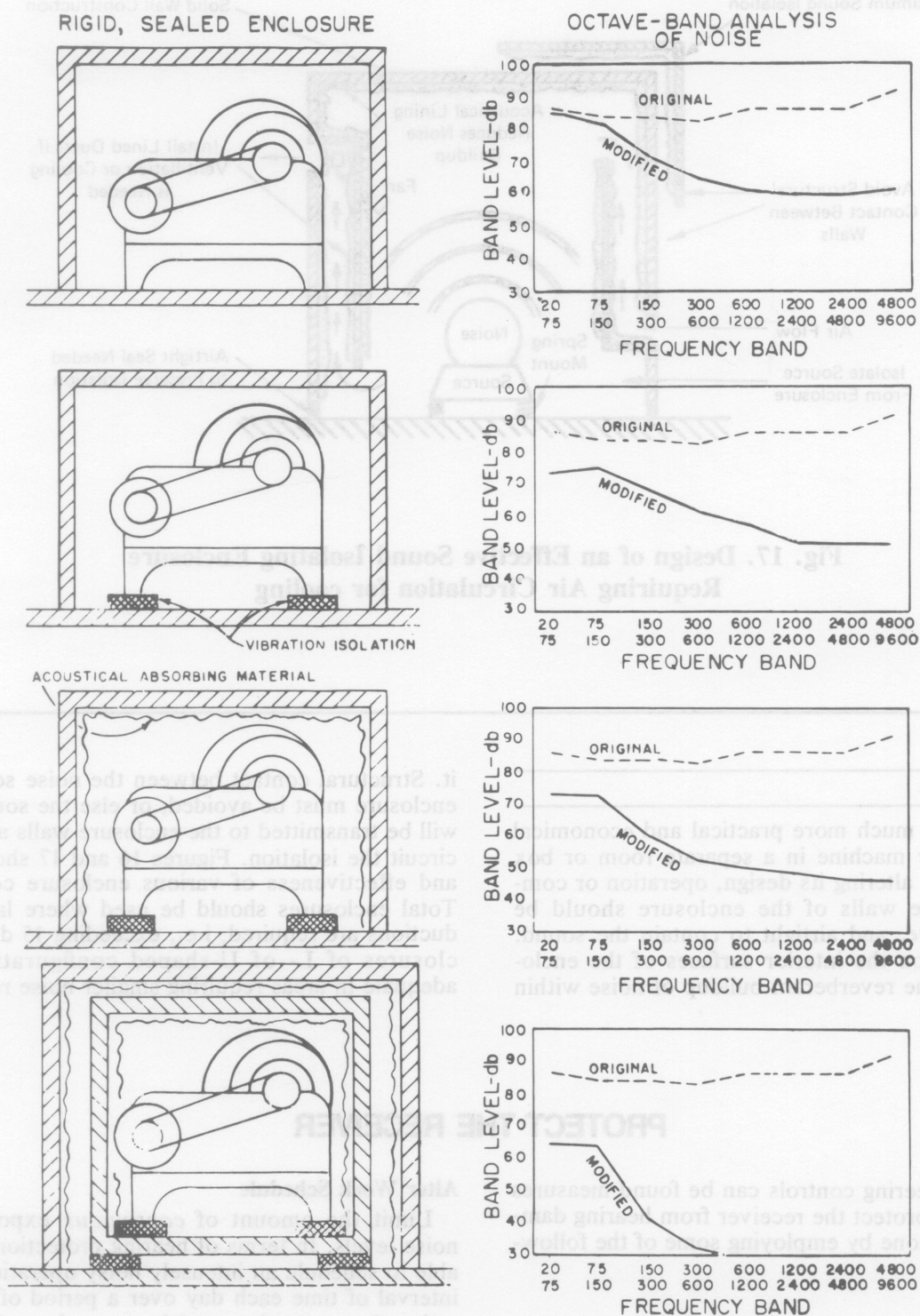


Fig. 16. Effectiveness of Various Noise Reduction Techniques

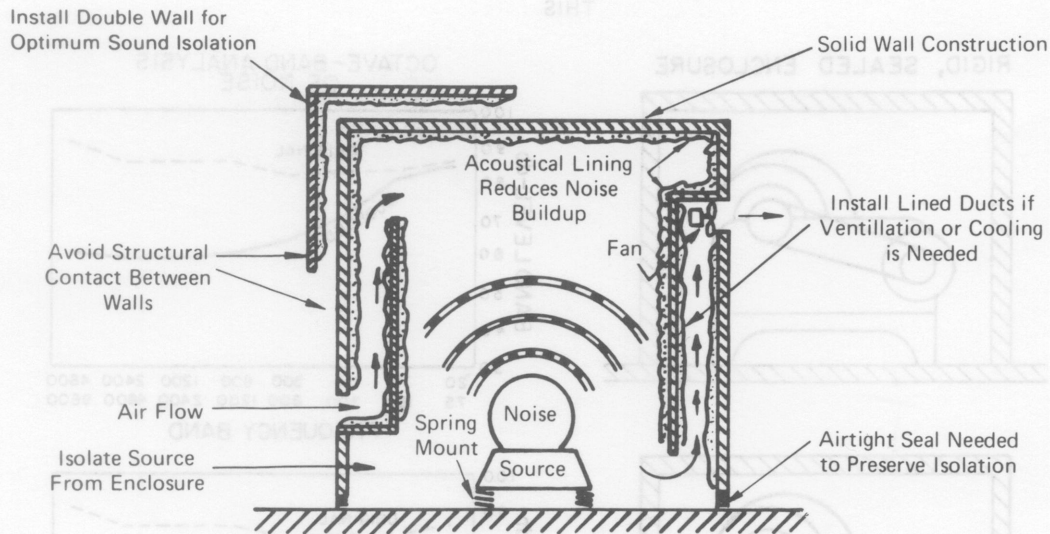


Fig. 17. Design of an Effective Sound Isolating Enclosure Requiring Air Circulation for cooling

7. Use Enclosures.

Sometimes it is much more practical and economical to enclose a noisy machine in a separate room or box than to quiet it by altering its design, operation or component parts. The walls of the enclosure should be reasonably massive, and airtight to contain the sound. Absorbent lining on the interior surfaces of the enclosure will reduce the reverberant buildup of noise within

it. Structural contact between the noise source and the enclosure must be avoided, or else the source vibration will be transmitted to the enclosure walls and thus short circuit the isolation. Figures 16 and 17 show the design and effectiveness of various enclosure configurations. Total enclosures should be used where large noise reductions are required, i.e., exceeding 15 dB. Partial enclosures of L- or U-shaped configurations may be adequate in areas requiring smaller noise reductions.

PROTECT THE RECEIVER

When no engineering controls can be found measures must be taken to protect the receiver from hearing damage. This can be done by employing some of the following techniques.

Use Ear Protectors

Molded and pliable earplugs, cup type protectors, and helmets are commercially available as hearing protectors. Such devices may provide noise reductions ranging from 15 to 35 dB. However, such devices should be used only as a last resort, after all other methods have failed to lower the noise level to acceptable limits.

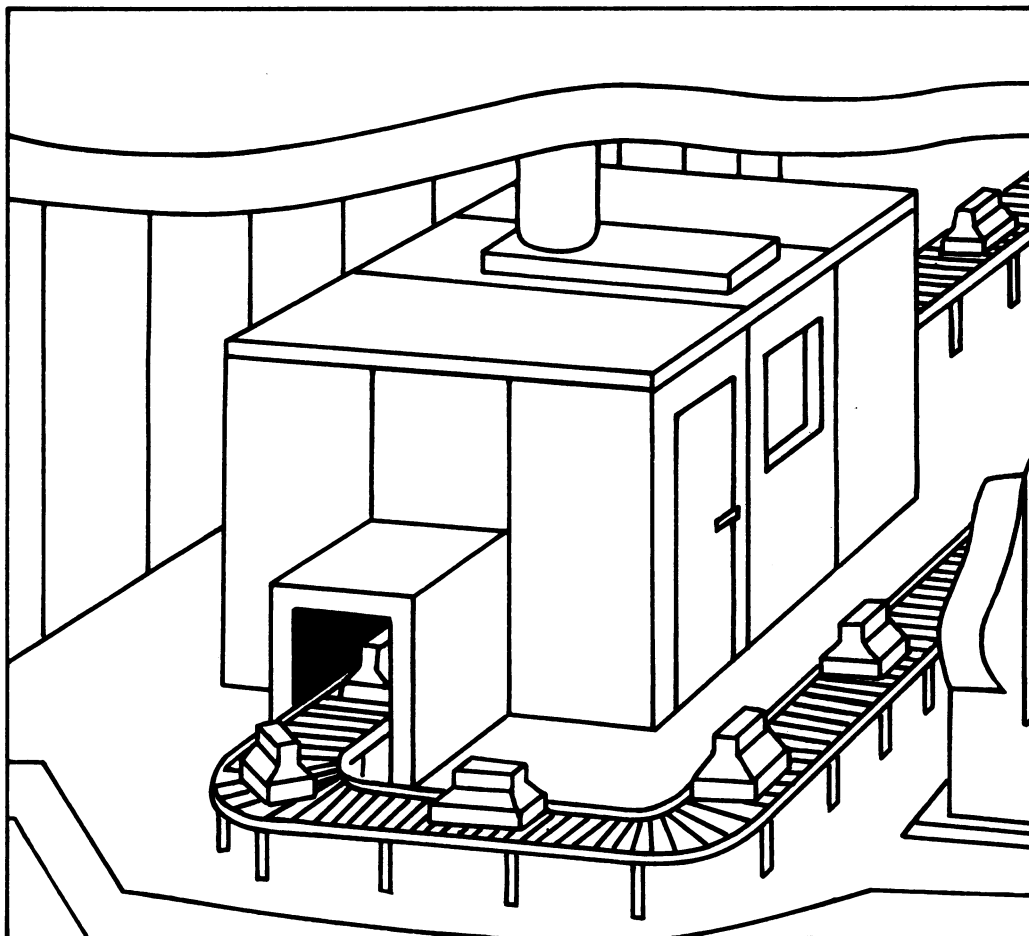
Alter Work Schedule

Limit the amount of *continuous* exposure to high noise levels. In terms of hearing protection, it is preferable to schedule an intensely noisy operation for a short interval of time each day over a period of several days rather than a continuous 8-hour run for a day or two.

In an industrial plant employing a large number of people, an intermittent work schedule would benefit not only the operator of the noisy equipment but also other workers in the vicinity. Indeed, this practice would be even more beneficial if the noisy work were performed at night or at some other time when a minimum number of employees would be exposed. This assumes, of course, that noise created at night would be confined to the plant area and thus not disturb residential areas.

Section III

Design Principles of Noise Control



Enclosures around shakeouts in foundries have reduced noise from about 100 decibels to about 86 decibels. The enclosures were constructed from four inch thick panels consisting of sound-deadening material inside steel linings. The doors for the enclosures were made of the same panels. Double observation windows were also installed. Moreover, the enclosures served to control dust and other air pollutants from the shakeout.

Edited from
The Industrial Noise Control Manual

by
National Institute of Occupational Safety and Health (NIOSH)
U.S. Department of Health, Education and Welfare
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June 1975

and
The Technical Feasibility of Noise Control in Industry
by

U.S. Department of Labor
Occupational Safety and Health Administration
August 1976

A. Modifying the Equipment: Noise "Source" Control

A full knowledge of the operation or process is needed to answer the basic questions: Can the machine or operation be eliminated or replaced by a quieter operation with equal or better efficiency (weld or rivet, etc.)? Can the present noisy machine be replaced economically by newer equipment designed with lower noise levels (perhaps as well for increased production)? Can the specific noise source be corrected by minor design changes (avoiding metal-to-metal contact by use of plastic bumpers, replacing noisy drives by quieter types, use of improved gears, improved maintenance, etc.)?

Can the specific machine elements causing noise be corrected by a local source approach rather than consid-

ering the entire machine as a noise source? (Later data covering the specific designs for barriers, enclosures, damping vibrations, vibration isolation, lagging or vibrating surfaces, mufflers and silencers for air and gas flows, reduced air velocities of free jets, etc., may be considered for the individual noise producing elements of the total operation.) Can the noisy machine elements be moved (such as pumps, fans, air compressors that service the basic machine but need not be an integral part)? Can the machine parts be vibration isolated to reduce airborne noise from vibrating panels or guards?

Quiet components are available to replace the noise-generating parts of certain machines. The equipment or components may need some engineering design and analysis to ensure that the machines are compatible with the manufacturing process. However, in many instances, off-the-shelf replacement items can be purchased for direct application.

1. Distance or Relocation

Can a noise source be moved further away from the operator? Distance reduces noise level from a point source by 6 dB per each doubling of distance in a free field. In a closed space such as a factory work room, reverberant sound will eventually determine when no further reduction by distance may be obtained. The distance at which this occurs is called the critical distance. Relocation may apply to machine service units such as pumps, fans, drives, hydraulic systems, and air and steam flows that may be relatively easily moved and do not need constant attention.

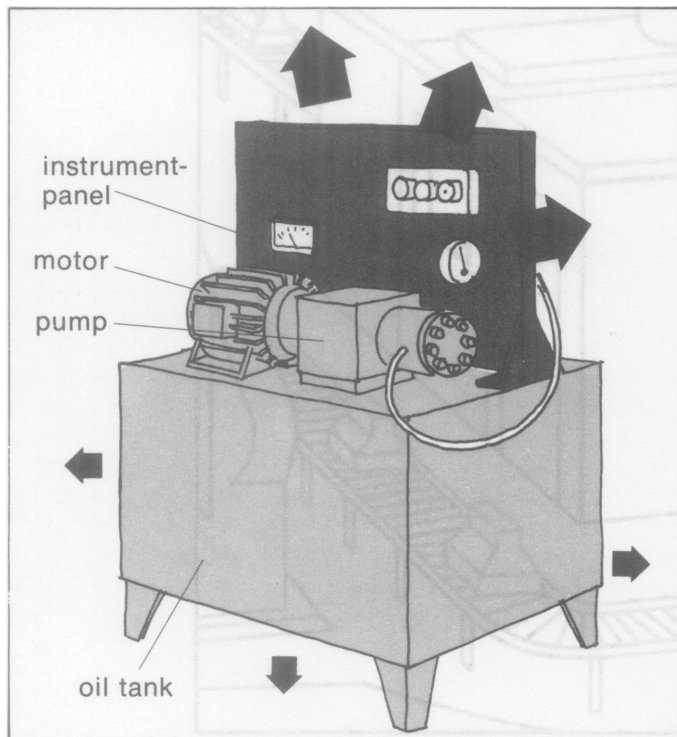
2. Vibration Isolation

Vibration isolation ensures that solid structures and large surfaces such as walls, cover plates, and machine enclosures cannot be excited to serve as large and effective sound radiators. The vibration isolator prevents vibratory energy from being fed into such a radiator by reflecting it back to the source.

Vibration isolation requires a resilient connector (such as a spring) that allows a lot of vibratory motion at one end without transmitting it to the other. Generally, the isolators are extremely effective at preventing the transmission of high-frequency vibration, while allowing the passage of low-frequency vibration. The precise frequency ranges of isolator effectiveness are specific to individual instances and depend on the stiffness of the isolator and on the masses and stiffnesses of the items to which it is connected. Often, a combination of isolators may be needed to isolate vibration over a broad range of frequencies. In any event, *all* solid ties between the isolated source and the neighboring path must be eliminated. A single solid connection can "short-circuit" the system.

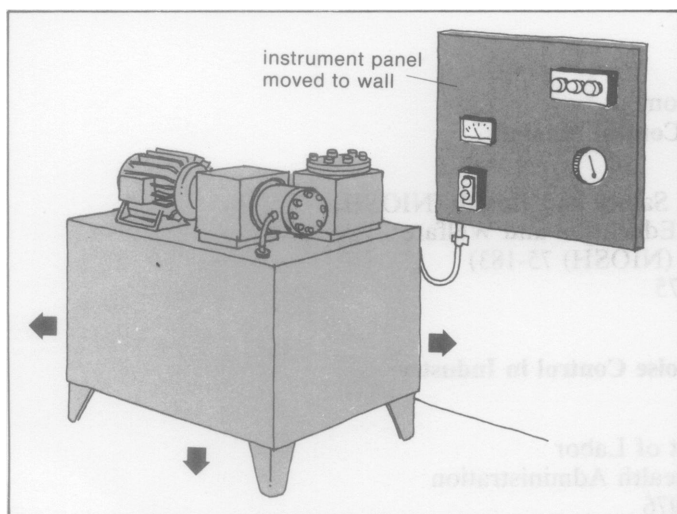
Vibration isolators are commercially available. They are selected by specifying the weight supported, the deflection required, and the lowest vibratory frequency of the unit to be isolated. They are made from elastomers (rubber in compression and shear, ribbed rubber); other compressible materials (cork);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

The practical problems of vibration isolation involve the motion of the isolated items and the requirement for



Vibrating surfaces should be made as small as possible or even removed from the actual noise source. For example, the above picture shows a hydraulic pump with an instrument panel. Although the source of the vibrations was the pump, the vibrating panel actually made the most noise.

By removing the instrument panel, as show below, the noise was reduced significantly.



suitable flexible inserts in all the connections across the isolator. A low-frequency isolator requires the selection of a very "soft" spring system, and this can result in excessive motion. In addition, the motion can produce alignment problems where several machines are connected by a single or multiple line of shafts. However, the use here of a single base plate, which itself is vibration isolated, can solve this problem.

Flexible service connectors, for all except high pressure hoses, can be simply designed by ensuring sufficient length to accommodate the movement and the inclusion of two right-angle bends in adjacent orthogonal planes (at right angles to each other).

Because of these problems, the isolation requirements of large machinery often must be undertaken by specialists. However, the isolation of common systems, such as pipe runs, calls for no major design process, as most isolators are specified by their manufacturers in terms of supported weight and frequency range of isolation. Finally, it is essential to ensure that maintenance procedures include a check on the effectiveness of the isolation to ensure that no "short circuits" have occurred.

3. Damping

Damping is the reduction of vibration and resultant noise by adding a layer or layers of vibration-absorbing material to either side of the vibrating surface. For example, metal parts striking a sheet metal pan cause noise that can be damped with a wide variety of materials including roofing paper, sheet lead, damping compounds, special tapes, acoustic lagging, and other commercially available materials to fit the problem.

4. Lagging

Lagging of pipes, ducts, and other radiating surfaces requires the application of a double-layer construction, consisting of a resilient inner layer (for example, 1 to 4 inches of glass fiber material) and an airtight heavy outer layer. In many cases lagging can be combined with or replace the thermal insulation on a pipe and, as such, presents no installation or maintenance problem. The outer coating of sheet aluminum or mild steel can often be retained, as long as this outer layer is isolated everywhere from the inner vibrating structure. This separation is essential since the wrapping effectively provides an outer nonvibrating surface, separated by an absorbent material to dissipate sound energy produced by the pipe. An acoustic "short-circuit," such as at a valve, where the outer jacket touches the pipe work, can allow the vibration to be transmitted directly and, hence, sound to be radiated.

Acoustic lagging requirements can be specified as part of the normal design supply and procurement process.

Some typical constructions and attenuations are given below (in dB):

	500 Hz	1000 Hz	2000 Hz
1-in. Molded fiberglass and aluminum foil covering	1.5	4.8	13.8
1-in. Molded fiberglass and lead impregnated vinyl	5.0	12.0	24.0
2-in. Molded fiberglass and lead impregnated vinyl	4.5	13.5	26.0

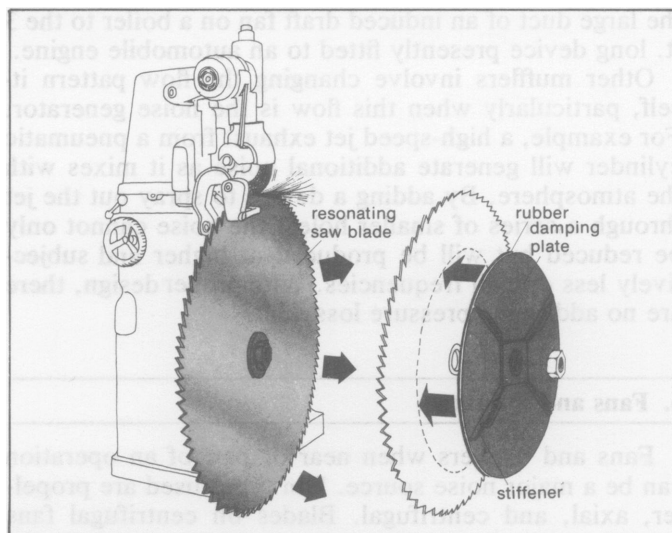
5. Mufflers (or Silencers) for Air and Gas noise

Mufflers are used to reduce noise associated with air or gas flow, such as at the intake of exhaust of engines, or at the inlet and outlet of fans, or the noise generated by a high velocity air or stream jet. Mufflers are also used in passageways to control the escape of noise in paths that must carry materials or personnel. A piece of acoustically lined duct may serve as a simple muffler through which punch press punchings may pass, while reducing noise escaping from the impacting region of the press.

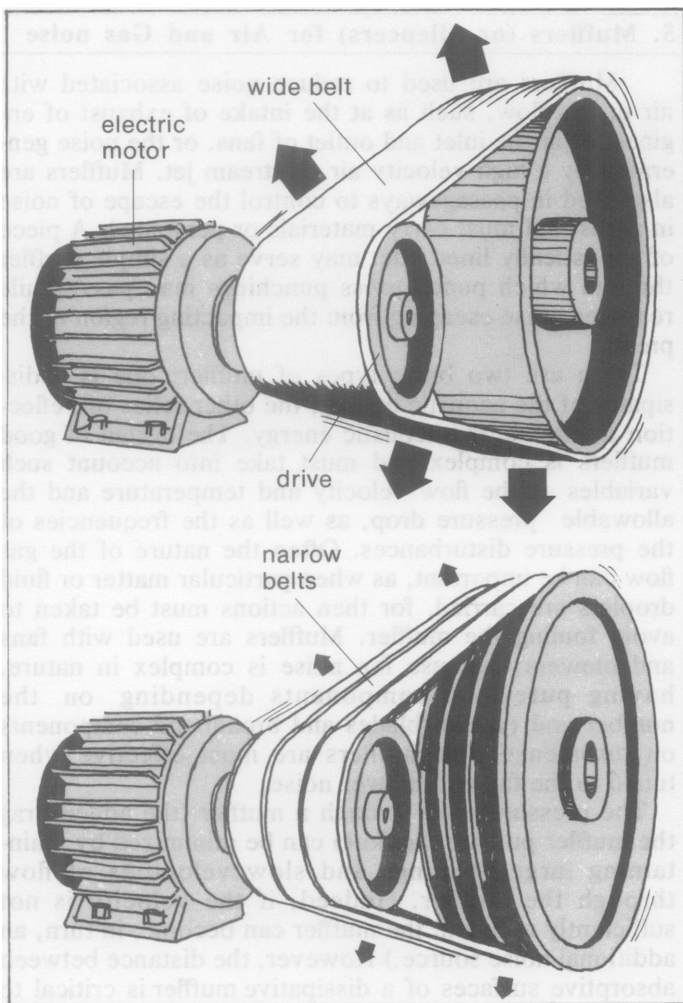
There are two basic types of muffler: one is a dissipator of the acoustic energy, the other relies on reflection to confine the acoustic energy. The design of good mufflers is complex and must take into account such variables as the flow velocity and temperature and the allowable pressure drop, as well as the frequencies of the pressure disturbances. Often the nature of the gas flow can be important, as when particular matter or fluid droplets are carried, for then actions must be taken to avoid fouling the muffler. Mufflers are used with fans and blowers; because fan noise is complex in nature, having pure-tone components depending on the number and type of blades and broadband components on turbulence, the mufflers are most effective when tuned to the fan and blower noise.

The pressure drop through a muffler (the added drag the muffler puts on the flow) can be minimized by maintaining large openings and slow velocities of flow through the muffler. (Indeed, if the velocity is not sufficiently reduced, the muffler can become, in turn, an additional noise source.) However, the distance between absorptive surfaces of a dissipative muffler is critical to the band of frequencies of sound absorbed, and it sometimes may be necessary to provide sets of mufflers in series designed to attenuate sound in different frequency bands.

The problem of contamination of the porous surfaces of the sound absorbing material can be solved by covering the surface with a very thin, nonporous, limp, but durable skin, which is designed to allow sound to pass through it, yet still contain the flow.



An example of noise damping is shown here by the process of sharpening a saw blade, which creates noise resonating from the blade. A damping plate can be attached to muffle the noise. Other ringing sounds from resonating surfaces can be quieted in this manner.



One wide belt creates more noise than several narrow belts.

The practical effectiveness of any design is likely to be limited by the available space, since it is theoretically possible to lengthen a muffler to produce any required attenuation (fading of sound). Practical design may range from an array of 15 ft. long absorptive splitters for the large duct of an induced draft fan on a boiler to the 3 ft. long device presently fitted to an automobile engine.

Other mufflers involve changing the flow pattern itself, particularly when this flow is the noise generator. For example, a high-speed jet exhaust from a pneumatic cylinder will generate additional noise as it mixes with the atmosphere. By adding a device to spray out the jet through a series of smaller holes, the noise cannot only be reduced but will be produced at higher and subjectively less critical frequencies. With proper design, there are no additional pressure losses.

6. Fans and Blowers

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, but 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 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 that can be constructed in maintenance shops include acoustical labyrinths, parallel baffle silencers, acoustic lined plenums, acoustic lined ducts, and acoustic lined bends.

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.

7. Air Jet Flow.

In industrial applications where high velocity air is discharged, shear-induced boundary layer turbulence can be a serious noise source. Normally, maximum levels from this aerodynamic noise occur in the 2000, 4000, and 8000 octave bands. If velocity can be reduced, the noise level is reduced.

A free jet impinging on a surface increases the noise level up to 6 dB.

Low noise level jets are available commercially that use a divider at the exit to change a single jet stream into multiple smaller jet streams. These devices should be tested to see if they can do the job required. Some hand air guns use a version of by-pass jet engines, in which a mantle of slower moving air is aspirated over the jet. Jet noise reductions of as much as 10 dB can be realized.

If the jet in question is from a vent, it could be moved to be vented outside the plant or it could be muffled.

Air operated tools can be equipped with commercially available exhaust air mufflers.

8. Hydraulic Systems.

Hydraulic systems, as part of a machine or operation, can have specific noise sources. Motor-pump assembly contributes most to the overall noise pattern, being vibrated both by overall vibration and by the blade tooth piston pass frequency plus harmonics. Noise levels depend on type of pump: gear pumps are more noisy than screw pumps, piston pumps are in between. Noise levels of most pumps increase with speed. Some screw pumps are available that, with a quieted electric motor produce about 81 dBA at 3 ft.

Fluid line noise sources are often sharp bends, flow restrictions, and undersize sections. These configurations cause cavitation and turbulence, causing vibration and noise.

Vibration isolation of the pump-motor unit will attenuate noise from the vibration of the floor. Other noise reduction means include substitution of a larger pump at reduced speed.

If the pipe size for avoiding turbulent flow is not economical, other means of attenuation must be used, such as storing energy elastically with a flexible hose or surge chamber, use of elastic spacers, wrapping and supporting of the line, use of isolation type hangers, or increase in pipe wall thickness.

9. Motor Air Noise.

Motor air noise, if found to be a problem, can be reduced by acoustic line air flow chambers which are available for some motors. Totally enclose fan cooled (TEFC) motors with integral quieting are also being manufactured. Less than 80 dBA at 5 ft. is claimed for motors up to 5000 HP.

10. Enclosed Drives.

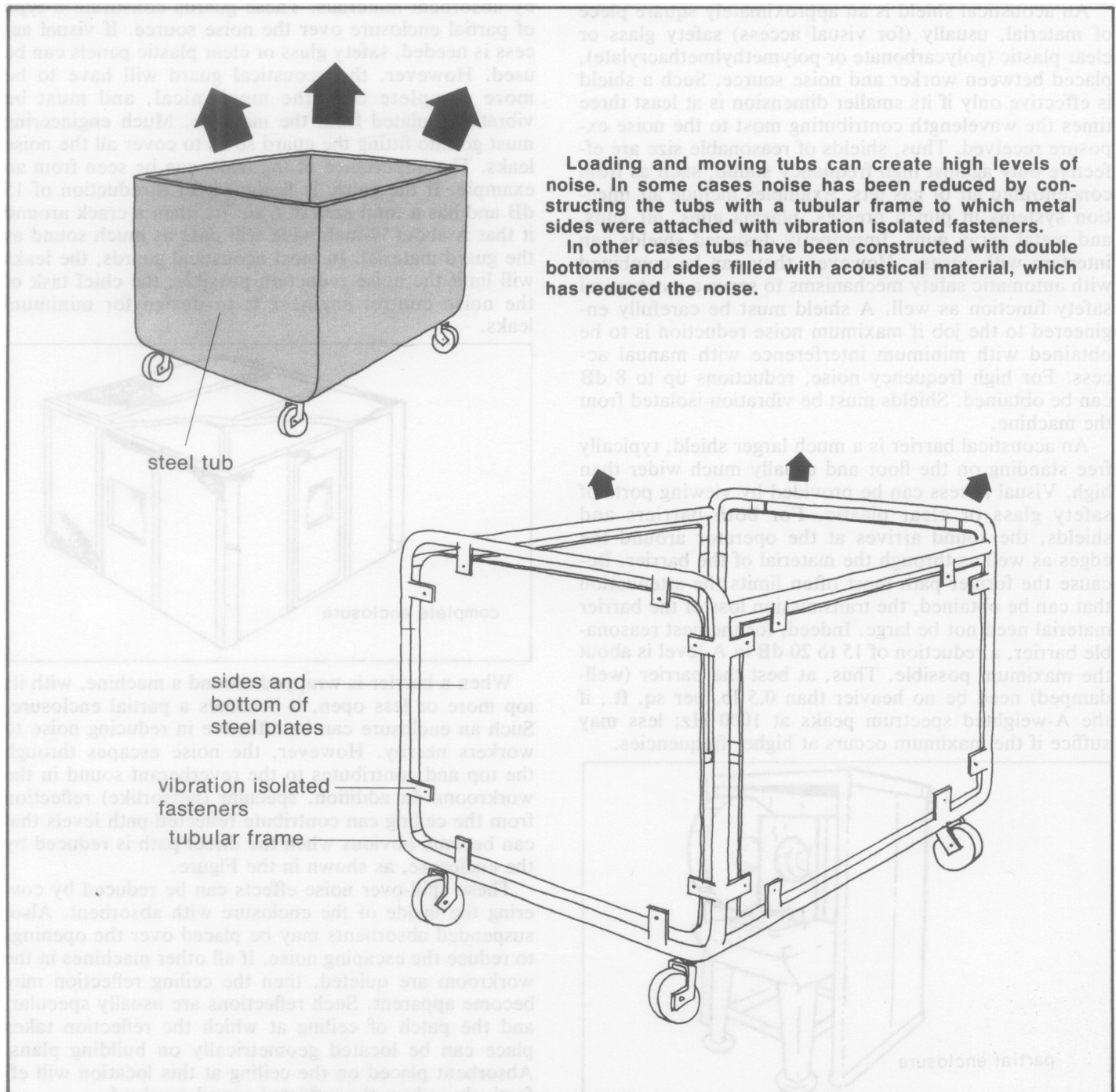
Vibrating surfaces of a drive enclosure are noise sources. Damping these surfaces reduces radiated noise. If the drive enclosure is a steel box structure, the inside can be lined with a combination absorption layer. (such as open cell polyurethane foam) with a damping layer backing. Such materials must be oil-resistant. If there are

air vent openings for cooling, noise traps can be added. 31

Quieter drives can also be considered, such as substituting belts for gears, "silent" chains for roller chains, and so on. Precision made and carefully aligned gears are always quieter than other types.

11. Balancing.

It is always preferable to reduce noise at the source by avoiding the generation of noise. Unbalanced rotating parts cause surfaces to vibrate and generate noise. All significant rotating parts should be balanced *in situ*, that is, in the machine at its final position. This is particularly true for large fans, where there may be unbalanced aerodynamic forces on the blades. Rotating mechanisms that drive reciprocating devices can use counterbalance weights.



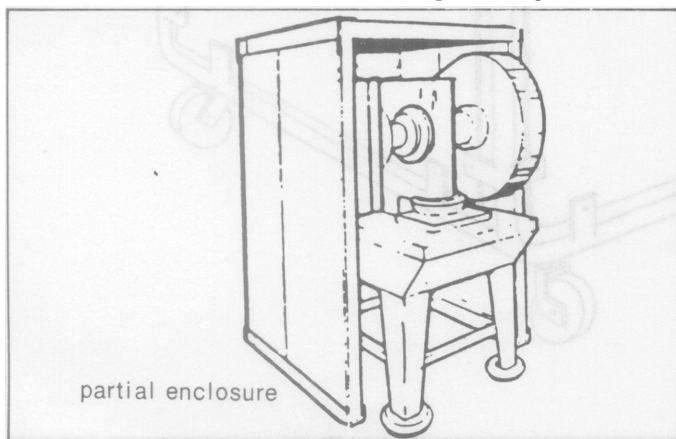
B. Building Enclosures and Barriers: Noise "Pathway" Control

After as much noise as possible has been reached at each source, the next step is to reduce noise along the *path* from the source to the receiver (operator). The sound may be blocked by acoustical shields, barrier walls, partial enclosures, or total enclosures. All these techniques depend on interposing in the path a material, called an isolator, whose wave transmitting properties are as different as possible from those of the path. In air paths, such materials are ideally solid, nonporous, and limp. For liquid paths, a stream of gas bubbles is a good isolator. Along a solid path, resilient vibration isolators perform the same function, weakening the path. Our discussion will be in terms of the most important path, in air.

1. Acoustical Shields and Barriers.

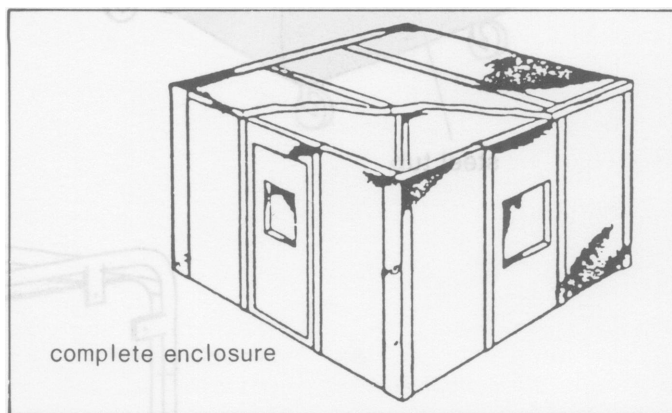
An acoustical shield is an approximately square piece of material, usually (for visual access) safety glass or clear plastic (polycarbonate or polymethylmethacrylate), placed between worker and noise source. Such a shield is effective only if its smaller dimension is at least three times the wavelength contributing most to the noise exposure received. Thus, shields of reasonable size are effective only against high frequency sound, such as from concentrated air or gas jets. Examples include air injection systems in punch presses, plasma guns, air guns, and metal spray guns. Improperly designed shields can interfere with access. However, they can be combined with automatic safety mechanisms to serve a mechanical safety function as well. A shield must be carefully engineered to the job if maximum noise reduction is to be obtained with minimum interference with manual access. For high frequency noise, reductions up to 8 dB can be obtained. Shields must be vibration-isolated from the machine.

An acoustical barrier is a much larger shield, typically free standing on the floor and usually much wider than high. Visual access can be provided by viewing ports of safety glass or clear plastic. For both barriers and shields, the sound arrives at the operator around the edges as well as through the material of the barrier. Because the former path most often limits the attenuation that can be obtained, the transmission loss of the barrier material need not be large. Indeed, for the best reasonable barrier, a reduction of 15 to 20 dB in A-level is about the maximum possible. Thus, at best the barrier (well-damped) need be no heavier than 0.5 lb. per sq. ft., if the A-weighted spectrum peaks at 1000 Hz; less may suffice if the maximum occurs at higher frequencies.



For the best results, at least the machine side of a useful barrier should be covered with an acoustical absorbent, preferably oil resistant and cleanable. The barrier material can be plywood; it ordinarily needs no added damping, and $\frac{1}{2}$ inch will usually be thick enough for a 10-dB reduction. If steel is used, damping must be added to control resonances. Handles and sometimes casters can be provided on the barrier for ease of moving. If the barrier is hinged (for stability), the joints can be severe noise leaks. These leaks can be controlled by a resilient strip of $\frac{1}{8}$ -inch-thick Neoprene over the gap. Use a width of at least three inches, placed on the concave side of the bend. Fasten by one long edge, with the other free to slide as the hinge bends.

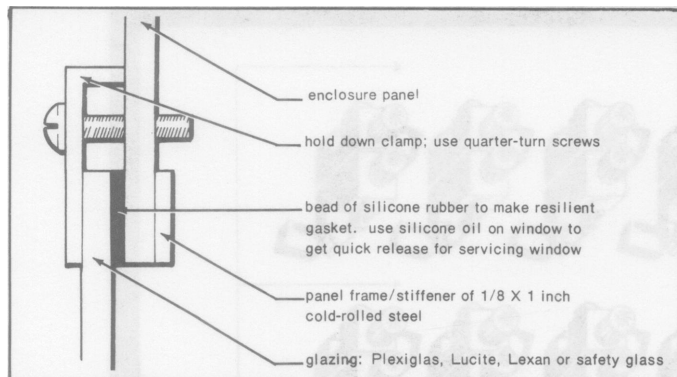
Machine guards for mechanical protection can often be replaced by acoustical guards, covered on the inside by absorbent materials. These guards constitute a type of partial enclosure over the noise source. If visual access is needed, safety glass or clear plastic panels can be used. However, the acoustical guard will have to be more complete than the mechanical, and must be vibration-isolated from the machine. Much engineering must go into fitting the guard so as to cover all the noise leaks. The importance of the leaks can be seen from an example. If the guard is designed for a reduction of 15 dB and has a total area of 6 sq. ft., then a crack around it that is about $\frac{1}{4}$ -inch wide will pass as much sound as the guard material. In most acoustical guards, the leaks will limit the noise reduction possible; the chief task of the noise control engineer is to design for minimum leaks.



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. However, the noise escapes through the top and contributes to the reverberant sound in the workroom. In addition, specular (mirrorlike) 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 the Figure.

These spill-over noise effects can be reduced by covering the inside of the enclosure with absorbent. Also, suspended absorbents may be placed over the openings to reduce the escaping noise. If all other machines in the workroom are quieted, then 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. Absorbent placed on the ceiling at this location will effectively reduce the reflected sound received.

Partial and total enclosures will usually need access for incoming material, product, scrap removal, operator, maintenance person, 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 weather stripping 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 quarterturn latches.



Doors, hatches, and windows must be airtight for an enclosure to be effective. An example of how a window is sealed is shown here.

Doors and hatches must be constructed with the same acoustical treatment as the enclosure panels and must be secured by vibration resistant latches.

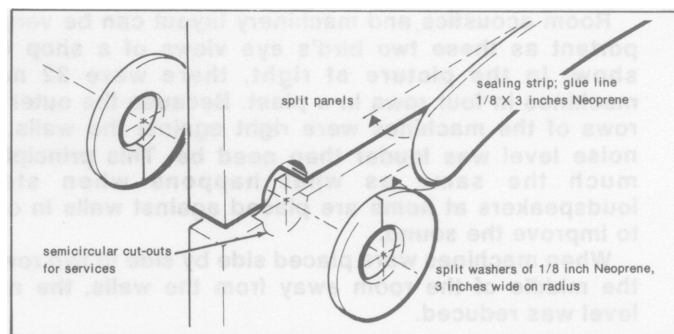
Windows for visual access may need added internal illumination to make visual monitoring easy and positive. Heat buildup should be no problem with an open top in a partial enclosure. Noise reduction also removes acoustic signals that some workers use in evaluating the performance of a machine. Hence, if the reduction is great enough, acoustic cues may have to be separately supplied. This is easily done by 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 of the tunnel determines the amount of noise attenuation obtainable. In the design, the absorbent 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.

2. Total Enclosure.

The next step of noise control, a total enclosure, has the same problems (and solutions) as the partial enclosure. The chief added problem is that of heat buildup. This problem is easily 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.

There is no doubt that the total enclosure will require a change in work habits, and as such will usually be resisted by all concerned. The shock of the change can be eased if the people most involved—the workers and the foremen—are provided an opportunity to enter into the



Enclosures must be airtight to be effective. Holes made in the enclosure to allow for wiring, control levers or other services can be sealed with Neoprene material.

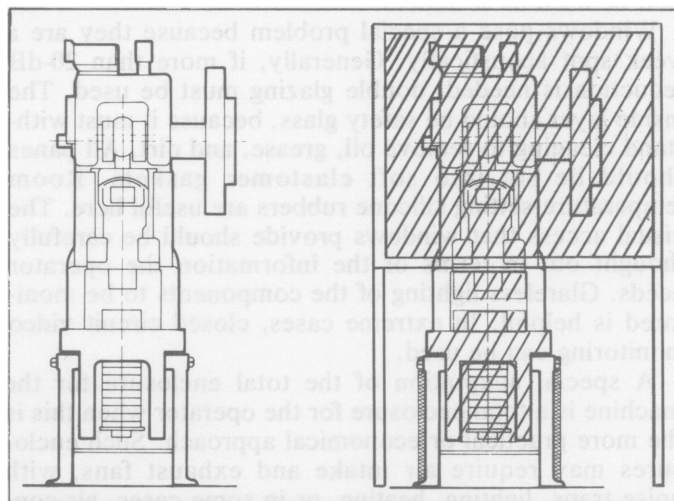
design discussions. Enclosures can also force consideration of modernizing equipment, say, for automatic feed by conveyor, so that less personal attention to the machine is required.

As a general matter, enclosures must 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 where the enclosure panel can be split. A resilient acoustical seal can then be made from two ring-shaped pieces of 1/8-inch (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, and resilient material.

For mechanical controls operating through an arc-shaped hole in a panel, the seal can be of abutted, multiple strips of Neoprene. The control lever should be as thin as possible. Better yet, replace it by a servo control operated from the outside.

Machine vibration may still create a problem by vibrating the floor, which then acts as a resonant sounding board to vibration-isolating mounts, using steel springs, or elastomers in shear.

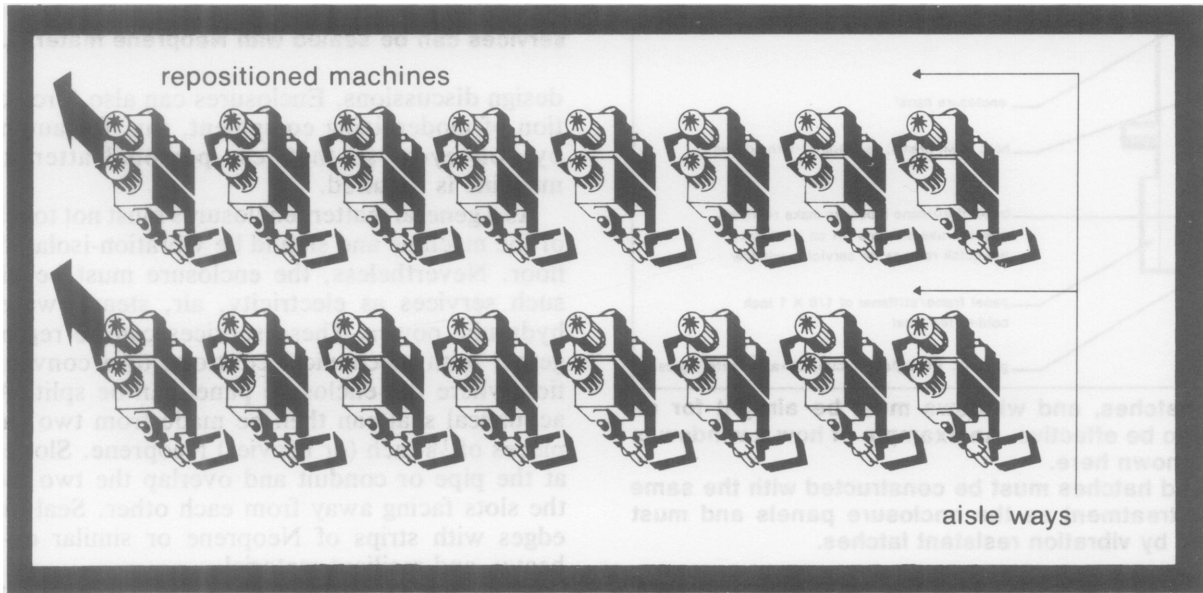
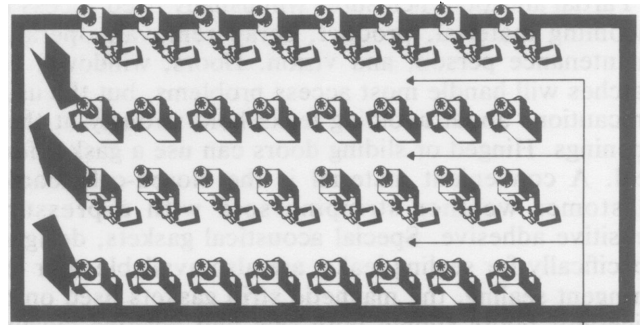
In any machine, the time comes when major repairs are due; additions or changes may also be called for.



The noise from a 60 ton press was reduced from 101 decibels to 90 decibels by enclosing the upper part of the press and the dies and by adding isolating and damping material to other parts of the press. The enclosure around the lower die remained stationary while the enclosure around the upper die moved with the ram.

Room acoustics and machinery layout can be very important as these two bird's eye views of a shop floor show. In the picture at right, there were 32 noisy machines in four rows in a plant. Because the outer two rows of the machines were right against the walls, the noise level was louder than need be. This principle is much the same as what happens when stereo loudspeakers at home are placed against walls in order to improve the sound.

When machines were placed side by side in two rows in the middle of the room away from the walls, the noise level was reduced.



The panels can be made separately and fastened in place with a gasket material (such as weatherstripping) to close off chance leaks. If the panel material is a metal, its resonances can be distributed more uniformly in frequency if the panel is reinforced by bolted-on angle iron (bolting adds more damping than welding). 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 a weak spot acoustically. Generally, if more than 20-dB reduction is needed, double glazing must be used. The inside layer should be safety glass, because it must withstand cleaning to remove oil, grease, and dirt. All panes should be set into soft elastomer gaskets. Room temperature-setting silicone rubbers are useful here. The visual access that windows provide should be carefully thought out in terms of the information the operator needs. 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 is recommended, such as an acoustic tile ceiling, and special care must be taken in window and door design to avoid leaks.

The most important information required for the

acoustical design of enclosures is the transmission loss. This quantity represents, in decibels, the reduction of sound power in going through an isolating wall. It is measured by a well-defined and accepted standard. The transmission loss varies considerably with frequency, and the term sound transmission class (STC) is sometimes used. This is a single number indication of average transmission loss. However, it applies specifically to speech sounds and acoustical privacy requirements. It should be used with caution in industrial situations, where sound spectra differ from those of speech and where reduction of A-level is the requirement. If a single number is needed, use the transmission loss at the band an octave below that for which the maximum A-weighted octave band level occurs at the operator position.

The noise reduction is the difference in level at operator and in enclosure after installation of the enclosure. It depends on several factors: the average transmission loss of the enclosure surfaces, the amount of absorption in the enclosure, and to some extent, the acoustics of the work room. The worker is usually close enough to the machine that room acoustics effects are not important.

3. Room Acoustics

In addition to the direct path from the noise source to the receiver (operator), there is also the sound reflected repeatedly from walls, ceiling, and other surfaces, such as equipment. The study of the sound fields generated by such reflections is termed *room acoustics*.

The sound level from a point source, with no reflecting surfaces nearby, changes at the rate of 6 dB drop per doubling of distance from the source. In a normal factory space with acoustically hard walls, floors, ceilings, partitions, and machines, sound is multiply reflected, and an operator may receive this reflected sound from essentially all directions. The result is a reverberant buildup of noise. This means that as the distance from the machine increases, the noise level will diminish for awhile but a point will be reached where little or no reduction is achieved. Beyond this distance is the reverberant field, and the distance at which the change-over occurs is called the critical distance, c . The reverberant field is the only portion of the total noise that is affected by changes in room acoustics. For most industrial situations the operator is inside the critical distance. Thus, the noise that he receives is affected but little by adding absorption to the walls or ceiling of the work room. This absorption will affect the sound level experienced by those who walk through, at some distance from the machines.

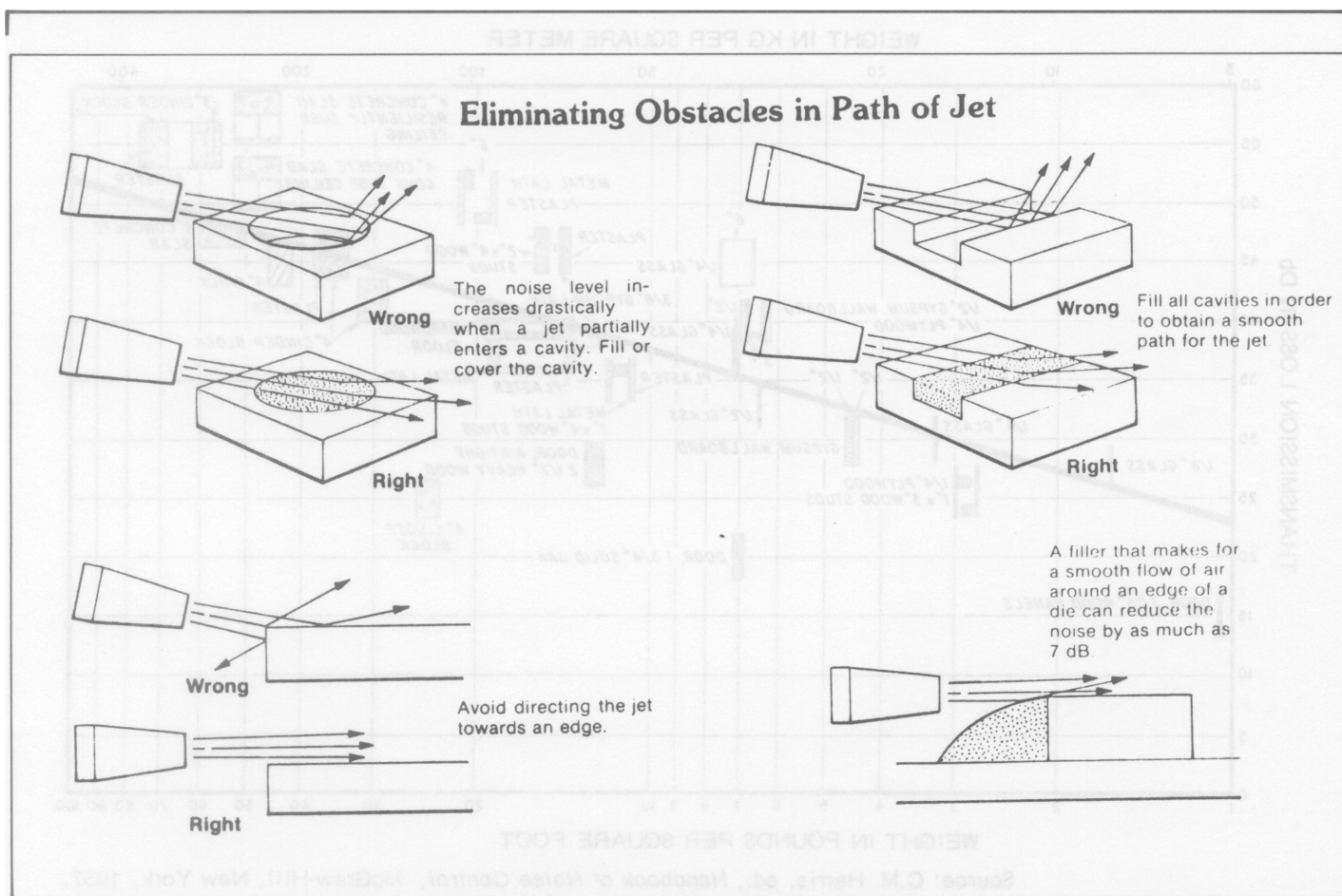
We again repeat the caution: adding room absorption will normally not reduce the direct noise from the source, which is what the operator receives. Indeed, adding absorption increases the critical distance, so the operator can be still further from his machine and still receive the major amount of noise from it.

4. Personnel Acoustic Booths

Employees exposed to high-level noise from a number of sources can often be protected by use of acoustic booths. These can range from small open-fronted telephone booth sized cabinets (into which the operator steps while observing the operation of a semi-automatic machine) to completely enclosed control consoles. In many cases, personnel acoustic booths can provide an island of protection; an employee exposed to high-level sound during part of his operations can be protected well enough to reduce his total exposure during normal working hours to less than the permissible exposure.

The design of worker enclosures requires suitable walls to produce the necessary sound reduction and also some internal sound absorption to prevent any reverberant build-up of transmitted sound. The use of fixed windows will allow the necessary orientation of the booth, which can be important if an open entrance is to be used. The design and location of such booths can require a careful review and measurement program of the acoustic situation and may entail some local room acoustic treatment.

As a refuge for operators, acoustic booths can help, in addition to reducing the noise exposure, by giving a sense of occupancy and responsibility for an area. The attitude of the operator can, then, be important both in terms of job satisfaction and efficiency.



A well engineered air ejection system can reduce noise by 10-15 decibels. Air turbulence, which creates a great deal of noise, can be reduced in three ways: 1) eliminate obstacles in the path of the jet, 2) reduce the velocity of

the jet, 3) use quiet design jet nozzles which are available from suppliers. Mechanical ejection systems are even quieter and can be used in many cases.

C. Noise Control Materials

This section describes the four types of materials most often used in noise control: absorbers and isolators for airborne sound, and vibration isolators and damping materials for controlling vibration solid-borne sound. Guidelines for selecting materials are also given, based on acoustic and nonacoustic considerations.

By far the best location for noise control is as close to the source as possible. Once the sound is airborne, it is difficult and expensive to control. Control at the receiver by ear plugs, ear muffs, or control booths is not usually included in the meaning of engineering control, which commonly refers to machine-oriented efforts at the source or along the early path.

1. Absorption Materials

With absorption, sound in air is changed into heat. Suitable materials are usually fibrous, lightweight, and porous. The fibers should be relatively rigid. If a cellular material is used, the cells must intercommunicate. Foams should be reticulated to the proper degree.

Examples of absorbers include acoustical ceiling tile, clothing, loss-type mufflers, and foamed elastomers. Physically the flow resistance of fibrous materials is the most important characteristic. For optimum results, the flow resistance must usually be increased as the thickness of the absorbent decreases, to maintain peak absorption.

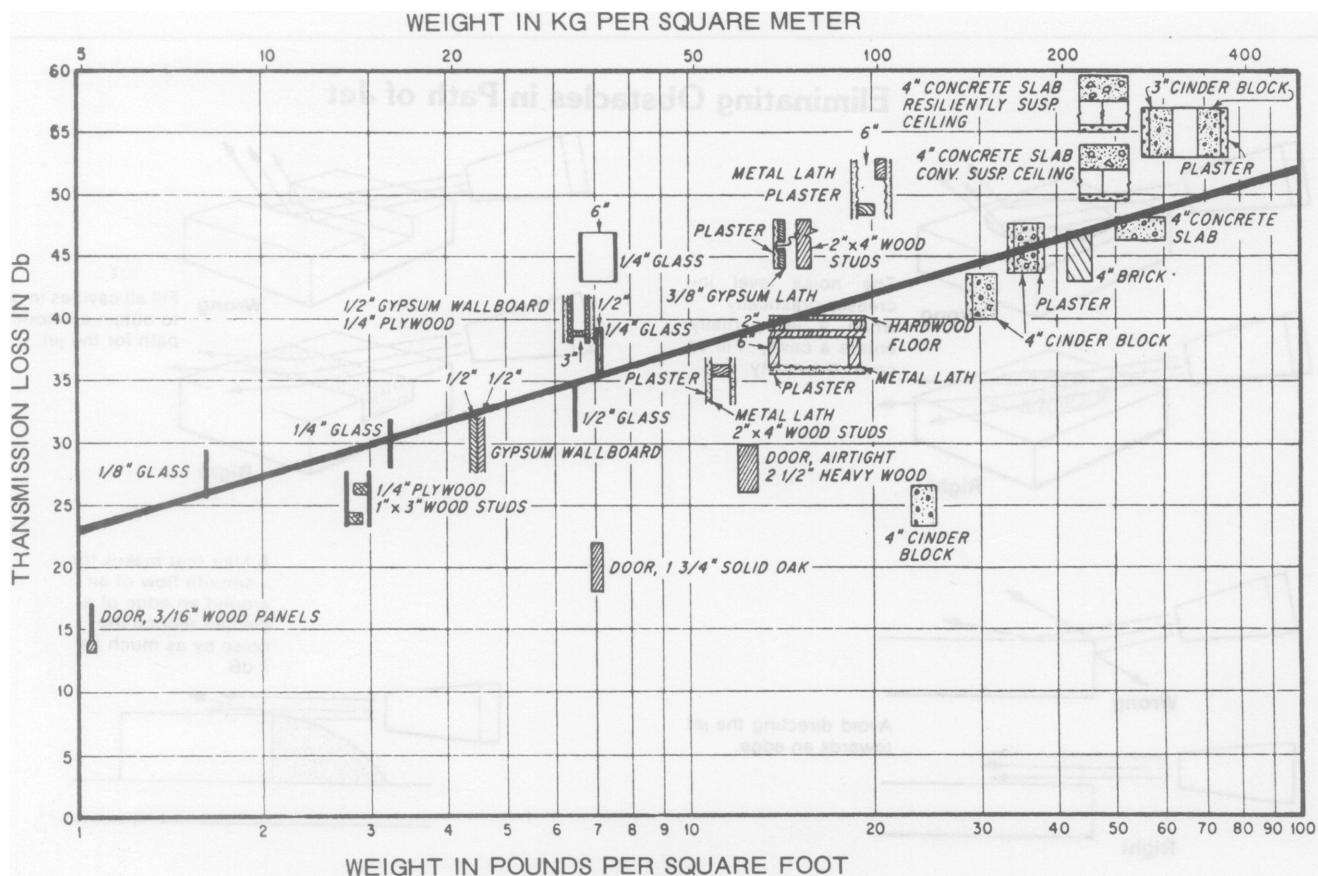
The low resistance can be sensed rather crudely by attempting to blow through the material. Comparison with an accepted material of the same thickness provides a personal calibration. The effectiveness of an absorbent is measured by the absorption coefficient. Ideally, this is the fraction of the sound energy flowing toward the absorbent that enters the material and is not reflected; thus, a perfect absorbent would soak up all the sound incident on it. Industrially useful absorbers have coefficients above 60% in the frequency range from 500 Hz and up.

Materials may have special facings. For resistance to grease and water that would clog pores, as thin plastic film covering is often used. Such films, as well as perforated hardboard facings, tend to produce a maximum in the mid-frequency absorption coefficient. Some thin construction materials, notably plywood, can show increased low frequency absorption by panel resonance, if they are not securely fastened down.

2. Damping Materials

Damping materials are used to reduce resonance effects in solids. Essentially, damping materials are absorbers for solid-borne sound and convert it into heat.

Damping materials are used in many applications. If a machine panel (such as a belt guard) is subjected to vi-



Source: C.M. Harris, ed., *Handbook of Noise Control*, McGraw-Hill, New York, 1957.

The most important aspect for better barrier material is weight—the heavier and denser the material, the more effective it is. This graph shows that the materials in the

upper right hand corner are more effective in isolating noise than the materials in the lower left hand corner.

Materials*	Frequency Hz					
	125	250	500	1000	2000	4000
Fibrous glass (typically 4 lb / cu ft) hard backing						
1 inch thick	0.07	0.23	0.48	0.83	0.88	0.80
2 inches thick	0.20	0.55	0.89	0.97	0.83	0.79
4 inches thick	0.39	0.91	0.99	0.97	0.94	0.89
Polyurethane foam (open cell)						
1/4-inch thick	0.05	0.07	0.10	0.20	0.45	0.81
1/2-inch thick	0.05	0.12	0.25	0.57	0.89	0.98
1 inch thick	0.14	0.30	0.63	0.91	0.98	0.91
2 inches thick	0.35	0.51	0.82	0.98	0.97	0.95
Hairfelt						
1/2-inch thick	0.05	0.07	0.29	0.63	0.83	0.87
1 inch thick	0.06	0.31	0.80	0.88	0.87	0.87

Light, fibrous and porous materials are good noise absorbers. This table shows the sound absorbing capacity of common *acoustical* materials used to line the inside of barriers and enclosures. A material is useful if it has a rat-

ing above 0.60 (that is, if it absorbs over 60% of the sound going through it) in the frequency range from 500 Hz and up.

Material	Frequency Hz					
	125	250	500	1000	2000	4000
Brick						
Unglazed	0.03	0.03	0.03	0.04	0.04	0.05
Painted	0.01	0.01	0.02	0.02	0.02	0.02
Concrete block, painted	0.10	0.05	0.06	0.07	0.09	0.08
Concrete	0.01	0.01	0.015	0.02	0.02	0.02
Wood	0.15	0.11	0.10	0.07	0.06	0.07
Glass	0.35	0.25	0.18	0.12	0.08	0.04
Gypsum board	0.29	0.10	0.05	0.04	0.07	0.09
Plywood	0.28	0.22	0.17	0.09	0.10	0.11
Soundblox concrete block						
Type A (slotted), 6 inch	0.62	0.84	0.36	0.43	0.27	0.50
Type B, 6 inch	0.31	0.97	0.56	0.47	0.51	0.53
Carpet	0.02	0.06	0.14	0.37	0.60	0.65

Some common *construction* materials are not good noise absorbers, as the above table shows. You will note that these materials do *not* have a rating above 0.60 (60%

absorption of sound) and thus usually must be used together with *acoustical* materials to be effective.

Material	Frequency Hz							
	lb/sq ft	125	250	500	1000	2000	4000	8000
Lead								
1/32-inch thick	2	22	24	29	33	40	43	49
1/64-inch thick	1	19	20	24	27	33	39	43
Plywood								
3/4-inch thick	2	24	22	27	28	25	27	35
1/4-inch 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 laminate-core)	2	15	25	28	32	39	42	47
Plexiglas								
1/4-inch thick	1.45	16	17	22	28	33	35	35
1/2-inch thick	2.9	21	23	26	32	32	37	37
1-inch thick	5.8	25	28	32	32	34	46	46
Glass								
1/8-inch thick	1.5	11	17	23	25	26	27	28
1/4-inch thick	3	17	23	25	27	28	29	30
Double glass								
1/4 x 1/2 x 1/4-inch		23	24	24	27	28	30	36
1/4 x 6 x 1/4-inch		25	28	31	37	40	43	47
5/8-inch Gypsum								
On 2 x 2-inch stud		23	28	33	43	50	49	50
On staggered stud		26	35	42	52	57	55	57
Concrete, 4-inch thick	48	29	35	37	43	44	50	55
Concrete block, 6-inch	36	33	34	35	38	46	52	55
Panels of 16-gauge steel, 4-inch absorbent, 20-gauge steel		25	35	43	48	52	55	56

This table shows another way of measuring the sound absorbing qualities of common materials—here stated as noise reduction in decibels (or “transmission loss”). Ob-

viously, the higher the number of decibels reduced at the various frequencies, the better the material as a noise isolator.

bration, it will radiate sound strongly at its resonant frequencies. Damping the panels or guards can thus reduce this radiated sound. In another application, parts that fall into (and are carried along) metal chutes can excite the chute panels by repeated impact. Damping materials along the chute surfaces will reduce the noise; these materials must also be selected with heat resistance and mechanical integrity in mind. Damped stock tubes are available for quieting screw machine operation. Panels for isolating enclosures can transmit large amounts of sound in the critical frequency region. Damping can greatly reduce the severity of the decrease of transmission loss in that region.

There are two types of damping materials: homogeneous and constrained layer. A homogeneous material is applied in a relatively thick cast, sprayed or troweled layer, depending on the thickness and type of metal to be damped. A constrained layer material consists of a thin layer of the actual damping (lossy) material, with a backing of thin metal or stiff plastic. The mechanical action is one of making the damping layer much more effective than if it were homogeneous. Constrained layer damping materials can be purchased as an adhesive/metal foil tape combination, where the adhesive is selected for its energy loss properties as well as its adhesion. These damping tapes are especially useful on thin panels (1/16-in. steel or less).

3. Vibration Isolators

Vibration isolators act on the same principle as isolators for airborne sound: introducing into the transmission path a material whose wave-transmitting properties are as different as possible from the medium carrying the wave. For vibration in solids, such materials are spring-like. Examples include resilient elastomer and metal springs, elastomer pads, and in extreme cases, air springs. The weaker the spring, usually the greater the isolation.

Solid rubber or rubber-fabric pads are not too effective, because the displacement is small and is not proportional to the load.

If an isolator is too weak vertically, it may not be laterally stable. There are available side-restrained metal spring isolators to avoid this difficulty. In extreme cases it may be necessary to use many isolators, all acting along lines that pass through the center of gravity of the machine. This use of materials is most effective when the vibration situation is reversed, i.e. when a delicate mechanism is to be protected from external shock and vibration.

The proper amount of damping is needed with vibration isolation in many applications. Steel springs alone are highly undamped; if they rest on elastomer pads, there is much improvement.

Air nozzles specially designed for noise control are available from suppliers.

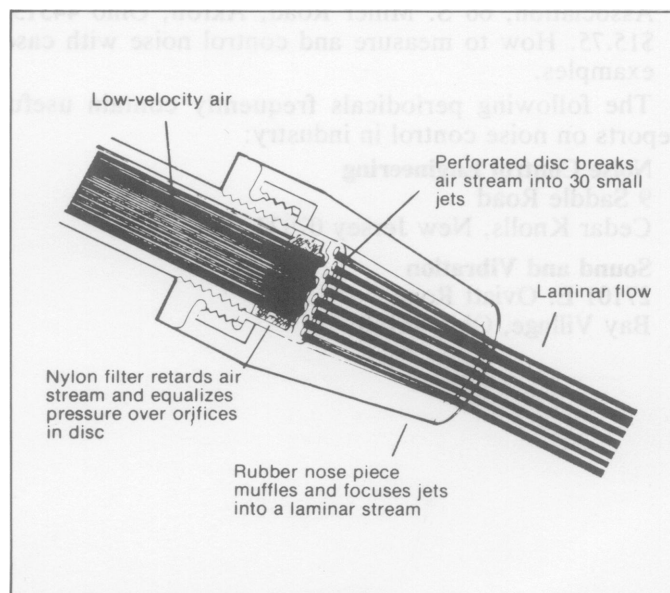
4. Material Selection

The most commonly used materials for control of noise in industry are isolators and absorbers for airborne sound and vibration isolators and dampers for solid-borne sound. Selection of materials is governed by many factors other than acoustical, and installed cost becomes less important than possible interference with production. Here we first discuss the acoustic factors and then consider the others.

Acoustic Considerations. Isolators for airborne sound have many configurations, ranging from a simple shield to a barrier to a total enclosure. The most important acoustical parameter is the weight per unit area: the heavier the barrier, the more isolation is obtained. A characteristic of most isolating materials, such as sheet steel, glass, or solid wood panels, is that they are resonant. At the frequencies for which the various types of resonances occur (and particularly in the coincidence region), the isolation afforded becomes much smaller. At frequencies above the resonance, the isolation again increases.

The interior of enclosures must be sound absorbent to prevent reflective buildup of sound within the enclosure. Often the functions of absorption and damping can be combined in a single composite material. The absorbent is usually a foamed polyurethane; the minimum thickness of the foam should be 1 inch. Special oil and water-impervious film coverings can be specified. This covering protects the material from becoming liquid soaked. However, deposits on the film must be removed periodically to prevent loss of high frequency absorption. Use a mild warm detergent solution, applied with a cloth. Wipe carefully to prevent damage to the film.

Absorbents protected by a film still have exposed edges. These may be sealed by a latex paint that anchors itself to the pores of the absorbent and closes the edges. An alternative is a thin film that is adhesively fastened over the edges. By choice of thickness of air space between the absorbent and the mounting surface, the shape of the absorption-frequency curve can be controlled. This can be matched to the need for maximum noise reduction in frequency regions determined by the noise measurements.



PRACTICAL CONCERNS ABOUT NOISE CONTROL

An acoustically appropriate noise control design should also be functionally acceptable. In certain industries, attention must be paid to ensure that the noise control treatment is technically feasible. For example, the food processing industry is subject to Food and Drug Administration and U.S. Department of Agricultural restrictions on the use of materials in processing areas; thus, noise control treatments in the food industry must anticipate the possibility of infestation or contamination. Acoustic materials that might shed dust can cause quality control problems in the printing and publishing industry.

However, there are a number of other concerns common to many industries. The following list provides examples of such concerns that have been expressed by users of industrial equipment as problems—real or imaginary—associated with noise control treatments.

Proper design can overcome these problems:

Heat build-up

Complication of existing machinery maintenance or creation of new maintenance necessities

Loss of accessibility for jam clearance

Loss of accessibility for production run change-overs, adjustment or setup, operational efficiency, or other routine manipulations

Decreased quality control

Restrictions of work flow or creation of safety hazards

Creation of new operator routines

Creation of fire hazards

Creation of added power requirements.

MORE INFORMATION ON NOISE CONTROLS

Two additional books which contain valuable information on how to control noise are:

Industrial Noise Control Manual, by NIOSH. How to measure and control noise. Contains many case examples of how to control this health hazard. Available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402 for \$3.25. The stock number is GPO: 017-033-00073. Include your check.

Industrial Noise Manual, American Industrial Hygiene Association, 66 S. Miller Road, Akron, Ohio 44313, \$15.75. How to measure and control noise with case examples.

The following periodicals frequently contain useful reports on noise control in industry:

Noise Control Engineering

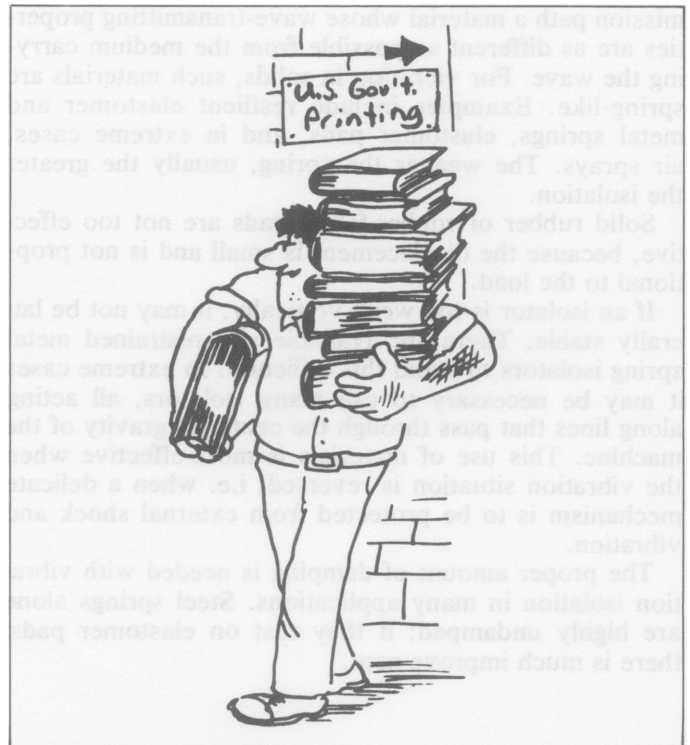
9 Saddle Road

Cedar Knolls, New Jersey 07927

Sound and Vibration

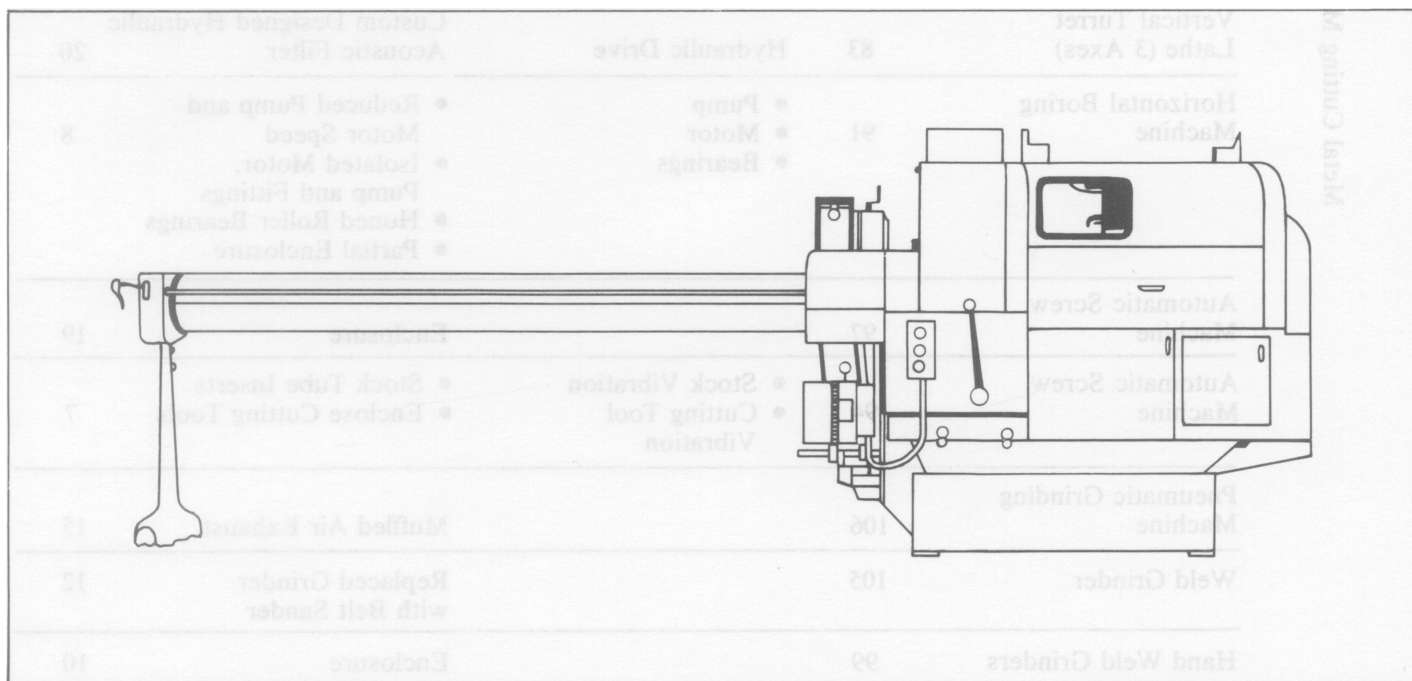
27101 E. Oviatt Road

Bay Village, Ohio 44140



Section IV

Noise Control of Specific Machines



Special enclosures around automatic screw machines have reduced noise from about 97 decibels down to under 80 decibels. The enclosure panels open up for complete accessibility. The enclosures can be installed on old machines or purchased from the manufacturer along with a new machine. The enclosures also provide better safety guarding and help control oil mist.

Taken from
**An Assessment of the Machinery Noise Problem
 of the Fabricated Metal Products Industry**
 by
 Environmental Protection Agency
 Washington, D.C.
 January 1976

Machine Class	Machine Type	Typical Noise Level before Treatment (dBA)	Major Noise Sources	Treatments	Typical Noise Reductions (dBA)
Metal Cutting Machines	Cutoff Saw	112		Enclosure	24
	Milling Machine	118	Workpiece Vibration	Damped Workpiece	14
	Vertical Turret Lathe	111	Tool Vibration	Damped Tool Holder	10
	Vertical Turret Lathe (3 Axes)	83	Hydraulic Drive	Custom Designed Hydraulic Acoustic Filter	20
	Horizontal Boring Machine	91	<ul style="list-style-type: none"> • Pump • Motor • Bearings 	<ul style="list-style-type: none"> • Reduced Pump and Motor Speed • Isolated Motor, Pump and Fittings • Honed Roller Bearings • Partial Enclosure 	8
	Automatic Screw Machine	97		Enclosure	19
	Automatic Screw Machine	94	<ul style="list-style-type: none"> • Stock Vibration • Cutting Tool Vibration 	<ul style="list-style-type: none"> • Stock Tube Inserts • Enclose Cutting Tools 	7
	Pneumatic Grinding Machine	106		Muffled Air Exhaust	15
	Weld Grinder	105		Replaced Grinder with Belt Sander	12
	Hand Weld Grinders	99		Enclosure	10
	Plate Grinder	108		Replaced Grinder with Planer	23
	Plate Planer	85			
	Shaper	103		Enclosure	
Metal Forming Machines	Hydraulic Press (800 ton)	100		Damping Material on Outside of Parts Handling Chutes	6
	Head Spinner	95		New Cams	1
	Perforator	98		Enclosure	12
	Blanking Press	98	<ul style="list-style-type: none"> • Frame • Clutch • Ram • Punch • Workpiece Supply • Workpiece Discharge 	<ul style="list-style-type: none"> • Die • Stripper • Press 	23
	Shears	100	Workpiece Transfer	Cover and Fill Rollers with Damping Material	11
	Pneumatic Shear	96	Exhaust	Mufflers	6
	Cold Header	97		Enclosure	12
	Staple Forming Machine	101		Enclosure	12
	Swager	112		Enclosure	12

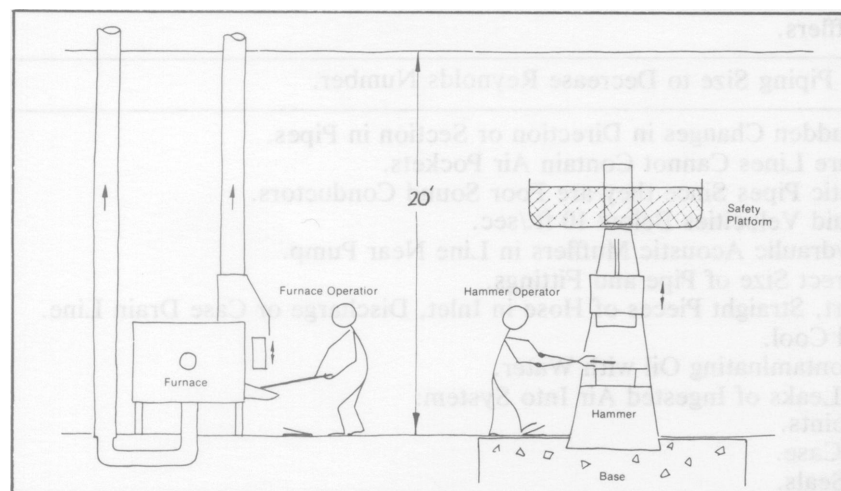
Machine Class	Machine Type	Typical Noise Level before Treatment (dBA)	Major Noise Sources	Treatments	Typical Noise Reductions (dBA)
Metal Forming Machines	Punch Press	100	<ul style="list-style-type: none"> • Die • Stripper 	<ul style="list-style-type: none"> • Increased Number of Steps • Substitute Mechanical for Air Parts Ejection • Add Cushioning under Die Block • Enclose Die Area 	15
	Forging Machine	98	Blower	Blower Moved to Outside Location	
	Upset Forging Press	100	Hydraulic Pump	Pump and Lines were Covered with Damping Material	15
	Power Press (20 ton)	98		Enclosure	
	Pin Machine	104		Enclosure	20
	Wire Drawing Machine	93	<ul style="list-style-type: none"> • Air Wipes • Motor • Drive 	<ul style="list-style-type: none"> • Enclosed Air Wipes, Motors and Belts • Changed from Cog Belts to V-Belts • Installed Plastic Gears in Gear Train (Plastic/Steel Gear Mix) 	4
	Wire and Cable Insulating Machine	101	Air Wipes	Resized Wiper Seals	11
	Cablemaking Machine	103	<ul style="list-style-type: none"> • Bearings • Drive 	<ul style="list-style-type: none"> • Partial Enclosure • Change Bearing Type • Close Tolerances and Gearing 	18
Joining Equipment	Automatic Spot Welding Machine	96		Enclosure	
	Riveting	121		Switch to Welding	6
Metalizing Equipment	Metalizing Machine	101		Enclosure	26
Other Machines	Twisting Machine	97		Enclosure	8
	Chipping Hammers	115		Replaced Chipping Hammers with Acetylene Torches	20
	Air Hammers	120		Enclosure	17
	Deburring Machine	107		Enclosure	15
	Tumbling Barrel	101	<ul style="list-style-type: none"> • Action of Parts Against Barrel • Action of Parts Against Parts 	Lined Barrel, Inside and Outside, with Rubber	11
	Tumbling Barrel	101		Enclosure	11
	Magazine Bar Feed Machine	94		Enclosure	11

Subsystem/ Component	Noise Source	Treatment
Gears/Gear Trains	<ul style="list-style-type: none"> • Load Fluctuations on Teeth • Elastic Vibration of Teeth and Gear Bodies 	<ul style="list-style-type: none"> • Lap Tooth Surface. • Use Finest Pitch Allowable. • Use Lowest Pressure Angle. • Maximum Recess and Minimum Approach. • Tip and Root Relief. • Overlap Ratio to be Exactly Integral—at least 2.0. • Alternate Hard Pinions with Soft Gears. • Alternate Steel and Nylon Gears.
	Bearings	<ul style="list-style-type: none"> • Use Sleeve Bearings in Preference to Antifriction Bearings. • Use Highest Viscosity Lubricant Possible.
	Misalignment	<ul style="list-style-type: none"> • Controlled Assembly. • Rubber or Neoprene Bushings. • Parallel Gearing Preferred to Crossed-Axis Gearing.
Antifriction Bearings	<ul style="list-style-type: none"> • Contamination • Brinelling • Bearings become Magnetized • Arcing from Stray Electricity Causes Pits 	<ul style="list-style-type: none"> • Keep Oil Clean. • Maintain Seals. • Design to Static Load. • Electrically Isolate Bearings.
Toothed Belt Drive	Belt/Pulley/Sheave Interactions	<ul style="list-style-type: none"> • Use Soft Material at Bottom Lands of Belt or Tooth Tip Lands. • Drive with Multibelts of Narrow Widths Runs Quieter than Single, Wide Belt. • Slant Belt with Idler Pulley Approximately 15 deg before it Contacts Wheel. • Use Barrel Shaped, Rather than Cylindrically Shaped Wheels. • Minimize Belt Tension. • Maximize Center Distance. • Minimize Belt Speed.
Headstock Drive	Belt/Sheave Noise	<ul style="list-style-type: none"> • True Belt Sheaves. • Cut Air Escape Grooves Around the Drive Pockets. • Balance Sheaves. • Minimize Belt Tension
Electric Motor	<ul style="list-style-type: none"> • Magnetic Noise • Unbalance of Rotor Assembly • Bearings • Brushes Sliding on Slip Rings • Rattling of Loose Components • Windage Noise • Rubbing of Stationary and Rotating Components 	<ul style="list-style-type: none"> • Balance Rotor Assembly. • Bearing Replacement. • Unidirectional Fan. • Resilient Motor Mounts. • Enclosure.
Mechanical Systems	Cams	<ul style="list-style-type: none"> • Smooth Surfaces. • Balanced Rotating Parts. • Minimize Mass and Area. • Accelerate No Faster Than System can Follow. • Try to Use Constant Acceleration.
	Gears	<ul style="list-style-type: none"> • Tight Tolerances and Fits. • Nonmetallic Material. • Damping Material on Gears.
	Bearings	<ul style="list-style-type: none"> • Journals—Thick Oil Film. • Ball—Good Surface Finish. • Needle—Good Surface Finish Plus Oil Film.
	Couplings	<ul style="list-style-type: none"> • Lubrication of Bearings. • Resilient Material Around Bearings. • Use Vibration Isolators

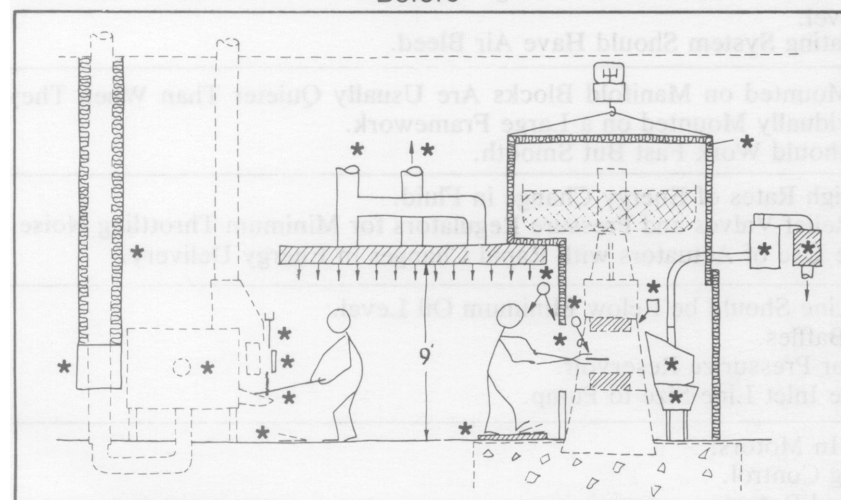
Hydraulic Systems	Pump	<ul style="list-style-type: none"> • Two Small Pumps are Quieter than One Large Pump. • Never Mount a Pump Rigidly on Anything that Resembles a Sounding Board or a Drum Head. • Larger Pumps Run at Lower Pressures and Lower Speeds Produce Less Noise than Small, High Speed, High Pressure Pumps which Also Cost More. • Fixed Displacement Pumps are Quieter than Variable Displacement Pumps—They are also Less Expensive.
	• General	
	• Cavitation	<ul style="list-style-type: none"> • Increase Suction Pressure: <ul style="list-style-type: none"> —Few or Large Valves and Fittings. —Large or Short Pipes. —Elevate or Pressurize the System. —Lower the Pump.
	• Case Resonance	<ul style="list-style-type: none"> • Add Attenuation Material.
	• Solid Body Vibration	<ul style="list-style-type: none"> • Rigid Body. • Massive Body.
Hydraulic Systems	• Pressure Pulse	<ul style="list-style-type: none"> • Delay Discharge Port Opening. • Controlled Backflow. • Use Large Displacement Pump Operations at Low Speed or Discharge Pressure. Noise is More Sensitive to Speed than to Pressure.
	Pump Motor	<ul style="list-style-type: none"> • Mount on Common Base to Facilitate Alignment and Isolation. • Isolate Complete Unit with Resilient Mounts. • Align Pump and Motor Shafts to Minimize Load on Bearings.
	Surges	<ul style="list-style-type: none"> • Add Accumulator(s). • Add Mufflers.
	Turbulence	<ul style="list-style-type: none"> • Increase Piping Size to Decrease Reynolds Number.
	Piping	<ul style="list-style-type: none"> • Avoid Sudden Changes in Direction or Section in Pipes. • Make Sure Lines Cannot Contain Air Pockets. • Use Plastic Pipes Since they are Poor Sound Conductors. • Keep Fluid Velocities Below 10 ft./sec. • Place Hydraulic Acoustic Mufflers in Line Near Pump. • Use Correct Size of Pipe and Fittings. • Use Short, Straight Pieces of Hose in Inlet, Discharge or Case Drain Line. • Keep Oil Cool. • Avoid Contaminating Oil with Water. • Seal All Leaks of Ingested Air Into System: <ul style="list-style-type: none"> —Pipe Joints. —Pump Case. —Shaft Seals. • All Fluid Return Lines in the Storage Reservoir Should be Below Minimum Fluid Level. • Recirculating System Should Have Air Bleed.
Hydraulic System	Valves	<ul style="list-style-type: none"> • Valves Mounted on Manifold Blocks Are Usually Quieter Than When They are Individually Mounted on a Large Framework. • Valves Should Work Fast But Smooth.
	Controls	<ul style="list-style-type: none"> • Avoid High Rates of Energy Change in Fluid. • Design Relief Valves and Pressure Regulators for Minimum Throttling Noise. • Minimize Use of Actuators with Rapid Changes in Energy Delivery.
	Reservoirs	<ul style="list-style-type: none"> • Return Line Should be Below Minimum Oil Level. • Include Baffles. • Elevate or Pressurize Reservoir. • Maximize Inlet Line Size to Pump.
	Mechanical Noises	<ul style="list-style-type: none"> • Treat as In Motors: <ul style="list-style-type: none"> —Bearing Control. —Balanced Rotors. —Misalignment Correction.

Pneumatic Systems	Exhaust	<ul style="list-style-type: none"> • Use Mufflers Which: <ul style="list-style-type: none"> —Use Sound Absorbing Material. —Use Acoustic Filter. —Use Diffusion at the Exhaust Exit. • Pipe Exhaust Away From Operator's Area. • Use Gradual Exhaust to Reduce Amplitude of Exhaust Pressure Pulse. • Use Baffles at Discrete Locations to Prevent Standing Waves. • Use An Expansion Volume to Drop Exhaust Pressure. • Minimize Exhaust Air Velocity. • Provide a Tortuous Path For Exhaust. • Use Lowest Operating Pressure That Will Provide Satisfactory Performance. 		
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Enclosures and Barriers	Control Option	Attenuation (dBA)	Unit Cost per sq. ft. or Each (\$)	Productivity Penalty
	Absorption	3-5	0.50- 2.00	None
	Damping	3-10	0.20 4.00	None
	Barriers	5-15	2.00- 3.00	Up to 15%
	"Glove Box" Booths	3-15	250.00- 400.00 ea.	Up to 20%
	Machine Enclosures	5-50	4.00- 8.00	Up to 25%
	Worker Shelters	4-20	250.00-3000.00 ea.	None



Before



After

Forging

Noise in forging operations has been reduced through the following techniques.

These diagrams indicate steps that have been taken to reduce noise in forging operations. Each star indicates where a modification was made to improve working conditions.

- 1) Resonance noise from gears has been damped.
- 2) Noise from tumblers, vibrator feeders, blast scoops, and furnace chargers has been damped.
- 3) Modifications in the air blow-off systems have been made.
- 4) Air release mufflers have been added to brakes and power cylinders on air operated hammers.
- 5) Hammers have been enclosed. A small opening was left at the operator's work station to allow for work. Enclosures were designed for complete removal in five minutes for maintenance.
- 6) Oil-fired burners were modified for noise control.

In addition improvements in the ventilation system have been made which are shown here. Fresh air is blown from an overhead plenum and contaminated air is exhausted out.

More details are available from the UAW Social Security Department based on research conducted by the Swedish Institute of Production Engineering Research.

Section V

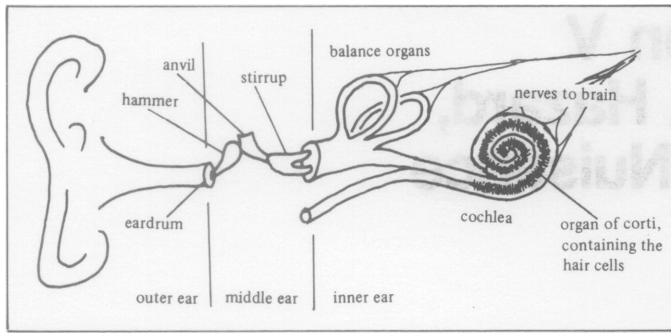
Noise Is A Hazard, Not Just A Nuisance



Noise can cause permanent hearing loss and can contribute to other medical problems. The current standard of 90 decibels is not strict enough to protect workers from these health problems.

At 90 decibels workers can have measurable hearing loss after a few years exposure. Therefore, the UAW is pushing for 85 decibels as a feasible standard. Even this level may not be strict enough. The Environmental Protection Agency (EPA) has identified 75 decibels as a long range goal for workplace exposure.

Nevertheless, meeting the current 90 decibel standard would be a welcome relief since noise levels above 90 decibels are common in industry.



How the Ear Works:

When sound vibrations hit the outer ear, the eardrum itself begins to vibrate. Connected to the eardrum in the middle ear are a series of bones which transmit the vibrations to the inner ear. A special snail-shaped organ called the cochlea in the inner ear finally receives the vibrations. In the cochlea there are thousands of tiny hair cells. These hair cells are very important since they change the vibrations into nerve impulses (the "message" of the sound) which are sent to the brain and the rest of the body.

Noise Damages the Tiny Hair Cells in the Inner Ear.

Too much noise will wear out the hair cells. Photographs taken through an electron microscope show the hair cells broken, bent out of shape, and completely missing as a result of noise.

The Upper Range of Hearing is Lost First, Interfering with Conversation.

The hair cells which are destroyed first are the ones which transmit high frequency sounds. A high frequency sound like the letter "S" will not be heard even though a low frequency sound like the letter "O" will be heard.

As you start to get deafened, at first you can't hear plurals, then, for example, you can't distinguish between fifteen and sixteen. Finally you can't understand what people are saying even though you can hear that they are talking.



Words may sound like grunts—"pass the sugar" may sound like "ar uh ugar." This is a gradual process, and not all people are affected equally. Perhaps it is too gradual for you to realize it's happening.

One day, someone says: "Didn't you hear what I said? I think you must be getting a little deaf. Your father was getting a bit deaf at your age. Perhaps it's in the family."

Perhaps the job is in the family too.

Mishearing, making embarrassing wrong replies to questions, combined with the mockery that many

deafened people suffer, can make you withdrawn, nervous to speak, isolated, miserable.

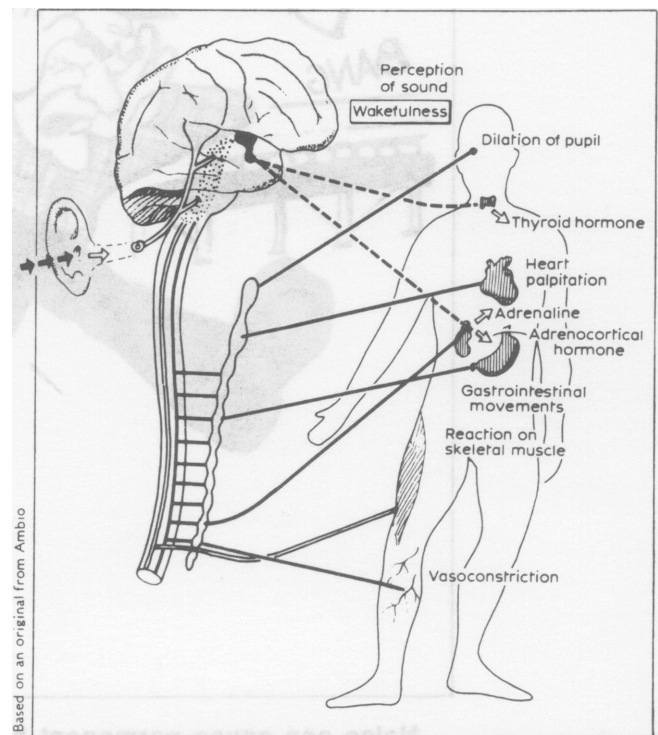
Noise Can Contribute to Nervousness, Anxiety, and Ulcers.

The nerve impulses sent to the brain are also sent to the rest of the body which stimulate various glands that produce hormones, like adrenalin.

Everyone knows a sharp noise in a quiet setting causes a person to startle. Constant levels of high noise causes a more or less similar body reaction: the body tenses and adrenalin flows.

Or to give a slightly different comparison, the sound of a grizzly bear growling behind you on a camping trip causes a certain stress reaction on the body. Constant exposure to loud noise can cause a similar reaction of stress.

In some cases this "alert" reaction is good since it helps a person avoid danger. But if the body is forced to remain tense and alert for long periods of time, it will begin to wear out and deteriorate.



As sound reaches the ear and is changed into nerve impulses sent to the brain, additional impulses are transmitted which reach the body's central nervous system and hormonal systems. The effects of noise on the entire body is thought to be caused in this manner.

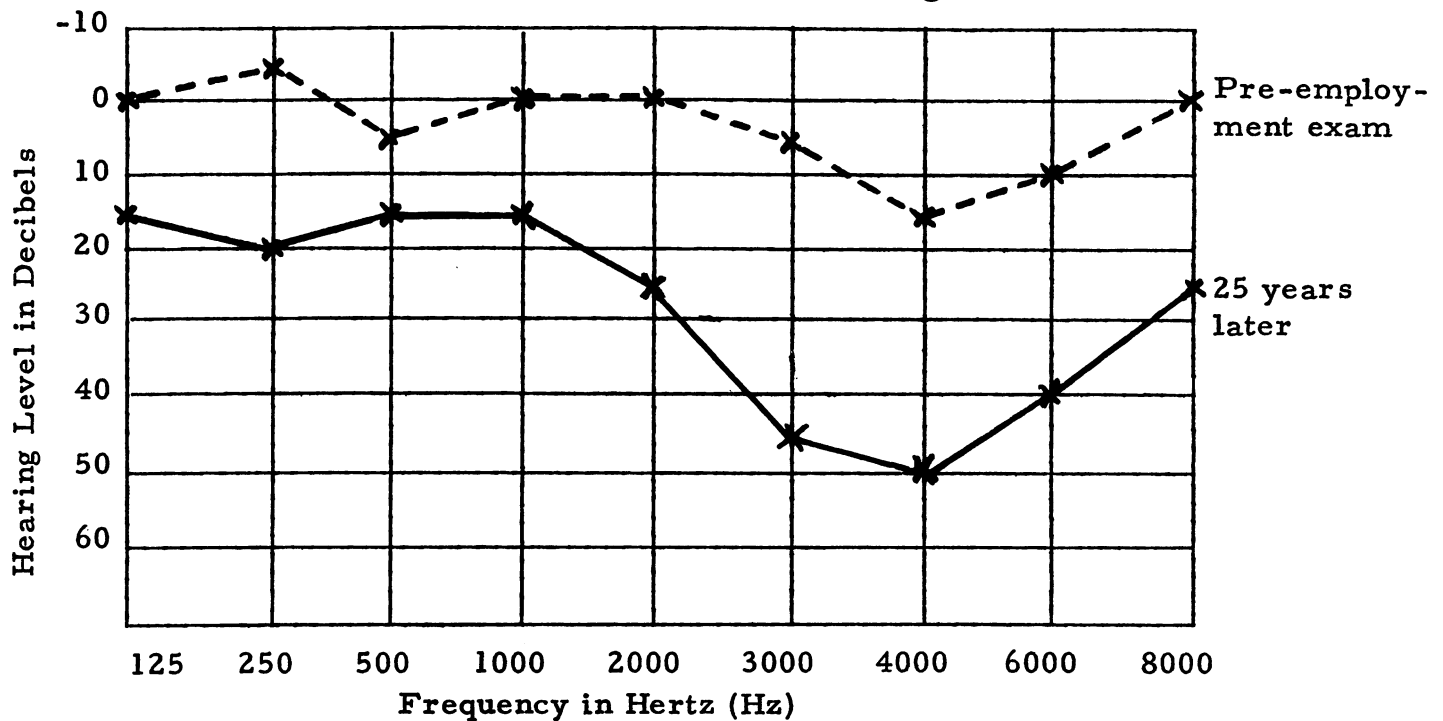
Noise May Contribute to Heart Disease.

Exposure to loud noise can cause the blood vessels to constrict. Thus, the heart has to work harder to pump the same amount of blood around. Through the years this may contribute to heart disease.

One recent study has indicated that workers in high noise areas have more blood circulation problems and heart problems than workers in non-noisy areas. Although other factors may be involved, it seems clear that noise contributes to these medical problems.

Much more research is necessary on these and other "non-auditory" effects of noise, especially as they relate to long term health problems.

How to Understand Your Audiogram



AN AUDIOGRAM SHOWING HEARING LOSS

This audiogram is typical of someone whose hearing was damaged by noise. It is difficult without a work history to determine what *sort* of noise caused the loss, but the pattern shown in the graph is typical of that caused by noise.

The numbers under the graph represent the various frequencies of sound heard during the hearing test.

The numbers to the left of the graph indicate how many decibels loud the sound is in the ear when it is first perceived by the person taking the test.

The dotted line on the upper part of the graph is taken from the pre-employment audiogram. The lower, solid line is the results taken after 25 years exposure to a noisy machine.

In this type of audiogram the lower the line, the worse the hearing.

Note that the hearing is worse and is lost first in the higher frequencies, especially at the 4000 Hz level.

Different type graphs can be produced by different sorts of audiometers, but most usually look something like the above one. Each worker should always ask for a copy of his or her audiogram and a medical opinion (written if possible) on the results.

Evaluating the Exposure.

The normal limits of hearing are about 10-15 decibels across the whole range of frequencies. Many people with good hearing actually have audiogram results at zero and in the minus range.

Any change at the 2000 Hz frequency is worrisome since this frequency is in the middle of the speech frequencies. Similarly any results worse than 20 decibels at 3000 and 4000 Hz is cause for concern.

A person with an audiogram like the one above most likely has trouble hearing people speak clearly.

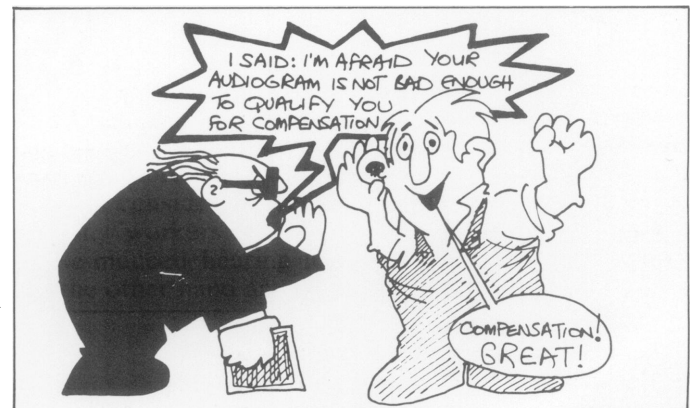
Compensation Schemes.

Most Workers' Compensation schemes take hearing loss at 500, 1000, and 2000 Hz and average them. Any result above 27 is compensable. In this case the hearing losses respectively are 15, 15, and 25, which average out to about 18 decibels loss. This is *not* enough to qualify for compensation, even though the worker is hard of hearing.

The U.S. Department of Labor uses a slightly different formula for federal employees. The hearing losses are averaged instead at 1000, 2000, and 3000 Hertz. Thus, in this case, the losses are 15, 25, and 45 respectively, which averages out to 28 and might qualify for a small amount of compensation.

Many reputable scientists believe that the loss at 4000 Hz should also be included in evaluations for compensation, but this usually is not done.

The whole issue of compensation for hearing loss is actually more complicated than indicated here and is in need of considerable reform. Most states do not provide for any workers' compensation benefits for long term noise-induced hearing loss. Some Canadian provinces on the other hand are making progress in this area.



UAW Social Security Department February 1978

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