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SOUND AND VIBRATION

Bothersome noise levels in buildings are receiving increasing attention. This article deals with some fundamentals of the subject, and emphasizes the need for competent counsel when problems arise. Also stressed is the need for attention to noise sources in a mechanical piping system, to help prevent noise problems while still in the design stage.

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This report deals primarily with noise pollution in mechanical rooms of buildings and factories and of the spaces in which humans live and work. Noise is defined as unwanted sound. Some form of noise is with us all of our lives. This noise can have an adverse effect and result in a feeling of annoyance which can vary from a mere awareness of the noise to having difficulty in understanding the speech of another person. Noise can become so intense so as to physically damage the hearing.

In order to understand noise and how to control it, we must have some means to describe its level.

The decibel is a term which is used to describe the level of noise. The definition in Webster's New World dictionary is "the decibel is a unit for measuring the volume of a sound, equal to the logarithm of the ratio of the intensity of the sound to the intensity of an arbitrarily chosen standard sound." To expand upon this definition it can be seen that a decibel is essentially a ratio of a measured quantity to an arbitrarily chosen reference which has the same units as the measured quantity. Examples are, the ratio of: sound intensity to reference sound intensity, sound pressure to reference sound pressure, acceleration to reference acceleration, etc.

Various means of assigning a comparative rating value to the decibel for airborne noise have been used, one of which is shown in the chart marked figure 1 on Page 4. The zero point of the chart as determined by experiment is generally taken as the lowest sound which can be detected by the normal human ear at a frequency of 1000 CPS.

An instrument to measure sound pressure has been developed, and by international agreement the sound level meter has been accepted as the instrument to be used to measure sound pressure in terms of decibels. The design and specification of the sound level meter is defined by both the U.S.A. Standards Institute and the International Standards Organization as an instrument which responds more to noise at some frequencies than to others in somewhat the same fashion as the human ear.

The decibel, however, as a single value number does not entirely describe a tolerable annoyance level. This is because at low frequencies the decibel reading must be comparatively high before the noise can be heard. In contrast we can hear noise in the frequency range of between 20-20,000 CPS even though the decibel reading is low. Sound level meters account for this in a general way by means of three distinct weighting networks.

No adequate measure of annoyance level of noise has yet been devised. Rating systems describing loudness using such units as the Sone, the Phon, a system to describe perceived noise level with the unit of Noys, a Speech Interference Level (SIL), a damage risk level criteria and others depend upon measurements in decibels made with the sound level meter. Space does not permit a complete discussion of the various systems here. All of these ratings depend upon measurements made with a sound level meter which indicates in terms of the decibel.

In general, people object mostly to high frequency sounds and are more tolerant of those at the lower frequencies.

Because humans react to the annoyance of noise, which can be heard as sound waves which travel through the air to reach the ear, the measurement of noise by the sound level meter, in decibels, is associated with the term “airborne” noise.

However, noise is also transmitted by wave forms which travel through solid media such as steel, concrete or water, to cause air pressure disturbances and consequently sound waves in air which then reach the ear as noise. Noise transmitted through solid media is called structure-borne noise, commonly described as vibration. Noise transmitted through water or other fluids is called liquid borne noise or water pressure pulsation.

The decibel adequately describes the level of the noise transmitted in both structure-borne and liquid-borne noise by keeping in mind that the decibel is a ratio of a measured quantity to a standard reference quantity. In structure-borne noise the measured quantity is acceleration and in liquid borne noise the measured quantity is pressure level.

Because the reference quantity for the level of airborne, structure-borne and liquid-borne noises is different, the value of the decibel in each case is not the same, but can be inter-related.

Annoyance from noise is generally more pronounced indoors; in offices, apartment houses, hospitals and schools where people expect quieter surroundings than in factories, airports and on the street. Noise levels which are tolerated in those latter areas, perhaps as being in the nature of things beyond control, will generally not be accepted by people indoors who expect a greater measure of noise control.

In buildings the principal sources of noise are the machines placed there for the comfort and convenience of the occupants such as the furnace, the air conditioner, the plumbing system, and domestic appliances. These systems, with necessary accessories such as fans, blowers, compressors, pumps, ducts, dampers, valves and piping all combine to generate and transmit sounds.

The sounds which become annoying may be transmitted by direct radiation from a portion of the equipment directly to the air, or may, from impact or vibration, be communicated directly to the building structure or they may be a combination of both.

Transmission paths may be entirely through the air as for example, through an open door or window into an adjacent room or the sound may be from a source which radiates into the air and may force an entire wall into vibration which is then transmitted as solid-borne energy to the structure and carried to a remote space where it is then re-radiated as sound from a surface which is forced into vibration. Mechanical energy, as from inherent unbalance in rotating machines, may be imparted directly to a portion of the structure and then be transmitted through solid media to force a vibration into a surface which in turn will radiate sound.

In the control of noise in buildings, the airborne sounds are most easily handled by absorption using such devices as acoustical materials on walls and ceilings, lined ducts or carpeted floors. The attenuation value of such items is quite high and can be relatively easily installed. The attenuation of most structural building materials is quite low and for this reason it is most effective to control structure-borne noise by isolating the source from the building by means of pads, rubber mounts and springs.

In order to minimize noise pollution we must first determine how much expense can be tolerated for the end result. In other words, how much noise reduction are we willing to buy? We must determine why we want to reduce a given noise; to minimize speech interference, to provide comfort or to prevent hearing damage.

Reducing noise at the source is always worth the attempt although unfortunately more often than not major results cannot be obtained. Much effort is being made by equipment manufacturers to provide quiet operating machines but the machine is only one part of a system so factors beyond the control of the machine manufacturer must be considered. As an example, a pump may be designed for quiet operation by the manufacturer by paying particular attention to the correct impeller and casing design to minimize hydraulic shock as the water passes from the vane tips of the impeller and enters the casing. Optimum velocity distribution of the water flow in the casing, proper shaft and bearing size to avoid shaft deflection, good hydraulic and dynamic balance of the rotating parts are important. A quiet- design electric motor might be used and yet the pump could be a source of noise in the overall system. This is so because even with the best design and quality control of the components, all rotating machinery will still produce movement of parts within itself which in turn develop energy to appear as sound. No technology has been discovered to eliminate all pump noises since they are inherent in the mechanical, electrical and hydraulic characteristics of the machine. However, all is not lost because by the same attention to detail and workmanship in the total system design, the inherent energy-producing parts of the machine can be made scarcely noticeable.

For example, the pump should be selected to operate near its best efficiency point. The pump must be properly installed so as to achieve good alignment with its driver. The piping system should be sized so as to have flow velocities of between 5-8 FPS. A pressure drop in the line of less than 10’ per 100’ of length will usually result in a 5-8 FPS velocity. The suction and discharge piping to the pump should be carefully planned to avoid abrupt changes. Reducers and increasers are best in increments of one pipe size. Avoid short radius elbows whenever possible. When they must be used install elbows 1 or more sizes larger than the system piping and use flanged increasers and reducers on either end. Avoid placing elbows directly on the suction and discharge of pumps, and upstream or downstream from valves and other fittings.

In applying a pump where quiet system operation is required, it is helpful to have a thorough understanding of the manner in which the pump will be expected to operate. It is desirable for the pump to operate at its Best Efficiency Point and within a reasonable range of H/Q near BEP. However, fluctuations in demand in some systems exceed what would be considered a reasonable range for quiet pump operation. In these cases it is necessary to consider other measures to insure quiet operation such as vibration isolators, flexible pipe connections, or other attenuating devices.

It must be recognized that any piping system is similar to a large group of tuning forks, any one of which can be set in resonance by a small exciting force. The exciting force can be the pump even though, by ear or by touch, the pump is quiet. A section of piping set into resonance may make noise itself or may in turn excite some other structural member which can amplify the small force into noise.

The path of transmissions may be broken by the use of flexible connectors to the pump. Also by determining the specific pipe section that is in resonance and altering its supports to eliminate the resonance. In general, it is more economical to use flexible connectors than to find the offending pipe section and then alter its supports.

When attempting to analyze a noisy pump installation first eliminate the obvious.

In most cases a reported noisy pump installation is accompanied by a report of faulty performance. First observe the operation of the pump to determine the probable cause. Refer to the installation and service instructions bulletins supplied with the pump and then check to make certain that the pump is properly installed and aligned, and that it is operating near its best efficiency point. It is generally wasteful of time to attempt to silence a unit that exhibits excessive vibration due to mechanical or operational difficulties such as an improperly aligned coupling or insufficient NPSH. A crackling or gravelley sound could mean the pump is cavitating or a rumbling noise means that the pump is working too far away from its best efficiency point at either too low or too high a capacity.

The length of time the pump has been in service can also be a clue, an older pump should be suspected of wear which permits more looseness of components with a consequent vibration due to excessive clearances.

Only after the pump has been arranged to operate mechanically well, and the noise is still present, is it necessary to look further for the reason.

Airborne noise which can be heard in the area immediately surrounding the pump is probably the most easily corrected. In most pump installations, airborne noise can generally be associated with the motor, assuming that the pump is properly installed and is operating in the correct range. Motor noise may be caused by its internal air baffling system, the fan, magnetic noise or bearings. On 3600 RPM motors, fan noise is usually found to be the problem while on 1800 RPM motors the more serious noise is magnetic and generally appears at a frequency of 120 CPS.

Corrective measures for airborne noise can be as simple as closing the door in the equipment room to prevent noise transmission to an occupied space. Noisy motors rightly fall in the province of the motor manufacturer who should be consulted for corrective action.

A pump may be the source of structure-borne noise even though it is properly installed and operated. This is because the pump acts as a sounding board and can transmit vibrations from outside sources, such as an adjacent machine or an unsupported pipe, and pass them along to the piping or down to and across a floor to a structural member of the building which in turn, acts as a sounding board to amplify a resonance into noise at some distance from the pump. Corrective action is to break the path of transmission by means of isolators.

In some cases high flow velocities in the discharge pipe line, caused by too small a pipe for the capacity or flow disturbances due to an excessive number of fittings and valves in the line, will cause a resonance which is attributed to the pump simply because the noise disappears when the pump is stopped. It may be necessary to change the piping system to achieve better flow conditions by using larger pipe and fewer fittings in order to reduce the noise or additional pipe hangers located at or near the point of resonance may cure the problem.

Tests have shown an inverse relationship between pump efficiency and liquidborne noise. Less liquidborne noise is found at higher pump efficiencies. Since higher efficiency in a pump is associated with minimum shock and turbulence, good fluid motion and little recirculation, it follows that the liquidborne noise levels should be low. Liquidborne noise is more affected by head ratings than by capacity ratings. Tests have shown that for a specific efficiency value, liquidborne noise levels were higher for higher head pumps.

Efficiency, however, is the primary factor in liquid- borne noise with head rating as a secondary consideration.

Another factor in liquidborne noise is the clearance between the impeller and the volute tongue. Each time the impeller vane tip passes the tongue, a pressure pulse is developed. The effect of this pressure pulse on liquid- borne noise level can be minimized by providing the correct amount of clearance between the tongue and the impeller. The amount of this correct minimum gap changes with specific speed, with the required clearance becoming greater with higher specific speed.

One way to describe the minimum clearance between the casing and the impeller diameter is in terms of diametrical clearance at the volute base circle expressed as a fraction of the impeller diameter. Some purchasers' specifications state that the impeller diameter should not exceed 85% of the maximum impeller diameter available for the pump. By strictly following this requirement it many times becomes necessary to select the next larger size pump to meet the head and capacity requirements. This usually will result in a less efficient pump for the job and the possibility of greater liquid-borne noise. The customer is thus penalized by preventing him from being able to take advantage of the lower price due to the smaller, properly designed pump whose planned clearances are sufficient to prevent noise when using the full diameter impeller.

By having the basic knowledge that the principal transmission paths of noise from a pumping unit are through the air surrounding the unit, through the piping to the structure, through the unit to the occupied space and through the motor electrical connections to the structures of the occupied space, any necessary corrective measures become rather obvious. Proper design of the entire water system, including the right pump selection for the system, will tend to eliminate noise problems before they happen.

To insure proper planning in the design stage, it is well to recommend that the system user obtain the services of an Acoustical Consultant, who is best equipped, to determine the need of specialized building elements such as resiliently isolated floors, which can be incorporated in the original construction. Reputable Acoustical and Vibration Control Consultants may be found in the listings of the local telephone directory.

Noise is a matter of degree and kind and can never be eliminated completely. But it most generally can be reduced to acceptable levels where it is present. Well designed pumps, properly selected, applied and installed in a system which is also properly designed and constructed, will not generate and transmit excessive noise.

Properly planning the entire system, including pumps, motors, controls, piping and plumbing layouts will return a handsome profit in a quiet, smooth operating water system.

In spite of all best efforts, many systems do not have the anticipated hydraulic and system characteristics. This is frequently due to changed and adverse suction conditions or an operating system with very different characteristics than was supplied to the pump manufacturer.

This frequently results in misunderstanding between manufacturer and user. It is desirable to have clear, accurate specifications of hydraulic conditions for the pump manufacturer to bid on. It is even more necessary to have a properly designed plumbing system as the finest, quietest pump can be made to generate noise unless it is installed in a proper total environment.

Table 1—Loudness of Common Noises

Loudness (db)	Source or Effect of Noise
140	Threshold of pain
130	Pneumatic rock drill
120	Loud automobile horn
110	Punch press
100	Automatic lathe
90	Noisy factory
80	Truck passing
70	Noisy office
60	Conversational speech
50	Private business office
40	Average residence
30	Broadcast studio
20	Rustle of leaves
15	Average threshold of hearing
0	Acute threshold of hearing

FIGURE 1