5

NOISE SOURCES

Professor Samir N.Y. Gerges
Federal University of Santa Catarina
Mechanical Engineering Department
Noise and Vibration Laboratory
Cx.P.476 - Florianópolis - SC
BRAZIL
gerges@mbox1.ufsc.br

Gustav A. Sehrndt* and Wolfgang Parthey
Federal Institute for Occupational
Safety and Health
Friedrich-Henkel-Weg 1-25
44149 Dortmund
GERMANY
parthey.wolfgang@baua.bund.de

5.1. INTRODUCTION

Industrial machinery and processes are composed of various noise sources such as rotors, stators, gears, fans, vibrating panels, turbulent fluid flow, impact processes, electrical machines, internal combustion engines etc. The mechanisms of noise generation depend on the particularly noisy operations and equipment including crushing, riveting, blasting (quarries and mines), shake-out (foundries), punch presses, drop forges, drilling, lathes, pneumatic equipment (e.g. jack hammers, chipping hammers, etc.), tumbling barrels, plasma jets, cutting torches, sandblasting, electric furnaces, boiler making, machine tools for forming, dividing and metal cutting, such as punching, pressing and shearing, lathes, milling machines and grinders, as well as textile machines, beverage filling machines and print machines, pumps and compressors, drive units, hand-guided machines, self-propelled working machines, in-plant conveying systems and transport vehicles. On top of this there are the information technology devices which are being encountered more and more in all areas.

Noise is therefore a common occupational hazard in a large number of workplaces such as the iron and steel industry, foundries, saw mills, textile mills, airports and aircraft maintenance shops, crushing mills, among many others. In many countries, noise-induced hearing loss is one of the most prevalent occupational diseases. According to a Environmental Protection Agency (EPA)/USA report in 1981, there are more than nine million Americans exposed to a daily average occupational noise level above 85 dB(A); this number has increased to about 30 million in 1990. Most of these workers are in the production and manufacturing industries (see Table 5.1).

Studies in Germany and other industrialized countries have shown that the proportion of those exposed to daily average noise levels above 85 dB(A) can generally be taken as 12 % to 15% of all employed persons; that is 4 to 5 million persons in Germany (Pfeiffer 1992). After many years of exposure to noise, there are numerous cases of occupationally related hearing damage recognized

* Present address: Gustav A. Sehrndt, Noise Control Consultant
Niesertstr. 42
48145 Muenster, Germany
gustavse@muenster.de

Table 5.1. Workers exposed to daily L_{Aeq} exceeding 85 dB(A). (EPA, 1981)

Agriculture	323000
Mining	400000
Construction	513000
Manufacturing and Utilities	5124000
Transportation	1934000
Military	976000
Total	**9270000**

as the occupational disease "noise-related hearing impairment" according to the Occupational Diseases Ordinance. An acquired noise-related hearing impairment which leads to a reduction in earning ability of 20 % and more is compensated for in Germany in the form of a pension. Table 5.2 shows the high percentages of those with impaired hearing due to noise in relation to other selected occupational diseases.

Table 5.2. Number and percentages for some selected occupational diseases/disorders in 1998 (total in Germany, from BMA, 1999).

	cases registered for first time		cases recognized for first time without indemnity		cases registered & indemnified for first time (reduction of earning ability ≥ 20%)	
Occupational diseases/disorders	number	%	number	%	number	%
meniscus	2398	2.8	418	2.0	275	4.5
damage from vibrations	1797	2.1	234	1.1	154	2.5
impaired hearing	12400	14.5	7439	36.5	1012	16.4
silicosis	2813	3.3	2100	10.3	391	6.4
skin disorders	23349	27.3	1855	9.1	582	9.5

A cross-section analysis in Germany of working equipment and processes in operational noise areas with a hearing impairment hazard has shown that 80 % of the - several million - sound sources can be attributed to machine operations, conveying systems, control and regulation devices and turbo machines, while 20 % are accounted for by manual working and conveying operations. About three quarters of the machine operations can be attributed to machine tools (Damberg, Foss 1982). The main concern of noise control is therefore the development, production and preferred use of low-noise working equipment and processes.

The avoidance or minimization of health hazards in the working process by the appropriate design of working equipment and processes, in other words by prevention, has also been elevated to a principle on an European level. With the establishment of regulations concerning the nature of machines, devices and installations in EU Directives and more specific European standards, it can be assumed that there is a high level of safety, health and consumer protection. This noise control principle is manifested in the definition and declaration of noise characteristics for products or machines and the description of achievable values by the standards.

5.2. INDUSTRIAL NOISE SOURCES

In this section, the fundamental mechanisms of noise sources are discussed, as well as some examples of the most common machines used in the work environment. The sound pressure level generated depends on the type of the noise source, distance from the source to the receiver and the nature of the working environment. For a given machine, the sound pressure levels depend on the part of the total mechanical or electrical energy that is transformed into acoustical energy.

Sound fields in the workplace are 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 mechanical noise, fluid noise and/or electromagnetic noise (Allen, 1970 and ISO/TR 11688).

The driving force for economic development is mainly the endeavour to produce consumer goods ever more cost-effectively. From the point of view of the machine manufacturer, this generally means offering products with a low space, material, energy and production time requirement (smaller, lighter, more economical and more productive). At the same time account is being taken increasingly of resource conservation and environmental friendliness, although the rise in noise levels which frequently goes along with increased output and productivity is often overlooked. Personnel are then exposed to higher noise levels than before, despite noise-reducing measures taken in the machine's design. This is because the noise emission rises non-linearly because of higher rotary and travelling speeds in machine parts.

For example, for every doubling of the rotary speed the noise emission for rotating print machines rises by about 7 dB, for warp knitting looms 12 dB, for diesel engines 9 dB, for petrol engines 15 dB and for fans is between 18 to 24 dB. For the purpose of comparison: the doubling of sound power produces an increase in emission of 3 dB only.

But even previously quiet procedures are often replaced by loud ones for reasons of cost, e.g. stress-free vibration instead of annealing for welded parts. In some cases new technologies also result in higher emissions; for example, with the use of phase-sequence-controlled electrical drives, the excitation spectrum shifts further to high frequencies, which results in a greater sound radiation from large machine surfaces. This means that some new noise problems are closely related to the use of modern technologies.

5.2.1. Mechanical Noise

A solid vibrating surface, driven or in contact with a prime mover or linkage, radiates sound power (*W* in Watts) proportional to the vibrating area S and the mean square vibrating velocity $< v^2 >$, given by;

$$W = \rho c S \langle v^2 \rangle \sigma_{rad}$$

where

ρ is the air density (kg/m^3),
c is the speed of sound (m/s) and
σ_{rad} is the radiation efficiency (see Gerges 1992).

Therefore care must be taken to reduce the vibrating area and/or reduce the vibration velocity. Reducing the vibrating area can be carried out by separating a large area into small areas, using a flexible joint. Reduction of the vibration velocity can be carried out by using damping materials at resonance frequencies and/or blocking the induced forced vibration. A reduction of the excitation forces and consequently of the vibration velocity response by a factor of two can provide a possible sound power reduction of up to 6 dB assuming that the other parameters are kept constant. Typical examples of solid vibration sources are: eccentric loaded rotating machines, panel and machine cover vibration which can radiate sound like a loudspeaker, and impact induced resonant free vibration of a surface.

5.2.2. Fluid Noise

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

The aerodynamic sound power generated by turbulent flow is proportional to the 6th to 8th power of the flow velocity ($W \sim U^{6 \text{ to } 8}$), which means that a doubling of the flow velocity (*U*) increases the sound power (*W*) by a factor of 64 to 254 or 18 to 24 dB respectively. Table 5.3 shows the effects of doubling of the typical velocity together with other primary mechanisms. Therefore care must be taken to reduce flow velocity, reduce turbulence flow by using diffusers and either remove obstacles or streamline them. The next few examples show the applications of these fundamental concepts to machinery noise reductions.

5.3. EXAMPLES OF MACHINERY NOISE SOURCES

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

5.3.1. Industrial Gas Jets

Industrial jet noise probably ranks third as a major cause of hearing damage after that of impact and material 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 levels at 1 m from a blow-off nozzle can reach 105 dB(A).

Table 5.3. Increase of noise given by the sound power level difference ΔL_w due to doubling of typical velocity (e.g. average flow velocity of gas jets, rotational speed of fans). [After Költzsch, 1984]

mechanism	example	Increase in sound power due to doubling typical velocity
pulsation	reciprocating compressor,	12 dB
turbulence	exhaust fan	18 dB
jet	compressed air expansion	24 dB

Reservoir compressed air pressure is usually in the range of 45 to 105 psi (300 to 700kPa). The air acceleration varies from near zero velocity in the reservoir to peak velocity at the exit of the nozzle. The flow velocity through the nozzle can become sonic, i.e. reaches the speed of sound. This results in a high generation of broad-band noise with the highest values at a frequency band between 2 to 4 kHz.

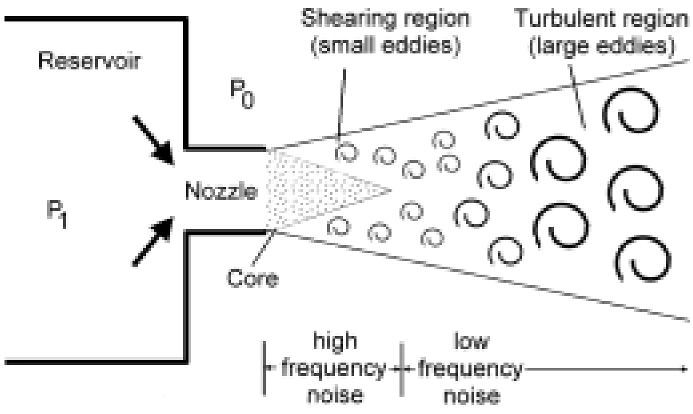

Figure 5.1. Noise sources in gas jet

The mechanisms of generation of the noise from gas jets results from the creation of fluctuating pressures due to turbulence and shearing stresses as the high velocity gas interacts with the surrounding medium (see Figure 5.1). High and low frequency bands of noise are formed, due to the complex radiation sources; high frequency noise is generated near the exit nozzle in the mixing region and the low frequency noise is generated downstream at the large scale turbulence. Therefore, the spectral character of gas-jet noise is generally broadband.

5.3.2. Ventilator and Exhaust Fans

It is rare not to find one or more ventilators or exhaust fans in each department of an industrial or manufacturing complex (see Figures 5.2 to 5.3). Fan and blower noise is the easiest and most straightforward noise problem to solve, using an absorptive type silencer.

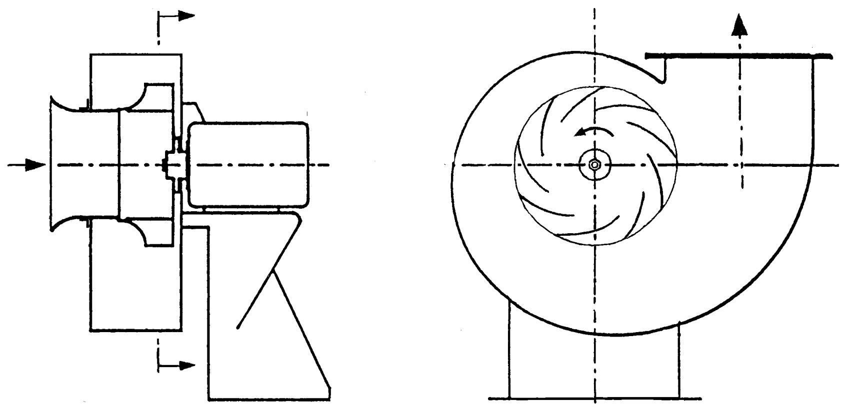

Figure 5.2 Example of a centrifugal fan, rotor with backward-curved blades

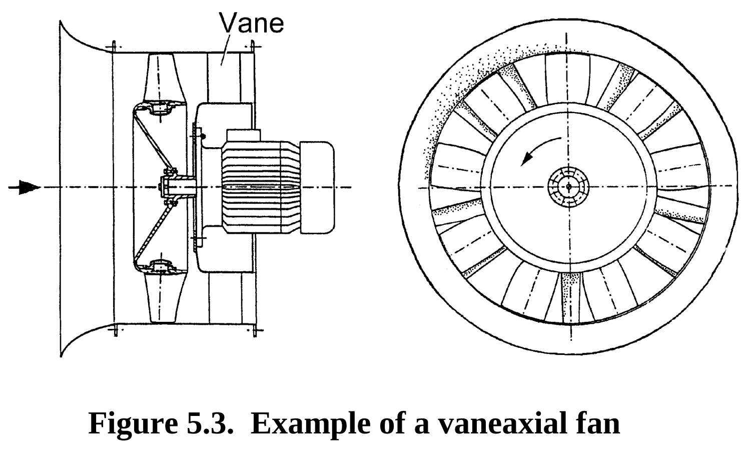

Figure 5.3. Example of a vaneaxial fan

Fans are used to move a large volume of air for ventilation, by bringing in fresh air from the outside, blowing out dust, vapour or oil mist from an industrial environment, and for a drying or cooling operation, etc. Industrial fans are usually low-speed, low-static-pressure and have a large

volume flow rate. Ideally, fans should operate at the maximum efficiency point on the pressure-flow curve characteristic. Therefore, the choice between axial or centrifugal fans is made by the manufacturer to satisfy maximum efficiency at a certain static pressure/flow rate.
Three basic noise sources are:

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

The sound power level (L_w) generated by fans (without the drive motor) can be ~~easily~~ predicted in the early project stages of an industrial installation using the Graham equation [Graham, 1972] for each of the octave bands from 63 to 8000 Hz.

$$L_w = K + 10\log_{10}\bar{Q} + 20\log_{10}P_a + C \quad \text{dB}$$

Where Q is the flow rate (m^3/sec), P_a is the static pressure (kPa), K is the specific sound power level for each of the octave bands based on a volume flow rate of 1 m^3/s and a total pressure of 1 kPa and C is a constant to be added only at the octave band containing the blade passing frequency, see examples for a radial fan similar to figure 5.2 and for a vaneaxial fan similar to figure 5.3 in table 5.4.

Based on the sound power predicted by the above equation, the sound pressure levels can estimated at specified locations in certain installations. The finite element, boundary element or ray acoustics methods are available in commercial software programs for these estimates (NIT, 1995) or a simplified diffuse field model can be used for sound pressure level estimate (Bies and Hansen 1996).

Table 5.4. Specific octave band sound power levels K in dB(re 1 pW) of three types of fans with wheel size under 0.75 m based on a volume flow rate of 1m³/s and a total pressure of 1 kPa (excerpt modified from Graham's table 41.1 in Harris 1991)

Fan type	Octave band center frequency [Hz]								C
	63	125	250	500	1000	2000	4000	8000	
Radial, backward-curved (figure 5.2)	90	90	88	84	79	73	69	64	3
Radial, straight blades (no figure)	113	108	96	93	91	86	82	79	8
Vaneaxial, hub ratio 0.6-0.8 (figure 5.3)	98	97	96	96	94	92	88	85	6

NOTE: The table gives average values which widely scatter due to the properties of the complete system with ducts. The column "C" contains minimum values which even in the case of the least noisy fan with backward-curved blades may be sometimes double as high.

5.3.3. Compressors

Compressors are usually very noisy machines with high pressure. There are several types of compressor: rotary positive displacement (lobed impellers on dual shafts, as shown in Figure 5.4), gear or screw compressors (Figure 5.5), reciprocating compressors (Figure 5.6) and liquid ring compressors (Figure 5.7) are the most common.

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 equivalent sound pressure levels can exceed 105dB(A). The noise generated from compressors is periodic with discrete tones and harmonics present in the noise spectrum.

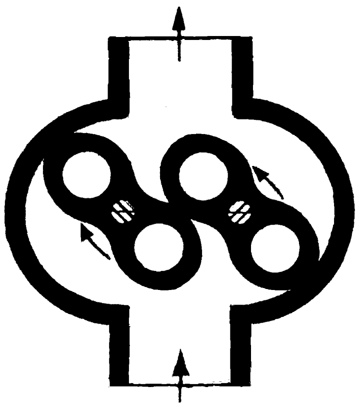

Figure 5.4. RotaryPositive Displacement Compressor

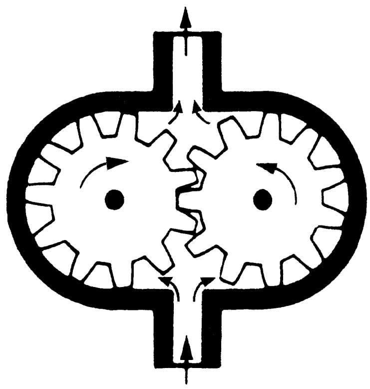

Figure 5.5. Gear Compressor.

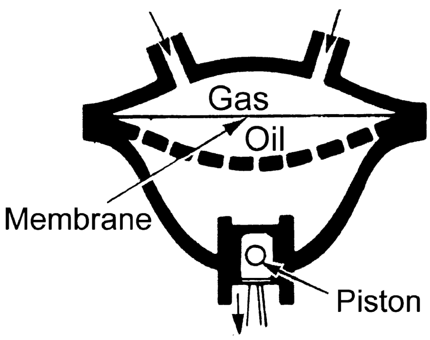

Figure 5.6. Reciprocating Compressor

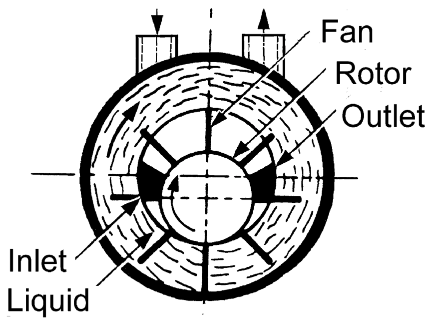

Figure 5.7. Liquid Ring Compressor

5.3.4. Electric Motors

Noise from electrical equipment such as motors and generators is generally a discrete low frequency, superimposed on a broadband cooling system noise. The electric motor converts electrical energy to magnetic and then mechanical energy with the output of a useful torque at the motor shaft. Part of the energy transformation is converted to heat, causing a rise in rotor, stator and casing temperature; therefore an electric motor must be supplied with a cooling fan system. The cooling fan can be incorporated inside as 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 their robust construction which can withstand a dirty environment. OPEN motors are less used due to possible contamination by the environment. An OPEN motor is sometimes (but not always) less noisy than a TEFC motor since the noisy fans are incorporated inside.

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. The cooling fan is usually the dominant noise source.

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, and/or motor mounting. Thus careful attention should be given to the vibration isolation, mounting and maintenance.

Noise generated by the motor fan is the dominant motor noise source, especially for TEFC motors. A sharp increase in noise occurs as the shaft rotational speed increases from 1800 to 3600 RPM. For large motors in the range of 1000 kW, 3600 RPM, a sound pressure level of as high as 106 dB(A) occurs. Measurements carried out in the laboratory for a range of TEFC motors from 25 to 2500 HP, no load, with and without the straight blade motor fan, show a difference of up to 50 dB(A) in the total sound pressure level. This large distribution of the fan noise is due to the fan shape. Motor fan blades are usually straight, so that the motor cooling is independent of rotation direction. Straight blade fans are very noisy, due to the large aerodynamic turbulent sound generated. Noise reduction in electric motors can be achieved by the use of an absorptive silencer (Gerges, 1992) or by redesign of the cooling fan, e.g. with irregular spacing of straight blades as in chapter10 (see Figure 10.17.).

5.3.5. Woodworking Machines

The woodworking industry has experienced noise level increases as a result of modern, higher speed, and more compact machines. The basic noise elements in woodworking machines are cutter heads and circular saws. Equivalent sound pressure levels (L_{Aeq}) in the furniture manufacturing industry can reach 106 dB(A).

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

1. Structure vibration and noise radiation of the work piece or cutting tool (such as a circular saw blade) and machine frame, especially at the mechanical resonance frequencies.
2. Aerodynamic noise caused by turbulence, generated by tool rotation and the workplace in the air flow field.
3. Fan dust and chip removal air carrying systems.

5.3.6. Pneumatic Tools

Compressed air-powered, hand-held tools such as drills, grinders, rivetting guns, chipping hammers, impact guns, pavement breakers, etc. are widely used within a broad spectrum of different industries. 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 turbulent flow generated as the compressed air passes the motor and by the aerodynamic noise generated in the air exhaust.
3. Sound radiation from tool vibration caused by air flow inside the tool.

The noise level of hand held tools can reach as high as 110 dB(A) at the operator's ear. Figure 5.8 shows a typical hand grinder.

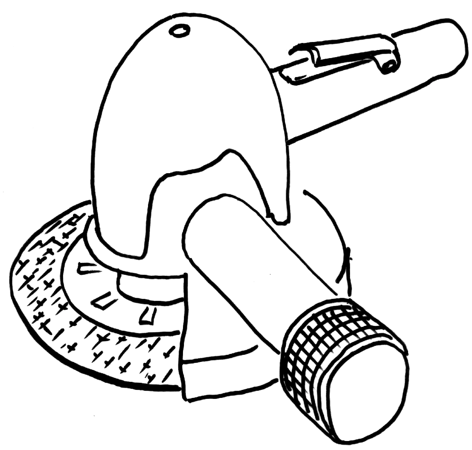

Figure 5.8. Typical Grinding Air Powered Hand Tool

5.4. TYPICAL NOISE LEVELS

As an example, data collected in Singapore in 1993 shows that only 366 factories out of 9051 factories have a hearing conservation program implemented. Table 5.5 shows a list of factories and number of workers with and without hearing conservation program implemented. Table 5.6 shows a list of 20 factories with a range of sound pressure levels and an average level for each. Data collected in Denmark on 55 pneumatic and electric hammers in different industries show an SPL of between 88 to 103 dB(A) (see Table 5.7).

Planing wood machine operators are exposed to an SPL maximum of 101 dB(A) and an SPL minimum of 96 dB(A) with an L_{Aeq} = 98 dB(A) for 8 hours, which is far above the acceptable risk values (AIHA-USA).

Data collected in a cigarette factory in Brazil show an SPL level of a compressed air cleaning process of up to 103 dB(A), with an L_{Aeq} = 92 dB(A) for 8 hours (Fredel 1990).

Economic calculations have shown that administrative and technical preventive measures are profitable. Technical progress during recent years has led to a decrease of the very high noise exposures, but not much change in moderate and low noise exposures. Measurements taken at some typical occupations show that the L_{Aeq} levels in the occupations shown by experience to have the worst noise have been 88-97 dB with highest peak levels of 101-136 dB (Table 5.8). In the referenced study, there were no findings of peak levels exceeding 140 dB (Pekkarinen, Starck,-1997). In most of the undeveloped countries, noise levels can exceed Table 5.6 values.

Table 5.5. Number of factories with Hearing Conservation Programs implemented in Singapore (Tan Kia Tang (1995)).

Singapore Standard Industry	Industry	All factories		Factories with Hearing Conservation Program(HCP)	
Code (SSIC)		Number of factories	Number of workers	Number of factories	Number of workers
38	Fabricated Metal Products	3698	219,521	199	24,093
3851	Shipbuilding and Repairing	116	21654	28	6,065
71 - 72	Transport, Storage and Supporting Services	60	4,320	10	4380
40	Electricity, Gas and Water	35	2,307	9	1,578
33	Wood and Wood Products	873	10,399	19	449
39	Other Manufacturing Industries	349	7,523	3	165
31	Food, Beverages and Tabacco	794	13,910	23	1,745
35	Chemicals and Chemical Products	903	28,439	29	2,014
34	Paper and Paper Products	927	16,839	17	1,676
32	Textile, Weaving, Apparel and Leather	867	26,635	6	380
36	Non - Metallic Products	186	4,425	4	118
37	Basic-Metal Industries	63	3,016	5	225
50	Construction	62	750	3	20
93	Social, Community, etc.	101	883	10	370
83	Engineering, Architectural Technical Services	17	246	1	24
Total		9051	339,213	366	34237

Table 5.6. Sound Pressure Levels in Manufacturing Industries in Singapore in 1993 (Tan Kia Tang (1995)).

	Industry	Number of Samples	Range L_{pA} (dB(A))	Average L_{pA} (dB(A))
1	Food manufacture	79	85-111	92
2	Manufacture of textile	28	85-108	93
3	Sawmill and other woodmills	32	85-104	93
4	Manufacture of furniture	54	85-115	93
5	Manufacture of paper and paper products	29	85-102	92
6	Printing and publishing	33	85-96	89
7	Manufacture of chemicals and chemical products	26	85-104	92
8	Manufacture of non-metal products	22	85-110	94
9	Basic metal industry	24	85-100	92
10	Manufacture of structural metal products	82	85-108	93
11	Manufacture of metal cans and containers	83	85-118	94
12	Metal forging and stamping	45	85-105	93
13	Manufacture of fabricated metal products	139	85-115	92
14	Manufacture of machinery	96	85-120	93
15	Manufacture of electrical machinery, apparatus and appliances	38	85-108	91
16	Manufacture of electronic products and components	83	85-103	90
17	Building and repairing of ships	42	85-110	95
18	Manufacture and repair of motor vehicles	24	85-105	92
19	Manufacture of aircraft	43	85-105	92
20	Other manufactures industries	33	85-105	91
	Total Average			92

Table 5.7. Noise from Pneumatic and Electric Hammers (Vedsmand, 1995)).

Product	Model/Type	Motive Power	Noise level A-weighted dB re 20µPa	Vibration Level (HA) dB re 10^{-6} m/s^2
AEG	PHM	EL/220V	101	142
Atlas Copco	TEX 11 S	Compressed air	95	142
Atlas Copco	TEX 22 S	Compressed air	100	147
Atlas Copco	TEX 23 E	Compressed air	99	136
Atlas Copco	TEX 25 E	Compressed air	97	141
Atlas Copco	TEX 32 S	Compressed air	98	150
Atlas Copco	TEX 33 E	Compressed air	94	140
Atlas Copco	TEX 42 S	Compressed air	94	146
Atlas Copco	TEX 43 E	Compressed air	96	142
Berema	REBEL 20	Electricity	92	140
Bosch	UHS 10	Electricity	88	142
Bosch	UHS 27	-	95	138
Bosch	UHS 12/50	-	88	146
Compair Holman	Zitec 9	Compressed air	98	148
Compair Holman	Zitec 12	Compressed air	97	148
Compair Holman	Zitec 14	Compressed air	97	146
Compair Holman	Zitec 20	Compressed air	98	148
Compair Holman	Zitec 27	Compressed air	95	149

The Canadian Center for Occupational Health and Safety (CCOHS) has developed a Noise Levels data base to bring together noise exposure data on a wide range of workplaces, operations, machinery and occupations. The contents of the data base have been compiled from data reported in journals, health and safety reports, and surveys by various industries and agencies.

Table 5.8. Average L_{Aeq} values and L_{Cpeak} values at different industrial workplaces (n = number of measurements) (Pekkarinen, Starck 1987).

Industrial Branch	n	L_{Aeq} dB(A)	L_{Cpeak} dB(C)
Foundry	24	93	127
Plastic packing	12	83	112
Metal packing	22	92	119
Printing press	24	93	119
Shipyard	28	92	134
Brewery	36	96	117
Porcelain fabric	9	88	128
Glass factory	7	95	113
Glass fibers factory	3	97	101
Confectionery factory	11	86	106
Weaving factory	13	95	119
Stretch factory	7	88	114
Paper mill	21	92	130
Saw mill	14	94	123
Copper tube factory	5	96	136

5.5. ROLE OF STANDARDS AND DATA BASES

5.5.1. Introduction

As illustrated in Figure 5.9, regulations and standards have an important influence on both the design of quiet equipment as well as the design of a quiet work place.
In the domain of machine safety, the Directive 89/392 (Annex I, section 1.5.8) of the European Union requires that machines are designed and constructed in such a way that hazards from noise emissions are reduced to the lowest level achievable with due regard to technical progress and technology available, primarily at the source.

In order to evaluate the noise emitted by machines, declarations of the noise emission based on the European Directives 86/188 (Art. 8, Par. 1b) and 89/392 (Annex I, Section 1.7.4f) are demanded. This enables potential buyers to select from comparable makers of machine, that machine with the highest noise-related quality (stimulation for manufacturers via the market). At the same time it enables the buyers to meet their statutory obligation for machine operators to use the least hazardous equipment possible (see EC Directive 86/188, § 5 (1)). Although there are no other statutory regulations, the international standards have a similar role to foster these intentions as shown in the structure of noise reduction of ISO 11690-1, see Figure 5.9.

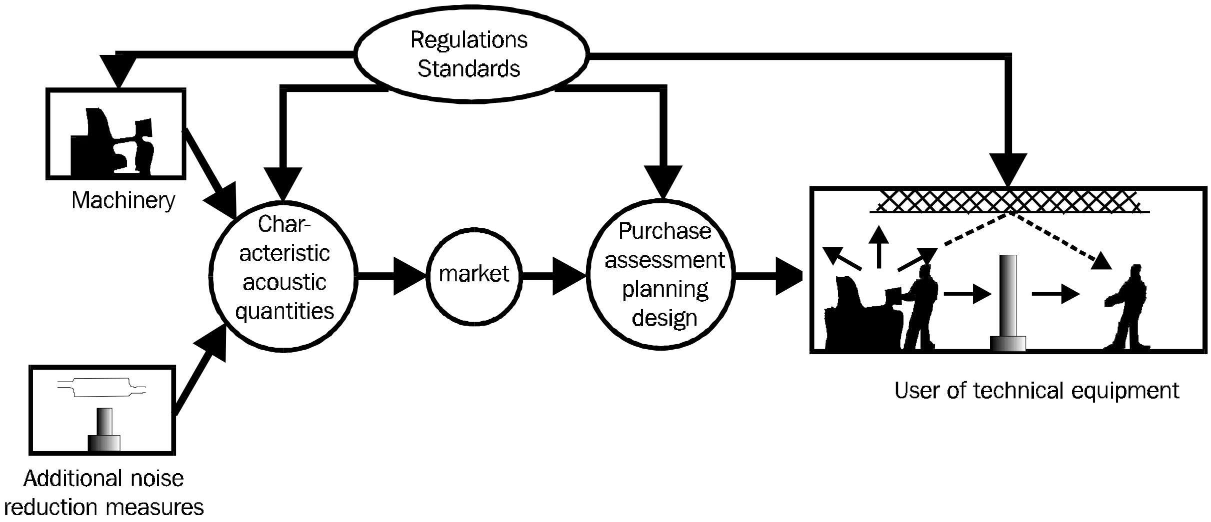

Figure 5.9. Role of regulations and standards

5.5.2. Framework Standards for Noise Measurement at Machines

The determination of the sound power is conducted internationally according to the ISO 3740 series, especially ISO 3744 and ISO 3746; the ISO standards have been revised since 1989. In these standards the enveloping measurement surface procedure is used to determine the sound power level. The subjects of the standards are in particular the selection of the measurement surface, the arrangement of measuring points, the determination of the environmental and background noise correction, the principles for the selection of the mounting and operating conditions and for determining measurement uncertainties.

The emission sound pressure level is determined internationally according to ISO 11201, ISO 11202, ISO 11203, ISO 11204. These standards address , as a complement to ISO 3744, selection of the measuring point or points for the workplace or workplace area and the environmental correction for one or more measuring points. Since the emission sound pressure level is taken as a criterion for the type and scope of the noise declaration in Europe, the precise determination and reproducibility should be stressed. A method which ensures the most correct possible environmental correction for a measuring point has now been developed and it is described in ISO 11204. ISO 11203 lays down procedures for calculating the emission sound pressure level from the sound power level. This procedure could be quite effective for smaller machines for which no precise workplace has been fixed (e.g. household appliances). ISO 11201 and ISO 11202 contain simplified procedures which are only applicable to a limited extent.

The type of noise declaration and a simplified verification procedure are given in ISO 4871. The verification procedures for noise emission already exist as International Standards (ISO 7574)

Most of the framework standards for determination,, declaration and verification of the noise emission have been completed. With the noise emission declaration (see Figure 5.10) for a machine, which is in Europe mandatory for the manufacturer or importer, there is the possibility for the first time of evaluating low noise level or noise quality. This creates the conditions for achieving noise reduction at source.

Noise emission declarations are also absolutely essential for forecasts by calculation

(ISO/TR 11690-3) of the noise impact (rating level) at workplaces and in the vicinity for the noise control planning of new workshops.

Machine model number, operating conditions, and other identifying information: Type 990, Model 11-TC, 50 Hz, 230 V rated load.		
DECLARED DUAL-NUMBER NOISE EMISSION VALUES **in accordance with ISO 4871**		
	Operating mode 1	**Operating mode 2**
Measured A-weight sound power level, L_{WA} (ref 1 pW) in decibels	88	95
Uncertainty, K_{WA}, in decibels	2	2
Measured A-weighted emission sound pressure level, L_{pA} (ref 20 μPa) at the operator's position, in decibels	78	86
Uncertainty, K_{pA}, in decibels	2	2
Values determined according to noise test code given in ISO XXXX, using the basic standards ISO YYYY and ISO ZZZZ. NOTE - The sum of a measured noise emission value and its associated uncertainty represented an upper boundary of the range of values which is likely to occur in measurements.		

Figure 5.10. Example of a noise declaration.

5.5.3. Machine-Specific Safety Standards: the Section "Noise"

In addition to the machine-specific noise measurement standards, noise also has to be included in a short section of a machine-specific standard with safety requirements for machines on an European and international level. Framework standards on the safety of machines lay down principles as to how the requirements of the EC Machinery Directive can be implemented, i.e., how the hazards arising can be recognized and avoided and how the safety of machines can be increased.

Where noise hazards (see EN 414 & EN 292, part 1) caused by machines, are significant, a noise section has to be formulated in a machine-specific safety standard. A safety standard should therefore include, as a safety requirement for the machine, a "noise reduction" section with the following sub-sections:

- Measures for noise reduction at the machine (ISO/TR 11688-1),
- Noise emission values (measurement, declaration, verification),
- Verification of noise reduction with reference to the achievable noise emission values (ISO 11689).
- Because there are some examples of international standards concerning safety of machines (e.g. agricultural machinery, gears) it seems sensible to follow these principles for International and European safety standards.

5.5.4. Framework Standards for Noise Reduction at Machines

To reduce noise at machines, standards have been drawn up which deal with the planning and design of low-noise machines (ISO/TR 11688 Parts 1, 2), the collection and evaluation of emission data (ISO 11689) and noise-related requirements for noise control devices and materials (silencers, enclosures, noise absorbers, baffles).

The standard ISO/TR 11688-1 gives an overview of the principles and methods a design engineer needs to design a low-noise machine or to communicate with an acoustic professional. The following approach is specified for the design engineer:

1. Specification of the design task (standards, state of the art, requirements for noise)
2. Concept phase (principles for solving the problem, comparison and selection of concepts, machine acoustics)
3. Detail design (calculations, detail drafts)
4. Investigations on prototype (measurement, evaluation, measures, comparison with requirements)

The standard ISO/TR 11688-2 describes the principles and basics of noise control development for existing and planned machines. Noise control devices and materials are to be covered as part of the machine, if they are integrated in it, e.g. enclosures, noise absorbers, partial enclosures, near-machine baffles. The reduction in emissions is thus expressed to an equal extent in the emission values.

It was intended, for instance, to supplement ISO/TR 11688 by a collection of examples in a form which enables it to be incorporated in CAD programs or databases. The same applies for the computation methods in ISO 11689 and ISO 11690. It is absolutely necessary to adapt to the needs of computer-aided design because other requirements from the environmental domain are to be implemented in a similar fashion, e.g. recyclability of products. Longer periods must be expected when it comes to the installation of databases containing characteristic values for noise reduction materials and components. The measuring standards have to be completed first.

5.5.5. Standards for Noise Reduction Devices and Materials

Since noise control devices and materials can of course also be used subsequently and in addition, standards were drawn up separately with noise-related requirements and measuring procedures for such devices/materials: for noise control enclosures (ISO 11546, ISO 11957), for noise absorbers (ISO 11654, ISO 10534), for silencers (ISO 7235, ISO 11691, ISO 11820, ISO 14163), noise baffles (ISO 11821, ISO 10053).

5.6. ACTUAL STATE OF NOISE EMISSIONS FROM MACHINES

The collection, presentation and evaluation of noise emission data are described in ISO 11689. In order to present the current state of noise emissions, the following must be defined in particular:

- Machine group (type, arrangement area, power),
- Noise emission value (L_{WA} , L_{pA}),
- Machine-specific noise measuring standard
- Representativeness of data,
- Type of presentation.

Within the actual state of noise emissions for a machine group, the machine with the lowest emission value has a higher noise control performance than that with a higher value. To describe the noise control performance of machines, ISO 11689 proposes that the emission data of a machine group be broken down with the help of two or three defined emission values (L_1, L_2, L_3) (see Figure 5.11). Different noise control performances are then obtained according to the level of the individual emission values of the machines in one group (see Table 5.9 for examples).

In Germany the actual state of noise emissions was drawn up for a series of machine groups in VDI-ETS Guidelines, e.g. for wood-working machines (VDI 3740, Table 5.9), metal-cutting machine tools (VDI 3742), reciprocating internal combustion (RIC) engines (VDI 3753), foundry machines (VDI 3757), hand-guided tools (VDI 3761) , machines for the forming of concrete blocks (VDI 3767) etc.

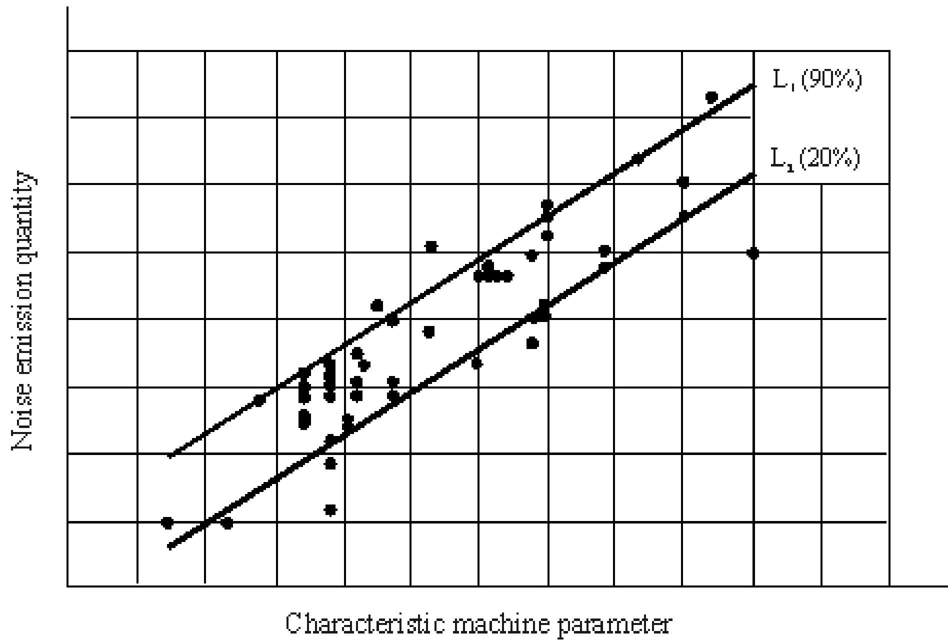

Figure 5.11. Typical noise emission as a function of machine parameter

Table 5.9. Noise emission values (sound power level L_{WA}) for surface planing machines (according to VDI 3740, Part 2).

Type of machine	Width of cutting tool in mm	Form of table lip	Operating state	Emission value (A-weighted sound power level L_{WA} in dB)					
				smallest		**medium**		**largest**	
Surface planing machine	<400	toothed	no-load	87	83	88.5	91	90	102
		untoothed		83		91.5		102	
		toothed	machining	95	94	97.0	99.0	101	105
		untoothed		94		99.0		105	
	≥400	toothed	no-load	82	82	92,0	93,5	101	102
		untoothed		90		97.0		102	
		toothed	machining	92	92	98.5	99.5	105	105
		untoothed		99		101.5		104	

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VDI 3742. Characteristic noise emission values of technical sound sources - Cutting machine tools (in German)

VDI 3753. Characteristic noise emission values of technical sound sources - Reciprocating internal combustion (RIC) engines (bilingual German & English)

VDI 3757. Characteristic noise emission values of technical sound sources - Foundry machines (bilingual German & English)

VDI 3761. Characteristic noise emission values of technical sound sources - Electric woodworking tools (in German).

VDI 3767. Characteristic noise emission values of technical sound sources - Machines for the forming of concrete blocks (bilingual German & English)

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INTERNATIONAL STANDARDS

Titles of the following standards related to or referred to in this chapter one will find together with information on availability in chapter 12:

ISO 3740; ISO 3744; ISO 3746; ISO 4871; ISO 7235; ISO 7574; ISO 9614-1, -2; ISO 10053; ISO 10534; ISO 11201; ISO 11202; ISO 11203; ISO 11204; ISO 11546; ISO 11654; ISO/TR 11688-1, -2; ISO 11689; ISO 11690-1, -2; ISO/TR 11690 -3; ISO 11691; ISO 11820, ISO 11821; ISO 11957; ISO 14163;

FURTHER READING

Canadian Center for Occupational Health and safety (CCOHS) - *Noise Level data base*.