NOISE CONTROL

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FOREWORD

This booklet is adapted from a publication of the Swedish workers protection fund (Arbetarskyddsfonden) and is printed with the permission of the fund. Established by national legislation and funded via a small levy on the total wage bill, the fund is operated jointly by the employers and trade unions. Its object is to make industry and industrial employees aware of safety and environmental questions, and to encourage the provision of an improved and safer working environment throughout swedish industry. To this end it conducts research and collates industrial experience on a number of different subjects, of which the effects and reduction of noise is one. The results of its work are then distributed to interested parties in a straightforward and understandable form for the benefit of the non-experts in individual factories who have to deal with the problems at first hand, as well as those with previous knowledge. It is hoped that this booklet will spread the benefits of this work to a wider audience than was originally possible.

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INTRODUCTION

Laws governing the safety and health of employed people exist in most countries of the world; the purpose being to create a suitable working environment and eliminate unsafe practices and processes. Work areas should be designed and laid out so that they are satisfactory both from the environmental and safety points of view. In this connection safety also implies that noise is kept at a level which is not likely to cause hearing damage.

If this requirement is given due consideration at the planning stages of new production plant and factories, and when replacing existing equipment and plant, it is nearly always possible to reduce sound from machinery and installations. In existing factories and work areas, significant noise reduction can often be achieved by relatively simple methods.

The safety organisation should be involved on questions of measurement and control of noise in the factory and take part in the planning of new or altered work methods and processes.

A noise control program should involve the following:

1. The preparation of a noise map after making measurements in all areas.
2. The setting of target noise levels for all areas.
3. A description of all measures planned, a cost analysis, and the attenuation expected.
4. The setting of priorities within a plan to achieve the agreed targets, stating start and finish times.

Noise and man

The development of society has lead to more and more sound sources giving higher and higher noise levels. Noise is one of the most widely and most frequently experienced problems of the industrial working environment.

Noise affects man both physically, psychologically and socially. Noise can

damage hearing
interfere with communication
be annoying
cause tiredness
reduce efficiency

Intense noise or long stays in a noisy environment can lead to permanent reduction of hearing sensitivity caused by damage to the sensory organs of the inner ear. This type of hearing damage can never be repaired.

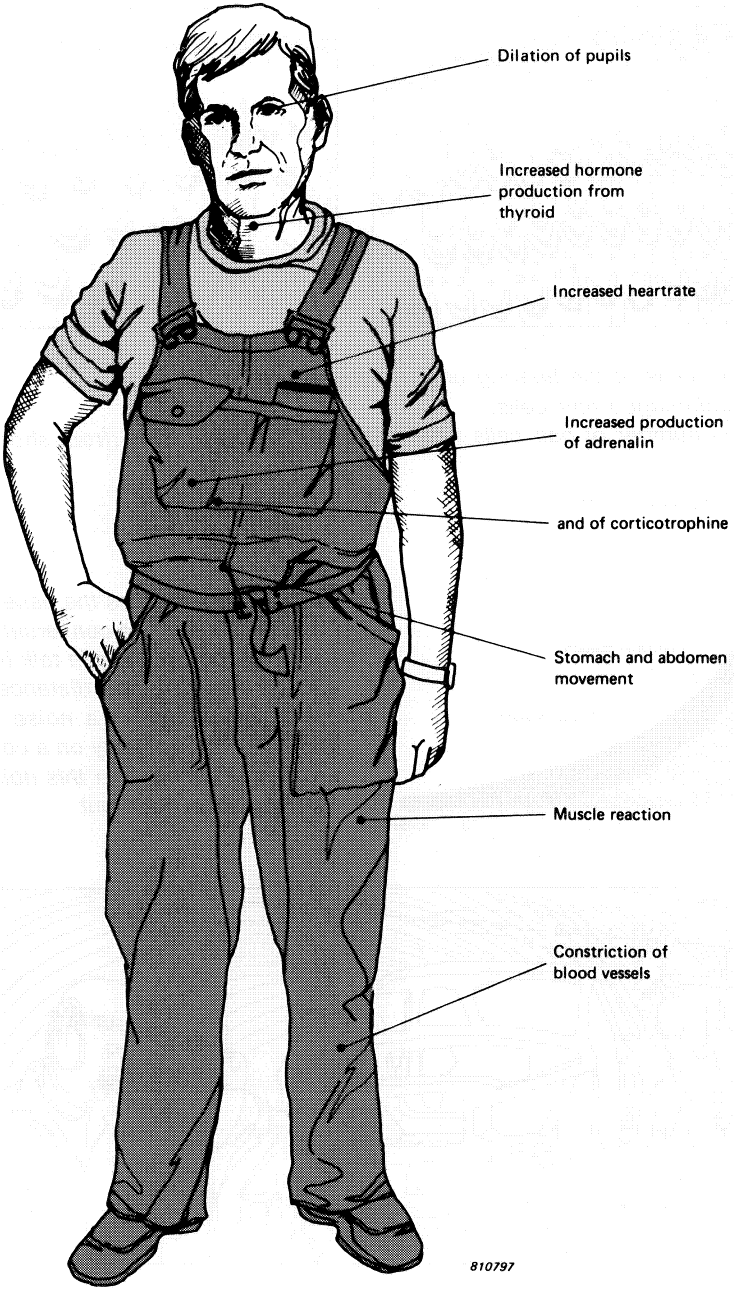
The risk of hearing damage increases both with the sound level and the time spent in the noisy environment, but the risk also depends on the characteristics of the sound. In addition, sensitivity to noise is extremely dependent on the individual. Some people may suffer hearing damage after only a short time, others can work for long periods, sometimes their whole working lives, in very noisy surroundings without suffering any demonstrable hearing damage.

After spending a short period in intense noise and then moving to a quieter area, quiet sounds can no longer be heard. This form of hearing loss is called temporary. If the noise had not been too intense or the duration too long, normal hearing returns after a period of rest.

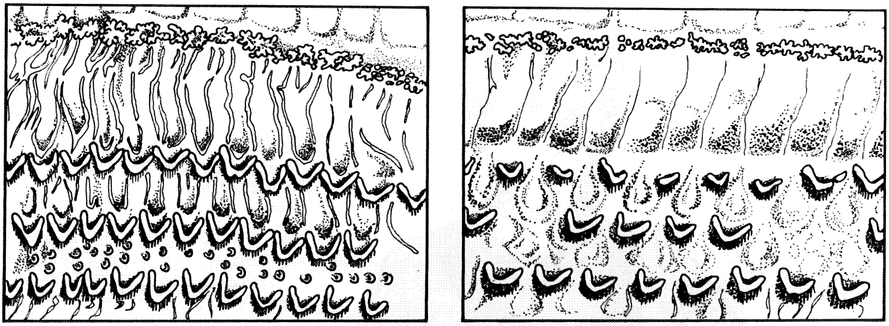
It is not only hearing which can be influenced by intense audible noise. Noise can also influence blood circulation and cause stress and other psychological effects. Industrial noise is often connected with other problems of the industrial environment, air pollution for example, having combined effects on health and well-being.

Noise can also be an accident risk in that warning signals or shouts are masked.

In order to carry out a conversation at normal distances, the sound level in a work place should be at most 65 to 70 dB. Noise significantly influences the ability to understand speech. At around 70 dB, for example, it is difficult to carry on a telephone conversation.



Sound which influences people via their hearing also has a number of other effects in the body



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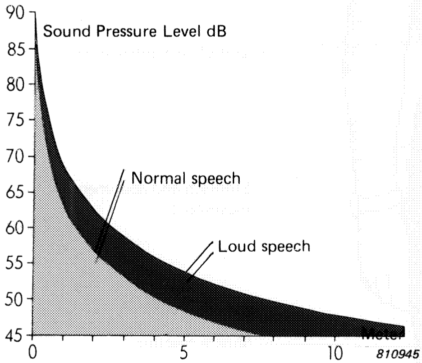
The hair cells of the hearing organ highly magnified
Left) undamaged hair cells;
Right) a number of hair cells have been damaged by noise (from shooting)



Noise greatly reduces the ease of both direct and telephone conversation. For example, two people can talk in a normal voice only up to a distance of one and a half meters in a noise level of 60 dB. In order to carry on a conversation at three meters in this noise level it is necessary to shout

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If the noise level is 85 dB or over it is necessary to shout directly into the ear to be heard

General boundaries between disturbing and non-disturbing noise are not easy to define. Judgement of a noise depends to a large extent on attitudes to the noise and to its source, at least where moderate noise levels are concerned.

Inaudible sound also exists. Very low frequencies can be perceived if they are sufficiently intense. Such sound is normally called infrasound and has been the subject of much attention and study in recent years, but in spite of this, knowledge of the effects on man are incomplete. It is known though, that intense infrasound (sound levels over about 100 dB at frequencies under 10 Hz) can give rise to, among other things, headache and tiredness.

Sound with frequencies above the range of hearing (approximately 20 000 Hz), ultrasound, has no important influence on the body at moderate intensities as far as is known. On the contrary, ultrasound is an important diagnostic technique in the medical examination of internal organs. Very intense ultrasound very rarely comes in contact with man as ultrasound is strongly absorbed during propagation through the air. If the eye is exposed to ultrasound however, it can cause the fluid in the lens to become more viscous.

In certain industries, for example steel making, high levels of infrasound can be found but in most cases it is audible sound which causes the greatest problems. This book is only concerned with audible noise.

Planning of noise reduction measures should be aimed at fulfilling one or more of the following three requirements:

1. Elimination of the possibility of hearing damage
2. Creation of a suitably quiet working environment
3. Avoidance of annoyance to third parties.

The first of these is overriding. Employees must not be directly exposed to noise over a legal limit. This limit varies slightly from country to country but is generally 90 or 85 dB averaged over a working day of 8 hours. If the noise level is higher than these values, an unprotected employee cannot spend as much as 8 hours in the environment. The higher the noise level the shorter the time allowed. For noises which contain pure tones, or shock and impact noise, special rules apply. ISO (International Standards Organisation) standards require the time spent in a noise environment to be halved for each 3 dB rise in the noise level above the set limit. If the 8 hour limit is set at 90 dB then, for example, 93 dB is allowed for 4 hours, 96 dB for 2 hours and 115 dB for less than 2 minutes.

Until noise control measures have reduced noise to an acceptable level, it may be necessary to use hearing protectors.

Their use should always be regarded as a temporary alleviation of a noise problem, not a permanent solution, and only where it is not possible to reduce the noise exposure by other means. First, all possible noise reduction measures should be exploited. Use of hearing protectors should be limited to:

1. work situations which can be regarded as abnormal or irregular, for example inspection and repair tasks.
2. use as a temporary solution while undertaking noise control measures.
3. occassions for which special dispensation has been given, e. g. temporary conditions, or where noise reduction is impossible for practical or safety reasons.

Acoustic concepts

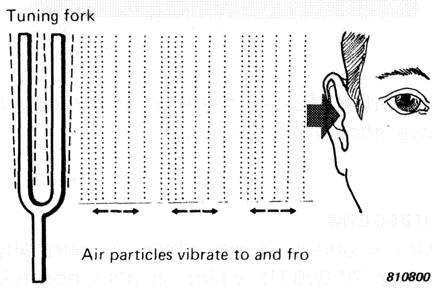
Within the field of acoustics and noise there are many special expressions and terms. Some of the acoustic concepts which occur most often are described here.

Sound

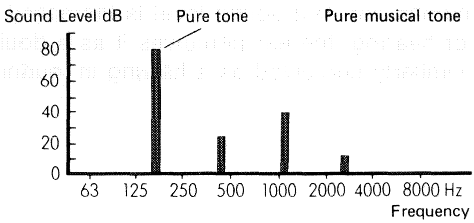
Sound is a wave motion which occurs when a sound source sets the nearest particles of air into motion. The movement gradually spreads to air particles further away from the source. Sound propagates in air with a speed of approximately 340 metres/sec. In liquids and solids the propagation velocity is greater; 1500 m/s in water and 5000 m/s in steel.

Noise and tones

A sound which is not desired is usually called noise. Sound may consist of a single pure tone but in most cases contains many tones at different frequencies



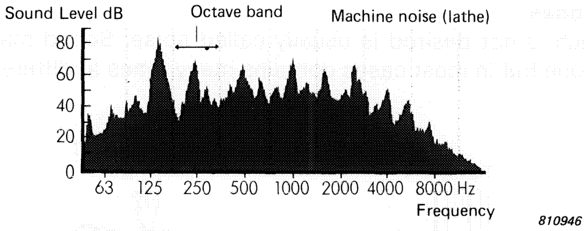
The sound source (the prongs of the tuning fork) vibrates and influences the air particles which eventually reach the eardrum and set it into vibration



A pure tone is represented as a column whose position is the frequency and whose height is the sound level. A musical note contains many pure tones with different frequencies and intensities, combined in a number of different ways which give the instrument its individual quality and intensities. The disturbance generated by a sound is not only dependent on its level. The frequency also affects disturbance as higher frequencies annoy more than lower frequencies. At the same sound level, pure tones disturb more than a complex sound composed of many tones.

Frequency, Hertz

The sound wave's frequency expresses the number of vibrations per second in units of Hertz, Hz. Sound exists over a very wide frequency range. Audible sound for young people lies between 20 Hz and 20 000 Hz. At low frequencies the air particles vibrate slowly producing bass tones. At high frequencies the air particles vibrate quickly giving soprano tones.



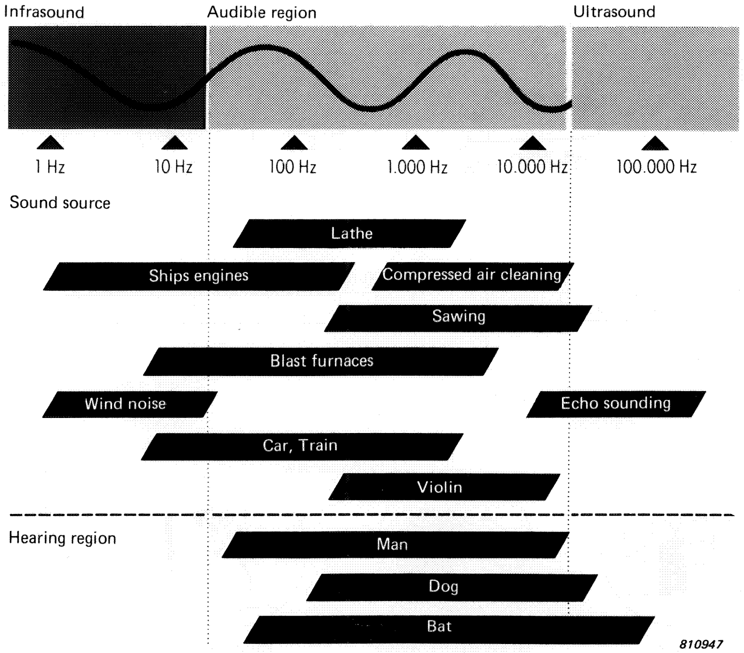
Noise is an irregular combination of tones at all frequencies. The octave band centre frequencies are shown on the scale

Infrasound and Ultrasound

Sound with frequencies under 20 Hz which is normally inaudible is called infrasound. Sound over 20 000 Hz which is also normally inaudible is called ultrasound.

Decibel dB

The intensity of a sound is normally presented as a sound level using a logarithmic unit, the decibel, dB. A sound level change of 1 dB can just be detected by the human ear. If a sound level is increased by 10 dB anywhere within the range of hearing, the ear perceives it as a doubling in loudness. A drop of 10 dB is similarly perceived as a halving in loudness.



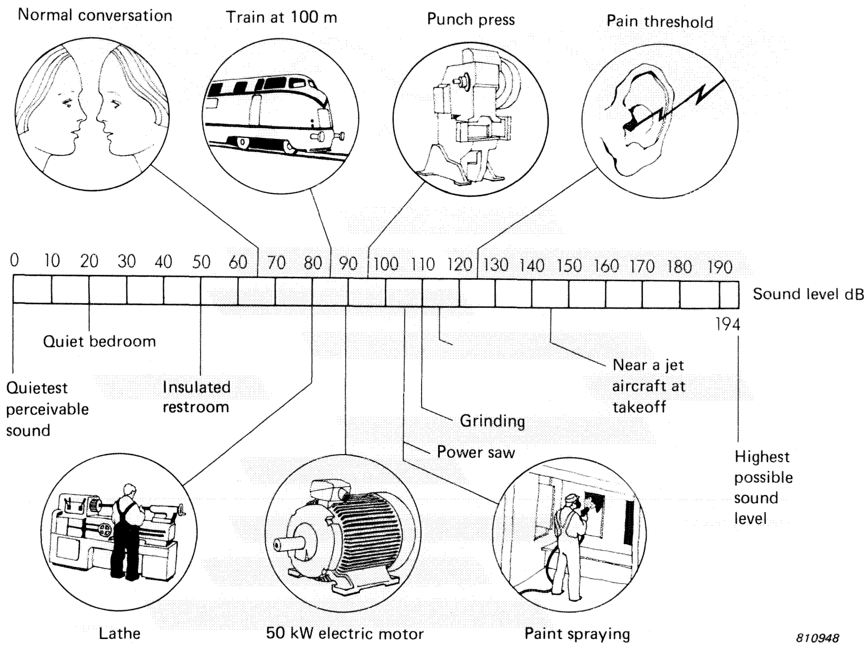
Approximate limits for the audible ranges of different mammals and the frequency ranges of different sound sources. At the same unweighted intensity, noise from a truck is less annoying than, for example, that of a circular saw

Sound Level Measurement, dB

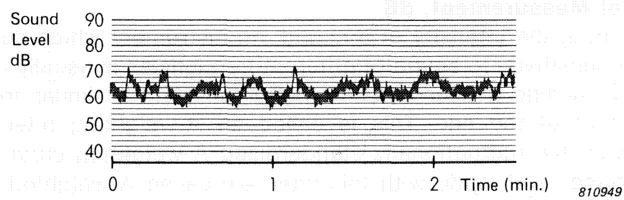
When measuring the intensity of a sound, an instrument which duplicates the ear variable sensitivity to sound of different frequencies is usually used. This is achieved by building a filter into the instrument with a similar frequency response to that of the ear. This is called an A-weighting filter because it conforms with the internationally standardized A-weighting curves. Measurements of sound level made with this filter are called A-weighted sound level measurements, and the unit is dB.

Equivalent Sound Pressure Level, $L_{Aeq,T}$

The sound from noise sources often fluctuates widely during a given period of time. An average value can be measured, the equivalent sound pressure level ($L_{Aeq,T}$). The $L_{Aeq,T}$ is the equivalent continuous sound level which would deliver the same sound energy as the actual A-weighted fluctuating sound measured in the same time period (T).



Example of some typical sound levels
Levels over 130 dB can cause immediate hearing damage



Recording of noise in a work area. During the measurement period the noise varies between 56 dB and 74 dB. The equivalent sound level ($L_{Aeq,T}$) for the period is 68 dB. This value can be obtained directly with a dosimeter or integrating sound level meter

Octave Band Filters

In order to completely determine the composition of a sound it is necessary to determine the sound level at each frequency individually. Usually values are stated in octave bands. The audible frequency region is divided into 10 such octave bands whose centre frequencies and bandwidth are defined in accordance with international standards. The centre frequencies of each consecutive octave band are twice the centre frequency of the previous one, and the upper frequency of each octave band is twice the lower frequency. The octave bands are usually referred to by their centre frequencies, so the 500 Hz octave band, for example, stretches from 354 to 707 Hz. The centre frequency is the geometrical average of the upper and lower frequencies, so that the centre frequency equals.

$\sqrt{\text{lower frequency} \times \text{upper frequency}}$ i. e. $500 \text{ Hz} = \sqrt{707 \times 354}$.

Conversely, the upper and lower frequencies can be found from:

lower frequency $= 1/\sqrt{2} \times$ centre frequency.

Upper frequency limit $= \sqrt{2} \times$ centre frequency.

Structure-borne and liquid-borne sound

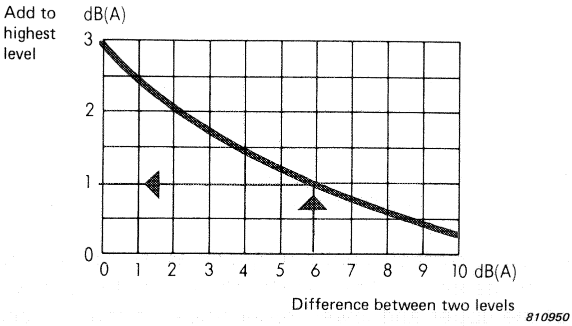
Sound usually means airborne sound, although sound usually arises as a vibration in some form. These vibrations can easily propagate over long distances as structure-borne or liquid-borne sound before audible sound is formed. Airborne sound can also arise directly from airflow, for example from disturbances in gases, including air, from equipment such as fans and/or gas exhausts.

Resonances

Sound can be amplified where there are resonances. These can occur both for airborne sound (for example in a closed or partly closed volume of air), or for structure-borne sound, (for example in a machine). Resonances appear at one or more frequencies corresponding to natural frequencies of the system, which are determined by, among other things, the dimensions, stiffnesses, and air volumes, in machines and equipment.

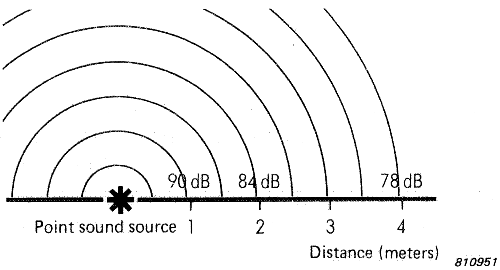
Addition of noise from several sources

Noise from different sound sources combines to produce a sound level higher than that from any individual source. Two equally intense sound sources operating together produce a sound level which is 3 dB higher than one alone and 10 sources produce a 10 dB higher sound level. Note that the dB values are not directly added as they are already logarithmic quantities.



Addition of sound from two sources
Example: A fan produces 50 dB measured at a certain location and a second fan gives 56 dB, measured at the same place. The difference is therefore 6 dB and according to the diagram, 1 dB should be added to the highest level. Both fans operating together therefore give 57 dB

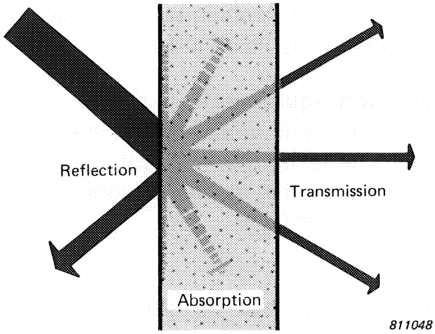
Attenuation by distance
Sound which propagates from a point source in free air attenuates by 6 dB for each doubling of the distance from the noise source. Sound propagating indoors is attenuated less than this value, because of contributions to the total sound level from reverberant sound brought about by reflection from walls and ceilings.



A small sound source, i. e. a point source which radiates freely into free space, produces 90 dB at one metre. The sound level at 2 metres will then be 84 dB, at 4 metres it will be 78 dB, etc.

Sound Insulation and Sound Reduction Coefficient

When a sound meets a wall or partition, only a small proportion of the sound energy passes through. Most is reflected back. A wall with 10 dB insulation allows 10 % of the sound energy through, (20 dB corresponds to 1%, 30 dB corresponds to 0,1% etc.). The sound insulation ability of a partition separating two rooms is called the sound reduction coefficient and is expressed in dB.



A proportion of the sound which is incident on a partition or wall is reflected, a proportion is transformed into heat i. e. absorbed, and a proportion goes through the wall to the other side, i. e. is transmitted. The sound reduction coefficient (sound insulation) of the wall determines what proportion of the incident sound is transmitted

Sound Absorption and Absorbents

Sound energy is absorbed whenever sound meets a porous material. Porous materials which are intended to absorb sound are called absorbents, and usually absorb 50 to 90% of the incident sound energy, depending on its frequency. In a room with a large amount of absorbent material the sound level reduces steadily with distance from a sound source. If the room is acoustically hard, i.e. has insufficient absorption, the overall sound level anywhere in the room can be just as high as in the vicinity of the sound source.

General noise control measures

When attenuating noise, consideration must always be given to the fact that sound is radiated both as airborne and as structure-borne sound i.e. vibrations. The majority of sound sources produce both airborne and structure-borne noise at the same time. In order to achieve a satisfactory result, a number of different noise control principles must be employed. The final chapter presents a brief description of noise control techniques which have been used with good results in a number of different types of plant.

Alteration of machines and equipment
In order to be able to carry out noise control measures effectively, many important factors have to be taken into account. Which machine or machines should be quietened? How is the machine tended? Will maintenance and servicing be made more difficult? etc.

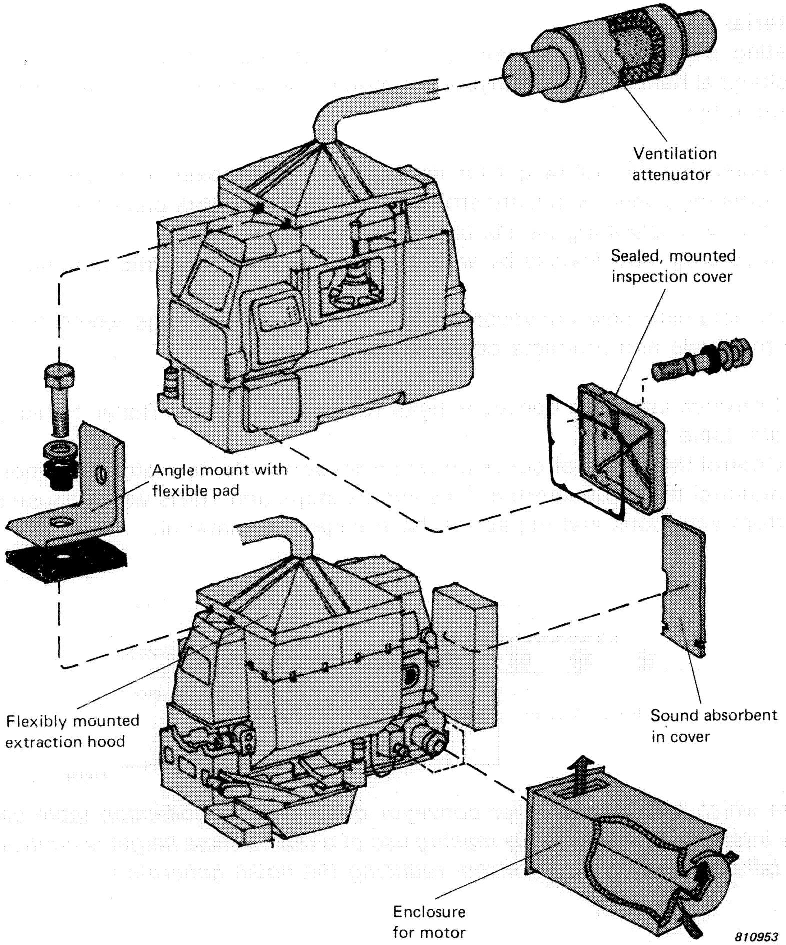
Machines
Machines and processes in use can be difficult to alter without adversely influencing production. Attempt, though, to avoid or reduce impact and rattle between machine components. Brake reciprocating movements gently. Exchange metal components with quieter plastic, nylon, or compound components where possible. Enclose locally particularly noisy components or processes.

New machines and processes can often be improved by the supplying factory by the same type of techniques but with further possibilities for making more extensive changes. Convince the designer to

1. choose power sources and transmission which give quiet speed regulation e. g. stepless electrical motors
2. isolate vibration sources within the machine
3. ensure that cover panels and inspection hatches on machines are stiff and well damped
4. provide machines with adequate cooling fins which reduce the need for air flows, and therefore fans.

Equipment
Existing equipment can often be attenuated just as much as new, without complicated operations. Typical sound attenuating measures are to:

1. provide air exhausts from pneumatic valves with silencers
2. change the pump type in hydraulic systems
3. change to a quieter type of fan or locate sound attenuators in the ducts of room or process ventilation systems
4. replace noisy compressed air nozzles with quieter types.



Different types of airborne and structure-borne sound prevention methods on a machine tool (a press)

In a new plant one can go even further by:

1. installing quieter electric motors and transmissions,
2. choosing hydraulic systems with specially stiffened oil tanks,
3. mounting dampers in the hydraulic lines
4. dimensioning these lines for a relatively low flow velocity (a maximum of about 5 m/s.
5. Providing ventilation ducts with sound attenuators to prevent transmission between noisy and quiet rooms via the ductwork.

Material handling

Existing plant can be altered so that impact and shock during manual or mechanical handling and transport of material and items is avoided. This may be done by:

1. minimising the fall height for items collected in boxes and containers
2. stiffening panels which are struck by material and work pieces and damping them with damping panels or materials
3. absorbing hard shocks by wear resistant rubber or plastic coatings.

When obtaining new conveyor equipment consider systems which transport raw materials and products quietly and steadily.

1. Consider choosing conveyor belts rather than rollers. Roller transporters are liable to rattle.
2. Control the speed of conveyor belt transports, etc. to match the amount of material to be transported. This avoids stops and starts which cause noise from vibrations and impact of the transported material.

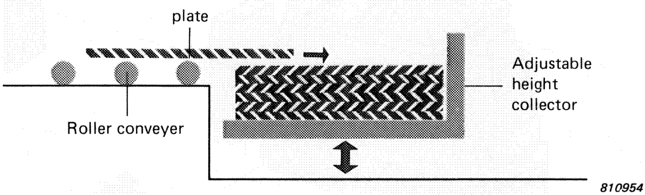
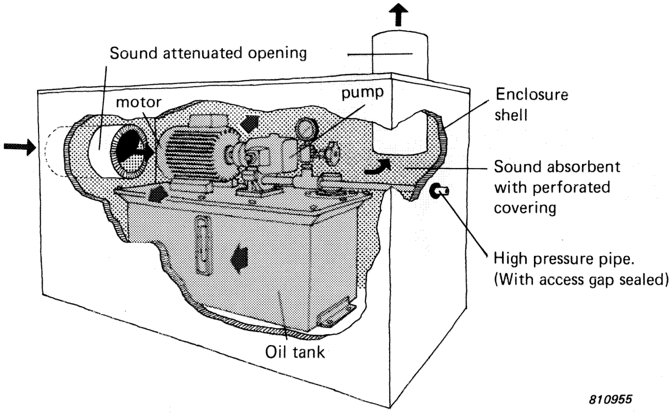


Plate which falls from a roller conveyor down on to a collection table causes very intense impact noise. By making use of a table whose height is controllable the fall height can be minimised, reducing the noise generated

Enclosure of machines

If it is not possible to prevent or reduce the noise at its source it may be necessary to enclose the entire machine. For this enclosure to be satisfactory:

1. use a sealed material e. g. panels of metal or plasterboard for the outer surfaces
2. provide the inner surface with a sound absorbent material e. g. mineral wool, glass wool or foam rubber or polyurethane material. A relatively simple sealed enclosure of this type can reduce noise by 15 to 20 dB.
3. Mount noise attenuators on any openings for cooling air
4. supply the enclosure with inspection hatches which are easy to open where this is necessary for operation or maintenance.

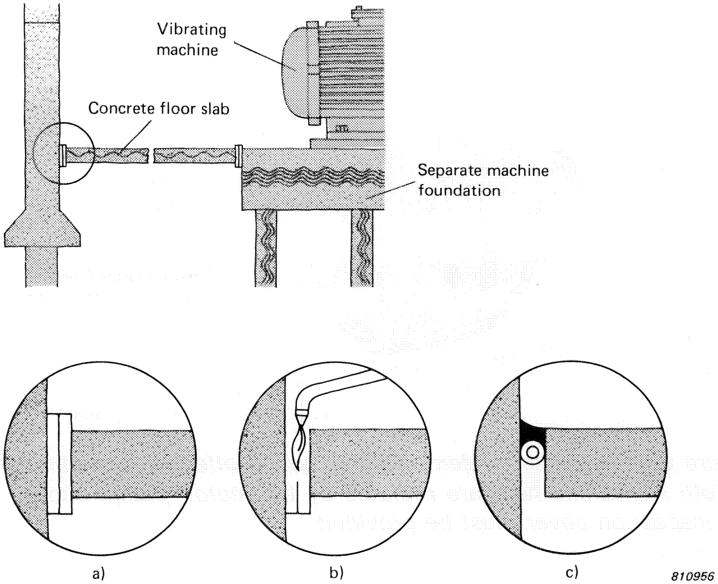


Enclosure of a hydraulic system requires sound attenuated ventilation openings. Both sound and heat are radiated by the motor, pump, and oil tank. A sealed inspection cover must be provided

Attenuation of Structure-borne sound

A typical cause of vibration in a machine is clatter resulting from wear or from loose bolts and screws. In this case it is relatively easy to reduce the intensity of structure-borne sound by repair and renovation. On the other hand it is more difficult to reduce vibration from a working machine in good condition. It is often possible to reduce structure-borne sound disturbance by preventing transmission of vibration from machines and equipment to the load-bearing structure of the building using the following principles:

1. vibration isolate machines with stiff or independent frames. Place the machine on a stable foundation with an elastic separating layer of e. g. rubber blocks or steel springs.
2. Place large heavy machines, which cannot be effectively vibration isolated, on special machine foundations which are otherwise completely separated from the building.
3. Vibration isolate machine panels wherever possible in order to minimise radiation of structure-borne noise. Panels should be elastically mounted on the machine frame thus reducing the vibration level transmitted to them. Alternatively, panels can be coated with a special damping material.



Severely vibrating machines require separate foundations and isolating joints between floor slabs to prevent the propagation of structure-borne noise. In this case two joints are used for more effective separation.

a) Before casting the floor, a thick strip of foamed plastic is placed in all the joints between the floor and the rest of the building structure.

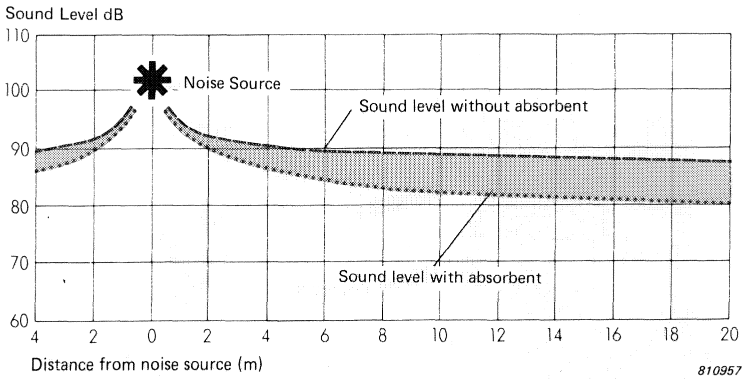
b) After the floor has been cast, the foam is pulled or burnt out and the joint inspected and cleaned out if necessary. There must be no bridging between the two structures, i. e. mechanical connection by, e. g. stones, or the isolation will be by-passed

c) The joint is then filled with a flexible material, e. g. a synthetic rubber tube and sealed completely with an elastic material of high density

Attenuation by using absorbents

In a workshop or in factory premises with hard materials on the ceiling, floor, and walls, nearly all the sound which reaches these surfaces is reflected back into the room.

In a room, the sound level from a machine first falls relatively quickly and then remains approximately unchanged as one moves away from it. This is because close to the machine its noise level falls approximately as if it were in a free field. However, at a certain point the reverberant noise level in the room, i.e. noise coming from all other sources including reflection from the room surfaces, becomes more intense than the direct sound from the single machine and dominates it. In such circumstances the noise environment can be improved by:

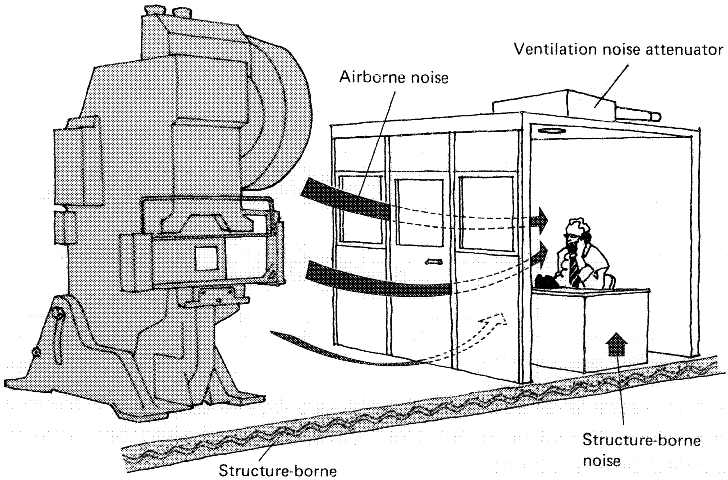


The sound pressure level at different distances from a source in a room without absorption and in the same room after a large area of absorbent material has been mounted on the ceiling

1. Covering the ceiling with an effective sound absorbing material, for example panels of mineral wool or glass fibre, which reduce reflected noise in the room. The reflected or reverberant sound can be reduced by 6 to 8 dB at distances away from the sound sources.
2. Mounting highly absorbent ceilings and walls, for example, 100 mm of absorbent with perforated panels over it, can reduce the reverberant sound by approximately 10 dB in a room with noisy production machinery in one part and relatively quiet work in the other. An attenuation of 10 dB is perceived as a halving of the noise.
3. Using local absorption on the walls and ceiling at the operator's position near a noisy machine to reduce local reflections, and thus lower noise levels by a few dB. This just audible change in sound pressure level is perceived as an improvement by those who work by the machine:

Noise sources can be localized and the sound pressure level reduces noticeably with distance from the sound source. If the surfaces of the room are highly reflective, the sound appears to be equally loud everywhere and to come equally from all directions.

Sound Insulated Rooms
Current developments within industry are directed towards automating machines and processes, whereby remote control of the process from a control or monitoring room becomes feasible. It is thus possible to limit the noise exposure of machine operators and process controllers to short periods when starting and servicing the machines, and repair and maintenance work. A few important rules of thumb are:



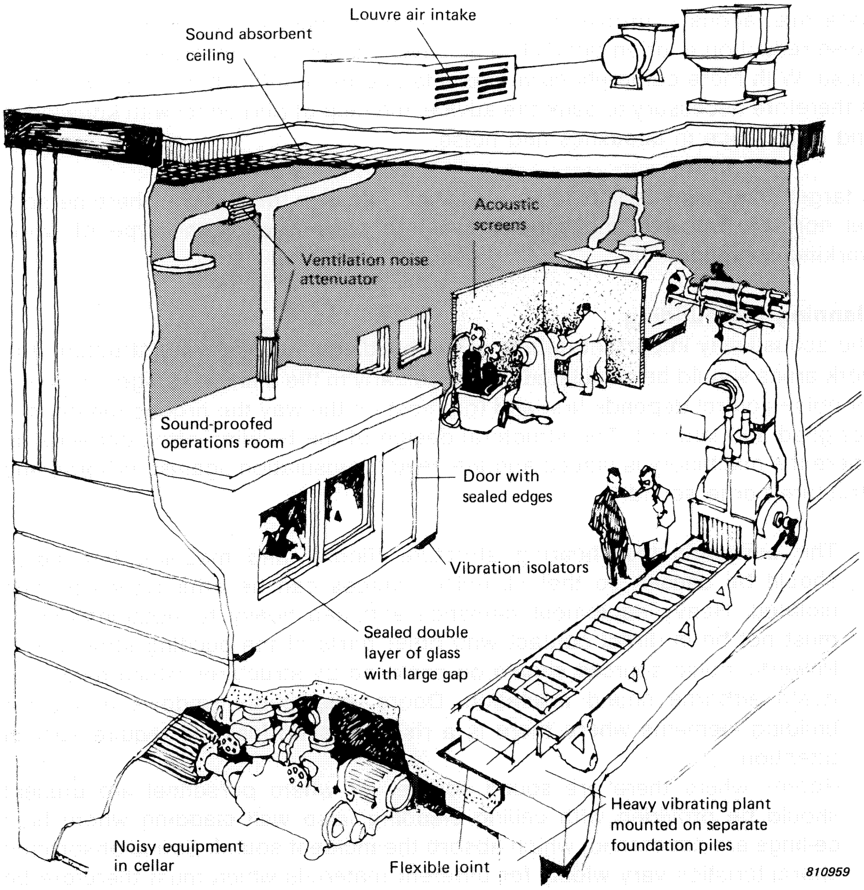
Noise problems in control rooms and workshop offices can be caused by direct airborne sound, (because of gaps around doors, windows, etc.), or by the transmission of structure-borne sound. Quite often there is both airborne and structure-borne noise disturbance

1. build control and monitoring rooms with good sound insulation properties
2. choose door and window designs which are well sealed
3. provide ventilation openings with attenuators or acoustic louvres and ensure that cable and pipe cut-outs are properly filled with a suitable acoustic sealant. Supply all control rooms in machine and process halls with good ventilation and cooling systems, otherwise there is a risk that doors will be opened to obtain sufficient fresh air. This naturally ruins attemps at good sound insulation.

Noise control of new projects

There are even better possibilities for achieving good acoustical conditions when planning new projects. By exploiting the best known techniques it is normally possible to reduce noise generation from machinery and processes compared with older plants. Acoustic problems should be taken into consideration right from the planning stage of the new building.

When choosing new installations, machinery, and equipment, as well as material handling methods, consideration must be given to the noise disturbance which it could produce. Continual effort should be made to change to quieter processes and working methods by introducing a greater degree of remote control. Personnel can then spend a proportion of the working day in relatively quiet control and operation rooms.



Example showing typical noise control measures which should be taken in an industrial building in order to minimise the propagation of noise

At the project planning stage of a new plant it can often be difficult to obtain an accurate basis for noise calculations. Measurement results from similar workshops and use of manufacturers noise data for machinery and other equipment to be installed are necessary to make reasoned judgements.

Even though the possibilities for noise control are good when designing new projects, good acoustic conditions cannot always be achieved everywhere. Undesirably high noise levels will still exist in some areas because machine design and production processes cannot immediately be changed.

As a rule, acoustic problems involve a large number of specialist areas, and noise reduction is often difficult to achieve without an extensive knowledge of these. With more comprehensive projects and more difficult noise problems, it is therefore necessary to seek the advice and help of personnel with knowledge and experience in acoustics and noise.

A target noise climate should be set for all places in the factory where personnel normally operate and should take into consideration the type of work, working conditions etc.

Planning the building

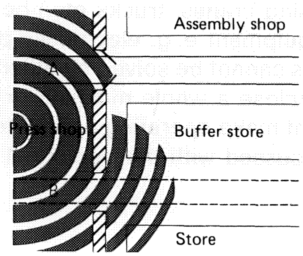
The acoustically important details of the building's load-bearing structure and work areas should be calculated and fixed early in the planning stage. The need for noise control depends first and foremost on the way the production plant is designed and laid out. The structural design of the building often depends on where the machinery is placed and the need for insulation against airborne and structure-borne sound.

1. The building's load-bearing structure, floors, and machine foundation should be chosen so that all noise sources can be effectively vibration isolated. Heavy equipment demands stiff and heavy foundations, which must not be in direct contact with other parts of the building structure.
2. Powerful noise sources should be enclosed by structures which give adequate airborne sound insulation. Doors, inspection windows and other building elements where there is a risk of sound leakage require special attention.
3. Rooms where there are sound sources or where personnel are present should be provided with ceiling cladding (also wall cladding where high ceilings are concerned) which absorb the incident sound. Sound absorption characteristics vary widely for different materials which must therefore be chosen with regard to the characteristics of the noise. Good sound characteristics can often be combined with good thermal insulation.
4. Office areas should be separated from building elements where vibrating equipment is installed by a joint of elastic material.
5. Walls and ceiling construction, windows, doors, etc. should be chosen so as to achieve the required sound insulation.
6. Mounting noisy equipment on light or movable partitions should always be avoided. If ventilation for cooling systems must be mounted on such a light foundation in any case e. g. a false ceiling, special efforts must be made to obtain sufficient vibration isolation.
7. In open plan offices and large rooms where there are several office functions carried out in the same room, there must be a ceiling with high sound absorption; and soft carpeting on the floor is also beneficial. It should be noted that it is especially important that sound absorption is also effective at low frequencies.

Noise Reduction Measures in rooms

The shape and size of an industrial workshop is determined to a large extent by the production processes and the flow of materials. The best possibilities for influencing the design and layout of a workshop occur, as mentioned earlier, in the early stages of planning. In the past, environmental questions have far too seldom been discussed in this phase, which often meant being trapped in a program of continuous work to obtain, among other things, satisfactory noise reduction. A few guidelines about the layout of the new plant are:

1. Work stations and machines should be so placed that the reduction of noise with distance can be exploited, i. e. that there is a certain distance between noisy and quieter activities. Ensure that space is allowed between screens and enclosures.
2. Ensure that separate areas are available for particularly noisy machines e. g. in cellars.
3. Work which requires a quiet working environment or which does not itself produce noise should be removed to a region with a low noise level. Work areas without noise can, if necessary, be screened from noisy surroundings. Where possible mount absorbent ceilings in such areas.
4. If noisy work is carried out close to a wall or any other reflecting surface, it should be covered with an absorbent material.
5. Workshop offices, rest rooms etc., should be provided with sufficient sound insulation and possibly mounted on isolators, or separated from the rest of the building structure by flexible joints, in order to avoid vibration transmission.
6. Fixed installations (ventilation equipment, cooling systems etc.) should be constructed with sound attenuation in mind, and mounted so that sound from fans etc. is prevented from spreading via ducts, pipes and the building structure itself. Normally a subcontracting ventilation firm will be responsible for attenuation of the system to a pre-agreed sound level.



Access doors should be so placed that the reduction given by screening or by increased distance from the noise source to the work area is exploited as much as possible. At access point A it is necessary to place a door in the separating wall in order to achieve sufficient noise reduction between the press hall and the assembly area. This is unnecessary at access point B

7. In open plan offices and large rooms, work areas must sometimes be located bearing in mind that noise occurs from certain processes while a relatively noise free environment is required for others so that, for example, conversation is easy.
8. Machine rooms (for compressors, ventilation and cooling systems where service and maintenance staff remain during operation) should be equipped with sound absorbent screens between noise sources.

Purchase and Installation of Machinery

Whenever new machinery is purchased, consider the possibility of achieving quieter production and material handling. Before deciding on a purchase, ascertain the sound pressure levels which the new equipment will cause as well as the feasibility of further noise reduction with possible suppliers. If improvements cannot be carried out within the financial restraints, preparations should be made for noise reduction at a later date without expensive alterations.

1. Machines and equipment which generate vibration should normally be isolated from the building itself, so that disturbing vibration or sound cannot be transmitted. Machines which cannot be vibration isolated because of their fundamental design or method of operation, e. g. large piston compressors, should be provided with their own foundations on supports which are completely separated from the load-carrying structure of the building.
2. Accessories, for example hydraulic plant and air compressors, which are located in separate rooms should be provided with attenuators which prevent the propagation of sound and vibration in the installation's connections, pipes and ducts).
3. Machines and equipment should be designed so that impact and shock are avoided as far as possible when handling raw materials or finished items. These should be slid down chutes rather than dropped into containers, for example.
4. With new purchases of transporting equipment, (conveyor belts, roller transporters, traversing cranes, trucks etc.) be aware of the availability of inherently quieter equipment e. g. electrically powered fork lift trucks.
5. When noise problems cannot be solved by other methods, a serious attempt must be made to enclose a whole machine or its particularly noisy parts. Solutions which might make operating or maintenance of the machine more difficult must be discussed with the personnel involved.

A program for noise control

For all noise control efforts a target noise level must be set. A highest level must be defined for each piece of equipment or room. The examples in the table below should be regarded as guidelines. It is not intended that these should apply rigidly at all times in the future, but should be attainable after a certain time; after which they should be reconsidered, and if necessary, lowered.

Example of guidline noise levels within a factory

TYPE OF ROOM	GUIDELINE HIGHEST SOUND LEVEL dB
Conference Room	35
Office	40
Workshop office, rest room	45
Laboratory, measurement or inspection room	50
Canteen	50
Changing room	55
Repair workshop	60
Production areas	75
Fan room, compressor room etc. normally unmanned	90

For work areas with special or particularly severe noise problems it may be advantageous to attack the problem in a number of stages, lowering the noise limit at each successful stage.

By systematically mapping the existing noise situation, a good picture of the noise intensity and distribution within the workshop can be obtained. In order to be able to plan and carry through a noise control program with difficult noise problems it is necessary to carry out as extensive a noise measurement programme as possible. Noise often comes from a large number of sources, (e. g. production machinery and material handling) and background noise (from ventilation, compressors, circulation pumps, etc.) which may be sited outside the workshop under consideration. When judging the risk of hearing loss in a place of work all the noise sources which would normally be in operation should be in operation during noise measurements.

On the other hand, in order to make decisions about individual noise control measures on the best possible grounds, each machine and noisy working process should be measured separately. Similarly, check those work processes, machine parts etc., causing the greatest noise. This forms a good basis on which to judge whether noise control is necessary and possible.

Background noise is often found to contribute significantly to the total noise. Every time a noise source is introduced into the workshop, the noise level is increased to some extent even though the noise level of the new machine may be relatively low.

While making a noise map it is important that the people who are to carry out noise control measures or are responsible for them, discuss the problems with the safety representative or the other employees in the departments affected by the work. They usually have thorough knowledge of the production equipment and can often contribute good practical ideas for improvements. To choose the most cost-effective noise control measures a table of the different measures needed on various machines and installations is useful. In addition, they should be costed against the amount of attenuation which could be expected. Each project should be described with simple sketches, including:

1. changes to machines which would reduce noise generation
2. alteration of equipment to avoid impact in machinery and when handling materials
3. enclosure of noisy machines or machine parts
4. mounting of attenuators in gas and air outlets as well as ventilation ducts
5. erection of sound absorbing screens, linings, and baffles in work areas.

The likely results for different types of noise control measures are as follows:

1. Mounting an absorbent roof or ceiling in a room will in general give a noise reduction of between 3 and 5 dB. Exceptionally, up to 10 dB can be obtained.
2. Damping of vibration of small production machines by applying damping material can give between 3 and 10 dB attenuation.
3. Factory-made screens can reduce noise from between 5 and 15 dB.
4. Leakage where pipes pass through walls as well as acoustic leaks between walls, screens, or enclosures, can produce large variations in the attenuation achieved. It is therefore important to seal air gaps carefully when carrying out this type of work.

Always obtain information on materials and costs from the supplier before making a decision on which actions to take. There are several factors which can influence the choice:

1. the intensity of the noise in the workshop (the first priority is to reduce noise which can cause hearing damage)
2. practical problems in carrying out the work
3. the number of persons who benefit from the improvements
4. the costs involved in the measures chosen.

It is often difficult to weigh up all these points, but long-term planning should ensure that the demand for a good working environment is fulfilled in all places of work.

When a large number of projects are planned, a time table describing each agreed project and stating the order in which they are to be completed is necessary.

A plan is also required to determine when machines can be taken out of production to be altered, when absorbents can be mounted, when personnel can be obtained to carry out the assignments, etc.

Methods of noise reduction

There are three main ways to reduce noise in the factory

1. reduce noise at the source
2. change to quieter methods of work
3. prevent or reduce propagation

Reduce noise at the source
It is often possible to reduce noise radiation from production equipment, material handling, and work in progress, for example by damping sound radiating panels, quietening power sources and transmissions, and reducing noise from compressed air exhausts.

Sometimes machine alterations or enclosures do not give sufficiently good results, and if it is the work process itself which causes intense noise it can be difficult to predict the results of noise control measures. In such cases effort might be better aimed at changing the working methods and processes themselves.

Change to quieter methods of work
In many cases changing the method of work is the only way to get to grips with noise generation. This often requires that production equipment or part of it must be replaced and one must be aware of the availability of less noisy equipment for both production and material handling. This requires co-operation between the buyer, supplier, designer, and safety organisation.

Prevent propagation
The noise in a workshop is often dominated by a relatively small number of intense noise sources. Personnel who are working on quieter machinery or with work which does not produce noise are very often unnecessarily exposed to other noise sources in the same room. If these sources are screened or provided with an enclosure the noise level is reduced both close to and far from the source, benefitting everyone in the room.

By setting up sound absorbing ceiling and wall panels, noise levels within the room far from the noise sources can be reduced. These measures however do not significantly reduce the noise exposure of personnel working on these machines.

Alteration and replacement of production equipment may mean that personnel monitoring this machinery need not be in its vicinity if monitoring can be carried out in a sound insulated control room. However this should not be exploited in order to avoid or cut down on noise control in areas where maintenance and repair staff spend the greatest proportion of their time.

In order to prevent vibration from noise sources spreading through the building structure and through machinery, it is often necessary to vibration isolate machines or introduce vibration isolating joints in the building.

Noise measurement

When planning noise control measures or forming a basis upon which to judge the noise of a projected plant, measurements are the most important starting point. Without existing measurements, or sometimes future predictions from existing measurements, of a noise situation, objective decisions about the need for noise control cannot be made, neither can its effectiveness after installations be judged.

Because of the large variety of noise characteristics and the corresponding large number of measurement and assessment techniques, great care is required in deciding which measurements to make and how to interpret them. The sound pressure level which is read from a sound level meter does not always give sufficient information to judge a hearing noise danger, or for use as a basis for a noise control program.

Both experience and special training are required to be able to carry out measurements in complicated situations. In many cases, though, a standardized sound level meter and relatively simple measurement methods are adequate.

The purpose of measurements

There are many different reasons for carrying out noise measurements in industry. The most usual are:

1. To determine whether or not noise levels are high enough to lead to permanent hearing damage. Equivalent sound pressure levels of over 85 dB for an eight hour working day should be investigated further.
2. To obtain a basis for noise control measures to be applied to machines and equipment.
3. To determine sound radiation from single machines unambiguously e. g. to compare with values stated in a noise guarantee or declaration.
4. To ensure that noise levels are not disturbing to 3rd parties e. g. residential areas.

Measurement instruments and methods should comply with the standards which apply to the noise measurements to be carried out. The standards include requirements for the measurement instrument, measurement method for noise from different types of machines, and assessment of noise annoyance and damaging effects. The most important international standards are those published by IEC (the International Electrotechnical Commission) and ISO (the International Standards Organisation). IEC is concerned primarily with the design and construction of instrumentation and ISO primarily with the measurement technique, experimental conditions, measurement parameters, and reduction of measured results to a common point of reference. Most are available in English and French and many have been adopted directly or with only small local changes by individual countries as their National Standards. The following sections contain simple rules for the choice of instrument and measuring methods according to the standards relevant to the particular country. On the other hand no attempt is made to describe in detail specialist topics such as impulse noise, infrasound, etc.

A sound level meter is designed to simulate the human hearing as closely as is possible and practical, while giving a repeatable and objective value. As the human ear responds not only to the level of a sound but also to its frequency, and to some extent duration, these parameters must be built into the sound level meter.

Frequency Weighting Networks

A number of frequency weighting networks have been standardized, orginally intended to be applied to different sound pressure level ranges. These are:

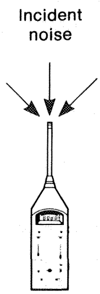
1. The A weighting network intended for quiet sounds
2. The B weighting network intended for sounds of medium intensity
3. The C weighting network intended for loud sounds
4. The D weighting network intended for the measurement of jet aircraft noise.

The A weighting network is by far the most widely used of these weightings and forms the basis of a large number of derived units e. g. $L_{Aeq,T}$ (the equivalent continuous sound pressure level) and L_{10} (the A weighted sound level exceeded for 10% of the measurement period). Because of its good agreement with subjective response to noise, the A-weighted sound level is now used for assessing noise of all levels and the D, B and C weighting networks are relatively infrequently employed.
Unweighted sound levels are usually only measured in connection with a frequency analysis e. g. for comparing the frequency spectrum of a machine after applying sound reduction techniques, with the spectrum produced by the same machine before.

Time Weightings

When choosing a suitable time weighting for the measurement the characteristics of the noise must be taken into account. The level of a noise always varies to a greater or lesser extent. The display of the measuring instrument, whether a traditional meter needle or digital display, always has a certain time constant and cannot follow rapid sound level fluctuations. In addition, the human eye cannot follow the rapid movement, so the display of a sound level meter is deliberately damped. There is normally a choice between three standardized time weightings or dampings.

1. "S" which has high damping giving a slow display movement; effective averaging time is approximately 1 s.
2. "F" has low damping giving a more rapid display movement; effective averaging time is approximately 0,125 s.
3. "I" which has a very fast rising time constant and a very slow falling time constant. This is intended to present a value which represents how loud the human ear judges a short duration sound, i. e. it is aimed at annoyance rather than hearing damage risk.
4. "Peak". In addition, a number of sound level meters have a further possibility i. e. measuring the actual peak sound pressure level of a short duration sound. This allows the peak values of a sound whose duration may be as short as 50 micro-seconds to be accurately recorded. It is aimed at hearing damage risk.



Time weighting	Sound level dB
S	93
F	100
I	102
Peak	127

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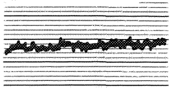
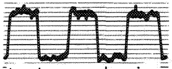
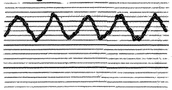
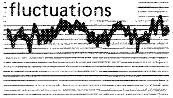
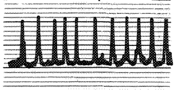
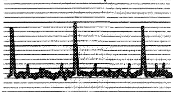
When measuring impulse noise, a sound level meter displays a different value dependent on the time weighting used. All will be very much less than the peak value if the impulse is very short, e. g. a hammer impact, gunshot etc.

0 5 10 15 20 s	Characteristics	Type of source	Type of Measurement	Type of Instrument	Remarks
Small variation 	Constant continuous noise	Pumps, electric motors, gearboxes, conveyers,	Direct reading of A-weighted value	Sound level meter	Octave or 1/3 octave analysis if noise is excessive
Intermittent noise  background noise	Constant but intermittent noise	Air compressor, automatic machinery during a work cycle,	dB value and exposure time or $L_{Aeq,T}$	Sound level meter Integrating sound level meter	"
Large fluctuations 	Periodically fluctuating noise	Mass production, surface grinding	dB value, $L_{Aeq,T}$ or noise dose	Sound level meter Integrating sound level meter	"
Large irregular fluctuations 	Fluctuating non-periodic noise	Manual work, grinding, welding, component assembly	$L_{Aeq,T}$ or noise dose Statistical analysis	Noise dose meter Integrating sound level meter	Long term measurement usually required
Similar impulses 	Repeated impulses	Automatic press, pneumatic drill, rivetting	$L_{Aeq,T}$ or noise dose and "Impulse" noise level Check "Peak" value	Impulse sound level meter Sound level meter with "Peak" hold	Difficult to assess More harmful to hearing than it sounds
Isolated impulse 	Single impulse	Hammer blow, material handling, punch press	$L_{Aeq,T}$ and "Peak" value	Impulse sound level meter Sound level meter with "Peak" hold	Difficult to assess Very harmful to hearing especially close

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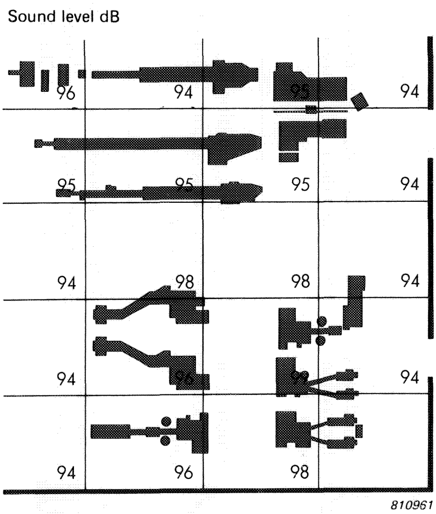
Noise characteristics classified according to the way they vary with time. Constant noise remains within 5 dB for a long time. Constant noise which starts and stops is called intermittent. Fluctuating noise varies significantly but has a constant long term average ($L_{Aeq,T}$). Impulse noise lasts for less than one second

$L_{Aeq,T}$ is a standardized form of long term average sound level using the A-weighting network described earlier. The A-weighted sound level is integrated and averaged over the duration of the measurement. This average is carried out using the equal energy principle. A person would be exposed to the same total sound energy whether he was exposed to the actual noise level including all its fluctuations or to the $L_{Aeq,T}$ of the noise exposure for the same duration of time. This is a very useful concept when dealing with typical industrial and environmental noise which fluctuates widely and contains short periods of intense or impact type noise. The noise exposure allowed for employees in industry is defined as a maximum $L_{Aeq,T}$ value for a normal working day. A wide variety of instruments for measuring noise with different characteristics in any situation can be attained today. B & K instrumentation for noise measurements is described in detail in the next chapter.

To extend the possibilities of measurement it is often practical to connect a tape recorder to a sound level meter in order to record the source noise. Later analysis of the recorded noise forms a better basis for a more extensive insight into the noise problem and better judgement. This is always to be recommended where a more complete description of the noise source or a better basis for taking decisions about sound reduction measures is required.



Grid mapping in a machine hall with a large number of closely spaced machines. Each grid is 6 × 7,5 m

In a room with closely placed constantly operating noise sources and many work stations it is usually advisable to draw up a noise map as a first step towards noise control. Measurements of this type are the only way to determine whether or not the working environment is satisfactory. To adequately describe individual noise sources (or work positions) more measurement points than are normally used for a noise map are required. It is a good idea to add a few extra points near particularly noise sources, as these will tend to be dominant and more likely to require treatment.

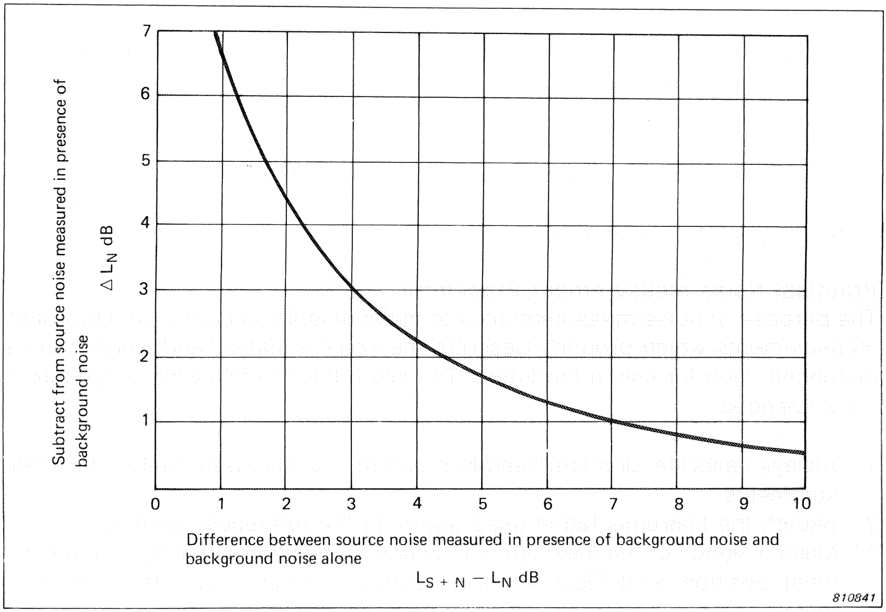
Practical Noise Measurement Procedure

The purpose of noise measurement is to make reliable, accurate, and thorough measurements which properly describe the noise situation and which can be depended upon for use in the future. To ensure this the following procedure is recommended.

1. Always calibrate all instrumentation before and also preferably after measurements.
2. Sketch the instrumentation used and note the reference numbers.
3. Make a sketch of the measurement situation, position of sources, measurement position, and local reflecting surfaces which may affect measurements.
4. When working outdoors note the meteorological conditions, especially wind direction and strength, temperature, and humidity.
5. Check the background noise level to ensure that it is sufficiently below the measurements being taken or correct if necessary.
6. Carry out the measurements noting down relevant equipment settings such as A-weighting, "F" time weighting etc.
7. Keep a log, noting changes made to equipment settings, unusual occurences, and make notes where relevant.
8. When tape or level recording, always make notes in the field directly on the tape or level recorder paper, where it is obvious when returning to it at a later date for further analysis.

Background Noise

Noise from unwanted sources, so called background noise, must be at least 10 dB below the level of the noise emitted by the source being considered, for measurements to be valid. If this is the case, the measurement is accurate to within 0,5 dB. The background noise must therefore always be checked before making measurements. However, if the difference between the source noise measured in the presence of background noise and the background noise alone lies between 3 and 10 dB, a correction may be made using the diagram. If this difference is less than 3 dB, the source noise level is less than the background noise level and a reliable value for the source noise alone cannot be obtained. If measurements are made in frequency bands, the background noise measured in each band should be at least 10 dB lower than the source.


7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
Subtract from source noise measured in presence of background noise
ΔL_N dB
Difference between source noise measured in presence of background noise and background noise alone
$L_{S+N} - L_N$ dB
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INSTRUMENTATION

Sound Level Meters and Portable Instrumentation

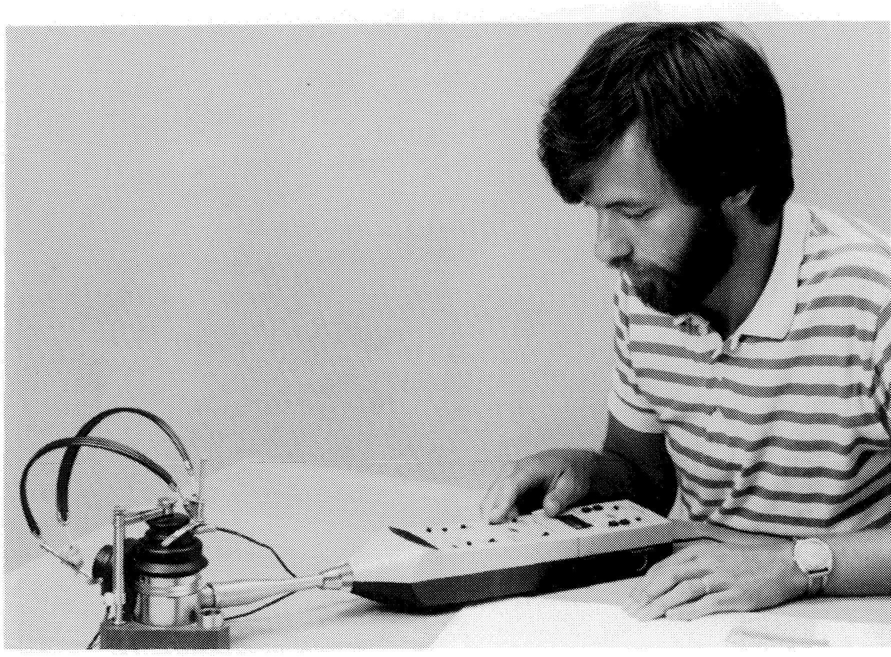
Sound Level Meters

The variety of noise measurements can range from a simple sound level measurement to a detailed statistical or frequency analysis of the signal, and may even involve further computation of the measured data to express the results in the desired form and units. The choice of the method depends of course on what the problem is and the ultimate use of the data that are to be obtained. Because there are a great number of different noise sources and various types of noise "environments" to which we are daily exposed, the selection of the appropriate measurement method and the corresponding equipment should be given careful consideration. In the following, an attempt will be made to guide the reader regarding which instruments are necessary for specific noise problems.

In order to be able to comprehensively measure the different types of noise, a wide variety of instruments exist, ranging from pocket size battery operated sound level meters to mains operated laboratory equipment. The simplest

Measuring noise from drilling operations using a hand-held Precision Integrating Sound Level Meter Type 2221 to obtain $L_{Aeq,T}$ and Peak level sound level meter Type 2232 is designed to make A-weighted measurements during a preliminary survey and to identify likely problem areas. This is a type 1 precision instrument which is ideal for measurement of steady noise, and highly suitable for less experienced pesonnel.

Fluctuating noise levels, a problem often encountered in typical industrial situations, make reading of the level on a conventional sound level meter difficult. To solve this problem, it is very often advantageous to average over a long time using an integrating sound level meter and obtain the equivalent sound pressure level, called $L_{Aeq,T}$. Nowadays, in many countries, national standards only refer to $L_{Aeq,T}$ measurements. To satisfy these requirements, most B & K sound level meters are of the integrating type. Type 2225 and 2226 are integrating sound level meters of type 2 precision in miniature format providing the user with the internationally standardized "F" and "S" time weightings and also an $L_{Aeq,T}$ measured over a period of time of one minute. A one minute integration period is very often enough to obtain a relevant $L_{eq,T}$ value. In addition the 2225 has a peak hold facility which enables the peak sound pressure level of impulsive noise to be measured accurately. In place of peak hold the 2226 has an impulse time weighting for measuring the impulse level of noise. The 2226 has, in addition, a max. RMS hold which can be used to measure the maximum



Audiometer calibration using a Precision Sound Level Meter Type 2235 with an 1/1-1/3 Octave Filter Set Type 1625 and Artificial Ear Type 4152 sound pressure level during for example a machine cycle. Both are exceptionally easy to operate even for those with little previous experience of noise measurements. In cases where integration has to be carried out over a longer period of time, for example, traffic noise survey, use can be made of integrating sound level meters Types 2221 and 2222. These are pocket size Type 1 precision sound level meters which can perform $L_{Aeq,T}$ (over a period up to almost 3 hours) and $L_{EA,T}$ (previously called SEL) as well as measuring RMS or Peak max levels. RMS max level is measured with time weighting "F" (Fast) by Type 2221, and "S" (Slow) by Type 2222.

For more specific measurements, or for investigating the causes of the noise problem, more sophisticated sound level meters are required: for example sound level meters with various measuring modes, frequency weightings, interchangeable microphones and possibility of adding filter sets.

The Precision Sound Level Meter Type 2235 includes A and C weighting networks as well as a linear response, and filter sets can be attached directly to its base. Various time weightings and detector modes are available. Type 2235 can either display the maximum RMS level in the previous second (IEC 651) or the RMS level occurring every second (Japanese standard); it can also hold this

On site frequency analysis with Sound Level Meter Type 2230 and Filter Set Type 1625, recorded on Level Recorder Type 2317

On site traffic noise measurement and statistical analysis with Modular Precision Sound Level Meter Type 2231

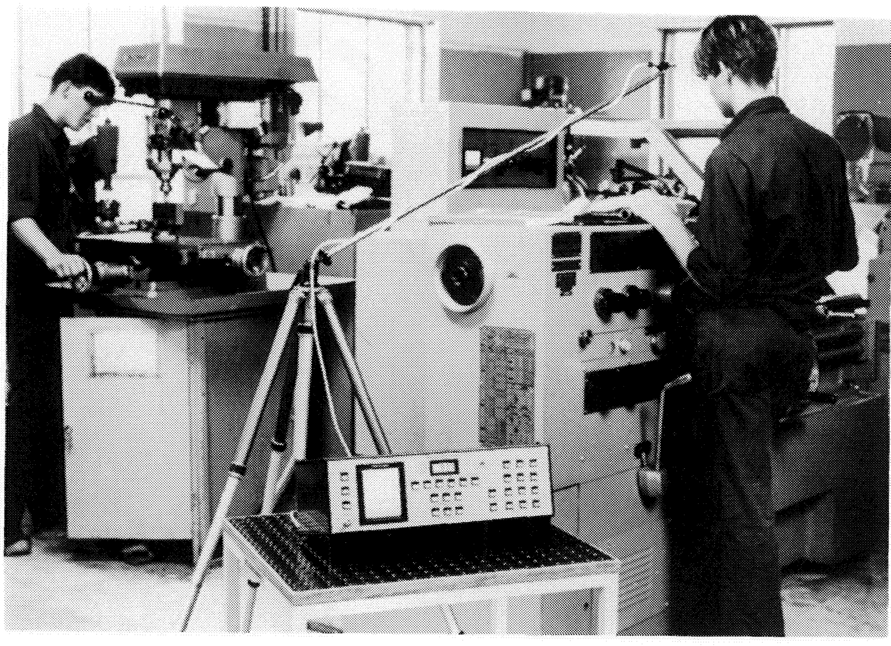
last value or the maximum level. The Impulse time weighting and the Peak detector mode of the Type 2235 make it well suited even when dealing with impulsive noise often found in factories; i.e. from presses, material handling, rivetting and product transport. The choice of polarization voltage enables use of various types of microphones as for example a pressure microphone for audiometer calibration.

Type 2230 can measure over any period of time, SPL, $L_{eq,T}$, $L_{E,T}$ and the max and min SPL. It also offers a choice for the time and frequency weightings. Type 2233 and 2234 are similar to Type 2230 with the following differences: Type 2233 can also measure the SPL in 1, 3 or 5 s intervals (Taktmaximalpegel in accordance with TA-Lärm, West Germany), and displays the measurement time instead of the minimum SPL; Type 2234 is very similar to Type 2230 but displays the SPL value occurring every second (Japanese standards) instead of the maximum SPL in the previous second. Type 2231 Precision Modular Sound Level Meter is the most versatile of all, fulfilling IEC Type 0 when used with an extension cable. Its basic design enables it to accommodate almost any type of signal and carry out precise measurements for all different types of noise. Depending on the type of post processing of results required, different interchangeable modules are available. These modules for example convert the

Measurement of noise dose received during a working day using a pocket-sized noise dose meter

2231 to a precision integrating sound level meter, a sound level meter for "Taktmaximalpegel", a statistical analyzer, etc. Type 2231 has a digital interface which can be connected to a printer, a computer, or used to externally control the 2231.

When making measurements prior to carrying out noise control work it is not usually sufficient to measure just the sound level. The frequency spectrum normally needs to be known as well. This enables prominent tones to be identified and the noise output at different frequencies to be correlated with particular parts of the machine or particular operations. This approach is particularly useful with regard to noise from motors, pumps, and impact (noise) where a machine is otherwise relatively quiet. Efforts can then be concentrated on the most significant contributor or contributors to the overall noise level. It is usual in noise analysis to use a constant percentage bandwidth filter; normally octave or 1/3 octave bandwidths, although even narrower bandwidths may be used if high resolution is required. A similar frequency spectrum measurement made after the modifications have been carried out, can give a useful indication of the effectiveness of the modification – a standard procedure in noise control work. Two filter sets Type 1624 (octave) and 1625 (octave and third octave) can be attached directly to the base of Sound Level Meters Types 2230, 2231, 2233,



Analysis of noise from a lathe using a Statistical Noise Analyzer Type 4427 with built-in printer

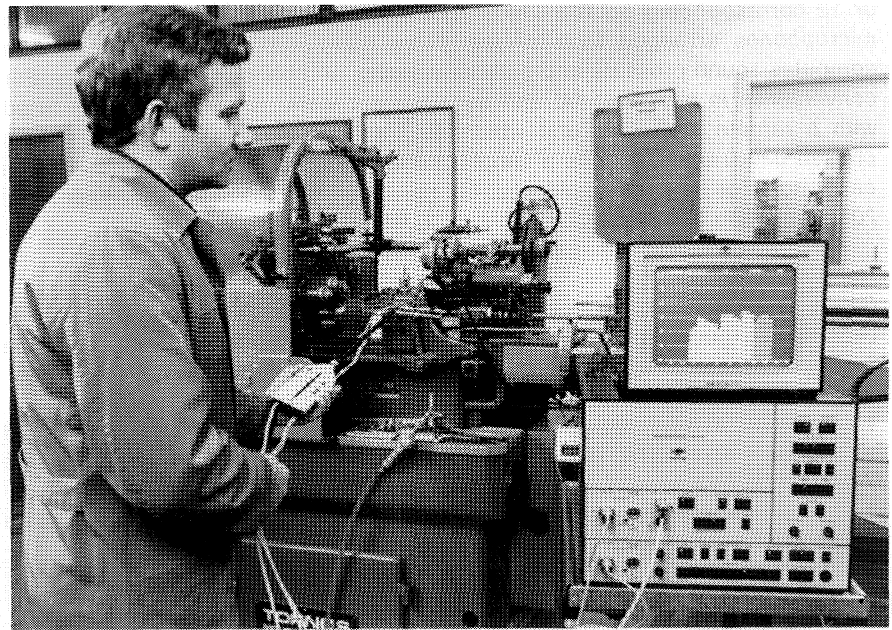
2234 and 2235, converting them into convenient frequency analyzers. The infra-ultrasound filter set Type 1627 can also be connected to all these sound level meters, but only the Type 2231 permits full use of the 1627 frequency range.

Noise Dose Meters

The Noise Dose Meters Type 4428 and 4434 are special types of integrating sound level meters designed specifically to measure the noise exposure of employees during their normal working day. They are self-contained and pocket-sized so that they can be worn by the employee while at work and thus measure his actual noise exposure, however much the noise changes or wherever he may be in the factory. The noise dose is a measure of the total A-weighted sound energy received by the employee and is expressed as a proportion of the allowed daily dose. It therefore takes into account not only the noise level but also the length of time the employee is exposed to it.

Noise Level Analyzer

In many cases a statistical analysis, i.e. the way in which noise varies with time, is also a useful parameter for understanding the problem. The Noise Level Analyzer Type 4427 offers a wide range of features for accurate and extensive on-site statistical analysis of acoustical events. The detector circuit provides F,



Sound source location using the Sound Intensity Analyzing System

S, I and Peak plus 3 s and 5 s Taktmaximalpegel responses in parallel with true linear 1 s $L_{eq,T}$ responses. A built-in IEC/IEEE or optional RS 232 C communication interface port provides for remote set-up and control. A built-in graphic printer/plotter allows fully annotated permanent records to be made.

Sound Intensity Analyzers
Sound intensity is a vector quantity which characterizes the net rate of flow of energy per unit area at a given position. Traditional sound pressure measurements register levels at the receiver, but only sound intensity measurements are able to reveal where the sound is coming from. When searching for noise sources on engines, machines, etc., the probe is moved by hand in the area of interest. Points of high intensity are immediately identifiable on one of the display units. The speed and precision with which the sources are located is impressive especially compared with old methods like lead wrapping etc. The probe is highly directional so that the direction of propagation can also be established.

The B & K system for intensity measurements employs a two channel real-time analyzer based on digital filtering techniques. Sound intensity spectra are displayed on an 11″ screen in either 36 one third octave bands (3,2 Hz to 10 kHz) or 12 corresponding octave bands. The intensity transducer consists of two microphones arranged face-to-face. From their output signals, the system computes sound pressure and particle velocity, and hence sound intensity. For convenience in experimental and development work, the probe can be fitted with a remote indicating unit which displays the intensity level in any one chosen band. Calibration is a simple matter with a conventional pistonphone calibrator. For narrower band analysis the Dual Channel Signal Analyzer Type 2032 may also be used.

Recording

Sound Level Meters have a display from which noise levels can be read directly. Data usually needs to be documented as well and stored for future reference and comparison. There are two ways of storing noise data:

1. by using a level recorder; this as the name implies records the sound pressure level either directly or from an on-the-spot frequency analysis as described earlier.
2. by using a tape recorder; this records the actual signal and can therefore be used at a future date for further analysis purposes.

Level Recorders

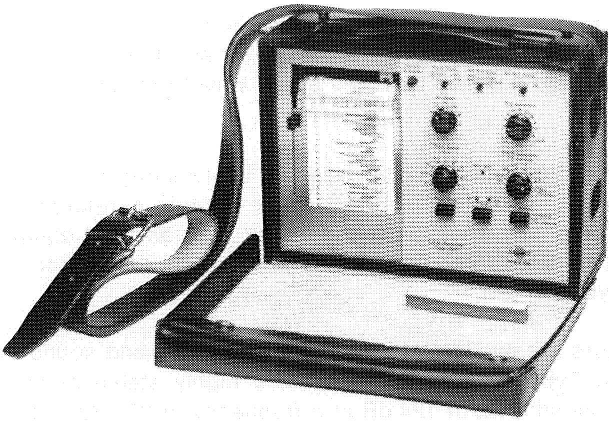
The level recorder can be used in the field to record and document a final result. Two battery powered fully portable level recorders are available, the single channel Type 2317 and the two channel Type 2309. All the sound level meters mentioned earlier connect directly to these two instruments. The Type 2317 is especially useful when measuring transient events such as machine run-ups and run-downs and machines which have a distinct cycle within which noise levels vary significantly. The two channels of the Type 2309 are extremely convenient for comparing, for example, the noise levels on two sides of a screen or partition, or checking the isolation of a machine foundation by simultaneously measuring the foundation and the floor vibration i.e. either side of the isolators, In this way a clear on-site judgement can be made and the evidence suitably documented.

Tape Recorders

There are a number of occasions when it is preferable, or even necessary, to record the actual noise signal as faithfully as possible;

1. to minimise the time spent on site and the equipment employed
2. analysis of the same data by a number of different techniques
3. analysis not possible in the field
4. the analysis of a particular event of short duration

The portable instrumentation Tape Recorder Type 7005/6/7 is a compact, lightweight instrument especially designed for multichannel recording of sound



Portable Level Recorder Type 2317

and vibration signals. Interchangeable units allow the choice of any combination of up to four direct or FM units covering the frequency range from DC up to 60 kHz. Normal sound and vibration signals from DC to 12,5 kHz, including infrasound and shock, can be recorded using the FM unit. For applications such as bearing condition monitoring and acoustic models, higher frequencies, up to 60 kHz, can be accommodated using the direct unit.

Tape recording also permits frequency transformation, in which a signal recorded at one tape speed is replayed at another. Using this technique, the frequency

4 Channel Tape Recorder Type 7005

range of low frequency recordings can be shifted up into the frequency range of normal audio frequency analysis equipment, or short duration sounds, shocks, etc., can be slowed down so that their actual waveform can be studied in detail.

Calibration

When recording level information using a level recorder or an actual signal using a tape recorder, the recording must contain a reference signal level before and preferably after the recording, so that analysis equipment can be correctly set up at a later date. Clear and careful calibration is the key to reliable analysis.

Two calibrators are available for sound level meters and sound measurement systems. The Type 4220 Pistonphone is a highly stable mechanical device producing a sound level of 124 dB at a frequency of 250 Hz, with a calibration accuracy of 0,15 dB suitable as a laboratory standard as well as for field use. The Sound Level Calibrator Type 4230 is an electromechanical device which produces 94 dB at 1 kHz with an accuracy of 0,3 dB. This is especially suitable for use with meters having a permanently connected A-weighting network which has zero attenuation at 1 kHz.

Laboratory measurement and analysis systems

The tape recording of data opens up a much wider range of analysis techniques not normally possible in the field but easy to perform in the laboratory. The heart of much laboratory measurement or analysis instrumentation is the measuring amplifier, such as the Type 2610 or 2636 which conditions, frequency weights and averages the signal, and where necessary connects with an exter-

Instruments for acoustic calibration: Pistonphone Type 4220 (left) and Sound Level Calibrator Type 4230 (right) nal filter. The level is then both displayed on a meter and output to an external recorder such as a Level Recorder 2307, which is a laboratory model with comprehensive facilities, to obtain a permanent record. The X-Y Recorder Type 2308 is a high slew rate instrument with fully controllable axes which is convenient for recording both frequency responses and signal waveforms.

The addition of a Band Pass Filter Set such as the Type 1618 enables analysis to be carried out in octave or 1/3 octave bands between 20 Hz to 20 kHz. Type 1617 has an increased frequency range up to 160 kHz and more comprehensive interconnection facilities for use with other instruments. The frequency analysis can be automatically recorded on the Level Recorder Type 2307 which remotely controls filter switching.

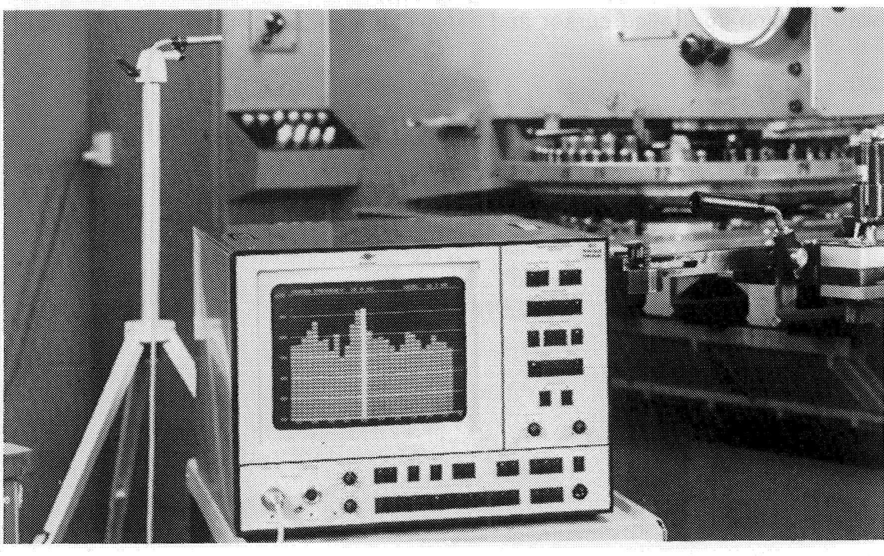
A continuous analysis in bandwidths of 23% (approx. 1/3 octave), 10%, 3% and 1% is possible using the Type 2120 Frequency Analyzer which also carries out and records the analysis automatically in conjunction with the Level Recorder Type 2307. A narrower bandwidth allows greater resolution of tones than does a fixed band filter set. This is particularly important when designing against noise in a fairly narrow bandwidth such as might arise in engine exhaust or ventilation systems.

For fast analysis of large quantities of noise data it is possible to speed up the analysis process by using a real time digital frequency analyzer such as the Type 2131. This is an octave and third octave band analyser with a wide range of facilities including type of averaging and time weightings, A weigting network, switch controlled cursor and extensive interconnection facilities, includ-

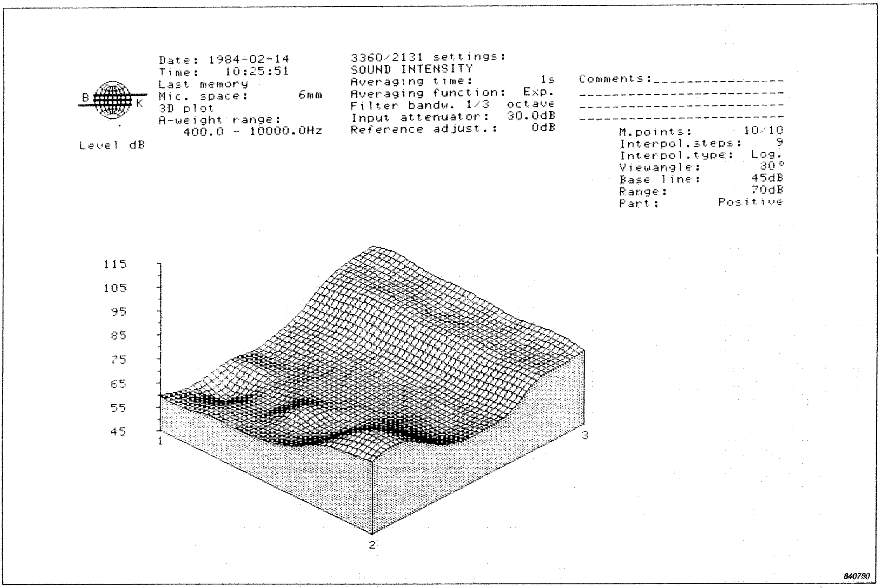
Analysis in octave or third octave bands using a Measuring Amplifier Type 2636 and the Bandpass Filter Type 1617 ing a signal interface to such peripherals as the Graphics Recorder Type 2313. Type 2313 is a fast digital printer and versatile system controller which with a dedicated application package greatly extends the measurement and control possibilities: 300 spectra storage, 3-D recordings, $^1/_{12}$ octave analyses, reverberation and decay measurements, etc, with the 2131 and the Application Package BZ 7001

All the previously mentioned filter sets and frequency analyzers were of the constant percentage bandwidth type i.e. the bandwidth of analysis is a fixed proportion of the centre frequency. This means of course that as the frequency is increased the absolute bandwidth of the analysis is also increased. For many purposes, analysis is required at constant frequency intervals. This is particularly true of noise and vibration problems associated with rotating machines and gearboxes, where multiple resonances and harmonics (which lie at constant frequency intervals and not constant percentage frequency intervals) are extremely important. Noise radiation at particular frequencies can then be correlated with fan blade passing or gear tooth meshing frequencies or their harmonics. The Heterodyne Analyzer Type 2010 is designed for this type of analysis, in bandwidths from 3,16 to 1000 Hz in a total analysis range from 2 Hz to 200 kHz. Again synchronisation with a level recorder allows analyses to be carried out completely automatically.

For fast analysis in constant bandwidths and real time, the Type 2033 High Resolution Signal Analyzer and the Dual Channel Signal Analyzer Type 2032 are



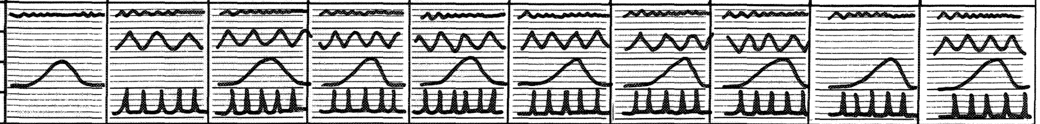
Real time analysis of punch press noise in third octaves using Digital Frequency Analyzer Type 2131



Three dimensional plot obtained with Sound Intensity Analyzing System Type 3360 and Graphics Recorder Type 2313

available. The time history of the signal may be captured automatically and displayed directly on the screen, and transformations between the time and frequency domains as well as wide range of data organisation and display facilities are pushkey controlled. Both Analyzers allow the operator to zoom in on any part of the frequency spectrum in order to obtain an increased resolution, and Type 2032 also enables Sound Intensity Measurements to be carried out.

These Real Time Analyzers are extremely powerful instruments, especially useful for fast analysis of large quantities of data for high resolution of the spectrum, and for transient or cyclical noise e.g. from a machine operation or where the noise is impulsive. As for the Type 2131, these analyzers can have improved features when connected to the Graphics Recorder Type 2313 with the appropriate Application Package.

Brüel & Kjær Type No.		2232	2225	2226	2221	2222	2230	2233	2234	2235	2231[1]
Type of Noise	Continuous										
	Fluctuating, Erratic										
	Noise events										
	Impulsive										
Typical Applications		General purpose. Noise survey.	General purpose. Noise survey. Assesment of hearing risk (2225), and noise annoyance (2226).		Occupational and community noise. Cyclical, fluctuating, impulsive noise. Single events.		Environment and factory noise. Cyclical and impulsive noise. Hearing damage assesment. See [7] and [8]			Gen. purp. Noise survey. Audiometer calibration	Almost any application by changing application module
							Frequency analysis with plug-in Filter Set				
Frequency Response	Weighted	A	A	A	A; Lin[2]	A; Lin[2]	A, C, Lin				
	Ext. Filters	—	—	—	—	—	Oct. or 1/3 oct. Filter Sets (+ infra and ultrasound for 2231)				
Measurement Modes	RMS[3]	F,S	F,S	F,S,I	—	—	F,S,I	F,S,I	F,S,I	F,S,I	F,S,I
	Peak	—	●	—	●	●	●	●	●	●	●
	Max. Hold	●	Peak only	●	F	S	●[4]	●	●[4]	●	●[4]
Averaging		—	$L_{Aeq,60s}$	$L_{Aeq,60s}$	L_{Aeq} SEL	L_{Aeq} SEL	L_{eq} SEL	L_{eq}, SEL L_{FTm}, L_{Im}	L_{eq} SEL	—	L_{eq}, SEL L_{Im}[5]
Pause		—	—	—	●	●	●	●	●	—	●
Dynamic range dB		70	60	60	60	60	70	70	70	70	70
Outputs		DC	DC	DC	AC	AC	AC, DC	AC, DC	AC, DC	AC, DC	AC, DC[6]
Complies with SLM standards	IEC 804 Type	—	2	2	1	1	1	1[7]	—[8]	—	1
	IEC 651/DIN Type	1	2[9]	2 (Imp)	1	1	1 (Imp)	1 (Imp)	—	1 (Imp)	1 (Imp)
	ANSI S1,4 Type	S1 A	S2 A	S2 A	S1 A	S1 A	S1	S1	—	S1	S1
Dimensions (H×W×D) cm		25×7×2	20×7×2				37×8×5				
Weight without batteries kg (lb)		0,46 (1,0)	0,37 (0,8)		0,4 (0,9)		0,86 (1,9)				

1) With Integrating Module BZ 7100
2) Lin weighting only with Peak measurements
3) RMS time constant: "F", "S", "I"
4) Plus min. Hold
5) Plus Taktmaximal Pegel L_{FTm} with Module BZ 7102
6) Digital output Option
7) 2233 measures L_{Tm} according to TA-Lärm
8) 2234 complies with Japanese proposed JIS standard
9) Except for RMS "Max. Hold"

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Practical examples of noise control techniques

In this chapter a number of noise control principles are presented in the form of general techniques with a practical example for each. These deal both with the factors which influence the generation of noise and its propagation in materials, structures and rooms. First and foremost, noise must be limited at source. When solving a noise problem, the question, "What is the cause of noise disturbance?" has to be answered. The technique described most often uses that method of noise reduction which directly reduces noise generation. Most techniques have a limited area of use, though, and may not be available for all possible situations.

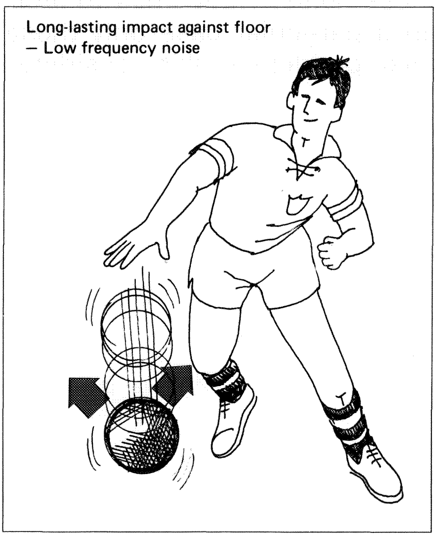
Noise can be caused by a large number of factors, and extensive measurements may often be required before a decision can be made as to which measure should be tried first. It is not usually sufficient to employ just one of the techniques shown to reduce noise. In most cases several different actions need to be taken to achieve the desired result.

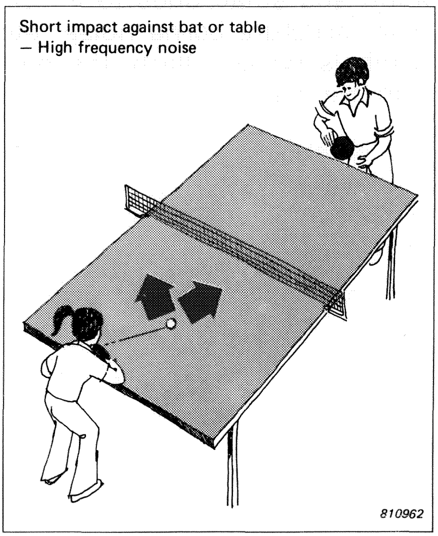
In order to make the drawings easy to understand, different symbols are used, e. g. large arrows to indicate high noise radiation and small ones to indicate less noise, wavy lines to indicate structure-borne noise, etc. In a particular case only those symbols which clarify the particular problem under consideration are used.

More rapid changes produce higher dominant frequencies

The dominant frequency of the noise produced by an impact is dependent upon the speed of the force, pressure, or velocity change which gives rise to the noise. A rapid change produces a shorter pulse which has higher dominant frequencies. The speed of this change is often determined by the resilience of the two impacting surfaces: The more they deform, the longer they are in contact and the lower the dominant frequencies are. When bouncing a basketball on the floor, the ball is in contact with the floor for a relatively long time. The dominant frequency is therefore low. When playing table tennis the ball is in contact with the bat or table for only a very short time. The dominant frequencies are therefore much higher.

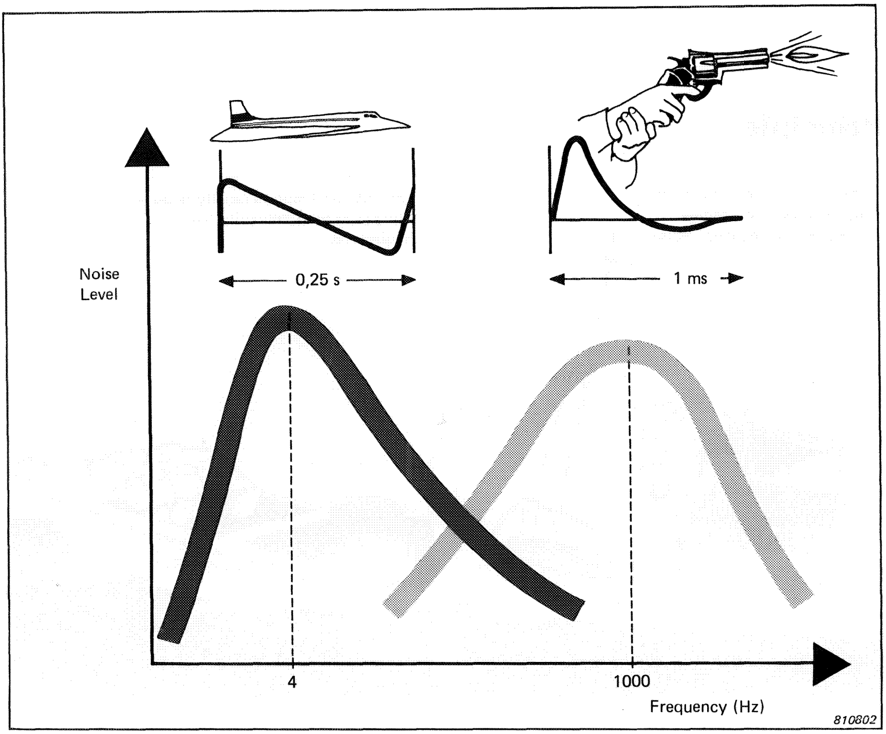
Principle





Example

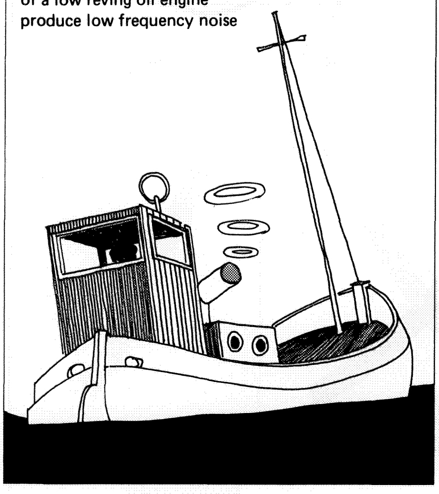
A sonic boom lasts approximately as long as it takes for the aircraft to fly through its own length. This may take e.g. 0,25 s. The dominant frequency is therefore about 4 Hz. A gunshot may last only 1 ms. Its dominant frequencies are therefore much higher, at about 1 kHz.



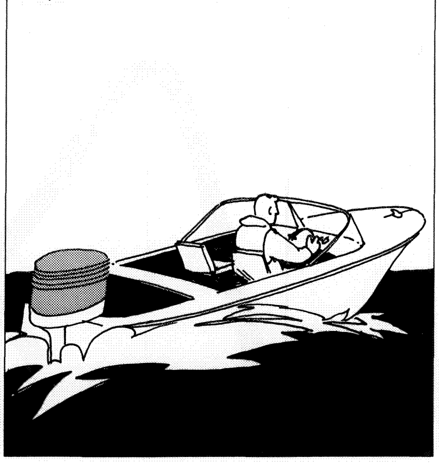
Slow repetitions give low frequencies, fast repetitions give high frequencies

A noise-producing event which repeats, generates frequencies which depend on the time between repetitions. A slowly repeating event gives rise to predominantly low frequencies and a rapidly repeating event gives rise to high frequencies. The level of the sound depends on the magnitude of the change which gave rise to it.

Principle



The distinctly separate beats of a low reving oil engine produce low frequency noise



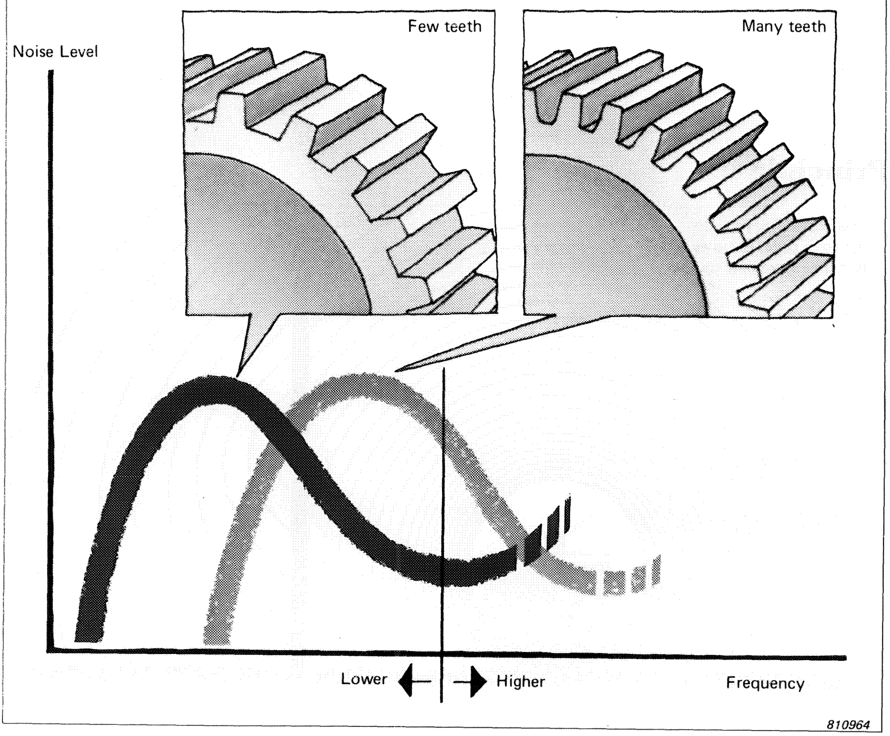
The outboard motors rapidly repeated firing gives predominantly high frequencies

810963

Example

Two gearwheels having the same size but one having twice as many teeth as the other will have predominant frequencies a factor of two apart. The main source of noise is the contact of one tooth on the corresponding tooth on the gearwheel in mesh with it. For the same diameter and speed of rotation the gearwheel with twice as many teeth will have twice as many tooth contacts per second and therefore radiate noise at twice the frequency of the other.

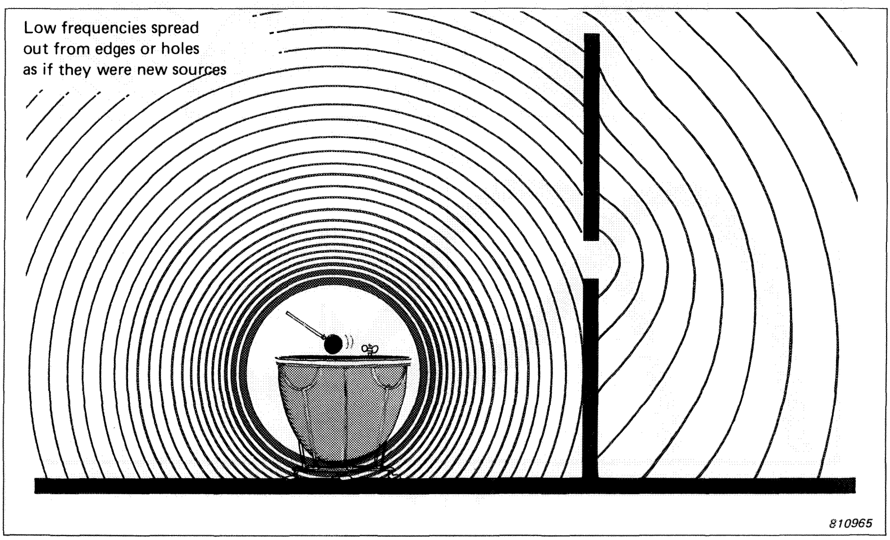
Two gearwheels have the same diameter but different numbers of teeth. At the same rate of rotation, the gearwheel with fewer teeth will produce lower dominant frequency than the other.



Low frequency sound bends round obstacles and through openings

Low frequency sound radiates approximately equally in all directions. It diffuses round edges and through holes without losing intensity, and reradiates from the edge or from the hole as if it were a new source, again equally in all directions. For this reason screens and barriers are not very effective against it unless they are very large.

Principle

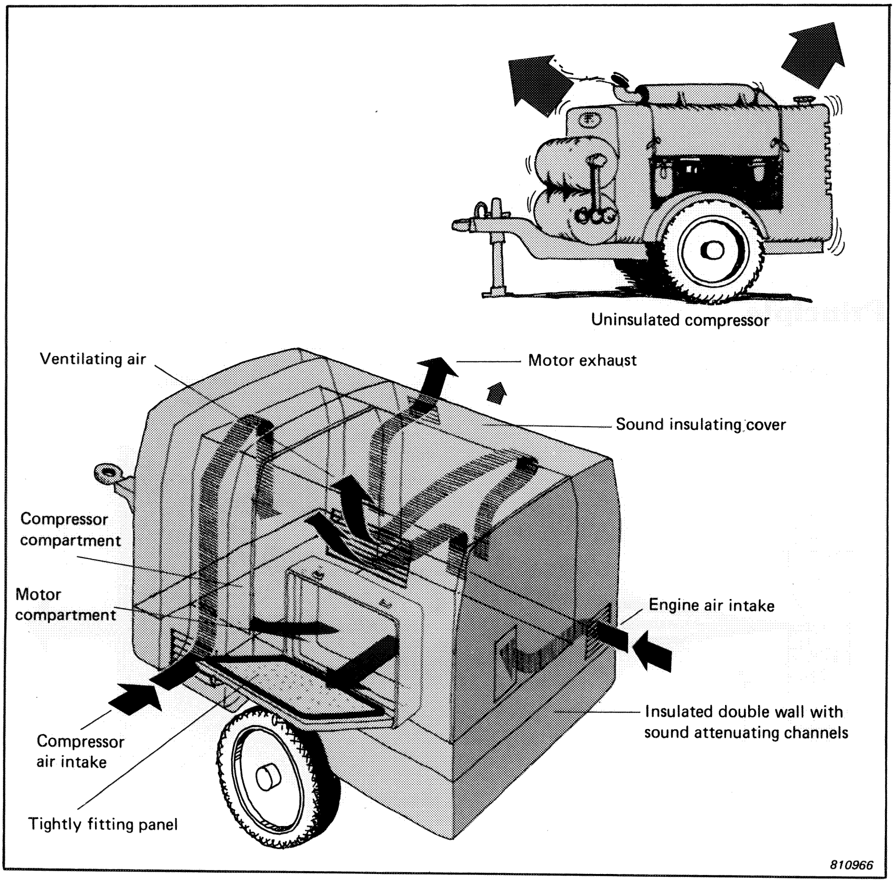


Example

Diesel driven compressors produce high levels of low frequency noise, even if they are furnished with efficient intake and exhaust silencers. Partly open or louvred covers for the intake of cooling air are of little use as noise attenuators. Noise easily radiates out through the openings and gaps.

Solution

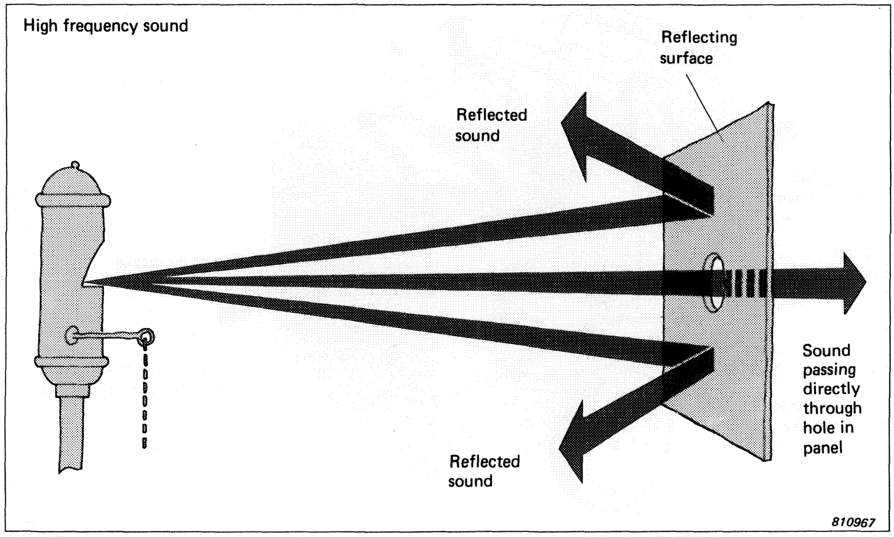
Effective quietening of a powerful compressor requires a well sealed cover eliminating air and noise leaks. The cover can be constructed as a double wall containing ducts with sound absorbent linings. Air for the compressor, for the engine, and for cooling purposes is carried through these ducts, entering and leaving via acoustic louvres. The exhaust silencer is also enclosed within the outer cover. All inspection hatches and access panels must also be tightly fitting and well sealed.



High frequency sound is highly directional and easy to reflect

High frequency sound is often produced by sources which radiate a high noise level in some directions but low levels in others. It can be reflected from a hard surface just as light is reflected by a mirror, and passes through holes in a panel like a beam without being diffused to the sides. Also it cannot diffuse around edges, so barriers are effective against it.

Principle

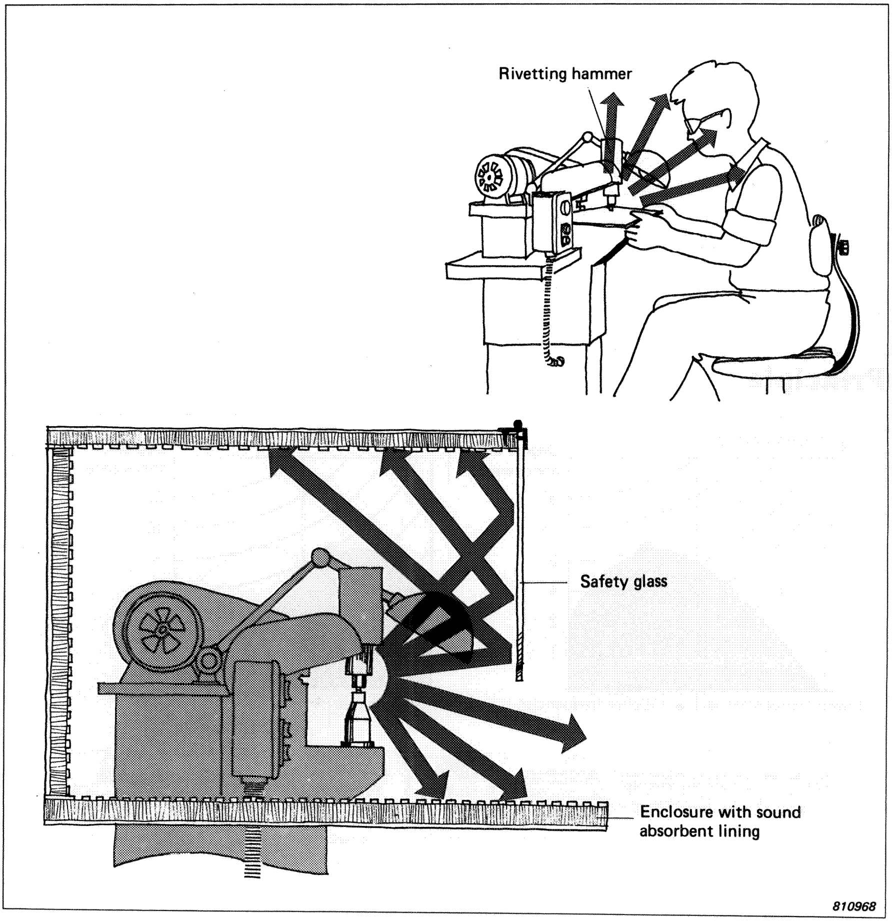


Example

Noise from processes which involve punching, hammering, or other forms of impact give rise to high levels of high frequency noise which can be dangerous to the operator.

Solution

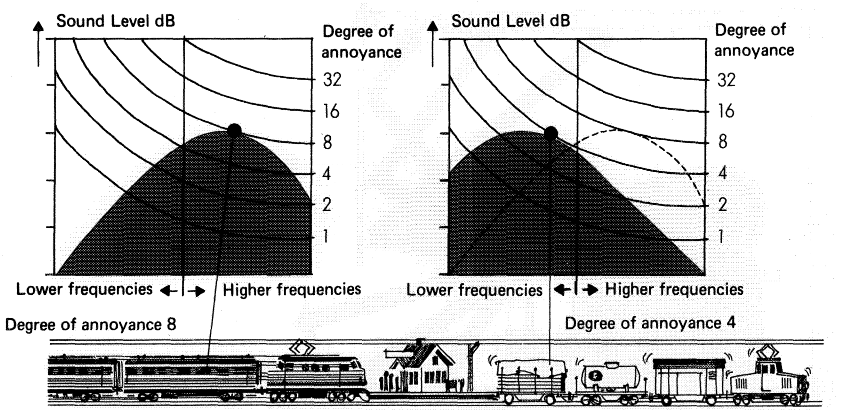
A local enclosure built around the noise source with an opening for access and safety glass to view the work protects the operator's ears from direct sound from the machine. Reflections from the safety glass and most direct sound in other directions are absorbed by the absorbent lining. The small area open for access emits sound only away from the operator's ears.



Close to the source high frequency noise annoys more than low frequency noise

The ear is more sensitive to high frequencies than to low frequencies; so to produce the same amount of annoyance, a low frequency noise must have a higher sound level than a high frequency noise. In some circumstances it may be possible to reduce the annoyance of a close noise source by moving the dominant sound energy to lower frequencies.

Principle



Two trains may produce the same sound energy. However, the passenger train's dominant frequencies are higher than those from the goods train and therefore more annoying.

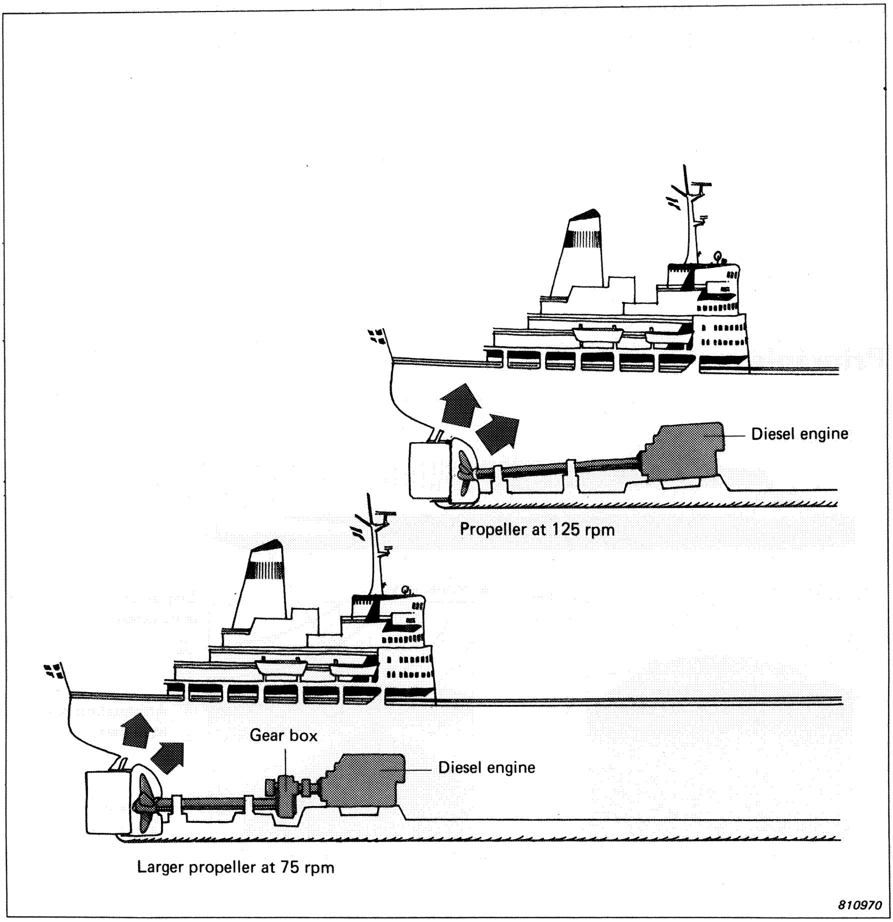
810969

Example

A ships propeller turns at the same speed as the motor, 125 revolutions per minute, and is the source of most noise on board.

Solution

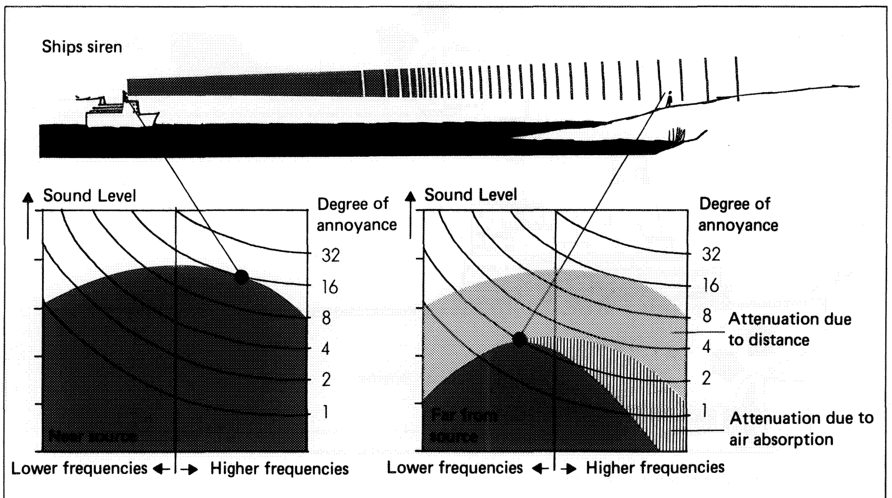
A design with a larger propeller driven through a gearbox at a lower speed lowers the dominant frequencies and reduces the annoyance caused.



Far from the source high frequency noise annoys less than low frequency noise

High frequency noise is attenuated much more, by absorption in air, than low frequency noise is over large distances. This is because absorption is dependent on the number of cycles, and there are more cycles of a high frequency sound than a low frequency in a given distance. In addition, it is normally easier to reduce or shield a source of high frequency noise. If noise in the vicinity of the source is not a problem, it may be possible to shift the dominant noise to a higher frequency which is effectively absorbed by the time it reaches the problem area.

Principle



A ships siren which screams on board sounds dull at large distances

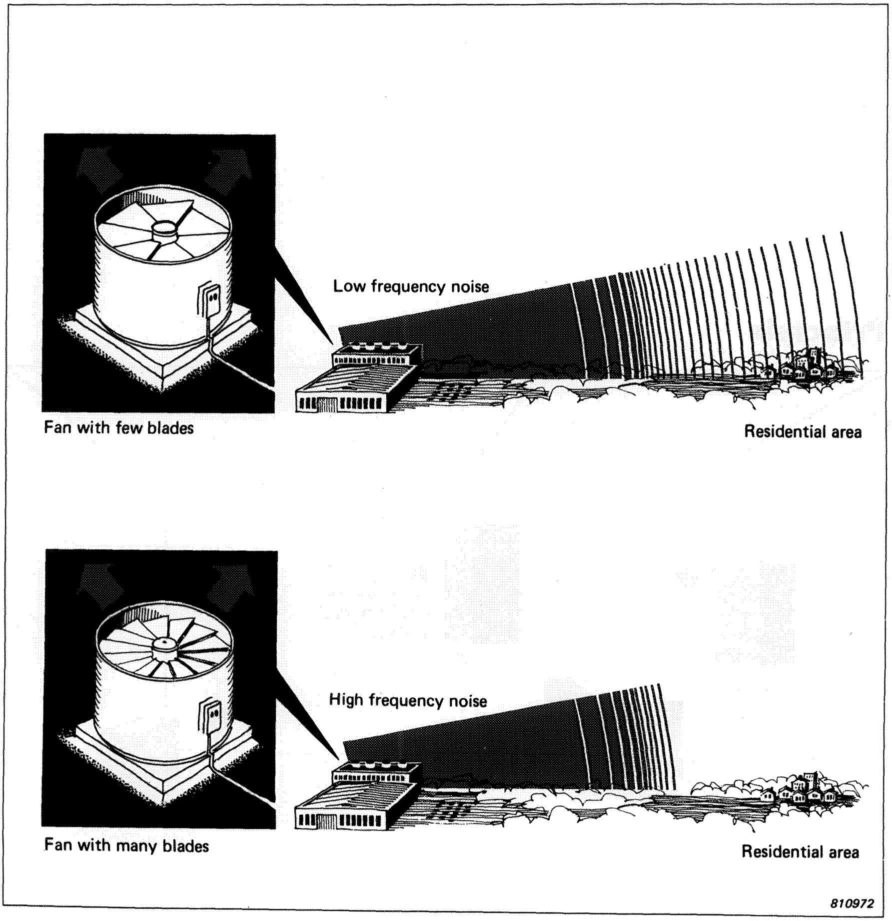
810971

Example

Low frequency noise from industrial fans causes noise annoyance in a distant residential area. High frequencies are attenuated on the way.

Solution

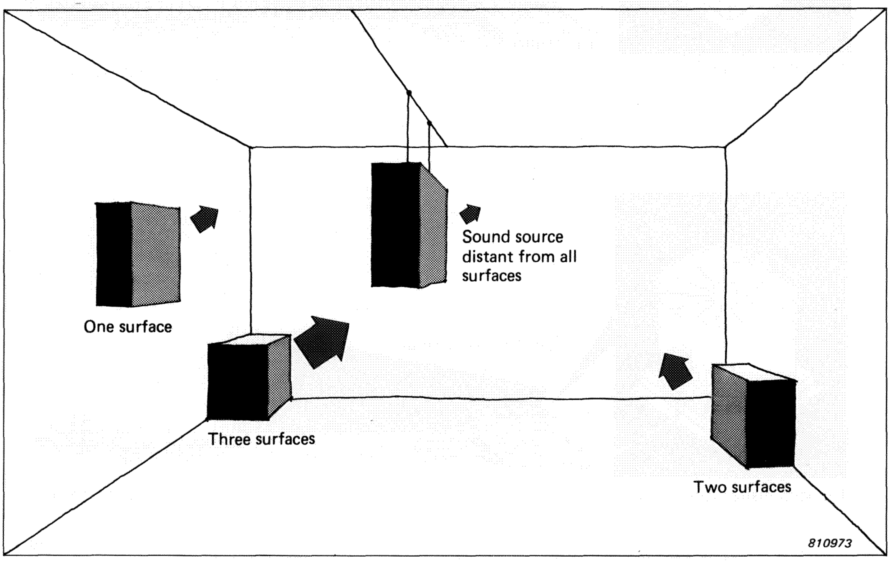
The fans can be exchanged with a type with more blades which shift the major sources of noise up in frequency. The higher tones are absorbed sufficiently by the atmosphere so that they are not a source of annoyance in the residential area, and the low frequency tones are no longer produced. The noise is also easier to attenuate at source.



Sound sources should be sited away from reflecting surfaces

The closer a sound source is placed to a reflecting surface, the more of the sound radiated is directed back into the room. The worst position is against three surfaces, i. e. in a corner. The best position is free-hanging: away from all reflecting surfaces.

Principle

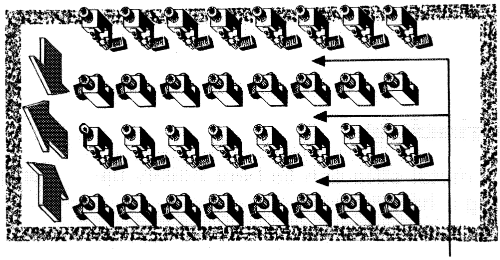


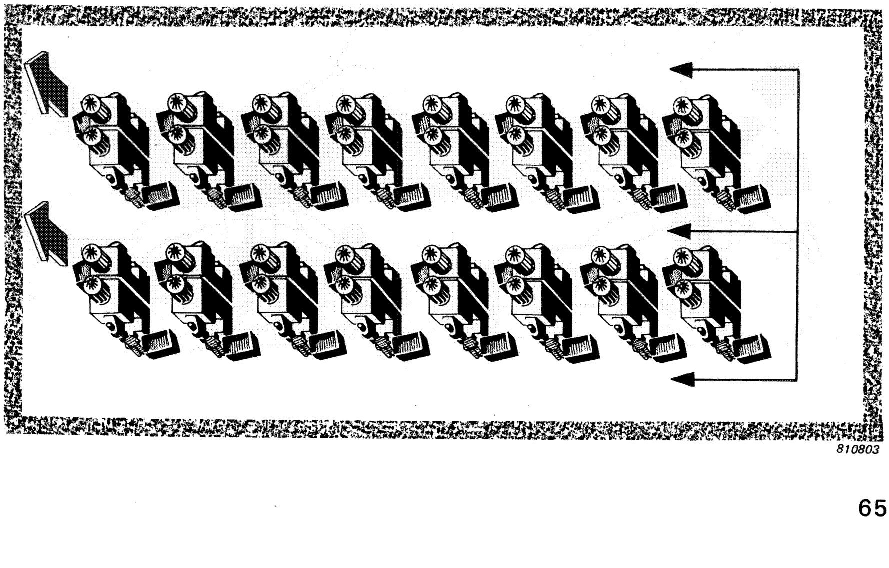
Example

In a machine hall a number of machine tools are placed in four lines, two of them against the walls, with three access lanes between them. This increases the noise from the two lines of machines placed next to the walls.

Solution

The machines along the walls are moved beside the other two lines so there are only two lines. The space along the walls is used as access lanes, of which there are still three, and the overall noise in the hall is reduced.





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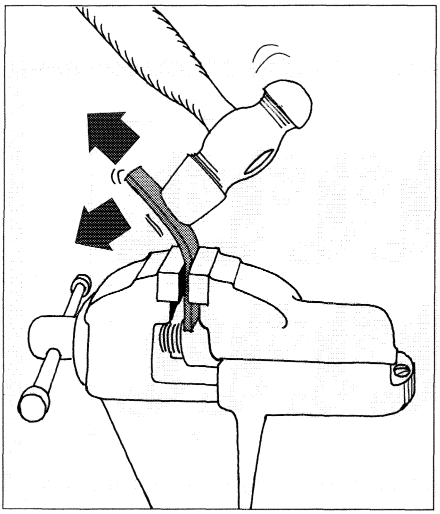
Changes in force, pressure, or speed, lead to noise

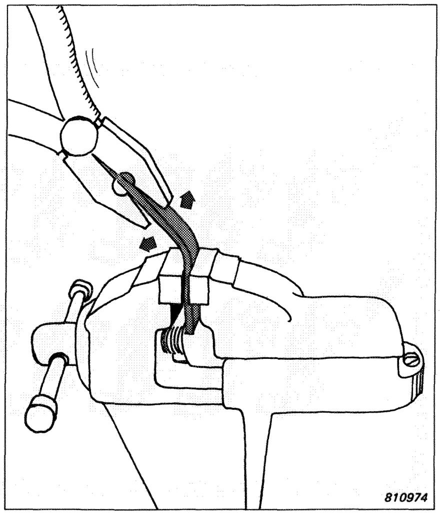
Noise always occurs where there is a change of force, pressure, or speed. Large changes produce the greatest noise, small changes produce less. In many cases the same result can be achieved either with the application of high power over a short period or with less power for a longer period. The first case causes high noise levels, the second, where the power required is small, produces much lower noise levels.

Principle

A metal strip can be bent noisily using a hammer

or quietly using pliers





Example

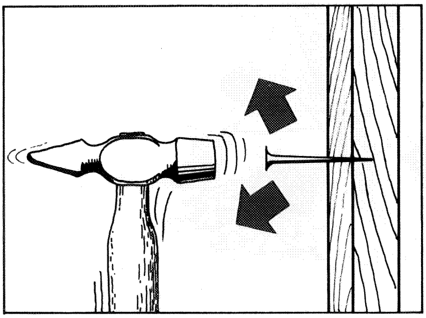
Panels and sheets can be fastened in a number of different ways, some of them very much noisier than others. Those involving impact e. g. nails and rivets are particularly bad from the point of view of hearing damage as they produce very high peak levels of noise.

Solution

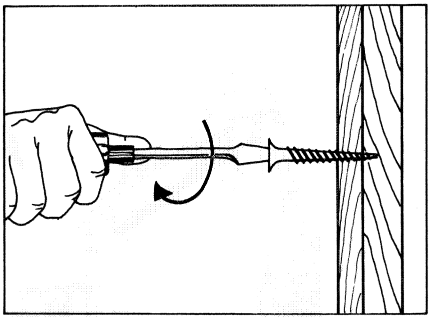
In many cases quiet methods such as screws and bolts can be substituted directly without loss of effectiveness or increase in cost, and with the advantage of improved access and ease of dismantling at a later date.

Two panels can be fixed together

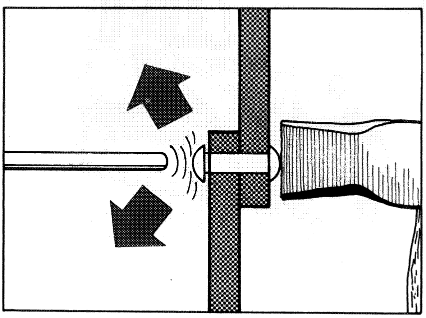
using nails — **noisy**



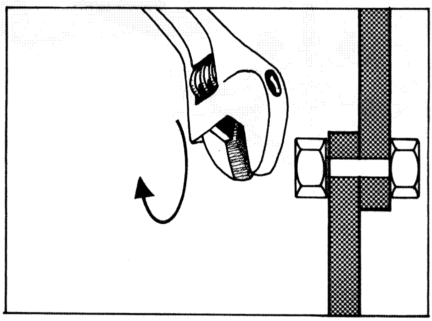
or screws — **quiet**



Steel sheet may be rivetted
Very noisy



or bolted — **very quiet**



810804

Example

Paving breakers have traditionally been handheld and usually pneumatically powered to reduce weight. High levels of impulse noise are produced both by the chipping process itself and from the exhaust. The operator is exposed to high levels of both noise and vibration.

Solution

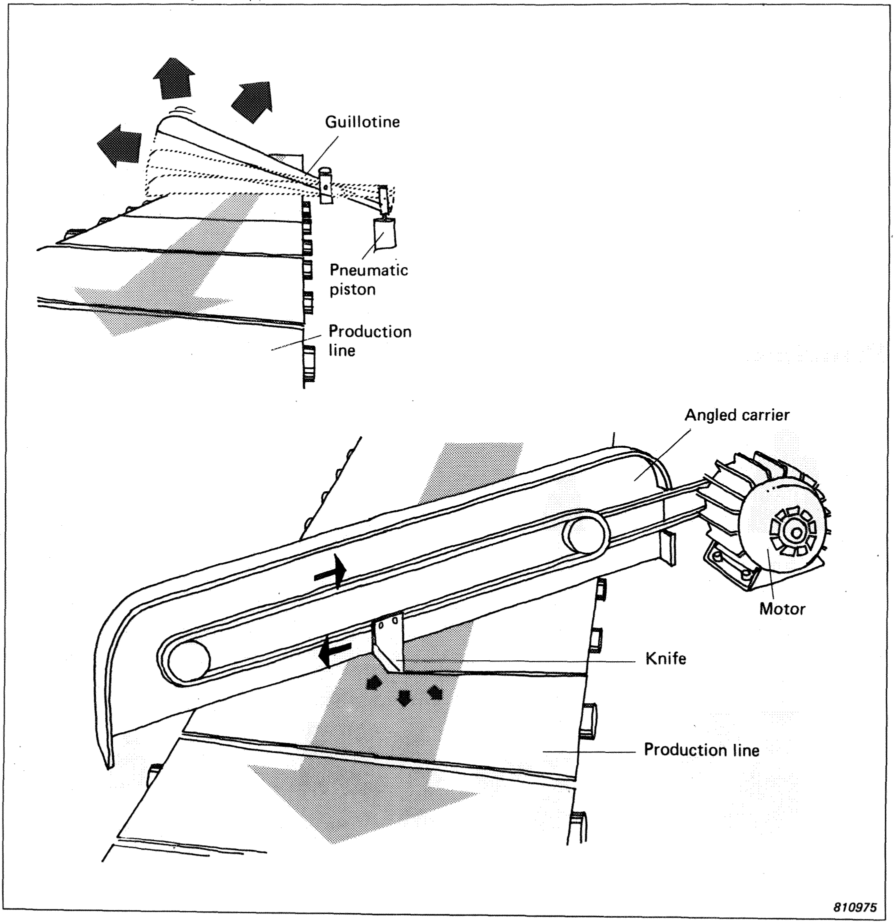
A tractor-mounted hydraulic ram driving a hammer can exert a very large static force as well as vibrate. The paving is fractured and the cracked surface can then be levered up by a bucket loader. The noise levels are lower and the operators are further from the source, often in noise protecting cabins.

Example

Cardboard in a carton machine is chopped using a guillotine. The knife must fall very quickly using high power in order to cut perpendicular to the production line, causing high noise levels.

Solution

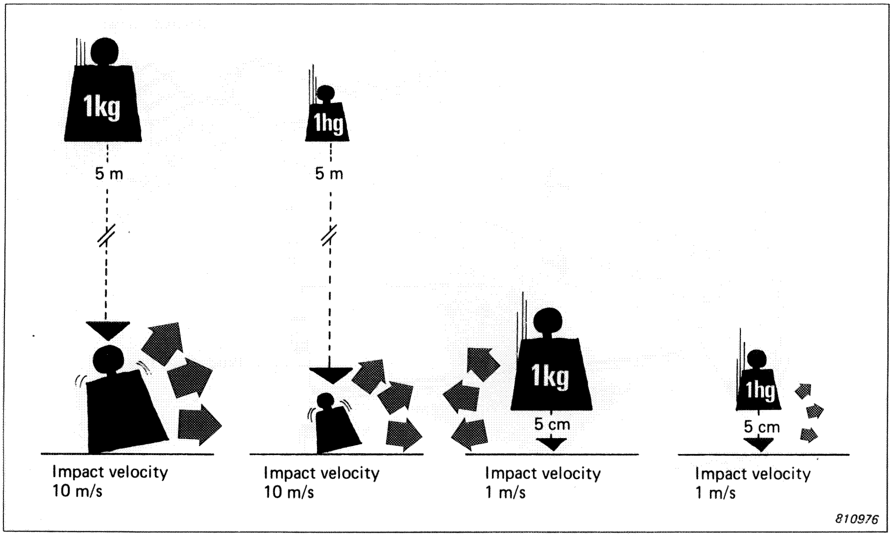
Using a knife which is driven across the production line, the material can be cut with a low force over a longer period, virtually silently. The knife must be set at an angle to the moving line of board to cut perpendicular to the direction of motion.



Low mass and low fall heights give least sound

The noise level generated when a panel is struck by a falling object depends primarily on the mass and velocity of the object. The greater the mass and fall height, the louder the noise, because greater energy is available for transfer into the panel via the impact. A reduction in height or in mass by a factor of ten reduces the noise generated by approximately 10 dB.

Principle

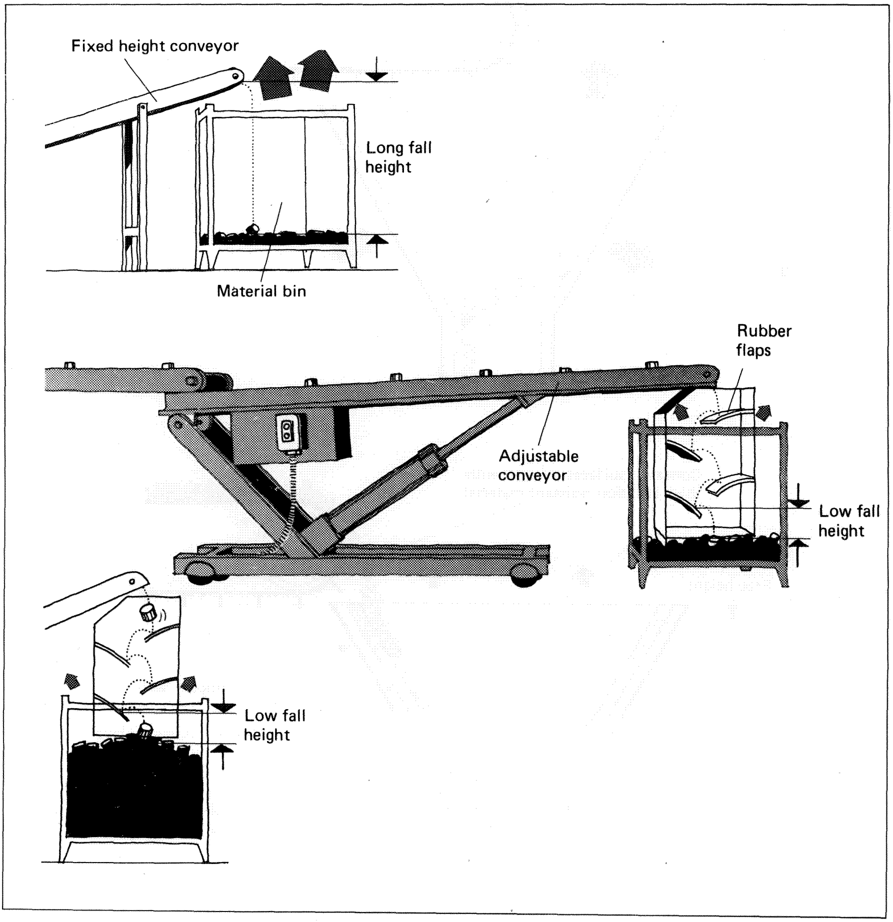


Example

Manufactured items are carried from the producing machine by conveyer and dropped into a collecting bin from a fixed height. When the bin is empty the fall height is large and the noise level is therefore high. There may also be danger of damaging the items.

Solution

The conveyer is constructed so that its height can be adjusted, and is supplied with a case with a number of rubber flaps inside to break the fall of the material. The fall height is therefore never greater than the distance from the collected material to the lowest rubber flap, the conveyer rising automatically as the bin fills.

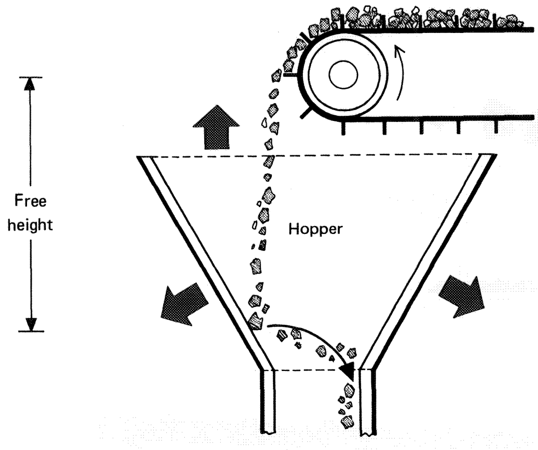


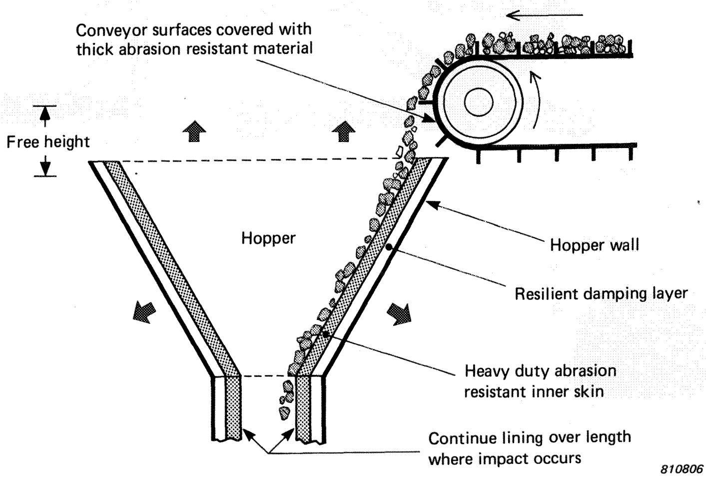
Problem

A material conveyer feeding a hopper deposits the material in the centre of the hopper and the fall height is therefore large. The hopper itself is also a very resonant structure.

Solution

Mount the conveyer so that the material falls on the edge of the hopper so that the free height is minimised. The interior of the hopper can be lined with wear-resistant material to absorb the impact better, and the external surfaces can be mounted with damping sheets to reduce resonances even further.



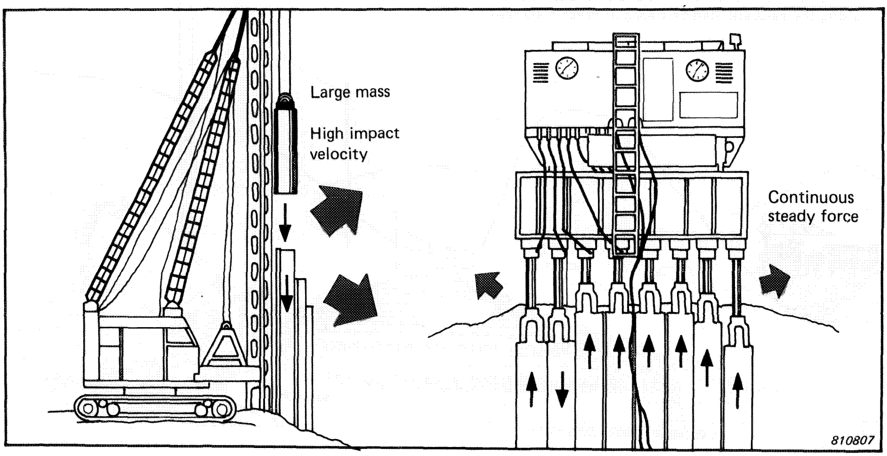


Problem

Sheet piles are normally driven via the impact of a heavy mass dropped from a great height, often powered up again by exploding a diesel charge. Dangerous local noise levels are generated both by the impact on the pile and from the explosion in this case, and annoyance may be caused at distances of up to several kilometers.

Solution

In many situations it is possible to use a completely different technique which avoids impact completely. A set of hydraulically operated rams grip a number of sheet piles simultaneously.
One pile is forced down at a time while the machine pulls upwards on all the rest, which anchor it to the ground. Vibration of the ram holding the pile being driven assists its progress. Impact is avoided completely and noise levels are as low as the hydraulic equipment allows.

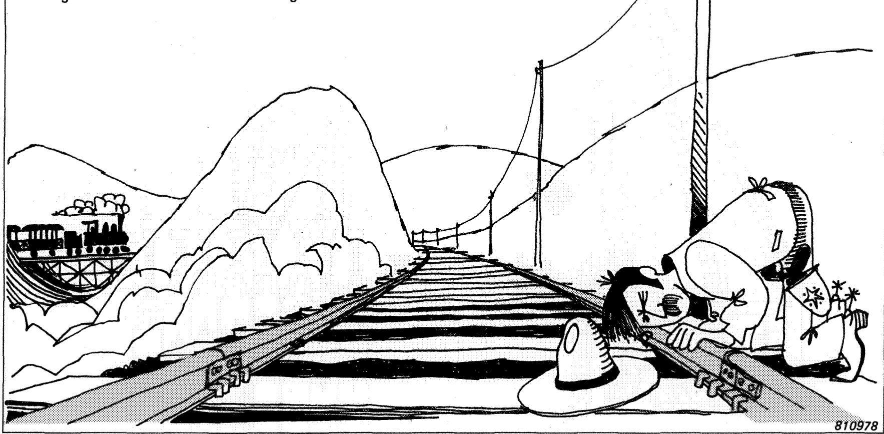


Structure-borne sound travels long distances

Vibration which gets into a structure, especially homogenous structures such as concrete buildings or ships, travels a very long way because of the very low internal damping of the structure. The energy does not reduce and as soon as a large surface, which acts as a loudspeaker, is connected to the vibrating structure, a high noise level is generated. It is best to isolate the structure from the source of vibration as near to the source as possible.

Principle

Vibration from the train is transmitted directly along the rails and can be heard at great distances

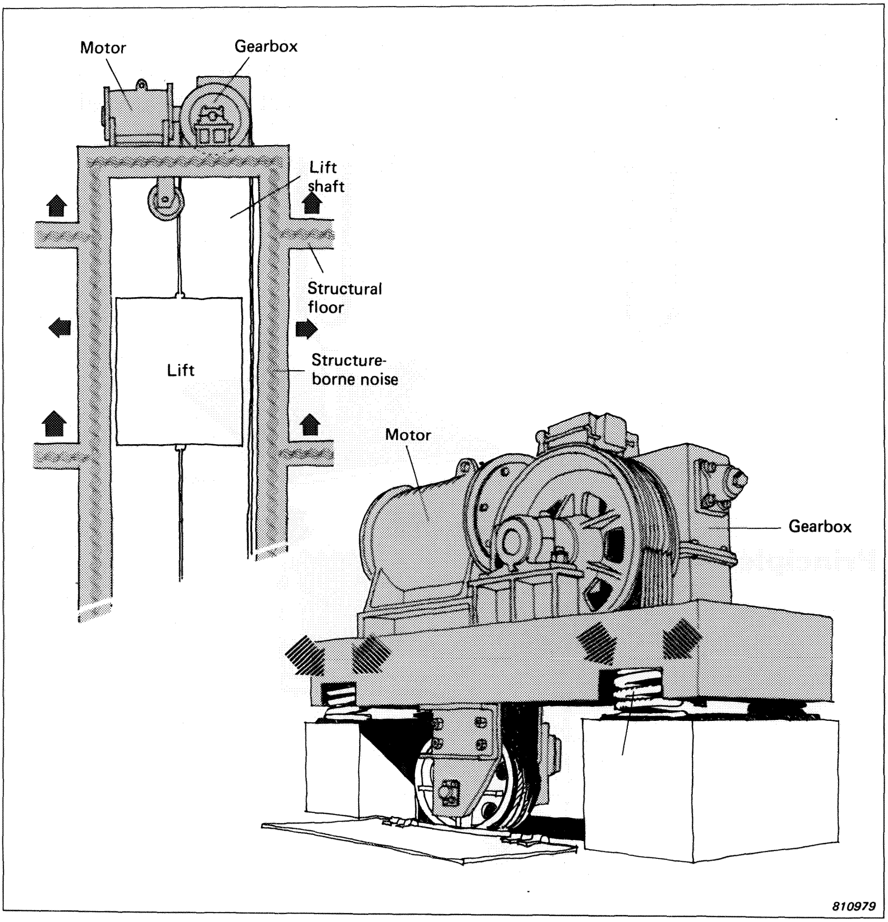


Example

Vibration and stop/start shocks from an elevator can be heard throughout a building. The sound is carried for large distances virtually unattenuated via the concrete slabs.

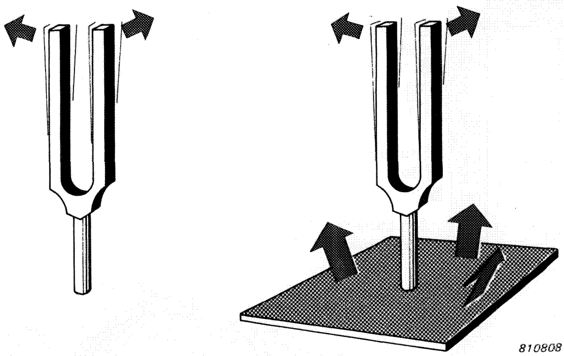
Solution

The winding machinery must be isolated completely from the building structure using a spring support. Further reduction can be achieved by building the lift shaft and driving mechanism separately from the rest of the building structure.



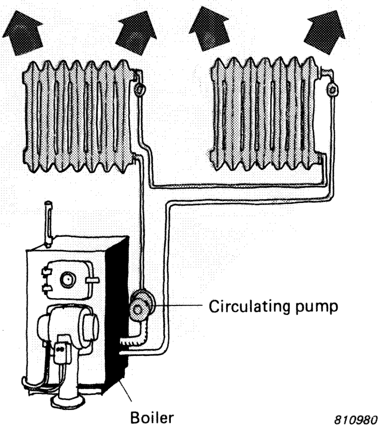
Structure-borne vibration needs large areas to convert it to airborne sound

The vibration of a small object will not generally give a high noise level because the area of air set in motion by the object will also be small. The vibration is thus badly matched to the air. However, connecting a large panel transfers the vibration energy into airborne sound much more effeciently by spreading the vibration over a much greater area which gives a high noise level. A tuning fork generates hardly any noise unless connected to a "sounding board". The circulation pump of a central heating system causes the pipework to vibrate, but little noise is transmitted until a large panel in the form of a radiator is connected; radiating not only heat, but noise as well.



810808

Principle



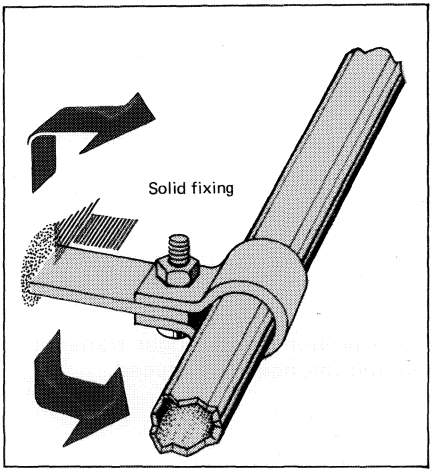
810980

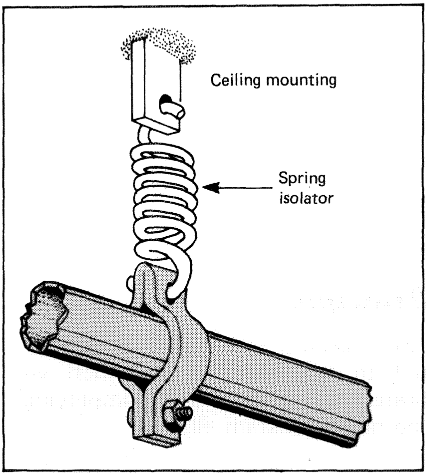
Example

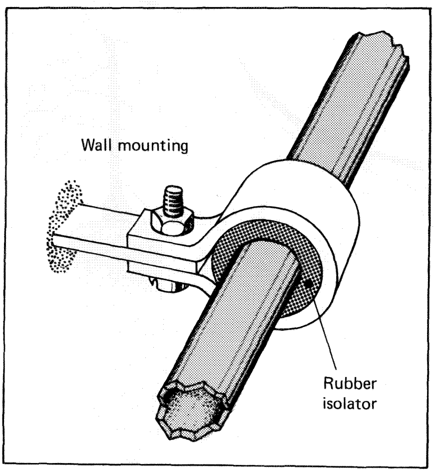
Structure-borne sound in a pipe, perhaps vibration from the circulation pump or noise from the fluid itself, has little opportunity to develop airborne sound as it is of small area. Fixing the pipe to a wall or panel gives the vibration a chance to excite a large area and therefore generate a high airborne sound level.

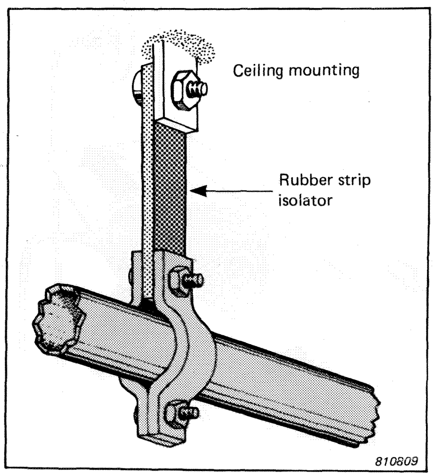
Solution

The pipework must be properly mounted and isolated from the wall or panels so that they are not set into vibration. This may be done using one of a number of different types of isolator employing springs, rubber strips, foam rubber washers, etc.







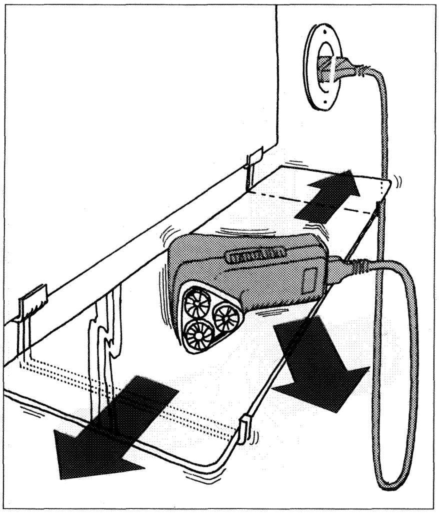


Small vibrating objects radiate less noise than large

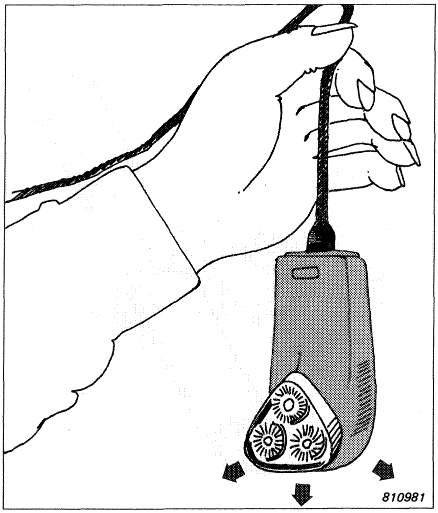
A small object may vibrate without giving rise to high noise levels because the surface cannot transfer the vibration energy into sound energy efficiently. Connecting a large panel to the object increases its ability to convert vibration to sound. As most machines produce some vibration, the size of the machine and its panels should be kept as small as possible.

Principle

The shaver's vibration is transmitted to the glass shelf which vibrates over a large area, amplifying the noise substantially.



The vibration is no longer transmitted and the noise is reduced.

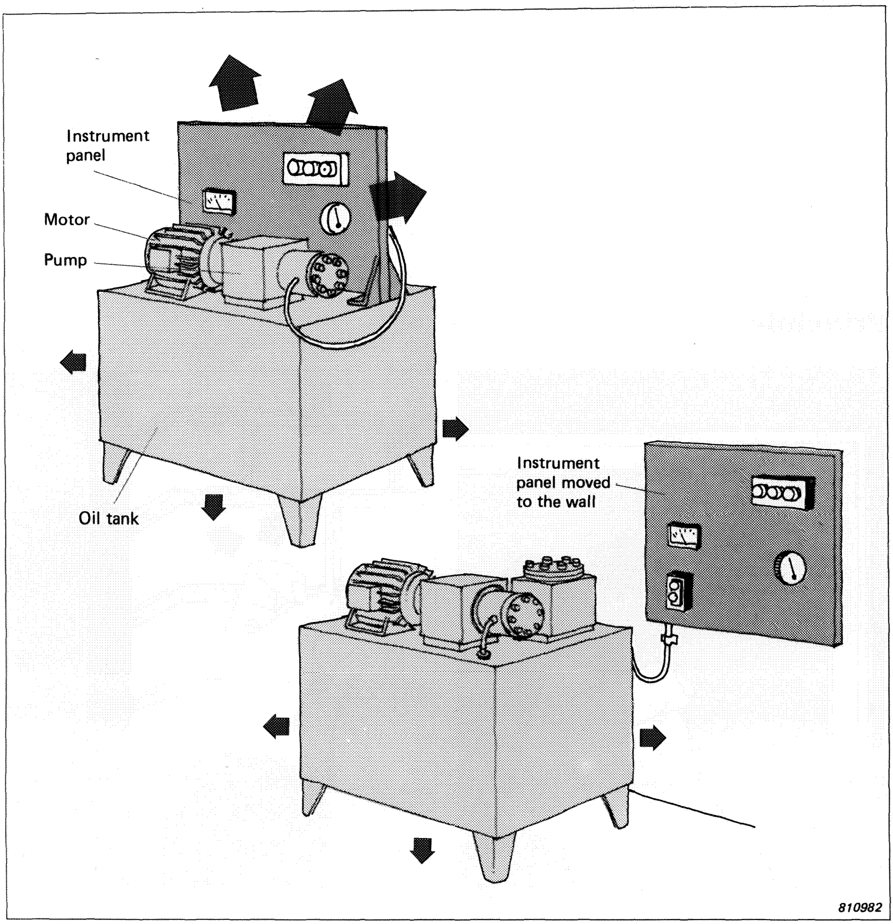


Example

A hydraulic supply system was a significant sound source even though the panels of the oil tank were damped by the oil inside. The chief source of noise was found to be the instrument panel which was set into vibration by the motor.

Solution

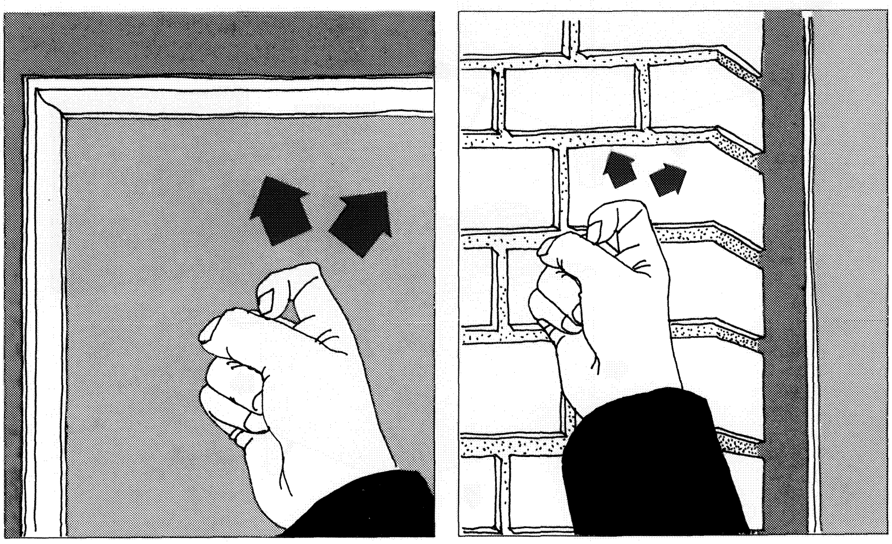
Removal of the panel from the machine uncoupled the source of sound from the source of vibration and reduced the sound level.



Vibrating machinery or parts of machinery should be mounted on a heavy foundation wherever possible

Tapping on a light partition generates noise because the partition is easily moved by the force of the tap and therefore transmits the sound. Tapping on a heavy masonary wall produces little noise because the force available is so small it cannot have much effect on the wall. To avoid noise transmission from motors, pumps, etc., they should not be mounted on the relatively flexible equipment which they serve but separately on heavy bases where possible.

Principle



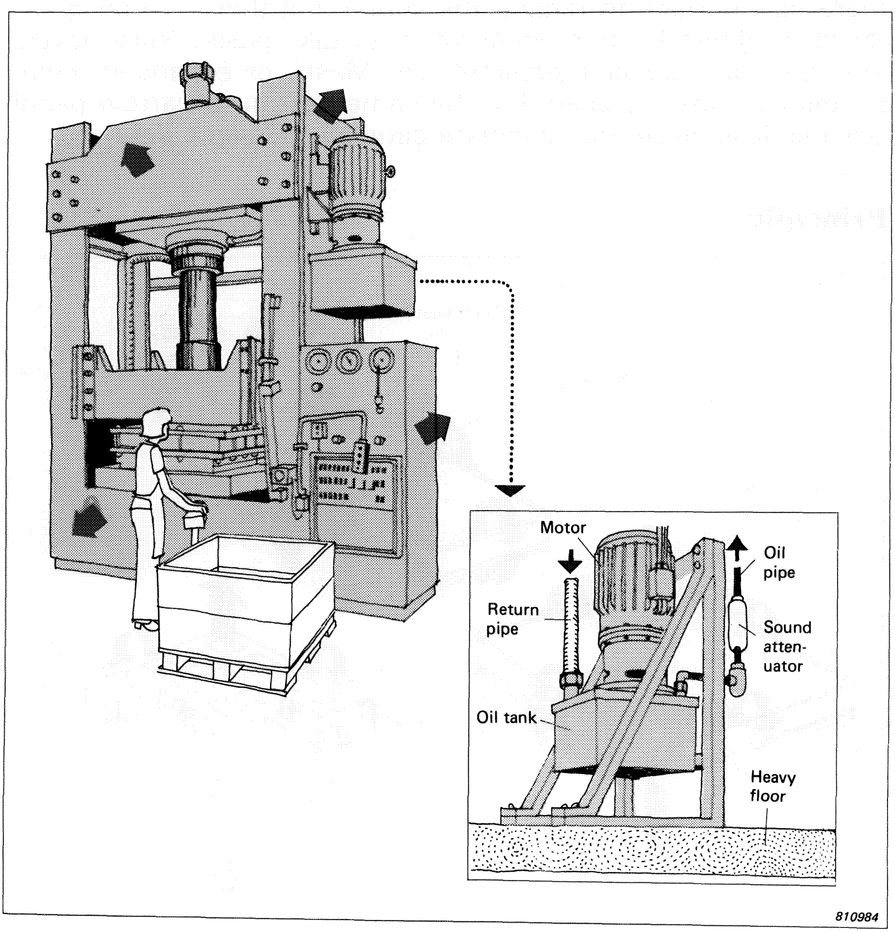
810983

Example

Pumps and motors serving large pieces of equipment such as hydraulic presses, machine tools, and turbines are often mounted directly on structural panels. These are set into vibration, radiating high noise levels from the entire area of the machine.

Solution

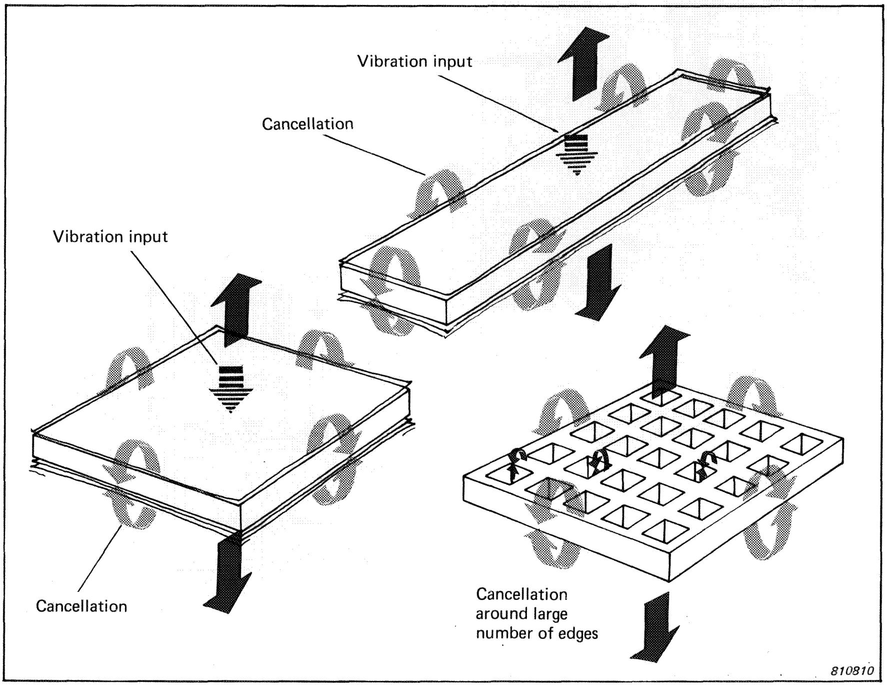
The services should be mounted, on isolators, away from the main frame of the equipment, on a solid floor whereever possible. Pipework carrying fluids should be connected via flexible piping and include attenuators to avoid the transfer of vibration via these connections back to the main structure of the equipment.



Free edges on panels allow pressure equalization around them and reduce radiated noise levels

It is not always possible to avoid the use of large vibrating panels which give rise to high noise levels. In many cases these may be replaced by a perforated panel or another type with a broken surface. A plain panel radiates noise from all its area efficiently as there are only four sides along which the sound pressure can be partially cancelled out by the negative pressure from the other face. If the panel is perforated, not only is there less surface to radiate the sound, but there are far greater possibilities for this equalization to take place. Noise levels are therefore reduced substantially. Mesh, or expanded metal panels can also be used. For the same reason, a narrow panel radiates less noise than a square panel of the same area.

Principle

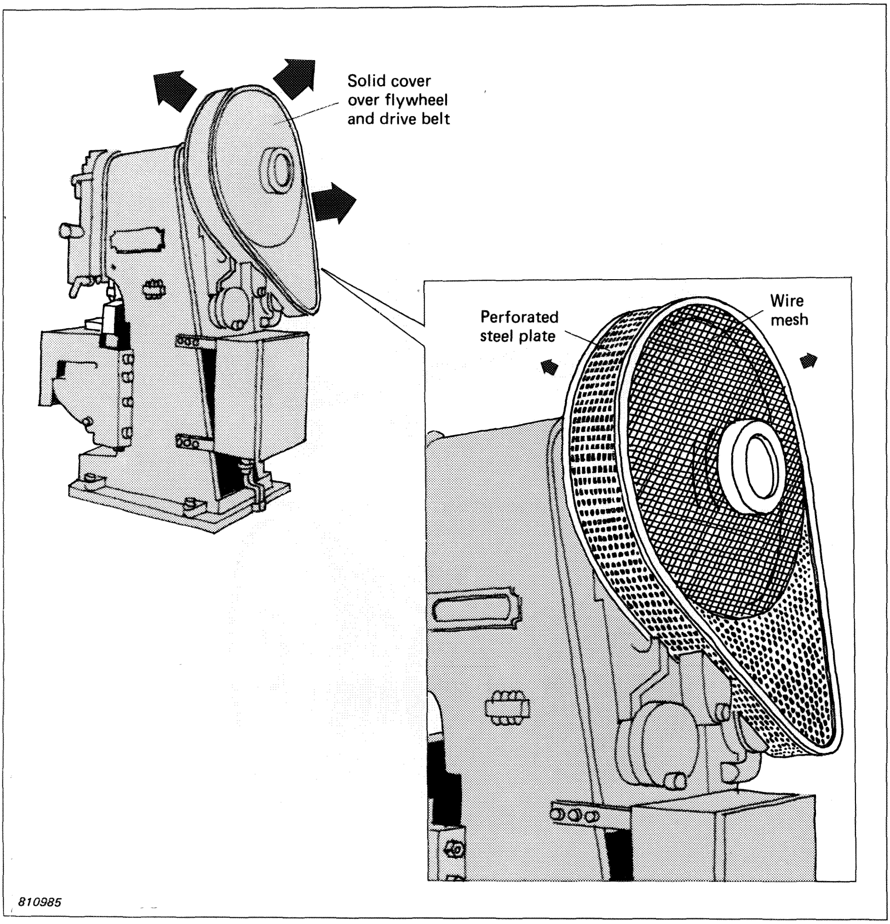


Example

The protective cover over the fly-wheel and belt drive of a punch press radiates noise efficiently.

Solution

A replacement cover of wire mesh reduces the noise radiation.

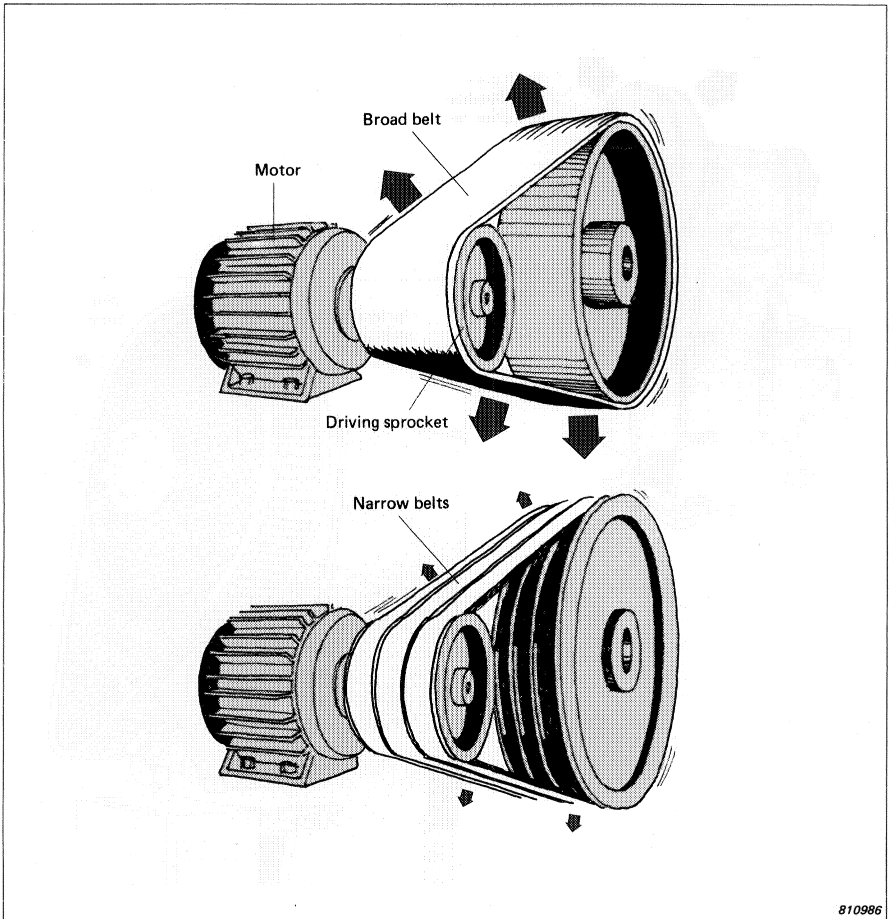


Example

Vibration of wide drive belts on industrial drives can lead to high levels of low frequency noise.

Solution

Replacing the single drive belt with a number of narrower drive belts with gaps between them increases the amount of cancellation which is possible between the top and bottom of each belt and between one belt and the next one. The noise level is therefore reduced.

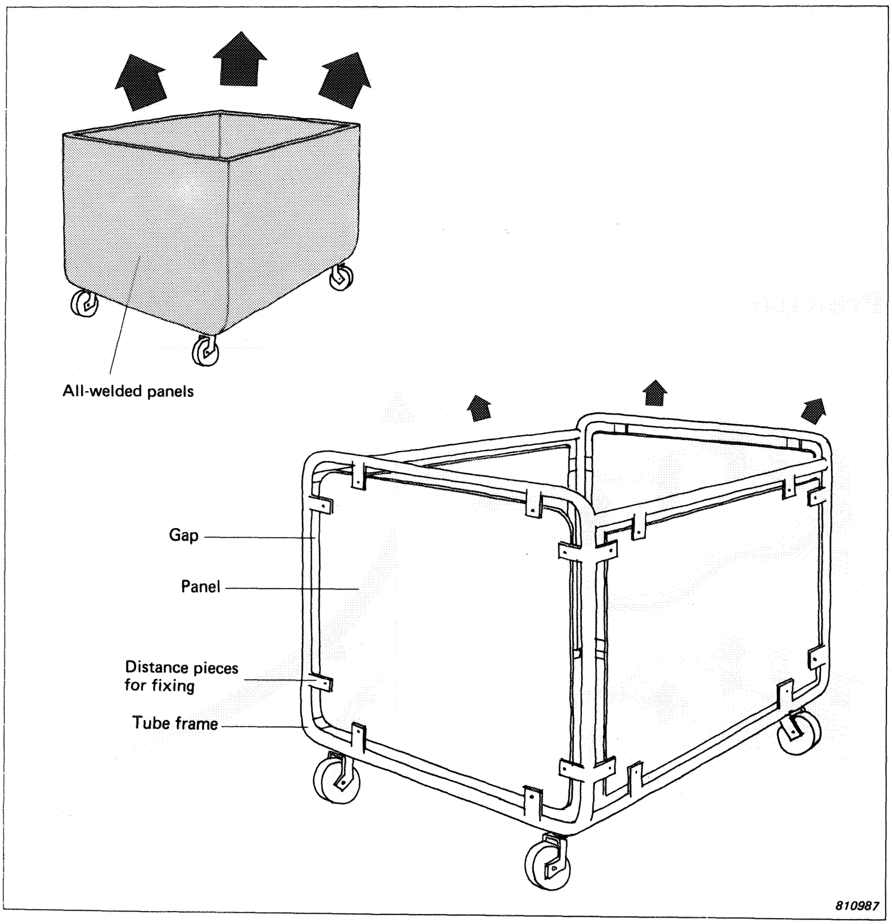


Example

Bins for the transport of material radiate noise when being loaded and emptied and when being transported over uneven surfaces. With this type of construction, pressure equalization can only occur around the upper edges.

Solution

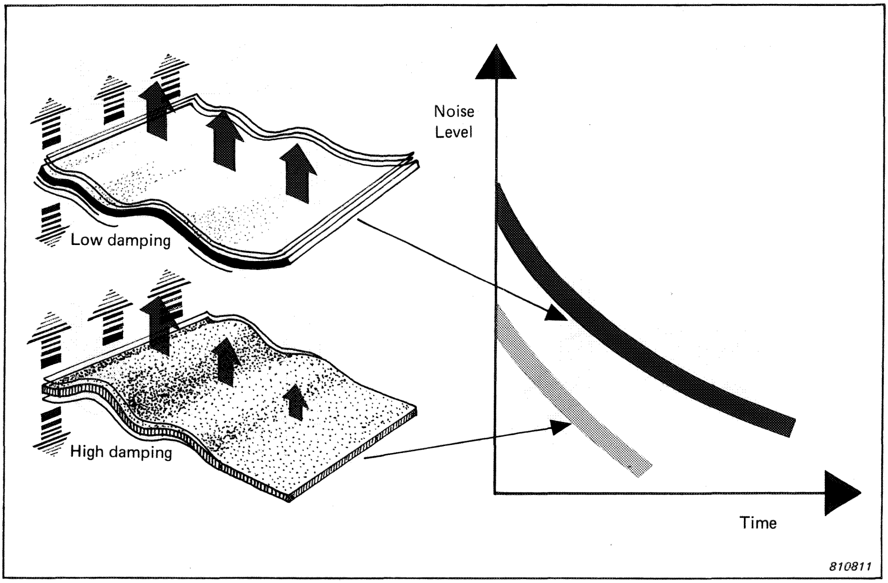
The side panels can be fixed to edge frames with narrow brackets so that there is a much greater length of free edge around which pressure equalization can take place. If the size of the material or components allows, the side panels may be made of wire mesh to reduce radiation further.



Damped structures give rise to less noise

If a panel is set into vibration, the level of vibration, and therefore the noise level will dimminish with time. The speed of this reduction depends on the material's internal damping. The higher the damping the quicker the drop in level. The damping also has an effect on the maximum level that can be generated from a given excitation; a well damped panel cannot be excited as much, as the resonances are reduced. Unfortunately most common metals have very low internal damping and a damping layer must usually be introduced in the form of a ready made laminate or as a spray or stick-on layer.

Principle

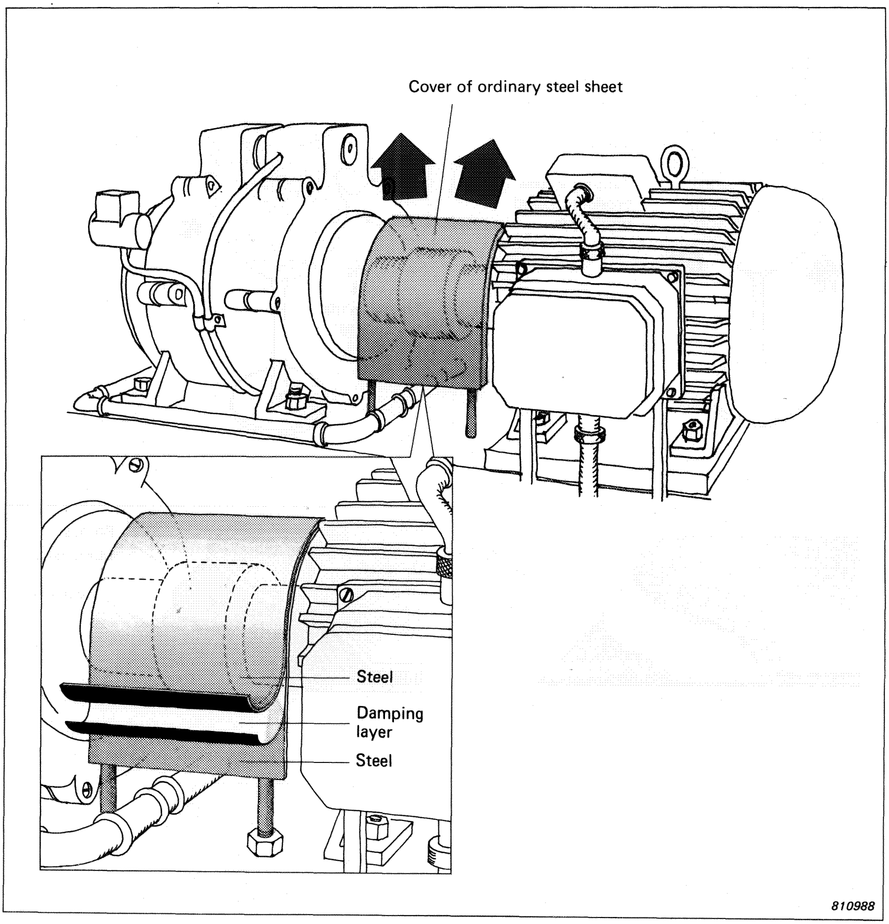


Example

Panels on machinery containing motors or pumps are prone to vibration and are therefore a normal source of radiated noise.

Solution

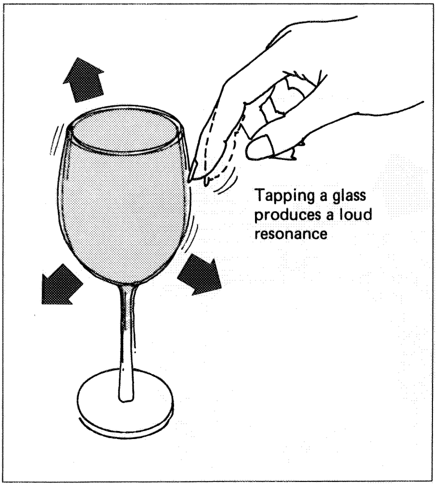
By using a laminated panel with high damping properties the noise can be reduced signficantly.

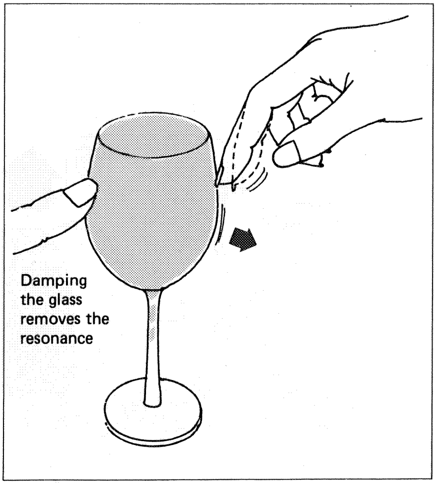


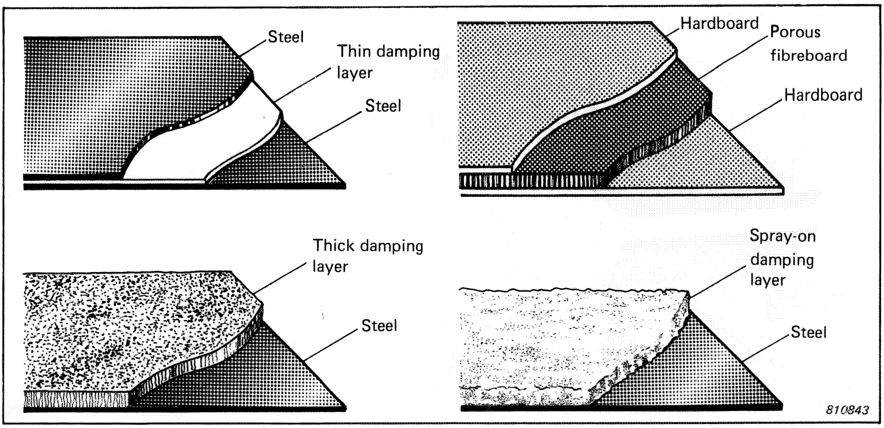
Resonances amplify noise radiation but can be damped easily

Resonances strongly amplify the noise emitted by vibrating panel and plates, especially in homogenous structures. However, relatively small additions of extra damping can reduce the resonance peaks, and therefore the noise radiated, enormously. Pieces of damping material, fixed to a work piece temporarily, are also very effective.

Principle





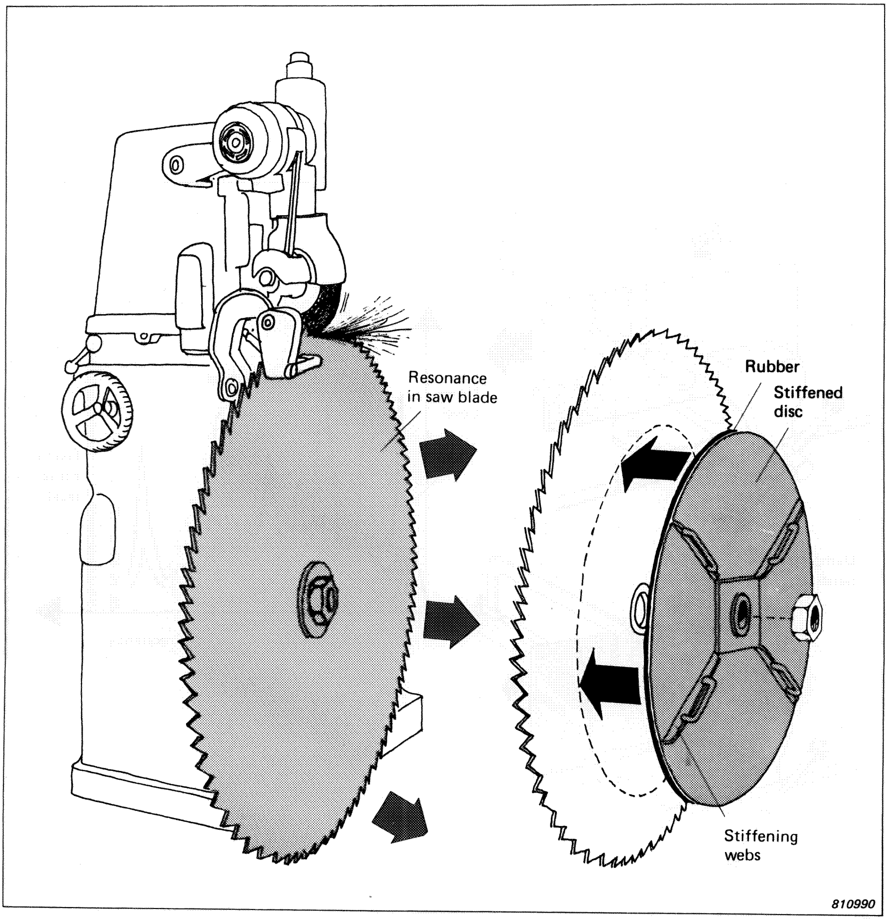


Example

A circular saw blade in a sharpening machine generates a high level of noise because of resonance and very low internal damping.

Solution

A disc of rubber damping material fastened to the blade by a stiff disc during sharpening, adds both mass and damping to the blade and reduces the amplification of the resonances.

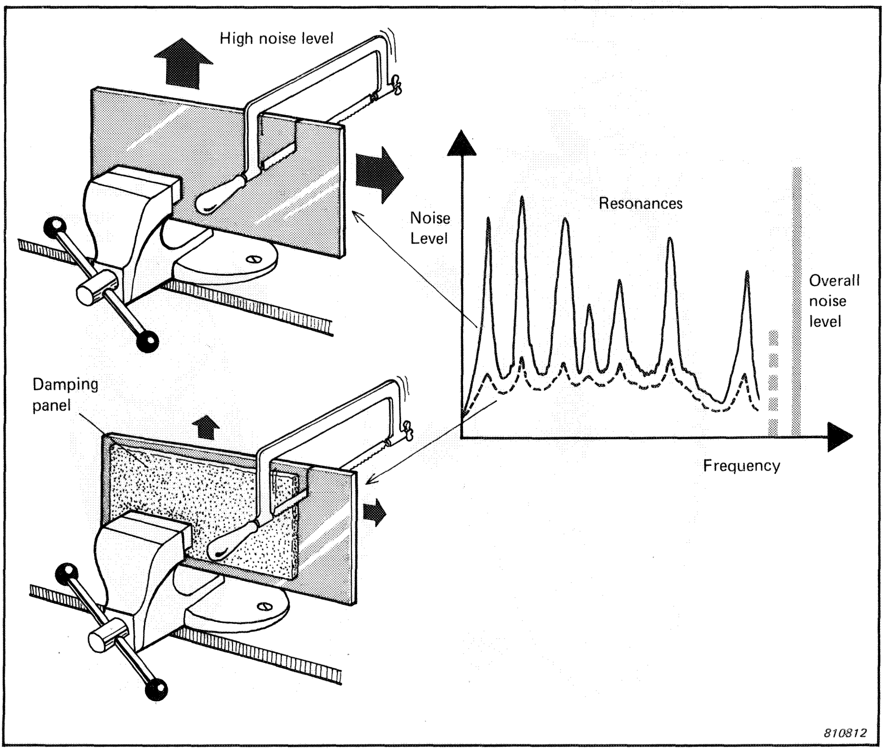


Example

During sawing operations on steel plate the sawing motion induces strong resonances in the work piece whose large area radiates a high level of screeching unpleasant noise.

Solution

Temporary addition of a magnetically held damping panel reduces the intensity of the resonances and reduces the noise to an acceptable level.

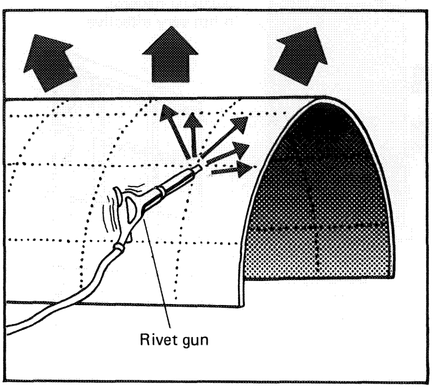


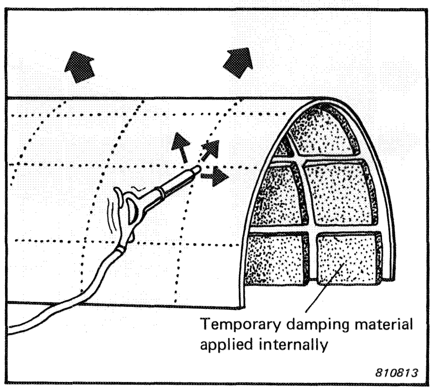
Example

The process of rivetting large structures such as aircraft, ship, or process plant components leads to high noise levels because of the impact caused and the large size of the component which efficiently converts the vibration energy into noise.

Solution

The application of temporary damping pads to the structure as it is rivetted reduces the intensity of the resonances and attenuates the vibration as it travels from the rivetting site to the rest of the panel.

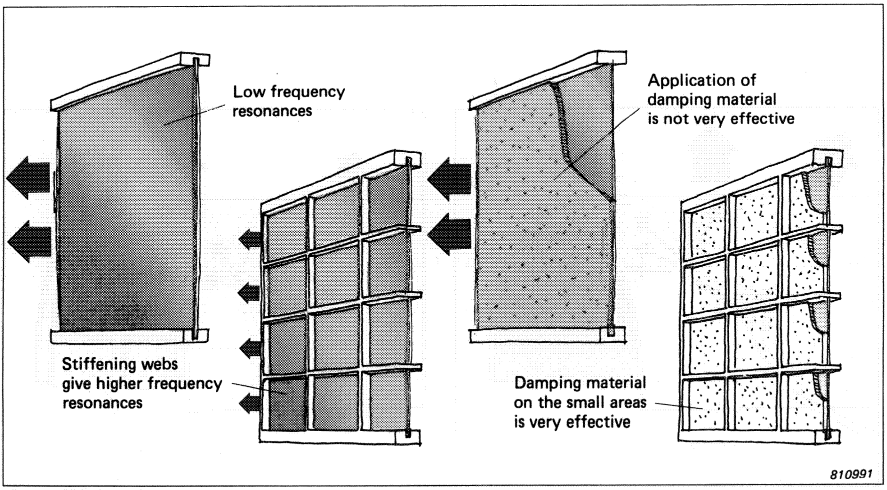




Resonances transferred to a higher frequency are easier to damp

Large vibrating plates and shells often have low frequency resonances which are difficult to damp out. If the plate or shell can be stiffened, the resonance is shifted to a higher frequency which is easier to damp. In some cases it may still be difficult or expensive to apply the damping material to the separate areas, and therefore advantageous to mount a thin damped panel over the stiffening webs.

Principle

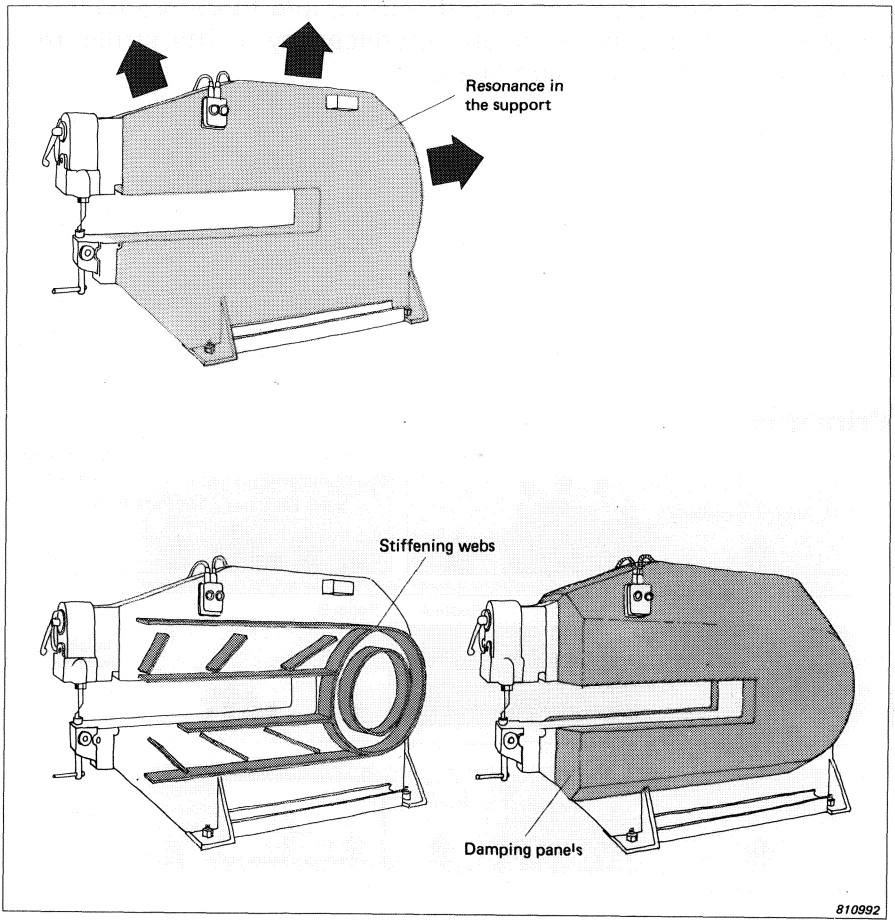


Example

The chief source of noise from a shearing machine proved to be radiation from the support and not from the workpiece as expected.

Solution

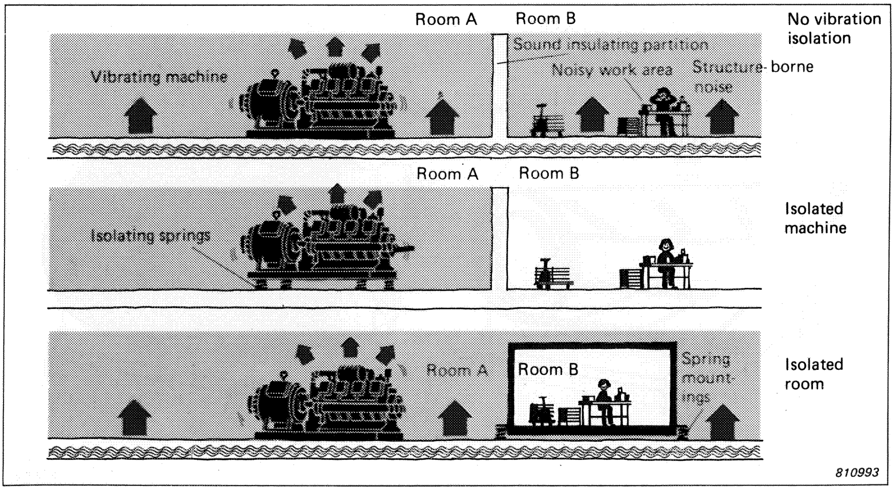
Stiffening webs were fitted to the support panels, and damped panels mounted on them.



Flexible mountings isolate machine vibration

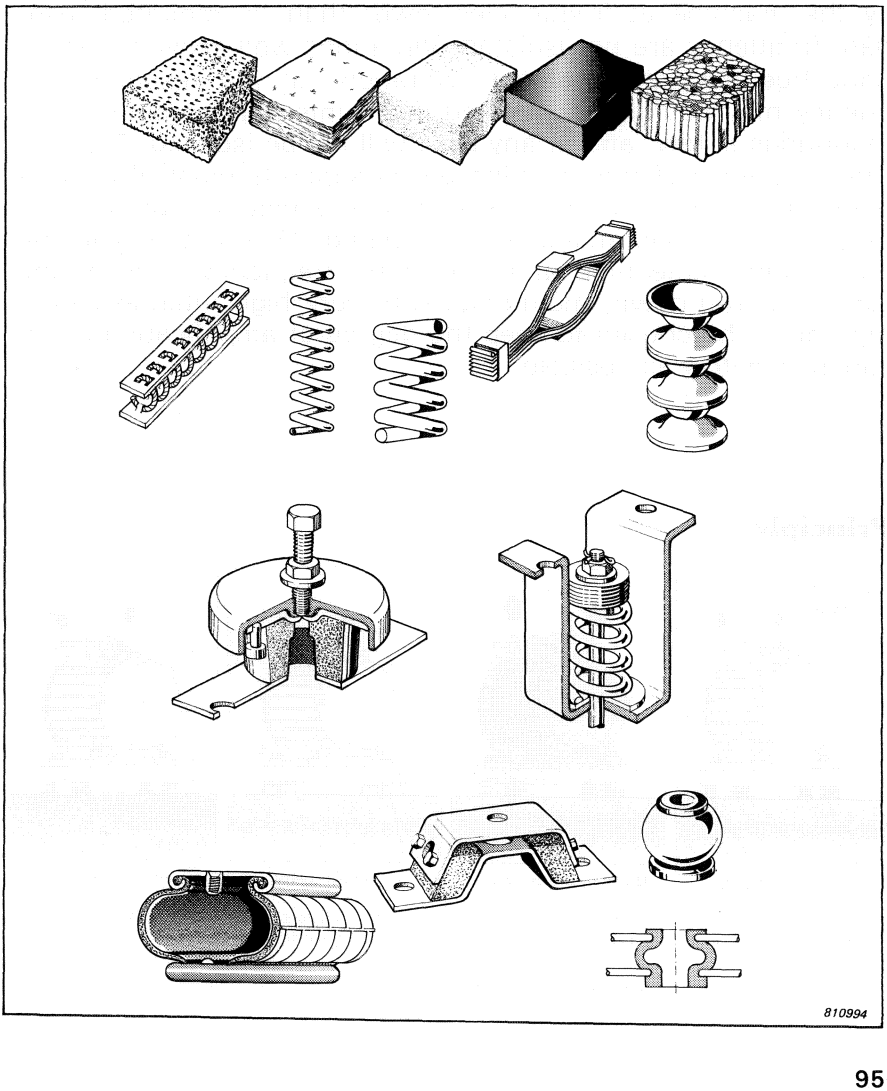
Nearly all structure-borne noise can be eliminated or at least significantly reduced by mounting vibration sources on flexible supports. In some cases it may be necessary to mount the receiver room on flexible mountings as well, e. g. where sensitive apparatus is used or for low level acoustic measurements. Normally it is preferable to isolate the source, or at least as near to the source as practically possible. In this way every region of the building is protected from structure-borne noise caused by the source. In many cases, especially in locations which are remote from the sound source, and therefore well insulated from the airborne sound produced by it, the structure-borne noise is the most significant.

Principle



Example

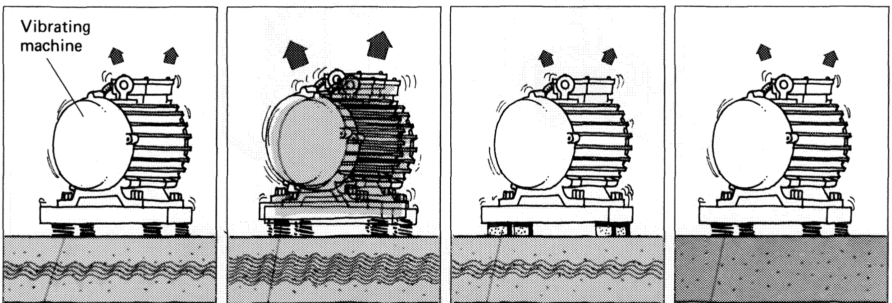
Flexible mounts for vibration isolation can be obtained in a wide variety of types and materials to cope with any load requirement and any practical situation. For mounting heavy machinery, individual springs are used, with or without additional damping; for mounting light structures, pads of cork, expanded polystyrene, foam rubber, or rubber are often employed. Ceilings, ducts, and pipework are normally suspended from spring hangers or artificial rubber straps. Other isolators for special purposes and some individual types are shown in the drawing.



Incorrectly chosen mountings can amplify vibrations

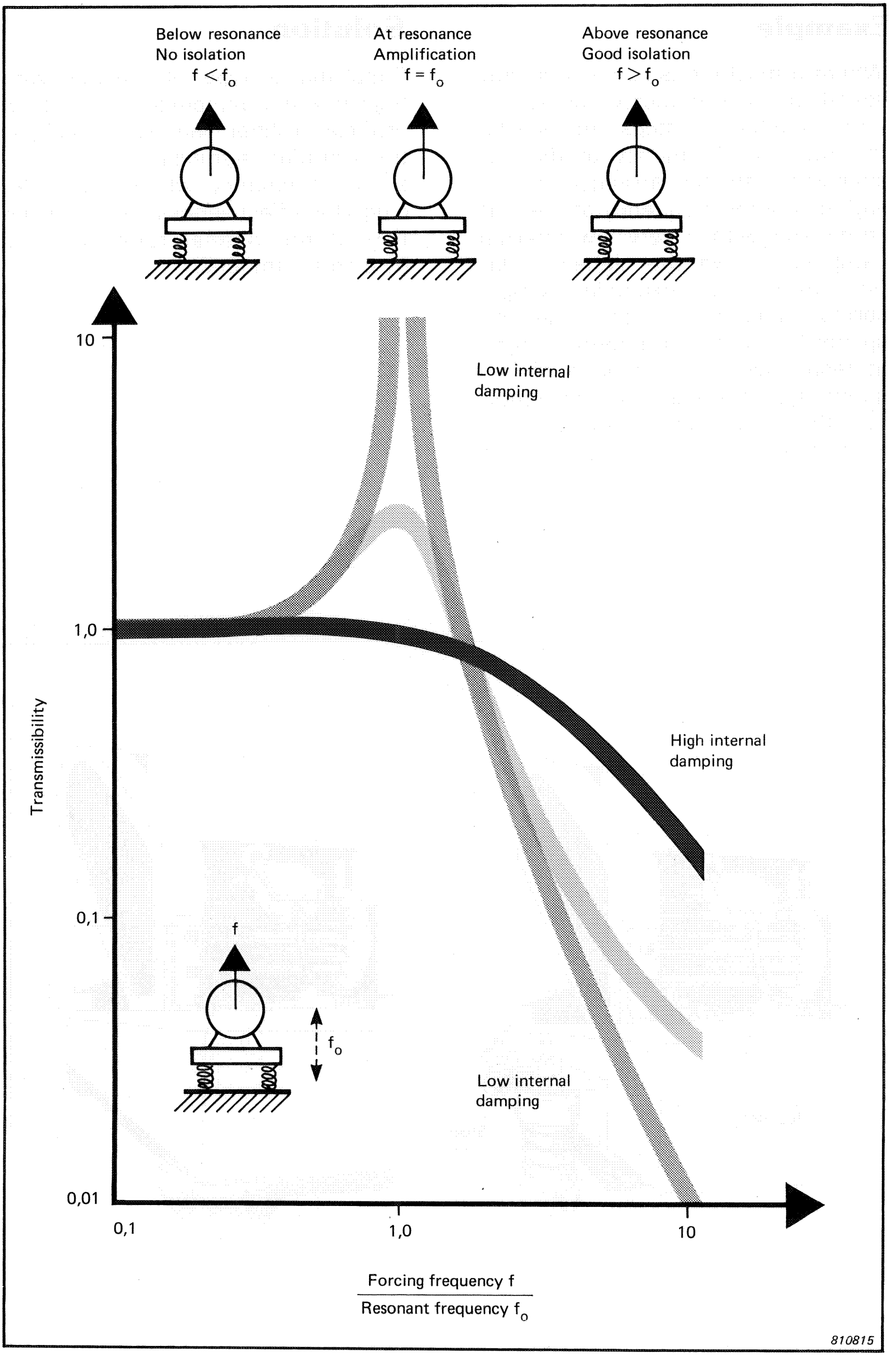
A flexibly mounted machine always has a characteristic resonant frequency on its mountings. This resonance is determined by the weight of the machine and the stiffness of the mountings. A light machine and stiff mountings give a high resonance frequency; a heavy machine and low stiffness of the mountings give a low resonant frequency. Vibration produced by the machine at frequencies lower than its mounted resonant frequency are not isolated. Vibrations well above the resonant frequency are isolated. Vibrations at the resonant frequency may be highly amplified if the internal damping of the mountings is low, and in any case will not be isolated. The natural frequency of the machine on its supports must always be below the normal running speed of the machine or the frequency of the vibrations to be isolated. Where the machine may spend some time at its resonant frequency, e.g. during run-up or run-down, mountings with very high internal damping should be chosen to keep the degree of amplification at resonance as low as possible.

Principle



No internal damping	No internal damping	High internal damping	No internal damping
Vibration frequency lower than resonance	Vibration frequency equal to resonance	Vibration frequency equal to resonance	Vibration frequency higher than resonance
No isolation	Dangerous amplification of vibrations	No isolation	Good Isolation

810995

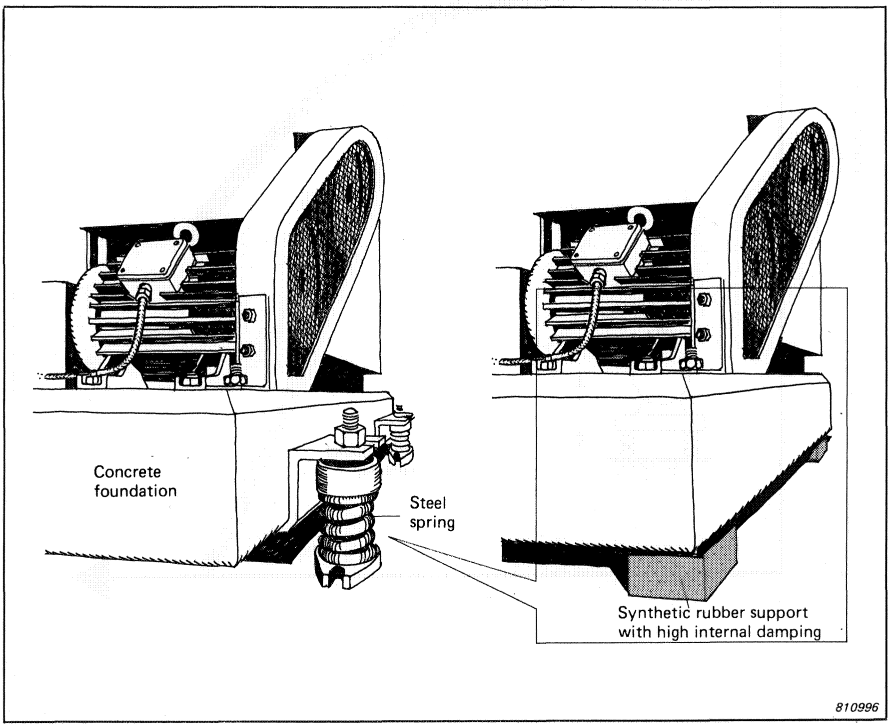

Below resonance
No isolation
f < fo
At resonance
Amplification
f = fo
Above resonance
Good isolation
f > fo
10
1,0
0,1
0,01
Transmissibility
Low internal damping
High internal damping
Low internal damping
f
fo
0,1
1,0
10
Forcing frequency f
Resonant frequency fo
810815

Example

Where a machine is run at a steady speed and continuously, without a large number of stops and starts, the resonant frequency of the suspension can be arranged to be well below the frequency of the machine and with a very low internal damping to give the highest isolation using, for example, simple spring isolators. If the machine spends a significant amount of time at resonance, e. g. because of frequent stops and starts of a compressor, this may lead to damage after a short time.

Solution

Supplying a type of isolator with high internal damping, e.g . pads of artificial rubber laminate, reduces the vibration significantly at the resonant frequency while only reducing the effectiveness of the isolation at the normal running speed by a small amount.

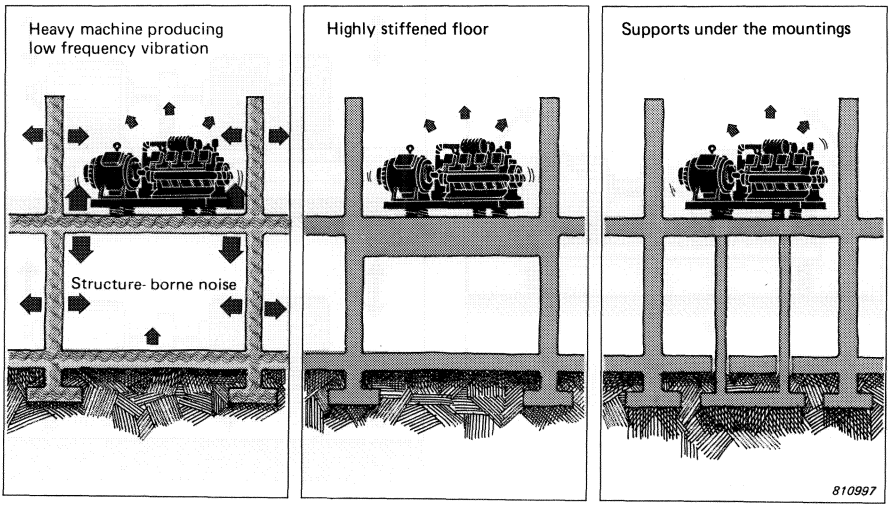


Example

A heavy machine producing low frequency vibration may cause the floor itself to resonate even though isolators of the correct rating are used. This problem is particularly common in concrete buildings, whose floors have low internal damping.

Solution

For the best isolation the natural frequency of the machine on its isolators should not only be well below the exciting frequencies from the machine, but should also be lower than the resonances of the floor. In practice, this may be achieved by reinforcing the floor structure to provide a more stiffer solid base. Alternatively, the machine may be mounted on pillars founded directly in the ground.

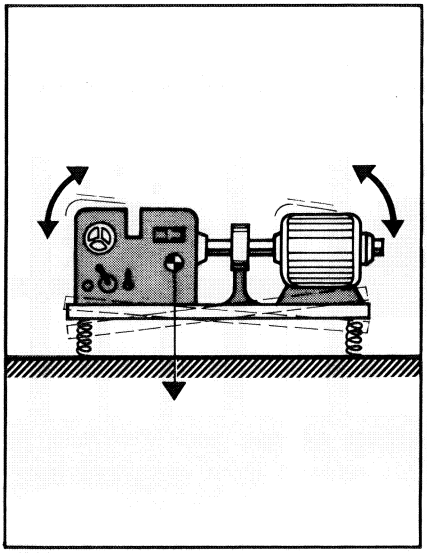


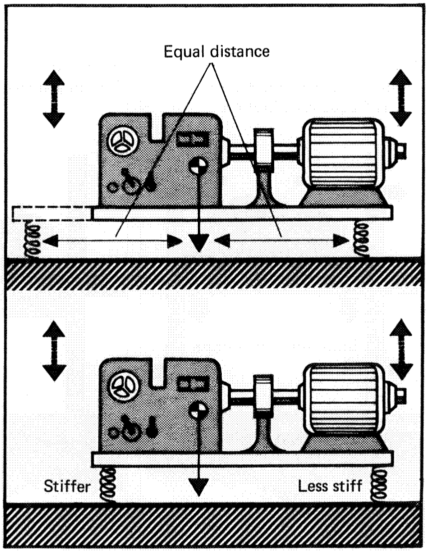
Displacement of all mountings must be equal to avoid rocking motions

Flexible mountings for a machine should be chosen so that the static deflection at each mount is the same. If they are different, rocking motions may be forced at higher frequencies than the up-and-down motion of the machine, which are not effectively isolated by the mountings. On a machine with non-uniform weight distribution, mountings nearer the centre of gravity must be stiffer than those more remote from it.

The most efficient isolation is obtained if the mountings are fixed so that lines joining their points of application on the machine pass through the centre of gravity.

Principle





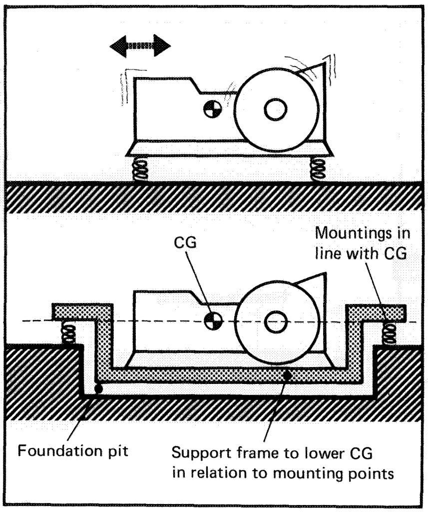
810816

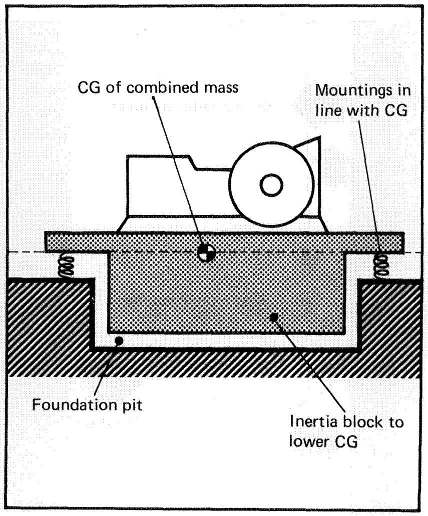
Example

If the centre of gravity of a vibrating machine is above the line of action of the horizontal forces from the mounting, there is the danger of setting up a rocking motion from this source. This is particularly a problem when dealing with out of balance forces on rotating machines where the sideways component is large.

Solution

Mounting the machine in a tray or on an inertia block enables the mounting points to be placed in the same horizontal plane as the centre of gravity.



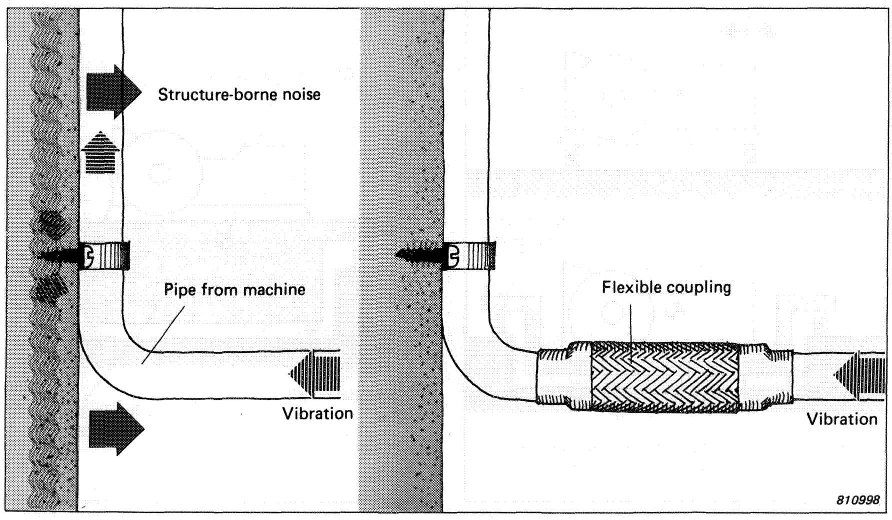


810817

Structure-borne sound via connections must be avoided

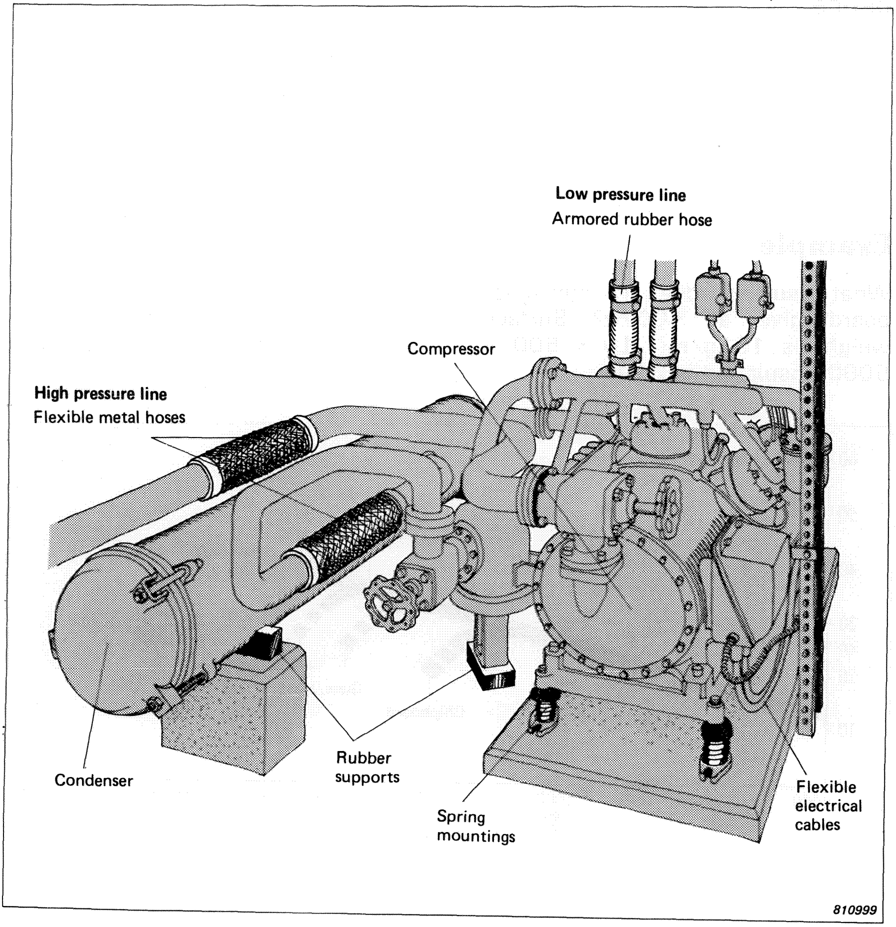
The most effective vibration isolation can be made totally ineffective if the vibration is transmitted by connections such as pipes, electrical conduits, supply ducts, etc. These must be flexible or contain flexible sections if vibration transmission is to be avoided.

Principle



Example

Refrigeration plant can be a serious noise source because of the large pressure changes in the fluid during its passage through the compressor unit. Careful vibration isolation of the entire plant is necessary, and all ingoing and outgoing pipework should be isolated from the plant by flexible couplings.

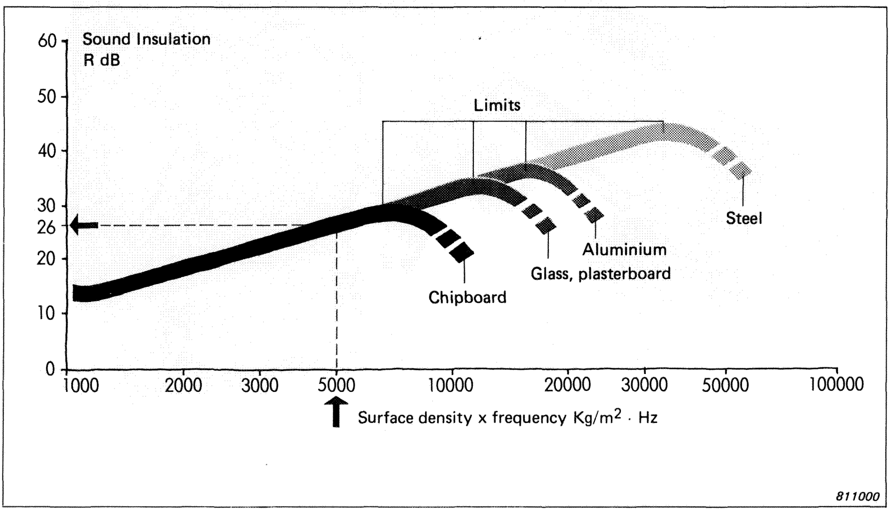


Insulation of single walls and panels depends on the surface density

When sound meets a wall, it sets the wall into vibration and sound is radiated from the other side. How much is radiated is a measure of the insulation of the wall, and is dependent on the surface density of the wall, i.e. its weight per unit area. In general, insulation increases as the frequency of the sound increases or the thickness of the wall increases, until a point is reached where it begins to fall off again because of coincidence.

Example

What insulation does 15 mm chipboard give at 500 Hz? Surface weight is 10 kg/m². 10 × 500 = 5000. Insulation is 26 dB.

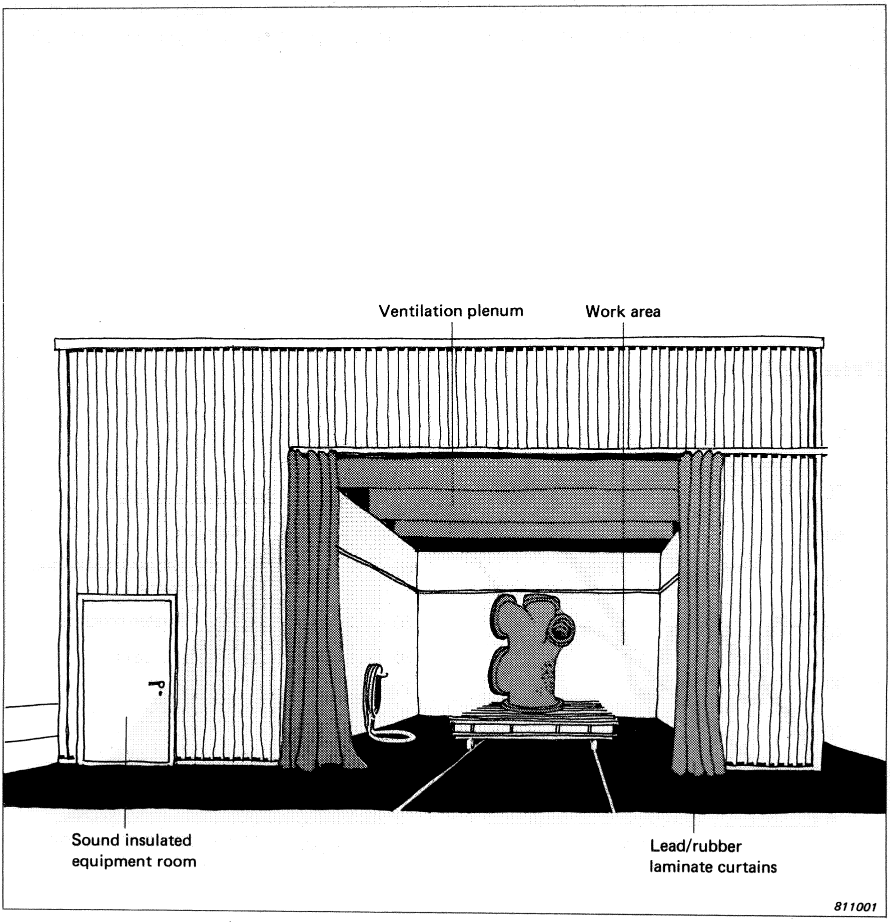


Example

A sand blasting system is the dominant noise source in a workshop, and is only separated from the rest of the area by thin curtains.

Solution

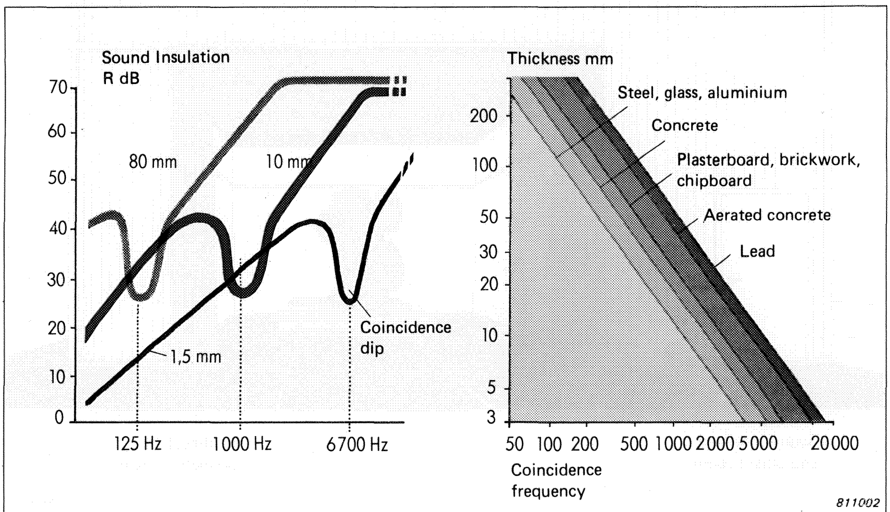
A sound insulated machine room can be built for the sand blasting plant and a partial enclosure erected round the work area. Access to this area is via heavy lead/rubber laminate curtains which have high insulation while being flexible and easy to fold to allow easy access to the work area.



Single walls have a region of poor insulation — Coincidence

A single panel has natural bending modes which are dependent upon the stiffness and thickness of the panel. When the wavelengths of the incident sound and the panel modes are equal, they vibrate in sympathy and the panel's insulation ability is reduced before increasing again as the resonance condition is passed through. The coincidence dip only disappears if the internal damping of the panel is high. As the thickness of a single wall or panel is increased, its stiffness rises relatively faster than its weight and the region of low insulation comes down in frequency. At some frequencies it is possible for a thinner panel to give better insulation than one of greater thickness.

Principle

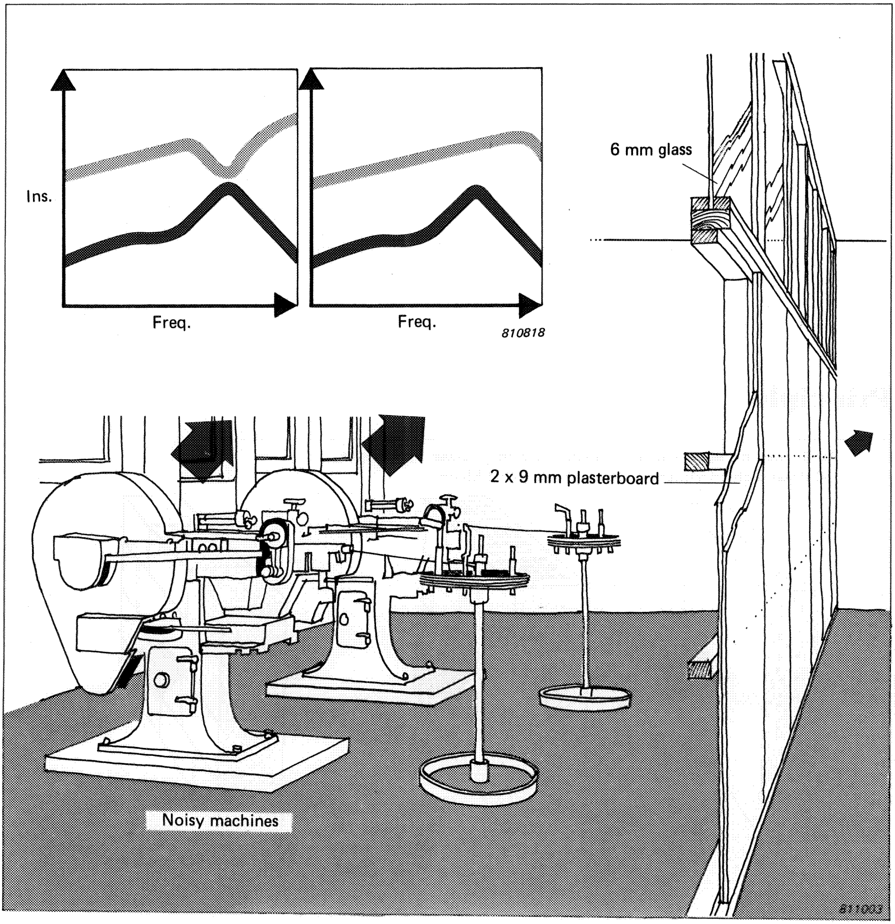


Example

One end of a workshop contained machines with a high noise output at 1000 Hz. The area had been separated from the rest of the workshop by a 25 mm chipboard partition with 6 mm windows. The insulation was not as expected because the partition had a coincidence dip at 1000 Hz, where the noise from the machines was also a maximum. The window's coincidence dip, on the other hand, was up at 2000 Hz.

Solution

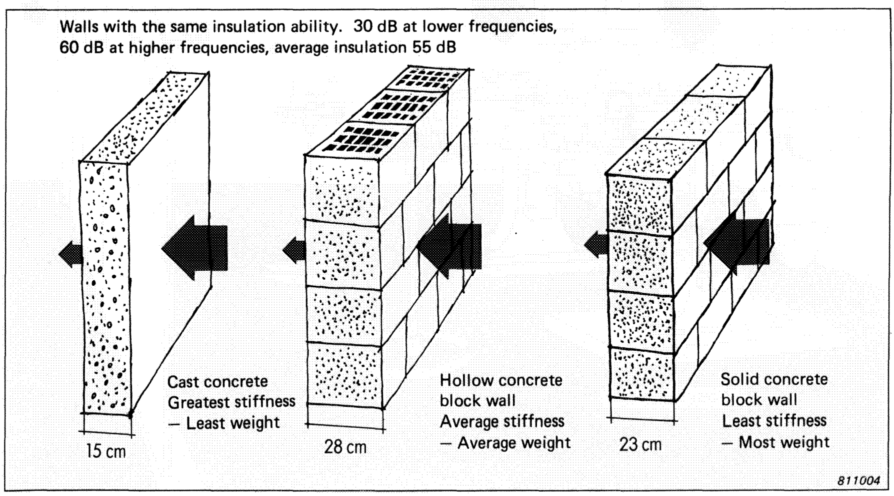
Exchanging the partition with one made of two layers of plasterboard improved the situation by 10 dB. Although the weight was about the same, the new partition's stiffness was only a quarter of the previous one. The coincidence dip was therefore much higher at approximately 2500 Hz.



Stiffness and weight are both beneficial in thick walls

Most practical single walls have coincidence dips around 100 Hz. At frequencies above this, the insulation increases both with increased weight and increased stiffness. A cast concrete wall has a greater stiffness than a block one and may give the same insulation value though be lighter.

Principle

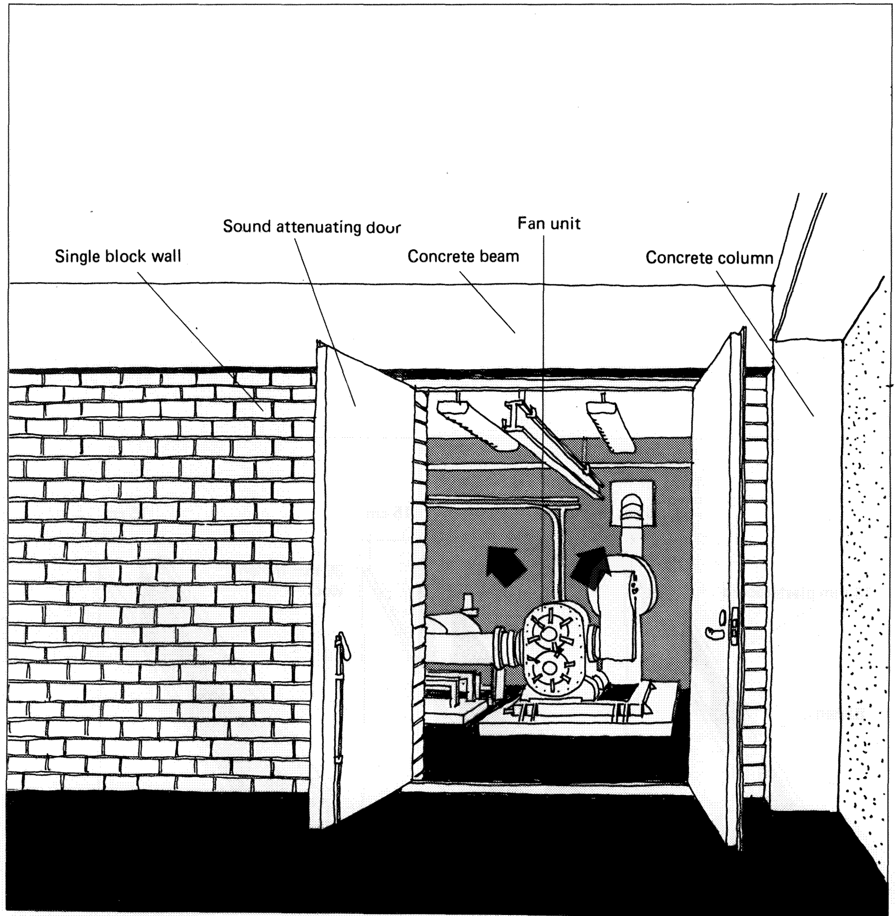


Example

The chief source of noise in an industrial building was found to be a fan unit.

Solution

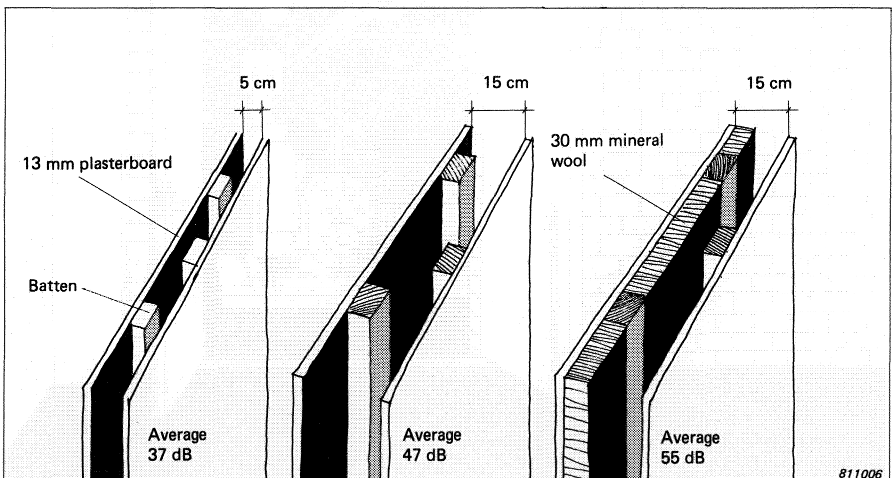
A single block wall was built around the equipment with access via sound attenuating doors. This type of construction was chosen because it had to resist damage from transport trucks and also help to support the heavily loaded floor above.



811005

Lightweight double partitions give good insulation

Two light partitions separated by an air gap give an insulation which increases as the air gap increases. If an absorbent material is placed in the gap, the insulation is further increased. The most insulation is achieved if the two panels are completely disconnected from each other, mounted on separate frameworks. If connection is necessary the highest insulation is achieved if the ties are as small, as few, and as elastic as possible. Insulation can be obtained which would normally require a single partition of 5 or 10 times the weight.

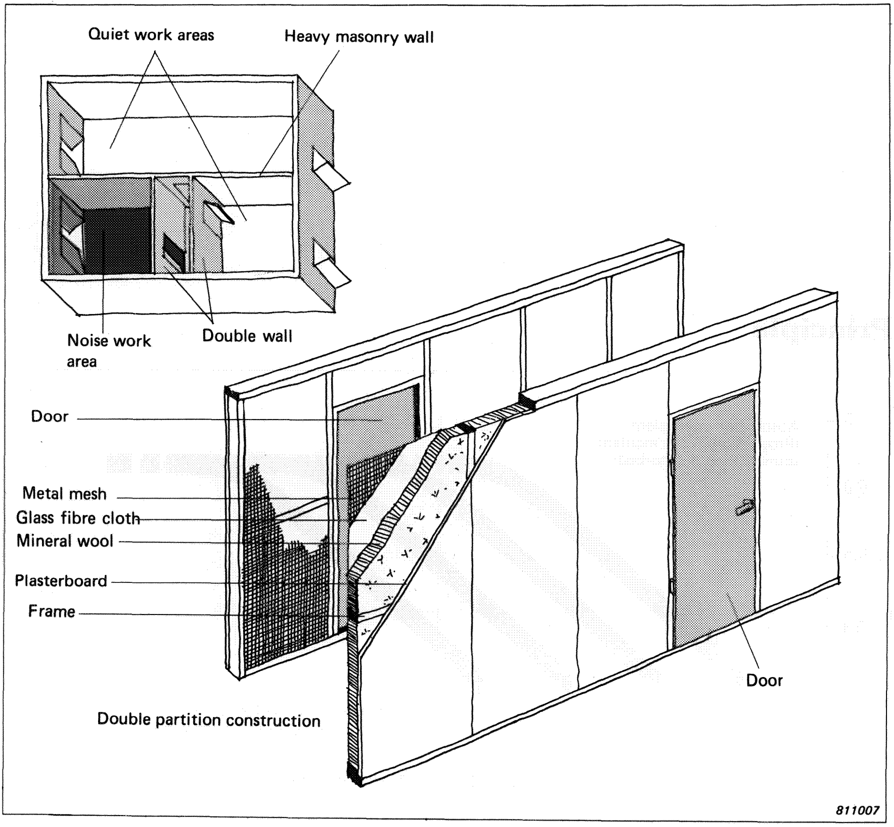


Example

Two connected workshops both contain noisy machinery, which is annoying in both locations.

Solution

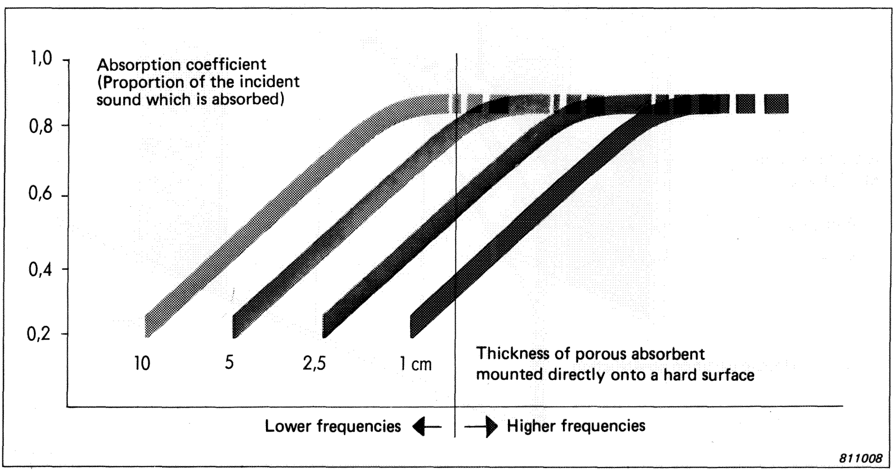
The Noisy equipment should be located together at one end of one of the workshops and a double partition constructed with a large air gap in the form of an air lock, a gap large enough to serve as a corridor to the two quiet rooms. The doors are placed at opposite corners so that even if one of them is open an insulation of at least 35 dB is achieved. When closed over 50 dB can be expected. To achieve the same insulation with a single wall would require heavy masonary or concrete construction and the use of a special sealed sound-proof door.



Thick porous layers are effective absorbers at both high and low frequencies

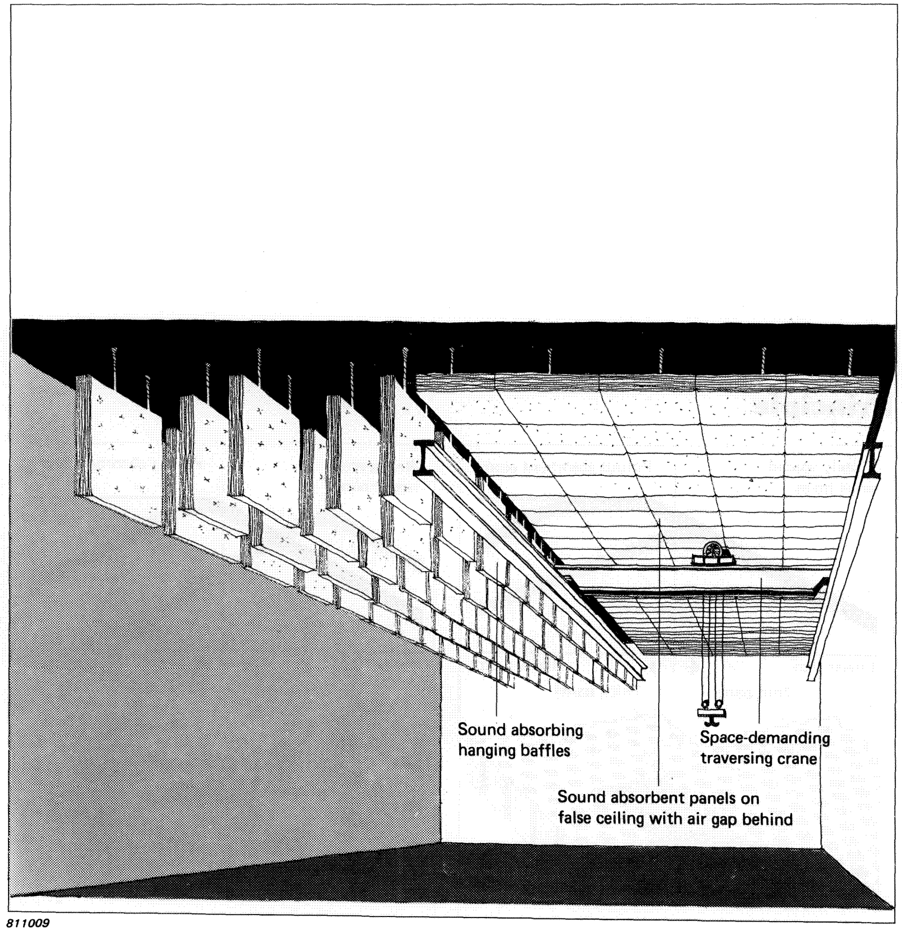
Porous materials through which air can pass are often excellent sound absorbers. Some examples are: Glass fibre, mineral wool, foam rubber, woodwool and sintered metal. If the material has closed cells the absorption is low. Thin layers are only capable of absorbing high frequencies, whereas thick layers can absorb over a wide frequency range including both high and low frequencies. To be effective below about 100 Hz a layer has to be impractically thick or mounted over an air space.

Principle



Example

A workshop with a high noise level, especially at low frequencies, has to be treated to reduce the noise levels over the entire frequency range. Hanging panel absorbers can be used in a large part of the workshop where the ceiling is free of obstructions. These are very efficient, having two absorbing sides to each panel. A traversing crane makes it impossible to use these in the other part of the workshop. Instead, horizontal absorbent panels are mounted well below the ceiling to obtain improved low frequency absorption. Except in regions close to a noise source it is possible to reduce the overall noise level by up to 10 dB.

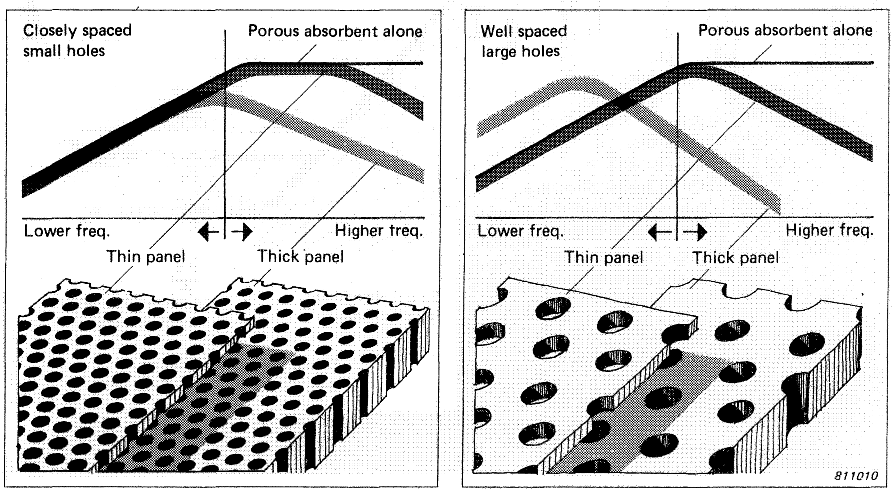


811009

Perforated panels over absorbent need not reduce its effectiveness

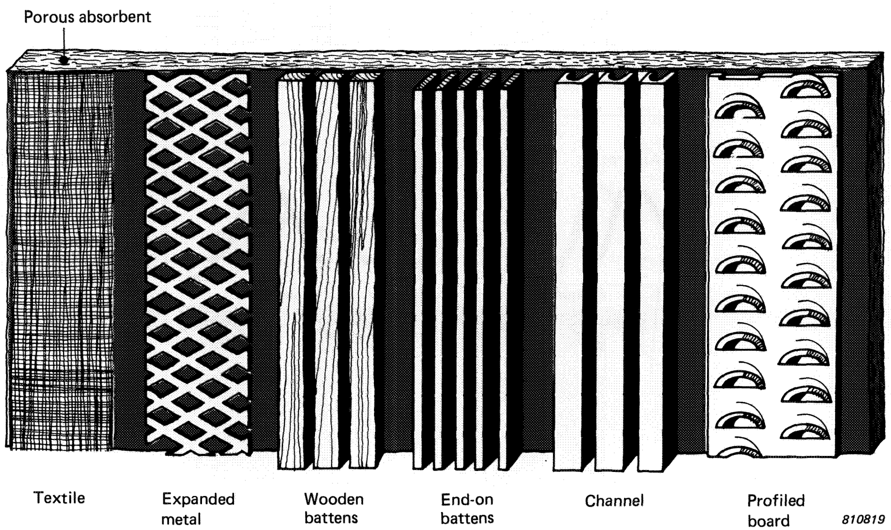
In order to protect the absorbent and improve its appearance it is often covered with a perforated material of some kind. This does not significantly alter the characteristics of the absorbent if the perforations are a sufficient proportion of the total area. A perforation ratio of 15% is sufficient for thin panels. The ratio must be greater, the thicker the panel becomes. In addition, it is generally better to perforate with many small holes than with a smaller number of large holse.

Principle



Example

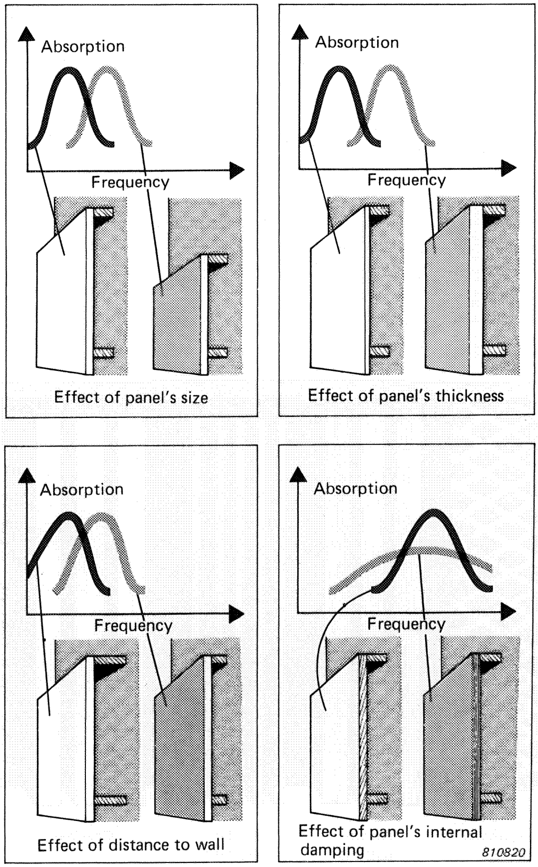
In order to improve the appearance in a building it is possible to choose from a wide variety of materials to cover large areas of absorbent. The only requirement is that the uncovered area is sufficiently large to allow the absorbent material to do its job satisfactorily. Textiles, wood strips, expanded metal, and various types of partially open panel can be used to create the desired appearance.



Panel absorbers are effective at low frequencies

Thin panels mounted on a framework absorb low frequencies well in a fairly narrow range, whose frequency depends on the size and thickness of the panel and its distance from the wall. The effective absorption bandwidth depends on the internal damping of the panel; high internal damping giving a wider frequency range. For a porous absorbent to be as good at low frequencies, it would have to be extremely thick.

Principle

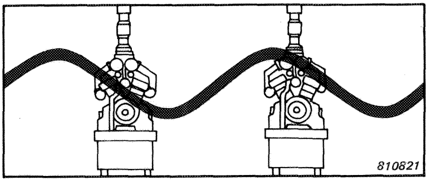


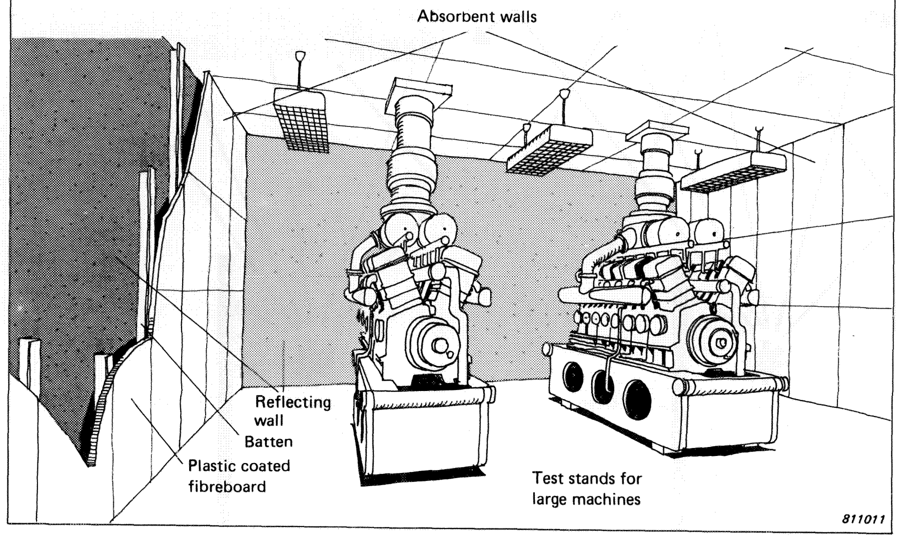
Example

In an engine test room a resonance is excited when the test engine is run at or near its normal speed. At speeds away from the normal running speed the resonance disappears completely.

Solution

The walls may be covered in panels fixed to a wooden frame, the dimensions being chosen so that frequency range includes the unwanted resonance. To make the panel effective at frequencies at either side of the resonance, a panel material with high internal damping should be chosen, e.g. a laminate or fibre board.

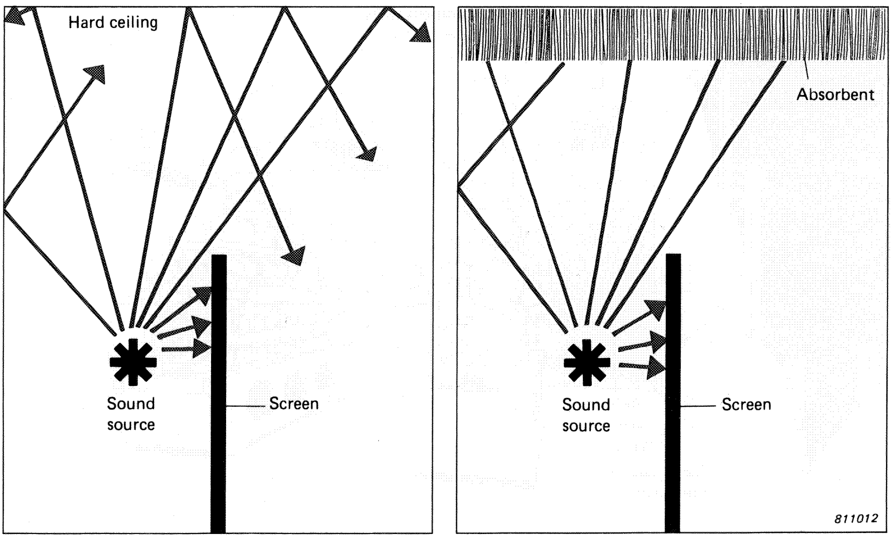




Screens should be combined with absorbent ceilings

Where the noise is dominated by high frequencies, a noise screen can be very effective against it. The screen is more effective the higher it is and the nearer to the source it is placed. However, if the ceiling above the source is non-absorbent, it reflects noise from the source into the "quiet area" on the far side of the screen. An absorbent ceiling prevents this reflection taking place, and improves the performance of the screen.

Principle

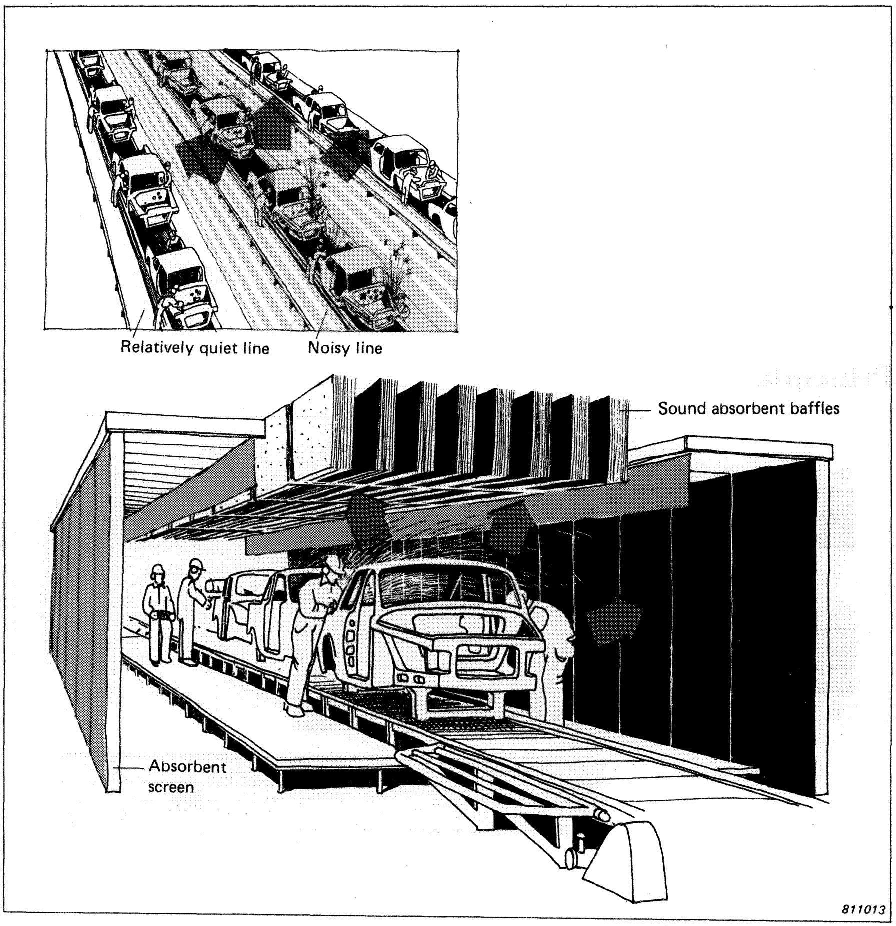


Example

In an assembly hall with a number of production lines running parallel, one of the lines produces much more noise than the others. Noise from body preparation produces high frequency noise which affects everyone in the assembly hall.

Solution

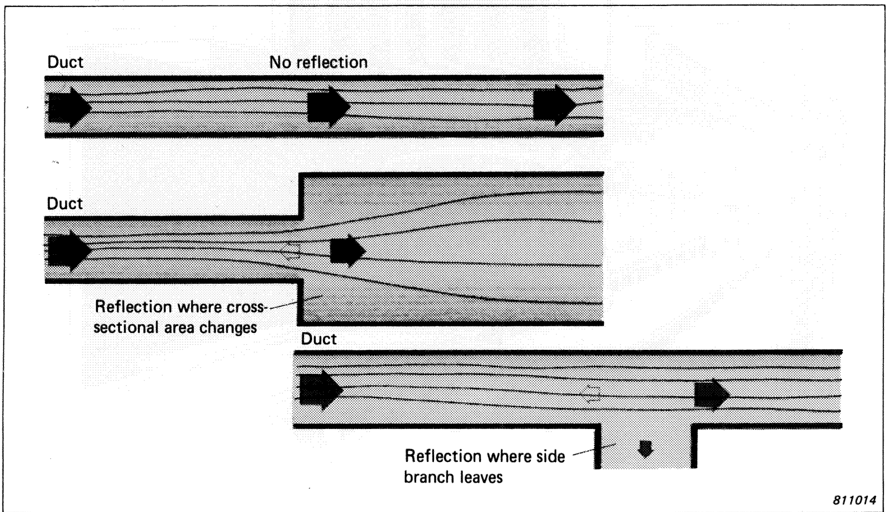
By using lightweight absorbent screens on both sides of the noisy line, and hanging sound absorbing baffles above it, the noise levels are reduced at the quieter lines while not worsening the situation for those actually working on the noisy line. If it had merely been enclosed in a sound attenuating tunnel without sound absorbents, the reverberent sound level would have increased locally.



Changes in ducts reduce noise transmission

At all changes along the transmission path, part of the sound energy is reflected back toward the source. In a duct this change may be the shape or area of the cross-section, bends, branches and wall material. This fact can often be exploited during design of a duct system to achieve a level of attenuation. Attenuation obtained in this way is termed reactive.

Principle

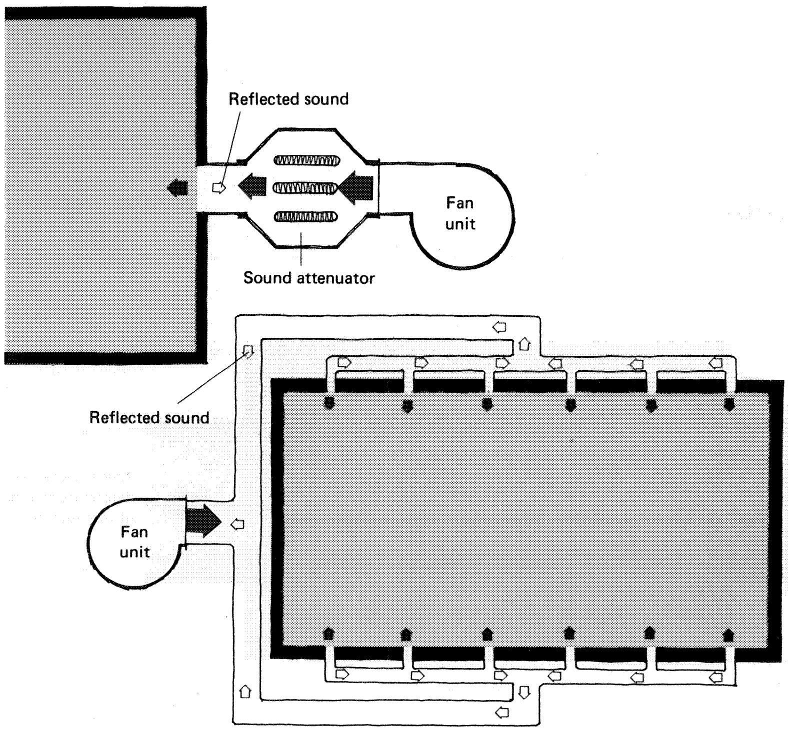


Example

A large landscaped office is to be fitted with a mechanical ventilation system. Space limitations prevent the use of an attenuator on the fan outlet large enough to provide the necessary noise reduction.

Solution

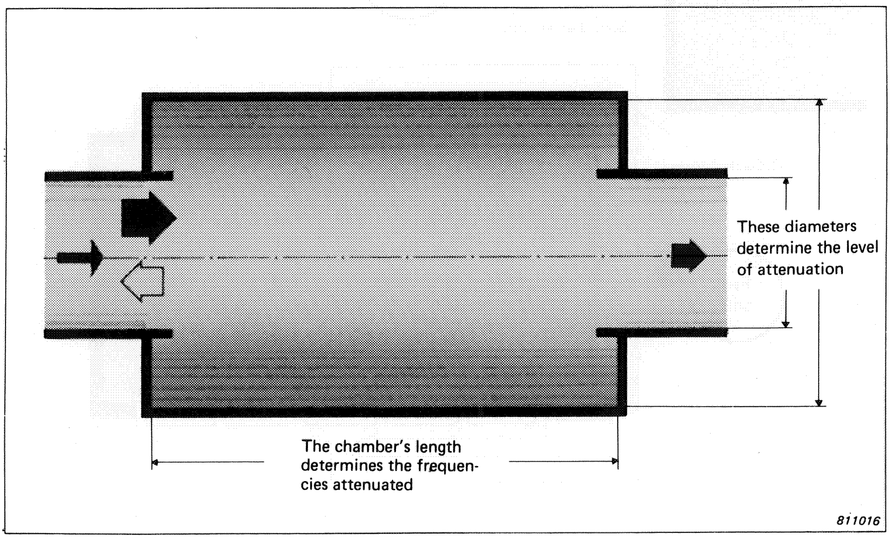
By making use of the sound reduction obtained when the duct contains a number of area changes, direction changes, and distribution branches, it is possible to achieve the required sound level limits at the delivery vents, even though the fan could not be sufficiently silenced at source. Absorbent on the duct walls and smooth bends avoid the generation of more noise and a better distribution of air is achieved around the office.



Reactive attenuators are efficient in a narrow frequency range

A reactive attenuator is an effective method of reducing low frequency noise over a limited frequency range, and is relatively compact. By coupling a number of attenuators of different sizes together, most conveniently within the same external casing, it is possible to cover an extended range of frequencies. Perforated tubes are often used within the attenuator to improve gas flow and provide some absorption.

Principle

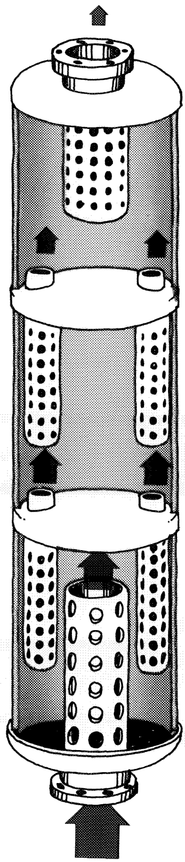


Example

Absorbent (resistive) attenuators are simple to design and produce, and provide noise reduction over a wide frequency range. However, the absorbent material can be easily blocked with residues and carbon deposits which make it less effective after a time, and absorption of combustible materials can cause a fire risk.

Solution

A multi-step reactive attenuator can be used in this case. It attenuates over a wide range of frequencies, is less sensitive to deposits, and rugged. The example shown is for a large piston engine, and is especially suitable where the motor speed only varies over a fairly narrow range.

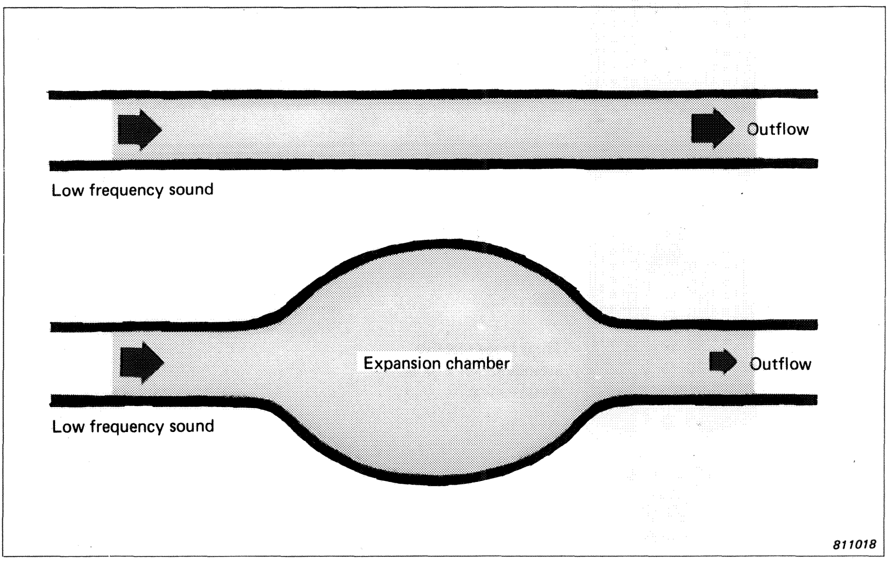


Three stage reactive attenuator for a large diesel engine

Expansion chambers are effective where low frequencies dominate

If a pipe or duct is provided with an enlargement or chamber, then the low frequency fluctuations are evened out. This is very effective where continuous pressure pulses are concerned, e.g. in engine exhausts or compressor outlets. The lower the frequency, the larger the chamber must be to be effective.

Principle

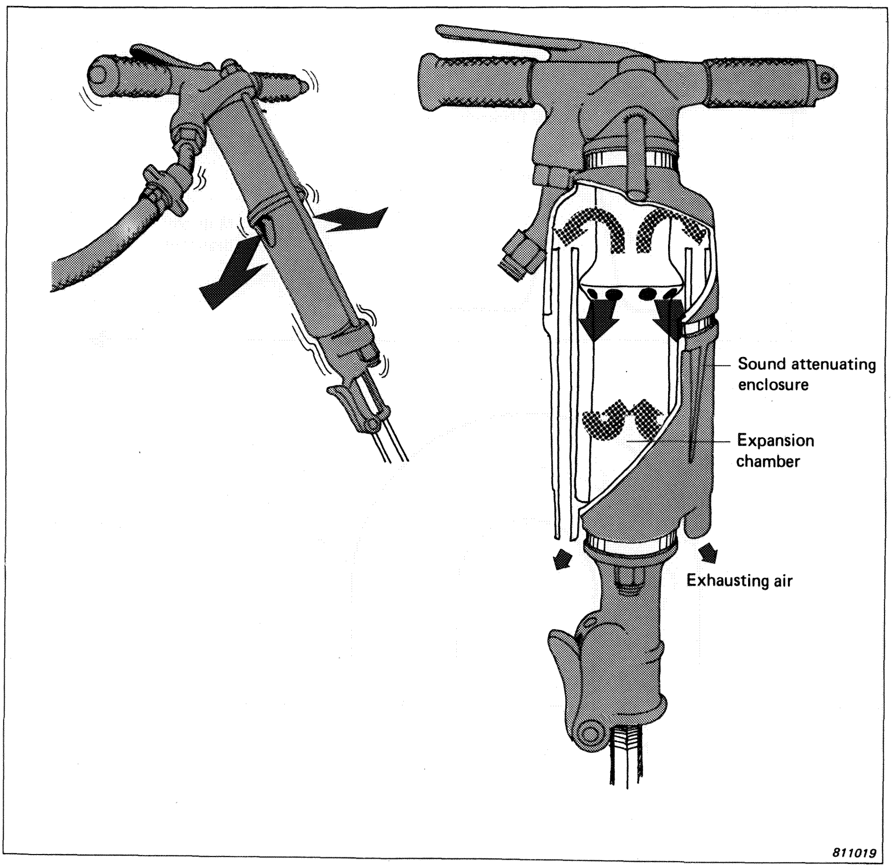


Example

The exhaust of a pneumatic drill produces both high and low frequency noise; low frequency from the repetitive pulses, and high frequency from the jet of gas escaping with each pulse.

Solution

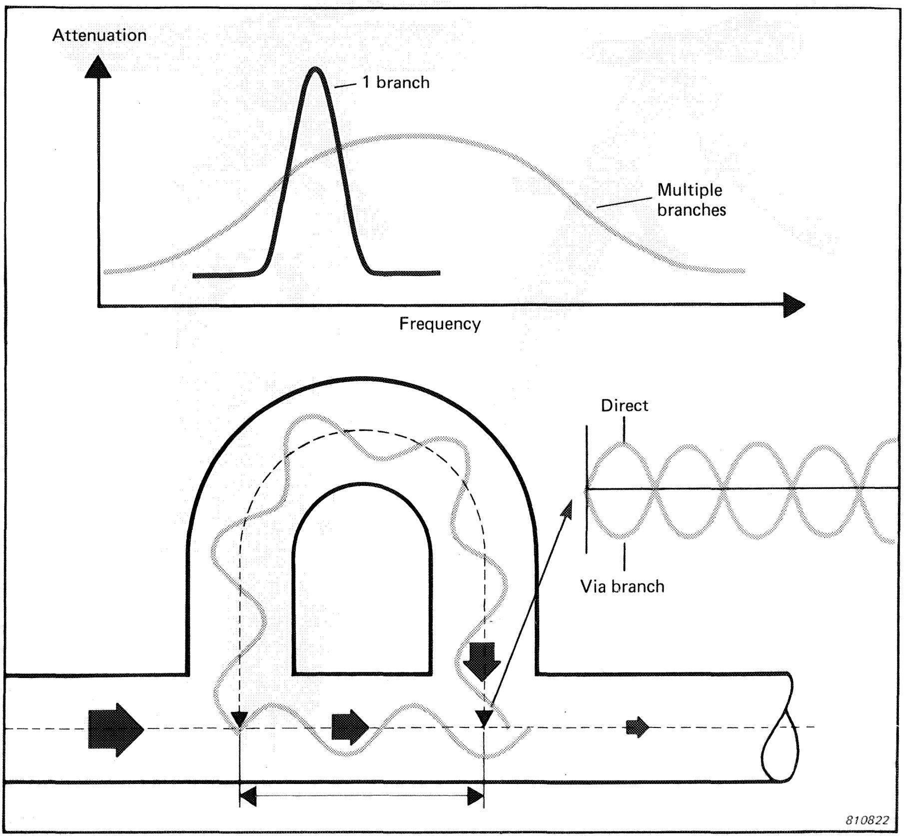
By surrounding the drill body with a jacket acting as an expansion chamber for the low frequencies, and as a noise screen for the high frequencies, the noise level is reduced substantially. Because the energy in the pulse is spread more evenly over a longer time by the jacket, the noise is also reduced in that way. As the impact of the drill on the concrete is an inherently noisy process which cannot be easily quietened, there is a limit to the amount of quietening which is worthwhile.



Pure tones can be reduced by interference

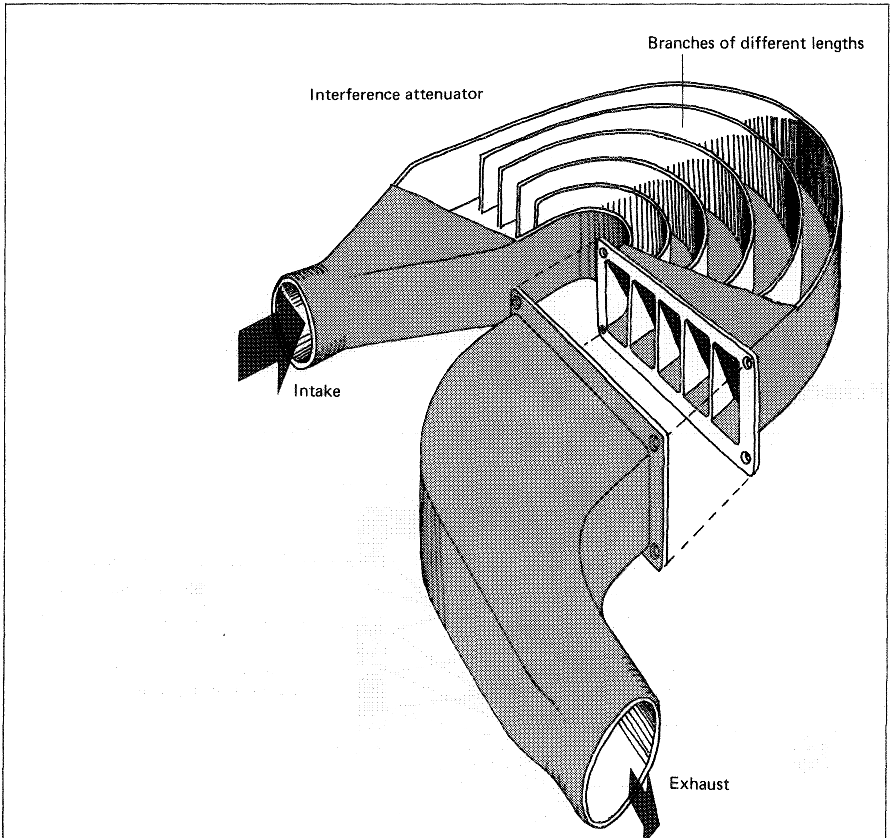
When a noise contains a predominant tone or a few tones, it can be substantially reduced by interference, i. e. the presence of two out of phase tones of the same frequency at the same place, which tend to cancel each other out. An interference attenuator consists of a branch which leaves and later returns to the main channel. Sound passing through it travels an odd number of half wavelengths further than in the main channel, so that when the two sounds meet again they are out of phase and cancel each other out.

Principle



Example

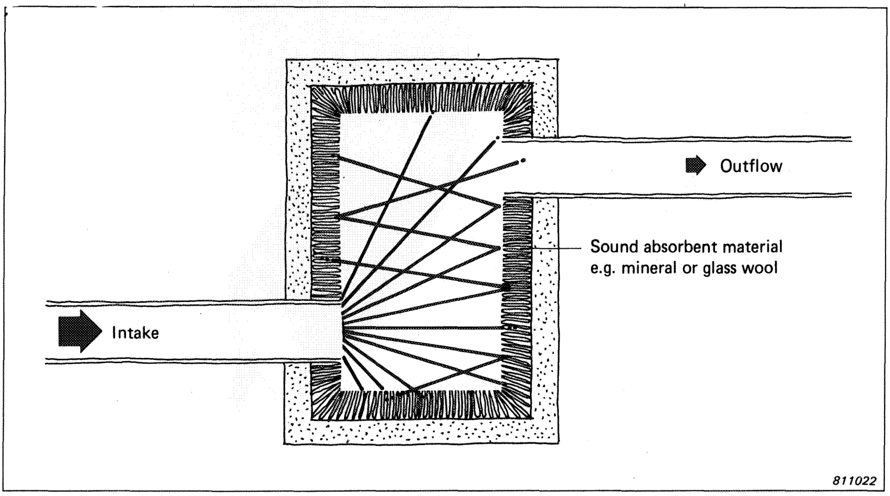
If a tone is not completely fixed, the bandwidth of the interference attenuator can be broadened by having a number of branches of slightly different lengths. The attenuation at a given frequency will be a little lower, however. This type of device is suitable for engines operating at a more or less constant speed, generator sets, for example, and for fan and blower units.



Unused spaces can be used as absorbent plenum chambers

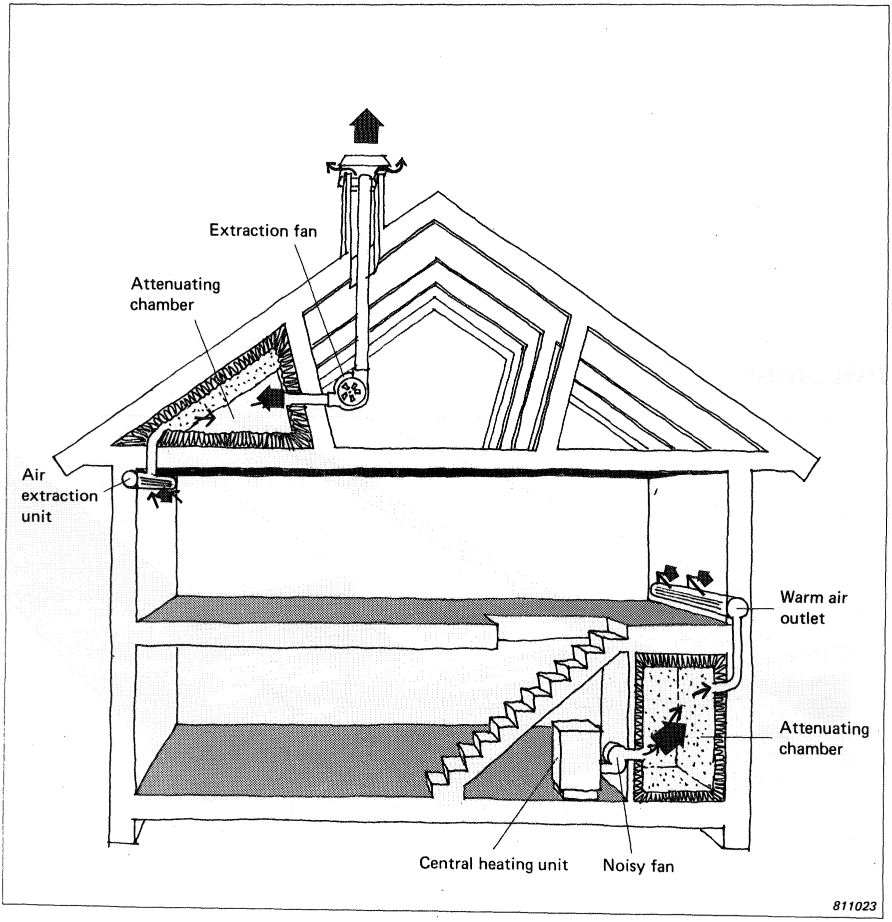
An absorbent room is a simple but effective sound attenuator. Ducts can be fed into a chamber whose walls are lined with sound absorbent material which absorbs the sound energy. To prevent the direct passage of high frequencies, the incoming and outgoing ducts should not be directly opposite each other. The larger the volume of the chamber and the thicker the absorbent lining, the lower the frequencies which can be effectively absorbed.

Principle



Example

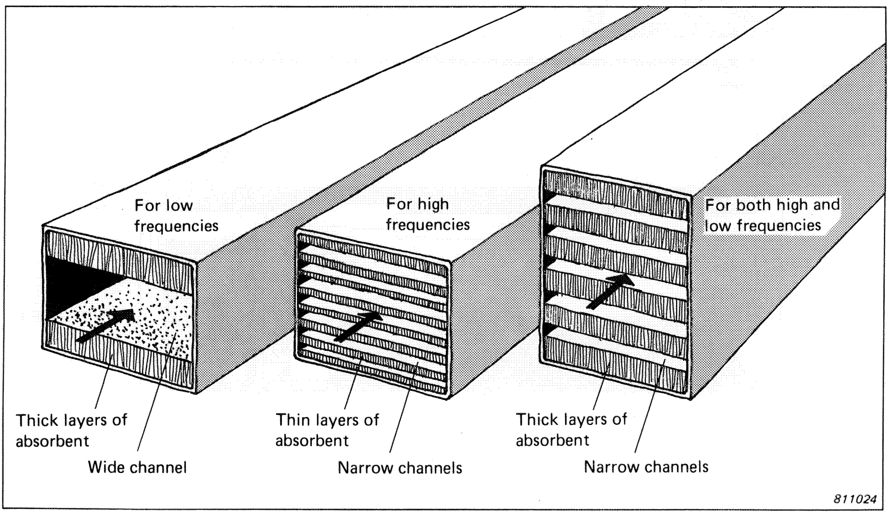
The shape of the space used as a plenum chamber is not important, as long as it is well lined with absorbent and large enough to deal with the lowest frequencies encountered, so any unused part of the building can be utilised. It should also be well sealed in order to prevent leakage of the air out of the system.



Absorbent attenuators are effective over a wide frequency range

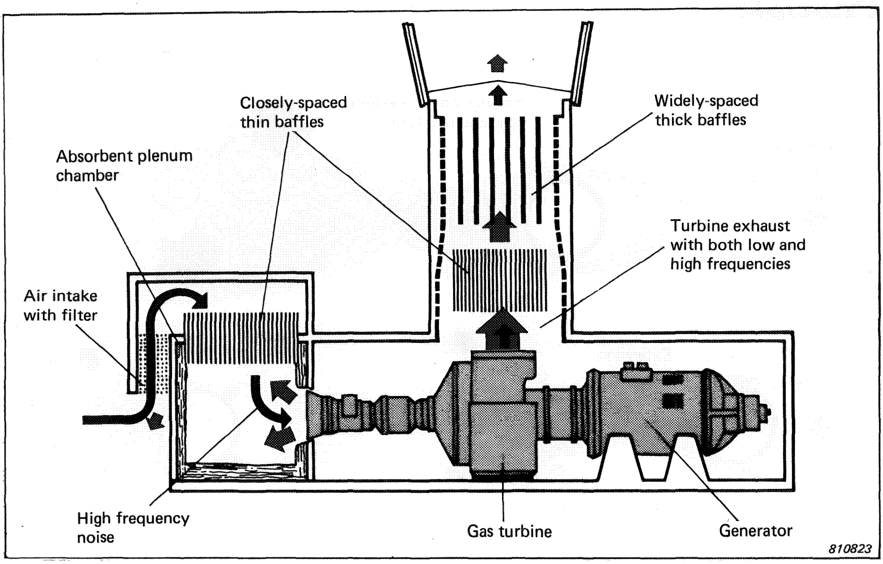
The simplest type of absorbent attenuator is a duct with sound absorbent material on the walls. The thicker the materials, the lower the frequency which can be absorbed. For higher frequencies though, thinner absorbent layers are effective, but the large gap allows noise to pass directly along. This layers and narrow passages are therefore more effective at high frequencies. For good absorption over the widest frequency range, thick absorbent layers and narrow passages are best.

Principle



Example

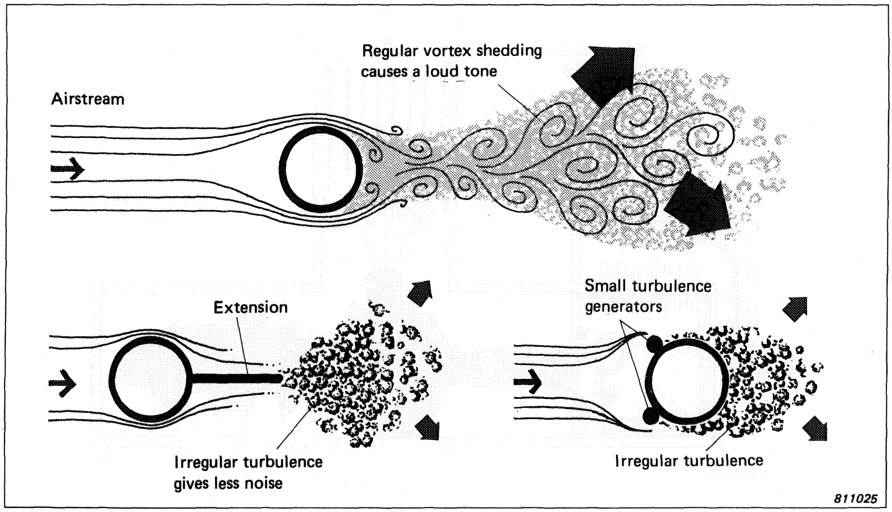
Gas turbine powered standby generator sets are used extensively both as emergency power supplies and to complement normal generating plant in peak periods. It can be necessary to quieten the set by anything up to 70 dB, over a wide frequency range. Extensive use is made of absorbent materials in the form of splitters, baffles, and linings on the walls of plenum chambers on both the intake and exhaust sides.



Wind generated tones can be avoided by profile changes or spoilers

When air flows past an object, a powerful pure tone, known as a Karman tone, can be produced at certain wind speeds. The tone is caused by the regular shedding of vortices from alternate edges on the downwind side of the object as the laminar boundary layer separates from the surface. In addition to a loud tone this phenomenon may also lead to severe structural vibration and damage if the modes of vibration of the object are at the same frequency. By lengthening the object in the direction of the air flow, i. e. by "streamlining", it is possible to keep the boundary layer attached right round the object, greatly reducing the tone level. Where the flow may come from any direction this method is not practicable, e. g. where chimneys are concerned. Spoilers can then be added to break up the air flow so that random turbulence is produced which does not generate the disturbing pure tone.

Principle

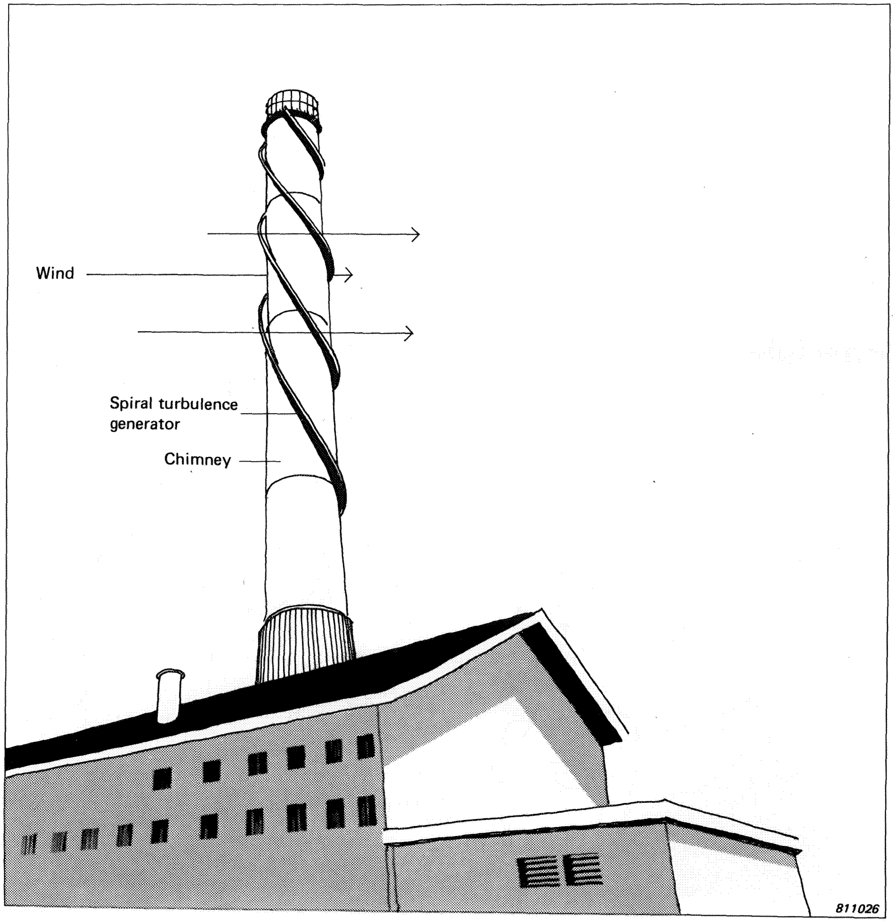


Example

At certain speeds the wind causes a powerful pure tone to be emmitted from the chimney.

Solution

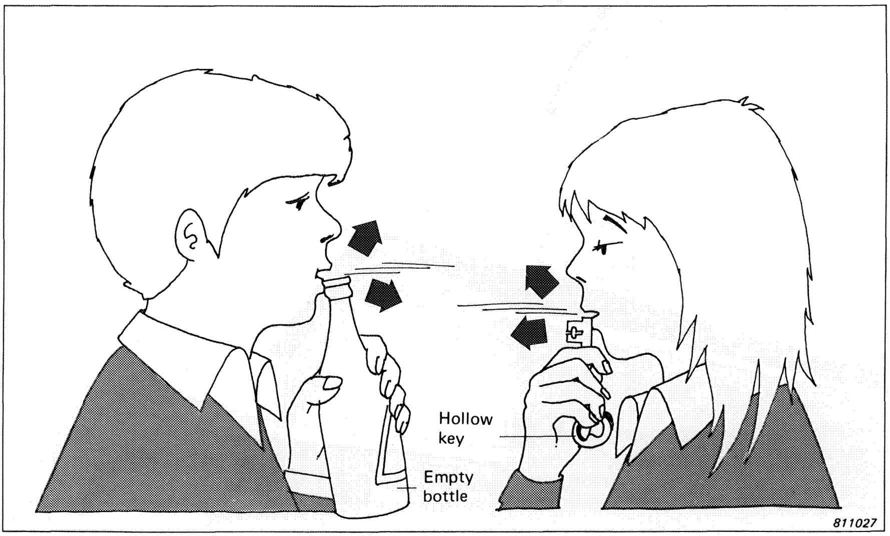
A spiral fin of metal mounted on the chimney causes local tubulence regardless of the wind direction, so regular vortex shedding and the tone which arises from it are avoided. The pitch of the spiral should not be the same all the way up. As well as presenting an irregular shape to a wind coming from any direction, the spiral also increases the strength and stiffness of the chimney.



Avoid air flows over cavities

When air is blown over openings with a cavity behind them, a loud pure tone is produced via what is called a Helmholz resonance. Wind instruments such as the organ and the flute operate on this principle. The frequency produced depends primarily on the volume of the cavity and the size of the opening to it. The larger the volume and the smaller the opening, the lower the frequency.

Principle

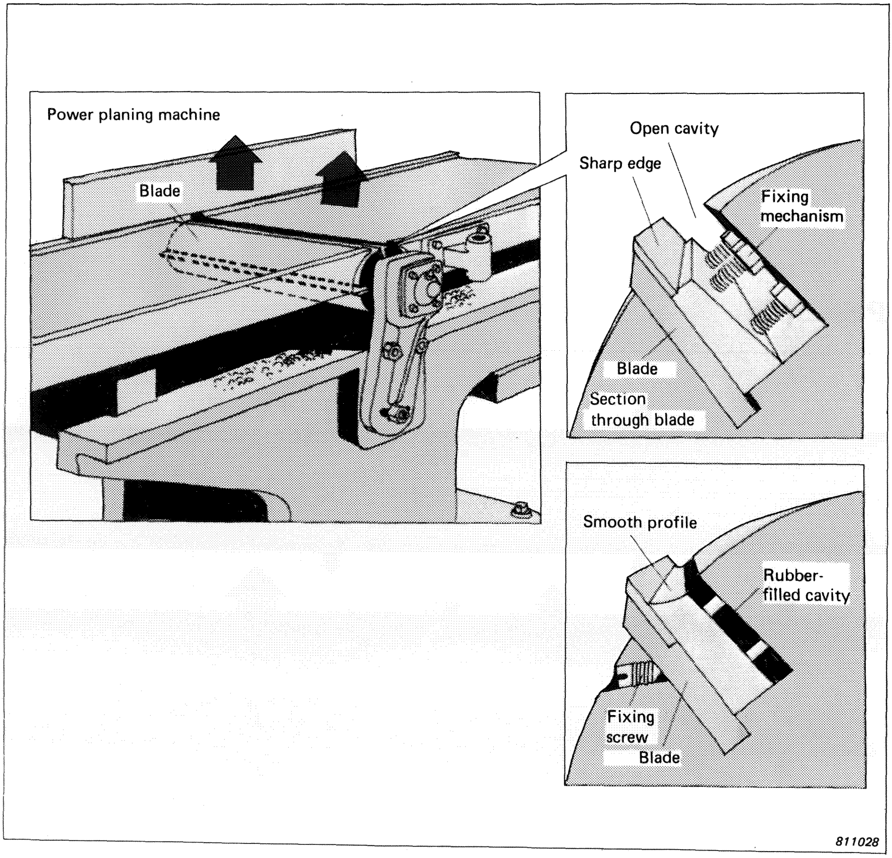


Example

When the cutter of a planing machine or saw blade screeches even when idling, it is often because the air passing over the blade excites the cavity behind the blade into resonance. In this case it is the cavity which is in motion and the air which is stationary, but the effect is the same. Turbulence formed by the passage of air over the cutter's edge produces a whistle which is amplified at certain frequencies, giving the sound its screeching character.

Solution

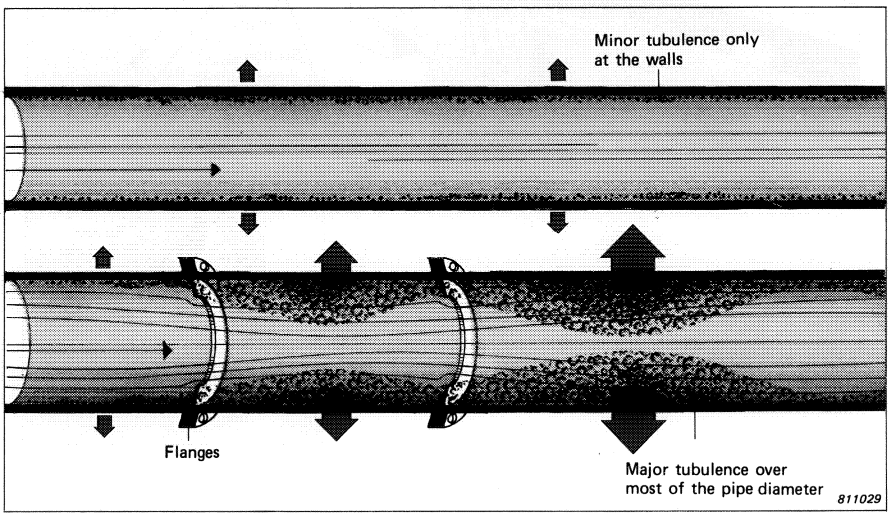
Rounding the edge reduces the whistle and partially filling the cavity avoids resonant amplification of the sound. Detail changes to the blade fixing mechanism are necessary to carry out these improvements.



Smooth ducts and pipes create less turbulence noise

Flow through pipes and ducts always gives rise to the generation of some turbulence and noise at the walls. If the flow suddenly has to change direction because of obstacles in the duct, or sharp bends, strong turbulence and high noise levels are formed, which increase with increasing speed. If the obstacles are near each other, the flow does not have a chance to settle down again and the turbulence is made worse by the second obstacle.

Principle

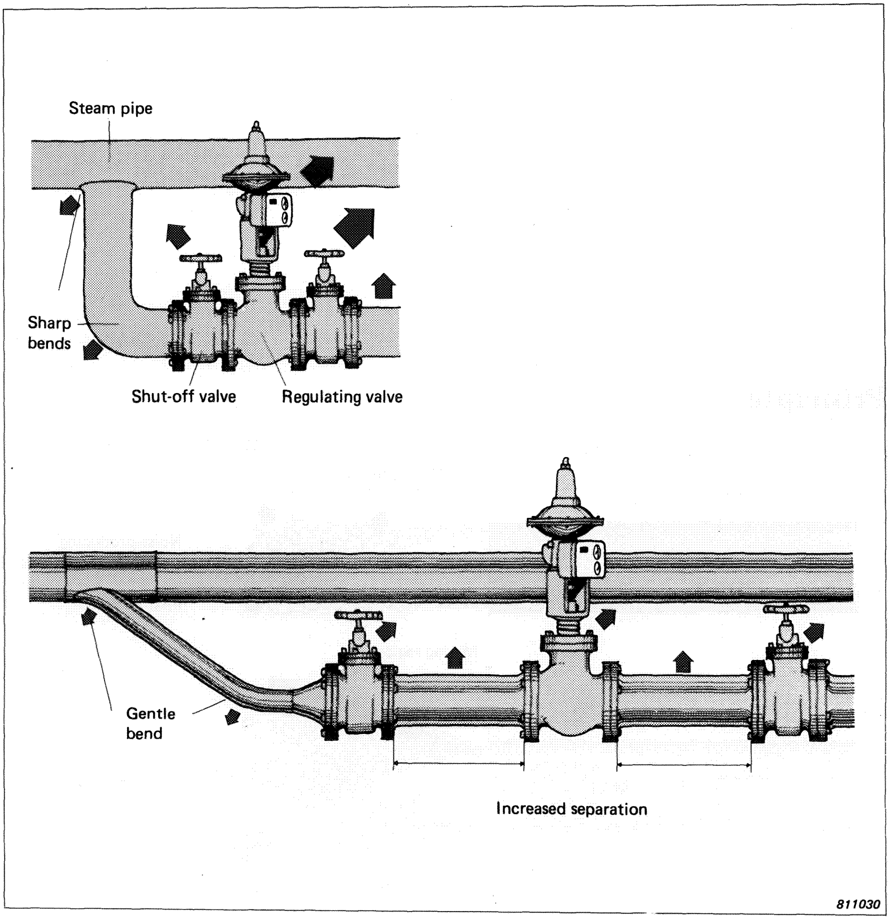


Example

Three valves in a branch from a steam system produce an unacceptable screeching noise. The branch has sharp corners and a number of closely spaced valves which produce turbulence noise.

Solution

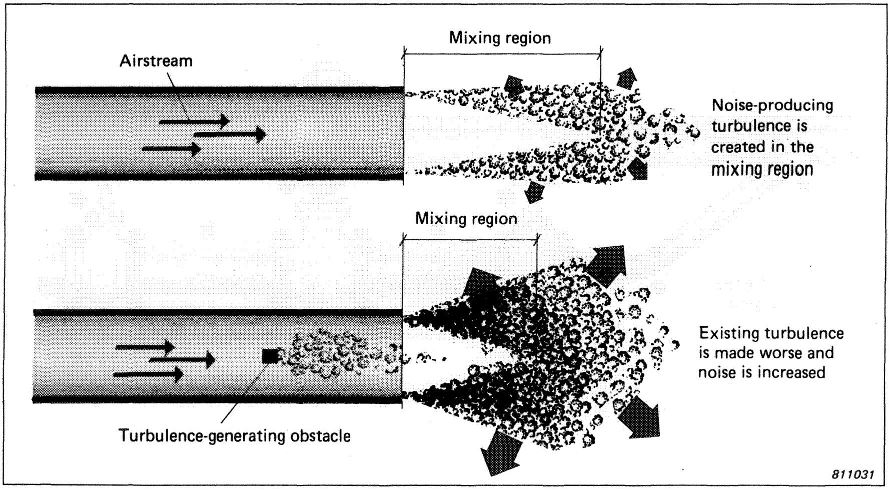
The bends can be made gentler to avoid the generation of so much turbulence, and the valves placed further apart. Any turbulence generated in the flow by one corner of valve has space to settle down before reaching the next.



Undisturbed flow gives rise to less exhaust noise

When a fast moving air or gas stream mixes with still air, turbulence is formed which radiates noise. If the stream is disturbed before the exhaust so that there is already turbulence in the flow, the mixing region amplifies the noise level further by up to 20 dB for the same exhaust velocity. A lower exhaust velocity leads to a lower noise level. Halving the speed leads to a noise reduction of about 15 dB.

Principle

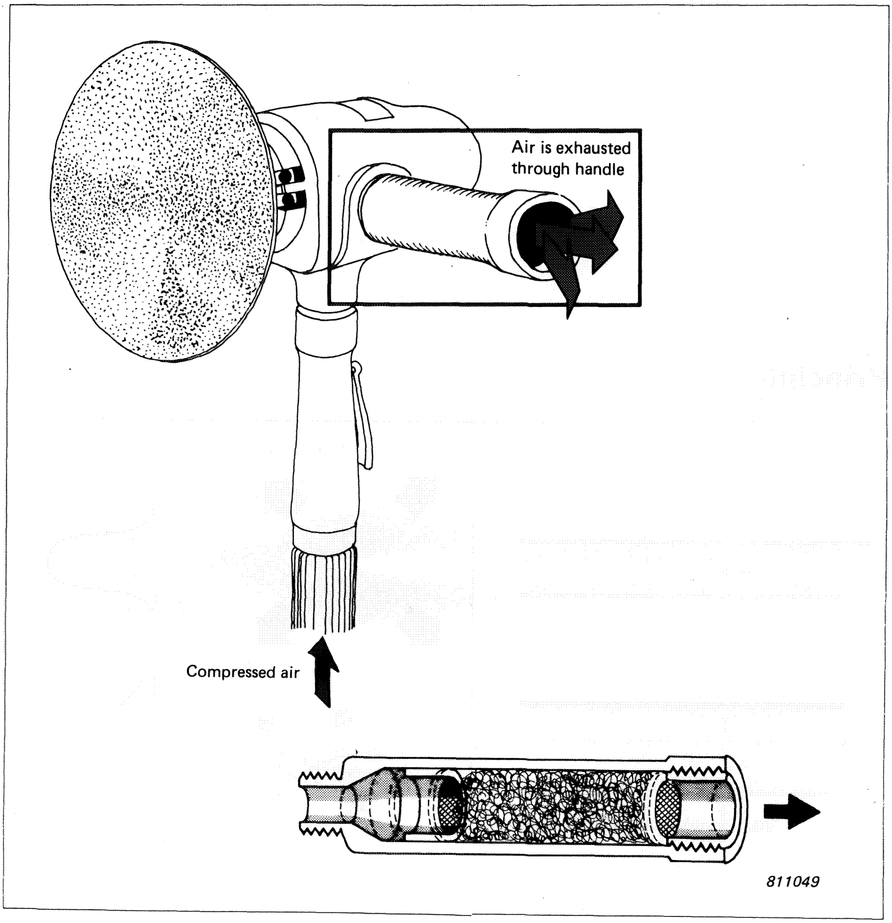


Example

The exhaust air from a compressed air driven grinder generated high noise levels. The air was already very turbulent on leaving the motor and entering the handle, which was hollow and acted as the exhaust. The turbulence noise was amplified in the mixing region.

Solution

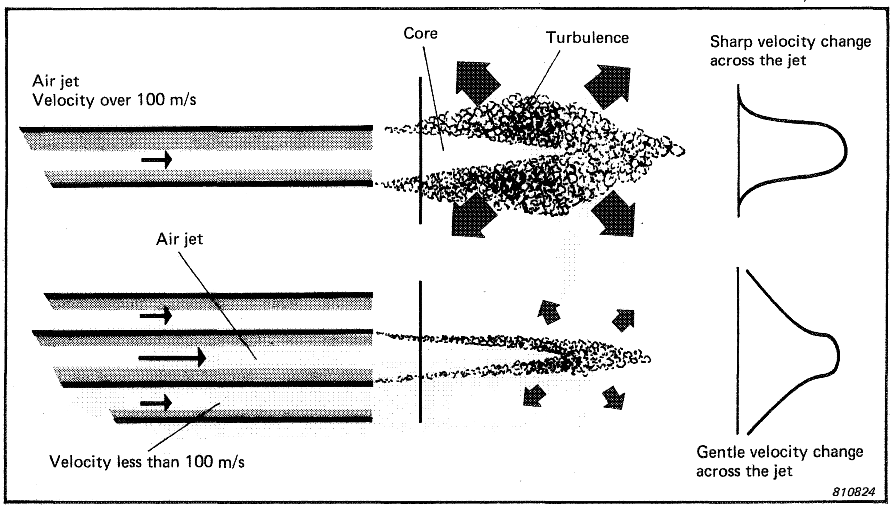
The handle was replaced with a new type with a steel wool packing kept in place by mesh washers at either end to allow easier transition into the air. The turbulence was smoothed by the air's passage through the porous material and the exhaust noise level was therefore reduced.



Jet noise can be reduced by an extra airstream

At velocities above about 100 m/s jet noise occurs. Because the formation of turbulence in the mixing region outside the exhaust is so violent, the condition of the airstream before the outlet is not important. Halving the outlet velocity reduces the noise level by approximately 20 dB under these conditions. The strength of the turbulence is determined by the relationship between the speed of the jet and the speed of the ambient air. The noise level can therefore often be significantly reduced by introducing an extra airstream with a lower speed alongside the jet, so that the velocity profile across the jet is less steep.

Principle

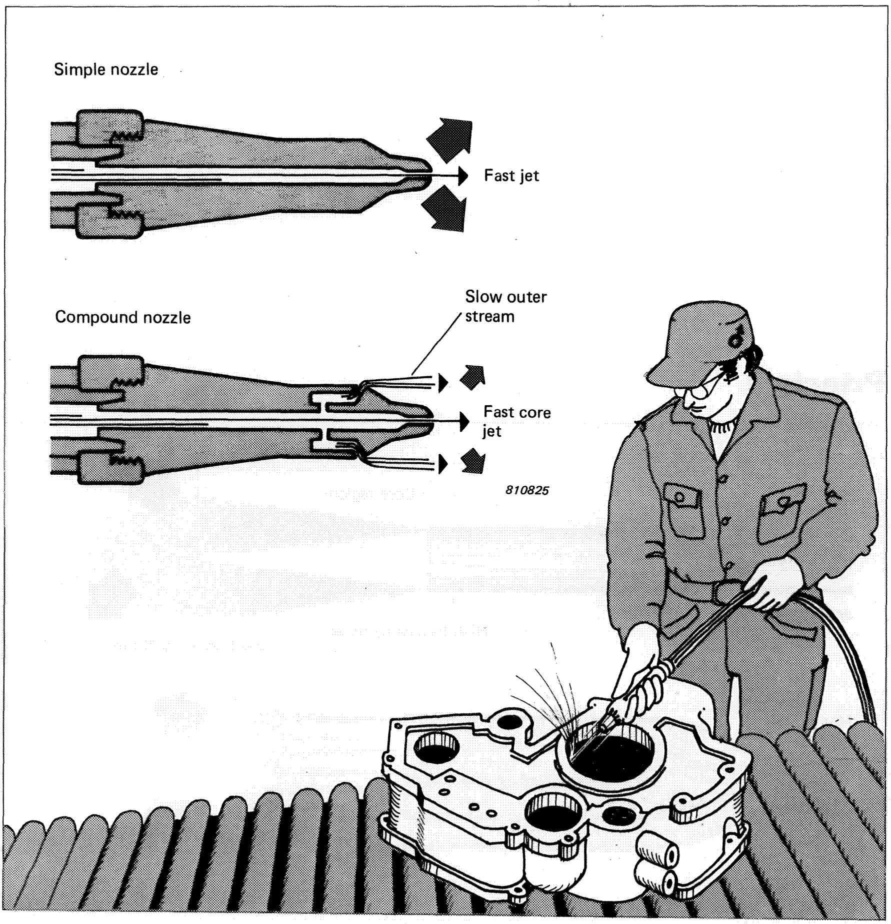


Example

Cleaning machine components with compressed air to remove swarf and dirt is often done using a single jet from a simple nozzle. The high velocity airstream required for this purpose gives rise to unacceptable high frequency noise.

Solution

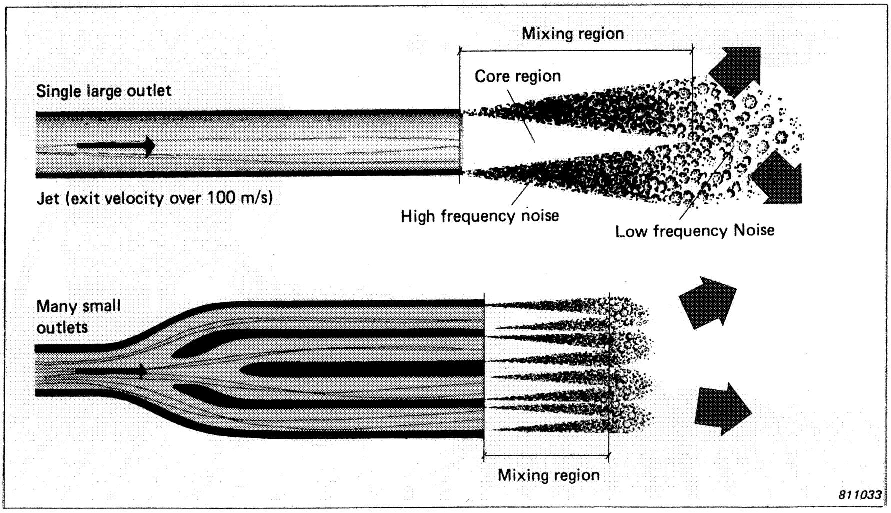
The simple nozzle can be replaced by a compound nozzle which feeds a lower speed annular airstream around the main high-speed airstream. The transition from the high speed of the central airstream to the still air is much less sudden and the noise level is reduced substantially.



Low frequency exhaust noise transformed to higher frequencies is easier to attenuate

If the outlet of an exhaust pipe is large, the noise which arises is predominantly low frequency; if it is small, high frequencies are dominant. By replacing a single large exhaust by a number of small ones with the same capacity, it is possible to reduce the intensity of the low frequencies. The high frequency noise level is usually increased, of course, but this is relatively easier to attenuate.

Principle

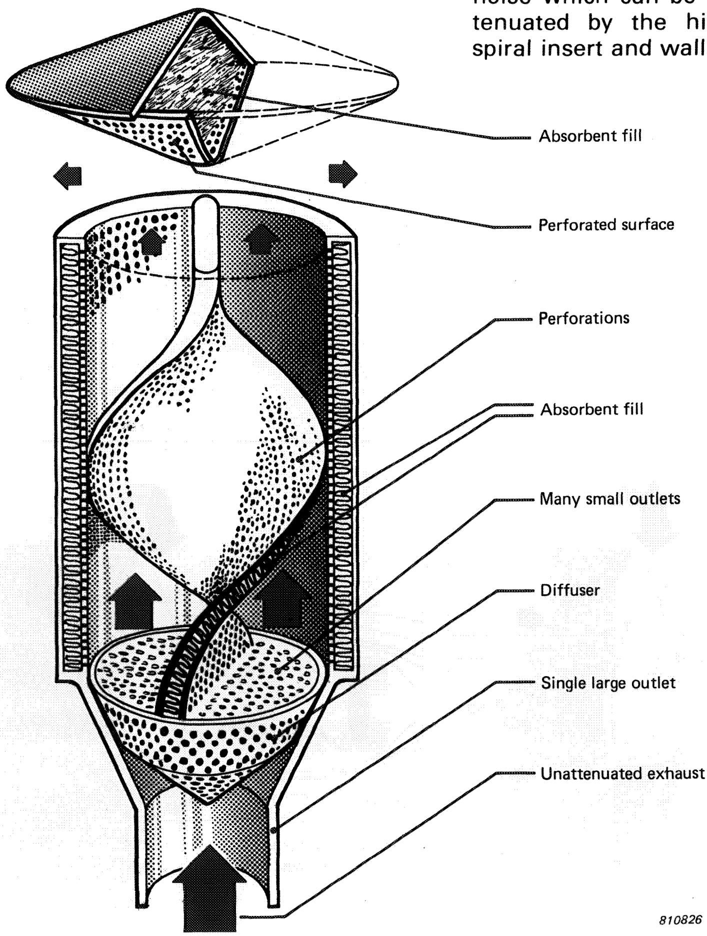


Example

In power stations and in many major industries large quantities of steam are produced, and safety valves may vent excesses to the atmosphere at high pressure several times a day, at the rate of many tons per hour. This requires large diameter pipes producing unacceptable levels of noise, mainly at low frequencies.

Solution

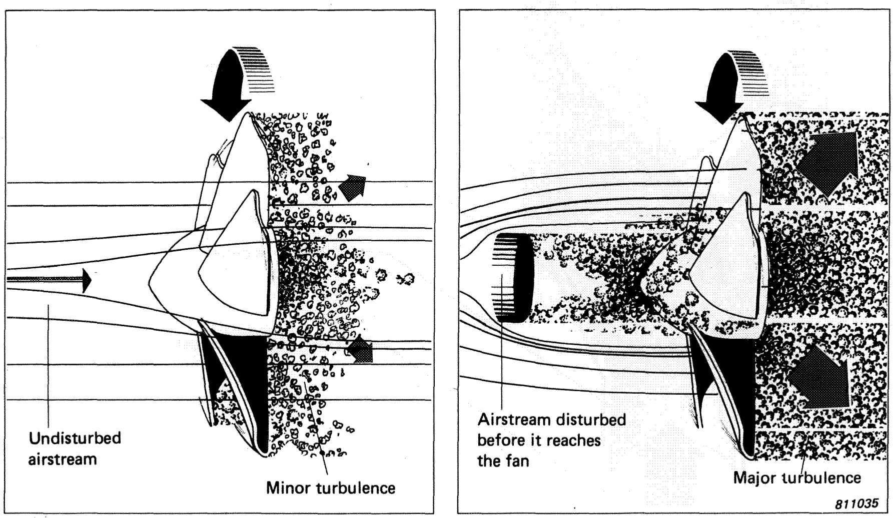
On the existing pipe, a diffuser and frequency transformer, followed by a high frequency attenuator, can be mounted. The diffuser lowers the exhaust velocity by a factor of four which results in a noise reduction of up to 40 dB compared with the original free pipe. The diffuser is made as a perforated cone which splits the single large jet into a large number of small jets generating predominantly high frequency noise which can be significantly attenuated by the highly absorbent spiral insert and walls.



Position fans in smooth, undisturbed flow

Fans generate turbulence which radiates noise. Existing turbulence in the incoming air is made worse by the fan and the noise is amplified. If there is sufficient distance from the source of turbulence to the fan, the turbulence has a chance to die down and the noise level is reduced. Fans should therefore be placed well downstream of obstacles, valves, corners, and changes of cross-section. The same principle also applies to liquids, e.g. ships propellors should operate in a smooth flow.

Principle

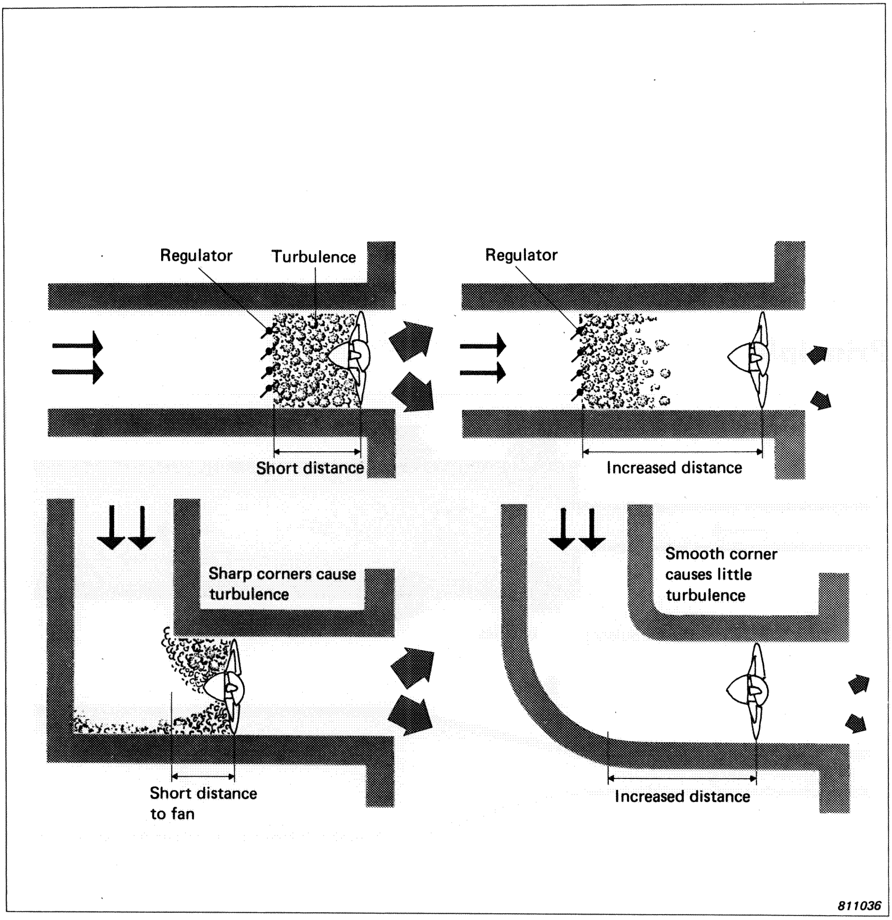


Example

In one case the fan is too close to an obstacle, in the other too close to a bend. In both situations disturbances are formed which cause increased noise after passing through the fan.

Solution

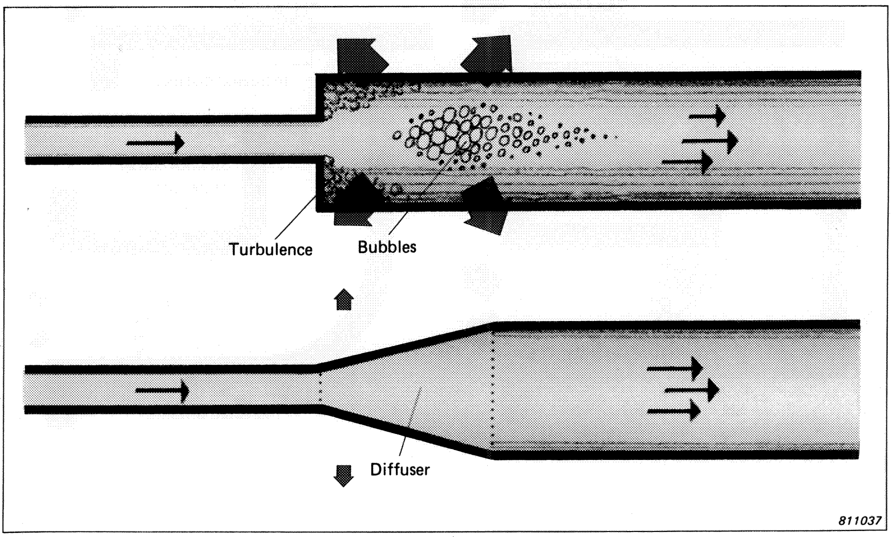
The regulator is moved further from the fan so that the turbulence has a greater distance in which to settle down. The bend should be made gentler to reduce the strength of the turbulence and the fan moved further downstream to increase the settling distance.



Flow noise in pipes is formed by sudden pressure changes

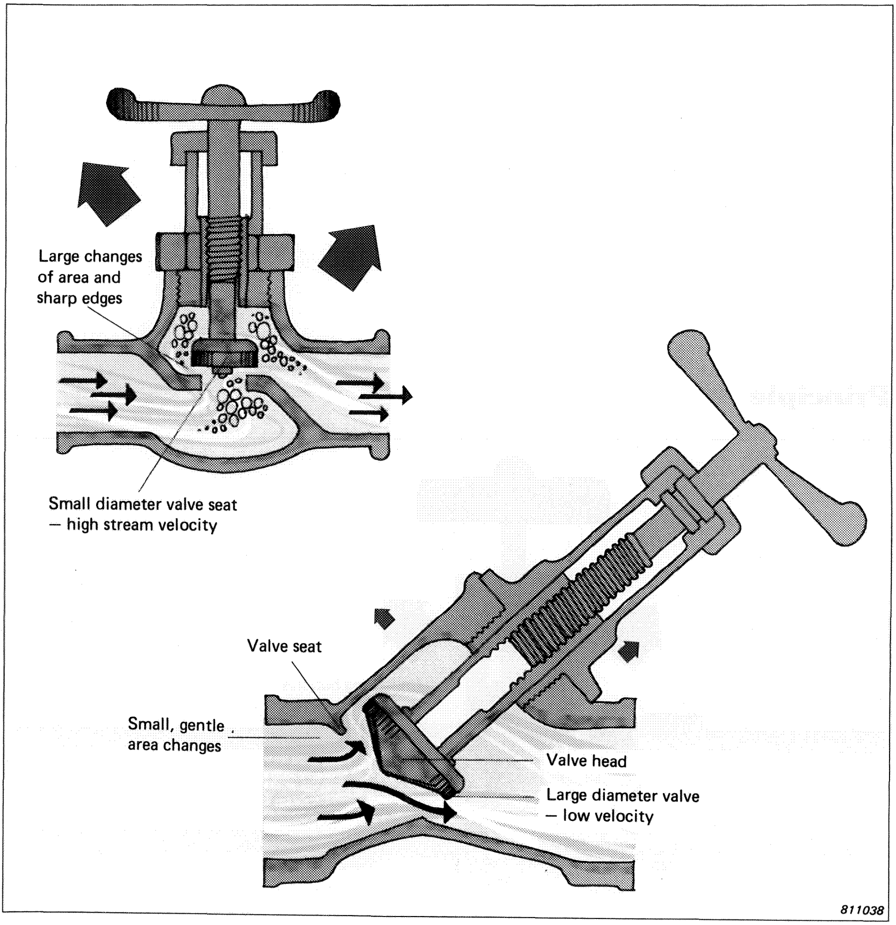
As in airflow, sudden pressure changes in pipes carrying liquids also give rise to noise. Air or vapour bubbles are released which cause noise, but they disappear again rapidly. The pressure change is most often caused by sudden area changes, and can be avoided by ensuring that all area changes are smooth and gradual.

Principle



Example

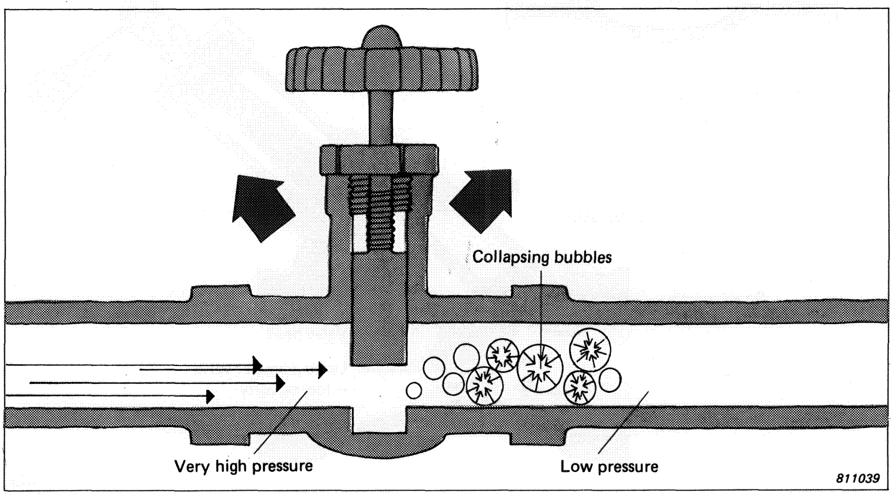
Regulating valves in fluid systems often have small seats which lead to a high local flow velocity around the valve at high pressures. Tortuous paths and sharp edges lead to the formation of strong turbulence. Sound is radiated directly from the valve and vibration is transferred along the pipe to appear elsewhere as structure-borne sound.



Sudden large pressure changes cause cavitation

If a pressure change is large and quick enough, vapour bubbles are formed which collapse again almost immediately, causing both intense noise and high levels of vibration. Cavitation, as this phenomenon is called, occurs with regulating valves, pump impellers, and propellers, and is very common in hydraulic systems where pressures are high. By lowering pressures in a number of smaller steps it is possible to avoid cavitation.

Principle

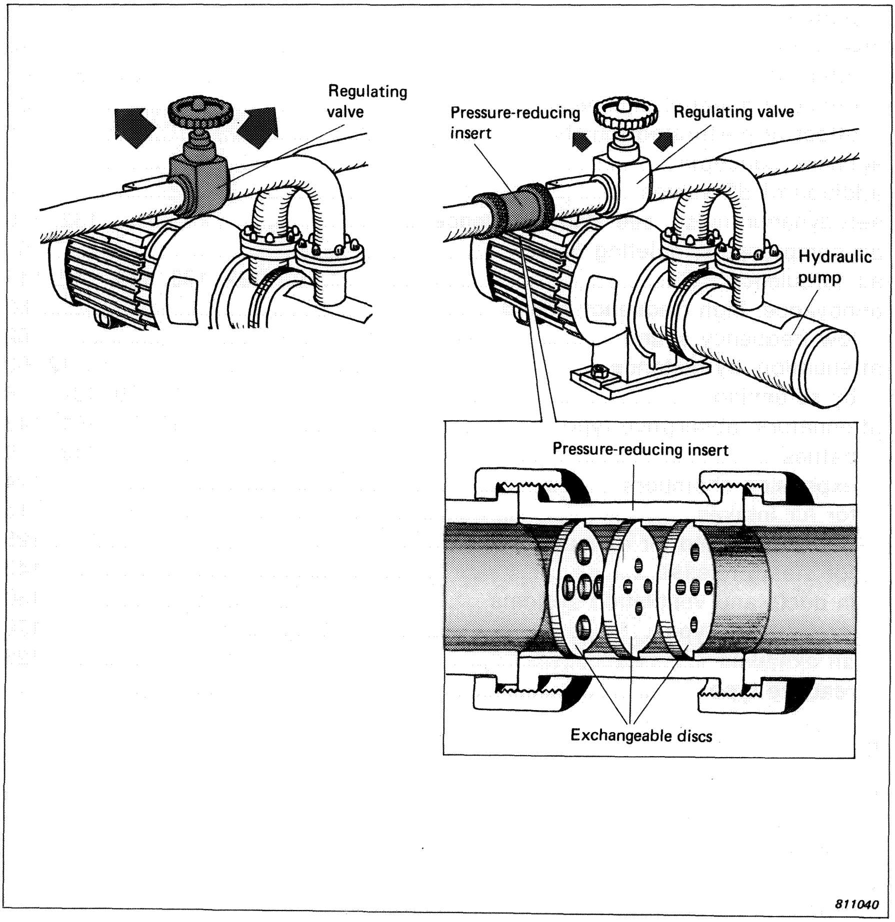


Example

The full capacity of a pump in a hydraulic system is only rarely exploited, so the pressure is usually reduced by means of a regulating valve. The sharp pressure change across the valve can give rise to unacceptable noise radiation from the valve, which may be spread as structure-borne sound throughout the building whereever the pump is connected.

Solution

A pressure reducer can be inserted into the pipe beside the valve. The insert contains a number of exchangeable discs with different perforations. Suitable discs are chosen to give a pressure drop no larger than that necessary to prevent cavitation.



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