NOISE MANAGEMENT

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Amendments to Doc85/10

Section	Change
3.1	Section on “Publication Terminology” (“shall” – “may”, ….) is added
all	Minor textual imrpovements
6	References are updated

1 Introduction

There is growing awareness and appreciation of the problems of noise in relation to the individuals and their environment.

Noise is an important issue for the Industrial gases industry. Many of our processes have large machines and equipment that are sources of noise. A large proportion of the complaint incidents reported to EIGA from member companies are due to perceived problems of noise.

National or local regulations have to be considered separately. If such regulations exist they must be followed as a minimum.

The issues associated with noise that require careful consideration may be considered in the following categories:

Worker Protection

- The physiological effects of noise on the individual.
- The psychological effects of noise including the danger of accidents or errors due to impaired communication.

The Environment

The nuisance caused to people and the external environment by the increase of unwanted noise.

Different individuals can experience nuisance differently and it should be realised that few problems fall distinctly into a single category; often elements of both categories are involved.

2 Scope and purpose

2.1 Scope

This publication has been produced to make designers, constructors and users of plant and equipment in the industrial gas industry, aware of the problems they are liable to encounter due to noise generation at industrial gas production and distribution equipment, locations and customer sites.

Guidance is given on methods for overcoming these problems and for ensuring that individuals are not exposed to noise that will damage their hearing or that noise pollution of the environment surrounding a factory will not be excessive from the humanitarian or legal viewpoints.

2.2 Purpose

The publication makes recommendations on:

- reviewing noise generating sources and reducing noise levels to the lowest practicable level;
- limits of noise beyond which workers should not be exposed;
- providing suitable PPE if noise reduction is not possible; and
- limits of noise contribution to the public environment from users plant and equipment.

The standards laid down in this publication can be met in a number of ways. In each case, however, attention is drawn to the simplest and most practical method of achieving the desired result.

The publication aims to provide examples of:

- various types of noise to aid identification;
- the method of measuring and calculating the level of noise output from a machine, a system or a complete plant;
- the effects of multiple sources on the total sound output;
- the effects of distance and materials in attenuating the noise levels;
- recommended maximum noise levels for different activities; and

- 'best industry practice' providing guidance to EIGA members on noise reduction measures.

3 Definitions

3.1 Publications terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May and need not

Indicate that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Attenuation

Attenuation is transmission loss or reduction in magnitude of a signal between two points in a transmission system.

3.2.2 Decibel (dB)

The decibel is a unit of level that denotes the ratio between two quantities that are proportional to power. It is the unit of measure for sound.

3.2.3 Decibel weighting sound levels (dB (A))

This is a unit of measure of noise that compensates empirically for the lack of sensitivity of the human ear to very low and very high frequencies of sound, thus simulating the response of the human ear to sound.

3.2.4 Plant boundary line

Outer perimeter of the plant property.

3.2.5 Sound intensity level

Sound power that crosses a surface perpendicular to wave direction.

3.2.6 Sound pressure level

Sound pressure refers to the pressure wave resulting from sound production, arriving at a point distant from the source.

3.2.7 Sound power level, equivalent noise level and ISO noise rating sound level

Refer to Appendix A.

3.2.8 Speech interference level

Arithmetic average of the octave band sound pressure level at 500, 1000 and 2000 Hz.

3.2.9 Working area

Area that a person has to enter and remain in for more than a few minutes, on a regular basis, during a normal working shift.

4 A Guide to the issue of noise in the industrial gases industry

4.1 Effects of noise

4.1.1 Physiological effects of noise

Exposure to excessive sound can lead to hearing damage. The effects of a number of separate exposures are cumulative, and the victim may well be quite unaware of the damage being done until it is too late. Excessive sound is not necessarily the only cause of deafness. It can be caused by noise of lower intensity damaging the delicate mechanism inside the ear. This type of damage will almost certainly not be obvious to the person who is suffering from it because it develops slowly. For example, it may take 10 years of exposure to excess noise for eight hours a day before the effects become large enough to be serious. Damage to the mechanism inside the ear is never reversible.

The kind of deafness that is produced by noise is one that makes it hard to hear faint sounds but leaves the loudness of ordinary sounds more or less unimpaired although it may distort them. The person often hears conversation at normal loudness though he may think that people do not speak clearly. Hearing loss usually occurs first at frequencies around 4000 Hz, as that part of the ear dealing with sound of this frequency seems to be especially vulnerable.

4.1.2 Psychological effects of noise

In factories and work places we are generally concerned with noise, or sound that is not desired by the individual. It should however, be appreciated that desired sound in the form of music and the like can be equally damaging to hearing and this is outside the influence of the workplace.

Noise, even at acceptable levels from the point of view of hearing damage, can cause considerable distress and annoyance, leading to complaints and even psychologically induced illness.

Whilst it is not within the remit of this publication to deal with this particular problem, it should be borne in mind that individuals vary considerably in their sensitivity to nuisance and people who complain should not automatically be held to be unreasonable.

4.1.3 Noise and the community

It is now widely accepted that it is not acceptable (and in many countries not legal) that any person or undertaking should degrade the quality of their neighbour’s environment by pollution in any form. Noise is a major pollutant in that noise nuisance is a major source of complaints and the effect of noise on local fauna (wildlife) should also be considered.

The most frequent causes of nuisance are changes in plant operation (start up, shut down, modifications of plant or surroundings and product deliveries or collections).

No new industrial establishments are allowed to increase noise above agreed levels within various zoned areas and in certain cases they should be designed to allow for future reductions in zone levels. Consideration should be given to plan noisy operations to times when they will not cause a nuisance.

4.1.4 European legal requirements

The EU legislation relating to noise is summarised in Appendix B.

There are three principle types of legislation relating to noise:

- on noise emissions by products (cars, trucks, aircraft and industrial equipment);
- on worker protection; and
- on permitted noise levels in the domestic environment.

Whilst the first two are directly applicable to the workplace, the last is more directed to communities and is dealt with in the Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise [1]. This directive aims to protect the public against unwanted noise in the domestic environment caused by traffic and other mechanical sources and to establish a common approach to avoid, prevent or reduce harmful effects on human health due to exposure to environmental noise. It has three principal elements:

- to harmonise noise indicators and assessment methods for environmental noise;
- to gather exposure information in the form of 'noise maps' which will form the basis for action plans at local level; and
- to make the information available for the public.

4.2 Noise control policy

It is essential for Companies to ensure their employees and neighbours are not being exposed to unnecessary or harmful noise. Management should ensure that its objectives in regard to noise control are clearly defined and accepted and that everyone plays their proper part.

A situation should never be allowed to exist in which an individual is exposed to damaging sound. Efforts should also be made to reduce noise at all frequency levels.

New purchased machinery must conform to relevant EU Directives and be CE marked. The CE marking protocol includes the measurement of noise levels and this can assist in the purchase of low noise machinery to fulfil the site noise criteria.

The action that is taken to reduce noise exposure is dependent on the following hierarchy of noise control, in descending order of priority:

- remove the noise source;
- reduce the noise level at source;
- reduce exposure time; and
- provide hearing protection.

NOTE All planned engineering work has to take into account the noise effects for new and modified processes, buildings and surroundings.

4.3 Noise management in the working area

4.3.1 Working area noise assessments

Assessments of sound levels throughout the plant and surrounding area shall be taken:

- on a regular basis following a prescribed measuring plan in order to confirm that no radical changes in noise pattern have occurred;
- subsequent to any change in operating procedure, working hours or equipment;
- to confirm conformity to relevant EU Directives, for example machinery directive; and
- to assess boundary level noise (see section 4.4.1).

- The assessment above should be completed with an individual dose level measure if needed to assess the sound exposure of a person.

4.3.2 Assessment levels

In accordance with directive 2003/10/ec , an assessment of daily operator exposure over an eight-hour period shall be made [2].

For the purposes of this Directive the exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure are fixed at:

- exposure limit values: LEX,8h = 87 dB(A) and peak = 200 Pa respectively;
- upper exposure action values: LEX,8h 85 dB(A) and peak = 140 Pa respectively; and
- lower exposure action values: LEX,8h = 80 dB(A) and peak = 112 Pa respectively.

Where operator daily exposure is found to be at or above the action level of 85 dB (A) over eight hours or the peak level of 112 Pa is exceeded, action should be taken to reduce noise levels and subsequent exposure meaning a programme of technical and/or organisational measures intended to reduce the exposure to noise.

Exposure limit applies with the hearing protection device (HPD) in place: eg the actual noise level the worker is exposed to at the ear. The action levels are measurement of the noise without any HPD in place.

Relating workplaces shall be marked with appropriate signs and also delimited; access to them shall be restricted where this is technically feasible and the risk of exposure so justifies; individual hearing protectors shall be used in such areas.

Where noise exposure exceeds the action level of 80 dB (A), individual hearing protectors have to be available to workers; workers receive information and training relating to risks resulting from exposure to noise. These exposure readings/action and limit values are individual not general. So while companies take noise readings in areas, the exposure shall be based on a person's working day. One worker's noise exposure could be very different to a colleague's.

As mentioned above the key duty of the employer is to reduce noise as far as is practicable. This should be emphasized. If the 8hr noise exposure exceeds an action level the employer has to under-take certain actions. The key action is to produce a noise reduction plan. Provision of HPDs should not be the main action, it should only be a temporary action.

Under no circumstances shall the exposure of the worker exceed the exposure limit values of 87 dB (A) or peak sound pressure of 200 Pa.

Additionally, the peak level of sound with very short duration (impulse sound) caused by e.g. cylinder stamping, should not exceed 140 dB(C).

Table 1 shows a comparison of different noise levels

Table 1—Comparison of noise levels

Noise Level dB (A)	Description
0	Threshold of human hearing
10	Sound proof room
25	Still day, deep in the countryside
35	Quiet bedroom, remote from traffic
55	Park, courtyard, garden away from traffic at night
60	'Quiet'
62	Normal conversation

Noise Level dB (A)	Description
72	Busy office, restaurant or canteen
78	'Moderately loud'
80	Loud orchestra in large room A quiet FLT (older designs may range up to 90 dBA) Mandatory hearing protection in Holland
85	Level at which hearing protection become mandatory
90	Heavy diesel engine lorry at 6m
100	'Very loud'
105	'Painfully loud'
110	Pop group at 1m
140	Jet aircraft taking off at 20 m Venting of a high pressure cylinder without silencer
150	Maximum level which the human body can withstand (very dangerous)

4.3.3 Control measures

If elimination of the noise source is not possible, and the noise has been reduced at source to as low a practically possible the next step in the hierarchy of noise control is to have control measures, some examples of which are given in section 4.6.

4.3.3.1 Education and training

It is imperative that all employees are made aware of the cumulative effects of exposure to noise and are shown as effectively as possible the results of unprotected working in noisy conditions. For example, by demonstration with prepared recordings which simulate the loss of hearing due to various degrees of noise exposure.

Training and information should be provided for all operators who have a daily exposure that exceeds 80 dB (A). This should include information on the results of noise assessments, the risks to hearing associated with excessive noise, nature of control measures including hearing protection, their maintenance and correct use, and the any requirements to participate in an audiometric testing program.

4.3.3.2 Warning signs and acoustic screens

All areas of the plant with noise levels above an equivalent level of 80 dB (A) must have all entrances marked with a notice of the type (or similar) shown in Figure 1.

Figure 1—Hearing protection - required sign

These notices should also be repeated inside those high noise areas where personnel will be required to enter frequently, for example, to perform routine maintenance or record parameters for the log.

The use of a visible sign is recommended in high noise level areas that must be entered from time to time.

Warning Signs and acoustic screens should be especially provided around repair, maintenance and any area where noise machines or tools such as pneumatic hammers, drills, etc., are in temporary use.

4.3.3.3 Hearing protection

Ear protection should be worn in environments with an equivalent sound level above 80 dB(A). For sound levels continuously above 85 dB (A) equivalent ear protection must be worn. All areas where ear protection must be worn shall be clearly defined by warning signs.

Employers must ensure that all employees wear the designated ear protection when working in noisy conditions and emphasise the dangers of exposure to noise.

As a sound level of 80 dB (A) is attained, it is generally known that a deterioration of hearing must be expected. It is for this reason that an ear protection should be worn already at this level rather than 85 dB (A) as prescribed for personnel in specified areas of noise generation.

4.3.3.4 Medical tests

Where employees are liable to work in noisy conditions for any length of time or exposure to noise is unavoidable, medical checks should be made at time of employment and thereafter at regular intervals to determine that noise induced hearing loss does not occur.

4.3.4 Working areas

4.3.4.1 General

The purpose of this section is to provide guidance on the acceptable sound levels in places of work.

Values stated are derived from these criteria:

- equivalent noise exposure during normal working hours shall not reach a level that could cause long-term hearing damage; and
- where speech communication and concentration are of a special importance noise levels must not impair the effectiveness of these functions.

In order to overcome the complexity of equivalent noise monitoring, simplified noise levels are given in the text which if adhered to should result in equivalent noise exposures not exceeding 80 dB(A) for 8 hours, in accordance with EU Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) [3].

Noise monitoring may be used if preferred to measure if the equipment is compliant for continuous monitoring of individuals. Various software packages may be obtained for this purpose.

4.3.4.2 Normal working areas

In areas where speech communication is a necessity, too high noise levels or disturbing noises may give rise to poor intelligibility. Under these conditions errors can easily be made which at best result in work disruption and at worst can lead to major accidents.

It is, therefore, essential that areas such as control rooms, plant offices etc., as described in 4.3.4.3, are provided with low enough noise levels for efficient speech communication should be as low as reasonable possible.

Normal noise level shall not continuously exceed 80 dB (A). It is recommended that the noise level in working areas is below 80 dB (A) and it shall not continuously exceed 85 dB (A).

A good guideline form industrial experience is that intermittent noise may exceed 80 dB (A) by not more than a maximum of 15 dB (A) for short periods of a few minutes assuming that the equivalent weighed sound level is still below 80 dB (A).

4.3.4.3 Control rooms and offices

The acoustical design of the control room and office areas shall be aimed at achieving acceptable communication sound levels.

With the plant running at normal operating point and all doors and windows closed in the above areas, the Speech Interference Level should be not more than:

- 60 dB (A) Desirable; or
- 65 dB (A) Maximum.

The sound measurements shall be taken in the middle of the control panel 1.5 m above the floor and 1 m away from the panel. Sound measurements in the offices shall be taken in the middle of the individual office and at a height of 1.5 m from the floor and away from any obstruction.

For work areas where the work requires a high degree of mental concentration for significant periods of time it is recommended that noise levels do not exceed 55 dB (A).

4.4 Assessment and control of community noise levels

4.4.1 Community noise level assessments

Site Assessments should be regularly conducted at all facilities:

- initially, to establish and document area background noise levels at new plant sites;
- if there is reason to believe that background noise has changed, then another survey shall be conducted before plant start-up;
- after plant start-up, while the plant is operating in its normal mode to, determine whether the facility complies with the design basis; and
- at any time, as necessary, for reasons including a change in operating conditions, before and after a plant modification involving new or different noise-generating equipment or in response to a noise complaint or notice of violation.

4.4.2 Plant boundary line

If the plant is located on or adjacent to the customer's property, the customer's boundary line may be used in lieu of the actual plant boundary for developing sound level criteria, provided the customer agrees.

If the plant boundary line sound pressure level criteria shall be based upon the applicable local regulations and the background sound level obtained from field test data.

Additionally, proposed or anticipated changes to the applicable regulations, future development of the area surrounding the plant and the area topography shall be considered in establishing the criteria.

4.4.3 Surrounding area classification

The sound levels shown in Table 2 should be used in establishing the plant boundary sound pressure level criteria.

Table 2—Surrounding area noise classifications

Area Classification	Design Basis ISO Noise Rating Sound Level	Reference Only Equivalent dBA
(a) Heavy industrial	75	82
(b) Industrial	70	77
(c) Industrial-commercial	60	67
(d) Commercial	55	62

(e) Daytime residential	45	53
(f) Night-time residential	40	49
(g) Critical residential or hospital	35	44

4.4.4 Determination of specific noise levels

4.4.4.1 Nearest point of annoyance

The particular plant boundary line noise level should be determined by consideration of the location of the closest unit of the various area classifications with respect to the plant boundary line.

For example:

If the plant is in a countryside area and the only dwelling nearby is a farmhouse, then classifications e/f in Table 2 would apply at the house.

If the plant lies in an area of multiple uses, for example - residential and light industrial (categories e/f and c) such as may be found in town centres, then the nearest points of annoyance for each group must be determined and the plant boundary levels calculated for these various uses.

Thus an allowable noise profile can be built up which may enable certain directional properties (for example screen effects) to be utilised rather than carrying an overall noise level determined by the most sensitive area.

4.4.4.2 Background noise level

Prior to construction of a new facility, sound measurements should be taken at the proposed new site to establish the existing background sound levels. This information should be used to determine the permissible boundary noise level of the new facility.

4.4.4.3 Arrangement of sound field testing

A detailed topographical map of the proposed plant location and surrounding area within a radius of several km shall be obtained, plus a copy of all applicable local noise regulations.

A preliminary review and evaluation of the local sound criteria shall be conducted prior to final site selection.

4.4.4.4 Location of measurement points

The location of the sound monitoring points shall be determined by reviewing the map of the area and sound regulations for the area.

It is suggested that the following monitoring points are included:

- along all the plant boundary line (sufficient points should be chosen to enable an accurate noise contour map to be constructed);
- at the nearest or adjoining commercial or industrial property; and
- at nearby residential or other critical areas within approximately 1.5 km of the plant boundary line.

1.5 km is the distance at which a large plant can be considered as a point source developing hemi-spherical propagation of sound for extrapolation and interpolation of noise levels.

4.5 Noise measurement

Everything that moves generates sound waves in any case where an object vibrates in a medium, closely passes or touches another object, pressure waves are generated, e.g. the rotating vanes of a fan or compressor or the pressure drop due to turbulent flow through a nozzle or valve are noise generators, which can be especially intense if shock waves are produced.

4.5.1 ISO standard measurement methods

These notes on methods of obtaining noise data are intended to comply with the methods determined by the latest copy of the relevant ISO standard. Where subsequent additions to these standards supersede the recommendations contained herein, these additions shall be followed.

4.5.1.1 Details of field test

The plant site sound measurement shall be in accordance with ISO 3744 and 3746 [4] and [5]. Sound readings should be taken when wind velocity is less than 5.5 m/s (20 km/h) with no rain, snow or fog in the test area.

Noise propagation at distances above 100 m is increasingly dependent on weather conditions. The measuring results are influenced, for example where snow lies, the ground is frozen, when it rains, snows, when it is foggy, at temperature inversions in the lower atmospheric layers or when there is much wind.

Furthermore it should be noted the major difference in noise propagation between a 'winter' forest – trees without any leaves - and a 'summer' forest. Therefore one should endeavour to eliminate those factors. A diminution of the sound level in the wind direction normally caused by shadow effect, buildings or vegetation is possibly lowered by sound refraction due to wind - and temperature inversion.

Sound emission in the direction of the wind is carried much further than against the wind direction. Emission against the wind results in attenuation of sound level. Thus, considerable deviations from calculated values can occur.

Sound Levels readings of both dBA and octave band shall be taken at all necessary locations and readings shall be obtained during both day and night.

If there are any particularly strong noises, efforts shall be made to identify and determine the frequencies, duration and direction of these noises in order to pinpoint the actual source.

Pertinent observations should be noted such as:

- Noticeable traffic noise.
- Aircraft noise.
- Industrial noise, etc.

In residential areas, it is important to note when the external noises stop at night. This will assist in determining equivalent noise levels during different periods.

4.5.1.2 Purpose of field tests

- Pre-Start up Sound Field Test shall be taken at the plant site prior to plant starting to check that the sound level in the area has not changed since the original sound field test was taken. Any increases in sound measurements taken prior to start up compared to the original sound field test should be brought to the attention of the Authorities. Site construction activity should not be taking place at the time of this test.
- Sound measurements shall be taken after the plant has been started up and is running at the normal operating point to determine if the plant sound meets the boundary line sound level criteria. If it does not meet the boundary sound level criteria then corrective action must be taken.
- The sound measurement for the various plant areas shall be carried out where the noise exposure could be considered to be high. Sound pressure level readings in dBA and also an octave band frequency analysis at 500, 1000 and 2000 Hz should be taken in:
    - the control room;
    - plant office areas;
    - work areas where personnel are continuously employed; and
    - maintenance areas.

Sound pressure levels readings in dBA shall be taken in tanker loading areas at various points within the area and for process & cylinder filling equipment areas taken at various points frequently occupied by the operating personnel.

NOTE Where noise is varied, intermittent noise dosimetry shall be carried out to determine average exposures. This technique is appropriate when assessing the equivalent noise level exposure for persons not having a fixed work place which is the method suitable for many tasks in the gas industry.

4.5.1.3 Instrumentation

The measurements should be made with a sound level meter as specified in I.E.C. publication 123 ‘Recommendations for sound level meters’ [6] or I.E.C. publication 179 ‘Precision sound level meters’ [7]. The A weighting network and slow response shall be used.

4.5.1.4 Measurement conditions within the plant boundary line

- Outdoor measurements should be made at 1.2 m to 1.5 m above the ground and if practical, at least 3.5 m from walls, buildings or other sound reflecting structures. Where circumstances necessitate, measurements may be made at greater heights and closer to the wall (for example 0.5 m in front of an open window) provided that this is specified and taken into consideration.
- Indoor measurements should be made at a distance of at least 1m from the walls, 1.2 m to 1.5 m above the floor and about 1.5 m from the window(s). In order to reduce disturbances from standing waves, the sound levels measured indoors should be averaged over ± 0.5 m about each of at least three positions. This is especially important when measuring low-frequency noise. The arithmetic average of the readings determines the value to be taken. The measurements should generally be made with the windows closed. If the room is regularly used with open windows, measurements should also be made under this condition.

4.5.1.5 Test procedure

- Review locations and sound level requirements for the test area or point;
- inspect instrument for external damage. Prepare the instrument for use in accordance with the instrument manufacturer’s instructions, and record calibration data on sound field test data sheet;
- take sound readings as required for the specific test;
- check calibrations after completing the sound measurements. The calibration of the instrument shall be recorded on the sound field test data sheet. The sound measurements shall be repeated if the calibration check indicates an error exceeding ±2 dB; and
- record atmospheric conditions on the sound field-test data sheet:
    - temperature;
    - barometric pressure;
    - relative humidity;
    - wind speed/direction; and
    - weather type (snow, rain, fog, etc.).

4.5.1.6 Report

After the sound measurement has been completed, it is recommended that a report should be issued containing the following:

- brief outline of applicable regulations;
- summarised result of tests with graphs and comments on compliance with regulations;
- brief description of test;

- copy of all data sheets (completed);
- map of the area with the plant boundary line; and
- all the sound measuring locations shown.

4.6 Best practices for noise reduction

4.6.1 Prevention by good design

It is usually better (on both economic and residual noise grounds) to plan a low noise level plant at the commencement of a project rather than to try to achieve a low residual noise level by modification after the plant has been built. Exactly the same applies to less complicated issues such as the purchasing of an equipment or machinery. Noise issues should be considered in plant Hazard and Operability Studies (HAZOPS) and risk assessments. It is also important not to introduce another risk when considering noise reduction measures.

This can be achieved by selecting low noise processes, attempting to purchase suitable low noise emission equipment (preferably with noise guarantee) and paying particular attention to plant arrangement and spacing. A badly arranged plant may be practically impossible to silence to an acceptable level. Equipment designers must endeavour to design noise-reducing characteristics into the units to eliminate noise generation, noise conduction and noise radiation.

Where it is desired to acoustically treat areas liable to oxygen enrichment, special care must be taken to ensure that all materials used are oxygen safe regarding fire hazard.

4.6.2 General measures to reduce noise

The main sources of noise from Industrial Gases operations are shown in Table 3.

Table 3—Typical noise sources in industrial gas plants

	Kind of Noise	Source	Category						
			1	2	3	4	5	6	7
Normal Operating Plant Noises	Continuous or Modulating	Compressor suction	x						
		Air Coolers, Blowers, Cooling Tower fans	x						
		Pressure let down valves	x	x					
		Pipes	x						
		Continuous Venting	x						
		Engines and Motors	x						
		Turbo Compressors	x						
		Reciprocating Compressors						x	
		Expanders & Turbines	x					x	
		Reciprocating Pumps						x	
		Centrifugal Pumps	x						
		Hydraulic Transmissions	x						
		Cylinder Handling					x		
		Cylinder Ring Testing					x		
		Transformers	x						
	Intermittent or Periodic	Switch Valves				x			
		Exhaust & Venting during production	x			x			
		Tanker Venting & Loading	x			x			
		Loading Areas (Cylinder Handling)					x		
		Cylinder Stamping					x		
		Carbide Handling					x		

	Kind of Noise	Source	Category						
			1	2	3	4	5	6	7
		Fork Lift Trucks					x		
Occasional Plant Noise	Continuous	Start up Venting Safety Valves Compressor Starting Sonic Alarms Maintenance & Repairs	x V	 x A	 R	 x x I	 O	 U	 S
	Short	Bursting Discs							x

Categories:

- Steady;
- non-steady;
- fluctuating;
- intermittent;
- impulsive;
- quasi steady; and
- isolated burst of noise.

There are two causes of noise generation that have to be considered:

- primary noise arising from the initial disturbance, for example roller bearing component vibration, compressor suction and discharge lines; and
- secondary noise arising due to transmission of a primary vibration to another structure or piece of equipment that resonates in sympathy with the primary vibration, for example foundation vibration pipe resonating or shaking wall panel flexing resonant room vibration.

Both of these sources need to be addressed. General noise reduction measures include the following:

- switch off unnecessary machinery or equipment;
- lower flow velocities;
- low or slow change of flow velocity reduce pressure in several steps by using a series of pressure reducing devices;
- lower speed of rotation;
- reduce amplitude of vibrating parts;
- avoid transmission of vibration;
- employ a low noise mode of operation e.g. flame cutting instead of mechanical cutting;
- on tankers eliminate transfer pumps if possible or use electric drives rather than mechanical or hydraulic drives;
- attenuation of sound by:
  - using *reflection* from barriers of dense material. Reflective surfaces cause increased noise levels inside an enclosure that could reduce the net noise reduction achieved by the barrier to almost zero;

- using *impedance mismatching*, that is layers of different materials to reduce the sound intensity, for example building a brick wall to cut out air barrier noise is very effective because the characteristic impedance (or resistance) of the wall is very much higher than that of the air; and
- using the *absorption* properties of some materials of high density (for example steel, lead), low stiffness (for example rubber) or high internal damping (for example nylon, mineral wool).
  - noise control between rooms, here are two variables which may be controlled:
- source side sound pressure level; and
- sound reduction index of dividing partition.

An evaluation of available solutions should be made before deciding the final method to be used

Some proposals may seem expensive at first sight but they might be the most economical solution if they eliminate the need for additional secondary noise reducing measures.

4.6.3 Effect of frequency on noise control

As a general rule high frequencies are easier to attenuate than low frequencies. Figures 2 and 3 show the impact of a frequency change on the distance that noise can be heard.

Principle

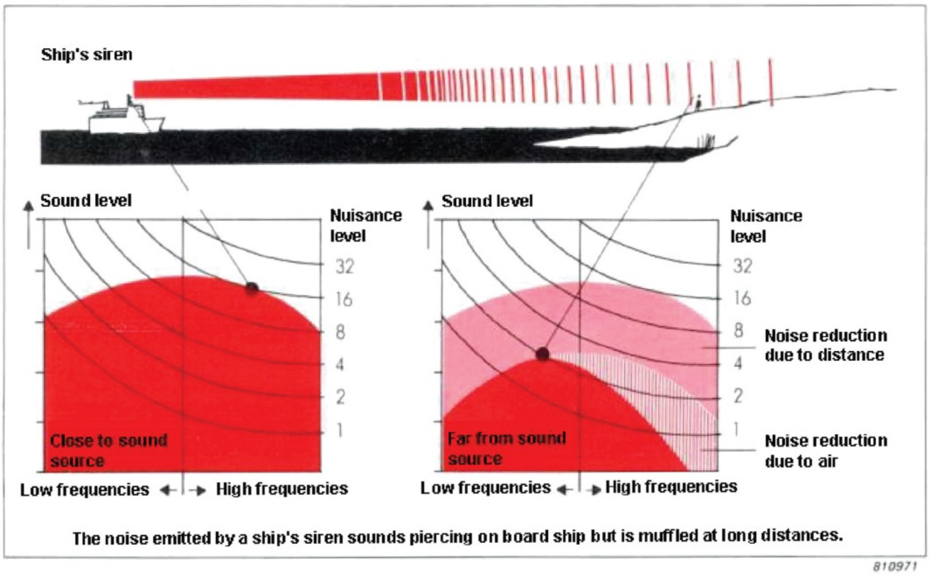


Figure 2—Principle of effect of frequency on noise control

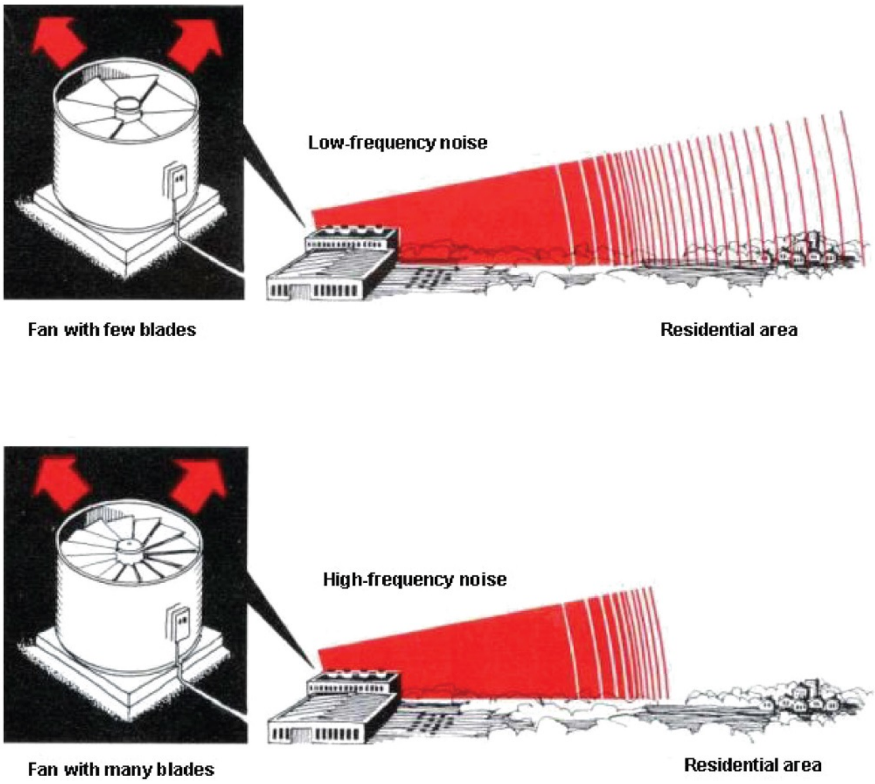


Figure 3—Example of effect of frequency on noise control

Different frequencies require different designs of absorption material, as shown in Figures 4 and 5

Principle

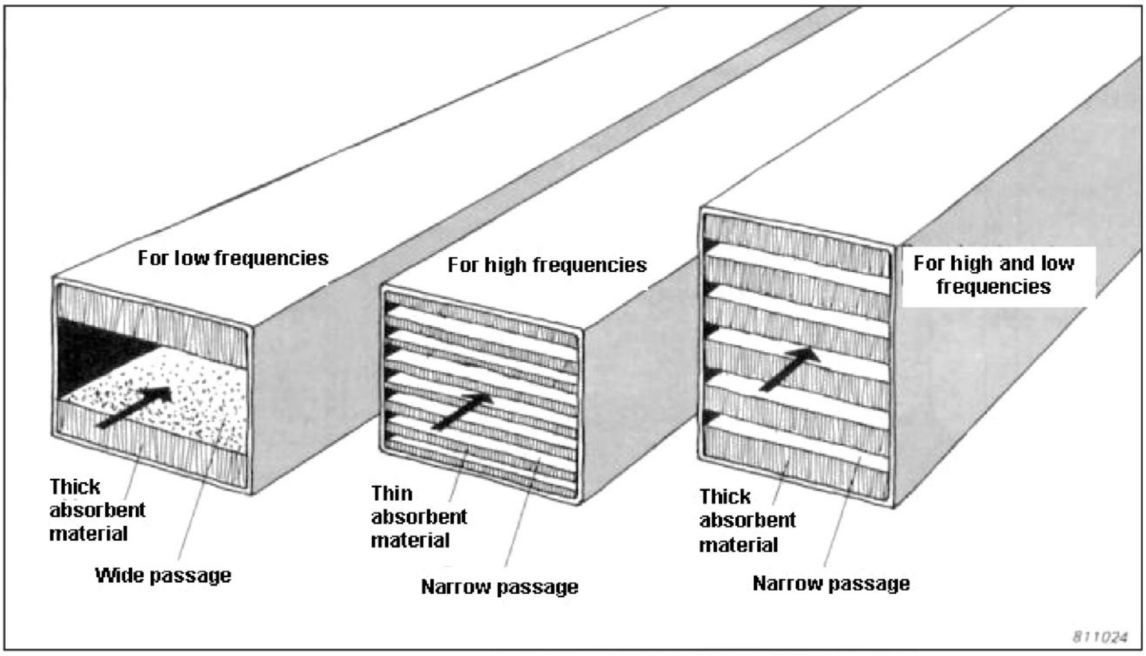


Figure 4—Principle of different absorbent materials for different frequencies on noise control

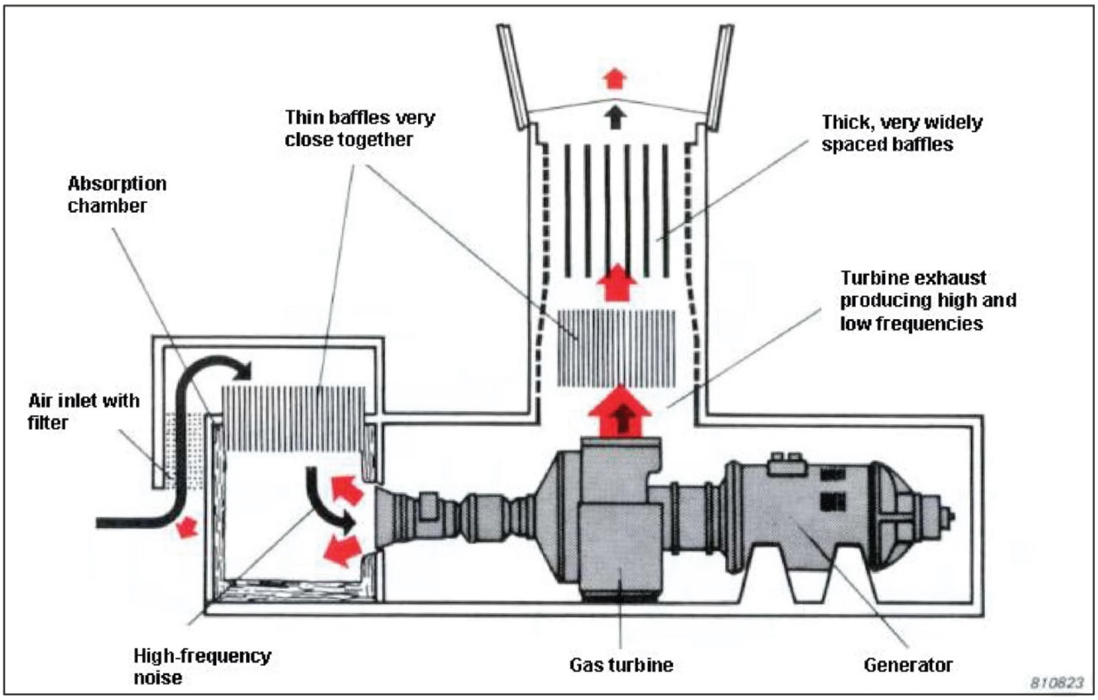


Figure 5—Example of different absorbent materials for different frequencies on noise control

4.6.4 Reduction in equipment and machinery noise

4.6.4.1 Purchase low noise machinery

4.6.4.2 Switch off unnecessary machinery or equipment

4.6.4.3 Lower speed of rotation

Use engine of higher performance than required at reduced load.

Check if 2 smaller engines of the same total performance can be installed and what would be their total noise level. (In general the overall noise of centrifugal compressor and centrifugal pumps increases in the proportion of 20 to 50 times the logarithm of the speed ratio).

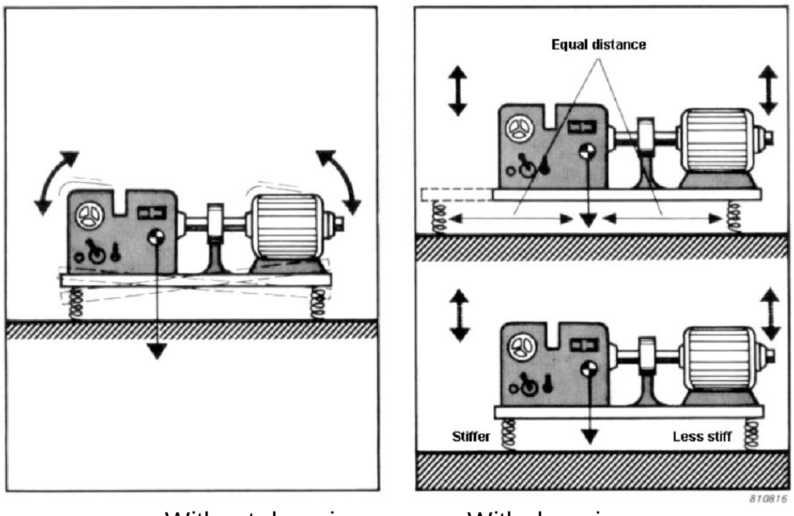
4.6.4.4 Reduce amplitude of vibrating parts

- align machine accurately;
- dynamic balance (only small amount of reduction but over the entire spectrum);
- low ratio of rotating mass to casing mass; and
- no major structural resonance shall be coincident with any strong forcing frequency.

4.6.4.5 Avoid transmission of vibration

- flexible mounting of machines and pipelines;
- torque transmission by separation of shafts;
- use of flexible couplings; and
- use metal/plastic sandwich material for damping.

Figures 6 to 12 illustrate these principles.



Without damping With damping

Figure 6—Principles of vibration damping (1)

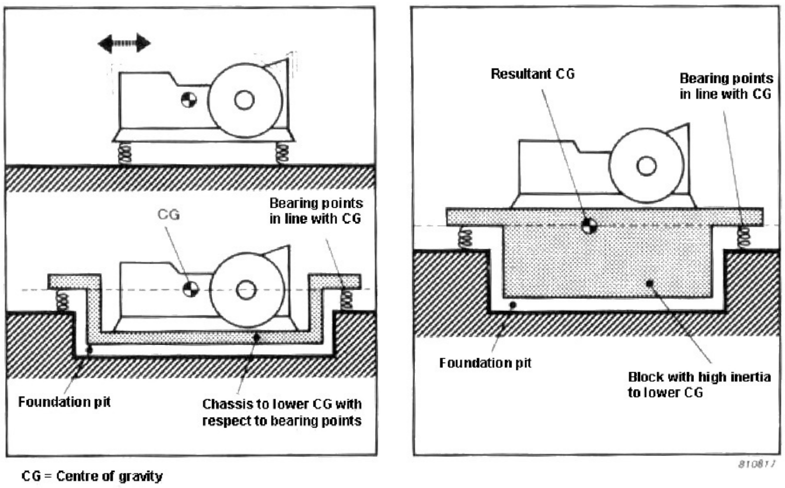


Figure 7—Principles of vibration damping (2)

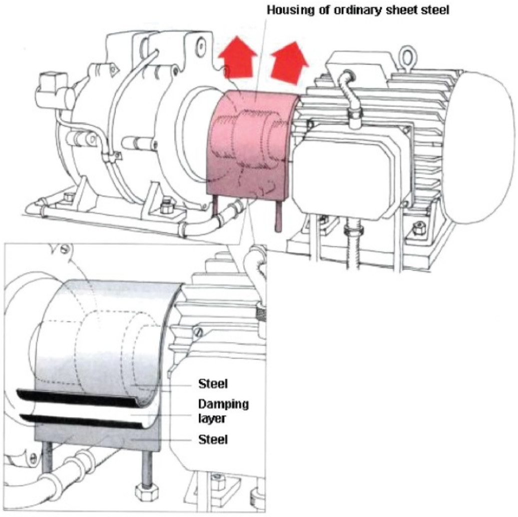


Figure 8—Principles of vibration damping (3)

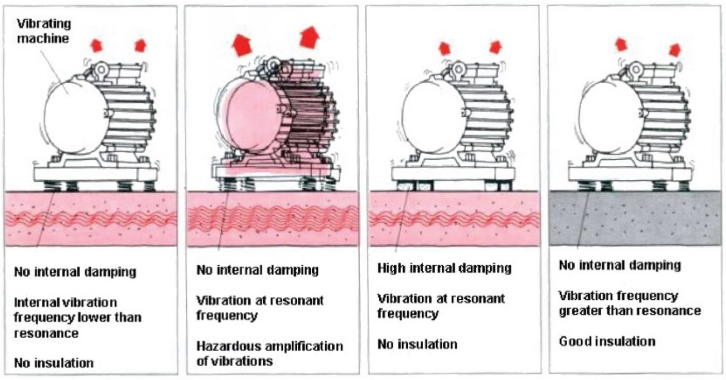


Figure 9—Principles of vibration damping (4)

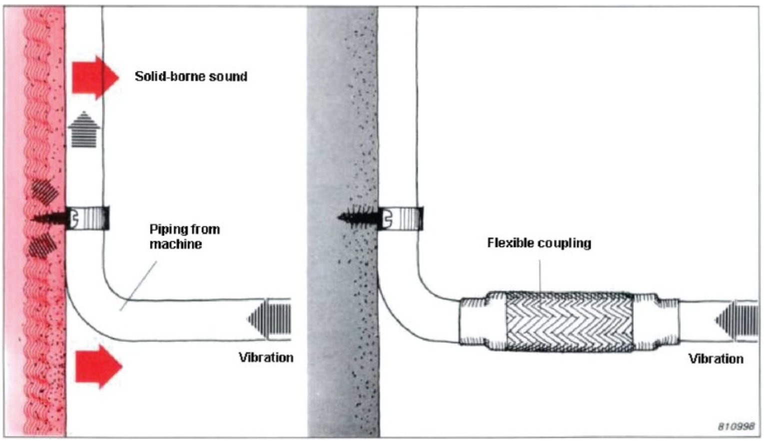


Figure 10—Principles of vibration damping (5)

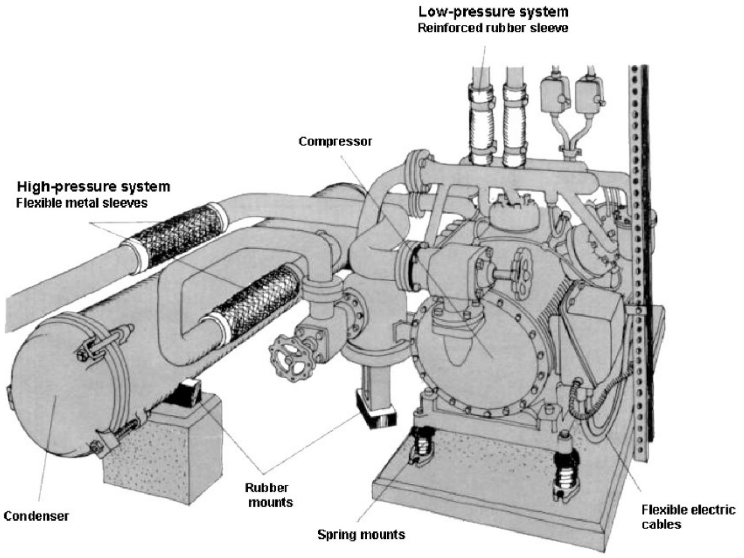


Figure 11—Principles of vibration damping (6)

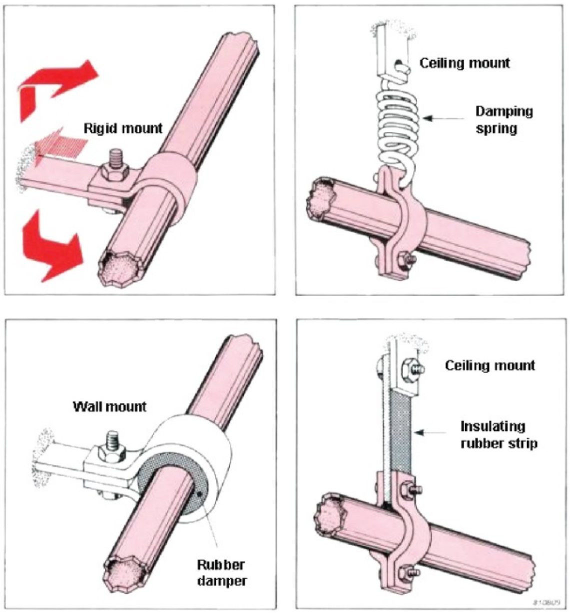


Figure 12—Principles of vibration damping (7)

4.6.4.6 Use of barriers and screens

Full use should be made of the screening capabilities of existing or planned structures, where possible, by arranging that the noise source is sited within the structure, or that the structure is located between the noise source and the point of annoyance.

Mobile acoustic barriers are available and should be used for temporary activities that may create noise. They can be set up and taken down easily and the simplest version consist of acoustic deadening material that can be set up on construction fencing and moved to shield noisy activities such as equipment testing during construction work or plant shut downs.

Due to size it is not normally economic to enclose a complete plant. Where large buildings such as compressor houses etc. are proposed, there is little point in constructing them of extremely high transmission loss material to stop top and side leakage. Corrugated sheets (as on cooling towers) or cinder blocks or even hi-density rigid polyethylene (as used on motorway noise barriers) should be sufficient. However, on the source side, the barrier can act as a reflecting surface and so should be covered in an absorptive blanket. One of the most effective methods is to submerge the main noise generating units in the ground and make good use of the capacity of the earth for sound absorption.

4.6.4.7 Enclosure of source

If other methods do not provide sufficient attenuation, then full or partial enclosure of the source must be considered. When totally enclosing noise sources such as machinery is done, due regard should be taken of the following hazards:

- build-up of heat within the enclosure;
- enrichment or deficiency of oxygen in the atmosphere inside the enclosure;
- build-up of explosive, flammable or toxic vapours within the enclosure; and
- avoid the deleterious effect of cracks and small openings in the enclosure walls.

4.6.4.8 Mechanical isolation

The mechanical isolation from the floor of any noise generator must be considered. Proprietary vibration isolating mountings are available for this purpose. If vibrations are transmitted to the building structure, then no amount of reduction of sound pressure level in the source room will reduce the levels in the receiving room.

4.6.4.9 Machine mountings

Even very small areas where the insulation is lessened contribute greatly to the transmission of noise. This can either occur as a hole or gap in the insulation or as a rigid attachment of a vibrating part to another structure.

It is important to avoid for example:

- rigid machine mounting;
- connection of machine (pipes etc) to suction/ discharge pipework;
- rigid support of ducts and pipes to building framework;
- sound transmission through ceiling voids around partition soundproofing; and
- poorly sealed service entries, gaps at edges of main partitions and around pipework and connections passing through ordinary windows, lightweight doors or storage areas fixed to walls.

It must be emphasised that any penetrations into an enclosure such as piping ducts, doors etc. must be well sealed as very small gaps or holes in the noise insulation allow considerable noise emission from and to the interior, thus greatly reducing the effectiveness or even negating the acoustics treatment. Gaps round pipes can be sealed with bitumastic compounds or mineral wool. Doors and panel joints should be provided with soft rubber seals.

4.6.5 Pressure relief and dump systems

Exhausts of this type form free jets surrounded by air at rest producing intense turbulent flow and thus pressure fluctuations. The frequency spectrum is very broad with maximum levels at frequencies determined by the exit velocity and jet size. To attenuate these sources, there are two options:

- reduce velocity by increasing pipe diameter using properly designed diffusing sections. In steam jets, inject water to condense some of the steam; or
- enclose the jet in a silencer (or muffle), which has an absorptive lining in order to provide a shield against direct radiation and to absorb the energy by multiple reflections inside the shroud.

Figures 13 to 15 illustrate these principles.

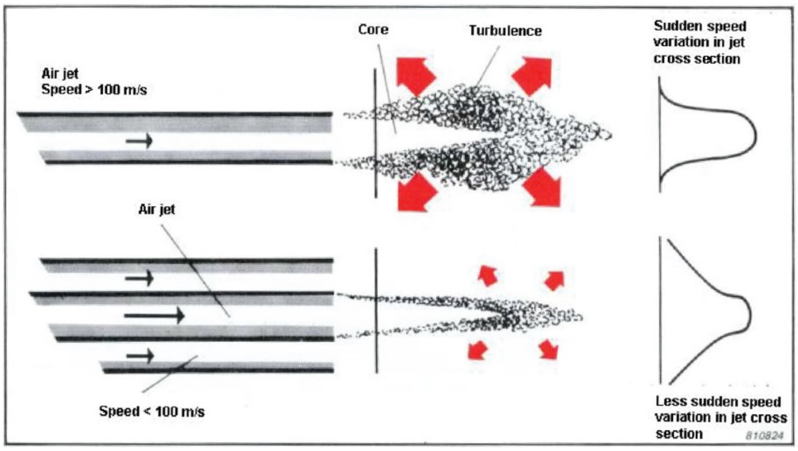


Figure 13—Multiple exhausts reduce turbulence and therefore noise (1)

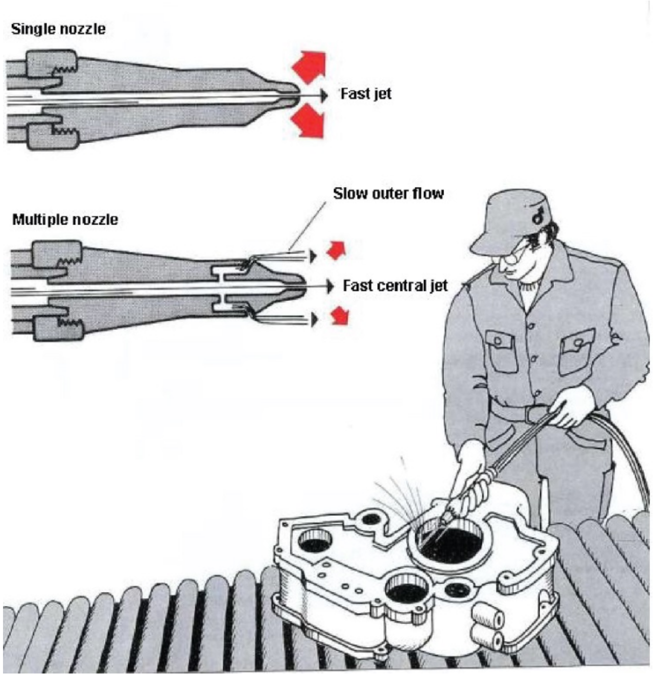


Figure 14—Multiple exhausts reduce turbulence and therefore noise (2)

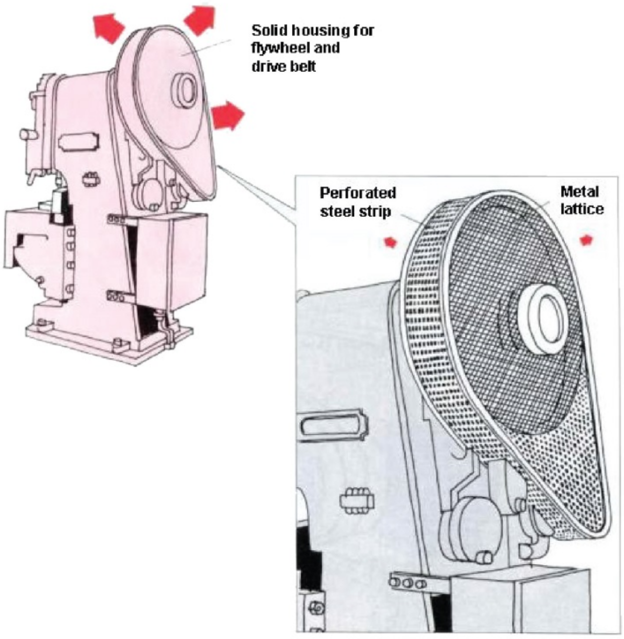


Figure 15—Addition of a lattice housing diffuses noise

4.6.6 Gas exhausts

Small volume, high-pressure relief exhausts have high characteristic frequencies, for example pneumatic hand tools, pneumatic valve and cylinder exhausts, high pressure gas cylinders.

An effective method of attenuation is to split the exhaust stream in several small diameter parallel streams by means of a multi tube exhaust device. A simple method of attenuation is to use a small diameter, thick walled PVC or rubber tube to pipe away the jet and allow friction losses to reduce the discharge velocity, although regard must be paid to limiting the backpressure potential in such a scheme and also to the compatibility of the materials with the intended gas service.

4.6.7 Control valves

Control valves function by introducing a pressure drop into the flow system. As the pressure drop increases, so velocity and turbulence increase thus generating more noise. Noise generation is usually a problem when the pressure ratio is high enough to produce sonic gas velocities.

If individual pressure drops can be limited to absolute pressure ratios of not greater than approximately 1.8 excessive noise should not occur. Where higher-pressure ratios are required, introducing a number of small ratio pressure drops in series may alleviate the noise problem.

Use of proprietary low noise valves which incorporate stepped pressure drops in the basic design. Typically 15 dB to 20 dB reductions at all frequencies have been obtained on some large critical flow valves.

Figures 16 to 19 illustrate the principles in 4.6.7

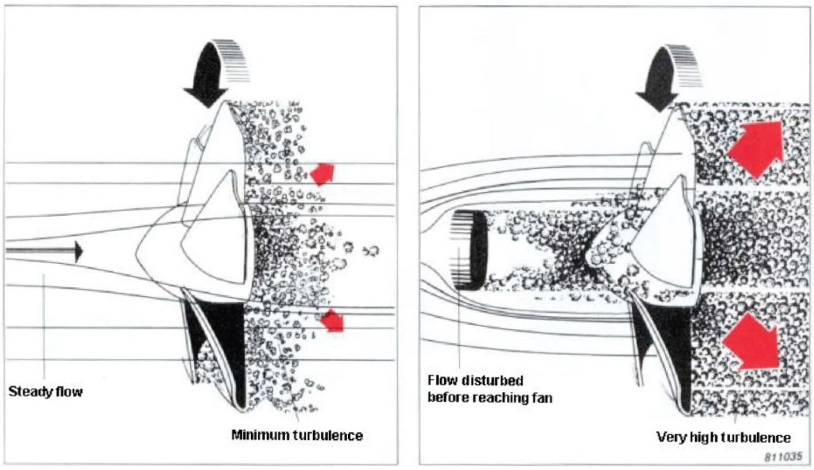


Figure 16—Control valve principles (1)

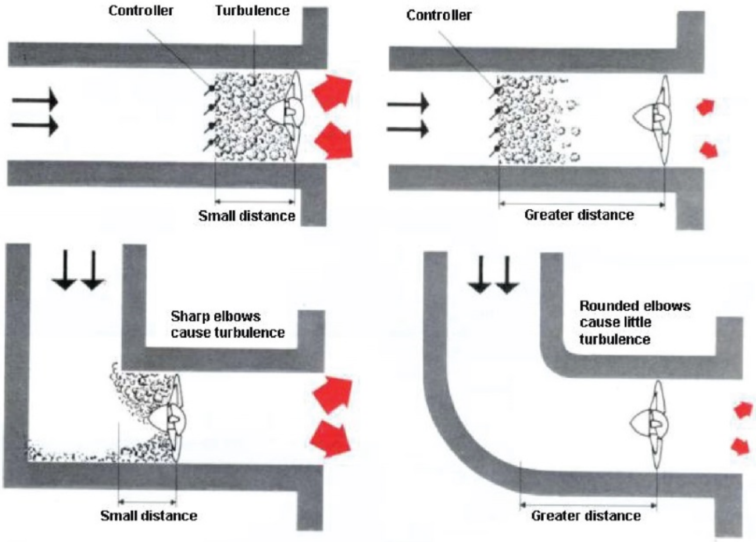


Figure 17— Control valve principles (2)

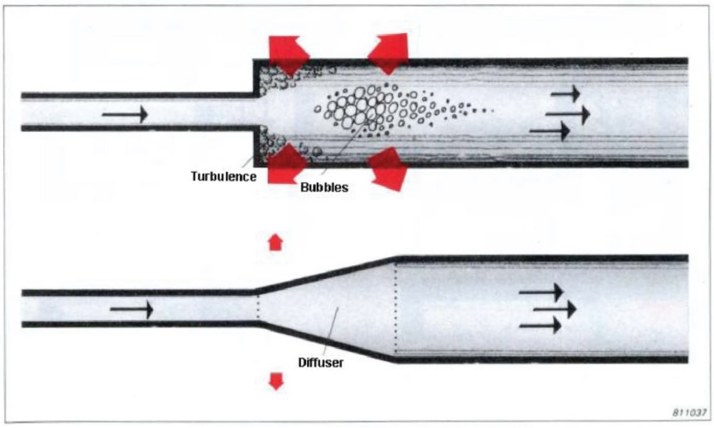


Figure 18— Control valve principles (3)

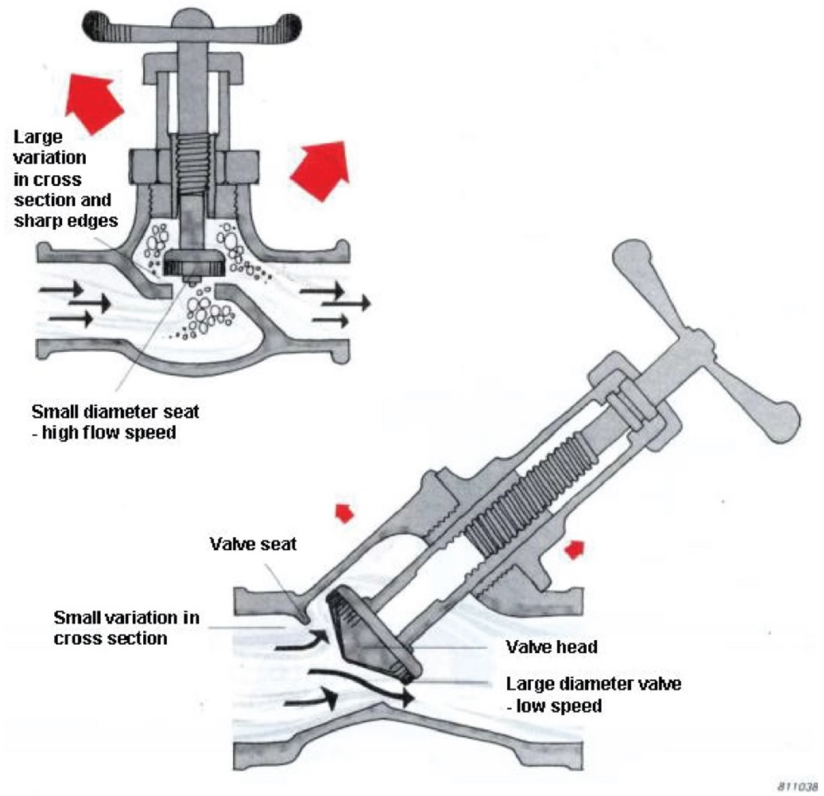


Figure 19— Control valve principles (4)

4.6.8 Plant pipe vibration

Pipe 'ringing' may also occur due to the presence of high frequency components in the jet noise spectrum. By choosing a series of lagging - possibly polyurethane foam (not for oxygen service) of mineral wool with an outer mass skin of lead, cement screed or similar around the pipe reductions can be made to remove the discrete frequency components. Also, for these measures to be effective, it is essential to replace rigid with resilient supports along the length of the pipe.

4.6.9 Cylinder loading and testing impact noise

Impact noise consisting of flat spectrum over a wide frequency range is produced when a solid body strikes a relatively large solid surface. The sharper the pulse and the shorter its duration, the higher is the frequency spectrum. As the pulse contains all frequencies – within a range – the struck surface will vibrate at one or more of its resonant frequencies - for example, a bell.

Thus a cylinder loading/testing area should have substantial damping built into the floor to reduce this resonant vibration:

- the addition of an unconstrained layer of proprietary damping compound to the material (rubber glue/paint); and/or
- use of a sandwich type flooring (or wall boarding) which consists of two separate skins of the material required, separated by a layer of visco-elastic damping compound.

In particularly noise sensitive locations the noise of cylinders knocking together can be mitigated by adding cylinder 'sleeves.'

5 References

Unless otherwise specified, the latest edition shall apply.

[1] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 *relating to the assessment and management of environmental noise*. Official Journal of the European Communities. L 189, 18/07/2002 P.0012.

[2] Council Directive of 12 June 1989 *on the introduction of measures to encourage improvements in the safety and health of workers at work (89/391/EEC)*. Official Journal of the European Communities. L 183, 29.6.1989, p. 1.

[3] Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 *on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)*. Official Journal of the European Communities. L 42, 15.2.2003, p. 38.

[4] ISO 3744:2010 *Acoustics -- Determination of sound power levels and sound energy levels of noise sources using sound pressure -- Engineering methods for an essentially free field over a reflecting plane*. www.iso.org.

[5] ISO 3746:2010 Acoustics -- Determination of sound power levels and sound energy levels of noise sources using sound pressure -- Survey method using an enveloping measurement surface over a reflecting plane. www.iso.org.

[6] IEC 61672-1:2013 *Electroacoustics - Sound level meters - Part 1: Specifications*. www.iec.ch

[7] IEC 61672-2:2013 *Electroacoustics - Sound level meters - Part 2: Pattern evaluation tests*.www.iec.ch

Appendix A—Noise fundamentals

General

Wave propagation is an important chapter of physics and involves many fields: optics, acoustics, and electromagnetism. The purpose of this section is to refresh concepts about sound waves.

Mechanical waves

When a wave propagates through a medium, the particles of the medium do not move along with the wave, they oscillate around their equilibrium position whereas the wave travels (immaterially) through the medium. A sinusoidal wave is an idealized representation of a mechanical wave, which can have a more complicated shape and composition.

Sound waves

Mechanical waves with frequencies between about 20 Hz and 20,000 Hz are called sound waves and are particularly important as they cause the sensation of hearing in our ears. Most of the sound that we hear is transmitted through air, but sound may also travel in liquids and solids.

Sound propagation

When no sound is heard the air is in equilibrium and has uniform density and pressure. When a sound is generated a wave starts from the source and propagates, moving the layer of fluid next to its front in the direction of its travel. This layer of fluid exerts a force on the neighbouring element of fluid and a moving region of compression forms: in this region the density and pressure of the fluid are higher than the equilibrium values.

The elasticity of the medium forces the layer of the fluid to return toward its equilibrium position by causing a region of rarefaction where the density and pressure are lower than the equilibrium values.

Although compressions and rarefactions move long distances, the fluid itself (air) does not move very far; as the sound wave propagates through the atmosphere, an element of the fluid moves back and forth around its equilibrium position.

If the medium through which the wave travels is a fluid (that is, a gas or a liquid), only longitudinal waves can be transmitted, due to the absence of elasticity of shear in fluids, to provide a restoring force.

The speed of sound

We assume that the compressions and rarefactions of the air are rapid enough so that there is not time for heat transfer to take place from one part of the medium to another. These conditions are met in sound waves and it is said that sound propagates adiabatically.

As we are mainly involved in ambient conditions of sound propagation, the gas may be treated as an ideal gas and in this case the speed of sound can be expressed with the following formula:

$$V = \sqrt{kRT} \quad \text{(m/s)}$$

$$V = \sqrt{\frac{kRT}{M}} \quad \text{(m/s)}$$

$$V = \sqrt{\frac{kRT}{M}} \quad \text{(m/s)}$$

Authors Note: Top formula taken from EIGA source - produced in MS Word formula (note value M is not included but is included in the associated key)

The Second formula has been built to include M as found by research

The third formula has been manipulated should you prefer larger characters in the fraction.

Please delete formulas as applicable to your needs

Where: k adiabatic factor, R specific gas constant, T absolute temperature, M molecular weight.

The adiabatic factor is given by the ratio of specific heat capacity at constant pressure to specific heat capacity at constant volume (k = Cp / Cv). It is dimensionless.

It is very important to use coherent units of measure (SI units) to find the speed of sound in m/s.

Example for a temperature of 293 K (20 C) at atmospheric pressure:

Fluid	air	helium	hydrogen
Speed of sound	v = 343 m/s	v = 996 m/s	v = 1306 m/s

For a real gas the above formulation is no longer valid, or it can be considered valid only in the limited range of low pressure and temperature far from liquefaction.

By using a wide range equation of state $P=P(\rho,T)$, able to describe the whole thermodynamic surface of the fluid (gas or liquid) it is possible to calculate the speed of sound in a real gas, variable according to pressure and temperature, whether in the gaseous or in the liquid state.

Sound waves also exist in solids as well as in fluids.

Table A-1 summarizes the speed of sound in some media: gases, liquids and solids.

Table A-2 reproduces the speed of sound in air (as a real gas) at some values of pressure and temperature.

Table A-1—Speed of sound in some medium as a function of temperature, at atmospheric pressure

Medium	Temperature (K)	Speed (m/s)	Physical state
air	273	331	ideal gas
air	293	343	ideal gas
helium	273	962	ideal gas
helium	293	996	ideal gas
hydrogen	273	1261	ideal gas
hydrogen	293	1306	ideal gas
water	273	1402	liquid
water	293	1482	liquid
sea water	293	1522	liquid
aluminium	-	6420	solid
steel	-	5941	solid
granite	-	6000	solid

Table A-2—Speed of sound in air as a function of pressure and temperature

Pressure (bar abs)	Temperature (K)	Speed (m/s)	Physical state
1.01325	70	939	liquid
1.01325	78.69	864	saturated liquid
1.01325	81.72	177	saturated liquid
1.01325	150	245	gas
1.01325	300	347	gas
1.01325	300	446	gas
100	70	1001	liquid
100	300	369	gas
100	500	472	gas

Pressure (bar abs)	Temperature (K)	Speed (m/s)	Physical state
300	70	1091	liquid
300	300	467	gas
300	500	535	gas

Hearing

When a sound wave arrives at a human ear, the ear converts the pressure changes due to the sound wave into nerve impulses that are processed and interpreted by the brain as something heard.

The average healthy young person can hear frequencies that span from 20 Hz to 20 000 Hz, with a ratio of 1000 between the higher and the lower limit. By remembering that the speed of sound in air is 343 m/s we can calculate the wavelength corresponding to the minimum and maximum limit of audible frequencies:

- For the lowest frequency $\lambda = 343 / 20 = 17$ m.
- For the highest frequency $\lambda = 343 / 20000 = 0.017$ m.

The ear is a sensitive detector of sound waves. See Figure A-1 for an indicative section of the human ear. As said above, the eardrum is subjected to a displacement under the pressure of a sound wave, and this displacement can be calculated, as can be found in many textbooks of physics:

- Displacement amplitude for the loudest sound that the ear can tolerate, in air: 1.1×10^{-5} m.
- Displacement amplitude for the faintest sound that the ear can detect, in air: 1.1×10^{-11} m.

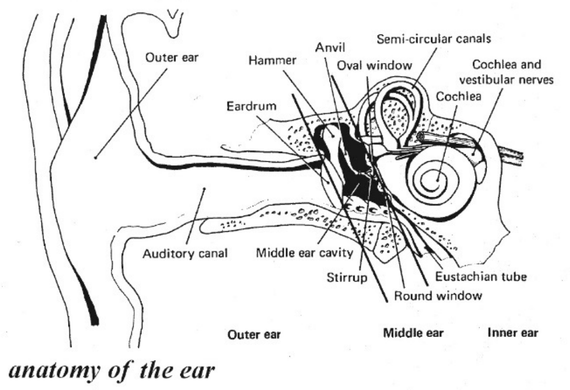


Figure A-1—Anatomy of the ear

Sound power level - the decibel

As will be shown below, the lowest sound power heard by the human ear in air, at the threshold of hearing, is 10 watt to 12 watt and the higher power the human ear can bear, at the threshold of feeling is 1 watt, for a sound with a frequency of 1000 Hz.

The ratio between the minimum and maximum levels of the above quantities is very high, so it is convenient to use a logarithmic scale for expressing the sound power.

$SWL = 10 \log (W / W_0)$ Sound power Level ,where $W_0 = 10^{-12}$ watt is a reference power.

Also SWL is dimensionless, it is given units of decibel (dB), after Alexander Bell (1847-1922).

The range of frequencies and powers to which the ear is sensitive can be represented by a diagram like that shown in Figure A-2, which is a graph of the auditory area of a person of good hearing.

The lower curve shown on the diagram (which decreases from 70 dB al 20 Hz, passes through 0 dB at 1000 Hz and then increases to approximately 20 dB at 10000 Hz) represents, at any frequency, the power level of the faintest pure tone of that frequency which a person can hear and it is extremely variable with the frequency itself.

The upper curve corresponds, at any frequency, to the power level of the loudest pure tone of that frequency which a person can tolerate: the upper curve is almost constant respect to frequency (120 dB). Above this curve a sensation of pain begins.

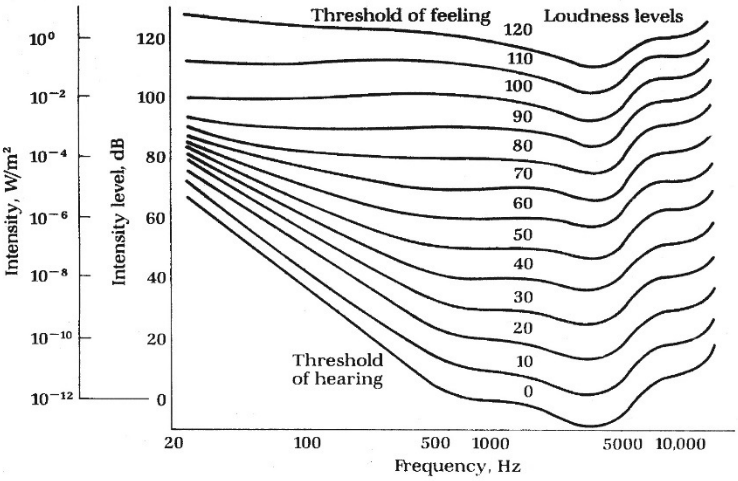


Figure A-2—Frequency range to which the ear is sensitive

By varying the power level of a sound with a frequency of 1000 Hz from the threshold of hearing (10^{-12} watt) to threshold of feeling (1 watt) the sound power level varies from 0 dB to 120 dB.

In fact:

- minimum SWL = 10 log (10^{-12} / 10^{-12}) = 0 dB; and
- maximum SWL = 10 log (1 / 10^{-12}) = 120 dB.

It is a rare occurrence for a body to vibrate with only one frequency, it will vibrate with many frequencies at the same time.

NOTE Originally, a scale of power level in *bel* was defined, but this unit proved rather large and hence the *decibel*, one-tenth of a bel, has come into general use. Sound power level is independent of location, because this concept refers directly to the sound source.

Example:

Calculate the SWL for a sound with a power W = 10^{-3} watt:

SWL = 10 log (10^{-3} / 10^{-12}) = 90 dB

Sound intensity level

In some cases, mainly for studies of sound propagation, it is useful to introduce the concept of sound intensity level.

When a sound wave leaves a source, the power spreads out and passes through areas of increasing surface.

The sound intensity I is defined as the sound power that crosses a surface perpendicular to wave direction:

I = W / A where W is the sound power and A is the crossed surface.

The unit of measure of intensity is power per unit area, or watt/m^2.

The sound intensity level is defined as

SIL = 10 log (I / I_0) sound intensity level ,where I_0 = 10^{-12} W/m^2 is a reference intensity.

See Figure A-3

Sound intensity level varies with the distance from the source: for a source of constant power, the sound intensity level decreases as the distance from the source increases.

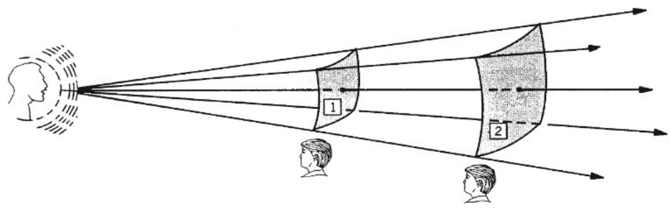


Figure A-3—Sound intensity level affected by distance

Sound pressure level

Sound pressure refers to the pressure wave resulting from sound production, arriving at a point distant from the source. It can be shown that the sound power W is proportional to p^2, where p represents the pressure amplitude of the wave, so we can write the sound pressure level as:

$SPL = 10 \log p^2 / p_0^2$ or $SPL = 20 \log p / p_0$ (Sound Pressure Level)

where $p_0 = 0.00002\ N/m^2$ is a reference pressure, corresponding to the reference power of $W_0 = 10^{-12}$ watt.

Sound pressure level varies with distance from the source, therefore an SPL calculation must consider the location with respect to the source.

NOTE In some textbooks SPL is indicated as L_p and SWL is indicated as L_w.

Example:

Calculate the SPL for a sound with a pressure $P = 0.4\ N/m^2$:

$SPL = 20 \log (0.4 / 0.00002) = 86$ dB

Table A-3 shows some typical sound levels.

Table A-3—Some typical sound levels

Sound source	**Decibel (dB)**	**SWL** [1] **(watt)**	**SPL** [2] **(N/m**[2]**)**
Jet engine at 30 m	140	10^2	‘00
Threshold of feeling	120	1	20
Amplified rock con-cert	110	-	-
Heavy machine shop	100	10^{-2}	2
Subway train	90		
Factory	80	10^{-4}	0.2
City traffic	70		
Normal conversation at 1 m	60	10^{-6}	$2\ 10^{-2}$
Office, classroom	50		
Library	40	10^{-8}	$2\ 10^{-3}$
Empty auditorium	30		
Whisper at 1 m	20	10^{-10}	$2\ 10^{-4}$
Falling pin	10		

Sound source	Decibel (dB)	SWL [1] (watt)	SPL [2] (N/m^2)
Threshold of hearing	0	10^{-12} (reference W_0)	2 10^{-5} (reference p_0)

NOTES

1) SWL = Sound poWer Level

2) SPL = Sound Pressure Level

Example:

Find the power W and the pressure p of a sound with the SWL = SPL = 80 dB:

SWL = 10 log (W / W_0) Sound power Level

W = W_0 $10^{(SWL/10)}$ = 10^{-12} 10^8 = 0.0001 watt

SPL = 20 log (p / p_0) Sound Pressure Level

p = p_0 $10^{(SPL/20)}$ = 0.00002 10^4 = 0.2 N/m^2

Although SWL is at first easier to understand, SPL is almost universally used for the main reason that nearly all instruments by which we measure sound respond directly to pressure, rather than power.

Sound power level (SWL) versus sound pressure level (SPL)

The sound power for a device is a constant for any given operating condition, regardless of the environment. For example a loudspeaker with a given electrical input produces the same SWL, whether in a small reverberant room or in an open field. But SPL is a function of the acoustic environment, distance and directivity of the noise generating device as well as the operating conditions.

By definition, the SPL created by a device will change if the acoustic environment is modified.

SWL cannot be measured directly.

It is a usual procedure to carry out the test measure in a known acoustic environment and make measurements of the SPL at a several points around the noise source.

Special reverberation chambers can be employed to reduce the number of SPL measurements required. Once the characteristic of the sound field is established, the SWL of the device can be calculated.

Addition and subtraction of decibel

Due to the logarithmic nature of the scale, simple addition of dB values is not valid, but the quantities SPL or SWL must be used; indicated as follows:

Example:

In a room there are three sound sources, find the total decibel:

Source 1	Source 2	Source 3
89 dB	91 dB	94 dB

- Use the Sound Pressure Level concept:

  SPL1 = 89 dB SPL2 = 91 dB SPL3 = 94 dB

  pressure level of source 1 p1 = p0 $10^{(89/20)}$ = 0.56 N/m^2

  pressure level of source 2 p2 = p0 $10^{(91/20)}$ = 0.71 N/m^2

  pressure level of source 3 p3 = p0 $10^{(94/20)}$ = 1.00 N/m^2 (p0 = 0.00002 N/m^2)

  The squares of the individual pressure must be added $ptot^2 = p1^2 + p2^2 + p3^2$

  $$ptot = \sqrt{(0.56^2 + 0.71^2 + 1^2)} = 1.35\ N/m^2$$

  SPLtot = 20 log (1.35 / p_0) = 96.6 dB

- Use the Sound poWer Level concept:

SWL1 = 89 dB SWL2 = 91 dB SWL3 = 94 dB

power level of source 1 $W1 = W_0\, 10^{(89/10)} = 0.000794$ watt

power level of source 2 $W2 = W_0\, 10^{(91/10)} = 0.00126$ watt

power level of source 3 $W3 = W_0\, 10^{(94/10)} = 0.0025$ watt ($W_0 = 10^{-12}$ watt)

The individual power must be added Wtot = W1 + W2 + W3

Wtot = 0.000794 + 0.00126 + 0.0025 = 0.004554 watt

SWLtot = 10 log (0.004554 / W_0) = 96.6 dB

For n sources the general formula can be used:

$$dbtot = 10 \log \left(\sum_{1}^{n} {}_i\, 10^{(dBi/10)} \right)$$

$$dbtot = 10 \log \left(10^{(89/10)} + 10^{(91/10)} + 10^{(94/10)} \right) = 96.6 \text{ dB}$$

Example:

In a room there are two sound sources for a total of 101 dB, a source of 99 dB is turned off. Calculate the remaining decibel in the room:

$$dBtot = 10 \log \left(10^{(101/10)} - 10^{(99/10)} \right) = 96.7 \text{ dB}$$

Example:

In a room there are two sound sources for a total of 80 dB, a source of 80 dB is added. Calculate the total decibel in the room:

$$dBtot = 10 \log \left(10^{(80/10)} + 10^{(80/10)} \right) = 83 \text{ dB}$$

If sources of equal SWL are added, the following rule can be used:

Number of sources	2	3	4	5	6	7	8	9	10	50	100
Decibel to add	3	4.7	6	6.9	7.7	8.4	9	9.5	10	17	20

Example:

In a factory there are 4 sources of 75 dB each:

dBtot = 75 + 6 = 81 dB

If two sources of different SWL are added the following rule can be applied:

Difference between the two sources (dB)	0	2	4	6	8	10	20
dB to add to the source of greater SWL	3	2.2	1.5	1	0.6	0.4	0

Example:

In a factory there are two sources, the first of 77 dB, the second of 83 dB:

Difference = 83 - 77 = 6 dBtot = 83 + 1 = 84 dB

Sound measurement

The most common types of measurement in the field of environmental noise assessment are overall and octave band measurements: most noise measurements are in term of SPL.

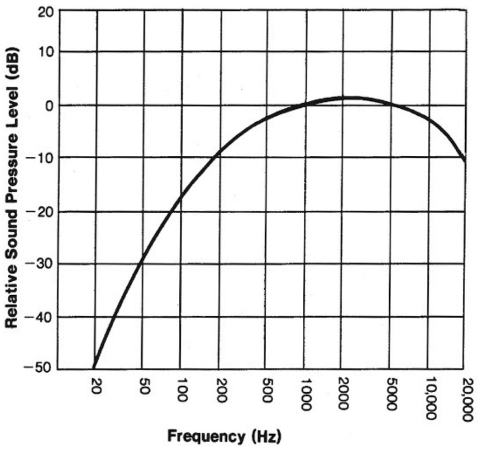
An overall measurement results in a single decibel value that describes the sound frequencies, taking all frequencies into account. In the normal hearing range of 20 Hz to 20 000 Hz, the human ear is more sensitive to frequencies between 200 Hz and 10 000 Hz. Most microphones do not attenuate or amplify sounds in this frequency range the way human hearing mechanism does.

The A-weighted scale was developed as a set of filters in sound level meters that simulate the frequency sensitivity of the human hearing mechanism: the readings on the A-scale correspond closely to the response of the ear.

The decibel measured by a sound level meter with an A-weighted scale is indicated as the dBA or dB(A).

NOTE 0 dB(A) corresponds to the threshold of hearing and 120 dB(A) corresponds to the threshold of feeling.

Figure A-4 and Table A-4 show the correlation between dB scale and dB(A).



IEC Standard A-Weighting Curve for Sound Level Meters

Figure A-4—Correlation between dB scale and dB(A)

Example:

a 125 Hz note of sound pressure level 70 dB would indicate 70 - 16.1 = 53.9 dB(A)

a 1000 Hz note of sound pressure level 70 dB would indicate 70 - 0 = 70 dB(A)

a 4000 Hz note of sound pressure level 70 dB would indicate 70 + 1 = 71 dB(A)

Analysis of sound

Sound does not normally consist of single frequency notes, but it is a highly complex combination of tones.

When dealing with mechanical equipment noise assessment or noise control, it becomes necessary to analyse the whole sound spectrum by performing a frequency band analysis. The term spectrum refers to a graph of SPL plotted against frequency. The most common type of spectrum analysis is known as octave band analysis, in which the frequency spectrum is divided into sections, called bands.

Band parameters are the following:

- a band has a lower (f_l) and an upper (f_u) limit;
- each band is identified by a centre frequency band (f_c), which is the geometric centre of the band ($f_c = \sqrt{f_i f_u}$)
- the frequency range of each band is that the upper limit is twice the lower limit ($f_u = 2f_i f_c = f_i\sqrt{2}$); and
- each successive centre frequency is twice its preceding centre frequency.

Table A-4 illustrates the characteristics of the bands used in sound analysis.

Table A-4—Octave band analysis (calculated)

Centre frequency of the band (Hz)	**f_c lower limit (Hz)**	**f_i upper limit f_u (Hz)**	**A-weighting scale correction (dB(A))**
31.5	22.3	44.2	-39.4
62.5	44.2	88.4	-26.2
125	88.4	176.86	-16.1

Centre frequency of the band (Hz)	f_c lower limit (Hz)	f_i upper limit f_u (Hz)	A-weighting scale correction (dB(A))
250	176.86	353.6	-8.6
500	353.6	707	-3.2
1000	707	1414	0
2000	1414	2828	1.2
4000	2828	5657	1
8000	5657	11 314	-1.1

Correlation among centre band f_c, lower band limit f_l, upper band limit f_u:

$f_c = \sqrt{f_i f_u}$ $\quad$ $f_u = 2f_i$ $\quad$ $f_c = f_i\sqrt{2}$

Weighted sound level

A certain noise was analysed into octave bands. The sound spectrum, as measured with the A-weighted scale is shown in Table A-5.

Table A-5—Sound spectrum measurements for a certain noise

Octave band centre frequency (Hz)	31.5	63	125	250	500	1000	2000	4000	8000
Measured dB	78	78	73	63	65	69	66	56	40
A-weighted scale correction (dB)	-39.4	-26.2	-16.1	-8.6	-3.2	0	+1.2	+1.0	-1.1
Corrected measure dB(A)	38.6	51.8	56.9	54.4	61.8	69	67.2	57	38.9

Calculate the total level.

$dB_{tot} = 10 \log (10^{(39/10)} + 10^{(52/10)} + 10^{(57/10)} + 10^{(54/10)} + 10^{(62/10)} + 10^{(69/10)} + 10^{(67/10)} + 10^{(57/10)} + 10^{(39/10)}) =$ 72 dB(A)

Relations between sound pressure level and sound intensity level

It can be shown that the correlation between SWL and SIL is expressed as follows:

SPL = SIL + 10 log K where K is a particular constant, function of the acoustic resistance of the medium, pressure and temperature.

In air at average ambient conditions the value of K is 1, the product of 10 log K is zero and the above correlation becomes:

SPL = SIL.

This equality will be used in the next sections.

Sound propagation from a point source.

As already stated in a previous section, the sound intensity from a point source of sound radiating uniformly into free space can be found from the power output and the distance from the source; spherical sound waves are emitted uniformly in all directions from the point source.

The same is valid for the sound pressure.

Two cases can be done:

- The point source in the space sends out sound waves uniformly in all directions. All the radiated power W passes through a sphere of radius r centered on the source.

  Sound Intensity Level SIL = 10 log (I / I_0),

  where $I = W / (4 \pi r^2)$ and the intensity reference is $I0 = 10^{-12}$ watt/m^2

  $SIL = 10 \log (W / (4 \pi r^2) / 10^{-12}) = 10 \log (W / W_0) - 10 \log (r^2) - 10 \log (4 \pi)$

  $SIL = 10 \log (W / W_0) - 20 \log r) - 11$

  $SPL = SWL - 20 \log (r) - 11$

- The point source lies on the ground and in this case the power is radiated into a hemisphere instead of a complete sphere.

  Sound Intensity Level SIL = 10 log (I / I0),

  where I = W / (2 πr2) and the intensity reference is I0 = 10-12 watt/m2

  SIL = 10 log (W / (2 π r2) / 10-12) = 10 log (W / W0) - 10 log (r2) - 10 log (2 π)

  SIL = 10 log (W / W0) - 20 log (r) - 8

  SPL = SWL - 20 log (r) - 8

It is interesting to observe that SPL decreases by 6 dB each time the distance from the source is doubled.

In fact: - 20 log (2) = - 20 log (r) - 20 log (2) = - 20 log (r) - 6

Example:

A compressor with an A-weighted sound power level of 104 dB is radiating uniformly over a flat non-absorbent ground: the sound radiation is on a hemispherical surface.

The Sound Pressure Level at 10 m is SPL = 104 - 20 log (10) - 8 = 104 - 20 -8 = 76 dB(A)

The Sound Pressure Level at 20 m is SPL = 104 - 20 log (20) - 8 = 104 - 26 -8 = 70 dB(A)

The Sound Pressure Level at 90 m is SPL = 104 - 20 log (90) - 8 = 104 - 39 -8 = 57 dB(A)

In general to determine the sound level which an equipment to be installed, as required for, will generate. For example for assessment of community noise, obtain the complete sound spectrum analysis of the equipment from the supplier and perform a complete analysis of the environment where the equipment is installed. Sound can be generated as a result of several disturbing elements, such as reverberant walls, compressor piping, fluid flow (valves, vents to the atmosphere, pressure reducing stations). Calculations can be made using theoretical plus empirical procedures.

Sound propagation outdoors

If the sound is generated by a point source, the procedure indicated at the previous section can be utilized as a preliminary guideline, because the case illustrated is, let say, more ‘geometric’ than ‘physical’. If the sound propagates outdoors the waves travel through air that is in constant motion: difference of temperature generates wind, turbulence and fluctuation, rain, snow, fog can be present, and obstacles generate reflections.

The above formulations are still valid, but they must be completed with some factors, more or less empirical:

$SPL = SWL - 20 \log (r) - Ao + DI\theta - Ae$ where:

SPL Sound Pressure Level at a receiver located far from the source.

SWL Sound power Level of the source.

r Distance of the receiver from the source.

Ao 11 dB for a point source in the space (radiating through a spherical surface).

8 dB for a point source on the ground (radiating through an hemispherical surface).

DIθ Directivity index of the source in the direction θ, i.e. the source is always a point, but it is radiating sound in a direction characterized by the angle θ.

Ae Excess attenuation caused by environmental conditions as detailed below.

The contributions to the attenuation factor Ae are the following:

Ae1 attenuation factor due to fluctuation of ambient pressure and temperature;

Ae2 attenuation factor due to absorption in air (as fluid type and humidity);

Ae3 attenuation factor due to rain, snow, fog;

Ae4 attenuation factor due to barriers;

Ae5 attenuation factor due to grass, shrubbery, trees; and

Ae6 attenuation factor due to fluctuation caused by wind, temperature, atmospheric turbulence, ground characteristic.

Sound propagation and frequency

The dependence of the sound absorption on frequency, temperature and humidity is of particular interest and has been investigated by several authors.

The attenuation factor Ae2 at a temperature of 20 °C may be calculated as follows:

$$Ae_2 = \frac{f^2 r}{\varphi} 10^{-8} \, dB$$

where:

f geometric mean frequency of band, Hz;

φ relative humidity, %; and

r distance of the receiver from the source, m.

Example

A fan with few blades radiates sound with a level of 90 dB at a frequency of 800 Hz, the relative humidity of air being 70% and the temperature 20 °C.

The attenuation factor for an observer at a distance of 500 m from the source is:

$$Ae_2 = 7.4 \frac{800^2 \, 500}{70} 10^{-8} = 0.3 \, dB$$

Let us suppose to increase the number of blades so as the frequency is 5000 Hz, the attenuation factor will be:

$$Ae_2 = 7.4 \frac{5000^2 \, 500}{70} 10^{-8} = 13 \, dB$$

By increasing the frequency of the equipment generating sound, the noise decreases for a quantity of 13 dB at a distance of 500 m.

Determination of a free field sound pressure level from a wide source

If the sound is generated by a wide source, i.e. the physical size of the noise source is large in comparison to the distance to the receiver; it may be convenient to use a sound pressure concept, instead of determining a radiated power level. For these cases, the noise level at the point of concern shall be calculated on an area ratio consideration basis, using a formula in which a term like log (A_2 / A_1) appears, in which A_2 is the area of the sound diffused at the point of concern and A_1 is the area of the extended source.

Determination of a near field sound pressure level

If possible, the test data shall be obtained at the distances specified for worker exposure locations.

If data cannot be obtained in an environment similar to the operating environment (for example actual installation is outdoors and data can only be obtained indoors), the effects of the test environment, such as attenuation or reverberation, shall be considered in calculations.

If the test data cannot be obtained at the worker exposure location because of high background noise at the microphone location, the sound pressure level shall be measured 120 mm to 250 mm from the surface of the equipment and extrapolated to the required distance.

Evaluation of the total sound pressure level at a location

Determine the total SPL at the point of concern by adding logarithmically the SLP from each source for each of the octave bands. Compare the total SPL with the maximum permissible levels: those installations whose calculated levels exceed the limiting criteria require acoustical treatment.

Determination of need for attenuation

Where the data or calculations indicate that the maximum permissible noise level in any octave band will be exceeded, acoustical treatment such as modifications of flow, addition of mufflers, enclosures, or alternative equipment design selections is required. A review of the calculations will reveal those items which require noise attenuation and the order of their significance for such treatment.

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Appendix B—EU directives on noise

- 70/157/EEC Directive on the approximation of the laws of the Member States relating to the permissible sound level and the exhaust system of motor vehicles (OJ L42 23.2.70);
- 84/532/EEC Directive on the approximation of the laws of the Member States relating to common provisions for construction plant and equipment (framework directive) (OJ L300 19.11.84);
- 84/533/EEC Directive on the approximation of the laws of the Member States relating to the permissible sound power level of compressors (OJ L300 19.11.84);
- 84/534/EEC Directive on the approximation of the laws of the Member States relating to the permissible sound power level of tower cranes (OJ L300 19.11.84);
- 84/536/EEC Directive on the approximation of the laws of the Member States relating to the permissible sound power level of power generators (OJ L300 19.11.84);
- 84/537/EEC Directive on the approximation of the laws of the Member States relating to the permissible sound level of powered hand-held concrete-breakers and picks (OJ L300 19.11.84);
- Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work;
- Directive 2000/14/EC of the European Parliament and of the Council of 8 May 2000 on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors;
- Directive 2002/49/EC Directive on the Assessment and Management of Noise;
- Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise);
- Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council;
- Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast);
- Website:http://osha.europa.eu/en/publications/publications-overview?Subject%3Alist=noise&SearchableText= ; and
- Guide from European Commission - Directorate-General for Employment and Social Affairs: ‘How to avoid or reduce the exposure of workers to noise at work’ *http://bookshop.europa.eu/eubookshop/publicationDetails.action?pubuid=10021205&offset=0.*