# The noise about fans

Fans are widely used to move air in a range of industries, including the cement industry. However, if not suitably insulated they can give rise to noise issues and impact the wellbeing of cement plant staff and local residents. In this article, Halifax Fan looks at noise levels from fans and how to reduce their impact.

■ *by **Dr John Irons**, Halifax Fan, UK, and **Jessie Jia**, Halifax Fan, China*

Two sinter cooling fans located close to each other with ducting

Sound is fluctuating air pressure created by a device. The sound pressure is the effect of the device, what is heard and measured. Sound power is the strength of the device, how much energy it is putting in to the air. Although the sound pressure depends on how close the person is to the sound source, the sound power is always the same. The sound power is related to the sound pressure by the area of an imaginary box around the sound source at the measurement distance:

Sound power = sound pressure x area

Humans need to be able to hear a very large range of sound levels and a very large range of frequencies. Therefore, the human ear is not linear in terms of amplitude or frequency. To mimic how the human ear works, a logarithmic scale is used for sound, called the decibel (dB) scale. The basic relationships are:

- $L_w = 10\log_{10}$ (sound power)
- $L_p = 10\log_{10}$ (sound pressure)
- $L_w = Lp + 10\log_{10}$ (area)

Music uses octave bands for frequency – from a frequency to twice this frequency is one octave band. For sound assessment octave bands are also used with 1kHz used as the middle of the main octave band and the other octaves defined from this. Third octaves (octaves divided into three) are used for more detailed measurement and diagnostics.

## Noise – definition and assessment

Noise is unwanted sound. It can cause hearing issues, induce stress and discomfort as well as a breakdown in communication. The sources of noise can be many, but this article will focus on one: industrial fans.

The noise a device produces can sound different from another, be it the hum of a transformer or the screech of steel rubbing steel. To make assessment and comparison simpler, single-value methods are used.

These single-value methods are based on adding the octave bands together with weight factors. The weight factors try to mimic how noise is experienced – the ear's behaviour. The main weightings used are:

- A weighting: approx hearing at 55dB
- B weighting: approx hearing at 70dB
- C weighting: approx hearing at 85dB.

Although the A weighting indicates how annoying a noise might be, it is the preferred weighting for assessing the impact of noise in terms of annoyance and hearing damage in an industrial context.

The nature of the noise also has an impact. Most people learn to ignore lower steady background noise but have issues with intermittent noise. Pure tones (eg blade passing tone) are discrete and harder to ignore, so have an amplified effect. One method of accounting for pure tones is to add a weighting. A typically tonal weighting is 5dB.

## Acceptable noise levels

The acceptable noise level depends on the objective of noise reduction. On industrial premises the noise is part of the production process, so the emphasis is on health and safety. Outside the industrial premises this noise is seen as a form of pollution, so in the community the emphasis is on annoyance.

Most countries recognise noise as a health and safety risk, and as a result, have regulations for noise at work. In the EU a level of 80dBA during the entire working day is seen as the threshold for significant hearing damage in a significant proportion of the population. Therefore, 80dBA is defined in the EU as the working noise level at which action must be taken. In other regions 85dBA is used. Hearing damage accumulates, so for each halving of the time the noise level can be 3dB higher. For example, for a two-hour period the action

Octave band sound meter

*"Most countries recognise noise as a health and safety risk, and as a result, have regulations for noise at work. In the EU a level of 80dBA during the entire working day is seen as the threshold for significant hearing damage in a significant proportion of the population. Therefore, 80dBA is defined in the EU as the working noise level at which action must be taken."*

level in the EU would be 86dBA. This can be referred to as $80dBA_{eq}$.

Local authorities impose environmental noise limits to minimise the effect of noise on the quality of life of local residents. Plant boundary limits are typically specified. However, after installation sensitive local residents or weather conditions may result in complaints 2-3km from the plant.

The local authority may then carry out noise assessments at these locations and require retrospective noise reduction measures. To continue operating the plant has to comply.

Environmental noise limits are much lower than 80dBA. People are more active during the day, so there are higher background noise levels and people are less aware of noise. This means that higher levels are acceptable during the day. As well as $dBA_{eq}$, the time variation of environmental noise is important. This is expressed as the share (in per cent) of the time the noise is above a certain level (eg dBA10 is the level the noise is above for 10 per cent of the time).

## Fan noise generation

When fans are used the noise comes from fluctuating fluid force, turbulence, interacting with a solid surface. This turbulence is associated with three main mechanisms: turbulent flow coming into the fan, boundary layer turbulence and vortex shedding/wakes from the blade trailing edge. The solid surface may be the impeller itself or the casing elements.

The 90˚ change in flow direction as the flow leaves the inlet cone generates inlet turbulence on a centrifugal impeller. For axial flow fans, the inlet turbulence can vary quite significantly, depending on what is in front of the fan. Therefore, the flow conditions upstream of the fan have a greater impact on the noise generated by axial fans than is the case for centrifugal fans. With axial fans impeller noise dominates.

For centrifugal fans the casing is used to generate pressure and is also a noise source. An experiment on a centrifugal fan found that adding the casing increased the noise above 100Hz by approximately 10dB, suggesting that scroll noise was dominant.

The main source of discrete noise is blade passing. It arises from vortex shedding/wakes being cut by a solid object (eg blades passing a vane) or from changes in the blade lift creating an associated pressure ripple. Turbulence drives the blade passing tone amplitude at higher flow (ie from about the middle of the pressure/volume curve) and the pressure ripple drives the blade passing tone amplitude at higher pressure (ie near the peak of the pressure/volume curve).

Fan performance is adjusted by changing the speed or adjusting the blade angle. Adjusting the blade angle can be achieved by moving the blades or using inlet dampers/guide vanes local to the fan. Inlet dampers/vanes change the blade angle by preswirling the flow local to the fan. In addition to the performance effect, inlet dampers/guide vanes generate noise of their own. The main source of noise is the pulsations created by the flow swirl, a vortex. The vortex pulsation frequency increases as the swirl angle increases

Cooler fan braced for stall

*"The main source of discrete noise is blade passing. It arises from vortex shedding/wakes being cut by a solid object (eg blades passing a vane) or from changes in the blade lift creating an associated pressure ripple. Turbulence drives the blade passing tone amplitude at higher flow (ie from about the middle of the pressure/volume curve) and the pressure ripple drives the blade passing tone amplitude at higher pressure (ie near the peak of the pressure/ volume curve)."*

and at a certain angle the vortex can become bi-stable, generating large flow fluctuations. Devices are used to minimise the vortex effects, but even with these there can be an increase in low-frequency noise.

When the pressure rise being asked of an impeller is too great, air recirculates through the blade passages and the fan is in stall. For axial fans this generates pulsations at the first blade natural frequency, which leads to blade failure.

For centrifugal fans stall tends to generate noise at multiples of two-thirds of the running speed. Further closing of a centrifugal fan leads to surge, with a standing wave in the duct.

In addition, it must be remembered that the fans have acoustic and mechanical natural frequencies. Therefore, running a fan at a different speed may produce quite significant changes in the sound, especially with respect to tonal noise.

## Measuring noise

Measurements in residential areas would typically include measurements local to the equipment, at the plant boundary and in areas where there have been complaints. It is not typical to leave a sound meter collecting data for a period of 1-8h to get a statistical measure of the noise. It is also usual to note environmental noise effects (eg traffic).

For a machine the basic method would be to measure around the machine at 1m from the surface or skid and at a height of about 1.5m. The measurement points should be no more than 2m apart with single samples being taken. The next step up from the standard survey, measurements on a grid describing an imaginary box around the machine, gives a more accurate assessment of the sound pressure and sound power but is not usually practical.

In-duct noise is the basis for fan noise predictions. Even casing break-out noise is usually based on the in-duct noise with an attenuation factor. With recognised in-duct tests methods, the declared accuracy is about 3dB. This is the accuracy that would be obtained if two people tested the same fan to the same standard. Using identical ducting and measurement arrangements could reduce this uncertainty significantly.

A factory in-duct noise test has the microphone inside the duct within a sample tube. If the temperature is below 60˚C and the dust load is low, a microphone with a nose cone on can be used in the duct.

In more hostile flow conditions a microphone at the end of a standpipe is used to measure the in-duct noise. The standpipe is to prevent the microphone becoming hot or clogged with dust. If possible, noise can be measured as it comes out of the duct (eg at the top of the stack). For attenuation across a silencer duct wall vibration can also be used.

Retrofitted dorsal fins to suppress inlet guide vane pulsations

## Predicting noise

The basis of any sound prediction method is sound power. Most fan companies would test a group of fans in their range. They would then predict the noise for the other fans and for the same fan at different speeds.

Early work on predicting overall fan sound power was carried out on heating and ventilation fans. The first method proposed had sound power at rated duty proportional to fan rated power (W) and fan static pressure (P):

$L_w = K + 10\log W + 10\log P$

Using the fan laws, the equation can be expressed as any combination of pressure, power and volume flow rate (Q), or size (D) and speed (N):

- $L_w = K_1 + 20\log P + 10\log Q$
- $L_w = K_2 + 20\log W - 10\log Q$
- $L_w = K_3 + 50\log N + 70\log D$

Although the equation was originally seen as being only of use where the fan manufacturer's data was unavailable, it became accepted almost as the standard method.

A term is also required for the fan efficiency. One method is to have a correction term that may be in the form of an iso-decibel chart (contours of a constant correction factor).

More complex sound formulae have been developed. The Institute of Sound and Vibration Research has proposed:

$$L_w = K + 7\log Q + 10\log P + 10\log((1-\eta)/\eta) + 30\log(U_t) + 15\log(\rho) + 15\log(\varphi+1+\psi+\psi^2)$$

where:
$\eta$ = fan efficiency
$U_t$ = fan tip speed
$\rho$ = gas density
$\varphi$ = non-dimensional flow rate
$\Psi$ = non-dimensional pressure.

Work in Germany that led to VDI 3731 – Characteristic noise emission values of

**Table 1: results of near-field sound survey**

| Location | Sound power (dBA) | |
|---|---|---|
| | 37Hz | 50Hz |
| Inlet duct | 102.2 | 108.8 |
| Fan case | 103.7 | 110.1 |
| Motor | 106.1 | 110.4 |
| Discharge duct | 107.5 | 113.1 |

technical sound sources - fans – proposed:

$$L_w = K + 7\log Q + 10\log P + 10\log((1-\eta)/\eta) + 10m\log(U_t/c)$$

where: m = constant, typically with a value of 1.5.

The octave band sound powers would typically be obtained by subtracting octave corrections from the overall value. To account for speed/flow shift effects, alternate octave corrections could be given for different speeds or tip speeds.

## Differences between predictions and measured values

Fan manufacturers usually have only limited knowledge of the installation, so will quote free-field sound pressure levels. Free-field is the sound pressure given if the equipment was running in a large open field. However, fans are normally installed in plant rooms. This can result in significantly-higher sound levels than the free-field predictions, with increases of 10dB being possible. For example, a predicted casing break-out sound pressure level of 85dBA can give over 95dBA on site. This is due to:

- Local effects – against a wall, the noise has 50 per cent less propagation area, resulting in a 3dB increase in sound pressure. Against a corner the increase is 6dB.
- Global effects – the relative size of the fan compared to the room and the sound absorption of the room affect noise levels. A large fan in a small room with hard walls would have a much higher sound pressure level than a small fan in a large room with sound-absorbing walls.

Some end users assume an environmental factor of 5dB, requesting that equipment meets 80dBA free field.

Fans tend to have flexible casings and be connected to even thinner-walled ducting. Therefore, casing and duct break-out can be a significant issue. Reducing break-out noise usually means increasing the thickness and/or lagging. However, situations do arise where the duct treatment does not match the fan treatment and the ducting becomes the major noise source. This is a more serious issue if the ducting extends for a long distance through the plant, emitting high sound levels over a large area. If there is no inlet/discharge fitted to the fan, the end user can note what is being done with the fan and design the ducting accordingly.

There are usually other sound sources local to the fan which influence the sound measured. For example, two similar fans close to each other double the noise measured at 1m, a 3dB increase.

Unexpected flow conditions can also give high vibration on the ducting and excessive low frequency noise. Given that these are not design conditions, the answer is to not run the fan in these conditions.

## Reducing noise

The first step in reducing noise is always to make the fan as quiet as possible. However, this can involve large costs.

In addition, the fan should be placed in the location where it is least likely to cause an issue. For example, it is not good practice to locate a noisy fan next to a plant boundary.

The silencing treatments that can be applied include:

- Inlet/discharge silencer – risk of blockage. Power loss through flow resistance.
- Cladding – can have expensive installation cost unless thermal lagging is sufficient.
- Panel treatment – local treatment of that panel can be effective.
- Acoustic enclosure – more expensive than cladding and less reliable. Lower reliability due to doors being open and panels not being replaced.
- Plant room – brick-built acoustic enclosure. Gives more restricted access and, due to the hard walls, high noise local to fan.

Typical cladding is rockwool covered in a thin sheet of steel. To be most effective, it is necessary to isolate the steel sheeting from the machine casing using, for example, rubber inserts.

Acoustic treatment is often trying to achieve high attenuation levels, up to 20dB. If five per cent of the equipment is exposed, the average sound pressure would have only been reduced by 13dB and locally the reduction would be much



*"The first step in reducing noise is always to make the fan as quiet as possible. However, this can involve large costs."*

less. Therefore, acoustic treatment requires being very thorough and careful.

A recent enquiry was made regarding two exhaust fans on a process. The fans were supplied unlagged with unlagged ducting. The question was asked as to what could be done to reduce the fan noise, at the time at a level of 100dBA. A survey indicated that the fan noise changed from 90dBA at 37Hz to 95dBA at full speed, 50Hz. To assess the benefits of sound treatment a near-field sound survey was carried out to rank the sound sources. The results are given in Table 1.

From the source ranking it can be seen that the biggest sound contributor is the discharge duct, but that both ducts, the fan casing and the motor need to be treated to meet 85dBA. The survey highlights the importance of duct break-out noise. It also highlights the need to carry out sound surveys at the maximum operating conditions where possible.

For noise in the community the tonal nature of the noise can be an issue. Halifax Fan has worked with a company that was under pressure to take corrective actions regarding noise complaints in the community. The solution provided was to fit a special cut-off in the casing, that reduced the tonal noise by 15dB. This has helped to resolve the community noise complaints.

## Hearing protection

If acoustic treatment is not possible, then hearing protection must be considered. In general, unless it is a temporary noise source (eg testing or maintenance), hearing protection should not be required.

The aim of hearing protection is to reduce the noise at the ears to an acceptable level. Ear plugs tend to be awkward to fit correctly and will have a typical sound attenuation of 15-25dB. Ear muffs tend to be uncomfortable over long periods but are easier to fit and will have a typical attenuation of 20-35dB. The maximum attenuation using ear plugs and ear muffs is 40dB, which is the attenuation of noise through the skull. This restricts the maximum working noise level to about 130dBA for even short-term exposure. ■