Machinery Noise Reduction.

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ABSTRACT

The emphasis on faster, lighter, more powerful and compact machinery has resulted in higher noise levels. Machinery noise reduction requires a fundamental knowledge of acoustics and noise control techniques. Three basic approaches to noise control problems should be considered: (1) solution at the noise source; (2) solution along the noise path, by blocking the noise propagation from the source to the receiver, and (3) solution at the receiver by isolation in a control room or by using hearing protectors. The optimum approach must be determined, by considering acoustical effectiveness, production compatibility and economy. It should be pointed out that hearing protectors are only a temporary solution, and an engineering solution at the source must be utilized as a permanent solution. The approaches to noise control presented in this paper focus on solutions at the source and along the noise path. Solutions are presented for the most common machines used in industrial installations, such as compressed air jets, ventilators and exhaust fans, compressors, electric motors, wood cutting machines and power tools. The solution techniques consider machine redesign, process modification and/or noise source elimination. Other techniques involve the use of enclosures, silencers, mufflers, noise isolation, sound absorption and vibration isolation, as well as active noise control techniques.

1. Introduction

Industrial machinery and processes are composed of various elements such as rotors, stators, gears, fans, vibrating panels, turbulence fluid flow, etc. Low noise machinery means lower surface vibration levels, lower impact levels with longer duration and low fluid velocity and turbulence. In this paper, the fundamental source mechanisms of solid and air vibration are discussed, and recommendations for noise reduction, along with some practical cases, are presented.

2. Noise Sources

Sound field in the workplace is usually complex, due to the participation of many sources: propagation through air (air-borne noise), propagation through solids (structure-borne noise), diffraction at the machinery boundaries, reflection from the floor, wall, ceiling and machinery surface, absorption on the surfaces, etc. Therefore any noise control measure should be carried out after a source ranking study, using identification and quantification techniques. The basic mechanism of noise generation can be due to solid and/or air vibration (Allen, 1970).

2.1 Solid Vibration

A solid surface vibration, driven or in contact with prime mover or linkage, radiates sound power given by:

$$W = z \cdot S \cdot \sigma \cdot V^2$$

where: z is the air impedance = = 415 [rayle] for normal conditions

S is the vibrating area [m^2]

V^2 is the mean square time/space average vibrating velocity [m^2/s], which can be measured by a vibration meter

σ is the nondimensional radiation efficiency.

The radiation efficiency R, varies from zero at low frequency ($L << \lambda$) to unit at high frequencies ($L >> \lambda$), where L is the largest linear dimension of the vibration surface and λ is the wavelength. Therefore care must be taken to reduce the vibrating area (S) and/or reduce the vibration velocity (V). Reducing the vibrating area can be carried out by separating a large area into small areas, using a flexible joint. A reduction of the vibration area by a factor of two gives a reduction of the sound power level of 3 dB. Reducing vibration velocity can be carried out by using damping materials at resonance frequencies and/or blocking the induced forced vibration. A reduction of the vibration velocity by a factor of two gives a sound power reduction 6 dB. Typical examples of solid vibration sources are: eccentric loaded rotating machines, panel and machine cover vibration which can radiate sound like a loudspeaker, impact induced free vibration on surface resonance.

2.2 Air Vibration

Air turbulence and vortex generate noise, especially at high air flow velocity. Turbulence can be generated by a moving or rotating solid object, such as the blade tip of a ventilator, by changing high pressure discharge fluid to low (or atmospheric) pressure, such as cleaning air jet or by introducing an obstacle into the high fluid flow.

The aerodynamic sound power generated by turbulent flow is proportional to the 8th power flow velocity (W a V8), which means that a doubling of the flow velocity (V) increases the sound power (W) by a factor of 254 or 24 dB. Therefore care must be taken to reduce flow velocity, reduce turbulence flow by using diffusers and remove obstacles or have them in stream line shape. The next few examples show the applications of these fundamental concepts to machinery noise reductions.

3. Machinery Noise Reduction

In this section, solutions are presented for the common machines used in industrial installations. For each case, the mechanism of noise generation is discussed and noise control measures are presented.

3.1 Industrial Air Jets

Industrial jet noise probably ranks the third as a major cause of hearing damage after that of impact and handling noise. Air jets are used extensively for cleaning, for drying and ejecting parts, for power tools, for blowing off compressed air, for steam valves, pneumatic discharge vents, gas and oil burners, etc. Typical sound pressure level at 1 m from the blow-off nozzle can reach 105 dBA.

3.1.1 Noise Sources

The reservoir compressed air pressure is usually in the range of 45 to 105 psi (3 to 7 bar). The air acceleration varies from near zero velocity in the reservoir to peak velocity at the exist of the nozzle. The flow velocity through the nozzle can becomes sonic, i.e. reaches the speed of sound.

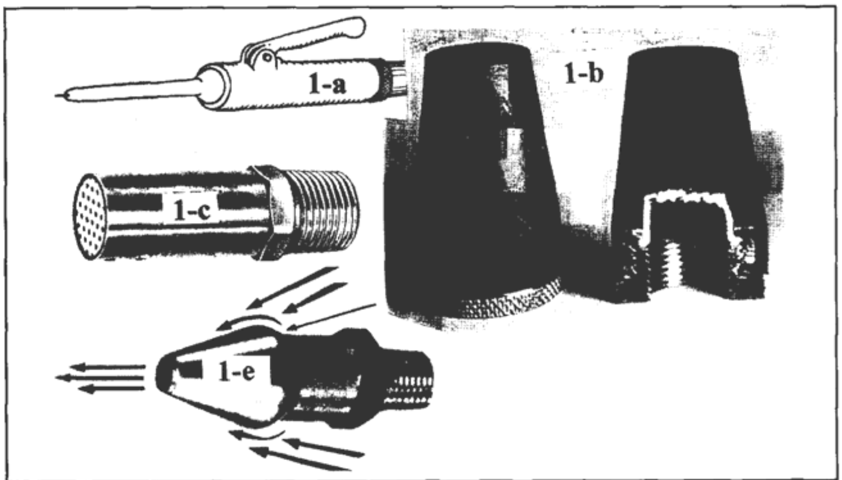

Fig. 1. Commercially available Classical nozzle (1-a) and low noise nozzles (1-b to 1-e).

This means high generation of broadband noise with highest values at a frequency band between 2 to 4 KHz.

3.1.2 Noise Control Measures

Two basic methods of noise control that are commonly used [see; (Lord, Evensen and Stein, 1977), (Huang and Rivin, 1985) and (Fredel, 1990)]: (1) reduction of the single high-velocity jet component (fig. 1-a) into a multiple small velocity components as in the multiple-nozzle with or without extended tube (see fig. 1-b and 1-c respectively) or by using restrictive diffuser nozzle (fig. 1-d) and (2) reducing the turbulent zone by creating a secondary flow enveloping the main jet flow, like that of shroud nozzle (fig. 1-e).

The choice of the low noise nozzle depends on its application. For cooling and drying purposes, a large flow rate with low thrust force is needed, like that of air shroud nozzle, while for ejection purposes, a high thrust directional force is needed, like that from multiple-nozzle.

Measurements were carried out in four factories in Brazil: a cigarette manufacturer, an engine piston manufacturer, an auto-vehicle compressor manufacturer and an agricultural storehouse, where the air jet was used for cleaning. In each case, the sound pressure level was measured at the operator ear position using the classical simple hole nozzle air jet gun and the same gun with a multi-nozzle type. The multiple-nozzle configuration was varied (number, diameter and disposition of holes) until the operator was satisfied with jet performance. A reduction between 5 and 9 dBA was obtained. Therefore it is recommended that several nozzles for a given application be tested before making a final selection among quiet nozzles. The presence of obstacle, as well as discontinuity or sharp edges on the flow direction increases noise, especially in high frequency bands. This impingement noise is strong, depending on the flow velocity (W a V 5 to 6). Hence, a small reduction of flow velocity yields appreciable reduction of impingement noise. In the case of ejection jet, care must be taken to avoid turbulence created as the jet flows over obstructions or sharp edges.

3.2 Ventilator and Exhaust Fans

Fans are used to move a large volume of air for ventilation, by bringing in fresh air from the outside, blowing out dust, vapor or oil mist from an industrial environment, and for drying or cooling operation, etc. Industrial fans are usually low-speed, low-static-pressure and large-volume flow rate. Fans can be classified as either axial or centrifugal type. Axial fans are noisier at high frequencies and centrifugal fans are noisier at low frequencies. Fans have to operate at the maximum efficiency point on the Pressure-Flow curve characteristics. Therefore, the choice between axial or centrifugal fans is made by the manufacturer to satisfy maximum efficiency at a certain static pressure/flow rate.

3.2.1 Noise Sources

Three basic noise sources are:

1. A broadband aerodynamic noise generated by the turbulent flow,
2. Discrete tones at the blade passing frequency Fp (Hz) given by: Fp = (Rotation in RPM x Number of blades/60), and the harmonics (twice Fp, three times Fp, etc.)
3. Mechanical noise due to mounting, bearing, balancing, etc.

Sound power level (Lw) generated by fans (without the drive motor) can be easily predicted in the early project stage of an industrial installation using the Graham equation (Graham, 1972).

Based on sound power prediction, the sound pressure levels can be estimated at specified locations in certain installations. The finite element, boundary element or ray acoustics methods can be used for these estimates. Commercial software packages based on the three methods above are available for these estimates.

Low flow rate, low static pressure fans are quieter. Fan selection is usually based on efficiency in carrying out the desired service, and noise parameter was not considered as a decisive purchase factor.

3.2.2 Noise control Measures

Two basic types of solutions are available; the use of the absorption silencer or of the recent electronic noise cancellation active silencer. Figure 2 and 3 show typical circular and rectangular absorptive silencers respectively. The project of such silencers must take into consideration the following parameters:

1. The sound power level spectrum generated by the fan.
2. The noise attenuation required which can be expressed as the Dynamic Insertion. Loss (DIL), that is the difference in sound pressure level with and without a given silencer installed in the duct system with airflow.
3. Pressure drop caused by the presence of the silencing which the fan can overcome.
4. Self-generating aerodynamic noise, due to the presence of the silencer.

The ideal solution is for the fan to be selected considering the above factors and supplied by the manufactories along with its silencers. In case a silencer is projected for a given fan already installed, the four factors above have to be considered in the silencer projector. It is recommended that professional silencer manufacturers be hired to satisfy the noise attenuation requirements, keeping the fan efficiency at the project point.

Since the basic mechanism of dissipative silence is sound energy absorption, silencers are more effi-

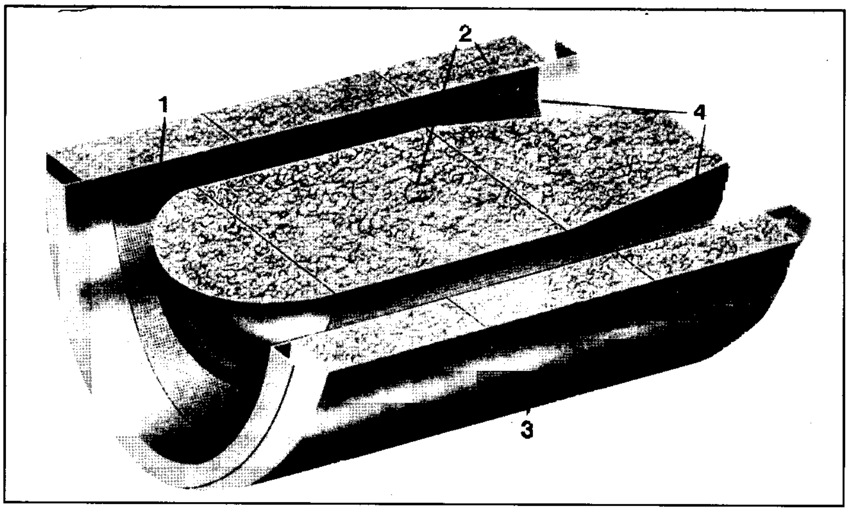

Fig. 2. Circular silencer: (1) perforated, galvanized steel; (2) fiber acoustic fill; (3) steel metal casing; (4) low turbulence air passages. (Bell, 1982).

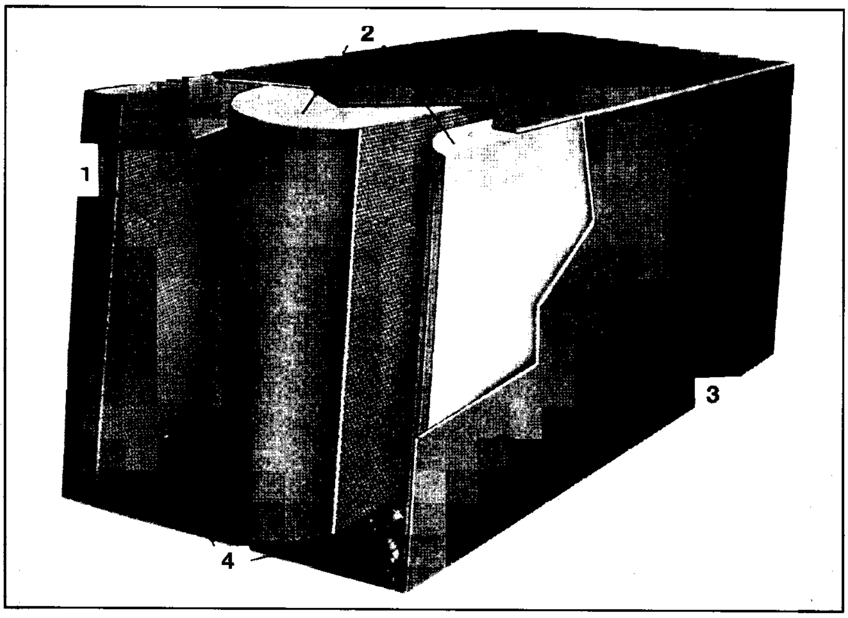

Fig. 3. Parallel baffle rectangular silencer. (1) perforated, galvanized steel; (2) acoustical materials fill; (3) sheet metal casing; (4) stream line inlet. (Bell, 1982).

cient at high frequencies, depending on the dimensions and thickness of absorption materials used. At a low frequency range, specially below 500Hz, a dissipation silencer has to be large to be able to get an appreciable noise reduction.

Active noise control silencers are efficient at low frequencies. Lueg's patent in 1936 was difficult to operate in analog electronic circuits, due to the precision needed, but recently, with the advances in digital technology and low cost digital electronics, this same invention could be economically implemented. In the active digital electronic silencer, the sound wave is captured and inverted, controlled and delayed, then injected to cancel the original wave. Such a silencer is available commercially and it can give up to 32 dB reduction at the blade passing frequency noise components. A hybrid compact silencer can be used to reduce the low frequency noise by the active control principle, and the high frequency noise by the dissipative mechanism.

3.3 Compressors

Compressors (or blowers) are usually racketing machines with high pressure. They are used for conveying materials or products. There are several types of compressors: the rotary positive displacement (lobed impellers on dual shafts, as shown in figure 4), gear or screw compressors, etc.

3.3.1 Noise Sources

The basic noise sources are caused by trapping a definite volume of fluid and carrying it around the case to the outlet with higher pressure. The pressure pulses from compressors are quite severe, and sound pressure levels can exceed, or 105dBA. Since the noise is periodic, discrete tones and harmonics are present in the noise spectrum.

3.3.2 Noise Control

Since the discrete low frequency noise (small number of lobes, blades, etc.) predominates, reactive chamber-type silencers (like those of vehicles) are effective. Generally, a silencer is required on both the inlet and outlet as shown in figure 4. Reactive silencers can also be perpendicular to the flow and work as a closed-side-branch. The pressure loss from the silencer is negligible in comparison with that from compressor. Also it is important to provide vibration isolation between the compressor and pipes by using flexible couplings, with sufficient transmission loss through wrapping (Bell,1982). Vibration isolation between the motor/compressor unit and floor is extremely important. The last noise sources are those transmitted from the compressor casing and mechanical-type noise (gears, bearing, etc.). Therefore in some installations, enclosing the compressors is necessary. Sound power data for compressors, fans and blowers are available from the manufacturers, Air Moving and Conditioning Association (AMCA) and/or American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for purchase specification purposes.

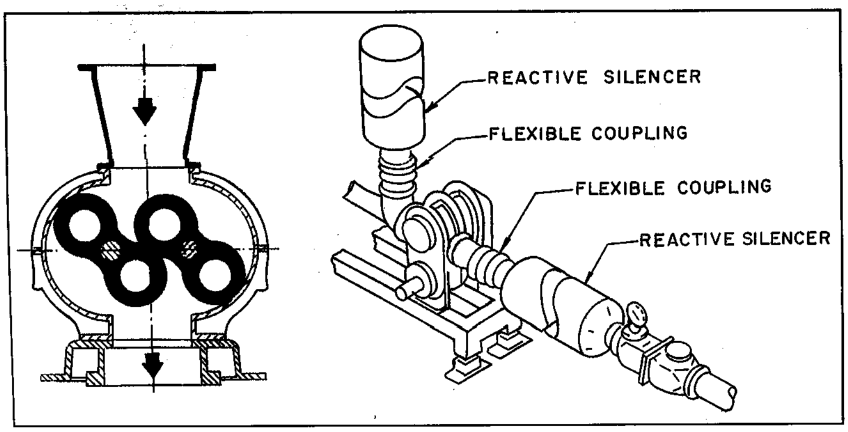

Fig. 4. Rotary positive displacement compressor, mounted with the inlet and outlet reactive silencers, flexible couplings.

3.4 Electric Motors

The electric motor converts electric energy to magnetic and mechanical energy with the output of a useful torque at the motor shaft. Part of the energy transformation is converted to heat giving a rise to rotor, stator and casing temperature. Therefore an electric motor must be supplied with a cooling fan system. The cooling fan can be incorporated inside in the case of an "OPEN" motor or outside as in the case of a "Totally Enclosed Fan Cooled (TEFC)" motor. TEFC motors are more widely used, due to robust construction which can withstand an aggressive environment. OPEN motors are less used due to possible contamination by environment. An OPEN motor is less noisy than TEFC motor since the noisy fans are incorporated inside.

3.4.1 Noise Sources

There are three basic sources involved in the noise generated by electric motors:

1. Broad-band aerodynamic noise generated from the end flow at the inlet/outlet of the cooling fan.
2. Discrete frequency components caused by the blade passing frequencies of the fan.
3. Mechanical noise caused by bearing, casing vibration, motor balancing shaft misalignment, motor mounting. These are project mounting and maintenance items, and therefore careful attention should be given to the vibration isolation, mounting and maintenance.

Noise generated by the motor fan is the dominant noise source, especially for TEFC motors. Sharp increase in noise occurs as shaft rotational speed increases from 1800 to 3600 RPM. For large motors in the range of 1000 CW, 3600 RPM, a sound pressure level of as high as 106 dBA occurs. The fan contribution alone is between 30 and 50 dBA. This large contribution of the

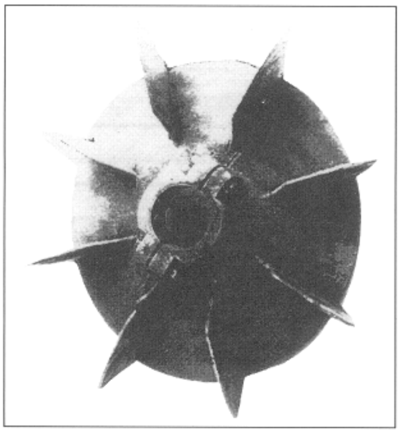

Fig. 5. Straight blade noisy motor fan.

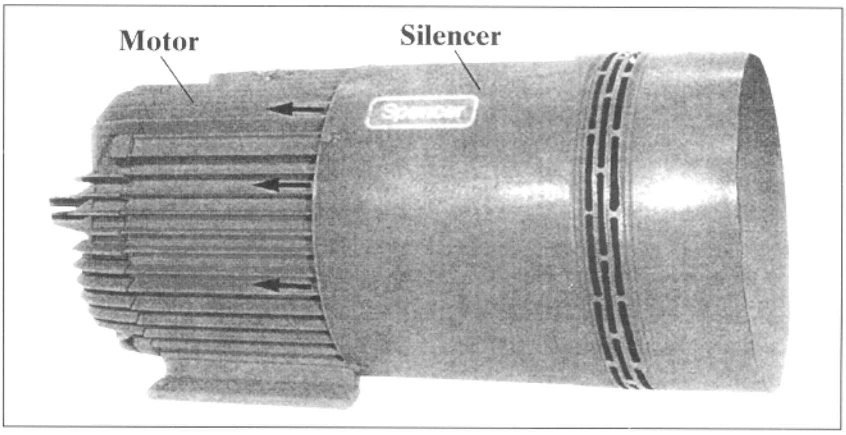

Fig. 6. Motor with a fan silencer. (Bell, 1982).

fan is due to the fan shape. Motor fan blades are usually straight (see figure 5), so that the motor cooling is independent of rotation direction. Straight Blade fans are very noisy, due to the large aerodynamic turbulence sound generated.

3.4.2 Noise Reduction

Since the dominant noise source is generated by the fan, an absorption-type silencer can be used (see figure 6). An overall reduction of 6 to 11 dBA can be expected. For large motors, total enclosure with low pressure loss at the inlets and outlets is used for significant noise reduction. Replacing a straight-bladed with a curved-bladed fan can give up to 8 dBA noise reduction, but care must be taken to use this motor in one rotational direction only (see figure 7).

3.5 Woodworking Machines

The woodworking industry has experienced noise level increases as a result of modern, higher speed, and compact machines. The basic noise elements in woodworking machines are cutter heads and circular saws. Equivalent sound pressure level in the furniture manufacturing industry can reach up to 106 dBA.

3.5.1 Noise Sources

Woodworking machinery uses operations, such as cutting, milling, shaping, etc. Two basic noise sources are involved:

1 Structure vibration and noise radiation of the work piece, cutting tool (such as a circular saw blade) and machine frame, especially at the mechanical resonant frequencies.
2 Aerodynamic noise caused by turbulence, generated by tool rotation and the workpiece in the air flow field. Noise is also generated from fan dust and chip removal air carrying systems.

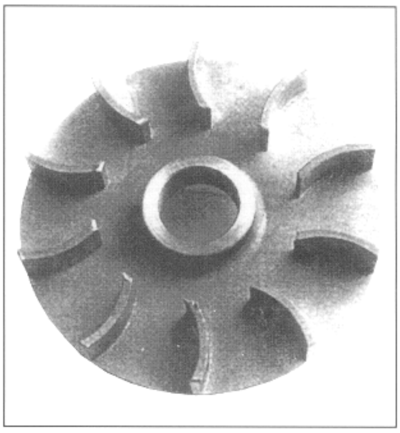

Fig. 7. Curved blade fan.

3.5.2 Noise Reduction

For noise control in woodwork machine tools, cost-effective operation and maintenance efficiency must be considered. Typical examples of noise reduction are:

1 Circular saw noise produces a sound pressure level of about 88dBA while idle, and 97dBA during cutting operation, depending on the rigidity of the material. The noise is generated by aerodynamic interaction of saw blade with surrounding air and the workpiece, and also by vibration

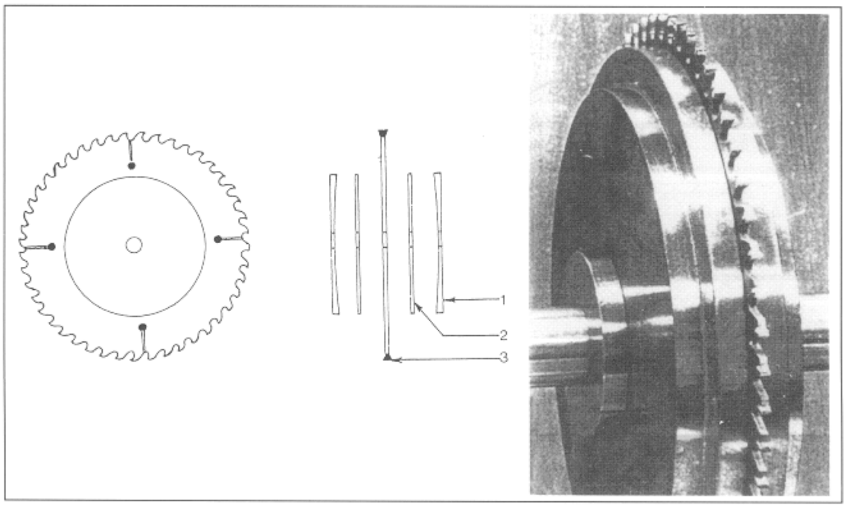

Fig. 8. Motor with a fan silencer. (Bell, 1982).

and sound radiation from the blade and workpiece. The noise reduction technique consists of blade design modifications with expansion slots and vibration damping glued to the saw plate (see figure 8).

2 Finishing planer with straight knife excites the workpiece and the machine frame by impact at feed-in, feed-out operation. Typical sound pressure level is from 95 to 102 dBA while idle to 100 to 105 dBA during cutting, for about 80% of the time. A helical carbide cutter head knife gives a noise reduction between 15 and 20 dBA due to the smooth and smaller contact areas with the workpiece (see figure 9). For slotting, notching and shaping operations, double-end planers are used. A cutter head with stagger curved tooth and an unequal number of teeth can spread the noise energy in a wider frequency band with a lower overall noise level (see figure 9).

3.6 Pneumatic Tools

Compressed air-powered-hand-held tools such as drills, grinders, riveting gun, chipping hammer, impact gun, pavement breaker, etc. are widely used within a board spectrum of different industries.

3.6.1 Noise Sources

There are three basic types of sources that dominate the noise generated:

1 Noise produced by contact between the machine and the working surface. The vibration transmitted from the tool tends to vibrate the working surface and work bench, generating high radiation noise, especially at mid and high frequencies.

2 Exhaust air noise caused by the turbulence flow generated as the compressed air passes the motor and by the aerodynamic noise generated in the air exhaust.

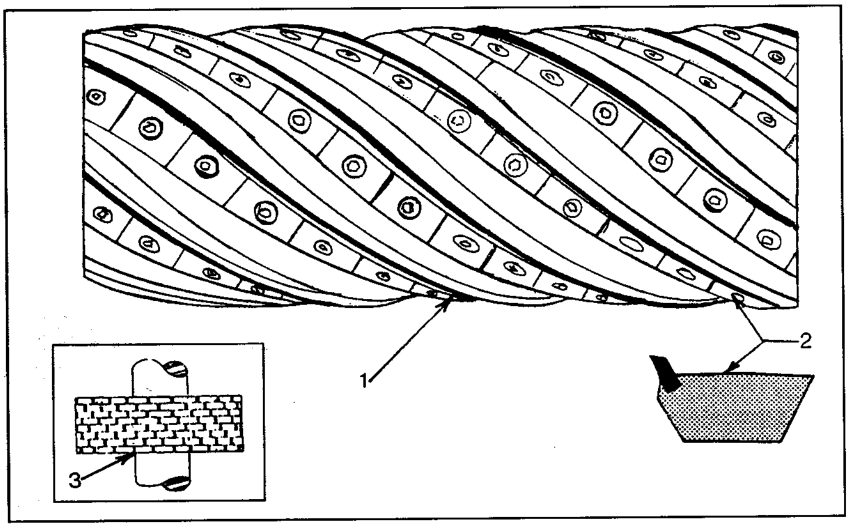

Fig. 9. Curved geometry cutterhead (1) with carbide-tipped (2) for planed. Tenoner head, with staggered tooth (3) for notching operations.

3 Sound radiation from the tool vibration caused by the air flow inside the tool.

3.6.2 Noise Control

Pneumatic tools are usually noisier than electric tools, because of the exhaust air noise. Noise reduction in pneumatic tools can be incorporated by manufacturer in the tool design. Principle techniques for noise control are:

1 Incorporated exhaust air muffler at the tool air exit.

2 Changing a pneumatic-hammer-type operation, such as in riveting to hydraulic-tool-type process. This means the same force applied over longer period of time.

3 The use of magnetic forces for fixation of the workpiece on the bench during operation, reducing the vibration of the work piece and bench area, and consequently reducing noise radiation.

Lower-noise modem tools available (Lindqvist, 1988), with price about double or triple the price of a similar noisy tool. These modem tools have noise reduction solution incorporated by the tool manufacturer. As a typical example; a modem grinder achieving a noise reduction from 82dB to 77dBA (running free), by incorporating a spring-loaded valve with a multi-hole muffler for exhaust air inside the support handle (see figure 10). This gives an almost constant back pressure inside the machine, regardless of air consumption.

4. Noise Reduction Elements

A large variety of noise reduction elements are commercially available. It is strongly recommended that machines and equipment be purchased with noise reduction elements incorporated so that to avoid any type of subsequent solution which may affect the machinery performance. Specification of machinery noise limit can force the manufacturer to develop low noise machines. Some of the most common noise reduction elements are:

1 A dissipative silencer which is usually used to reduce noise from the inlet and/or outlet of ventilators. Since it is based on the absorption mechanism of acoustic materials, it is effective for mid and high frequency ranges (see figure 2 and 3).

2 A reactive silencer which uses the principle of an acoustic impedance mismatch, reflecting noise back to the source. It is effective at low frequencies and widely used for compressors and engines with low rotation speeds or few blades (see figure 4).

3 - Enclosure which is very practical and widely used, where sound energy is trapped inside, keeping a low background noise outside (Berger, 1986). Enclosure has to meet operation and maintenance requirements of the machine, such as the necessity of having inlet and outlet openings for refrigeration. Lower transmission loss "TL" elements, such as openings and windows can greatly reduce the total noise isolation. Therefore silencers with high TL can be installed at the refrigeration inlet and/or outlet.

4 Barriers which can be used to reflect back noise and reduce noise propagating in a specified direction.

5 Vibration isolators which are made of metal spring, elastomeric mounts or resilient pads and used to reduce vibration transmission from machine to floor or from machine duct outlet to connecting ducts.

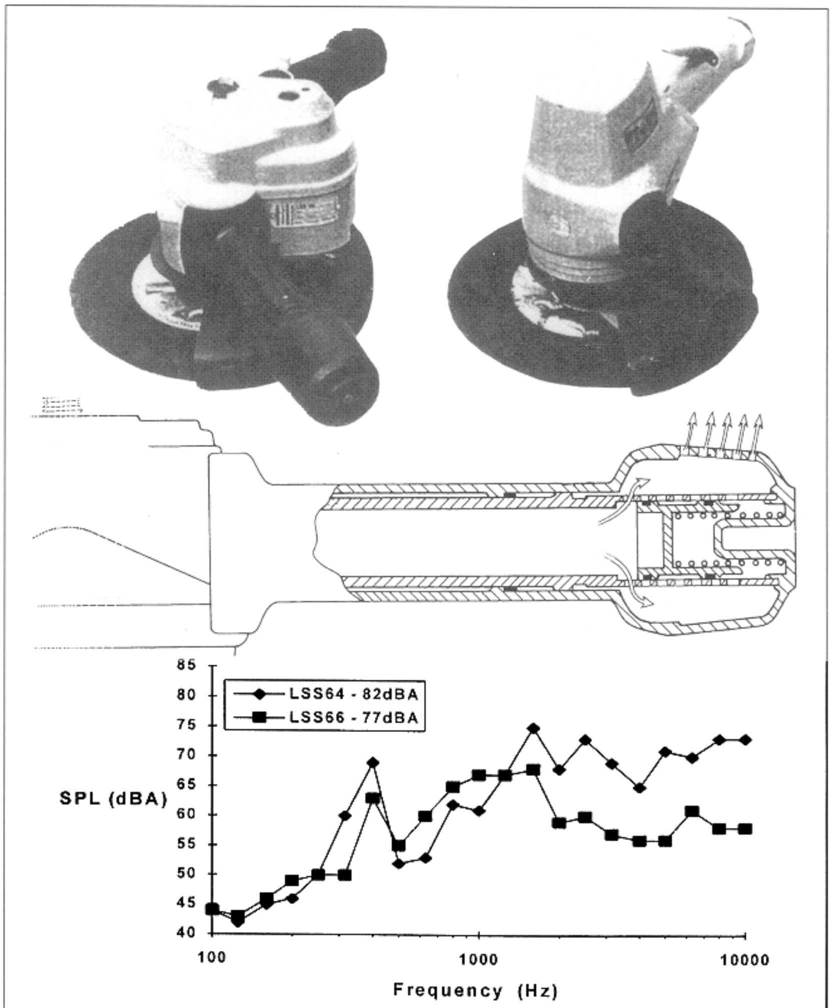

Fig. 10. Old noisy model LSS64 (top right) and new model LSS66 (top left) Atlas Copco surface grinders, showing the multi-hole muffler exhaust at the hand (middle figure) and the noise spectrum with reduction from 82 to 77 dBA.

5. Recommendations for Machinery Noise Reduction

General recommendations for machinery noise reduction at the source and/or along the propagation path should involve the application of the basic principles of noise and vibration control such as:

1 Reducing dynamic forces exciting vibrating surfaces specially at resonance frequencies.

2 Providing vibration isolation for machine mounting and flexible joints for pipe connections, to reduce vibration transmitted.

3 Reducing speed and flow velocity of machines and increasing duration of impact force, thereby reducing noise.

4 Reducing vibration levels at resonance, which can be achieved by placing damping material or shifting away the structural resonance frequencies from excitation frequencies. Acoustic resonance should be avoided by adding absorption materials and/or changing configurations.

6. Conclusions

Engineering noise control is a multidiscipline subject, involving not only noise control concepts but also detailed information of the machine operation mechanisms, installation, maintenance, etc. Any noise control solution for an existing machine or process should involve the production, operation and maintenance departments, for this reason guarantee an operational solution and fewer objections to the elements installed for noise reductions.

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