CHAPTER 46

CONTROL OF COMMUNITY NOISE FROM INDUSTRIAL SOURCES

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INTRODUCTION

There are many potential sources of community noise in an industrial plant. However, there are only six general classes of noise sources: a) power generating units, b) fluid control systems, c) process equipment, d) atmospheric inlets and discharges, e) materials handling, and f) plant traffic. Although not a source, architectural and engineering deficiencies also contribute to community noise by allowing plant noise to escape into the community.

Within each of the above classes, there are several types of machines or processes that create the noise. The actual noise source within each machine or process is due to one of a very limited number of physical noise generating mechanisms.

Before describing each of the major industrial noise source categories, the physical generating mechanisms will be outlined, after which the machines, processes and systems in industry that generate community noise will be described. This will be followed by a discussion of the response of people to noise in the community and the methods for delineating or comparing community noise levels. The chapter concludes with a presentation of methods of reducing industrial noise in the community and the outlook for future needs and methods of noise control.

NOISE GENERATION

The noise generating mechanisms which occur in industrial machinery are: impact, gas flow phenomena, perturbations in fluid flow, combustion, friction, dynamic imbalance of reciprocating and rotating machines, and magnetic excitation. Each type will be discussed briefly with respect to the types of industrial machinery and processes and their particular systems of noise generation, transmission paths, and radiators.

Impact

The most familiar of the industrial impact phenomena are probably those from the forge hammer and the punch press. These produce intentional impacts which occur as a direct result of the energy in a flywheel or force of gravity on a drop hammer's mass being expended on the workpiece.

Other sources of impact include: repetitive chipping and scraping, bulk handling of small parts, e.g., tumbling, and the use of negative clearances in some processes. Another class of impacts is unintentional. This occurs when poor machine design, installation, or maintenance permits over-travel of machine elements.

Gas Flow Phenomena

The sound of escaping air or steam is probably the most familiar gas flow noise. However, other conditions associated with gas flow, such as turbulent flow and flow around obstacles, can produce noise. Where the obstacle is a sharp edge, it is possible to generate intense tones. Similar intense acoustic signals are generated by flow across spaced obstructions such as stiffeners in a duct. Flow across the face of a cavity will produce noise which can be amplified by other parts of the mechano-acoustic system.

Air flow causes noise. The hissing noise made by a high-pressure air line open to the atmosphere and the swishing noise of the air flowing past the open window of a car are both examples of air flow noise. There are two separate mechanisms at work here. In the open air-line case, the sound is generated by the non-uniform flow. In other words, the eddies or turbulences within the air stream generate noise, and the larger the difference in velocity between the air stream and the stagnant surrounding air, the more noise which is generated. In the second case, the obstacles in the air stream cause vortices downstream of the obstacle. Since it takes time for the vortices to form, be shed and be followed by another, a periodic system, the sound generated is characterized by tonal quality. Noise from such air flow generators can be amplified many times to produce intense whistles as will be discussed later. The usual sources associated with noise generation by air flow include fans, obstacles in air streams, leaks and open bypass valves in the air handling system, whether of high or low pressure.

The siren effect is responsible for many types of gas flow noise. A siren basically is a device which emits puffs of air in a cyclic pattern. Classically, it consists of an air supply and a rotating disc with holes that match one or more holes in the air supply. When the holes of the disc are aligned with those of the air supply or "wind box," air can escape freely. At other times, the air is essentially cut off. The repetitive release of air makes a sound of tonal character. The volume of air released at each matching of the holes determines the intensity of the noise produced. The siren effect is responsible for the noise of compressor inlets and air turbine discharges. Also, a similar sound is made by a power saw's teeth which cause perturbations in the air near the blade as the teeth pass fixed portions of the saw.

A special type of gas flow phenomenon which generates flow noises is the production of large volumes of hot, turbulent gases as a result of combustion of fuels, whether solid, liquid or gaseous. The expansion of the gas as it is produced and heated causes intense local acoustical disturbances. This gives combustion noise its distinctive low-pitch rumbling sound. Where combustion takes place unevenly, the noise is rough and uneven. In some instances the acoustic signal is so strong as to extinguish the flame which is reignited by a pilot flame or the heat of the burner, and this cyclic behavior can generate serious vibration, often resulting in structural damage. The noise is often an intense low frequency pulsation.

Friction

Another source of noise generation is friction. Although we generally associate energy losses due to friction with heat, friction causes two kinds of noise generation. The first is a series of miniature impacts as the imperfections in one surface are forced over another surface without any lubrication. The sound is somewhat like that from air noise and the sound output is a function of surface smoothness and speed. The second type of friction noise is stick-slip noise. Here, the friction causes a moving part to stop or slow down imperceptibly and as the driving force builds up, the friction is overcome and the parts slip by each other for an instant. Then, they grab again. This action produces high stresses in the parts and the sticking and slipping phases occur at high speeds, thereby producing an intense, high frequency phenomenon. Where the combination of part size and shape permit effective radiation of this type of sound, an intense sound will be radiated.

Dynamic Imbalance

Almost any kind of dynamic imbalance in high speed machinery will cause mechanical vibrations. Where the appropriate acoustical conditions exist, the vibrations will be converted into acoustical energy. This energy may be radiated efficiently by some machine parts and housings. Typical sources are fans, pumps, engines, (both reciprocating and turbine) and compressors. Imbalance forces may be transmitted through bearings. Although bearing noise is partly friction noise, bearings can generate noise by the impact of imperfections in the bearings on other bearing parts at high speed. This causes vibrations which are readily converted to sound by the castings and housings. Generally, bearing noise is not a major source.

Magnetic Excitation

Although electrical machines are not generally considered as noise generators, motors, generators and transformers are capable of being major noise sources. The magneto-acoustic forces occur as a result of the magnetic forces on conductors and rotor and stator. Since there is no magnetic bias field like that due to the permanent magnet in a loudspeaker, the magnetic fields developed at both the positive and negative swings of the power supply line voltage in AC machines cause an unidirectional force. Thus, for each cycle of the line frequency there is a magneto-acoustic force of twice the frequency. Because of non-linearities in the magnetic and mechanical systems, the acoustic output can have a high harmonic content. The radiated sound can, therefore, be rich in mid-frequency components. In some transformers and motors, the maximum levels occur for signals at six and eight times the line frequency.

In addition to the magnetic excitation, motors and generators produce noise from the radial blade fans used to cool the device by forcing air through or across the casing, and from the shear produced in the air as the slots on the rotor pass those on the stator.

Noise Amplification and Radiation

Except for a few of the sources mentioned such as fans, sirens, and air hoses, little noise would be radiated from equipment if it were not for subsystems which may be resonant or are efficient radiators. The most familiar resonant subsystem is the organ pipe. Without the pipe tuned to a resonance frequency desired, the noise made by the jet edge would be weak and would have little tonal quality. The pipe causes sound which has traveled to the far end to be reflected and transmitted just in time to reinforce the pressure variation at the jet, where a new, stronger signal is transmitted from the jet. The process repeats until an equilibrium situation occurs and a tone is radiated. There are other factors influencing the sound output of an organ pipe type of generator, such as the spacing of the nozzle and jet and their relative angular positions.

Cavities with small necks produce the familiar whistle when air is blown across the mouth. Castings can "ring like a bell," and machined parts such as gears can produce bell-like tones. Sheet metal panels can resonate over a wide frequency range, vibrating as either plates or membranes. The theory for these subsystems is presented in most vibration texts. Some specialized subsystems include machine shafts at the critical speed, gas furnace burners, cup burners, in which the source is inside the resonant structure, and machine room floors consisting of lightweight structural members.

Efficient radiators, formed by large surface area flexible bodies, may be combined with resonant subsystems. A small acoustical resonant subsystem, one side of which is formed by a large steel sheet, will drive the steel sheet as the coil in a loudspeaker drives the paper cone. The steel sheet will radiate the noise very effectively.

EXTERIOR SOURCES OF INDUSTRIAL NOISE

Power Sources

Furnaces and heaters provide the energy for a variety of industrial processes including the refining and fabricating of metals, generation of electricity, petro-chemical processes and a variety of kilns. In some new combined cycle plants, the hot gases operate gas turbines and then the same gases at lower temperature and velocity heat water in heat recovery boilers, the steam from which operates one or more steam turbines. Also, fossil fuel boilers generate steam for a wide variety of industrial processes. The basic process in all cases is combustion which by its nature produces thermal and pressure perturbations in the air which propagate as sound waves. Because of the slow rate of flame-front propagation and the high energy release involved in the combustion, the perturbations, and thus, the sound waves produced, are of low frequency and high intensity.

Furnace and boiler noise is often mixed with induced or forced draft fan noise, but where combustion is rough, the low frequency rumble is often clearly distinguishable. The pressure pulsations can readily shake windows and cause doors to rattle against their stops.

Both steam and gas turbine systems radiate considerable noise from both turbine casing and the connected ducts and piping. The gas turbine's inlet and discharge are often open to atmosphere. Without mufflers they generate noise which is generally unacceptable. The inlet radiates the intense noise at compressor blade-passing frequency and the discharge radiates the combustion noise. The inlet blade-passing sound is a high pitched signal like a siren. The exhaust noise is like the sound of jet aircraft exhaust.

Electrical power transmission systems can cause three types of acoustical noise that can easily be heard in many rural and suburban locations at levels quite high, with respect to the ambient noise. These are substation transformer hum, high voltage corona and switch-gear and circuit breaker operations. Transformer noise is usually highest in level at light loads occurring generally late at night. Transformer noise is characterized by the pure tone harmonics of 120 Hz. As the load on the transformer is adjusted, the signal changes character. In open country, substations can be heard for distances up to half a mile or more. The levels at 1000 feet can run in the 45 dB (A) range.

Corona noise which sounds like frying has a range of 50 to 70 dB (A) below the lines, and approaches these levels at houses along the transmission line right-of-way. It is highest in level when the corona discharge is most severe, during periods of high humidity, rain and fog.

The noise from air quenched circuit breakers is an explosive sound like a gunshot. When the circuit breaker operates, air at over 800 pounds per square inch gauge is used to cool and quench the breaker gap as the breaker opens. The result is a high pressure acoustic pulse which can run as high as 95 dB (A) at 1500 feet.

Fluid Control Systems

Pumps, both within and outside of buildings in industrial plants, generate high level noise. Generation of noise in pumps is caused by sudden changes in any of the flow parameters, volume, velocity and pressure, by turbulence, and by the mechanical noise generated by the bearings, seals, couplings and loose parts. The noise is transmitted along piping and conduit and is readily radiated from the pump casing, equipment enclosures and lightweight structural and building shell components.

Compressors generate noise at the inlet because of the rapid changes in velocity that occur as the inlet is either opened or closed in a reciprocating compressor or as the blades pass the cutoff in a centrifugal compressor. In axial flow compressors, the noise originates through the interaction of the fixed and rotating blades at the blade passing frequency. This noise is radiated from the casing of the compressor, connected structural members, and housing elements as well as from the downstream piping and ducting.

Fans and blowers generate noise in a manner similar to compressors, but work at lower static pressures. Many fans are exhaust or induced draft devices which are ducted on one side, but open directly to atmosphere on the other side. The noise generated by a fan will, in general, be a minimum at the most efficient operating point for the fan. Materials-handling blowers have an additional noise source, the interaction of the blade and the material itself, e.g., the scrap blower in a paper-board plant.

Any obstruction in a fluid flow system causes a change in velocity and can generate vortices at the trailing edge of the obstacle. In addition, many flow control devices obstruct the flow, e.g., fire dampers, and may generate severe turbulence downstream. This results in the generation of vortex noise, turbulence noise, and in some cases, intense pure tones due to the interaction of the vortices with some resonance condition in the pipe or duct.

Process Equipment

The term process equipment encompasses a wide range of systems and machines. Typical examples will be given, but it should be fairly easy to compare any process or machine to the list of sources, radiating systems and resonators in order to determine the acoustical system responsible for the noise associated with the particular device or system in question.

There are numerous sizes of mills ranging from table-mounted units to those enclosed by a large building, with basically the same process in each. A number of heavy hard rods, balls or knives within the mill, work upon the material to be milled, dividing the substance under the pressure of the balls, rods or knives until the material is reduced in size to the range desired. It may then be separated by size using vibrating screens, mechanical separation or flotation separation. In any case, the housing of the mill is acted upon by a large number of impacts. Because of the large relative area, the housing radiates the milling sound quite well. Connected with the mill are sets of gears, belts and bearings, which also generate large forces because of the energy being transmitted is high. Thus, a mill may generate bearing and gear noise in addition to the sound of the milling itself.

Crushers, particularly ore and stone crushers, require large amounts of power which is released in the destruction of the bonds holding together the particles of the material being worked. The result is a rapid series of high energy impacts. Crushers are often located out-of-doors or in lightweight sheds, and in either case radiate low frequency noise as well as bearing and drive equipment noise from the crusher structure, enclosure, or building.

Saws

Circular saws generate noise by siren action as the teeth pass fixed elements in the saw and as they pass into and out of the material being worked. Saws also ring in the manner of a gong, due to a plate resonance which can be excited readily by the teeth as they strike the work and by the siren tone. Even if used indoors, saws can generate noise which radiates into the community.

Cooling Towers

Among the major outdoor noise sources are the cooling towers used as heat exchangers in industrial processes, power generation and air conditioning. The cooling water is sprayed into an air stream resulting from the action of a powerful fan or blower. The water flows over a "fill" material which enhances evaporation by providing a large surface area for contact with the air stream. The combined heat transfer due to evaporation and conduction provide the required cooling. The noise generated by the fans and blowers is similar to what can be effected from such fans. However, they often generate low frequency noise because of low speeds and few blades. These conditions are dictated by the fact that these are low static pressure, large volume devices of great physical size. Another component which generates cooling tower noise is the water splash. This contributes a distinctive high frequency sound to cooling tower noise. When the fans are turned off, the splashing noise can be quite annoying.

Flare Stacks

In the petro-chemical field the disposal of waste gases is often accomplished by burning them at the top of a tower where the products of combustion can mix with ambient air and can diffuse sufficiently to reduce both concentration and temperature. The result is that the combustion takes place in the open at the top of a tower, providing clear line-of-sight sound propagation to the neighboring community. The sound is generated both by steam injection often used to suppress smoke, luminosity and instability of combustion, and by combustion instabilities often related to moderate and high wind velocities, flowrates and port characteristics.

Mechanical Power Transmission

The transmission of mechanical power can readily generate high noise levels as a result of friction and impact noise sources. Slight imperfections in gear teeth cause acoustically significant perturbations in the force transmitted. These perturbations are often amplified by resonators in the gear-shaft system and are effectively radiated by the machinery housing. The mechanical perturbations also shock-excite some components such as gears which then are free to vibrate at their resonance frequency. Here again, the part and its associated structure and housing may radiate the sound into the community.

Belted systems can generate noise by several means, the most common of which is friction noise. In general, belt generated noise is not a major problem until other noise sources are eliminated. Chain drive systems are basically impact generators as long as they are well lubricated, but if not lubricated, they can become friction noise generators and in some cases, the friction load on the bearings increases the bearing noise.

Bearings in transmission systems are usually designed to minimize friction. However, poor maintenance and overloading can soon turn bearings into high level noise sources. Since they are attached to the structure and often the machine housing, they can cause considerable noise to be radiated into the community.

High Pressure Atmospheric Inlet and Discharge

Rapid pressure fluctuations such as those occurring at the discharge of a diesel engine, or the inlet of a compressor, are radiated from the inlet or discharge as acoustic signals. The signal usually has a tonal quality or contains a pure tone (and harmonics) at the rate at which the port(s) open or close. At the engine discharge, the pulsations may have initial pressures at many times atmospheric pressure. In compressors, the large volume involved often leads to high velocities in attached piping. The pulsations from the compressor inlet are transmitted as high velocity perturbations down the pipe to the atmosphere where the pulses look very much like the exhaust pulsations from an engine.

Continuous flow discharge from steam, air and gas lines, and blow down from high pressure vessels and piping systems generate high level noise through turbulent mixing of the jet with the ambient air. At pressure about twice atmospheric, the flow from an air line becomes sonic; that is, the velocity at the outlet is at the speed of sound. At pressures above this, the velocity remains sonic, but the nature of the flow changes and can be supersonic downstream. In either case, high acoustic pressures are generated. The noise level is a function of the eighth power of the Mach Number below sonic velocity and depends mainly on the square of the pressure ratio across the opening above sonic velocity. The exact level is influenced, however, by the temperature (second power), molecular weight and compressibility factor for the gas (both inversely as the second power).

Materials Handling

The noise caused by materials handling is among that most often heard outside of many plants. Fork-lift trucks and front loaders and a variety of cranes moving around the yard generate noise with their motors and sometimes with their loads. Electrically operated cranes of large capacity can be heard over large distances late at night and are sources of complaint mainly because of the pure tone component. Conveyors make noise from two major sources, the material conveyed striking the sides of the chute or enclosure, and the bearings and rollers on which the moving belt, or in some cases, the material themselves move. Belt conveyors impose large loads on the bearings and rollers and these, in turn, can generate noise which is readily radiated by the enclosure and structure. The sound of the large number of wheels of the skate-wheel conveyor, because of the nature of the wheels and the structure, can radiate at levels which may exceed acceptable community goals.

Large vibrating shakers used to empty hopper cars radiate low frequency signals into the community by means of the large radiating area of the side of the car. The noise is often a maximum level below 30 Hz and can rattle doors, windows and the china and glassware in a house at several hundred feet. The noise level at the house is usually 80 dB or more at the exciting frequency. At this level, no earth vibrations will be measured and the signal may only be heard by a skilled observer when the area is noisy at higher frequencies. This is due to the reduced sensitivity of the ear at low frequencies, as well as the masking of low frequency noise and tones by high frequency noise. However, the low frequency acoustic waves cause the walls of the building to vibrate and, in turn, cause relative motion between doors, windows and shelves and the rest of the structure. High frequency vibrators (actually 60 and 120 Hz) will also radiate effectively when attached to large sheet metal hoppers. However, the noise level can be six to 15 dB higher when internal springs and rubber dampers break or slip out of position.

Other out-of-doors noise sources are the impact of large parts on other parts of loading platforms, the operation of dockside and platform elevators, and the use of powered material handling tools.

Plant Traffic

One of the most difficult noises to define and control in a modern industrial plant is traffic noise. The sources are trucks for the delivery and shipping of goods, rail cars in the shipping and classifying yards, and the employee automobile traffic. These sources might be only a moderate contributor during the day, but at night they may stand out against a much quieter ambient noise level. This will be particularly true where the plant operates a second shift and plant noise drops in level just before the outward flow of cars. Also early morning deliveries, before plant opening, can cause distinctive and annoying noise.

Architectural Deficiencies

The design of industrial plants must take into account the types of noise that will be generated within the plant. Openings made in the plant to install new equipment create a problem to be dealt with carefully. Among the most important items to consider are the adequacy of the basic structure and enclosure, and the prevention of any openings through which noise can escape inadvertently. Plant ventilation must be accomplished without allowing the vent openings to act as transmission paths between the internal noise and the community.

THE RESPONSE OF THE COMMUNITY TO INDUSTRIAL NOISE

The noise which is heard in a given location from sources far and near, including readily identified noises such as passing cars or barking dogs, is the *ambient* noise for that location. Removal of, or shutting down, all local sources under investigation leaves the only sound arriving at the measuring location the *background ambient* noise. The background ambient noise in a community usually consists of distant transportation noise.

Acceptability of Noise in the Community

Noise in the community may or may not be acceptable to the workers and citizens in the area. Without some "acceptable" noise to mask the more distant sounds and day-to-day activities of our neighbors, we should find life intolerable. Thus, the ambient noise serves a useful social function, as long as it stays within certain bounds. Noise becomes unacceptable in any particular situation when it is distracting, especially during creative activity and when it interferes with sleep or with speech communication. It is also unacceptable when it interferes with the ability to hear speech or the sound portion of television, radio or recorded programs. Industrial noise can probably be acceptable at these relatively high levels, 50 dB (A) or more, out-of-doors when it meets certain criteria:

a) it is continuous,
b) it does not interfere with speech communication (on the patio, at the dinner table, or in the office),
c) it does not include pure tones or impacts,
d) it does not vary rapidly,
e) it does not interfere with getting to sleep, and
f) it does not contain fear-producing elements.

There are many other parameters which influence the acceptability of noise by individual residents or groups of residents exposed to any particular noise. Thus, although physical measurement of the sound level is important, it cannot effectively predict the response of any specific neighborhood or community to a particular noise source. In fact, the relationships as will be determined later, between the community and the operator of the noise source, and the responsiveness of the local political authority, may have a greater influence on acceptability of a noise than the noise level or quality.

Measurement and Evaluation

Both the A-weighted sound level and octave band analyses have been the major physical methods for measuring noise for purposes of evaluating its effect on the community. Octave band analysis permits the comparison with contours such as the noise rating chart or a municipal code. Studies have shown that even though it was designed for another purpose, the A-weighting does rank human response to noisiness and loudness quite well over a wide range of levels. Other schemes using manipulation of octave band data such as the Perceived Noise Level (PNL or PNdB)[1] or loudness[2] in sones have been used with some success for particular applications. The PNL is derived from equal noisiness contours similar to equal loudness contours but with a sharp increase in sensitivity in the range 1500 and 8000 Hz. In an effort to provide a single reading comparable to the A-weighted measurement, the D-weighted curve based on the 40 Noys perceived noisiness contour has been used.

None of the methods used except Composite Noise Rating (CNR),[3] based on the Noise Level Rank Curves (Figure 46-1) have shown any relation between noise and the community response.[4] Recent efforts to use single number

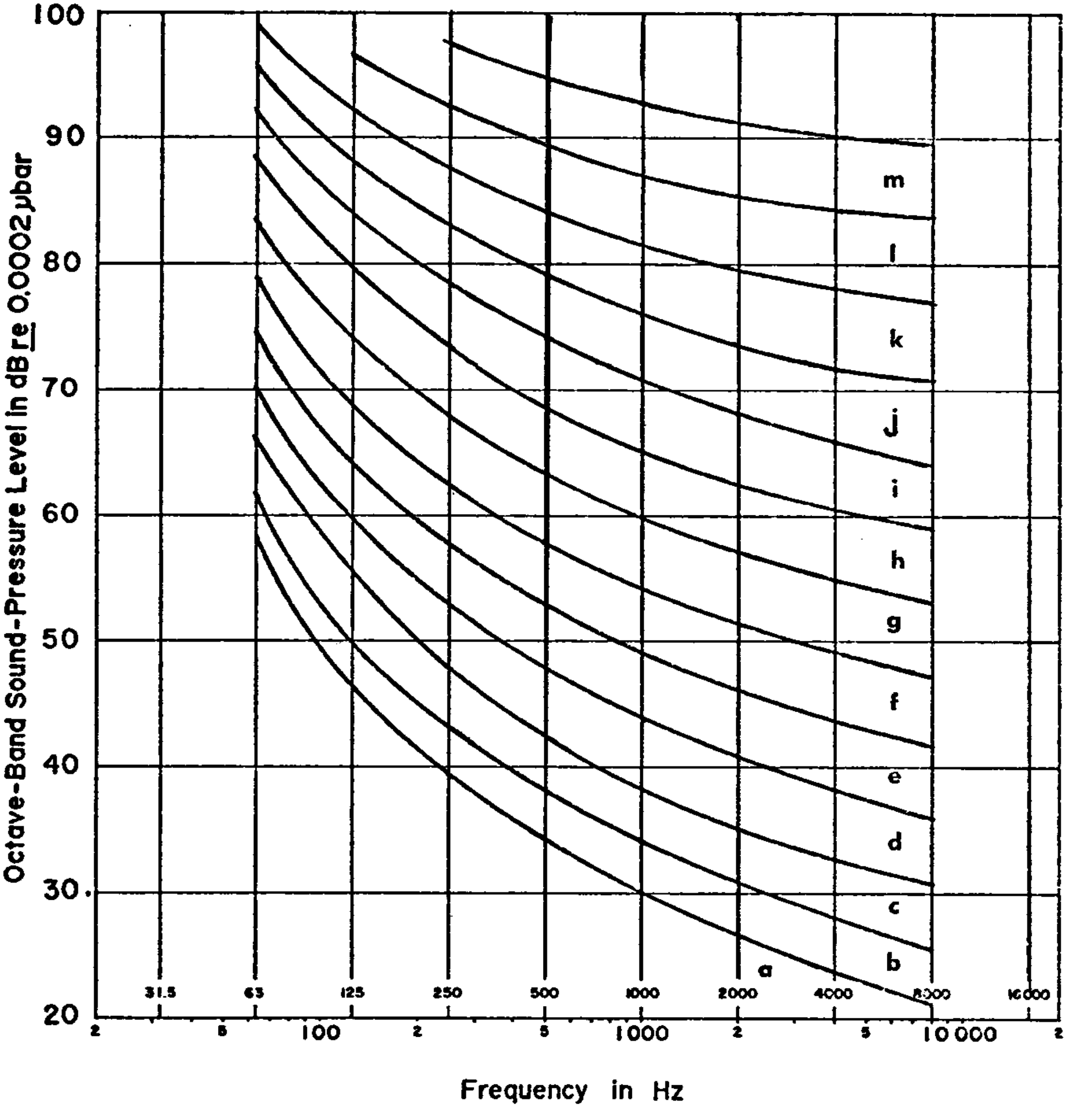


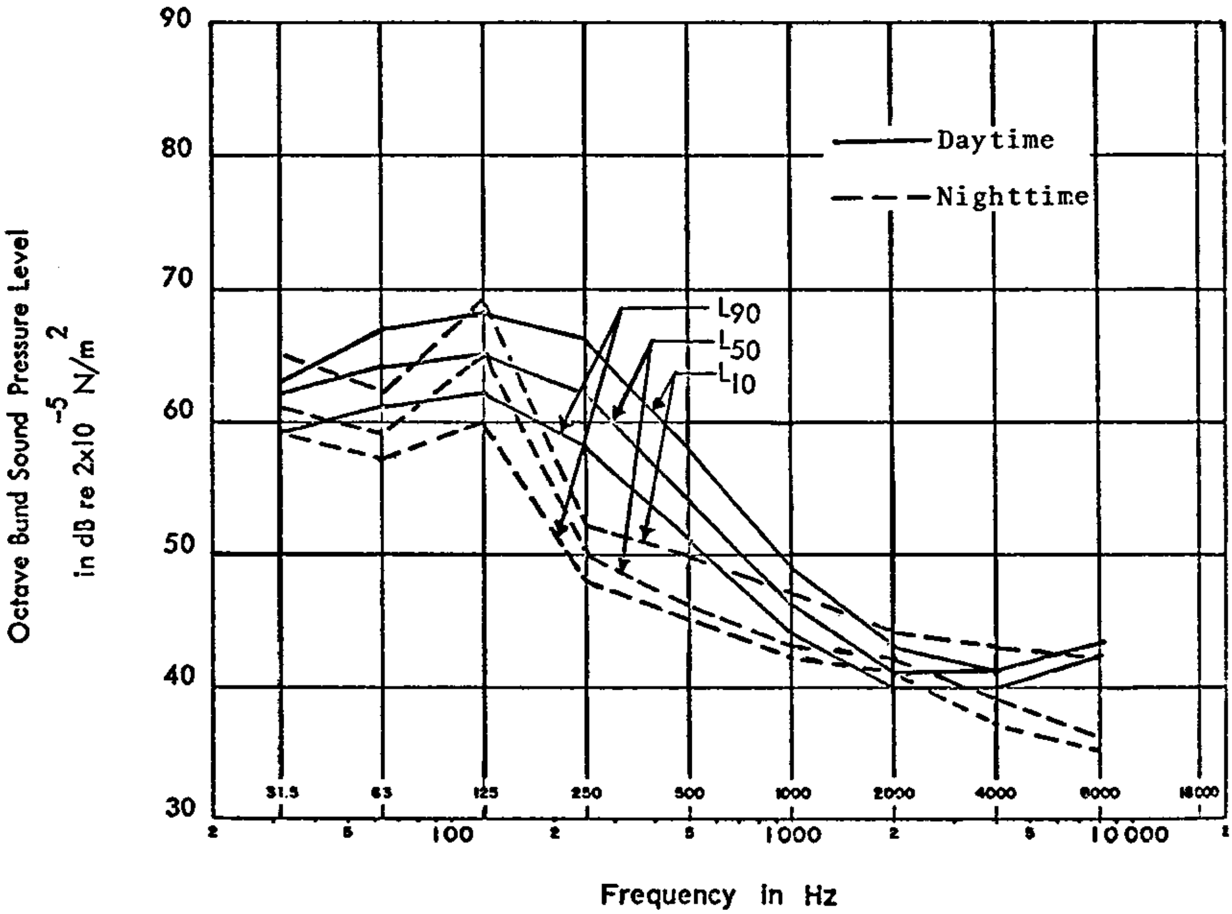
Figure 46-1. Noise Level Rank Curves.

measures such as the A-weighted level alone or Noise Pollution Level (NPL) have not been successful.[5,6] A new effort using the A-weighted level modified by the same factors used in CNR has been proposed by Eldred and tested in a number of situations. Called "Normalized Community Noise Equivalent Level (NCNEL), this measure is based on the daily time history of the noise exposure expressed in terms of the A-weighted reading occurring in three periods: day, evening, and night. A table of adjustments covering the nature and extent of the exposure, the ambient levels against which the noise is heard and the attitude of the persons exposed, is used to adjust measured values, (Table 46-1). When the adjustments are made, the NCNEL may be plotted on a chart that indicates the expected range of response of those exposed.

Noise Pollution Level (NPL),[5] which is currently quite popular, attempts to use the statistical properties of the noise exposure to describe its noisiness. NPL is defined as $L_{eq} + 2.56 \times s$ where L_{eq} is the energy average of the noise as indicated on a level recorder or on a statistical analyzer. Here, s is used as the standard deviation of the noise levels from a large number of one second samples taken during the measuring period. Unfortunately, NPL does not distinguish between the quiet residential background on which are superimposed many children at play and passing neighbors' cars versus the rather steady but high noise level of a downtown commercial area. There is not enough information in the statistics alone to describe the noises that do or do not cause a large standard deviation. One common treatment of data is the use of the tenth and ninetieth percentile of the measured levels to indicate the nature of the noise exposure. The 90 percentile values are considered to be the background ambient (the noise levels are above this value 90 percent of the time, while the 10 percentile values are those of the intrusions). The spread between the two is related to the standard deviation, but the absolute levels indicate its effect on speech communication.

Effect of Social-Political Environment

The response of a community or neighborhood to an industrial noise is, as has been noted above, not necessarily related to the level of the noise. There are many influences, not the least of which is an interaction between the industry and the municipal council and the citizens. It is sometimes two-sided and sometimes three-sided, but it is invariably a process of accommodation on each side. Whenever an industry proposes to locate a plant in a municipality, it has decided to do so on the basis of at least a preliminary investigation of the site. Corporate officials will have talked to local officials and there is some anticipation on both sides that the industry will provide jobs and tax income to the community and that the municipality will welcome the industry by accepting the gaseous, particulate, and liquid wastes and the increase in street traffc. However, after the initial decision to build a plant is made, the company must submit plans for zoning approval at one or



U.S. Environmental Protection Agency: Noise from Industrial Plants, Report NTID 300.2. Washington, D.C.

Figure 46-2. Example of Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} percentile values were obtained from 100 samples with one second integration time.

TABLE 46-1

Level Rank Chart. To Obtain Composite Noise Rating of a Noise Exposure (CNR), the Sound Spectrum is Plotted on the Chart and the Highest Level Rank Band Penetrated, Determine the Level Rank. The Level Rank is Then Adjusted One or More Steps According to the Table.

LEVEL RANK CORRECTIONS FOR CNR

a)	Very Quiet Suburban	+1
	Suburban	0
	Residential Urban	−1
	Urban Near Some Industry	−2
	Heavy Industry Area	−3
b)	Daytime Only	−1
	Nighttime	0
c)	Continuous Spectrum	0
	Pure Tone(s) Present	+1
d)	Smooth Temporal Character	0
	Impulsive	+1
e)	Prior Similar Exposure	0
	Some Prior Exposure	−1
f)	Signal Present: 20% of Time	−1
	5% of Time	−2
	2% of Time	−3

more public meetings. Officials must answer questions from municipal officials and the public. The process may have to be repeated four or five times. Finally, the plans must go to the municipal governing body where public and local officials can repeat the process. Some citizens groups have been known to arrive with lawyers and experts, while the company arrives with top officials and its experts. After appropriate parrying, each side offers some accommodation, and then the governing body may decide to approve the plans or ask for resubmittal. In all of these proceedings, noise is likely to be an important consideration. When the decision to accept the plant is given, the company involved may withdraw its plans and seek another site in a different municipality because it has sensed the hostility of the community that it will have to live with for many years. Even where the approval is granted, the municipality still maintains control. When the plant is completed it cannot be occupied without a certificate of occupancy. This must be issued by the building inspector who will have been monitoring construction. If he and the other officials are not satisfied, no Certificate of Occupancy will be issued until the "deficiencies" are "corrected." Finally, the municipal and state health officers and the state labor department must approve the plant and its operations.

Thus, the process of accommodation works to maintain some moderation of the noise radiated into a community neighboring an industrial plant (Figure 46-3). Even where a plant has existed for many years in reasonable harmony with its neighbors, a change in the plant that allows an increase in sound levels in the neighboring community is likely to cause an immediate response on the part of the neighbors. In some cases this results in demands for lower noise levels than existed prior to the change. In some cases the interpersonal relations between plant officials and neighbors may result in continuing skirmishes that preclude any satisfactory accommodation on the part of the parties involved. Even when the plant offers to buy neighboring homes at a premium, some neighbors may refuse, even if almost all of the remainder of the neighbors have left what was a substandard housing area.

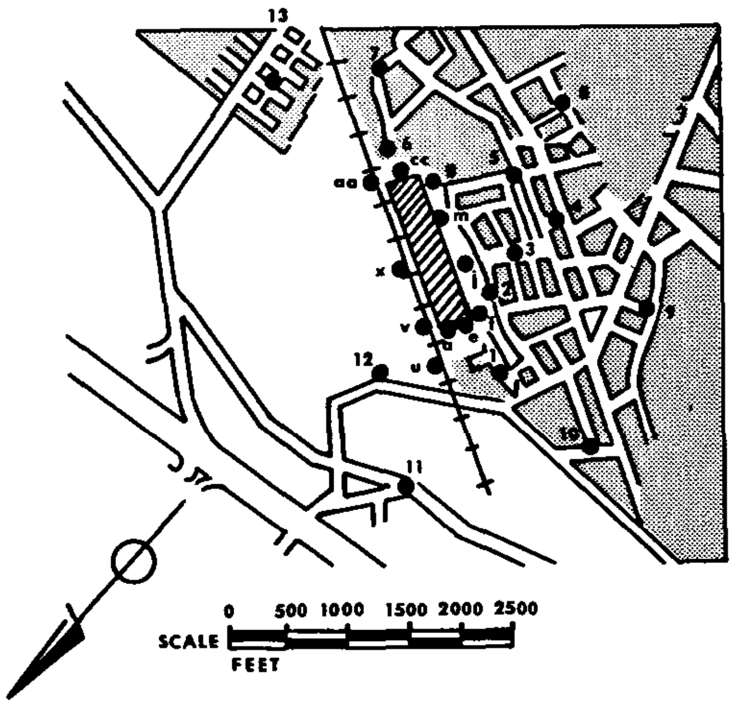
In some locations, single individuals have kept up such fights with major industries and have forced local officials to take legal action for violations of local health statutes even though the enforcement results from a personal vendetta. In general, the accommodation process has maintained the noise levels in communities across the country at levels just below that at which neighbors will complain (Figure 46-4). These noise levels may be higher than is socially desirable, but often they are also just below the noise from transportation noise sources, nearby highways, truck routes, and parkways.

The current effort to abate transportation noise may leave industrial noise as the major noise source in some areas. With the industries now clearly setting the ambient level, it may be that a new round of accommodation will occur.

THE CONTROL OF INDUSTRIAL NOISE SOURCES

Industrial noise sources expose both the employees within the plant and the neighbors in the community. Often the same machine producing levels of 90 to 100 dB (A) around the machine indoors can be heard in the nearby residential neighborhood at levels from 40 to 60 dB (A). Some industrial noise sources as outlined earlier are out-of-doors and may or may not expose employees to hazardous noise levels, but because they can generate high levels of noise they can be heard at distances up to a mile from the plant. Close to the plant the noise levels may be well above the ambient, and can be unacceptable. The following section discusses the general methods of quieting industrial noise sources, and in some cases, mentions specific hardware.

The first requisite for a noise reduction program is a carefully done noise survey. Made at or near the plant boundary or closer, it should be possible to identify the major contributors to the noise in every direction around the plant. It may be necessary to make some measurements during a shutdown, and others close to small machines, to examine how much noise they might contribute to the total sound level in any given direction. With this information, the amount of noise reduction required at each machine may be evaluated. From the physics of the situation it is clear that if three or four different sources contribute about equal energy at a given point at the plant boundary, and thus, in the community beyond, *all* must be quieted to some degree. Clearly, if four machines generate roughly the same noise with about the same spectrum, eliminating the noise from two will only cause a three dB drop in level, and shutting down three would yield about



Community Noise Levels in dB(A)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Weekend	46	54	45	39	41	43	-	-	48	41	41	51	43
Weekday	50	59	44	42	42	40	44	40	41	44	39	53	43
Weeknight	52	61	46	40	43	45	43	40	41	41	42	49	42

Plant Property Line Noise Levels in dB(A)

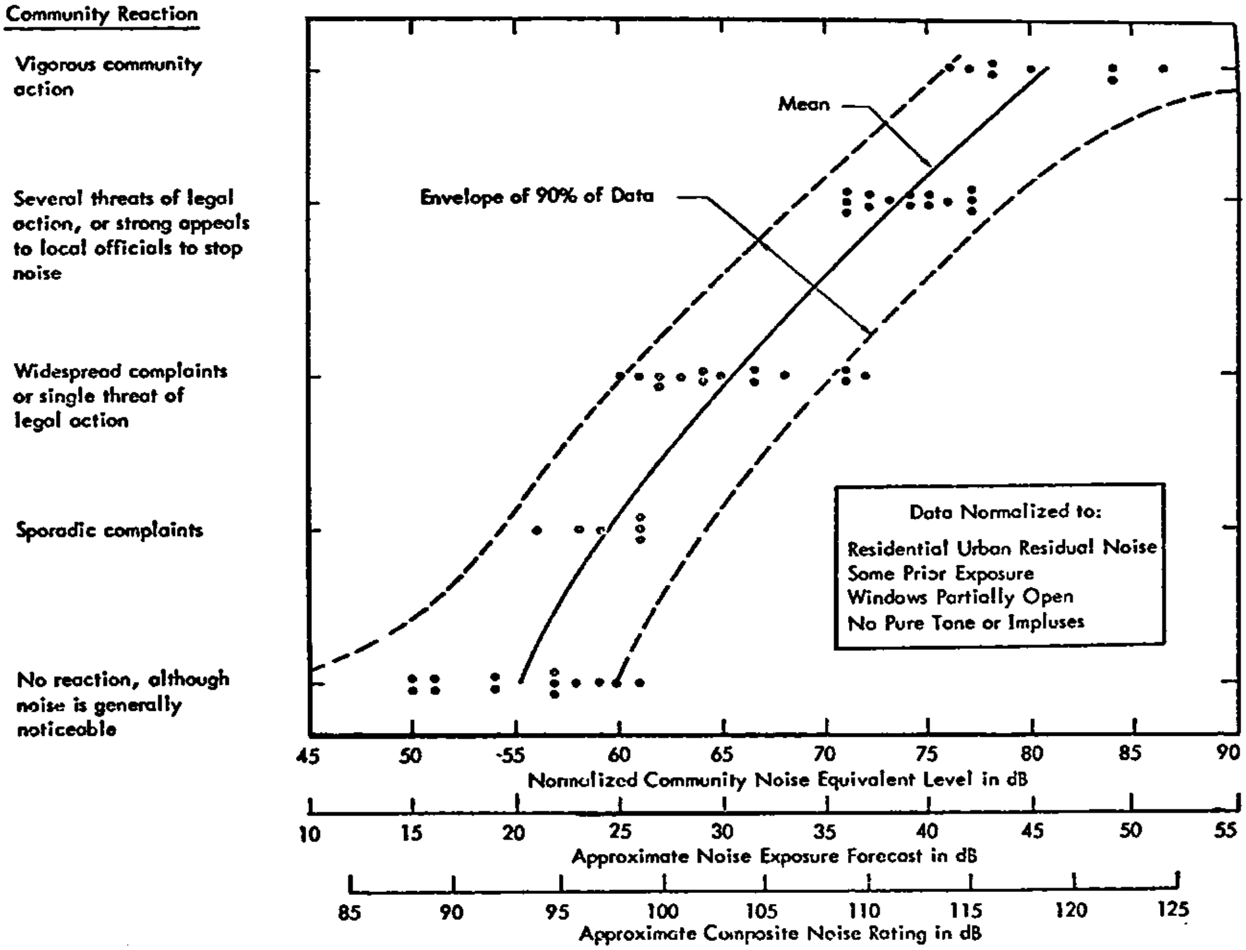
	a	e	f	j	m	q	cc	aa	x	v	u
Weekend	50	62	59	68	55	41	44	40	60	65	52
Weekday	49	64	61	68	59	49	50	49	66	68	55
Weeknight	51	64	63	69	58	48	41	46	61	65	54

Key

- Industrial Noise Source
- Residential Area
- Railroad Track
- Highway
- o Measurement Location

U.S. Environmental Protection Agency: Noise from Industrial Plants, Report NTID 300.2. Washington, D.C.

Figure 46-3. Example of a Noise Survey around an Industrial Plant. Levels were measured directly with a sound level meter.



U.S. Environmental Protection Agency: Noise from Industrial Plants, Report NTID 300.2. Washington, D.C.

Figure 46-4. Relationship of Normalized Community Noise Levels and Other Human Response Scales and the Expected Community Response. (From Community Noise, U. S. Environmental Protection Agency Report NTID 300.2).

six dB reduction. Thus, a careful examination of the options is in order after the data are assembled.

Once the decision to quiet a given machine is made, detailed sound measurements and a study of the entire machine on a systems basis is in order. The sources within the machine must be identified, the various transmission paths for acoustic energy must be found by both inspection and measurement (acoustical and vibration), the radiators must be located, and finally, the resonators or feedback mechanisms must be found. When this study is completed, it will probably be clear what measures will provide the most noise abatement at the least cost. It may be possible to modify the source, leaving the path and radiators alone, or it may be possible to operate on two, three, or more of the system elements to varying degrees yielding an optimized-cost treatment of the system to produce a specific minimum required noise reduction.

Source Noise Reduction

Intentional impacts are used in forging, shearing and stamping. The desired result is achieved only by an impact. Source reduction is difficult, although in shearing and stamping, die design and rate of operation do have a major influence on the noise. Also, the nature of the metal being worked strongly influences die design and noise output. Increasing the total time for the actual work on the material will usually reduce the sound output. This may reach a limit when the total stroke time is used for work. Any further change leads to a reduction in output. Many parts of presses and shears radiate the noise unnecessarily. It is possible to enclose partially some automatic presses; and large radiating surfaces, including belt and chain guards, can be damped as described below. The use of plastic shields and snap-out barriers close to the stamping dies should permit a reduction of several dB at the operator's position.

Unintentional impacts can be found by inspecting the clearances with the machine operating with illumination from a stroboscopic light source just off synchronism with the machine. Extreme care must be used not to touch parts that look like they are "standing still." It may be necessary to provide viewing ports or to use mirrors to make the required inspection, but the results may be surprising. Rods and levers that appear to clear other parts when the machine is "turned over by hand" will whip at high speed with some being in mechanical resonance. Others may just be inadequately designed for the task. Rattling case parts can also be spotted by use of the strobe lamp. The obvious answer is redesign of the part, either using a more suitable section to prevent flexure or better connection at "crank-to-lever arm" connections that whip sideways. Each situation is different, and some will tax the designer's ingenuity. The problem is basically mechanical design, not acoustical.

Gas flow noise sources can often be controlled through the use of mufflers. Mufflers for high pressure lines are made in sizes for pipes from 1/8 inch diameter up to 60 inches in diameter. They can provide extremely large reductions in noise level when correctly designed and made. The sizes from 2½ inches up are often called snubbers and are offered in a wide range of styles including steam and water separator units. Units for compressor inlet and engine discharge are designed to operate in the appropriate temperature range while handling the pulsations encountered in the respective services. These differ from units designed to quiet continuous high pressure supersonic gas flow discharges where a special inlet diffuser section is required. In every case the muffler must be designed to withstand the high forces that occur both on the casing and on the internal baffles and tubing. Also, they must be fabricated from appropriate materials for the service intended.

Small and miniature mufflers find application on production line valve discharges. Spool valves are particularly easy to quiet using small units. The number of unintentional discharges through disconnected lines or bypass valves is surprising. In some cases these can be capped, thus preventing wastage. In other cases slight changes in process control can be made to eliminate the discharge.

Another solution to valve discharges to atmosphere is to manifold the discharge lines to a header which may serve as a muffler because of the large expansion ratio from the inlet pipe to the header. In other cases the collected discharge can be piped away to an outlet where the residual noise will be no problem or a single muffler of appropriate size used.

In some instances it is clear that the use of high pressure air is unnecessary, but it is used because it is available. A pressure reduction device (regulator) at or near the machine can reduce the sound output considerably.

Valve noise in high pressure systems and the noise from centrifugal compressors radiated by the piping can best be eliminated by "lagging" the piping or valve.[7] The use of a two- to four-inch thick medium density mineral wool or glass fiber "spacer" covered by a one lb./sq. ft. jacket of lead can yield high frequency noise reductions of 30 to 50 dB. Higher reduction values may be obtained, but it is difficult to cover every valve and pipe support. Actually, flanking transmission usually begins to predominate beyond about 50 dB of reduction. The jacket may be sheet metal or any appropriate weather resistant material providing the required weight. Asphalted roofing felt, leaded vinyl and leaded neoprene have been used in some applications.

The control of perturbations in fluid flow is usually a job for the machine designer. This involves the design and spacing of the fixed and stationary blades in compressors, the blade shape and cutoff design in centrifugal pumps and blowers and fans, and the nature of flow control in positive displacement pumps. In general, these devices lose efficiency rapidly when changes are made from the optimum design. However, casing design to minimize cavitation in pumps can yield lower noise output. Use of pressure equalization chambers, snubbers and mufflers in both liquid and gas systems and lagging have been the accepted methods to date.

In fans and blowers every effort made to reduce the tip speed of the unit does help to reduce noise, but tip speed alone is not an adequate index of fan noise output. Noise in fans and blowers may be increased by having struts or braces in the air stream such that, with axial flow units, the blades cut the wakes made by the obstruction. This can produce intense tones when the blade-passing frequency coincides with the vortex shedding frequency of the air-flow obstruction system. In low pressure air handling systems noise generated by turbulence at turns, dampers and mixing boxes can usually be avoided by good design. However, air conditioning style mufflers can be used. These are usually a series of sound absorbing baffles on six to 12 inch centers. The sheet metal work is relatively light for residential and commercial building use. Special industrial grade mufflers are available, fabricated from heavier gauge metal with better assembly. Here again, material of construction is governed by the environment and the gas handled. These mufflers have sometimes been applied to cooling tower inlets. Cooling tower discharges may be equipped with mufflers, but their effect on the fan characteristics may be so great as to raise the source noise and yield no net effect on the sound output.

One way to eliminate noise is to get rid of the source by modifying the process or system. Many industries faced with problems related to cooling tower noise use wells and return the water to the ground after passing it through a heat exchanger. In many cases local streams used for process water have been used for cooling, but current and proposed restrictions on thermal pollution will keep cooling towers in the picture for some time to come. The use of natural draft cooling towers solves most of the noise and discharge temperature problem, but these are large and costly structures.

A change in design and operation can often effect the appropriate noise reduction, sometimes at a cost in efficiency. In one case, when night operation of one cell of a three cell cooling tower caused neighbors to complain, the electrical circuits were modified, the motors rewound for two-speed operation and two cells were operated at about half-speed at night. The fan noise varies as the fifth power of velocity and operating two units only brings it back up three dB. This yields a net drop of about 12 dB.

Another case of changing processes is to switch from deep drawing to spinning for fabrication of large objects of circular section. A change from oil fired combustion with high pressure air for atomization and combustion to gas firing with a totally-enclosed muffled burner has been used successfully on single and multiple burner furnaces. Also, the switch from induced draft operation where muffling hot stack gases is difficult, to a forced draft system with inlet mufflers, results in considerable noise reduction. The noise radiation formerly from the top of the stack now takes place at ground level where buildings act as barriers.

Mechanical damping, most familiar as automobile undercoating, can reduce the amplitude at resonance frequencies in a panel or even in structural members, thus reducing radiation and feedback to the source, and in turn, reducing the driving forces. Damping can be effected by applied coatings of mastic or fibrous materials such as jute or wood fibers and foams. Also, friction between two metal surfaces not adhered to one another over their entire surface is used. Air trapped within the space between two plates may provide added damping. The most effective damping may be obtained with a thin layer of elastomeric damping compound between the sheet to be damped, and a thin constraining layer, such as metal foil or a lightweight metal sheet. Although damping is conventionally applied to large metal enclosures, it may also be used to control resonance of gears and sheaves by applying damping to the web or "spokes" as a constrained layer or a filler compound for hollow parts. With some components it may be possible to apply a damping disc or other mating form on one or both sides of a resonant part.

Considerable noise is generated by loose parts, rattling covers, worn bearings, and broken equipment. Reductions on the order of six to 10 dB may be achieved through maintenance alone, and in some cases, spectacular results are possible when cases are resealed or even just screwed back onto the structure.

Transmission Path Noise Control

It is sometimes difficult to determine what part of a system is the source and what is the transmission path. Sometimes the decision is arbitrary. In any case, a muffler may be used along the path or at the end of a line to eliminate not only noise generated at a given machine, but flow discontinuity noise generated at turns, dampers and valves along the way. It is sometimes necessary, especially in the case of high temperature exhausts, to split the muffling between a unit near the engine and one near the discharge. The unit near the engine will reduce the input to the exhaust pipe and minimize the possibility of shock wave formation, and the discharge unit will remove any noise signals introduced along the way and clean up any small shocks formed. As mentioned above, manifolds are useful for collecting the discharge from several small lines and can act as mufflers. This does not always work because of resonances with the header or manifold. Appropriate baffles and inlet diffusers inside the header or manifold will prevent problems with resonance.

Inside plants, and out of doors, large barriers[8] and partial enclosures provide considerable attenuation of noise, provided the barrier or enclosure is located close to the source and is not negated by reflections from a wall behind the equipment. Barriers with acoustical material on the surface facing the source wtih similar material on the wall behind can be quite effective. Enclosures are similar to barriers until they are fully sealed. Fully sealed enclosures provide varying degrees of noise reduction determined by the frequency of the noise and the transmission loss (TL) of the panel material. The TL is generally higher for more massive materials. However, even a one-to-four pound per square foot material such as damped sheet metal or cement asbestos board will yield a reduction in the A-weighted sound levels of 20 to 30 dB. If the seal on an enclosure is broken for ventilation, the TL will be reduced greatly, unless a vent muffler is installed. Such mufflers are produced as standard hardware by several manufacturers who also manufacture complete enclosures, and duct and blow-off mufflers. The vent mufflers may be equipped with fans having explosion-proof motors as required.

The use of acoustically absorbing material similar to acoustical ceiling tile can provide some reduction for interior noises heard out of doors and for some out-of-doors operations such as at loading docks. The materials used for industrial application must be fire resistant and should be applicable to large areas. Spray-on materials were popular for some time, and the recent trend away from asbestos fibers toward open cell urethane foams and cellulose materials should also provide appropriate results. Sheets of mineral or glass fiber board with perforated or decorative open-faced material (expanded metal) are also useful although they require structural support. The perforated metal must have relatively small holes on close centers, typically no more than one-half inch centers and holes from 0.06 to 0.15 in diameter. The holes and spacing should yield an open area of more than 15 percent, preferably 30 to 40 percent. The most effective acoustical materials will have high sound absorption coefficients in the frequency range in which the noise levels are highest. However, good high frequency absorption is usually desirable. For industrial applications it is not sufficient to look at the "Noise Reduction Coefficient" because this is the average of the individual coefficients for the test frequencies 250, 500, 1000, and 2000 Hz, and since the noise to be controlled is in the 2000 to 4000 Hz range (air discharges and cleaning jets), the sound absorption values at 2000 and 4000 Hz are critical to the noise reduction.

An interesting and useful facet of area noise control with acoustical material is that the entire ceiling and walls of the plant need not be covered. A coverage of 60 percent spread over the entire area of the ceiling is almost as effective as the entire ceiling and usually a lot less expensive. Wall treatment near the source of noise is always effective. Examples have indicated 12 dB reduction at remote locations due to corner treatment close to a machine.

There are some situations where muffling, enclosure, or machine modification are not readily feasible, but moving the machine is quite simple. Moving a small positive displacement blower from one side of a plant building to another can yield 20 to 30 dB reduction at the fence on the side of the building facing its original location. This works as long as the other side does not face a residential area also. This uses the plant as an acoustical barrier. There are numerous applications of this barrier effect, and they are an economical way of accomplishing the desired purpose. It may take some ingenuity. As an example, many plants face highways and other transportation complexes, while the rear faces nearby residential zones. Although routine plant design does not locate major items of equipment along the face of the plant, it may turn out to be a reasonable design; suitable decorative screening is a low price to pay for the acoustical benefit.

Because plant buildings are designed for the protection of employees and equipment from the weather, they often do not include noise control considerations. Louvers, windows and doors may all serve to provide effective ventilation and materials flow. However, they also permit noise flow from the interior to the neighboring community. There is much to favor gravity flow ventilation, and employees in some plants resist the use of mechanical ventilation unless it is accompanied by air conditioning. However, closing up the louvers or using acoustically treated louvers and forced draft ventilation with muffled fans will solve many noise problems. Curtain wall plants using corrugated sheet skins that are not sealed, or damped, may let sound out through both the wall and leaks. Plant design must account for the high noise levels inside and the large radiating area provided by the walls. Also, loading dock and plant storage yards where active materials handling is carried out at night may require some planning in order to control noise. The use of perimeter storage sheds as barriers can effect noise control.

Administrative Procedures for Noise Control

Traffic noise, especially for the end of the second shift and early morning arrival, can readily be effected through an education or training program for the employees. This must be a positive and continuing program and make use of appropriate traffic control systems within the parking lot and around the plant. In some cases the use of multiple exits help. The problem of employees' talk at side yards adjacent to neighboring residential property can also be controlled through a continuing education and internal public relations program.

PLANT NOISE ABATEMENT

A number of sources discussed at the beginning of this chapter require a multistep approach or multielement approach in order to quiet the entire system. Steam power stations, for instance, require noise control of fans, blowers for forced and induced draft, materials handling systems, burner noise in fossil fuel systems, and steam and gas turbines when those facilities are used. Heaters and furnaces in petro-chemical and process industries may require mufflers for the high pressure blowers, cooling blowers and the burners themselves.

Transformers are extremely difficult to quiet internally, although premium transformers are available which provide a modest amount of noise reduction. The most common technique today is to build partial enclosures around the transformers using special sound absorbing concrete blocks which are "tuned" to absorb the transformer generated signals.

Circuit breakers have received moderate attention with respect to quieting, but because they are not activated frequently they should not be a consistent problem. Location in an appropriate area is probably the most convenient method of handling them. Corona noise is currently under study.

Another area in which a multielement approach must be used is in process industries where each machine or process element must be examined for noise generating capability and then quieted according to need. Large mills located inside buildings may cause no community noise problems so long as the building is well sealed. In some cases, the building supports the mill and radiates the noise. On the other hand, rock crushers located within a sand and gravel operation may be totally exposed to the neighbors. In this situation, a partial enclosure of appropriate sound absorbing and transmission loss material combined in one shell would reduce the noise sufficiently to eliminate community complaints. Such materials are commercially available. Items such as switch valves, blow down lines and high pressure air or gas bypass lines should all be equipped with appropriate mufflers.

Material handling devices such as fork lifts, motors, and cranes can be quieted by attention to the engine inlet and discharge mufflers. Electrically operated overhead cranes may require a small motor enclosure with forced air cooling if the unit is to operate out-of-doors at night and not be heard by neighbors. Conveyors are subject to both quieting through maintenance and improvement in bearings, or they may require partial or total enclosure. Conveyors that carry materials adjacent to or through a community overhead, may require a partial enclosure with only the top open.

These are but a few examples of the application of noise reduction techniques to the outdoor noise generators discussed at the beginning of this chapter. However, an examination of each piece of equipment or each process in the larger system or process being studied should make clear those methods of noise control which are applicable and those which *may* be applicable if the effort is warranted.

FUTURE OUTLOOK FOR INDUSTRIAL NOISE CONTROL

As the citizens in the community become more conscious of noise and more aware of the noise in their environment, it appears that there will be an increasing demand for a quieter environment. Not every community today wants to increase its tax base at the expense of new industrial plants and their prospective noise sources. It thus appears that more stringent noise control requirements currently exist and are becoming commonplace.

In the light of the potential need for more stringent requirements, it is heartening to note that the knowledge in the field of industrial noise control is increasing and that a large body of technology is available to industrial machinery and industrial plant designers to achieve the desired acoustical goals. The payoff is an economic one. It costs money to carry out the design and development work for quieter machines and plants. The cost is not reasonable unless all industries within a given product area are required to meet the same criteria. This is discussed in detail in studies by the Environmental Protection Agency in its report to Congress. For a discussion of the Environmental Noise Control Act of 1972 as passed by the House of Representatives see the October 18, 1972, issue of the Congressional Record, p. #10287.

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